RESEARCH REPORT

Distribution Retrofit: Proper Retrofit Furnace Sizing

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Distribution Retrofit:
Proper Retrofit Furnace Sizing

for

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Ottawa, Ontario

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EXECUTIVE SUMMARY

The Building Performance Section of the Saskatchewan Research Council (SRC) was contracted by Canada Mortgage and Housing Corporation (CMHC) to examine simple methods for determining the required retrofit furnace size for Canadian residences.

This project was intended to test simple procedures for furnace sizing in retrofit situations and quantify the advantages of proper furnace sizing when replacing heating systems.

During the course of this project the SRC found twenty-six residences willing to participate in the project. Ten of these homes had actual meter readings for the month of January in at least one year, while all twenty-six homes had long term utility records.

Three methods of determining the required retrofit furnace size were employed during this project. The most detailed of the three methods consisted of plotting the natural gas consumption per day versus the heating degree days per day for the same period. In all cases this provided a linear relationship. By extrapolating this linear relationship out to fifty three heating degree days per day (corresponding to the 2.5% design temperature for Saskatoon (-35°C)), the peak heat loss of the home could be determined. The other two methods also determined the peak heat loss using a linear relationship of the natural gas consumption per day versus the heating degree days per day but only used two meter readings. The second method used the meter readings taken by the utility company every three months, while the third method used meter readings that were taken at the start and end of January.

When estimating the predicted retrofit furnace sizes the peak heat loss for each home (found using each of the methods) was increased by forty percent (the maximum suggested by F280). All of the homes were still dramatically over sized (from 1.22 to 3.86 times larger than forty percent over peak heat loss).

Modelling of the effects of furnace over sizing using the HOT2000 residential modelling software package indicated that there are no energy costs or savings associated with over sizing of mid- and high-efficiency furnaces. This does not agree with some of the information that is published. In fact the published information about mid- and high-efficiency furnaces almost always indicates that proper furnace sizing will reduce the energy consumption of the heating system. There are also publications that indicate high-efficiency (condensing) furnaces operate better if they are oversized and have shorter run times.

ACKNOWLEDGMENTS

The authors extend their thanks to the homeowners in the furnace sizing project for their enthusiasm, willingness to learn, and commitment to the project and energy reduction, and to CMHC for funding this project.

Thanks also go to Mr. Don Fugler, CMHC Project Officer, for his assistance in planning and ongoing development of the project.

DISCLAIMER

This study was conducted by the Saskatchewan Research Council for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretation, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

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RÉSUMÉ

La Société canadienne d'hypothèques et de logement a commandé une étude auprès du service responsable de la performance des bâtiments au Saskatchewan Research Council (SRC) pour qu'il examine des méthodes simples pour déterminer la capacité thermique requise du générateur d'air chaud dans le cadre de travaux de rattrapage éconergétiques dans les résidences canadiennes.

Ce projet avait pour objectif de mettre à l'essai des méthodes simples pour déterminer la capacité des générateurs d'air chaud à la suite de travaux de rénovation éconergétiques, ainsi qu'à quantifier les avantages découlant de l'installation d'un générateur d'air chaud de remplacement de capacité adéquate.

Au cours de ce projet, le SRC a trouvé 26 résidences dont les propriétaires ont accepté de participer à l'étude. Pour dix d'entre elles, on détenait des relevés de compteur réels pour le mois de janvier pour au moins une année, tandis que pour l'ensemble des 26 résidences, on disposait de données à long terme des services publics.

Trois méthodes de détermination de la bonne capacité de générateur d'air chaud ont été utilisées. La plus détaillée consistait à dresser un bilan de la consommation quotidienne de gaz naturel par rapport aux degrés-jours de chauffage pour la même période. Dans tous les cas, il en a résulté une relation linéaire. En extrapolant cette relation jusqu'à 53 degrés-jours de chauffage par jour (c'est-à-dire 2,5 % de la température de calcul pour Saskatoon [-35 oC]), on a pu déterminer la perte thermique de pointe pour la maison. Les deux autres méthodes ont mené au même résultat grâce à la relation linéaire de la consommation quotidienne de gaz naturelle par rapport aux degrés-jours de chauffage, mais en n'utilisant que deux relevés de compteur. La deuxième méthode employait des relevés des services publics effectués tous les trois mois, tandis que la troisième méthode utilisait des relevés du début et de la fin janvier.

En estimant la capacité prévue du générateur d'air chaud, la déperdition de chaleur de pointe pour chaque maison (trouvée à l'aide de chaque méthode) s'est accrue de 40 % (le maximum recommandé par F280). Dans toutes les résidences, la capacité du générateur d'air chaud était encore beaucoup trop importante (de 1,22 à 3,86 fois supérieure à une capacité de 40 % au-dessus de la perte thermique de pointe).

L'utilisation du progiciel de modélisation résidentielle HOT2000 pour repérer les effets d'un générateur d'air chaud dont la capacité est trop grande a indiqué qu'aucune économie d'argent ou d'énergie n'est réalisée par l'installation d'un générateur d'air chaud à moyen et à haut rendement. Cela ne correspond pas à certains renseignements publiés à ce sujet. En fait, l'information publiée sur les générateurs d'air chaud à moyen et à haut rendement (à condensation) indique pratiquement toujours qu'un générateur d'air chaud de capacité adéquate réduira la consommation d'énergie du système de chauffage. Certaines publications affirment également que les générateurs d'air chaud à haut rendement (à condensation) fonctionnent mieux et moins longtemps s'ils ont une surcapacité.

