On-Site Performance of Air Source Heat Pumps

Brice Le Lostec, Researcher, Energy Technologies Laboratory (LTE), Hydro-Québec, Shawinigan, Québec, Canada
Hervé-Frank Nouanegue, Researcher, Energy Technologies Laboratory (LTE), Hydro-Québec, Shawinigan, Québec, Canada

Abstract: A pilot project consisting of 22 test sites was carried out in Quebec, Canada during the heating season to measure the energy savings associated with the use of heat pumps for space heating. The sites participating in the project were divided into three different categories according to their respective space heating system. Sixteen sites were equipped with an air handling unit with a built-in heat pump (10 sites with a single stage air source heat pump and 6 sites with a cold climate air source heat pump (5 variable speed compressors and 1 two-stage)) assisted by an electric coil in the unit. The remaining 6 sites were equipped with a ductless split heat pump system supplemented by independent electric baseboard heaters.
Monitoring was conducted for 21 months (from September 2011 to May 2013). The results show that the performance of a single stage heat pump provides similar energy savings regardless of their capacity. The energy savings of these heat pumps were about 28% compared to the heating demand. For heat pumps designed for cold climates it was found that these systems are more efficient than the single stage heat pump systems. The energy savings of these heat pumps were about 45% compared to the heating demand. For the ductless heat pumps, which operate with the same technology as cold climate heat pumps, energy savings of 25% were attained, compared to the heating demand.

Key Words: Heat pump, performance, cold climate, single stage, two-stage, variable speed compressor

1 INTRODUCTION

In Quebec's cold climate, the space heating load is responsible for more than 50% of the province's overall energy consumption in the residential sector. In an effort to reduce the amount of energy dedicated to space heating, air-to-air heat pumps represent an interesting alternative to conventional systems. The heat pump market in Quebec is composed primarily of central air-to-air heat pumps and ductless split heat pumps. Different types of heat pumps are available: single stage, two-stage and variable speed compressors.

In a cold climate, heat pump performances deteriorate as the outdoor temperature drops and must be shut down at a certain point. For instance in Quebec, single stage heat pumps are typically switched off at outdoor temperatures below -12°C. Air handlers must be equipped with an auxiliary space heating system (electric resistance, gas or fuel) in order to fulfill the heating needs of homes when necessary.

Ductless split heat pumps are typically installed in living rooms. They are mainly used to meet the space cooling load demand during the summer and with the benefit of also meeting a portion of the space heating load during the colder months. But the energy supplied by these heat pumps compared to other sources has not been measured. Typically auxiliary heating systems used to meet the space heating load and operating independently of the split heat pump system include electric baseboard heaters, hydronic radiators and radiant floor or ceiling panels

Many experimental and theoretical studies have assessed the energy performance of heat pumps in cold climates. Karlson et al. (2006) found that the energy performance of heat pumps increased from 1991 to 2001. He also found that new technologies like crankcase heaters or thermostats to switch off heat pumps at low temperatures (cut-off points) have resulted in the installation of heat pumps in cold climates. Le Lostec and Nouanegue (2012) tested three heat pump technologies (two-stage, booster and variable speed compressors) in a laboratory. The experimental results were used to validate a numerical model. The results demonstrated that the energy savings were in the order of 50% and that between 70% to 99% of the required heating energy can be theoretically fulfilled by these types of cold climate heat pumps.

Laboratory tests are used to define the Heating Seasonal Performance Factor (HSPF) of heat pumps. This factor, which is defined in many standards in North America including CSA-C6656 (2006), is used to rate the performance of heat pumps. Many studies indicate that this factor is not always accurate and does not represent the true performance of heat pumps, especially in cold climates. Francisco (2004) and Fairey et al. (2004) demonstrated that the HSPF to evaluate the performance of heat pumps is not consistent. Models (BIN, Cd coefficient) used to define the HSPF are known to not be very accurate (ASHRAE 1985). This value is however pertinent for comparison purposes between similar heat pump technologies. On the other hand, Fairey et al. (2004) demonstrated that climate has an important effect on the HSPF value. Few studies have compared heating performance factor (HSPF) with performances measured on real in situ installations for single stage heat pump and cold climate heat pump.

Consequently, there was a need to study the behaviour of heat pumps in an actual house located in a cold climate. This experimental study needed to be undertaken on a relatively large number of houses to be able to collect information on different heat pump technologies, different sizes of houses and different heat pump capacities. A pilot project consisting of 22 test sites was conducted during the heating season in Quebec, Canada to evaluate the energy saving associated with the use of heat pumps for space heating. The sites participating in the project were divided into three different categories according to their respective heat pump system. The heating systems included six heat pumps classified in the cold climate category, ten single stage heat pumps and six ductless split heat pumps. An auxiliary electrical system was installed in the air handler in the houses with the two first technologies. The ductless split heat pump systems were combined with independent electric baseboards. The monitoring campaign lasted for 21 months (from September 2011 to May 2013). This paper presents the energy performance results of these three different categories of heat pumps during the heating season.

