Final report on the project to measure the effects of ECM furnace motors on gas use at the CCHT research facility

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Canadian Centre
for Housing Technology

Centre canadien des
technologies résidentielles

Final Report on the Effects of ECM Furnace Motors on Electricity and Gas Use: Results from the CCHT Research Facility and Projections

Gusdorf, J.; Hayden, S.; Entchev, E.; Swinton, M.;
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Canada

The Canadian Centre for Housing Technology (CCHT)

Built in 1998, the Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing. The twin houses offer an intensively monitored real-world environment with simulated occupancy to assess the performance of the residential energy technologies in secure premises. This facility was designed to provide a stepping-stone for manufacturers and developers to test innovative technologies prior to full field trials in occupied houses.

As well, CCHT has an information centre, the InfoCentre, which features a showroom, high-tech meeting room, and the CMHC award winning FlexHouse™ design, shown at CCHT as a demo home. The InfoCentre also features functioning state-of-the art equipment, and demo solar photovoltaic panels. There are over 50 meetings and tours at CCHT annually, with presentations and visits occurring with national and international visitors on a regular basis.

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Prepared For:

Canada Mortgage and Housing Corporation
The Office of Energy Efficiency, NRCan
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The heating and the cooling projects were actually separate, with some different partners and funding arrangements for each. All results have been combined into this final report. The various partners have agreed to this because of their compatibility, and the logic and usefulness of combining this information.

Acronyms & Abbreviations

A/C	Air conditioning or air conditioner.
ACEEE	American Council for an Energy-Efficient Economy
ACT	The Advanced Combustion Technology Lab, a part of NRCan and a project partner.
CCHT	The Canadian Centre for Housing Technology, a part of NRC. Where the ECM tests were conducted.
CMHC	The Canada Mortgage and Housing Corporation, a project partner.
COP	coefficient of performance of an A/C, watts of cooling / watts input..
ECM™	Electronically Commutated Motor. A trademark of General Electric.
EER	energy efficiency ratio of an A/C, Btu/h of cooling / watts input.
EGD	Enbridge Gas Distribution, a project partner.
GAMA	Gas Appliance Manufactures Association.
GHG	Greenhouse Gases.
HOT2000	A building energy simulation program.
kWh	kilowatt-hour.
L	litre.
NRC	The National Research Council of Canada.
NRCan	Natural Resources Canada.
OEE	The Office of Energy Efficiency, a part of NRCan and a project partner.
PSC	Permanent Split Capacitor motor.
RH	relative humidity.
y	year.

Executive Summary

An evaluation of the impact of Electronically Commutated Motors (ECM*) on electrical and gas energy use has been carried out at the Canadian Centre for Housing Technology (CCHT) in Ottawa, Canada. The purpose was not only to demonstrate the ability of the high efficiency ECM motor technology to save large amounts of electrical energy in moving air in forced air heating and cooling systems, but also to quantify the amount of any extra natural gas that would be required during the heating season, and extra electrical energy that could be saved in the cooling season, in a climate that is typical of the Canadian winter heating season.

The two CCHT houses were benchmarked (run with the normal permanent split capacitor (PSC) fan motors in both) to show that their operation was nearly identical for 17 days during the heating season, and for 29 day during the air conditioning season. Heating season testing was done over 29 days between February 15th and May 25th 2002, and clearly showed significant reductions in the use of electricity, and corresponding increases in natural gas use. Cooling season testing occurred over 41 days between August 1st and October 3rd 2002, and showed reductions in electricity use for both the furnace fan and the air conditioner compressor.

The HOT2000 energy simulation model was used to generalize the results to an entire year, for both mid- and high-efficiency furnaces in a variety of house types in four Canadian cities. The house types are R-2000, typical new, typical existing, typical row, and typical row with ⅓ horsepower (HP) fan motors. (All other houses have ½ HP motors). The cities are Winnipeg, Toronto, Ottawa and Moncton. Excluding the rows with ⅓ HP motors, the results for houses that operate the furnace fan in continuous circulation mode can be summarized as follows:

- Savings of electricity are more than 1,500 kWh/year in all cases. For houses without air conditioners, they range from 1,535 kWh/y in a new house in Ottawa and existing house in Toronto to 1,823 kWh/y in a row house in Moncton. With air conditioning, the range is from 2,795 kWh/y in an existing house in Winnipeg to 2,991 kWh/y in a row house in Moncton. As a percentage of electrical use by the entire house, the savings range from 13% to 18% without air conditioning, and from 20% to 25% with air conditioning. Electrical savings are independent of furnace efficiency

- Increased use of natural gas due to an ECM is greater than 150 m^3/year in all cases. It ranges from 152 m^3/y in an R-2000 house with a high efficiency furnace in Toronto to 222 m^3/y in an existing house with a mid-efficiency furnace in Moncton. The percentage increase in gas use for the entire house ranges from 4.7% in a typical existing house with a high-efficiency gas furnace in Ottawa to 9.7% in Moncton R-2000 and row houses with medium-efficiency furnaces. For the detached houses, the less energy efficient houses have larger increases in m^3, but as a percentage of total they are smaller. Increases are higher with mid-efficiency furnaces.

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* ECM is a trademark of General Electric.

- Natural gas prices in the four cities vary by 37%, and electricity prices vary by 60%, so one might expect net dollar savings to be most dependent on the price of electricity. In Winnipeg, which has the lowest electricity (and gas) prices, net savings due to an ECM are the smallest, ranging from $14 to $30 per year without air conditioning, and $81 to $106 with air conditioning. In Moncton, with the highest electricity (and gas) prices, the net savings in houses without air conditioning are the highest at $38 to $75, but the net savings with air conditioning are intermediate at $144 to $182. In Toronto, with intermediate electrical (and gas) prices, the net savings without air conditioning are intermediate ($40 to $ 68), but the savings with air-conditioning are the highest ($147 to $180). (Savings in Ottawa are $1 to $7 less than in Toronto). So net annual savings from an ECM can vary from $14 to $180 depending on the price of electricity and other factors. In detached houses, net savings are almost always higher in the more energy efficient ones, and are higher with high-efficiency furnaces.

- If electrical savings are assumed to be from coal-fired electricity, net reductions in greenhouse gas (GHG) emissions due to an ECM range from 1,314 to 1,674 kg CO_2/y without air conditioners, and from 2,703 to 2,964 kg CO_2/y with air conditioners.

- If GHG emissions are based on provincial mixes of generating fuels, the effects of ECMs on GHG emissions range from an increase of 381 kg CO_2/y – in Winnipeg where most electricity is hydro-electric – to a decrease of 312 CO_2/y. Only Moncton showed any decreases; in the other cities the smallest increase was 73 kg CO_2/y.

The effects of ECMs on GHG emissions depend strongly on whether the saved electricity is coal-fired or produced by the average provincial mix. This is a controversial topic, with some people convinced that coal is always the "swing fuel," and others claiming that this exaggerates the GHG reductions. Using the provincial mix probably underestimates reductions because it is likely that generation from fossil fuels would be reduced before those from capital intensive nuclear and hydro generation (both considered to produce no GHGs). For this reason, it seems most likely that ECMs do result in net GHG reductions in most or all cases, but the size of the reductions is debatable.

In houses that do not operate furnace fans in continuous circulation mode, the effects of ECMs are positive, but far less significant. The ranges are: Electrical savings: 128 to 434 kWh/y, natural gas increases: 11 to 29 m^3/y, net dollar savings: 5 to 20 $/y, GHG reductions (coal) 116 - 424 kg CO_2/y, and GHG effects (provincial mix): increase of 50 to reduction of 25 kg CO_2/y. However, ECMs would allow such houses to switch to continuous circulation with no significant increase – usually a decrease – in utility bills. Continuous circulation provides benefits of more even distribution of fresh air and temperatures, and is especially important in houses that use the furnace fan to distribute fresh air to the house. Thus, ECMs can be part of a package promoting better circulation, comfort and health.

Gas utilities serve a mixture of houses that do and do not have continuous circulation. Some are involved in replacing furnaces, and so have an opportunity to promote furnaces that have ECMs and the capability of continuous circulation. Thus, the results have clearly demonstrated that ECMs can offer a unique gas load building opportunity to gas utilities, can save the typical homeowner money on overall energy costs, and offer benefits to the environment through reductions in GHGs associated with conventional electric power generation. The project has shown and confirmed that ECMs offer a unique fuel switching opportunity for natural gas to displace electricity with an overall efficiency about twice that of the best technology that currently exists for generating the same amount of electricity directly from natural gas.

The results also demonstrate the usefulness of the CCHT houses for carrying out important research projects on overall energy use, and their very sensitive ability to measure secondary and tertiary results of a very small change in one of the houses

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This report includes the material on ECMs in heating mode that was covered in the previous *Final Report on the Project to Measure the Effects of ECM Furnace Motors on Gas Use at the CCHT Research Facility*. This report also includes results and projection for air conditioning

Résumé

À Ottawa, au Canada, le Centre canadien des technologies résidentielles a mené une étude visant à évaluer l'effet d'un moteur à commutateur électronique (ECM*) sur la consommation d'électricité et de gaz naturel. L'étude avait pour objectifs particuliers ce qui suit : faire la démonstration des capacités d'une technologie à base d'ECM à économiser de grandes quantités d'énergie électrique par déplacement d'air à l'intérieur de systèmes de chauffage et de climatisation à air forcé ; établir la quantité supplémentaire de gaz naturel nécessaire durant les périodes de climatisation. Pour toutes ces données, il fallait tenir compte des conditions climatiques caractérisant habituellement les périodes de chauffage de l'hiver canadien.

Afin de démontrer que leur fonctionnement était presque semblable pendant 17 jours au cours de la saison de chauffage et 29 jours au cours de la saison d'air climatisé, les deux maisons du Centre canadien des technologies résidentielles ont fait l'objet d'une comparaison de référence. Dans les deux cas, les maisons étaient dotées de moteurs de ventilateur avec condensateur auxiliaire permanent.

La vérification pendant les 29 jours de la saison chaude s'est faite précisément entre le 15 février et le 25 mai 2002. Il a alors été clairement démontré une réduction substantielle de la consomation d'électricité et une hausse correspondante de la consommation de gaz naturel. La vérification pendant les 41 jours de la saison de climatisation s'est faite précisément entre le 1er août et le 3 octobre 2002. Il a alors été démontré une réduction dans la consommation d'électricité, tant pour ce qui est du ventilateur de la chaudière que pour le compresseur du système d'air climatisé.

Le modèle de simulation énergétique HOT2000 a servi à généraliser les résultats obtenus dans une année entière, cela dans le cas de chaudières à moyenne et à grande efficacité installées dans divers types de maisons construites sur le territoire de quatre villes canadiennes. Les types de maisons sont les suivants : la Maison R-2000, la maison neuve courante, la maison déjà construite courante, la maison jumelée courante et la maison jumelée courante dotée de moteurs de ventilateurs de 1/3 de ch. (Toutes les autres maisons sont dotées de moteurs de 1/2 de ch.) Les quatre villes concernées sont Winnipeg, Toronto, Ottawa et Moncton.

Si l'on excepte les maisons jumelées courantes dotées de moteurs de ventilateurs de 1/3 de ch, les résultats obtenus dans le cas de maisons où fonctionnent des moteurs de ventilateurs selon un mode de circulation continue se résument ainsi :

- Dans tous les cas de figure, les économies d'énergie électrique atteignent les 1 500 kWh par année. Pour ce qui est des maisons dénuées de systèmes d'air climatisé, on a découvert que ces économies atteignaient les 1 535 kWh par année dans une maison neuve construite à Ottawa et dans une maison déjà construite de Toronto contre 1 823 kWh par année dans une maison jumelée de Moncton. Avec l'air climatisé, les économies obtenues atteignent 2 795 kWh par année dans une maison déjà construite de Winnipeg contre 2 991 kWh par année dans une maison

* ECM est une marque de commerce de la société General Electric.

jumelée de Moncton. En pourcentage de l'électricité consommée dans la maison tout entière, les économies atteignaient de 13 à 18 p. 100 sans air climatisé, et de 20 à 25 p. 100 avec air climatisé. Les économies réalisées au chapitre de l'électricité ne sont pas dépendantes de l'efficacité énergétique des chaudières concernées.

- Dans tous les cas, la consommation de gaz naturel consécutive à la présence d'un ECM est plus élevée de 150 m^3 par année. Elle s'échelonne de 152 m^3 par année dans une Maison R-2000 de Toronto munie d'une chaudière à haut rendement énergétique à 222 m^3 par année dans une maison déjà construite de Moncton munie d'une chaudière à moyen rendement énergétique. La hausse en pourcentage dans la consommation de gaz naturel pour une maison tout entière s'échelonne de la manière suivante : elle est de 4,7 p. 100 dans une maison courante déjà construite d'Ottawa munie d'une chaudière au gaz à haut rendement énergétique contre 9,7 p. 100 dans une Maison R-2000 et une maison jumelée de Moncton munies de chaudières à moyen rendement énergétique. Les maisons jumelées à faible rendement énergétique présentent une hausse plus importante en mètres carrés, toutefois, au pourcentage du total, elle est plus basse. Les hausses étaient plus importantes avec des chaudières à moyen rendement énergétique.

- Comme les prix du gaz naturel et de l'électricité dans les quatre villes variaient respectivement de 37 p. 100 et de 60 p. 100, on pouvait s'attendre à ce que les économies nettes en dollars soient beaucoup plus dépendantes des prix de l'électricité. Ainsi à Winnipeg, ville où les prix de l'électricité et du gaz naturel étaient les plus bas, les économies nettes avec la présence d'un ECM étaient les moins élevées, s'échelonnant de 14 à 30 $ par année sans air climatisé, et de 81 à 106 $ par année avec air climatisé. À Moncton, ville où les prix de l'électricité et du gaz naturel étaient les plus élevés, les économies nettes dans les maisons sans air climatisé étaient les plus importantes, s'échelonnant de 38 à 75 $ par année, et de 144 à 182 $ par année avec air climatisé. À Toronto, ville où les prix de l'électricité et du gaz naturel étaient intermédiaires, les économies nettes avec la présence d'un ECM étaient intermédiaires, s'échelonnant de 40 à 68 $ par année sans air climatisé, et les plus élevées avec air climatisé s'échelonnant de 147 à 180 $ par année. À Ottawa, les économies se chiffraient entre 1 et 7 $, soit moins qu'à Toronto. Par conséquent, les économies annuelles nettes réalisées avec un ECM peuvent varier de 14 à 180 $ en fonction des prix de l'électricité et d'autres facteurs. Pour ce qui est des maisons jumelées, les économies nettes sont presque toujours plus élevées dans les bâtiments à haut rendement énergétique, tout en étant supérieures dans les bâtiments munis d'une chaudière à haut rendement énergétique.

- Si l'on part de l'hypothèse que les économies en électricité se rapportent à des centrales alimentées au charbon, la réduction nette des émissions de gaz à effet de serre avec la présence d'un ECM atteint de 1 314 à 1 674 kg de CO_2 par année sans air climatisé, et de 2 703 à 2 964 kg de CO_2 par année avec air climatisé.

- Si les émissions de gaz à effet de serre se fondent sur les mélanges de combustibles utilisés dans chaque province, alors les conséquences de la présence d'un ECM sur ces émissions vont d'une hausse de 381 kg de CO_2 par année - à Winnipeg, particulièrement, où il s'agit d'hydro-électricité - à une baisse de 312 kg de CO_2 par année. Seule la ville de Moncton ne montre aucune décroissance. Dans les autres villes, la plus petite hausse était de 73 kg de CO_2 par année.

L'influence des ECM sur les émissions de gaz à effet de serre dépend fortement de la possibilité que l'électricité soit produite par des centrales alimentées au charbon ou à l'aide de mélanges de combustibles propres à chaque province. Il s'agit là d'une question controversée, alors que certaines personnes sont convaincues que le charbon est toujours le « combustible du plein rendement » et que d'autres croient que l'on exagère la réduction des émissions. Le recours aux mélanges de combustibles des provinces va entraîner une sous-estimation des réductions parce qu'il est probable que l'on restreindra la production à partir de combustibles fossiles avant celle par énergie nucléaire et hydro-électricité, deux procédés exigeant de grands capitaux (mais considérés comme n'entraînant aucune émissions). Par conséquent, il semble très probable que la présence d'ECM va aboutir, dans la majorité si ce n'est dans la plupart des cas, à des réductions nettes des émissions de gaz à effet de serre, toutefois, l'importance de ces réductions peut porter à discussions.

Dans les maisons où aucun ventilateur de chaudière ne fonctionne en mode continu, les effets d'un ECM sont positifs, mais très peu importants. Voici les chiffres qui s'y rapportent : les économies en énergie électrique, de 128 à 434 kWh par année ; la hausse de la consommation en gaz naturel, de 11 à 29 m^3 par année ; les économies nettes en argent, de 5 à 20 $ par année ; la réduction des émissions de gaz à effet de serre (charbon), de 116 à 424 kg de CO_2 par année ; les répercussions en émissions de gaz à effet de serre (mélanges des provinces), d'une hausse de 50 à une réduction de 25 kg de CO_2 par année. Cependant, les ECM permettraient à ces maisons de se convertir à la circulation continuelle sans hausse importante - habituellement, il y aurait une baisse - des factures énergétiques. Une circulation continue donne l'avantage d'une distribution plus équitable d'air frais et de températures adéquates dans la maison. Cette circulation est particulièrement importante dans les bâtiments où l'on fait appel au ventilateur de la chaudière pour distribuer de l'air frais dans les pièces. Donc, les ECM peuvent faire partie intégrante d'un ensemble servant à promouvoir l'amélioration de la circulation de l'air, du confort et de la santé.