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1 Introduction / Background

The Building Performance Section of the Saskatchewan Research Council (SRC) was contracted by Canada Mortgage and Housing Corporation (CMHC) to examine simple methods for determining the required retrofit furnace size for Canadian residences.

This project was started on August 30, 2002 and completed in January 2003.

2 Objectives

The objectives of this research project were:

- to develop recommendations and to test simple procedures for furnace sizing in retrofit situations.
- to quantify the advantages of proper furnace sizing when replacing heating systems.

3 Scope

SRC located twenty-six residences willing to participate in the project, which was six more than required by the original contract. Of these twenty-six homes ten had actual January natural gas consumption readings. All twenty-six homes had long term utility records.

All twenty-six houses were examined using the historical plot method and the three month consumption method. Ten of the homes were also analyzed using the actual January natural gas consumption values. Using each of these methods the required retrofit furnace size was determined.

Six of the houses were chosen at random and modelled using the HOT2000 residential modelling software package (version 8.72).

After the analysis was performed a presentation was made to the twenty-six home owners involved in the project explaining the project and it findings. The handout that was provided to the homeowners is included in Appendix B.

4 Methodology

An internal company e-mail was sent to the Saskatoon employees of the Saskatchewan Research Council asking for volunteers for the project. From this initial solicitation ten homes were obtained that had actual January natural gas consumption values. A second e-mail was sent out for volunteers that did not necessarily have actual January data. This second e-mail and personal contacts produced another sixteen volunteers. All twenty-six of the homes were located in Saskatoon which has annual average heating degree days of 6077 °C-days.

This section explains in detail how each of the three methods examined were used to predict the required retrofit furnace size.

4.1 Historical Consumption Plot Method

The historical consumption plot method was used on all twenty-six houses. Historical natural gas utility records were obtained from the home owners and SaskEnergy (the natural gas utility). It should be noted that some of the home owners read their own meters more frequently than the utility company does (every three months). The home owners' meter readings and the actual meter readings from the utility were used in this method. Table 4.1.1 shows the meter readings obtained for House V (first and second columns).

Table 4.1.1: Example Data for House V

1	*2*	*3*	*4*	*5*	*6*
Date	Meter Reading (100 ft^3)	Consumption (m^3)	m^3 / day	Cumulative HDD	HDD / day
2000/12/1	9431	---	---	40572.6	---
2001/3/1	9869	1191.8	13.24	43556.5	33.15
2001/6/5	71	549.6	5.73	44781.1	12.76
2001/9/5	146	204.1	2.22	44901.3	1.31
2001/12/3	360	582.3	6.54	46173.2	14.29
2002/3/6	845	1319.7	14.19	49013.3	30.54
2002/6/4	1091	669.4	7.44	50635.7	18.03
2002/9/4	1162	193.2	2.10	50805.2	1.84

The values in the consumption column were calculated by subtracting the previous reading out of the current reading and then multiplying by the meter factor, which in this case was 2.721 cubic metres per one hundred cubic feet. Continuing with the example of House V, the consumption between December 1, 2000 and March 1, 2001 was found to be:

$$Consumption = (9869 - 9431) * 2.721 = 1191.8m^3$$

The cubic metres per day values in the fourth column were found by dividing the consumption value by the number of days between readings.

The cumulative heating degree days shown in the fifth column were calculated from Environment Canada weather data for Saskatoon. Heating degree day (HDD) values are calculated using the average daily temperature. Eighteen degrees Celsius is defined as the temperature where no heating or cooling is required. Therefore, if the average daily temperature was seventeen degrees Celsius that would equal one heating degree day, or to show this in the form of an equation:

$$HDD = 18^{o} C - AvgDailyTemperature$$

The heating degree days per day in the sixth column were calculated by subtracting the previous cumulative heating degree days from the current cumulative heating degree days and then dividing by the number of days in between.

A spreadsheet of data similar to Table 4.1.1 was created containing the data for all twenty-six of the homes. Using these data, graphs of natural gas consumption per day versus heating degree days per day were created for each house. The plot for House V is shown in Figure 4.1.1.