2 METHOD

2.1 Heat Pumps

The 22 test sites were located in the Trois-Rivières and Montreal regions. Table 1 presents a description of the heat pumps installed in the 22 houses. Variable speed compressors were classified under cold climate heat pumps. There were three sizes in all 5.25 kW (1.5 tons), 8.8 kW (2.5 tons), and 10.5 kW (3 tons).

The systems were installed between 2005 and 2011. The single stage heat pumps were older than the others. They were installed in 2005 while those in the cold climate and ductless heat pump categories were more recent (2011). However, this study did not take the age of the systems into account. Any maintenance activities on the equipment were also not included in the study. However, the systems were tested to assess their adequate operation before the beginning of the measurements.

The installation of measurement instruments was completed at the end of November 2011. The measurement campaign therefore only included part of the heating season (December 2012 to May 2012) in the first year. However the entire heating season in the second year (May 2012 to May 2013) was measured. This study is based on data from the second year of the measurement campaign only.

As mentioned earlier, a cut-off temperature is usually introduced in the control system of a single stage heat pump to stop its operation when the performance of the heating system could be dramatically reduced due to low outdoor temperatures. For the purpose of this study, the cut-off temperature for 4 single stage heat pumps was set at -18°C to measure their performances down to -18°C.

Two-stage heat pumps include two compression stages. When the heating demand is low, the control system activates the first stage. As the demand increases above a certain limit, the second stage is activated. This technology reduces the cycling frequency.

This effect is also found in the variable speed technology where the power of the compressor is controlled to produce the needed amount of energy. But the variable speed technology is developed to maintain a relatively high heating capacity until very low temperatures are reached. Therefore, there was no need to change the cut-off temperature for two stage and variable speed heat pump. Usually, the capacity of this category of system is higher than or equal to 3 tons. This is why some 3-ton single stage systems were also included in the study for comparison purposes.

The ductless heat pumps in the study were all variable speed with the same capacity. They can also be classified in the cold climate category because of the technology used. They are normally installed in the living room and condition part of the house. The cut-off temperature for this category of pump is not defined. However, data shows that they can function effectively down to a temperature of -25°C.

The sites were evaluated to obtain their Energuide rating (NRCAN (2013)) with the results summarized in Table 1 below. The sites were classified from “New house with some energy efficiency improvements” to “Energy efficient new house”. The energy behaviour of the studied houses are all relatively similar.

Table 1: Heat pump descriptions and sites rating

Heat pumps	ID	Installation date	HSPF (IV)	SEER	Energuide rating	City (Canada, Qc)
Central (2.5 Tons) Single-stage	1	--/06/2011	8.5	15	72	Boucherville
	2	--/06/2011	8.6	15	73	Beloeil
	3	30/06/2005	8.4-8.6	13	76	Laval
	4	30/06/2005	8.4-8.6	13	80	Greenfield Park
	5	30/06/2005	8.4-8.6	13	-	Dollard des Ormeaux
	6	12/07/2005	8.4-8.6	13	75	Pincourt
	7	18/06/2005	8.4-8.6	13	68	Lachine
	8	18/06/2005	8.4-8.6	13	79	Dorval
Central (3 Tons) Single-Stage	9	22/06/2005	8.4-8.6	13	73	Anjou
	10	13/06/2005	8.4-8.6	13	78	Chambly
Central (3 Tons) Variable speed	11	11/05/2011	9.4	15	76	St-Charles Borromée
	12	22/07/2001	9.4	15	69	Greenfield Park

	13	--/05/2011	9.4	15	81	Boucherville
	14	--/01/2011	9.4	15	75	Laprairie
	15	--/11/2011	13	20	81	Trois-Rivières
Central (3 Tons) Two-stage	16	30/09/2011	9.8	16	83	Bécancour
Ductless (1.5 Tons) Variable speed	17	22/06/2011	10.3	20.2	74	Mascouche
	18	29/09/2010	10	19.2	67	Laval
	19	29/07/2011	10	19.2	80	St-Félix de Valois
	20	06/06/2011	10.3	20.2	79	Blainville
	21	28/06/2011	10.3	20.2	82	St-Jérôme
	22	--/--/----	10	19.2	-	St-Charles Borromée

Note: Measurements on installation 5 stopped in December 2011

The heating consumption of each site was calculated based on measurements. For each studied technology, sites with a similar total heating consumption value were chosen because this value provided a good indication of the heating demand involved, which correlates to the behaviour of each site's heat pump. Figure 1 shows the heating demand of the chosen sites. As a result, 13 of the 22 sites were used to evaluate and compare these different technologies.