Les entreprises publiques de distribution gazière alimentent une variété d'habitations qui disposent ou non d'un système de circulation continue de l'air. Comme ces entreprises favorisent le remplacement des chaudières, elles ont la possibilité de faire la promotion de systèmes dotés d'ECM qui ont la capacité d'assurer une circulation continue. Ainsi, les résultats obtenus ont clairement démonté que les ECM pourraient offrir aux entreprises publiques de distribution gazière une occasion unique d'assurer la charge en gaz naturel des bâtiments, permettraient aux propriétaires courants de maisons d'économiser sur les coûts énergétiques globaux, et garantiraient des avantages sur le plan environnemental grâce aux réductions d'émissions de gaz à effet de serre découlant de la production classique d'électricité. Toute l'entreprise a démontré et confirmé que les ECM représentaient une occasion inégalée de se convertir au gaz naturel pour remplacer l'électricité, le tout avec une efficacité énergétique globale d'environ le double de ce qu'elle est en ayant recours au meilleur procédé actuel afin de produire de l'électricité en quantité équivalente directement à partir du gaz naturel.

Les résultats obtenus ont également servi à démontrer l'utilité des maisons construites par le Centre canadien des technologies résidentielles en ce qui concerne la réalisation d'importants projets de recherche relativement à la consommation globale de l'énergie. On a pu alors constater les capacités très relevées des responsables du Centre à évaluer les effets secondaires et tertiaires provoqués par les petits changements qui pouvaient se manifester dans l'une ou l'autre de ces maisons.

Le présent rapport englobe les données sur les ECM en mode de chauffage, données examinées dans le précédent *Final Report to Measure the Effects of ECM Furnace Motors on Gas Use at the CCHT Research Facility*. Cet ouvrage renferme également les résultats et les prévisions concernant la climatisation de l'air.

Table of Contents

1.0 Introduction

Electronically Commutated Motors (ECM™)* are brushless, permanent magnet DC motors with integrated controls. ECMs are significantly more efficient than the Permanent Split Capacitor (PSC) motors used in most residential furnaces today. The efficiency improvement is especially evident in applications that utilize reduced circulating air flow rates, as is often done in systems with continuous fan operation. Thus, using a natural gas furnace with an ECM instead of a PSC motor should reduce electrical consumption. In turn, the decreased electrical consumption should increase the amount of natural gas required to heat the house, since much of the electricity used by the motor ends up as space heat, and the more efficient motor produces less heat. The net effects should be to save the homeowner money – since natural gas is less expensive than electricity, and to reduce greenhouse gas emissions. During air conditioning, an ECM should save electricity directly and by reducing the load on the air conditioner, with no corresponding increase in gas use.

Two partnerships supported this research. In the heating season, The Buildings Group and The Office of Energy Efficiency (OEE) at Natural Resources Canada (NRCan), and Enbridge Gas Distribution provided financial support. For the cooling season, support was provided by The Buildings Group, OEE, Canada Mortgage and Housing Corporation (CMHC), Manitoba Hydro, and Enbridge Gas Distribution. The Canadian Centre for Housing Technology (CCHT) was used to measure the effects of an ECM by installing one in a furnace in one of the identical CCHT houses, while leaving the PSC motor installed in the furnace in the other house. The two houses were then operated under identical side by side conditions.

1.1 Reasons for testing an ECM

At lower speeds ECMs can save over 60% of the electricity used by PSC motors. For example, manufacturer's literature and preliminary tests showed that in low speed circulation a typical PSC furnace fan motor will use 350 to 500 Watts while an ECM will use 75 to 125 W at a comparable speed. Further, ECMs are adjustable over a larger range and maintain high efficiency at very low speed, which is a real advantage for achieving adequate ventilation at low energy cost. In contrast the PSC does not have the same flexibility to go to the lower speeds and its efficiency gets worse as its speed is reduced. The PSC is typically set at half speed for ventilation purposes and if this speed is higher than required for continuous circulation, which is usually the case, it wastes energy due to both its higher speed and inefficiency. The ECM could be set to a lower rate at which it will use 22 to 35 W, thus saving even more electricity. In a modern, airtight house in which the furnace motor runs at low speed continuously for fresh air circulation, the electrical savings with an ECM should be very significant as the furnace blower

* ECM is a trademark of General Electric.

system spends most of the time in circulation mode. During the heating season, increased use of natural gas would negate part of these savings since the heat balance requires more natural gas to be burned. However, since natural gas is less expensive than electricity, the homeowner's savings would still be substantial.

If the house is air conditioned, then the same heat balancing requirement will reduce the amount of electrical energy used by the air conditioner with an ECM, resulting in even more savings. Reducing the use of electricity should result in a net decrease in greenhouse gas emissions which can be very substantial if the electricity is coal derived. This is easily evident in the cooling season but it also occurs in the heating season even though more natural gas will be used. Taking both the efficiency differences for producing heat at home with gas (80 to 90%) versus electricity from coal at a central power plant (~30% with transmission and distribution losses), and the chemistry differences between natural gas and coal, it follows that the GHGs may be reduced by a factor of about 5 during the heating season by this unique fuel switching scenario.

1.2 Reasons for Using the CCHT Houses

The Canadian Centre for Housing Technology (CCHT) is a facility designed for doing controlled experiments on residential technologies. It includes two highly instrumented, identical, unoccupied houses. Occupancy is simulated by computer controlled operation of lights and appliances, use of hot water, and generation of heat to simulate the presence of occupants. Repeated testing under identical conditions (benchmarking) has shown that the two houses use almost exactly the same amounts of energy for space heating, air conditioning, hot water and utilities. Information on the CCHT is available on its web site, www.ccht-cctr.gc.

The identical houses at the CCHT were ideal locations for the ECM test for two reasons. First, having two identical houses at the same site allows the effects of a relatively small change in one of them to be clearly shown in the collected data, rather than based on an analysis of space heat loads derived from outdoor temperatures, wind speeds and solar radiation. Second, using the CCHT avoids problems of furnace certification and liability. In general, replacement of a furnace fan motor with a different type of motor is not common practice because changes in the airflow over the heat exchanger can result, with adverse consequences to the performance and longevity of the product (overheating or corrosion). Therefore, the furnace certification would be voided if the fan motor were replaced with a different type from that included in the original certification test report. Because the CCHT research facility is located on Federally owned land and is unoccupied, furnace certification was not an issue.

1.3 The Houses and Testing Conditions

The two CCHT houses are built to the R-2000 Standard. Each is two storeys with 223 m^2

(2,400 ft^2) of floor area, not counting the full basements. Their design heat loads at -25 °C are 12.9 kW (46.4 MJ/h or 44,000 Btu/h). The rated output of the furnaces is 19.78 kW (67,500 Btu/h), so they are oversized by 53%. Oversizing the furnace will increase the impact of switching to an ECM, but oversizing of this magnitude is common practice. The temperature range during the space heating period was -17.3 to +25.5 °C, resulting in heating loads of 4.7 to 438.2 MJ per day, and furnace gas consumption of 6.0 to 563.9 MJ/day. Their design cooling loads at 31 °C are 6.95 kW (25.0 MJ/h or 26,400 Btu/h). The rated output of the air conditioners is 7.03 kW (25.3 MJ/h or 26,700 Btu/h) The temperature range during the air conditioning period was 4.1 to 34.8 °C, resulting in air conditioner compressor consumption of zero to 33.44 kWh/day.

During this project, the furnace fans ran continuously, operating a higher speed when the furnace was firing or the air conditioner was on, and at a lower speed when they were not. This is the recommended practice in newer, more airtight houses in which the furnace fan circulates air from a heat recovery ventilator or ventilation fans. However, actual practice seems to vary across the country. A study by Unies in 1997[1] showed that in Quebec about 50% of respondents operated their furnace fans continuously, while in the rest of Canada only about 20% did. This is confirmed by a more recent study in Manitoba.[2] Continuous fan operation does increase the impact of switching to an ECM, and hence the real value of an ECM will be determined by the dominant ventilation practice in any region of the country. Up to date ventilation practice information is thus vital to understand the true value of an ECM. This may be especially true for southern Ontario which probably has the highest use of high efficiency gas furnaces, and summer air conditioning, in the country. For several years now it has been the practice to install only high efficiency furnaces in new construction and it is suspected that continuous ventilation may well have become the preferred practice. In Section 4 the HOT2000 simulation software[*] is used to project results with and without continuous furnace fan operation.

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[*] http://buildingsgroup.nrcan.gc.ca/software/hot2000_e.html

2.0 Methodology

2.1 House Preparation

Thermocouple grids were made and installed in the furnace supply and return ducts in each house. These grids consist of several thermocouples connected together so that they measure the average temperature of several points, thus accounting for variations in air temperature that can occur in furnace ducts. The grids were connected to one of the existing data loggers, which was programmed to bin the temperatures (and other variables) according to whether a furnace was in heating or circulation mode. This allowed for continuous, precise monitoring of the furnace return and supply air, and for measurement of heat gains due to the motors. During the space heating period, exterior-mounted, white plastic shades were installed on two of the south-facing windows of each of the houses. Testing in previous years has shown that these shades reduce solar gains to the point that conditions are more representative of more typical house heating requirements. The CCHT houses were actually designed to maximize solar gain and as such their conventional heating requirements are less than typical homes of similar size. Making these changes allows testing to accommodate more typical conditions, and it also allows the furnaces to operate over a wider range of loads. During the air conditioning period, the shades were removed to provide a wider range of cooling loads.

2.2 Installation of Data Loggers

The permanent CCHT data collection system was used throughout this project. In addition, NRCan's Advanced Combustion Laboratory (ACT) installed a Campbell Scientific CR10X in each house with the following sensors:

Furnace Return Air Temperature, Single Thermocouple
Furnace Return Air Temperature, Thermocouple Grid
Furnace Supply Air Temperature, Single Thermocouple
Furnace Supply Air Temperature, Thermocouple Grid
Motor Temperature
Motor Consumption
Air Flow
Flow times ΔT
RPM of the ECM

All points were binned according to fan speed.

2.3 Benchmarking

Benchmarking consists of running both of the CCHT houses under identical conditions for several days to verify that they are using the same amounts of energy. Conditions that are kept identical in the two houses include thermostat set-points (and resulting indoor temperatures), balanced ventilation rates through heat recovery ventilators, furnace airflow rates in heating, air conditioning and circulation modes, hot water use, and internal gains from lights, appliances and simulated occupancy. Once benchmarking has shown that the consumptions of the two houses are essentailly identical, then an experiment can be conducted by making a change in the Test House while leaving the Reference House unchanged. Benchmarking for space heat was done for a total of seventeen days, including eleven days before the first installation of the ECM, and six days between tests with the ECM. Benchmarking for air conditioning was done for twenty nine days, including eighteen days before the first tests with the ECM, nine days that were interspersed with ECM testing days, and two days after the ECM tests. All benchmarking and testing was done using the KeepRite Model NTC7075 BFA3 mid-efficiency natural gas furnaces in both houses, and the Heil Super High Efficiency 9000 Model # CA9024VKD2 compressors.

2.4 Testing a PSC Motor and ECM in the Fan Test Rig

In addition to the testing at CCHT, a KeepRite blower-assembly was tested in the CMHC Fan Test Rig at NRCan's Advanced Combustion Laboratory (ACT). The assembly was tested with the factory supplied PSC motor and with an ECM programmed to run at various rates. The Fan Test Rig can measure air flows and temperatures more precisely than they can be measured at the CCHT, so that the heat gains from the two motors in their various speeds can be determined precisely. This testing also allowed the efficiency of the motor-blower combinations to be determined and compared.

2.5 Installing an ECM in the Test House Furnace

A new motor bracket was purchased and attached to the ECM to facilitate motor switching. Switching between the PSC motor and the ECM involves physically switching the motors, providing AC power to the ECM, connecting thermostat leads to the ECM, and changing the thermostat fan switch from Auto to On. Motor switching can now be accomplished in about half-an-hour. The PSC motor was the original ½ horsepower (HP) motor supplied with the furnace and run in the second-highest of its four speeds during heating, in its highest speed during air conditioning, and in its lowest speed during circulation, as is normal for PSC fan motors. The ECM was a ½ HP ECM™ motor made by General Electric.

2.6 Measuring Duct Air Flows and Programming an ECM

As mentioned in the introduction, ECMs can be programmed to lower speeds than PSC motors, and energy savings are significantly increased by the lower ECM speeds. Thus, in order to take full advantage of the ECM, its circulation speed was set as low as was considered compatible with good circulation and air quality.

With the PSC motor in circulation speed, the air flows from thirteen supply ducts were measured using the CMHC bag inflation test and a heated-thermistor anemometer. The ECM motor was programmed for several circulation airflow rates, and the lowest rate that still provided adequate ventilation to all rooms was used. The air flow rates used in this project were:

Circulation Mode:	PSC:	454 L/s,	ECM:	204 L/s
Heating Mode:	PSC:	622 L/s,	ECM:	595 L/s.

With the PSC motor in circulation mode, the average main floor supply duct flow was 9 L/s, and the minimum was 4 L/s. With the ECM at the above circulation flow, the average was 6 L/s, and the minimum was 4 L/s. Thus, reducing the circulation airflow does not appear to reduce the minimum air supply to occupied rooms, and the proportional circulation of ventilation air by the furnace fan remains relatively constant. This is confirmed in **Section 3.5** by comparisons of temperature differences between the houses.

The intent was to have the heating mode flows of the two motors equal. The 4.5% difference between them is due to the fact that the ECM is adjusted in steps, and is probably within the level of accuracy of the airflow measurements, and the variability caused by different house designs and duct layouts. Air flow was measured with a Eldridge Products mass flow meter. Flow was measured at nine points representing equal areas in a 16" x 16" (406 mm x 406 mm) duct. Ten measurements were averaged at each of the nine points, and then the nine averages were averaged to get the flow.

The ECM was set to have time delays that are as close as possible to those of the PSC motor. There is a delay between the time that the burner fires and the fan goes into heating speed, and a second one between the time the burner goes off and the fan returns to circulation speed. The PSC delays are set by DIP switches on the furnace control panel, and were left at the factory settings. The ECM delays are programmed in steps. The delays are:

After burner fires:	PSC:	30 seconds,	ECM:	30 seconds
After burner stops:	PSC:	140 seconds,	ECM:	150 seconds.

At the end of the space heating period, the ECM was reprogrammed to have an air conditioning speed as close a possible to the PSC's. With the PSC motor, the air conditioning flow was measured at 681 L/s, and the ECM program was adjusted to give a flow of 710 L/s, or 4% higher. Again, this is within the limits of ECM adjustability and measurement accuracy. The furnace was factory set to have delays of 30 seconds from the time the air conditioner compressor goes on until the PSC motor goes into high speed, and from the time the compressor stops until the PSC goes into circulation speed. It was not possible to program the ECM for similar delays, so it was programmed to "slew" or ramp between its circulation and air conditioning speeds at the slowest possible rate, which was 43 seconds. A manufacturer installing an ECM might well choose to use ramping rather than abrupt speed changes because ramping may be better for motors and less noticeable by occupants.

2.7 Selection of Valid Data Points

For both benchmarking and ECM results, only complete calendar days with uniform conditions were used. Days were excluded if there was problem with the simulated occupancy that could possibly have made a measurable difference in furnace or air conditioning electricity or gas consumption. Also excluded were days in which the motor was switched, or in which there was a change to or from other experiments that were done during the same months. For space heating, days of *normal conditions* are defined as non-excluded days in which there was some gas use in each house. Days with less than and more than 50 MJ of furnace gas consumption in the Reference House are analysed separately, as explained in Section 3.2.5. For air conditioning, all non-excluded days are considered normal.

2.8 Projecting Results

The HOT2000 house energy simulation software was used to project the results from the specific days of testing at the CCHT houses to complete years at the CCHT, and to other houses, locations and furnaces. Projections were done with and without continuous circulation, and with and without air conditioning, and results are compared. Net greenhouse gas (GHG) reductions were calculated in two ways. First, on the assumption that saved electricity displaces coal-fired electricity. Although each location has it own mix of fuels for generating electricity, one can argue that reductions in demand will result in reductions in coal-fired generation. Even in Manitoba where most generation is by hydro power (zero GHGs), excess electricity is sold to the U.S. where it can displace coal. Second, GHG reductions were also calculated based on the actual mix of generation fuels in each province.

3.0 Results

3.1 The Benchmark

3.1.1 Benchmarking for Heating

Figure 1 shows the results of the benchmarking for the space heating period of this project, using the graphing technique for side by side testing developed by Mike Swinton. The coordinates of each point are the furnace gas consumption in each of the two houses for one calendar day. If the consumption in both houses were exactly the same each day, then all points would fall exactly on the 1:1 (45°) line, the slope and intercept of their linear regression would be exactly one and zero, and the correlation coefficient (r^2)* would be one. Any significant deviations from these values would indicate that the houses are not operating identically.