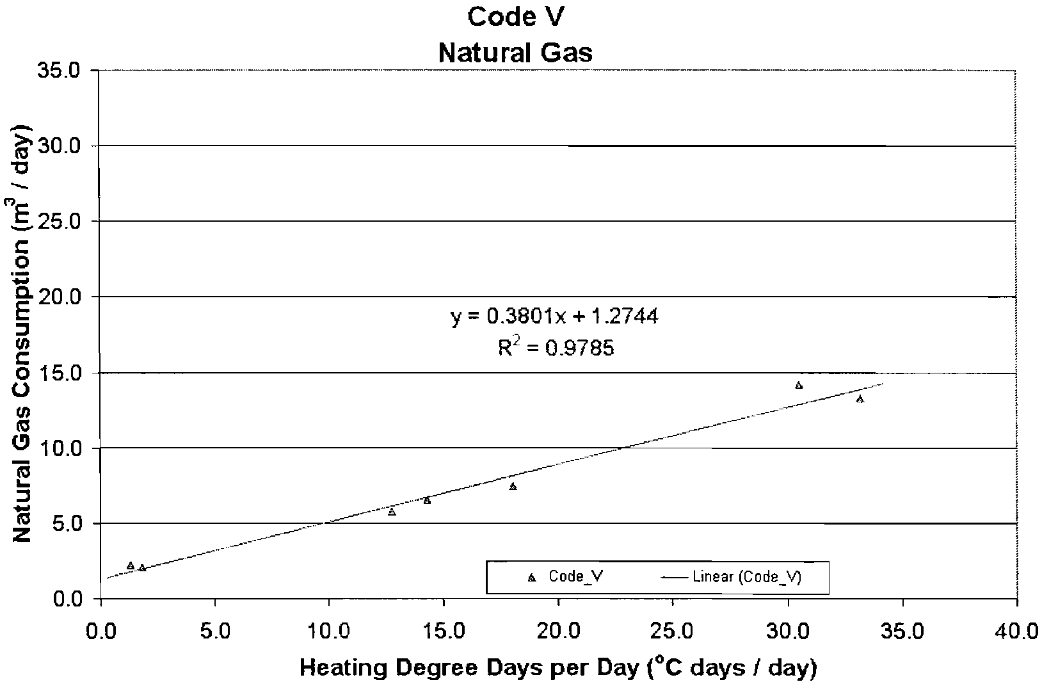

Figure 4.1.1: Plot of Natural Gas Consumption Versus Heating Degree Days

Once the data were plotted linear best fit lines were fit to the data and the slopes and intercepts of these lines determined (Figure 4.1.1 shows the line and equation for House V). Using these equations to extrapolate the data out to 53 heating degree days (HDD) (which is the January 2.5% outdoor design temperature for Saskatoon, Saskatchewan, corresponding to -35 °Celsius [On average, only 2.5% of the hours (18.6 hours) in January have colder temperatures.]), the peak natural gas consumption was determined for each of the homes.

The peak natural gas consumption values determined in this manner include the consumption of other natural gas consuming items in the households, such as hot water heaters, ranges, barbeques, garage heaters, clothes dryers, and fireplaces. SaskEnergy provided average daily natural gas consumption values for the typical residential natural gas appliances. Subtracting the natural gas consumption values for each of the other natural gas appliances in the homes provided the peak natural gas consumption values for the heating systems alone.

As all three methods are the same from this point to the end of the calculations, the other methods shall be discussed up to determining the peak natural gas consumption values for the heating systems before the remainder of the calculations are discussed.

4.2 Actual Utility Readings Method

The actual utility readings method (three month method) was also employed on all twenty-six houses. This method employed actual meter readings performed by the utility and reported on the monthly utility bills (meter readings are done every three months in Saskatoon). Unlike the historical consumption plot method which used multiple readings this method only uses two readings (preferably encompassing the month of January). Continuing to use House V as the example, Table 4.2.1 shows the data used for this method.

Table 4.2.1: Example Data for House V

1	2	*3*	*4*	*5*	*6*
Date	Meter Reading (100 ft^3)	Consumption (m^3)	HDD for the Period	Other Appliances (m^3)	m^3 / HDD
2001/12/3	360	---	---	---	---
2002/3/6	845	1319.7	2840.1	306.0	0.3569

The values in each of the first three columns of this table were calculated in the same manner as for the historical consumption plot method. The heating degree days for the period were determined by subtracting the cumulative heating degree days at the first reading from those at the second reading.

The consumption values of the other appliances were determined by multiplying the average estimated daily consumption of each of the natural gas appliances in the households by the number of days between the two readings.

The metres cubed of natural gas per heating degree day values for each of the houses were calculated by subtracting the consumption of the other appliances from the consumption values and then dividing by the heating degree days values for the periods between readings.

Multiplying the metres cubed of natural gas per heating degree day values by fifty three heating degree days per day (design temperature for Saskatoon) provided the peak natural gas consumption values of the heating systems in each of the homes.

4.3 January Consumption Method

The January consumption method was applied to the ten homes that had actual January natural gas meter readings. For this method to work meter readings need to have been taken near the start and end of January. Table 4.3.1 shows the homeowner read data for House K in the first two columns.

Table 4.3.1: Example Data for House K

1	2	*3*	*4*	*5*	*6*
Date	Meter Reading (100 ft^3)	Consumption (m^3)	HDD for the Period	Other Appliances (m^3)	m^3 / HDD
2002/1/2	9570	---	---	---	---
2002/2/1	9699	351.0	951.1	98.7	0.2653

The consumption values for each house (column three) were calculated in the same manner as the previous two methods.

The values in columns four, five, and six were calculated in the same manner as for the actual utility readings method.

Multiplying the metres cubed of natural gas per heating degree day values by fifty three heating degree days per day (design temperature for Saskatoon) provided the peak natural gas consumption values of the heating systems in each of the homes.

4.4 Common Calculations

Once the heating systems peak natural gas consumption values were found using any of the three methods described, the heating systems' steady-state efficiencies were assumed, measured, or obtained from the heating systems' specifications. By multiplying the peak natural gas consumption values of the heating systems by the steady-state efficiencies, the heating systems' peak outputs were calculated. The peak outputs equal the peak heat losses of the homes.

It is recommended by the Canadian Standards Association (CSA)-F280 that heating systems should be no more than 40% greater than the design load, so the peak heat losses were multiplied by 1.4 to determine the maximum required heating systems outputs for the retrofit systems. Assuming that the retrofit heating systems would be either eighty or ninety percent efficient, the required retrofit heating systems inputs were calculated for each home by dividing the forty percent over sized peak heat losses by either 0.8 or 0.9.

By dividing the current heating systems sizes by the heating systems sizes recommended by each of the three methods the estimated over sizing ratio for each home was calculated.

4.5 Modelling

Energy consumption computer models were developed for six of the homes examined during this project, using HOT2000 v8.72. For the properly sized heating system case the heating system in each of the homes was set to the size indicated by the historical plot method. The properly sized heating systems include the maximum 40% above peak heat loss that is allowed by CSA-F280. Three additional modelling runs were performed on each of the homes using heating systems that were 40%, 80%, and 120% over-sized.