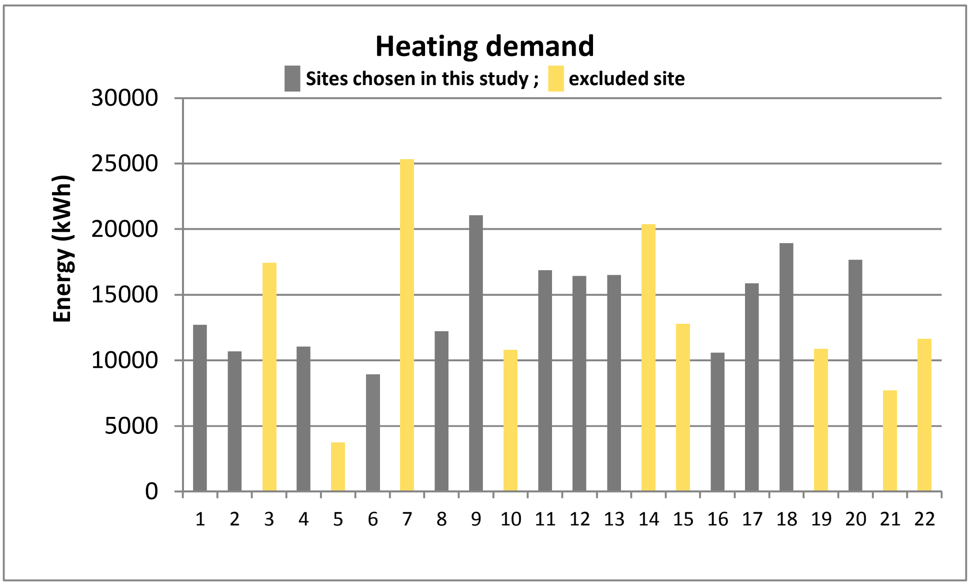

Figure 1: Heating demand for all houses

The balance point is defined as the temperature at which the heat pump heating capacity equals the space heating load. The balance point (Figure 2) was estimated for each chosen site. In the case of 2.5-ton single stage heat pumps, the balance point was at about -12°C. The value obtained for the 3-ton single stage heat pumps was slightly higher (around -8.5°C) while the balance point calculated for cold climate heat pumps was -26.5°C. The balance point of ductless heat pumps was estimated at -1°C. This value is caused by the sizing of ductless heat pumps regardless of the space heating load.

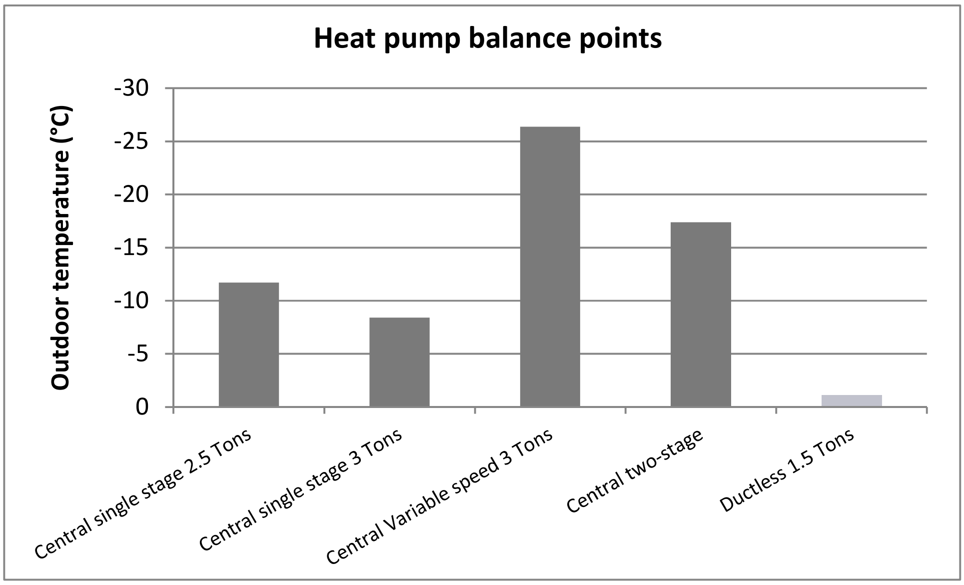

Figure 2: Heat pump balance points

2.2 Weather

Weather data was provided by the weather stations in Montreal (Dorval) and Trois-Rivières. The data was imported from the SIMEB site (https://www.simeb.ca/). As shown in Figure 3, the outdoor temperature pattern in the two areas during the studied period was similar.