The benchmarking results are considered excellent, and show that the operation of the two houses was almost identical, so that any significant differences during ECM testing are due to the ECM. The seventeen benchmark points were collected on January 19th through 29th, March 27th, and May 2nd through 6th, 2002. The Reference House gas consumption varies by a factor of almost one hundred, from 6 to 564 MJ/day, and the Test House consumption varies from 4 to 558 MJ/day. The furnace capacity is 1709 MJ/day (67,500 Btu/h), so the benchmark goes from almost no furnace use to 33% of furnace capacity, which is close to the range that would be used in most heating seasons. The plotted results have a slope of 0.9891, an intercept of 2.99 MJ/day, and an r^2 of 0.998. Daily differences in gas consumption range from -10.93 to +11.78 MJ or -41.6 to +6.9%. When the two days with less than 50 MJ consumption in the Reference House are excluded (See Section 3.2.5), then the differences range from -3.5% to +6.9%. The average consumptions are 281.16 MJ in the Reference House and 281.10 MJ in the Test House, a difference of less than 0.1%. Thus, benchmarking gas consumption varied significantly from day to day, especially at low values where one or two furnace firings a day can make a large difference. But, on average the quantities are not significantly different. The complete set of daily benchmarking data for heating is shown in Table A1 of Appendix A.

These space heat benchmarking results are very consistent with benchmarks from two previous projects. The first was done from November 1999 through January 2000 for a test of combo heating and hot water systems. The second was during November 2001 for a window shade project. There were no external shades on south facing windows during these earlier benchmarks, but the shades were installed for the ECM benchmarking. Table 1 compares the

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* Formally, r is the correlation coefficient, and r^2 is the coefficient of determination, but we follow the common practice of calling r^2 the correlation coefficient.

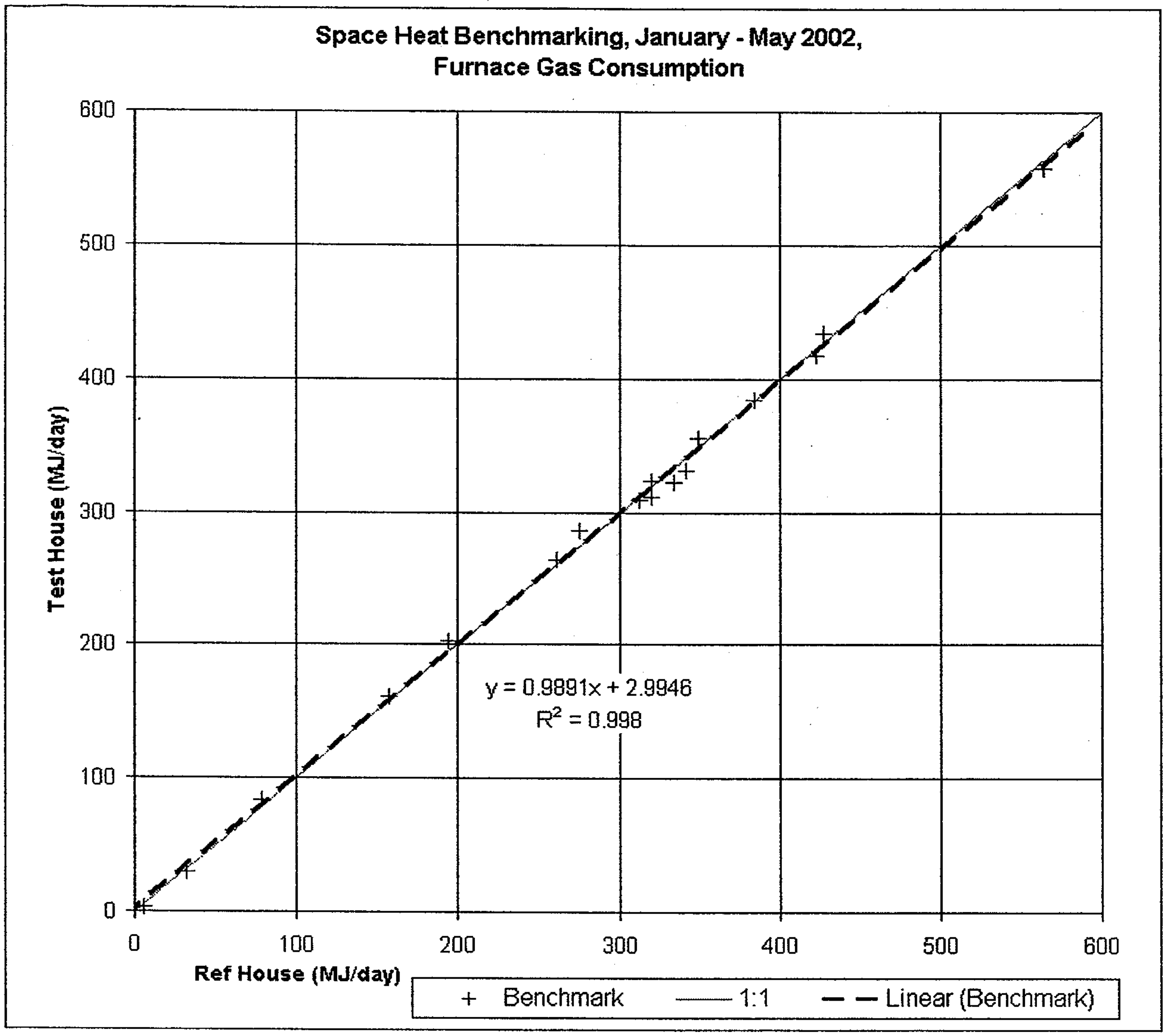

Figure 1. Space Heat Benchmark for this Project.

Project & Dates	n	Slope	Intercept	r^2
Combo, Nov '99 - Jan '00	36	.993	1.37	.997
Shades, Nov '01	15	.998	4.30	.998
ECM, Jan '02 - May '02	17	.989	2.99	.998

Table 1. Comparison of Three Space Heat Benchmarks.

three benchmarks in terms of number of data points (days), slope, intercept, and r^2. This comparison shows that the Test House uses slightly more heating fuel when the space heat demand is very small, while the Reference House uses slightly more at other times. More importantly, it shows that the performances of the two houses have remained extremely close and consistent over the last two-and-a-half years, and under different conditions.

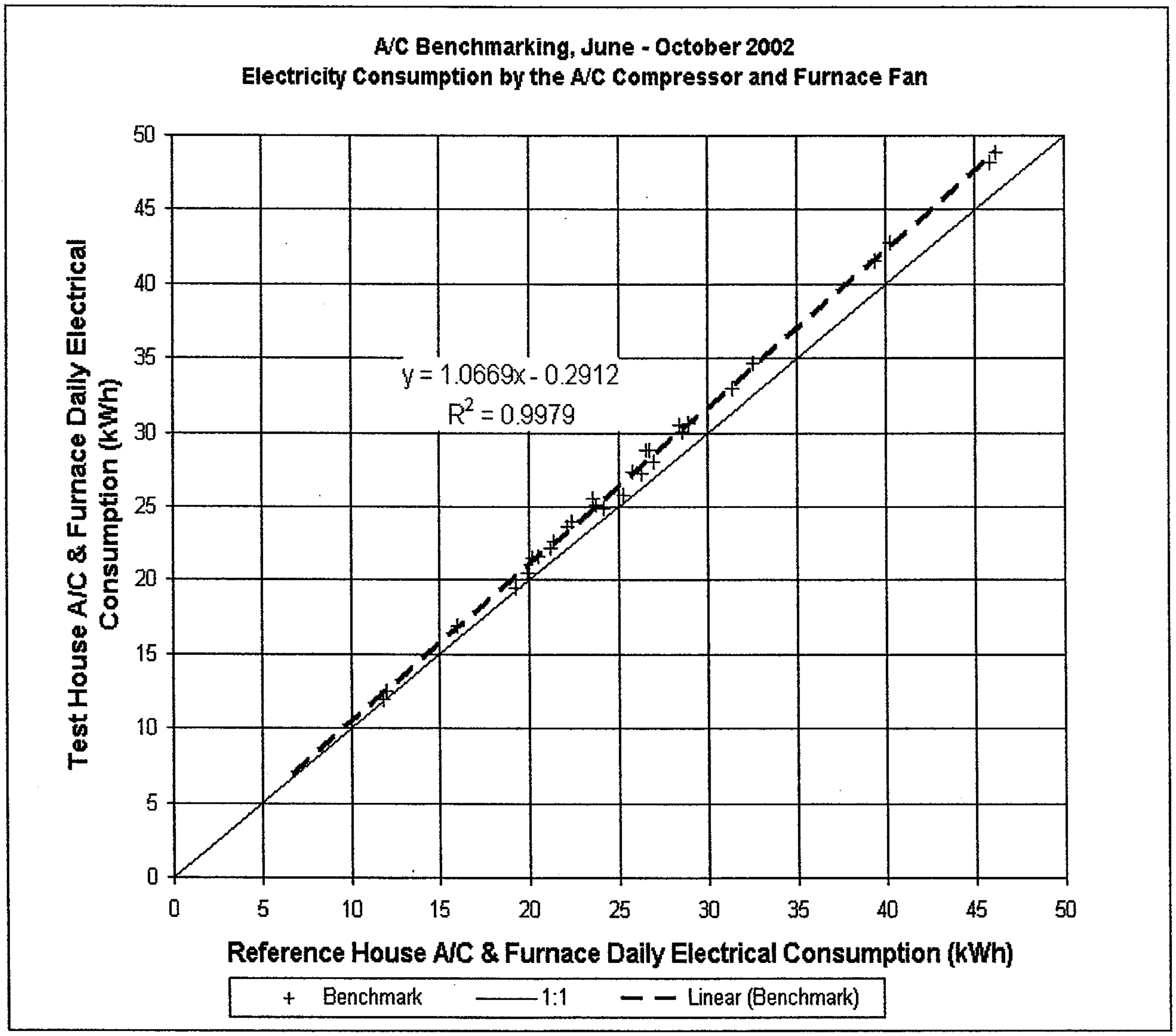

Figure 2. Air Conditioning Benchmark for this Project.

3.1.2 Benchmarking for Air Conditioning

Figure 2 shows the benchmarking for the air conditioning period of this project. The points are based on the sum of daily electrical consumption of the air conditioner compressor and the furnace fan. The coordinates of each point are this sum for each of the two houses. As with the space heat benchmark, ideally all points should lie on the 1:1 line.

The air conditioning benchmark is not as close to perfect as the one for space heat, because the Test House consistently uses slightly more energy than the Reference House, and the difference between them increases with daily energy use. Nevertheless, the correlation coefficient (0.9979) is still close to perfect, and as long as there is a clear and consistent difference between the benchmark and the results with an ECM, then the results are still useful. The twenty nine benchmark points were collected on June 27 through July 14, August 28 and 29, 17 through 24 September, and 5 and 6 October, 2002. The Reference House consumption varies from 11.788 to 46.137 kWh/day, and the Test House consumption goes from 11.909 to 48.827 kWh/day. The averages are 27.551 kWh/day in the Test House, and 26.096 kWh/day or 5.6% less in the Reference House. Air conditioner on-time varies from 2.311 to 19.583 hours/day in the Reference House, and from 2.283 to 20.200 in the Test House. Energy use by the compressor alone varies by a factor of more than eleven, from 2.980 to 33.442 kWh/day in the Reference House, and from 3.002 to 34.931 kWh/day in the Test House.* This daily benchmark data is shown in Table A2 of Appendix A.

3.2 Effects of the ECM during Heating

This section and the following one describe the results of the tests with the ECM in the Test House furnace, and the PSC motor in the Reference House furnace. Tests with identical conditions, and with some gas consumption in both houses, occurred on the following 29 days in the year 2002:

15 - 17 February
3 and 5 March
20 - 25 March
21 - 30 April
14 - 18 May
21, 22 and 25 May

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* Consumption and on-times are not proportional because the consumption of the A/C compressor increases with indoor and outdoor temperature as shown below.

There were also three days in which the Reference House furnace used no gas, but the Test House furnace did. These days were the 23rd, 26th, and 27th of May, 2002, and they are analysed separately. During the first four days of June 2002, the ECM's circulation speed was increased so as to be equal to that of the PSC motor, and these days are also analysed separately. All results described below are for the 29 days between February 15th and May 25th unless otherwise noted.

3.2.1 Motor & Furnace Electricity Consumption

The power use (watts) of the ECM and the PSC motor were measured in one-time tests using a BMI Powerprofiler meter, and the results are shown in Table 2.* The first two rows show the results with the reduced ECM circulation flow rate (Section 2.6), and the last row shows the results with the ECM circulation flow as close as possible to the PSC's. In heating speed, the PSC motor used 423 Watts while the ECM used 246 W, or 58% as much as the PSC motor for a nearly equal flow rate. With the reduced ECM circulation rate (on which the main results of this report are based), the PSC motor used 316 W while the ECM used 22 W, or only 7% as much. With the circulation rates nearly equal, the ECM used 146 W, or 46% as much as the PSC motor. As shown in Table 2, the ECM is over one-and-a-half times as efficient as the PSC in heating speed, and is more than six times as efficient in reduced circulation mode, where efficiency is defined as airflow over motor power. With equal circulation rates, the ECM is still twice as efficient, showing that electricity savings and therefore increased gas use are not dependent on the reduced circulation rate. See Section 4.2 for an analysis of aerodynamic efficiency.

Mode	Motor Power (W)			Air Flow (L/s)			Flow/Power (L/s·W)		
	ECM	PSC	ECM/PSC	ECM	PSC	ECM/PSC	ECM	PSC	ECM/PSC
Heating	246	423	58%	591	658	90%	2.40	1.55	155%
Circulation	22	316	7%	218	486	45%	9.91	1.54	644%
Equal Circ.	146	316	46%	463	486	95%	3.17	1.54	206%

Table 2. Comparison of ECM & PSC Power and Flow Rates.

* The flows in Table 2 are not exactly the same as those in Section 2.5 because they were taken at a later time when a better watt meter was available. Flows can change due to conditions of filters, etc., and measurement accuracy is probably about ±5%.

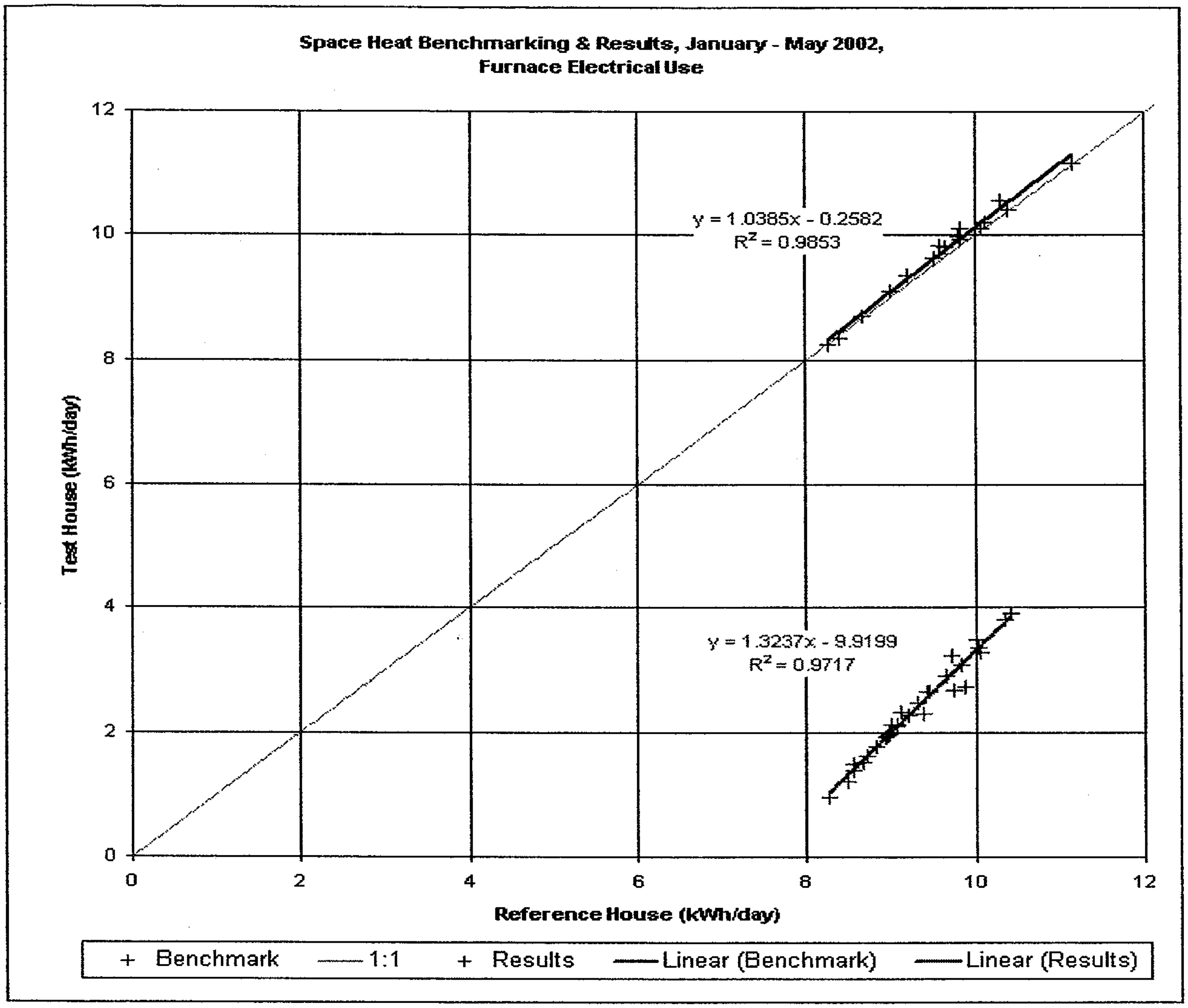

Figure 3. Electricity Use by the Furnaces during Space Heat Period Benchmarking & ECM Testing.