5 Results

Of the twenty-six homes volunteered for this project one was an apartment style condominium (Home U), the majority were bungalows, with the remainder being two stories. One home (Home W) was heated by a boiler system, while all the rest were heated using forced air furnaces (conventional, mid-efficiency, and high-efficiency units).

5.1 Furnace Specifications and Natural Gas Appliances

Information on the current furnaces and other natural gas appliances in each of the homes were solicited from the participants. Table 5.1 shows the furnace brand, model number, rated input, rated output (if available), and the number of natural gas appliances in each of the homes. It should be noted that the only homes that have furnaces with inputs smaller than 50 cubic metres per day (m^3/day) (75,000 British Thermal Units per hour (Btu/hour)) are those that changed their furnaces recently as part of a separate CMHC project examining retrofit possibilities on existing homes (Homes C and D) and the one apartment style condominium unit examined (Home U).

Table 5.1: Furnace Specifications and Numbers of Natural Gas Appliances

House	Furnace					Existing	Other Natural Gas				
Code	Brand / Model #	Input	Input	Output	Output	Efficiency	DHW	CD	Stove	FP	BBQ
		(BTU / hr)	(m^3 / day)	(BTU / hr)	(m^3 / day)	(%)	#	#	#	#	#
A	Lennox G8-110T	110,000	74.76			72.0%	1	0	0	0	0
B	Rheem RGDA-100CBEA	100,000	67.96	76,000	51.65	76.0%	1	0	0	0	0
C	Carrier Weather Maker 9200	60,000	40.78	56,000	38.06	93.0%	1	0	0	0	0
D	Bryant Plus 90 (high/low) (60k/39k)	60,000	40.78	56k / 36k	38.06/24.47	93.0%	1	0	1	0	1
E	Rheem Classic 90 Plus	105,000	71.36			72.0%	1	0	0	0	0
F	ICG HAS-150	150,000	101.94	120,000	81.55	76.0%	1	0	0	0	0
G	Clare Brothers Ltd. HBG-138-M	125,000	84.95			72.0%	1	0	0	2	0
H	Lennox G24M/4-100R-2	100,000	67.96	82,000	55.73	82.0%	1	0	0	0	0
I	Lennox G8-180-1	180,000	122.33			75.0%	1	0	0	0	0
J	Olsen HBS-130	130,000	88.35	98,800	67.14	76.0%	1	0	0	0	0
K	Lennox G24M2-75A-2	75,000	50.97	61,500	41.80	82.0%	1	0	0	0	0
L	Lennox GH6-1207	120,000	81.55			72.0%	1	0	0	0	1
M	Lennox GH6-80T	80,000	54.37			72.0%	1	0	0	0	0
N	Lennox G8Q3-120-1	120,000	81.55	91,200	61.98	76.0%	1	0	0	0	0
O	ICG (11GD-140-D)	140,000	95.14	112,000	76.11	80.0%	1	1	0	0	0
P	Trane XE80	120,000	81.55			72.0%	1	1	0	0	0
Q	Coleman	105,000	71.36	84,000	57.09	80.0%	1	0	0	0	0
R	Lennox GH-91-2	91,000	61.84	72,800	49.47	80.0%	1	0	0	0	0
S	Lennox G8110T	110,000	74.76			72.0%	1	0	0	0	0
T	Lennox Elite Series (G26-100)	100,000	67.96			72.0%	1	0	0	0	0
U	ICG UGD-60-S	60,000	40.78	48,000	32.62	80.0%	0	0	0	0	0
V	Lennox G5-120-1	120,000	81.55	96,000	65.24	80.0%	1	0	0	0	0
W	1907 Andrew Stove Co.					72.0%	1	0	0	1	0
X	Carrier	150,000	101.94	114,000	77.47	68.0%	1	0	0	0	1
Y	Anthes HGB120	120,000	81.55	96,000	65.24	80.0%	1	0	0	0	0
Z	Anthes HGB100	100,000	67.96	80,000	54.37	76.0%	1	0	0	0	0

Btu / hr = British thermal units per hour
m3 / day = cubic metres per day
CD = clothes dryer
FP = fireplace
DHW = domestic hot water
BBQ = barbeque

5.2 Retrofit Furnace Sizes

Table 5.2: Recommended Retrofit Furnace Sizes

Note: all of the predicted furnace sizes in this table include the 40% oversizing as per F280.