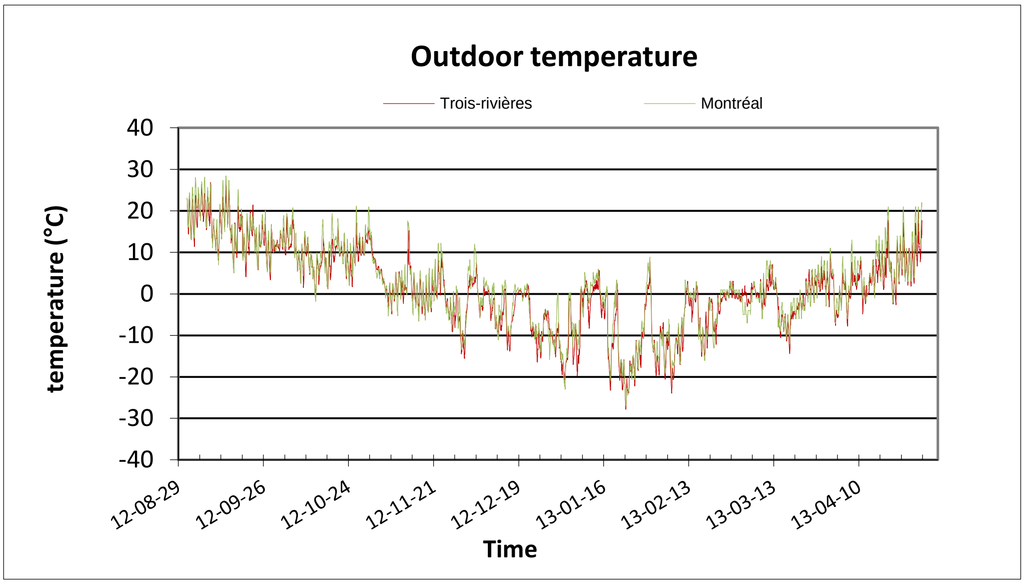

Figure 3: Outdoor temperature

Figure 4 presents the degree days calculated for the 2012-2013 heating season compared to the historical average. The heating demand seems to be lower than normal for the measured period, which would indicate that the effect of the cold climate on the heat pumps could have decreased because there were more days where the heating demand could be fulfilled by single stage heat pumps. Table 2 shows the number of hours where the temperature was below -12°C. This represents about 10% of all the hours in that year's heating season. Thus, the relevance of the study remains valid.

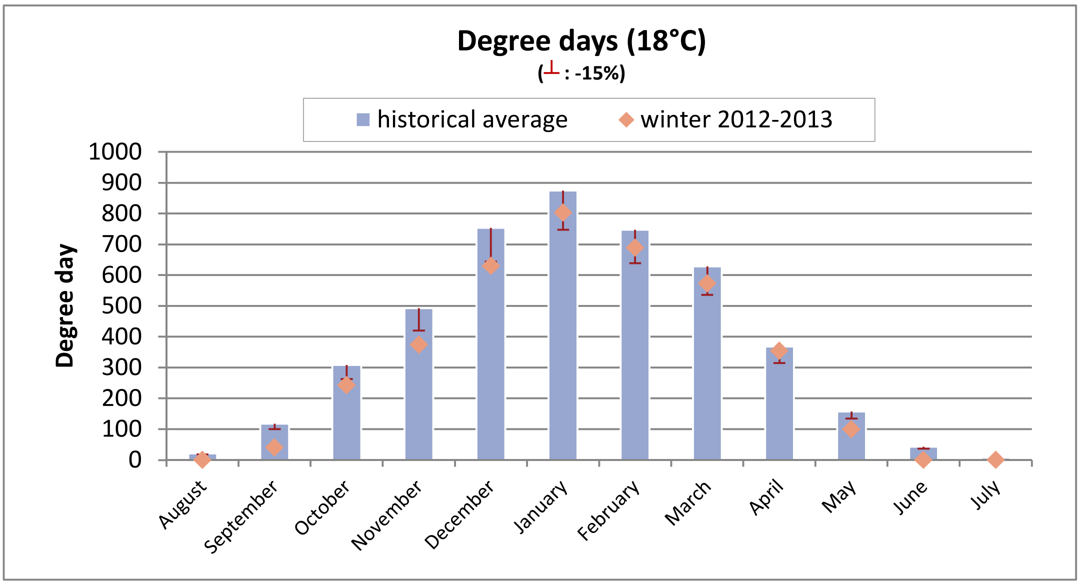

Figure 4: Degree days for the heating season

Table 2: Hours below -12 °C

Site	2012-2013
Trois-rivières	599 h
Montreal	466 h

2.3 Data Acquisition

The purpose of the experiment was to acquire data from heat pumps in operation that provided information about their real performance. Thus, it was necessary to measure all the elements of the systems to be able to calculate the energy balance of each system, the electric power related to each system's operation as well as the temperature and airflow rate. The measured data therefore included:

- the electric energy consumed by the heat pumps for compression
- the electric energy consumed by the air handlers for air supply
- the electric heating power from auxiliary heaters
- the air velocity in the air handlers
- the temperature and relative humidity at the inlet and outlet of the air handlers
- the outdoor temperatures provided by the nearest weather stations (Montreal and Trois-Rivières)

All the measurement instruments were calibrated. The uncertainties in the energy consumption measurements were less that 1% and the uncertainties for the temperature ranges were about ±0.2°C, which resulted in a relative uncertainty of about 10%.

Data was acquired at intervals of 88 seconds. For safety purposes, the minimal storage capacity of the data loggers was set at 3 weeks to provide enough time for any maintenance operations in the event of problems with the data acquisition system. The data was imported from the data loggers every week.

The electric consumption of the HVAC equipment was measured at the electric panel. For the air handler units, the air velocity was measured but not used for flow rate calculations because of difficulties in accurately calculating the actual flow rates. The method proposed by Johnson (2005) was used to determine the flow rates, whereby the heating power delivered by an electric heater with a known capacity is used to calculate the flow rate in the air handler. This method has often been used in different studies (Johnson (2005)) because of its simplicity and precision. However, a radiation effect of the heaters on the temperature sensors was observed in some installations. This phenomenon led us to exclude some sensors in the data treatment. It was suggested that the uncertainty of this method was less than 15% (5 to 15 %). The air velocity was used to detect the type of ventilation (constant, controlled or intermittent) and therefore define an operation period.