A CCHT electrical meter in each house measures the consumption of the furnace, which includes the controls and draft-inducing fans as well as the motor. Daily results from these meters show that on average the furnace with the PSC motor uses 9.29 kWh/day, and the furnace with the ECM uses 2.38 kWh/day, a reduction of 74%. The results are graphed in Figure 3, and daily values are shown in Tables A1 & A3 of Appendix A. During benchmarking, the values for both houses are almost identical, as would be expected. During ECM testing, the difference in kWh/day is relatively constant, averaging 6.91 and varying from 6.49 to 7.32. The Test house consumption as a percentage of the Reference House's averages 26%, and ranges from 12 to 38%, being highest when the furnace spends the greatest amount of time in heating mode. This is due to the fact that the difference between power for heating and for circulation is bigger in the

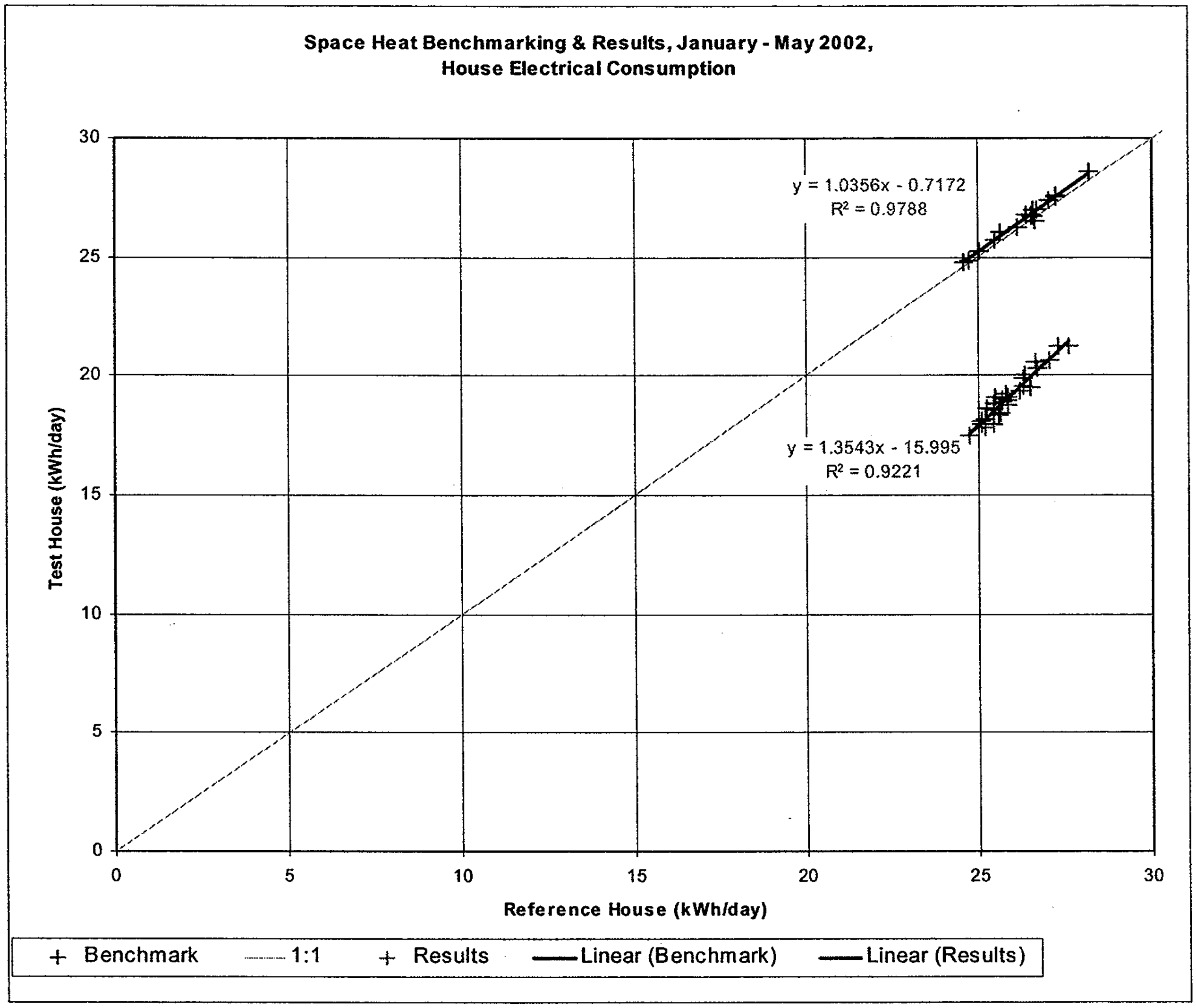

Figure 4. Electricity Use by the Houses during Space Heat Period Benchmarking & ECM Testing.

ECM than for the PSC, so the ECM's energy use grows more quickly as the furnace spends more time in heating.

3.2.2 House Electricity Consumption

Internal electrical consumption* during benchmarking and ECM testing is shown in Figure 4. During benchmarking, the daily values in the two houses were nearly identical and averaged 26.8 kWh in the Reference House and 27.1 kWh in the Test House. These values are fairly typical of Canadian houses. During ECM testing, the Reference House averaged 25.9 kWh/day, while in the Test House averaged 19.1 kWh/day. Thus, the house with the ECM saved an average of 6.8 kWh/day, and used 74% as much as the house with the PSC motor. This shows that ECMs have the potential to make substantial reductions in normal electrical bills. Daily consumption in the Reference House varied from 24.8 to 27.6 kWh/day, while in the Test House it varied from 17.5 to 21.2, and the difference varied from 70 to 78%. Thus, the savings to the whole house are relatively constant despite the large variations in the amounts of time the fan motors spend in heating speed. This indicates that significant electrical savings are not dependent on the particular conditions of these results. Daily values are shown in Table A5 of Appendix A.

3.2.3 Gas Consumption

The results described below are for the same 29 days from February 15th and May 25th, as those in the last subsection, unless otherwise noted. During these days, furnace gas consumption in the Reference House varied by a factor of 65, from 6.8 to 440.3 MJ/day. In the Test House, it varied by a factor of 17, from 27.8 to 474.0 MJ/day. Thus, the data represents a wide range of space heat loads, including loads that are probably close to the maximum for the houses.

The average furnace gas consumption in the Reference House was 213.7 MJ/day, while in the Test House it was 243.4 MJ/day. Thus, the lower electrical consumption of the ECM resulted in an average increased gas consumption of 29.71 MJ/day or 13.9%. The difference varied from 11.83 to 51.75 MJ/day or from 3.6% to 311.7%. The difference in MJ/day shows no relationship with Reference House consumption, but the percentage difference, defined as (Test-Ref)/Ref, is greatest when gas use is least, as would be expected since at lower space heat loads the extra heat from the PSC motor constitutes a higher percentage of the total load. The daily values of furnace gas consumption and differences are shown in Table A3 of Appendix A.

Figure 5 compares daily values of furnace gas consumption of both houses during benchmarking and ECM tests. It includes the benchmark points shown in Figure 1, and the

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* Internal electrical consumption is total electrical consumption minus consumption by two outside lights, the control room, and the air conditioner compressor. The control room in the garage contains the CCHT monitoring and occupancy simulation systems, and is thermally isolated from the house. The air conditioner was not used during the space heating period.

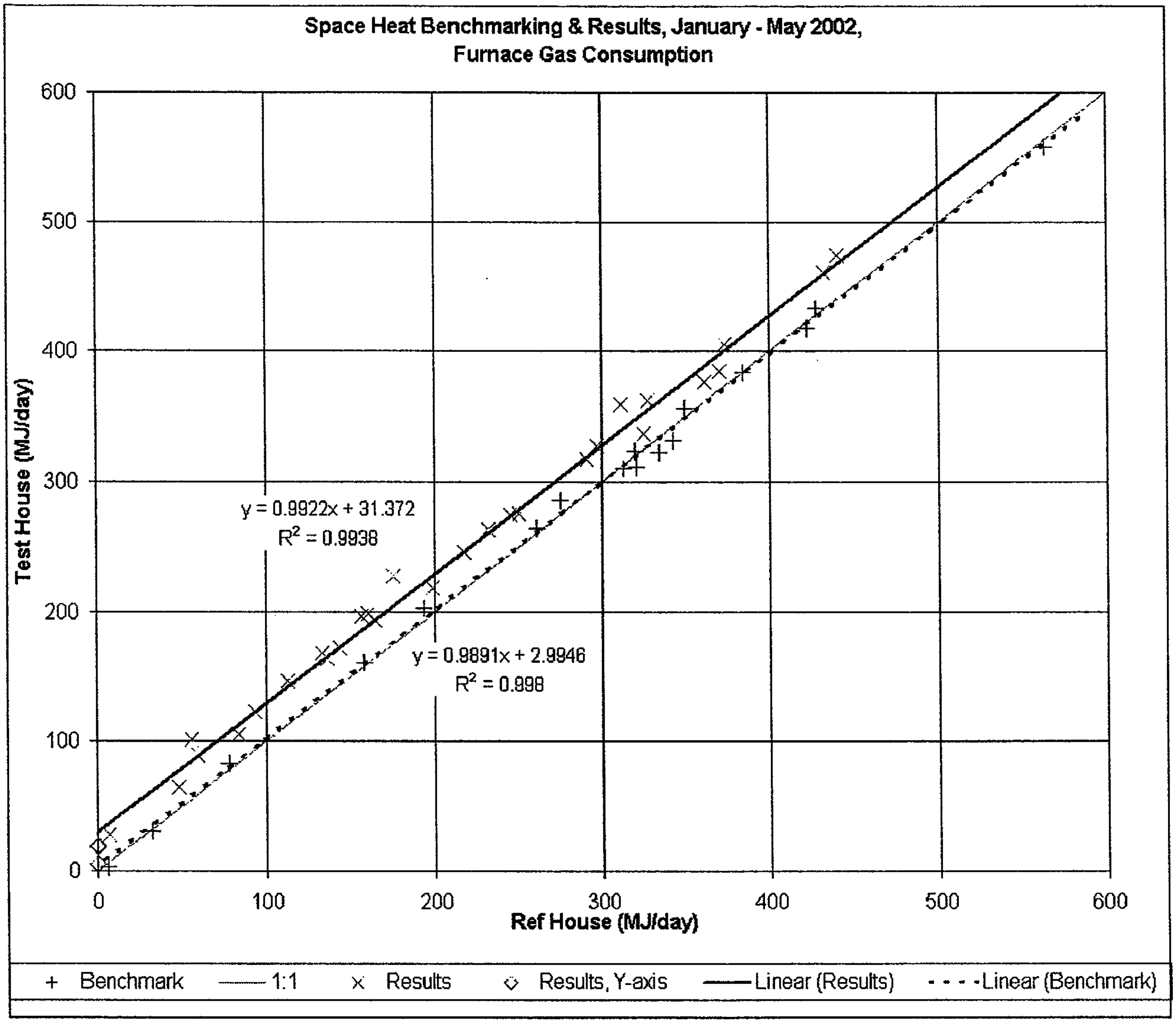

Figure 5. Space Heat Benchmarking and Results for Normal Conditions.

25th, when there was furnace gas consumption in both houses. They are shown as X's, and are included in the correlation of the results. They constitute the results of testing under *normal conditions*. Theoretically, they should lie on a straight line above the 1:1 line, and with a slope of less than one. The line should be above the 1:1 line because the lower electricity use of the ECM causes gas consumption in the Test House to be higher. The slope should be less than one because the difference between the PSC and ECM electrical use is higher when the furnace spends less time in heating mode (see the numerical analysis in Section 3.5.) Figure 5 also includes three points with no furnace gas consumption in the Reference House (two are indistinguishable), shown as diamonds (◇) on the Y-axis. They constitute a separate series that should lie on the Y-axis between the intercept of the normal condition points and the origin.

The linear correlation for the normal condition points has a slope of 0.992 and a intercept of 31.37 MJ/day. Its correlation coefficient (r^2) is 0.994. The intercept is slightly larger than the average difference in gas consumption (29.71 MJ/day), as would be expected since the slope is less than one. The benchmark and results lines are clearly distinct. Both have r^2's of over 0.99, and no individual point of one line crosses the correlation line of the other. Thus, the increased furnace gas use due to the ECM is clearly shown in the results.

3.2.4 Low Furnace Gas Use and Confirmation of Non-utilizable Internal Gains

As furnace gas consumption in the Reference House gets small, one would expect the relationship between Reference and Test gas consumption to depart from linearity. This is because the Reference House should approach and then enter a range in which all its heating demands are met by heat given off by the PSC motor, while the Test House still uses natural gas to meet its heating needs. The Reference House should eventually reach a point where the heat from the PSC motor exceeds its total heat demand. Beyond this point, the excess PSC motor heat would be wasted because it would cause the temperature in the Reference House to go above the set-point, and would be dissipated in higher heat losses from the house before it could reduce the next demand for space heat. This wasted heat from the PSC motor is an example of a non-utilizable internal gain.

The effects of the non-utilizable PSC motor heat is shown in Figure 6 which shows that the difference between house temperatures gets large as Reference House furnace gas consumption goes below 50 MJ/day. The daily average temperature of each house is found by averaging the 24 hourly values from the thermocouple nearest to the thermostat. The temperature difference is then the average for the Reference House minus that of the Test House. For Reference House gas use above 50 MJ/day, the differences are all 0.1 °C ±0.07, which is close to the accuracy of the thermocouples. Below 50 MJ/day, the difference rises rapidly to 0.69 °C. Thus, non-utilizable internal gains result in the two houses departing from identical conditions, since the temperature in the Reference House becomes slightly higher. However, this does not invalidate the observed changes in electricity and gas consumption during these periods. Occupants are unlikely to respond to short-term changes of less than a degree by , e.g., changing thermostat settings or opening windows.

The effect of wasted PSC motor heat can also be seen in the difference between gas use in the two houses, as shown in Figure 7. The percentage of extra gas use in the Test House, as a function of gas use in the Reference House, grows rapidly as gas use in the Reference House decreases, becoming infinite when the Reference Houses uses no gas. These results all confirm that below 50 MJ/day of Reference House furnace gas consumption, the relationship between the furnace gas consumption in the two houses departs from linearity, and should be analysed separately. The 50 MJ/day cut-off makes sense in terms of the relationship between gas and electric heat from the furnace. At that level, over 40% of the total furnace heat of the Reference House comes from the PSC motor in circulation mode, i.e., during times when the temperature is above the thermostat setting and there is no demand for space heat.*

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* Gas: Output: 50 MJ/d x 0.777 (eff) = 38.850 MJ/day.
Operation: 50 MJ/d / 71.2125 MJ/h = 0.7021 h/day.
Electric: Heating: 0.7021 h/d x 1.764 MJ/h x 0.94 (eff) = 1.164 MJ/d
Circulation: (24 - 0.7021) h/d x 1.260 MJ/h x 0.94 = <u>27.594 MJ/d</u>
Total: 28.758 MJ/d
Total Furnace Heat: 38.850 + 28.758 = 67.603 MJ/d
Heat from PSC in circulation: 27.594 / 67.603 = 40.8%

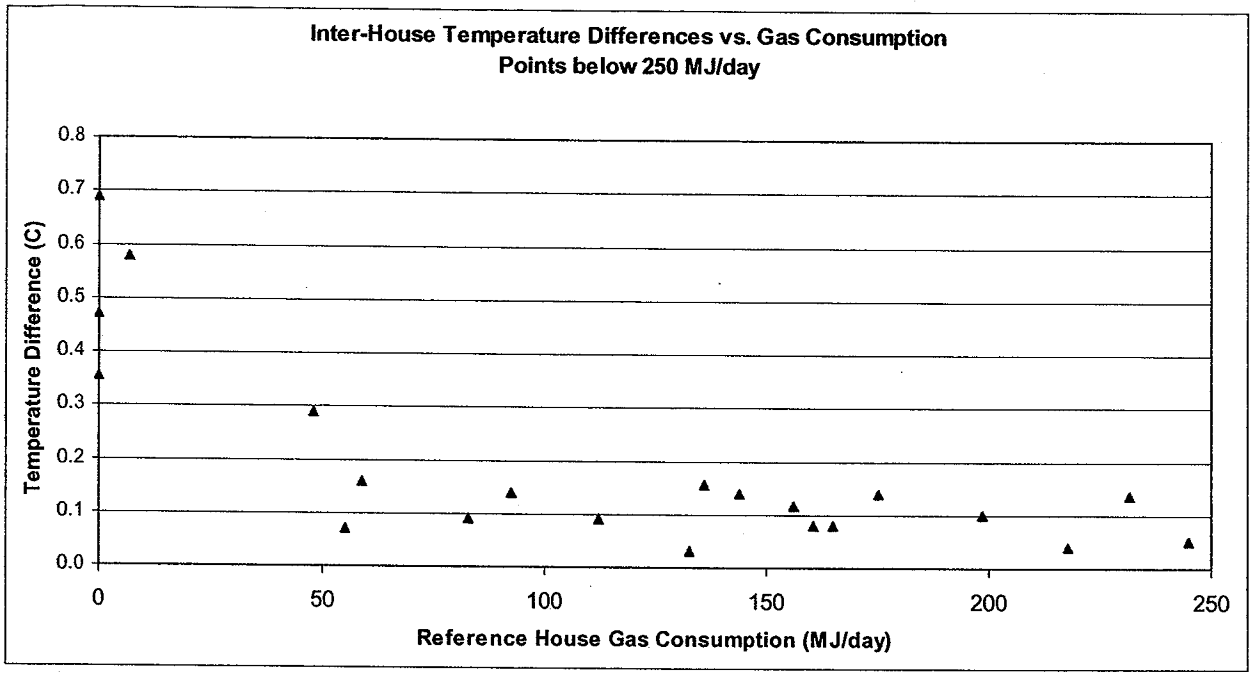

Figure 6. Inter-House Temperature Difference vs. Reference House Gas Consumption.