House	Predicted Furnace Input Size if Replaced with 80% Model						Predicted Furnace Input Size if Replaced with 90% Model					
Code	January Method		Historical Records		Utility Readings		January Method		Historical Records		Utility Readings	
	80%	80%	80%	80%	80%	80%	90%	90%	90%	90%	90%	90%
	$(m^3$ / day)	(BTU / hr)	$(m^3$ / day)	(BTU / hr)	$(m^3$ / day)	(BTU / hr)	$(m^3$ / day)	(BTU / hr)	$(m^3$ / day)	(BTU / hr)	$(m^3$ / day)	(BTU / hr)
A	**24.54**	36115	**25.46**	37470	**25.41**	37390	**21.82**	32103	**22.64**	33307	**22.59**	33235
B	---	---	**34.00**	50031	**32.72**	48143	---	---	**30.22**	44472	**29.08**	42793
C	**37.84**	55680	**38.93**	57283	**34.67**	51022	**33.64**	49493	**34.60**	50918	**30.82**	45353
D	**27.43**	40366	**29.76**	43786	**25.43**	37416	**24.38**	35881	**26.45**	38921	**22.60**	33259
E	**47.88**	70454	**45.68**	67213	**43.12**	63450	**42.56**	62626	**40.60**	59745	**38.33**	56400
F	**37.77**	55571	**38.65**	56870	**31.25**	45989	**33.57**	49396	**34.35**	50551	**27.78**	40879
G	**24.93**	36683	**24.80**	36493	**23.36**	34379	**22.16**	32607	**22.04**	32438	**20.77**	30559
H	**28.50**	41930	**28.14**	41408	**26.00**	38265	**25.33**	37271	**25.01**	36807	**23.12**	34013
I	**40.25**	59225	**42.59**	62664	**39.52**	58154	**35.78**	52644	**37.85**	55701	**35.13**	51693
J	**29.68**	43678	**51.74**	76126	**47.52**	69918	**26.39**	38825	**45.99**	67668	**42.24**	62149
K	**20.18**	29688	**22.44**	33023	**19.56**	28776	**17.93**	26390	**19.95**	29353	**17.38**	25579
L	---	---	**37.91**	55782	**37.24**	54793	---	---	**33.70**	49584	**33.10**	48704
M	---	---	**23.38**	34408	**22.70**	33409	---	---	**20.79**	30585	**20.18**	29696
N	---	---	**22.00**	32374	**20.61**	30326	---	---	**19.56**	28777	**18.32**	26956
O	---	---	**27.66**	40704	**24.63**	36236	---	---	**24.59**	36181	**21.89**	32210
P	---	---	**45.73**	67297	**44.72**	65801	---	---	**40.65**	59819	**39.75**	58489
Q	---	---	**38.90**	57244	**35.74**	52594	---	---	**34.58**	50884	**31.77**	46750
R	---	---	**34.21**	50334	**31.03**	45656	---	---	**30.41**	44742	**27.58**	40583
S	---	---	**30.69**	45158	**28.67**	42186	---	---	**27.28**	40140	**25.48**	37498
T	---	---	**36.56**	53801	**32.45**	47752	---	---	**32.50**	47823	**28.85**	42446
U	---	---	**18.14**	26699	**17.37**	25553	---	---	**16.13**	23732	**15.44**	22714
V	---	---	**25.38**	37348	**26.48**	38970	---	---	**22.56**	33198	**23.54**	34640
W	---	---	**53.01**	78000	**53.25**	78352	---	---	**47.12**	69334	**47.33**	69646
X	---	---	**35.43**	52137	**33.57**	49391	---	---	**31.50**	46344	**29.84**	43903
Y	---	---	**33.13**	48746	**30.39**	44719	---	---	**29.45**	43330	**27.01**	39750
Z	---	---	**43.87**	64560	**39.89**	58696	---	---	**39.00**	57386	**35.46**	52174

Table 5.2 shows the recommended retrofit furnace size for each of the homes using the historical records and utility readings methods. The table also shows the recommended retrofit furnace size based on the January method for the ten homes that had actual January readings.

Comparing the results of the January method to the historical records method (assumed to be the most accurate of the three methods) provided the following results for the 80% efficient retrofit option. The difference between the two methods was maximum at 22.05 m^3/day (32,450 Btu/hr) for Home J and minimum at 0.13 m^3/day (200 Btu/hour) for Home G. The root-mean-square (RMS) difference of all of the January method predictions from those of the historical plot method was 7.14 m^3/day (10,500 Btu/hour). After discussions with the Home J owner it was felt that the January meter readings (performed by the home owner) may have been in error. If Home J is removed, the maximum difference between the two methods drops to 2.34 m^3/day (3,445 Btu/hour) with an RMS difference of 1.63 m^3/day (2,400 Btu/hour). Therefore, ignoring Home J, the January method matched the predictions of the historical plot method to within ± 7% for all homes.

Comparing the results of the utility readings method to the historical records method provided the following results for the 80% efficient retrofit option. The difference between the two methods was maximum at 7.39 m^3/day (10,875 Btu/hour) for Home F and minimum at 0.05 m^3/day (75 Btu/hour) for Home A. The RMS difference of all the utility record method predictions from those of the historical plot method was 2.99 m^3/day (4,400 Btu/hour). Therefore, the utility readings method matched the historical plot method to within ± 7% for all homes.

Examining the 90% efficient retrofit furnace predictions, it is found that the January and utility record methods are both once again ± 7% from the historical plot method.

Figure 5.1 shows the currently installed furnace size and the recommended retrofit furnace size suggested by each method if the current furnace were replaced with an 80% efficient unit.

As can be seen quite readily in Figure 5.1 the current furnaces are all largely oversized, with the exception of Home C who recently replaced their furnace as part of a separate CMHC project. The amount that the current furnaces are oversized according to each of the three methods is shown in Figure 5.2.

As the home owner was unable to determine the specifications of their 1907 Andrews Stove Company boiler it was not possible to determine the oversizing ratio for Home W. The oversizing ratios of the other homes range from 1.22 up to 3.86.