All temperature and flow rate measurements were not carried out on the ductless heat pump to avoid measuring equipment in the living room. For ductless heat pumps, the heating capacity was estimated using the data on the performance of the ductless heat pumps, based on electric consumption measurement. The difference in heating output between manufacturer curves and laboratory tests is about 2% to 8 % for 3-ton central variable speed (Le Lostec and Nouanegue (2011)). We assumed that error of using manufacturer heating output curves for the ductless systems is less than 10 %.

2.4 Performance Calculations

The performance calculations were performed based on the thermal balance of the heat pumps. The thermal balance was determined by calculating the amount of energy provided by the heat pumps and other heating equipment as well as the electric energy consumed for all the heating needs of the households. It is important to note that the calculated energy does not include the space heating demand of the garages since the heat pumps did not condition these spaces and garages have no ventilation.

The air handler heating energy (Q_c) is the total energy provided for the heating demands of each house either by heat pumps or an electric furnace. The value was determined by calculating the heating power ($\dot{Q}_c$) transferred to the air passing through the air handler at each time step (Δt).

$$Q_c = \dot{Q}_c \times \Delta t = \dot{m}_{air} \times cp_{air} \times \left(T_{out,avg} - T_{in,avg}\right) \times \Delta t \tag{1}$$

where $\dot{m}_{air}$ is the air mass flow rate, cp_{air} is the heat capacity of the air, $T_{out,avg}$ is the outlet temperature of the air handler and $T_{in,avg}$ is the inlet temperature of the air handler.

The heating capacity of ductless heat pumps was estimated using their data on the performance and the electric consumption measured.

The electric energy was measured by a wattnode. This equipment counts up the number of pulses (δ) generated within a timestep. Each pulse represents a certain amount of energy. Therefore, it was easy to determine the electric energy consumed at each timestep using a specific proportional coefficient (k).

$$Q_w = k \sum_{timestep} \delta \tag{2}$$

The electric energy was calculated on the following equipment (w):

- Baseboards
- Electric furnaces
- Heat pumps

The total heating energy demand (Q_h) was determined by adding the air handler heating energy to the baseboard heating energy.

$$Q_h = Q_c + \sum_{baseboard} Q_w \tag{3}$$

The total electric energy consumption (Q_e) for each site was calculated by adding all the measured electric energy of the equipment involved in the heating of each house.

$$Q_e = \sum_{heat\ pump} Q_w + \sum_{furnace} Q_w + \sum_{baseboard} Q_w \tag{4}$$

The performance was determined by the energy savings (E) calculated over the heating period. It represents the amount of energy that was not consumed because of the use of heat pumps. It was calculated by removing the total electric energy from the total heating energy of each house.

$$E = Q_h - Q_e \tag{5}$$

This value was also given in percentages ($E_{\%}$) to facilitate the analysis.

$$E_{\%} = \frac{Q_h - Q_e}{Q_h} \tag{6}$$

A seasonal COP was evaluated for the heat pumps. This value represented their heating performance. The heating energy and the electric energy of the heat pumps were used to calculate the COP.

$$COP = \frac{Q_c}{Q_e} \tag{7}$$

3 RESULTS AND DISCUSSION

3.1 Energy Savings

The annual heating demand is presented in Figure 5. For houses equipped with 2.5-ton single stage heat pumps, the heating energy was around 11,000 kWh. For houses equipped with the 3-ton central variable speed, the total heating energy was close to 16,600 kWh, and for houses with ductless heat pumps, it was about 17,500 kWh.