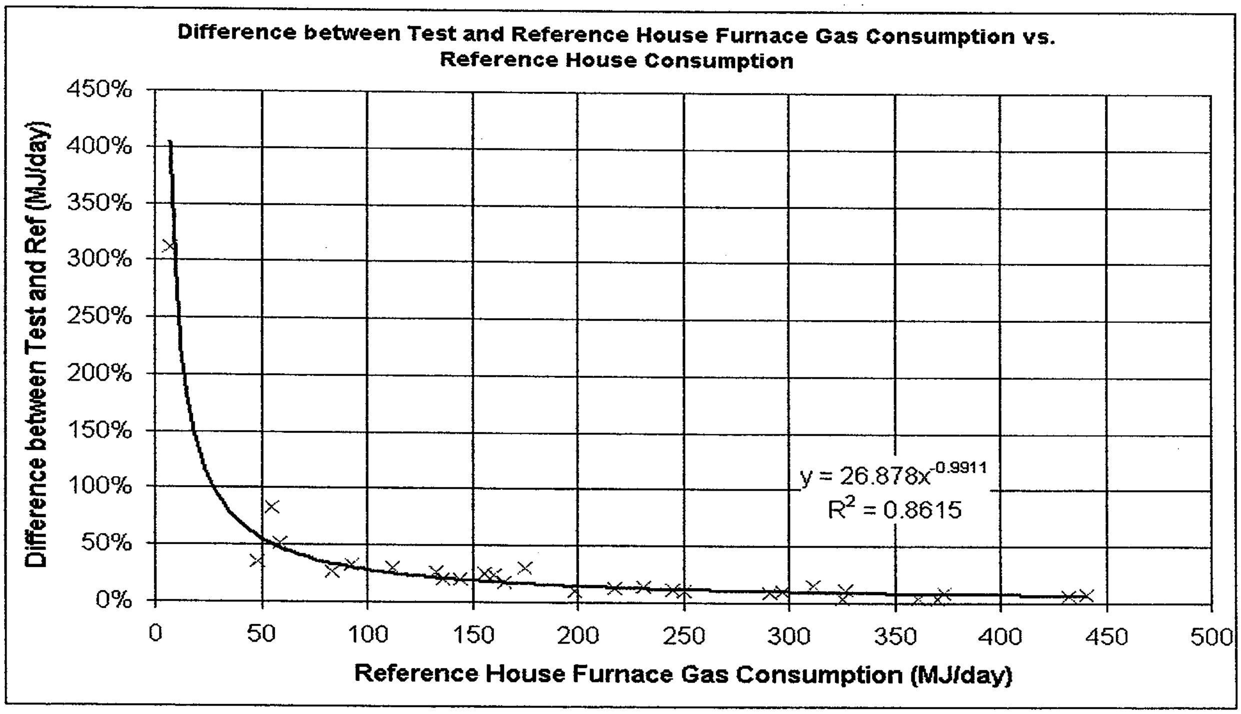

Figure 7. Difference between Test and Reference House Furnace Gas Consumption as a function of Gas Use in the Reference House.

3.2.5 Results with Gas Use Above 50 MJ/day

Based on the last sub-section, points with Reference House gas consumption of less than 50 MJ/day should be excluded from the analysis. The results of excluding these two normal condition points are shown in Table 3. The slope decreases from 0.9922 to 0.9777, the intercept increases from 31.372 to 35.584 MJ/day, and r^2 decreases insignificantly from 0.9938 to 0.9934. Compared with the analytical results derived in Section 3.5, the slope with all 29 normal condition points is slightly closer, but the intercept with the two points excluded is significantly closer. Thus, excluding the points with Reference House consumption less than 50 MJ/day provides a better fit with the analytical values.

	Slope	Intercept	r^2
All 29 points	0.9922	31.372	0.9938
Ref House > 50 MJ/day	0.9777	35.584	0.9934
Analytical line	0.9864	34.093	1

Table 3. Results with and without low gas consumption points, and analytical results.

3.3 Effects of the ECM during Air Conditioning

Valid days of air conditioner testing with the ECM installed in the Test House occurred on the following 41 days in the year 2002:

1 - 22 August
31 August - 15 September
26 - 28 September
1 and 3 October

Testing was also conducted on 29 and 30 September, but the air conditioners did not come on in either house on those days.

The air conditioner compressor for each house is a Heil Super High Efficiency 9000 Model #: CA9024VKD2. Its rated energy-efficiency ratio (EER) is 10.7, so its coefficient of performance (COP) is 3.14.* Testing for EER is done under standard conditions and includes both the compressor power, and a fan motor power which can be that of an actual motor or a default amount, and is not specified.[3] For purposes of analysis, it is useful to have the COP of the compressor alone. Under the rating conditions, the compressor COP is 3.82. However, both the cooling capacity and the input power vary with indoor and outdoor temperature. At conditions typical of the air conditioning period, the compressor COP is 3.60.[4]

3.3.1 Electricity Use: Furnace Fan, Compressor, and Air Conditioning

In discussing the results for space heating the following terms are used:

- *A/C* is used to refer to the air conditioner or to air conditioning.

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* EER is cooling capacity in Btu/h divided by input power in W. COP is cooling capacity in W divided by input power in W, or EER / 3.413. The input power includes compressor and motor power. The standard rating conditions are:

Inside:	T_d (dry bulb) = 80 °F = 26.7 °C,
	T_w (wet bulb) = 67 °F = 19.4 °C, (RH = 50%).
Outside:	T_d = 95 °F = 35.0 °C,
	T_w = 75 °F = 23.9 °C (RH = 40%).

- Electricity used by the *furnace fan*, or simply the *fan*, is electricity used by the furnace to move air, either during A/C or in circulation mode when the A/C is not operating. It includes the electricity used by the fan motor itself, plus a small amount for the furnace controls.

- Electricity used by the *compressor* is the electricity used by the A/C compressor unit located outside the house.

- Electricity used for *air conditioning* (A/C) is the sum of electricity used for the fan and for compressor. This is the amount of electricity used to air condition the house.

As noted in Section 3.1.2, the benchmarking for A/C was not as close to perfect as it was for heating. The difference between the A/C benchmark and the 1:1 line must must be factored out of the results to determine the actual effect of the ECM on A/C energy. This is done in detail in Appendix B and summarized here.

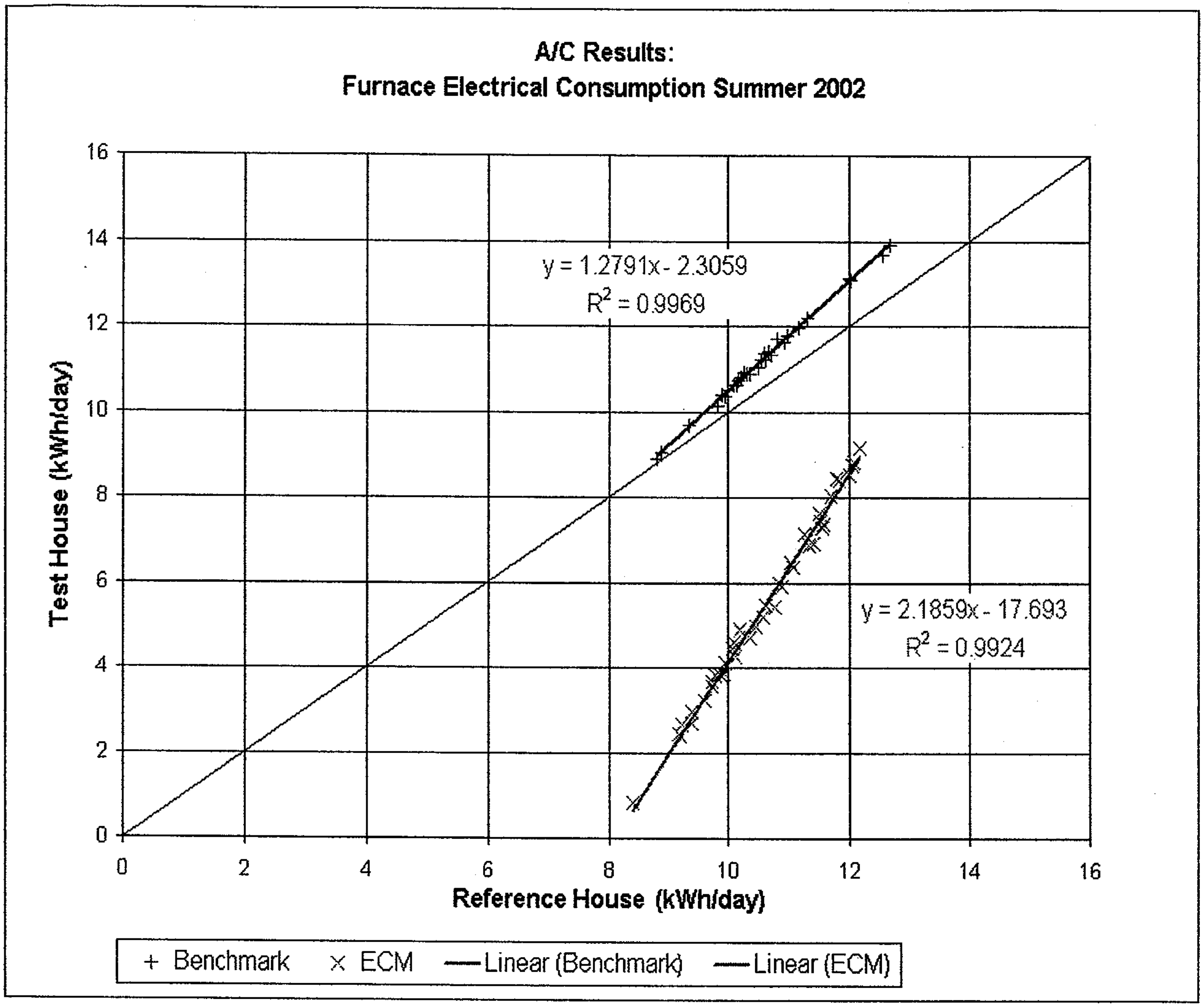

Figure 8. Electricity Use by the Fans during the A/C Period: Benchmarking & ECM Testing.

- Figure 8 shows the electricity use by the fans during both benchmarking and testing.
  - The difference between the benchmark and the 1:1 line is the benchmark offset.
  - It shows that the PSC motor in the Test House used more energy then the one in the Reference House during benchmarking.
  - Although the Test House PSC motor was replaced by the ECM during testing, its influence on compressor energy must be calculated and factored out.
  - The difference between fan energy use in benchmarking and testing is very clear despite the benchmark offset.

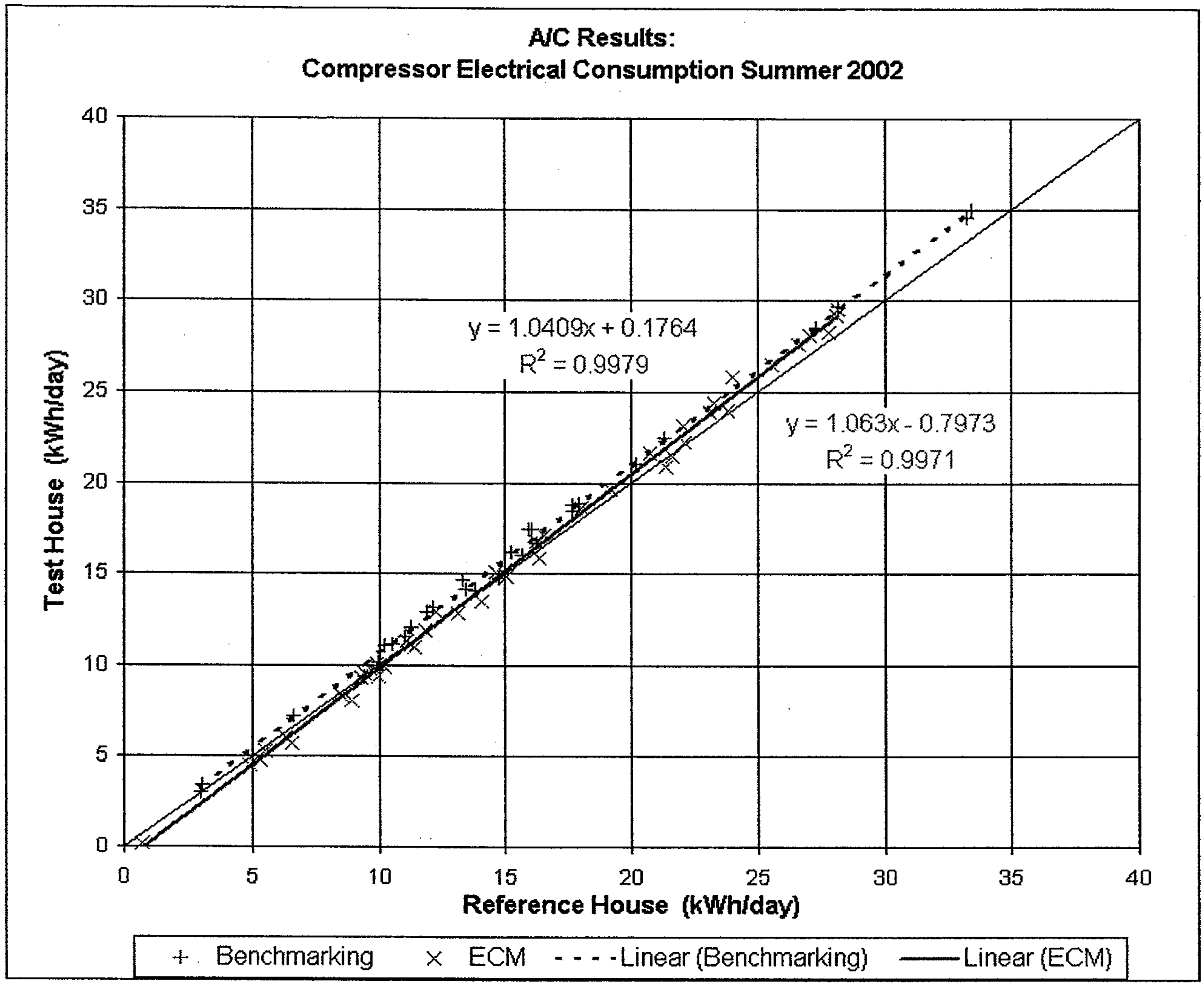

Figure 9. Electricity Use by the Compressors during the A/C Period: Benchmarking & ECM Testing.

- Figure 9 shows the electricity used by the A/C compressors during benchmarking and testing.
  - The difference between benchmarking and testing is small as would be expected. It should be the difference between the fan energies divided by the COP of the compressor.
  - Part of this difference is due to the difference between the two PSCs, and part is due to the difference between the PSC and the ECM.

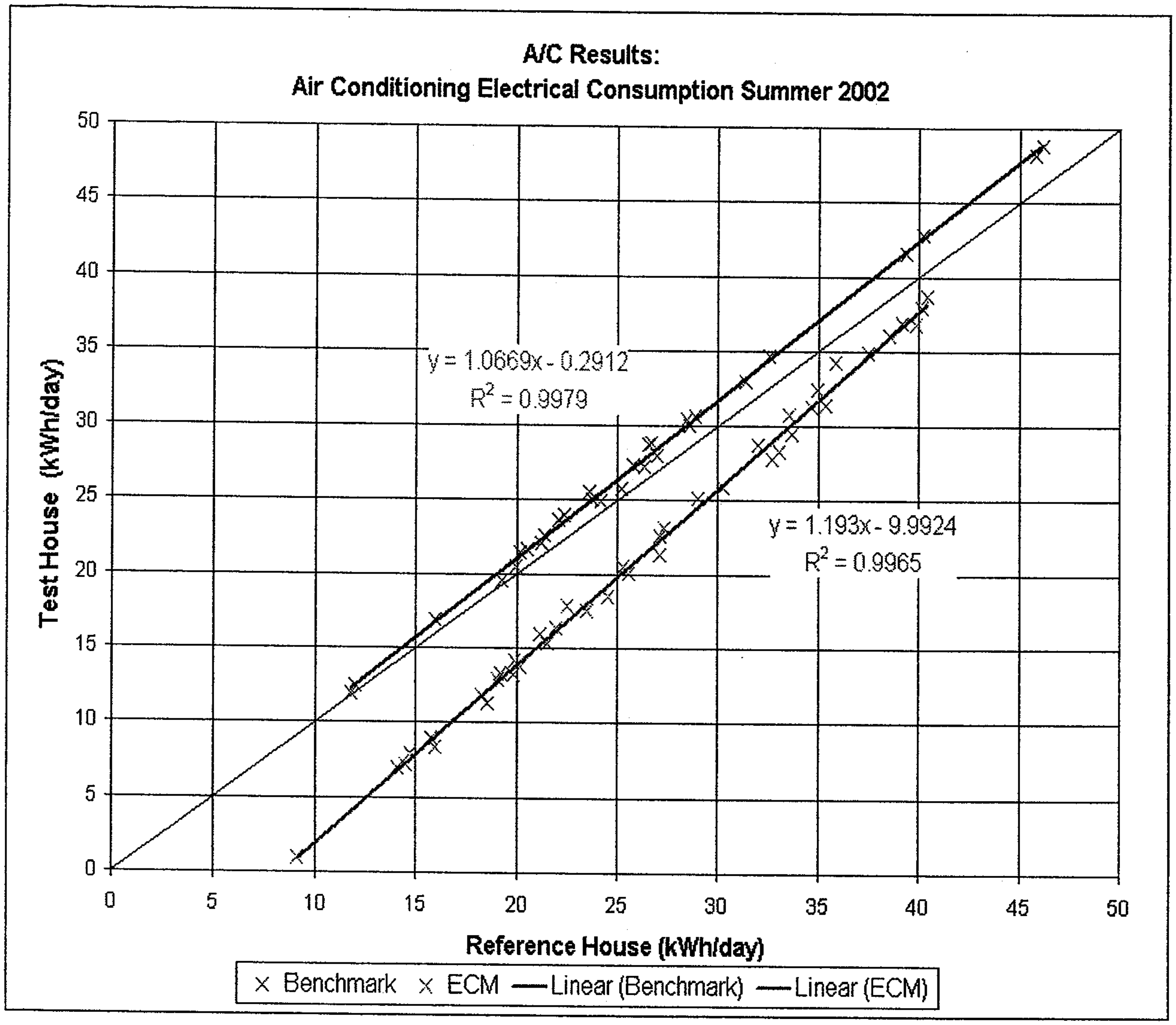

Figure 10. Electricity Use by the Air Conditioners during the A/C Period: Benchmarking & ECM Testing.