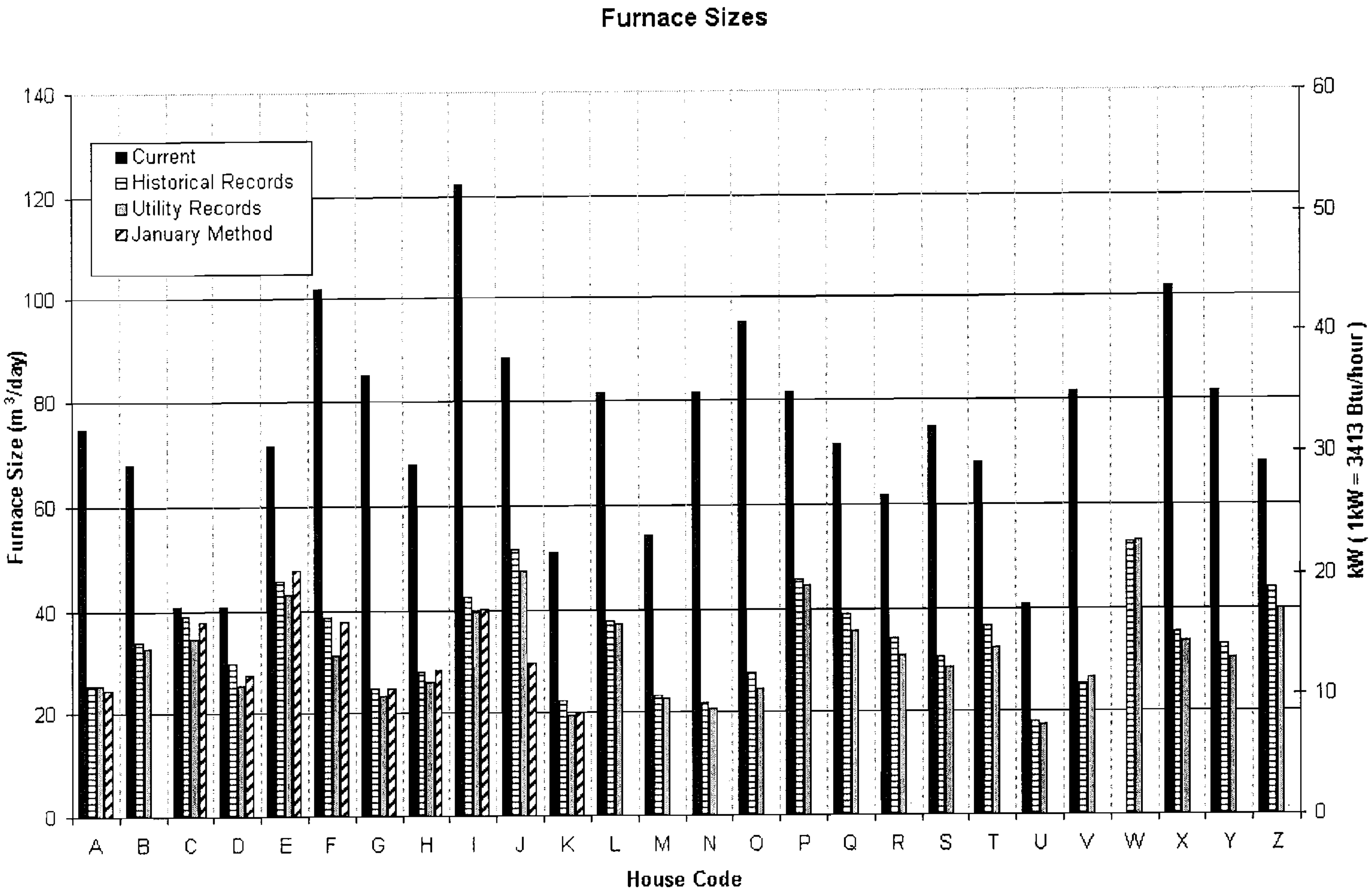

Figure 5.1: Furnace Sizes
(current and recommended retrofits assuming replacing with an 80% efficient furnace)