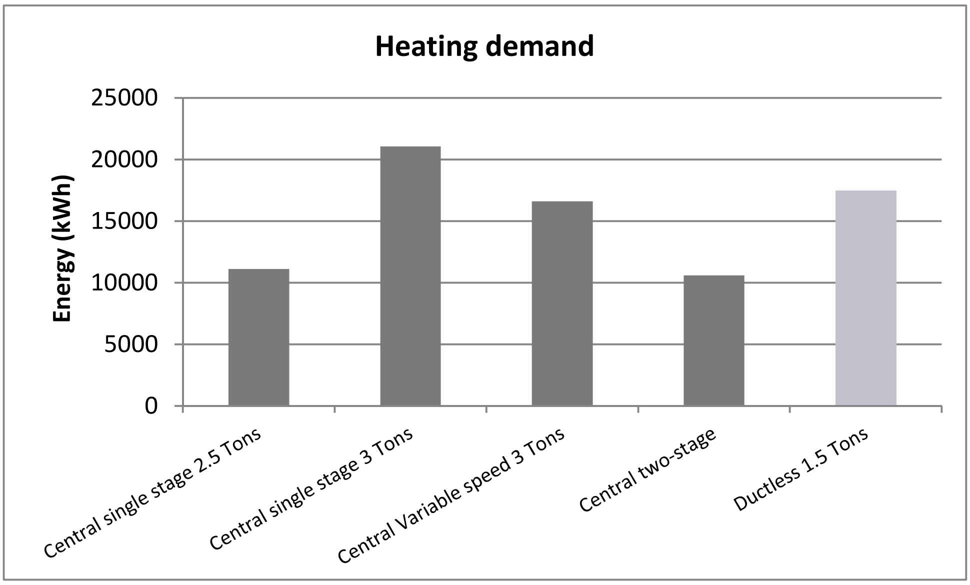

Figure 5: Heating demand

The energy savings in kWh are shown in Figure 6 and in percentages in Figure 7. The results show that the mean value of the energy savings with the 2.5-ton single stage heat pumps was 3,100 kWh while the savings calculated for the 3-ton single stage pumps was 6,100 kWh. However, the percentage values of these two variables were around 28% for all single stage heat pumps. It can therefore be concluded that, even if more energy is saved with higher capacity heat pumps, the fact that they are installed in larger houses does not increase the relative energy savings. The performance of the two-stage heat pump was similar to the two other single stage heat pumps. The cycling decrease did not seem to increase the heat pumps' performance.

The main objective of this study was to evaluate the performance of cold climate heat pumps (variable speed) in actual climatic conditions in Québec. As seen in Figure 6, the energy savings were around 7,500 kWh with this particular type of equipment. Compared to the 3-ton single stage heat pumps, this result shows that the cold climate pumps generate a significant increase in energy savings due to lower temperature balance point. The capacity of the cold climate heat pumps have the capability of providing space heating energy efficiently until the temperature falls below -20°C to -25°C. Figure 7 shows that the energy savings generated by the cold climate heat pump was about 45%, while the single stage pumps only generated about 28% in energy savings. The capacity of single stage heat pumps allows them to meet the required heating demand down to temperatures of -8°C to -10°C. At lower temperatures, the auxiliary electric heaters must operate to meet the space heating load since there is insufficient heating capacity by the heat pump. The heating capacity of cold climate heat pumps have the capability of meeting the heating load down to temperatures of -25°C efficiently (COP >1), thus avoiding the use of auxiliary heaters.

The heating energy of the sites where ductless heat pumps were installed was similar to the sites with 3-ton cold climate heat pumps were installed. The results show that the energy savings for the ductless heat pumps was around 4,400 kWh. This value represents 25% of the total heating energy of the households meeting a significant portion of the heating demand through equipment usually installed for cooling purposes. Compared to the cold climate heat pumps and based on their capacity, ductless heat pumps meet relatively the same proportion of the total heating energy of a household. This indicates that ductless heat pumps affect the house where they are installed according to their capacity more than based on the size of the heated zone of the house where they are installed. It would be relevant to analyze the energy savings of ductless heat pump with regards to their sizing, and to compare them with the savings generated by central cold climate heat pumps of a similar size.

We observed that not all ductless systems were used for heating. For example heat pump #22 did not generate any energy savings when used for heating, because it had not been activated by the household.

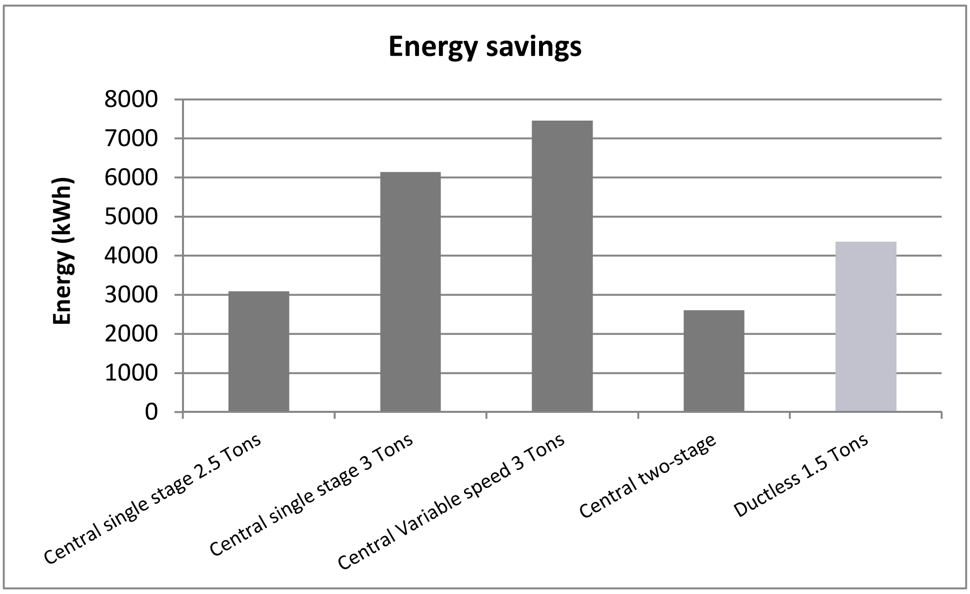

Figure 6: Energy savings (kWh)