- Figure 10 shows the electricity used by the A/Cs (fans plus compressors) during benchmarking and testing.
  - During benchmarking, the Test House uses more than the Reference House due to fan and compressor differences.
  - The difference between benchmarking and testing is clear.

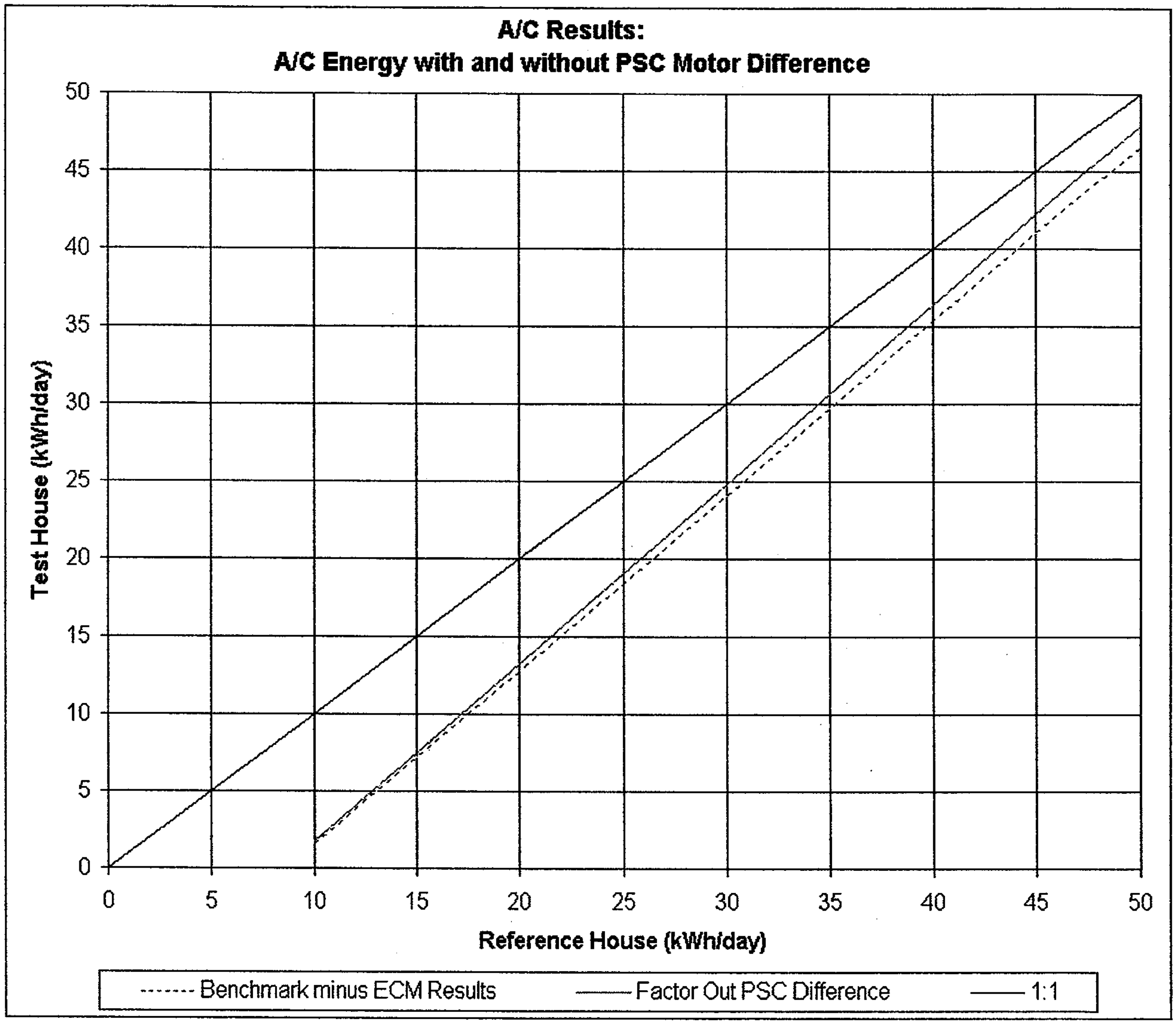

Figure 11. A/C Benchmark minus ECM Results, with and without PSC Difference.

- Figure 11 factors out the benchmark offset.
  - The difference between the 1:1 line and the dotted line is the difference between the benchmark and test results. In effect, the benchmark line of Figure 10 has been pushed down to the 1:1 line, and the test line has been pushed down by the same amount, becoming the dotted line.
  - The solid line factors out the fan benchmark offset, and is the best estimate of what the test results would have been with a perfect benchmark.

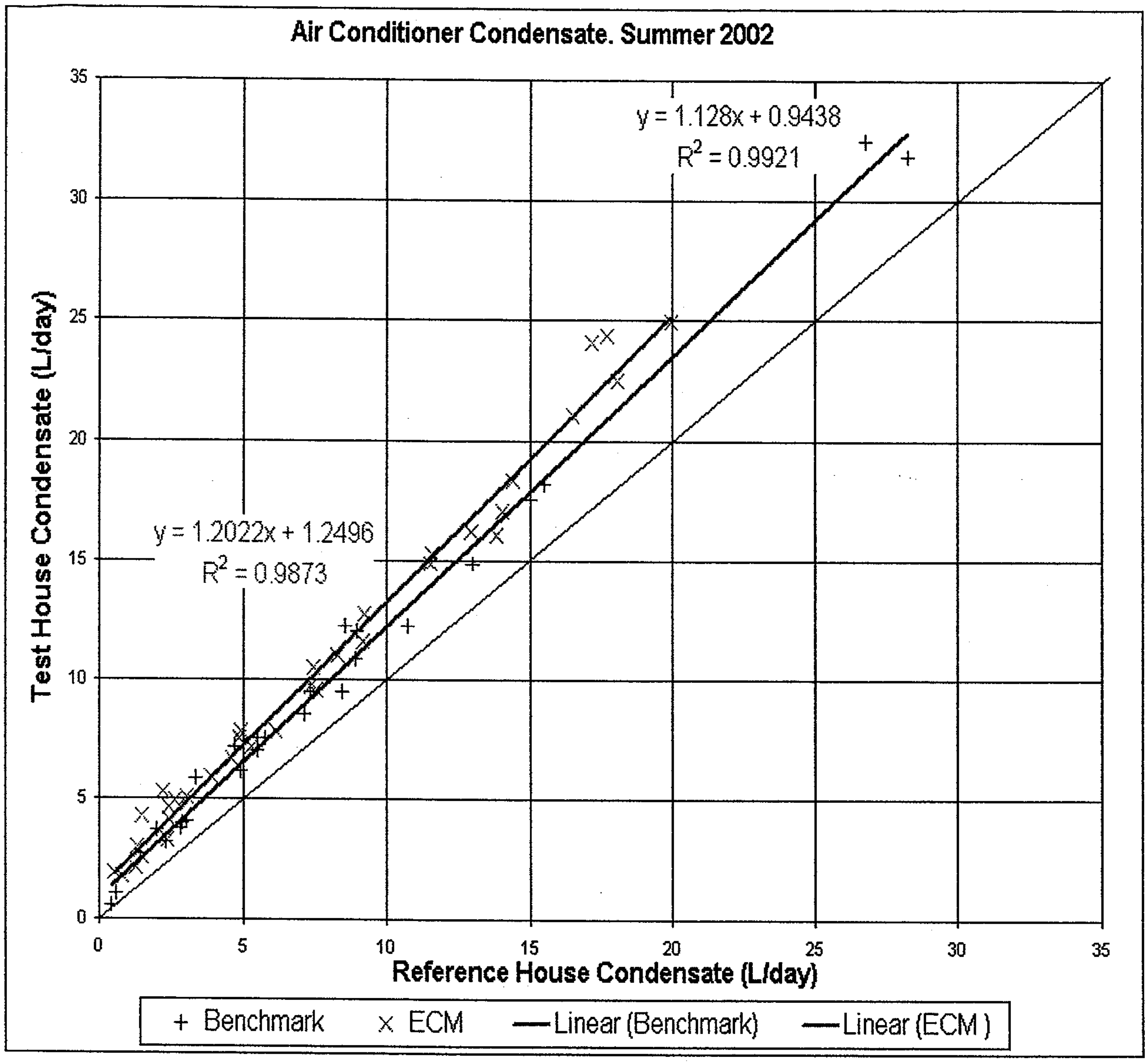

Figure 12. Condensate from Air Conditioners during the A/C Period: Benchmarking & ECM Testing.

Thus, with a perfect benchmark, if the electricity that the A/C (fan plus compressor) with the PSC motor uses is x, then the amount that the A/C with the ECM would use y is

$$y = 1.1647x - 9.8894.$$

This is the equation that defines the solid line in Figure 11. With a perfect benchmark, the average difference between the Reference and Test House A/Cs would have been 5.493 kWh/day, or 20.7% of the Reference House A/C use.

3.3.2 Condensate

During the air conditioning period, the amount of water condensed by the A/C evaporator coil in each house was measured using a tipping scale. The daily amounts of condensate during both benchmarking and ECM testing are shown in Figure 12. During benchmarking, significantly more condensate is produced in the Test House than in the Reference House. The reason for this difference is not known. It may be due to differences in the way air flows over the evaporative coils in the two houses. There are splits into three separate ducts immediately above the evaporator coils, and this could cause complicated and different flow patterns over the coils in the two houses. The additional cooling energy required to condense the excess condensate in the Test House accounts for 39% of the additional Test House compressor energy during benchmarking. With the ECM installed in the Test House, its excess condensate is even larger than during benchmarking, as would be expected. The ECM heats the air passing over the evaporator coil less than the PSC motor does, and more water will be condensed from the cooler air. The difference between the amounts of condensate during benchmarking and during ECM testing increases with increasing A/C load. This also makes sense, since at higher loads the A/C runs longer, and has more time to condense water, and also because high A/C loads are often partly due to high moisture content in the outdoor air.

Condition	House	1 - 7 July, 2002			8 - 14 July, 2002		
		Bsmt	1st	2nd	Bsmt	1st	2nd
Benchmarking	Ref	56.9	48.6	44.7	53.6	47.3	45.3
	Test	55.0	46.1	41.7	52.3	45.4	42.1
	Difference	1.9	2.5	3.0	1.3	1.9	3.2

Condition	House	5 - 11 August, 2002			12 - 18 August, 2002		
		Bsmt	1st	2nd	Bsmt	1st	2nd
ECM Testing:	Ref	53.4	46.8	44.7	58.9	50.8	46.3
	Test	51.0	43.9	39.3	55.2	46.9	40.9
	Difference	2.4	2.9	5.4	3.7	3.9	5.4

Table 4. Average Relative Humidities in the Houses during Benchmarking and ECM Testing for Air Conditioning. All quantities are Percent RH.

The larger amounts of condensate in the Test House result in lower levels of relative humidity (RH), as shown in Table 4. Each of the one-week periods of benchmarking or ECM testing in the table are preceded by at least three days of the same condition. RH levels in the basements, main floors and second storeys of the houses are compared. In all cases, the RH in the Test House is lower, and the differences are larger during ECM testing than during benchmarking. This is completely consistent with the above differences in amounts of condensate. Because an ECM will cause lower humidity levels in a house, occupants may feel cooler and set their A/C thermostats to higher temperatures, thus saving even more electricity.

3.3.3 Summary of A/C Results

Despite the imperfect benchmark for the air conditioning period, the energy savings due to the ECM are clear. Higher energy use for both PSC motors and compressors contribute to the higher A/C energy use in the Test House during benchmarking. The higher benchmark condensates in the Test House are consistent with its higher compressor energy use. The higher benchmark energy use by the PSC motor in the Test House is not relevant to the results of ECM testing because the Test House PSC motor was replaced by the ECM. The calculated energy saving due to the ECM at a given A/C load is the difference between the 1:1 and solid lines at that load in Figure 11. The percentage savings due to the ECM at the CCHT are:

- For the fan 48%,
- For the compressor 4%,
- For the A/C (fan plus compressor) 21%, and
- For the house: 13.9%.

Savings for the compressor are relatively small because, as explained above, they should be the fan savings (in kWh/day) divided by the COP of the compressor.

As shown in Appendix E, and summarized in Section 3.5, the results for the A/C system are very close to the theoretical results. As shown in Figure 11, the equation for the relationship between the two A/C systems is

$$y = 1.16x - 9.9,$$

while the line based on the numerical analysis is

$$y = 1.18x - 11.7.$$

Given the uncertainties generated by the differences in the amounts of condensation in the two houses, and other factors discussed in the analysis, this can be considered a very close fit.

3.4 Other Results

3.4.1 House Temperatures & Air Circulation

In order to investigate whether reduced circulation airflow with the ECM resulted in inadequate circulation, temperatures in a number of points in the two houses were compared. If differences at specific points were larger during the ECM testing than during benchmarking, this could be considered evidence that the ECM's circulation airflow was not adequate, while a lack of such differences would indicate that the ECM's airflow is adequate. Three five-day periods during which there were significant temperature variations within each house were selected. Two were ECM test periods and the third was benchmarking. Temperature comparisons were made at eight points on the main floors – including floor, mid-height and ceiling points, and in the basement.

The temperature difference between a given point in the Test House and the same point in the Reference House is called the inter-house temperature difference. These differences ranged from -0.73 to +1.08 °C on the main floors, and from -1.19 to +0.36 °C in the basement, and occur during both ECM testing and benchmarking. In order to determine whether these differences are greater during ECM testing, temperature deviations – the absolute differences between the inter-house differences were calculated. The largest deviation was 0.46 °C and occurred in the basement, while the largest on the main floor was 0.40 °C. The great majority or points have deviations of less than 0.2 °C, which is close to the level of accuracy of the thermocouples. Deviations are slightly higher in the basement, possibly due to the lack of sufficient air return there. Thus, this investigation of temperature differences does not produce any evidence of inadequate ECM airflow. The investigation is described in more detail in Appendix C: Inter-House Temperature Differences in Benchmarking and ECM Tests.

3.4.2 Results from the Fan Test Rig

NRCan's Advanced Combustion Technologies Lab (ACT) used their CMHC fan test rig to measure the characteristics of the KeepRite blower assembly with an ECM and PSC motor identical to those used in the CCHT houses. The fan test rig allows duct pressure differences and airflow rates to be measured more exactly than in the CCHT houses, and can adjust pressure differences to specified amounts. It also allows motor power to be measured precisely. The blower assembly with the two motors were compared in a number of ways: airflow vs. power, efficiency vs. power, and efficiency vs. airflow. Efficiency is the aerodynamic system efficiency of the motor-blower system defined as:

$$S_{eff} = ((P_S + P_R) \times Q) / W$$

where

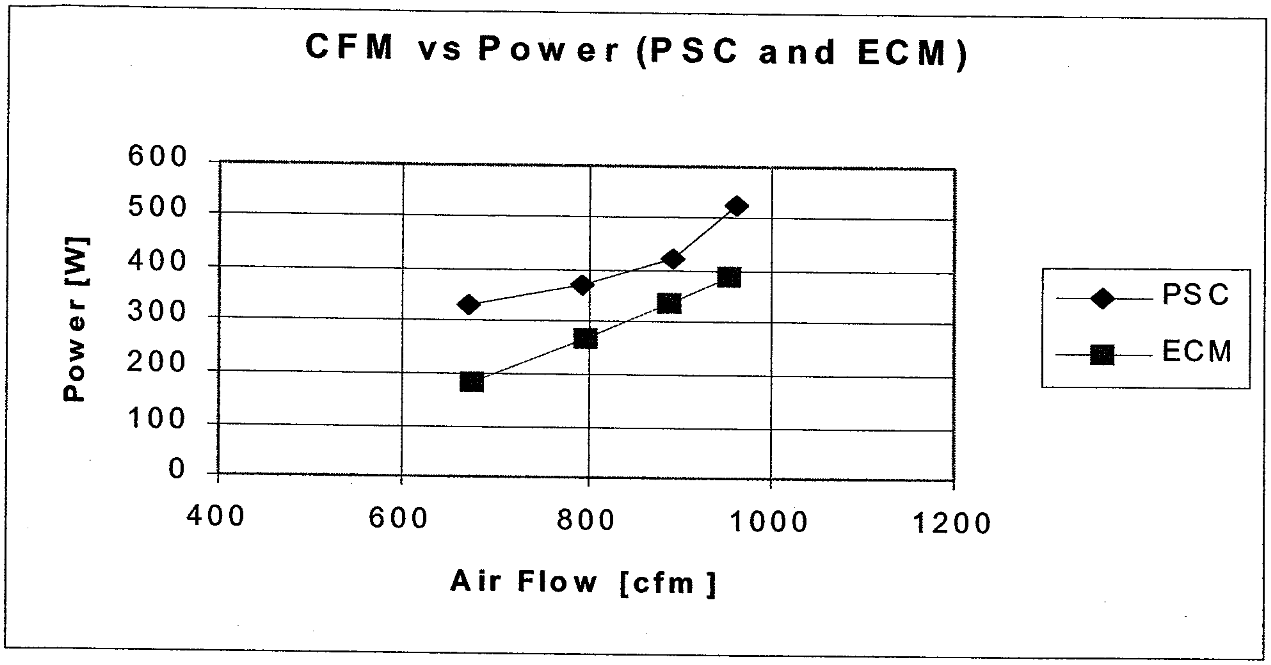

Figure 13. Power vs. Airflow for the ECM and PSC Motor, ACT Fan Test Rig.