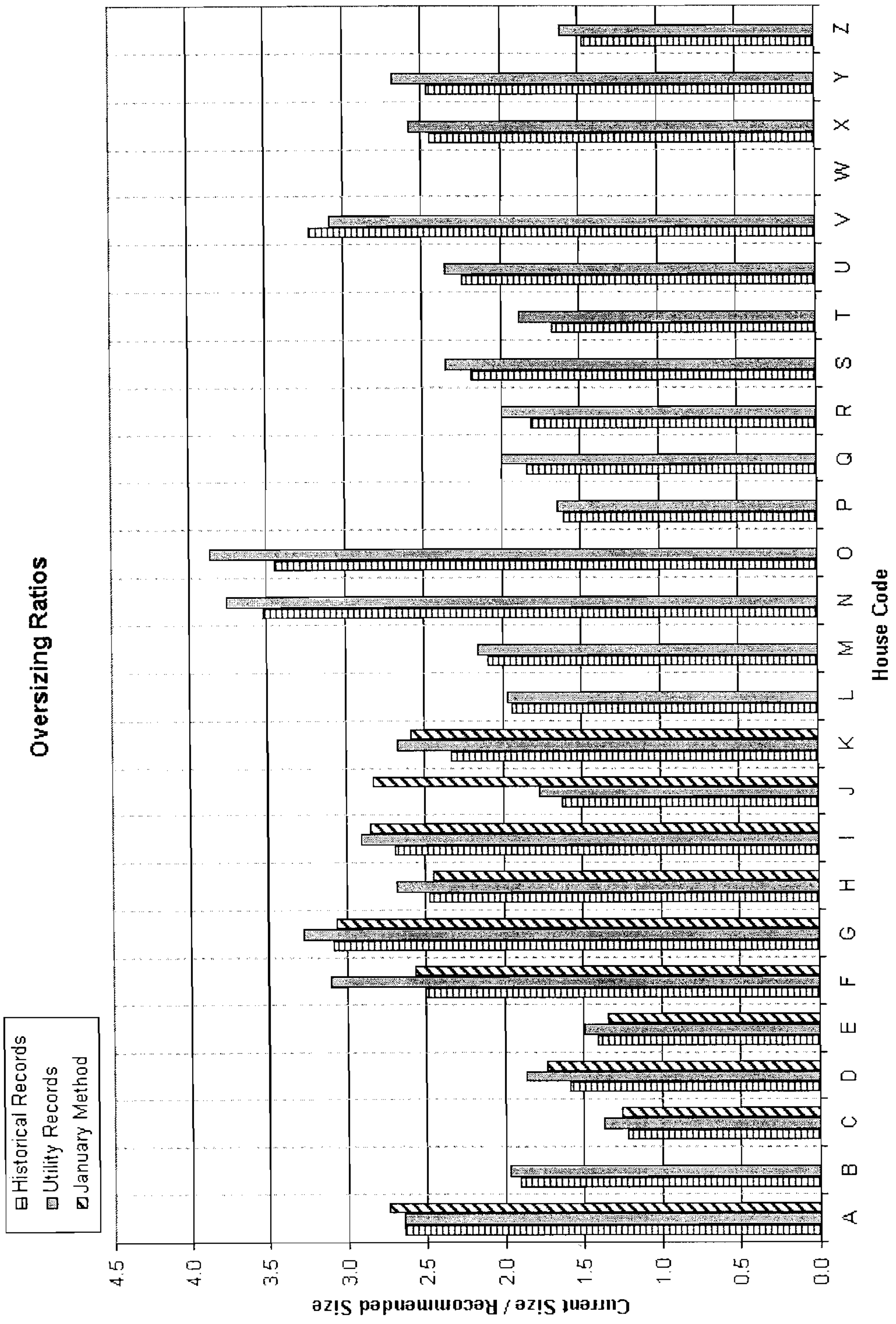

Figure 5.2: Oversizing Ratios
(if replacing current units with 80% efficient furnaces)

5.3 HOT2000 Modelling

The six homes examined using HOT2000 were bungalows and two-storey houses.

Difficulties with creating the model for House I prevented it from providing useful results for the oversizing models. The difficulties encountered caused the base case model to over predict the natural gas consumption of the home by more than 40%.

Each of the homes was modelled using a condensing furnace that was properly sized (according to the historical plot method discussed previously), 40% over-sized, 80% over-sized, and 120% over-sized according to the historical plot method. The properly sized furnace size includes the 40% above peak heat loss that is allowed by CSA F280. The results of these modelling exercises are shown in Table 5.3. Natural gas (N. G.) is shown in cubic metres (m^3) and electricity in kilowatt-hours (kWh).

Table 5.3: Heating System Consumption Values of 90% Efficient Condensing Furnaces (HOT2000)

House Code	0% Oversizing		40% Oversizing		80% Oversizing		120% Oversizing	
	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)
A	2432	439.5	2432	439.5	2432	439.5	2432	439.5
C	2074	374.8	2074	374.8	2074	374.8	2074	374.8
D	1708	2464.2	1658	3449.9	1608	4435.5	1558	5421.2
E	3493	631.3	3493	631.3	3493	631.3	3493	631.3
K	1802	325.6	1802	325.6	1802	325.6	1802	325.6

* Furnace fan motor sizes calculated by HOT2000 software package

As shown in Table 5.3 the HOT2000 models showed that the only home that had differences in heating system energy consumption between the different heating system sizes was Home D which was modelled with a continuously running fan. It should be noted that the natural gas and electrical consumption results are *identical* for each of the furnace sizes, which seems highly unlikely. The reason that the natural gas consumption drops for Home D as the furnace size increases is that the larger furnaces have larger fan motors producing more heat.

These HOT2000 results indicate that there is no penalty for over-sizing a condensing furnace. The above results should be viewed with caution though as HOT2000 does not appear to take into account:

- the electrical consumption of the induced draft fan unit, nor
- the fact that the larger units would cycle more frequently, with each cycle being accompanied by a pre- and post-burn purge of the combustion chamber.

The modelling also does not take into account the reduced efficiency associated with having greater flow restriction in the duct work as the furnace size increases and the associated increase in warm air flow. One of the key determinants of furnace efficiency is adequate warm air flow over the heat exchanger in the furnace.

Modelling was then performed examining the other extreme for over-sized furnaces. Table 5.4 shows the results obtained from HOT2000 for the same homes heated by 78% efficient naturally aspirated furnaces with standing pilot lights.

Table 5.4: Heating System Consumption Values of 78% Efficient Naturally Aspirated Furnaces

House Code	0% Oversizing		40% Oversizing		80% Oversizing		120% Oversizing	
	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)
A	3510	482.3	3590	481.8	3672	481.6	3754	481.4
C	3021	409.4	3090	409.0	3159	408.8	3230	408.6
D	2596	2464.2	2582	3449.9	2560	4435.5	2553	5421.2
E	4812	677.4	4917	676.8	5024	676.8	5131	676.3
K	2628	351.5	2688	351.3	2749	351.3	2810	351.1

* Furnace fan motor sizes calculated by HOT2000 software package

As can be seen by the HOT2000 results in Table 5.4, the effects of furnace over-sizing on low efficiency furnaces is quite dramatic with minor reductions in electrical consumption due to the reduced burn times and large increases of natural gas consumption due to furnace oversizing. Table 5.5 shows the same data with each of the fields normalized to the consumption of the properly sized unit.