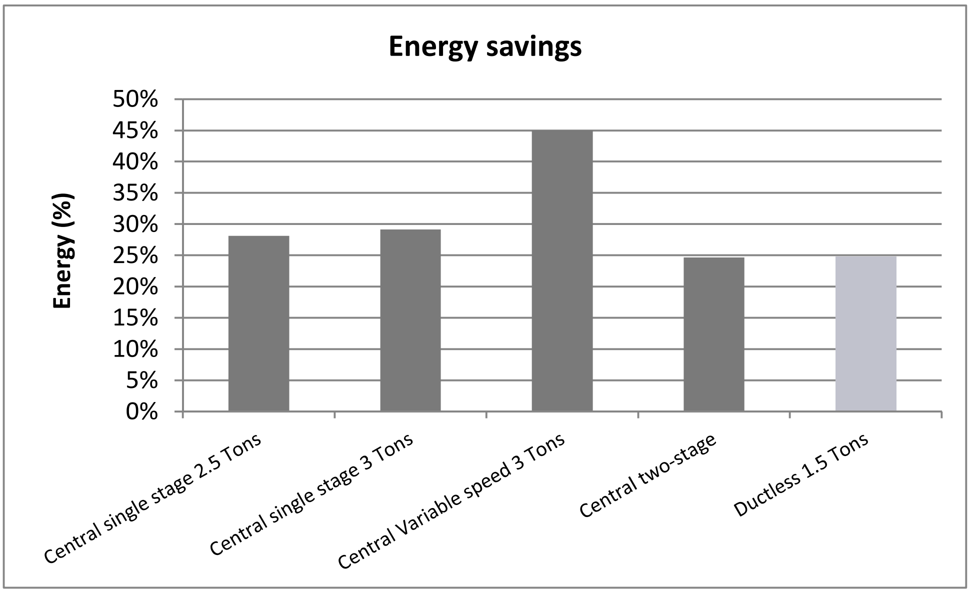

Figure 7: Energy savings (%)

3.2 Standard Performance Coefficient HSPF

The Heating Seasonal Performance Factor (HSPF) represents the rating of a heat pump in specific conditions, and is defined by the CAN/CSA-C656-05 standard. It is defined as the total space heating required during the heating season (BTU) divided by the total electric energy consumed (W) for space heating. The BTU/hr/W HSPF unit can be changed to a (W/W) COP unit by dividing the value by 3.413. A test procedure is defined within this standard to estimate the thermal capacity and the heating performance of the heat pumps at various temperature levels. This performance data is used in a BIN model to calculate the energy provided by the heat pump to heat the houses. Some variables such as the heating demand of the houses are estimated according to the capacity of the heat pumps and can affect the HSPF.

In this study, the COP was defined as the total space heating measured during the space heating season (kWh) divided by the total electric energy consumed (kWh) for space heating. This coefficient of performance took into account the time it takes to defrost the equipment and the cycling behaviour of some of the heat pumps. It was therefore relevant to establish a comparison between the HSPF and COP.

Figure 8 presents the comparison of the measured COP of the heat pumps and the HSPF (zone 5) provided by the heat pump manufacturers. For the comparison of the COP and the HSPF, axes of COP and HSPF in Figure 8 are consistent. Our first observation was the difference in amplitude of the COP compared to the HSPF. For single stage heat pumps, the HSPF was about 7.5 (equivalent COP of 2.2) while the COP measured was 1.4. The HSPF of the cold climate and ductless heat pumps was respectively 8.2 and 8.9 (equivalent COP of 2.4 and 2.6). The COP of the cold climate heat pumps was 1.9 and even lower for the ductless heat pumps at 1.3. It can therefore be concluded that the HSPF always overestimates the heating performance of this type of equipment. In HSPF rating, the equipment's operation is idealized because the HSPF criteria are the following:

- Heat pumps provide all the heating needs for temperatures over the balance point
- When below the balance point, auxiliary heating devices compensate by providing additional heat to the energy provided by heat pumps at their maximum operation
- Cut-off options provided by the installer are not considered

Based on this observation, the HSPF of single stage heat pumps is more overestimated than the HSPF of cold climate heat pumps. The balance point of single stage heat pumps is higher (-10°C) than the balance point of cold climate heat pump (-25°C). In addition, the cut-off point is at about -12°C for single stage heat pump while cold climate heat pumps can operate down to -28°C. So it is not recommended to compare the HSPF of different technologies.

As a result of these basic criteria, the HSPF ratings are often overestimated. The HSPF calculation method does not take into account the equipment's operation at very low temperature. The heating demand and the performance of heat pumps are evaluated for an outside temperature of 8°C, 1.7°C and -8.3°C. A more accurate evaluation of cold climate heat pumps should include an evaluation at low temperatures (-18°C for example). In Québec's cold climate, the HSPF is not adequate to evaluate the performance of heat pumps. However, it can provide a good idea for the classification of heat pumps based on similar technologies.