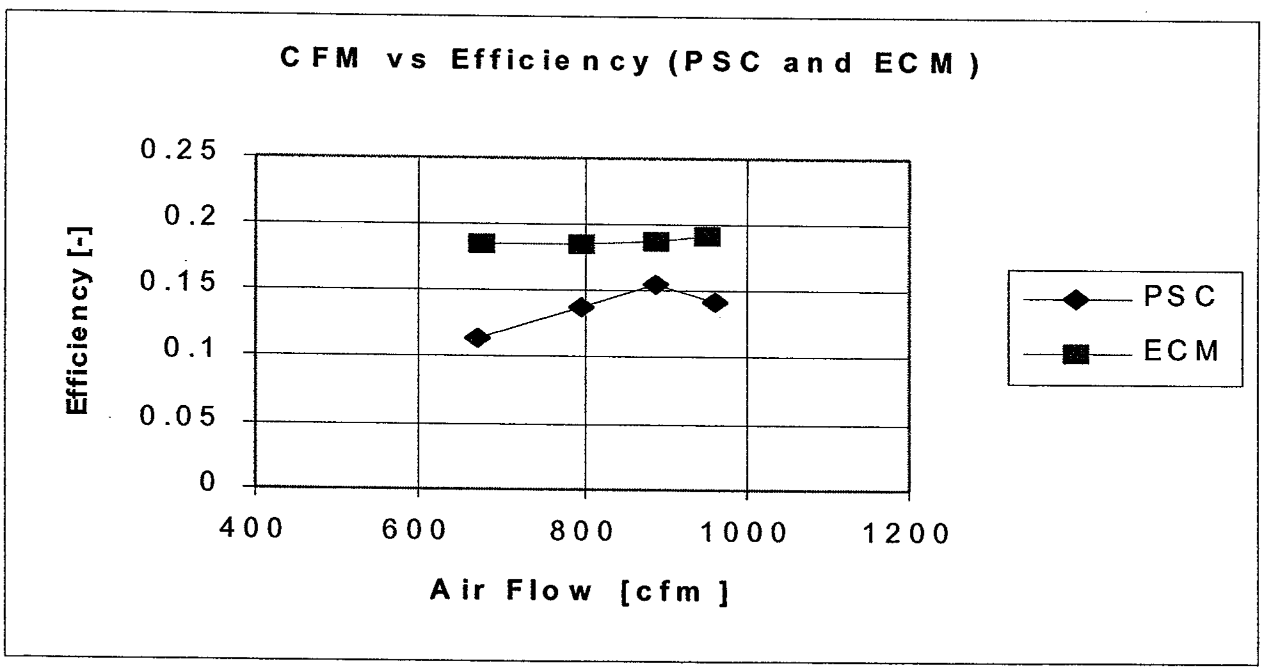

Figure 14. Efficiency vs. Airflow for the ECM and PSC Motor, ACT Fan Test Rig.

S_{eff} = efficiency of the fan system (fan and motor) (decimal percent),
P_S = static pressure of supply air (maintained at 60 Pa),
P_R = static pressure of return air (Pa),
Q = airflow (m^3/s), and
W = fan power (Watts)

Figure 13 shows the relationship between airflow and fan power across the range of the PSC motor. At each of the PSC motor's flow rates, the ECM uses less power. The difference is smallest at the PSC's medium-high setting (~900 cfm, the second-highest rate, and the one that is normally used for heating), and is larger at the other three rates. The ECM is also capable of being set to flow rates lower than any of the PSC's, and its power continues to decrease at these lower rates. Figure 14 shows that the ECM maintains a relatively high efficiency throughout its range while the efficiency of the PSC motor is always lower, and drops significantly above and below its medium-high setting.

The efficiency of the motor-fan system with the PSC motor varies from about 11 to 16%. The maximum efficiency of the motor-fan system with the ECM is less than 20%. The electrical efficiency of the ECM varies from about 75 to 85%, and fan efficiencies of 65% are practical (Ref 1). This indicates that potential savings from properly designed and sized fans are even larger than those from ECM motors, and the combination of efficient fans and ECMs could increase typical motor-fan efficiencies from 15 to 50%.

3.5 Analytical & Empirical Results

The theoretical values of the slope and intercept of the line defined by the daily furnace gas consumptions at the two houses during ECM testing (Figure 5), and for the "factored out" A/C results (Figure 11) can be calculated from the power draws and efficiencies of the system components. The numerical analyses are found in Appendix D for heating and Appendix E for air conditioning. This section presents some implications of the analysis, and compares the analytical and empirical results.

3.5.1 Heating

Table D-1 in Appendix D shows the effects on slope and intercept of the gas consumption curve (Figure 5) of varying some parameters by plus or minus 10%. An increase in either the slope or the intercept means an increase in gas consumption caused by a decrease in fan motor electrical consumption. None of these variations has a significant effect on the slope which varies by only 0.6% from its minimum to its maximum. The parameters that significantly affect the intercept are: "motor efficiency,"* furnace efficiency, and the difference between PSC and ECM power in circulation mode. Each has an approximately proportional change in the intercept. "Motor efficiency" is fixed; since the fan motor is located inside the blower wheel, most of its energy will end up in the air stream, and this is desirable during heating. Decreasing furnace efficiency will increase the electrical savings and gas consumption due to an ECM, but in the larger context of saving energy and decreasing environmental impacts, this is clearly not desrirable. Thus, the only valid and significant way to use ECMs to maximize gas consumption within overall energy savings is to maximize the difference between the electricity consumption by the two motors in circulation speed. This can be done by proper sizing of the ECM, and by setting its circulation speed as low as is compatible with good air circulation and indoor air quality.

As shown in Table 3, there is a very close relationship between the empirical and theoretical results, especially when the two points with Reference House gas consumption less than 50 MJ/day are excluded. The slope based on the 27 data points is 0.9% smaller than the theoretical slope, and the intercept is 4.4% greater than the theoretical one. This degree of accuracy in the measurement of a secondary effect (increased gas consumption as a result of decreased use of electricity) can be considered excellent, and confirms the CCHT's ability to measure such effects accurately.

3.5.2 Air Conditioning

Savings due to an ECM correspond to decreases of the intercept and/or the slope. Either decrease will increase the difference between the energy consumption of the A/C with the PSC motor (which corresponds to the 1:1 line in Figure 11) and the A/C with the ECM (which corresponds to the "factored out" line). Table E-2 in Appendix E shows the effects of varying the relevant parameters by plus or minus 10%. In all cases, cases the effect on the intercept is the opposite of the effect on the slope, so the net effect at the average Reference House load is also calculated and compared.

As is the case with furnace efficiency, increasing the COP of the compressor decreases the benefits of an ECM, but the decrease is rather small: 0.9% for a 10% increase in COP. The largest increase in ECM benefits comes from increasing the difference between the circulation wattages of the two motors; a 10% increase in ΔM_c results in a 3.6% increase in ECM benefits. Thus, as with furnaces, the best way to increase the benefits of an ECM motor is by maximizing the difference between the wattages of the PSC motor and the ECM in circulation mode. This can be done by setting the ECM circulation speed as low as is compatible with good air distribution and indoor air quality.

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* The rate at which motor electricity is converted to heat in the furnace duct. It appears to be about 94%.

As shown at the end of Section 3.3.3, the theoretical equation for the line of A/C electrical consumption is

$$y = 1.18x - 11.7.$$

The equation of the line produced by the project results with the difference between the PSC motors factored out (Figure 11) is

$$y = 1.16x - 9.9.$$

Compressor power and COP vary with outside and inside temperature and with inside humidity, as shown in Table E-1 and Figure E-1 in Appendix E. Given the uncertainties generated by these variations, and by the differences in the amounts of condensation in the two houses, this can be considered a very close fit.

3.6 An ACEEE Study on Energy Efficient Fan Motors

A recent study for the American Council for an Energy Efficient Economy (ACEEE)[5] predicts much larger effects than this report does from ECMs and similar energy efficient motors. The ACEEE study uses Gas Appliance Manufactures Association (GAMA) data on annual electrical use by high-efficiency gas furnaces to separate them into those with and without energy-efficient motors, and then to calculate the annual electrical savings and gas increases due to efficient motors. The GAMA ratings are based on operation of the furnace fan only when the furnace is producing heat.[6] Thus, all of their findings are for no continuous circulation.

For Wisconsin the ACEEE predicts electrical savings of 617 kWh/y without A/C, and 742 with A/C, and 23 therms (65 m^3) of increased natural gas consumption. This can be compared with our projections for Toronto, which according to the GAMA map of heating load hours is in the same zone as Wisconsin. In a typical existing house with a high-efficiency furnace we project 324 kWh/y without A/C, 372 kWh/y with A/C, and 26 m^3 of increased gas. Thus, the ACEEE's projections are 1.9 to 2.5 times as large as those in this report. Our PSC used about 1.68 times as much power, and energy per year, as our ECM. Their average PSC seems to use about 2.7 times as much as their average ECM. (See row 3 (60 - 76 kBtuh) in Table A1-2 of the ACEEE report). Their results may be a product of aggregating all furnaces that appear to have efficient motors and all those that don't, and then using the difference between the average GAMA annual electrical use for the two sets. This involves other factors besides motor efficiency, eg, motor size and pressure drop through the furnace. Peter Edwards (*ibid*) used a very similar method to separate furnaces with and without ECMs, and found that it worked well, but was not 100% effective, i.e., some of the models that he could identify by model numbers were not in the correct category. He also found that the GAMA fan electrical data can be "very fuzzy" for multi-stage furnaces.

The ACEEE study cites a report by General Electric[7] that, on average, "estimates 2.38 times the savings for ECM motors that ACEEE does," and assumes "that GE did not include estimates of the value of gas required to make up for reduced electricity waste by the motor." Thus, the projected effects of ECMs in this report appear to be quite conservative, but since they are based on measured consumption differences in a single type of furnace, they may well prove to be more accurate.

According to the ACEEE study, motors that use basically the same technology as ECMs are called by a variety of names including BPM, ECPM, ICM and DCPM, and manufactures other than General Electric "are developing advanced motors that could give nearly the efficiency of the BPM at lower cost." They state that current wholesale costs are US$25 for a ½ HP PSC motor, and at least US$100 for the same size ECM. They "expect a long-term (mature technology) incremental cost of $25-65, which would appear as a consumer price increase of $50-130". Citing industry sources, they say that approximately 150,000 BPM motors are sold for furnaces each year, giving them a 2.5% share of the US market, and "as much as 20% of the condensing furnace market". For comparison, Peter Grinbergs[8] of Nutech Energy Systems Inc in Ontario says their current wholesale price for an ECM is US$170 which results in an additional charge to consumers of around C$450.

Other potential benefits of ECMs mentioned in the ACEEE study include: longer motor life due to soft starts and simpler design, better control of temperature and particulate matter, ability to maintain design airflow as static pressure varies, and ability to respond to changes in humidity by varying airflow.

4.0 Projections to Complete Years, and to other Furnaces, Houses & Climates

The results from the CCHT houses show the effects of the ECM for seventy particular days in a particular house with a particular furnace and air conditioner. To be generally useful, these results must be projected to entire years, and to other houses, locations and furnace types. As described in Appendix F, HOT2000 was found to be a suitable tool for projections. An existing model of the CCHT Reference house was copied and modified for the ECM and PSC motor, compared with the results, and used to project the results to an entire typical heating season. Then new models were created for the following furnaces, house types and cities:

1. Furnaces: Mid-efficiency (82% steady-state efficiency), and high-efficiency (92% efficiency).

2. House types: R-2000, typical new, typical existing, typical row housing, and typical row housing with a ⅓ horse power (HP) fan motor (the motors used in the tests, and in all other projections are ½ HP).

3. Cities: Toronto, Ottawa, Moncton and Winnipeg, .

The house types for each city were based on housing archetypes previously developed by SAR Engineering Ltd. and the Buildings Group.[9] Each house type has different volumes, insulation levels, windows, and airtightness levels for each of the three provinces that the cities are found in. The typical new house archetypes were based on the National Energy Use Database (NEUD) *Survey of Houses Built in Canada in 1994*.[10] The R-2000 houses have the same volumes with improved airtightness, windows and insulation values to meet the current R-2000 standard. Typical existing houses were based on the archetypes for 1961 - 77, and typical row houses are typical existing houses reduced to a volume of 350 m^3, and with one-half the wall and window area. Standard values are used for temperature settings, hot water temperature and consumption, and electricity consumption for lights and appliances. Current examples of prices of electricity and natural gas in each city were used. No attempt was made to account for the range of prices available to consumers, nor for possible future prices.

During initial projections, an inconsistency was found in the HOT2000 results. For houses without continuous circulation, the air conditioner compressor used more energy with an ECM than with a PSC motor. This lead to a complete rewriting of the HOT2000 air conditioner model, based on comparisons with the more detailed hour-by-hour model in the ESP-r building energy simulation model. This improvement in HOT2000 happened at a time when its air conditioning model is becoming more important since air conditioning is becoming a more significant part of residential energy use in Canada, and HOT2000 is being used increasingly in other countries.

4.1 Operating Conditions: Air conditioners & Furnace Fans

Furnace fans can operate at three different speeds: high speed for air conditioning, medium speed for heating, and low speed for continuous circulation. When the air conditioner or furnace is running, the fan always runs at the corresponding speed. However, when neither the furnace nor the air conditioner is active, the fan may operate in its continuous circulation speed, or it may be off. Since houses may or may not have air conditioners, and may or may not have continuous circulation, projections of ECM savings were done under four conditions:

1. Air conditioning and continuous circulation,
2. No air conditioning and continuous circulation,
3. Air conditioning and no continuous circulation, and
4. No air conditioning and no continuous circulation.

Together, these conditions cover the range of potential ECM effects. The first should show the greatest difference between a PSC motor and an ECM since the fan motor will be in use continually for the entire year, and will spend a large amount of time in circulation speed where the difference between the PSC motor and ECM is greatest. The last should show the smallest difference since the motor will only be on when the furnace is operating, and will never be in circulation speed. The conditions with air conditioning assume that windows are kept closed all year, and the air conditioner operates whenever required to keep the house below the set-point of 25 °C. Other intermediate conditions are possible. For example, windows could be open and air conditioning off except during the hottest periods, or the furnace fan could be used as a "summer fan" to circulate cool air from the basement during hot periods. Modelling all of these conditions would be too cumbersome, and their effects are within the range of the conditions that are modelled.

4.2 Calculations of GHG Savings

ECMs save electricity and cause more natural gas to be consumed for space heating, so their effects on emissions of greenhouse gases (GHG) depends on the actual effects on the two fuels, and the GHG intensity of the fuels. The GHG intensity of natural gas is straight forward, but the intensity of electricity depends on the mix of fuels used to generate the electricity, and the GHG reductions from savings of electricity depends on which of these fuels will be displaced by the savings. This report calculates GHG reductions from electricity savings in two ways. The first assumes that all electricity savings displace coal-fired electricity generation. Although each location has it own mix of fuels for generating electricity, reductions in demand result in reductions in coal-fired generation. Even in Manitoba where most generation is by hydro power (zero GHGs), excess electricity is sold to the U.S. where it can displace coal. The second way is based on the actual mix of generation fuels in each of the provinces in which projections are done. Table 5 shows the GHG intensities used in this report. The measure of GHG intensity is kilograms of carbon dioxide equivalent (kg CO_2) per fuel unit, and the fuel units are cubic meters for natural gas and kiloWatt-hours for electricity. Both are also shown in kg CO_2/GigaJoule for comparison.[11]

Fuel	Greenhouse Gas (GHG) Intensity		
	kg CO_2/m^3	kg CO_2/kWh	kg CO_2/GJ
Natural Gas	1.9124	-	51.367
Electricity from Coal	-	1.1	305.56
Electricity, Manitoba	-	0.010694	2.9706
Electricity, Ontario	-	0.073914	20.532
Electricity, New Brunswick	-	0.212889	59.136

Table 5. Greenhouse Gas Intensities.