Table 5.5: Heating System Consumption Ratios Compared to 0% Oversizing

House Code	0% Oversizing		40% Oversizing		80% Oversizing		120% Oversizing	
	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)
A	1.00	1.00	1.02	0.999	1.05	0.999	1.07	0.998
C	1.00	1.00	1.02	0.999	1.05	0.999	1.07	0.998
D	1.00	1.00	0.99	1.40	0.99	1.80	0.98	2.20
E	1.00	1.00	1.02	0.999	1.04	0.999	1.07	0.998
K	1.00	1.00	1.02	0.999	1.05	0.999	1.07	0.999

As shown in Table 5.5 the increase in natural gas consumption due to an oversized furnace is as high as 7% for a furnace that is 120% oversized. The homes examined during this research project were over-sized from 22% (for a home that was recently retrofit) up to 286%.

Table 5.6 shows that the results for a mid-efficiency, induced draft furnace follow the same trend as for the condensing furnace. HOT2000 does not appear to be taking in to account the pre- and post-burn purge cycles that accompany each firing of the furnace unit drawing conditioned air out of the home, and therefore, increasing the heating load on the home. As well, HOT2000 does not appear to take into account the electrical consumption of the induced draft fan unit as there is no place to input the electrical consumption of that fan unit.

Table 5.6: Heating System Consumption Values of Mid-Range Induced Draft Furnaces (HOT2000)

House Code	0% Oversizing		40% Oversizing		80% Oversizing		120% Oversizing	
	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)	N. G. (m^3)	Electrical (kWh)
A	2736	439.5	2736	439.5	2736	439.5	2736	439.5
C	2333	374.8	2333	374.8	2333	374.8	2333	374.8
D	1921	2464.2	1865	3449.9	1809	4435.5	1753	5421.2
E	3930	631.3	3930	631.3	3930	631.3	3930	631.3
K	2027	325.6	2027	325.6	2027	325.6	2027	325.6

* Furnace fan motor sizes calculated by HOT2000 software package

The modelling results of the HOT2000 software package are found to be somewhat unsatisfactory as the results for the different oversizing amounts were identical. Unfortunately, during this research program no better software for modelling the energy consumption of furnaces was located.

The published literature on over sizing of high-efficiency furnaces is quite contradictory. Articles that can be found in places like the National Post's Business magazine (2003) or SaskPower's Residential Energy Check web-site indicate that over sizing of high efficiency furnaces causes them to operate inefficiently and use up to 20% more power than necessary. But, other publications like the Office of Energy Efficiency's Heating with Gas (2001) state:

> " Contrary to conventional and mid-efficiency furnaces, where efficiency decreases with furnace oversizing, condensing furnaces are actually more efficient when they are oversized and run for shorter periods."

6 Discussion and Analysis

From the data collected and the analysis performed it is quite clear that the currently installed furnaces in the homes in this study are greatly oversized. The home with the smallest amount of oversizing is the one which previously changed its furnace based on recommendations made using the historical plot method.

Actual consumption data for January is much harder to obtain in Saskatchewan than the utility's actual readings, which the utility company gathers through reading the meters once every three months. For the ten houses examined using all three methods the January method and the utility readings method both provided values similar to those predicted by the historical plot method (± 7%).

The results of the modelling, using HOT2000, show that over-sizing of naturally aspirated furnaces causes an increase in the amount of natural gas consumed of up to 7% for 120% over-sized units. The HOT2000 models did not show any differences in energy consumption for the mid- and high-efficiency furnaces.

No matter what kind of furnace is used, low-, mid-, or high-efficiency, if the furnace fan is going to be run continuously instead of intermittently then furnace over-sizing has large effects. For all three styles of furnace the electric power consumed during the heating season by a continuously running furnace fan doubled when the furnace went from properly sized to 120% oversized using the fan sizes calculated by HOT2000. The only houses involved in this research project that were not more than 120% oversized were the houses that had been retrofit as part of a separate CMHC research project.

7 Summary

By soliciting within the company and by personal contact twenty-six volunteers were found who were willing to have their homes examined during this project.

The homeowners were asked to provide the make, model, input size, and output size of their current heating systems, and to provide a list of the other natural gas consuming appliances in their homes. One of these homes was unable to determine the input specifications of their current heating system and as such the amount that their system was oversized could not be determined. Of the twenty-five remaining homes ten had actual January consumption values.

SaskEnergy, the natural gas utility company in Saskatchewan, provided eighteen months of consumption values for each of the homes (actual and estimated readings).

The furnace combustion efficiencies were determined by one of three methods: input / output specifications, measurements, or estimates based on the year and type of furnace.

The data from each of the houses was applied to the three estimation methods to determine the required retrofit furnace size for each home. These estimates showed that all of the homes studied have largely oversized heating systems (unless they have recently been retrofit using the historical plot method). The

January method provided retrofit furnace sizes within ± 7 % of the values provided by the historical plot method. The utility reading method provided retrofit furnace sizes within ± 7% of the values provided by the historical plot method.

According to the HOT2000 models oversizing of furnaces makes a large difference for naturally aspirated furnaces but no difference for mid- and high-efficiency furnaces that operated their fans only for heating. For all furnaces, if the fan is run continuously or for air-conditioning, the electrical consumption increases proportionally to the amount that the furnace is oversized.

8 Recommendations

It is recommended that:

- field tests of mid- and high-efficiency furnaces be performed to determine the actual differences in performance due to furnace oversizing
- a study should be undertaken to determine if the increased cycling frequency of the furnace due to oversizing has any bearing on the maintenance costs or lifetime of the heating system (in conjunction with a study of newer electronic thermostats)
- field tests should be undertaken to determine the differences in resident comfort levels that may be attributed to furnace oversizing (ie. colder rooms further from the furnace, increased noise of larger fans, frequent temperature swings, etc.)

9 References

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