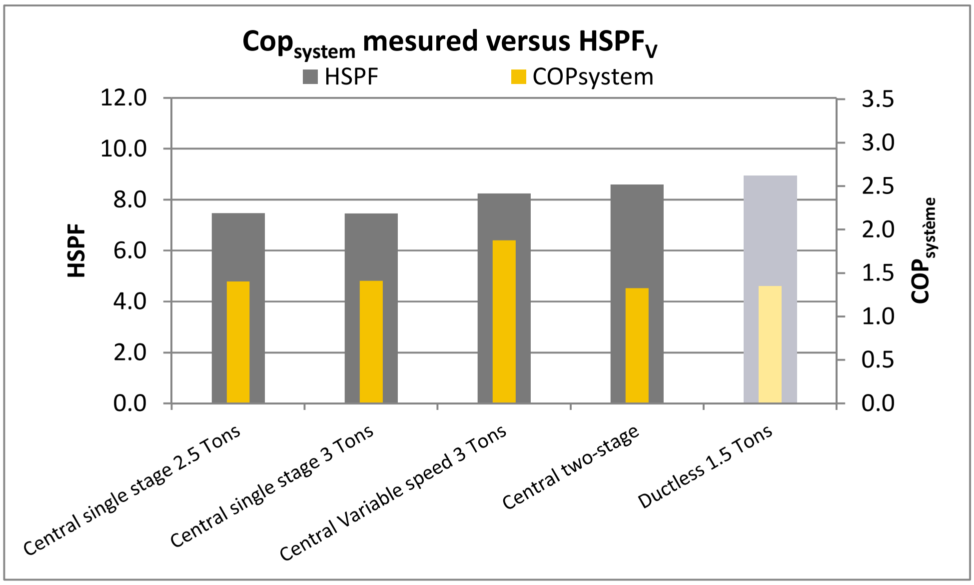

Figure 8: COP$_{system}$ measured compared to HSPF

4 CONCLUSION

The purpose of this study was to evaluate the heating performance of different technologies of heat pumps in the specific climate of Québec. Therefore, a study was conducted on 22 houses in the Montreal and Trois-Rivières regions acquiring the thermal properties of the houses and installing data acquisition equipment to monitor the performance of various heat pumps in a real household setting. The monitoring campaign lasted for 21 months (from September 2011 to May 2013). The weather in the two areas was very similar. After an analysis of the thermal behaviour of the houses, 13 of them were chosen to calculate energy parameters that permitted evaluation and comparison of the heating performance of the heat pumps installed in those houses. The heat pumps were classified under three main categories: single stage, variable speed (or cold climate) and ductless.

The results show that the performance of single stage heat pumps generates similar energy savings regardless of their capacity. The energy savings with all the single stage heat pumps were in the vicinity of 28%. It was also found that cold climate heat pumps proved to be the most efficient heat pump system evaluated in this study achieving energy savings of 45%. On the other hand, ductless heat pumps, with a technology that is similar to that of cold climate heat pumps, generated energy savings of 25%. Compared to the cold climate heat pumps and based on their capacity, ductless heat pumps meet relatively the same proportion of the total heating energy of a household.

By comparing the HSPF of the heat pumps provided by the manufacturers with a measured seasonal COP, it was shown that the HSPF is not an accurate indicator for the evaluation the energy savings (%) generated by heat pumps when comparing standard ASHPs to cold climate ASHPs. The COP of the cold climate heat pumps was higher than the COP of the single stage heat pumps. This indicates that the HSPF can indeed be used to classify heat pumps based on similar technologies, which is the main objective of this parameter.

Certain installation and operation parameters such as set back points, cut-off points or the use of zonal heating (baseboards) can have a significant effect on the overall performance of a household's heating system. This will be analyzed in the future. Also, it would be relevant to analyze the effects of cut-offs, equipment sizing or methods for using auxiliary heating elements below the balance points in the calculation of the HSPF. For ductless heat pumps, data on performance will be compared with laboratory tests.

5 REFERENCES

Karlsson F., P. Lidbom, M. Axell, U. Lindberg. 2006, "Air to air heat pumps evaluated for Nordic circumstances", *IEA Heat Pump Newsletter*, Vol. 24, n. 4/2006.

Johnson R. K. 2005. "Monitoring of two air source cold climate heat pumps", *Johnson Research*, LLC, CEATI Report No. T041700-7014.

Le Lostec B., H.F. Nouanegue, E. Dumont, 2012. "Performances des PAC air-air pour le climat du Québec," *eSim Conference 2012*, Halifax.

Tran C.T. 2012. "Méthode de mesure in situ des performances annuelles des pompes à chaleur air/air résidentielles," Thèse de doctorat, *École nationale supérieure des mines de Paris.*

Francisco P.W. 2004. "Understanding heating seasonal performance factors for heat pumps," *ACEEE Summer Study on Energy Efficiency in Buildings,* Pacific Grove.

Fairey P., D. Parker, B. Wilcox. 2004. "Climate impacts on heating seasonal performance factor (HSPF) and seasonal energy efficiency ratio (SEER) for air source heat pumps" *Florida Solar Energy Center,* Report No. FSEC-PF-413-04.

NRCAN 2013. "Choosing and Using Appliances with Energuide," *Natural Resources Canada*, ISBN 978-1-100-22074-1.

Le Lostec B., H.F. Nouanegue. 2011. "Performances d'une thermopompe centrale à vitesse variable," Institut de recherche d'Hydro-Québec, Report No. LTE-RT-2011-0093

Standards Council of Canada 2006. "Performance standards for split-system and single-package central air conditioners and heat pumps," *Standards Council of Canada*, CAN/CSA-C656-05.