The values of kg CO_2/GJ in Table 5 clearly show that if saved electricity is generated from coal, then an ECM will definitely reduce GHG emissions. Electricity from coal is almost six times as GHG intensive as natural gas, so saving electricity and using more natural gas will significantly reduce GHG intensity, regardless of differences in their efficiencies of use.* However, if electrical GHG intensity is based on provincial fuel mixes, the situation is very different. In Ontario, and especially in Manitoba, electricity is less GHG intensive than gas, so substituting gas for electricity could result in significant increases in emissions. In New Brunswick, electricity is 15% more GHG intensive than gas, so the net effect on emissions could depend on their efficiencies of use.

How to best calculate the GHG reductions from electrical savings is controversial. Some people are convinced that coal is always the swing fuel, while others believe that this assumption exaggerates GHG reductions because natural gas, oil or hydro power may be the swing fuel.

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* Table 5 is based on the energy content of the fuels. Fan motor electricity appears to be converted to heat with an "efficiency" of 94%. Natural gas is used with efficiencies of 82% and 92% in the projections for mid- and high-efficiency furnaces. Thus, substituting gas for electricity results in smaller GHG reductions than would be indicated by the kg CO_2/GJ values alone.

Effects of ECM Furnace Motors on Electricity and Gas Use

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-tricity	Nat Gas	Net	Elec-tricity	Nat Gas	Net
						Fan	A/C	Total					Furn	Total								
CCHT with A/C	PSC	3545	2,541	15617	X	X	X	X	X	1,937	2,649	X	X	X	X	X	X	X	X	X	X	X
	ECM	999	2,229	12763	2854	72%	12%	18%	$241	2,121	2,834	184	9.5%	7.0%	$83	$158	3139	-353	2786	211	-353	-142
CCHT without A/C	PSC	2001	0	11523	X	X	X	X	X	1,937	2,649	X	X	X	X	X	X	X	X	X	X	X
	ECM	427	0	9949	1574	79%	N/A	14%	$133	2,121	2,834	184	9.5%	7.0%	$83	$50	1732	-353	1379	116	-353	-236

Table 6. HOT2000 Projections of ECM Effects for a typical Year at the CCHT Houses.
Energy Costs: Electricity: 0.0845 $/kWh, Natural Gas: 0.4494 $/$m^3$, including taxes.

Notes: Total kWh/y includes electricity use for lighting and appliances for the entire year.

Total natural gas use includes use for hot water for the entire year.

Using provincial averages probably underestimates the effects of reductions because capital intensive nuclear and hydro plants (counted as zero GHG emitters) are less likely to be reduced than fossil fuel plants. Imports and exports among provinces and countries further complicate the situation. This report presents GHG reductions calculated by both methods, and allows readers to make their own judgements.

4.3 Projection Results

4.3.1 Continuous Circulation Fan

Table 6 shows the projections of the results for a typical Ottawa year in the CCHT house, based on the HOT2000 weather files. Without air conditioning, the ECM saves 1,574 kWh per year, which is worth $133 at current Ottawa prices. (All prices in this section include applicable taxes). This is 79% of the PSC motor's consumption, and 14% of the total electricity used by the house with the PSC motor. This decrease in electrical consumption results in the use of an additional 184 m^3 of natural gas, worth $83 at current prices. This is 9.5% of the gas used by the furnace, and 7.0% of the total which includes gas use for domestic hot water. The net savings to the homeowner would be $50 per year. When GHG emissions are calculated on the basis of electricity from coal, then the reduced use of electricity results in a decreased GHG emissions of 1,732 kilograms of CO_2 equivalent per year (kg CO_2/y), the increase in natural gas results in an additional 353 kg CO_2/y, so the net reduction is 1,379 kg CO_2/y. The house with the PSC motor would cause 17,742 kg CO_2/y to be emitted, and the ECM reduces this by 7.8%. When GHG is calculated based on Ontario's mix of generating fuels, then electrical savings produce a reduction of 116 kg CO_2/y, and the net effect is an increase of 236 kg CO_2/y, or 4%. (Emissions due to natural gas are unchanged).

With air conditioning in the CCHT house, the ECM saves 2,854 kWh/y which is 18% of the total electricity used with the PSC motor, and is worth $241. The furnace fan saves 2,546 kWh/y or 72% of the PSC consumption, while consumption by the air conditioner compressor is reduced by 312 kWh/y or 12%.* Increases in natural gas consumption and emissions are the same with and without air conditioning. Net savings are $158 per year. On the coal-electric basis, GHG reductions are 3,139 kg CO_2/y from electricity, and 2,786 kg CO_2/y, or 12% net. On the provincial mix basis, GHG emissions from electricity are reduced by 211 kg CO_2/y, and net emissions are increased by 142 kg CO_2/y, or 2%.

Details of the projections to other cities, houses and furnaces are shown in Tables F4 - F11 in Appendix F. Tables F4 and F5 show the results for Toronto. For houses with mid-efficiency

* Fan and A/C savings do not add exactly to total savings due to the way HOT-2000 handles these numbers internally. Differences are less than 1% of total savings, and are not significant in the context of modelling accuracy.

furnaces (Table F4), there is a progression of increased furnace electricity and gas use from the energy efficient R-2000 to the less efficient typical new, and to the least efficient typical existing house. (The typical existing house has a smaller amount of total electricity because it has no mechanical ventilation). Savings of electricity due to the ECM are smaller in the less efficient houses, both as kilowatt hours per year (kWh/y) and as percentages of furnace electricity. Increases in cubic meters of natural gas per year (m^3/y) due to the ECM are higher in the less efficient houses, but the percentage increase is lower. Due to its smaller size, the typical row house, despite being much less efficient than the R-2000, uses only a little more furnace electricity and gas, and the electricity savings and increased gas use due to the ECM are also close to the R-2000's. The row house with the ⅓ HP fan motor uses and saves less electricity than any of the others, and its increased use of natural gas is also the smallest.

As would be expected, the use of an air conditioner makes no difference to natural gas consumption, but does increase the use of electricity by the furnace fan and by the house (total). Comparing houses with and without air conditioning, those with air conditioning show the following characteristics: An ECM results in larger savings, both by the fan and the house. For the total house, the percentage saving due to an ECM is greater, while for the fan, the percentage saving is lower, except in the typical existing house where they are same with and without air conditioning.

The highest net savings to the household occur in the R-2000 house. Without air conditioning, its ECM saves 1,606 kWh/y worth $136, and causes the use of an additional 170 m^3/y of gas worth $76, for a net saving of $59 per year. With air conditioning, it saves 2,940 kWh ($249) for a net saving of $172. The typical row with air conditioning saves slightly more electricity (2,965 kWh worth $251) for the same net saving as the R-2000, but without air conditioning, its electricity and net savings are a little smaller. Electrical and net savings decline in the typical new and existing houses, and the typical existing house has the smallest net savings of all houses with ½ horse power motors: $40/y without air conditioning, and $147 with. The typical row with a ⅓ HP motor shows the lowest net savings: $37 and $111. Electrical savings due to ECMs range from 1,074 to 1,606 kWh/y without air conditioning, and from 1,946 to 2,965 kWh/y with air conditioning. The increases in natural gas range from 120 to 202 m^3/y.

When saved electricity is assumed to be generated from coal (Section 4.2), then the projections show significant reductions in greenhouse gas emissions due to ECMs in all houses. The R-2000 and typical row house are virtually tied for the greatest reductions, with each of their reductions within 1% of the other's. In the row without air conditioning, the GHG reduction is 1,428 kg CO_2/y, and in the R-2000 with air conditioning it is 2,909 kg CO_2/y. GHG reductions get smaller in the typical new and existing houses, and are smallest in the typical row with a ⅓ HP motor: 952 kg CO_2/y without air conditioning, and 1,912 with. With one exception, all houses show savings of well over a tonne of GHGs per year without air conditioning, and well over two tonnes with air conditioning. Savings from the row with ⅓ HP are just under those amounts. When saved electricity is assumed to be generated from the mix of fuels used in Ontario, then an

ECM results in net increases in GHG emissions in all houses. The increases are smallest in the row house with a ⅓ HP motor: 149 kg CO_2/y without air conditioning, and 85 kg CO_2/y with air conditioning. Of the houses with ½ HP motors, the R-2000 has the lowest increases (207 kg CO_2/y without air conditioning and 108 with). The typical new house has larger increases, and the typical existing house has the highest of all: 271 kg CO_2/y without air conditioning and 178 with.

Thus, if saved electricity is coal-fired, then ECMs have projected GHG reductions in the order of one to three tonnes per year. If saved electricity is from the Ontario mix of generating fuels, then ECMs have projected GHG increases in the order of 0.1 to 0.3 tonnes per year. If the actual GHG intensity of saved electricity is somewhere between the two assumptions, then the actual effects of ECMs in the Toronto houses will almost certainly be net reductions in GHG emissions.

Projections for the same Toronto houses with high-efficiency furnaces are shown in Table F5. All values for electricity should be identical to those with the mid-efficiency furnace because the outputs of the furnaces are the same, so they should run the same number of hours, and use the same amount of fan energy. (Air conditioners are identical). In fact, most electrical values in Tables F4 & F5 are identical, and all are within 1%. Variations are due to internal working of HOT2000, and are insignificant in terms of modelling accuracy. Natural gas consumption is significantly smaller with the high-efficiency furnaces, as would be expected. Increases in gas use due to ECMs are also smaller with high-efficiency furnaces (107 - 180 m^3/y), but as a percentage of furnace gas, they are identical. (As a percentage of total gas they are smaller). Because high-efficiency furnaces have the same electrical savings as mid-efficiency units, but smaller increases in natural gas use, they have higher net dollar savings and better effects on GHG emissions. The rankings of the houses in terms of savings and emissions are the same as with mid-efficiency furnaces. For the houses with ½ HP fan motors, dollar savings range from $65 to $180 per year, coal-electric GHG reductions from 1,345 to 2,944 kg CO_2/y, and Ontario mix GHG increases from 73 to 230 kg CO_2/y.

It is interesting to note that the R-2000 house uses more energy for the air conditioning compressor than any of the others. One might think that a better insulated house that has windows with lower solar heat gain coefficients would use less air conditioning energy. However, in Canada air conditioning load is generally more dependent on internal heat gains than on gains from outside the house.[12] In descending order of air conditioning energy the houses are: R-2000, typical new, typical row, typical existing, and row with ⅓ HP fan motor. This is true for all the locations for which projections are done, including projections with and without continuous circulation, with one exception.

Tables F6 & F7 show the result for the four types of houses in Ottawa. The house models used in Toronto and Ottawa are identical, and Ottawa is somewhat cooler in both the heating and cooling seasons. Differences between the two cities are small, but each Ottawa house uses more furnace gas and less electricity for air conditioning. This generally results in higher fan energies and smaller electrical savings due to ECMs in Ottawa. Increases in natural gas use are always higher in Ottawa, and net dollar savings are always smaller. With coal-fired electrical savings, reductions in GHGs are mostly smaller, and with the provincial mix increases are larger. Electrical savings due to ECMs range from 1,061 to 2,948 kWh/y, and natural gas increases range from 108 to 211 m^3/y. If the row houses with ⅓ HP motors are excluded, the minimums are 1,535 kWh/y saved and 153 m^3/y increased.

Tables F8 & F9 show the results for the four house types in Moncton. The pattern of furnace electrical use, and electrical savings due to an ECM are similar to those in Toronto. The increase in electricity use due to an ECM is the highest in all four cities – 1,222 to 1,823 kWh/y without air conditioning, and 1,957 to 2,991 kWh/y with air conditioning. Increased gas use due to an ECM is also the highest of all four cities – 133 to 222 m^3/y with mid-efficiency furnaces, and 118 to 198 m^3/y with high-efficiency. Moncton's electricity prices (0.0896 \$/kWh) are slightly higher than Ontario's, and gas prices (0.5073 \$/m^3) are significantly higher. The result of these factors is that net homeowner savings are generally lower than those in Toronto except for existing and row houses. With coal-fired electric savings, net GHG reductions are the highest of all four cities: 1,091 to 1,674 kg CO_2/y without air conditioning, and 1,957 - 2,991 kg CO_2/y with air conditioning. Based on the provincial mix of generating fuels, New Brunswick's electricity has the highest GHG intensity of the projection locations, and is the only location with electrical GHG intensity higher than that of natural gas (see Table 5). This gives ECMs in Moncton the best effect on GHG emissions based on the provincial generating mix. Without air conditioning, they range from an increase of 59 kg CO_2/y to a decrease of 56 kg CO_2/y, and with air conditioning all cases show decreases ranging from 168 to 312 kg CO_2/y. Thus, both methods of assigning GHG effects to reduced electrical consumption result almost entirely in reduced GHG emissions due to ECMs.

Tables F10 & F11 show the results for Winnipeg. Winnipeg has the coldest climate of the four cities, and its R-2000 and typical new houses have the highest gas consumption, except for existing houses and row houses in Ottawa. ECM electrical savings range from 1,065 to 1,725 kWh/y without air conditioning, and from 1,928 to 2,941 kWh/y with air conditioning. Gas increases range from 109 to 211 m^3/y. With coal-fired electric savings, net GHG reductions range from 939 to 1,536 kg CO_2/y without air conditioning, and from 1,888 to 2,930 kg CO_2/y with air conditioning. Based on the provincial mix of generating fuels, Manitoba has by far the least GHG intensive electricity, which results in ECMs causing strong increases in GHG emissions: 196 to 383 kg CO_2/y without air conditioning, and 187 to 371 kg CO_2/y with air conditioning. Winnipeg has the lowest cost of electricity of the four cities (0.0559 \$/kWh), so the net savings to Winnipeg homeowners are small: \$14 to \$30 per year without air conditioners, and \$63 to \$106 with air conditioners.

Effects of ECM Furnace Motors on Electricity and Gas Use

To summarize the above results for all cities, houses and furnaces:

- Savings of electricity are more than 1,000 kWh/year in all cases. For houses without air conditioners, they range from1,061 kWh/y in a row house with a ⅓ HP fan motor in Ottawa to 1,832 kWh/y in a row house in Moncton. With air conditioning, the range is from 1,928 kWh/y in a row house with ⅓ HP motor in Winnipeg to 2,991 kWh/y in a row house in Moncton. Excluding row houses with ⅓ HP motors, the minimum electrical savings are 1,535 kWh/y without air conditioning, and 2,795 kWh/y with air conditioning. As a percentage of electrical use by the entire house, the savings range from 12% to 18% without air conditioning, and from 17% to 25% with air conditioning.

- Based on coal-fired electricity, net reductions in greenhouse gas emissions due to an ECM are over 900 kg /year of CO_2 equivalent in all cases. For houses with air conditioners, they are over 1,800 kg CO_2/y. Excluding the row houses with ⅓ HP motors, net GHG reductions in houses without air conditioners range from 1,314 to 1,674 kg CO_2/y, and with air conditioning, from 2,703 to 2,962 kg CO_2/y.

- Based on provincial mixes of generating fuels, the effects of ECMs on GHG emissions range from an increase of 383 kg CO_2/y to a decrease of 312 CO_2/y. Only Moncton showed any decreases; in the other cities the smallest increase was 60 kg CO_2/y.

- Natural gas prices in the four cities vary by 37% from 0.3696 to 0.5073 \$/m^3, and electricity prices vary by 60% from 0.0559 to 0.0896 \$/kWh, so one might expect net dollar savings to be most dependent on the price of electricity. In Winnipeg, which has the lowest electricity (and gas) prices, net savings due to an ECM are the smallest, ranging from \$14 to \$30 per year without air conditioning, and \$63 to \$106 with air conditioning. In Moncton, with the highest electricity (and gas) prices, the net savings in houses without air conditioning are the highest at \$38 to \$75, but the net savings with air conditioning are intermediate at \$108 to \$182. In Toronto, with intermediate electrical (and gas) prices, the net savings without air conditioning are intermediate (\$37 to \$ 68), but the savings with airconditioning are the highest (\$111 to \$180). (Savings in Ottawa are \$1 to \$7 less than in Toronto). So net annual savings from an ECM can vary from \$14 to \$180 depending on the price of electricity and other factors.

- Increased use of natural gas due to an ECM is greater than 100 m^3/year in all cases. Excluding houses with ⅓ HP fan motors, it ranges from 152 m^3/y in an R-2000 house with a high efficiency furnace in Toronto to 222 m^3/y in an existing house with a mid-efficiency furnace in Moncton. The percentage increase in gas use for the entire house ranges from 4.7% in a typical existing house with a high-efficiency gas furnace in Ottawa to 9.7% in Moncton R-2000 and row houses with medium-efficiency furnaces.

Thus, in houses with continuous circulation, the use of ECMs for fan motors would have significant benefits as:

- a demand side management (DSM) tool for reducing demand for electricity,
- a means of reducing emissions of greenhouse gases, assuming that saved electricity is coal-fired, or has a GHG intensity between that of coal-fired electricity and electricity from the provincial mixes of generating fuels,
- a means of reducing homeowners' utility bills, and
- a means of increasing gas sales.

Although the reductions in utility bills are very dependent on the relative prices of gas and electricity, and are small in some places, they are the least significant to a DSM tool. If gas utilities are willing to promote the installation of new furnaces with ECM fan motors, this would have significant benefits in the other three areas, and would also save consumers money.

4.3.2 No Circulation Fan

Tables F12 through F19 in Appendix F show the projections for the same four cities (Toronto, Ottawa, Moncton and Winnipeg) without continuous operation of the furnace fan. All conditions are the same as in the previous section, except that the furnace fan operates only when there is a demand for space heat or air conditioning. As would be expected, the effects of an ECM without continuous circulation are much smaller than with. The difference between the wattages of PSC motors and ECMs are greatest in circulation mode, and without this mode the motors run for far fewer hours in a year.

Tables F12 & F13 show the results for Toronto. Savings of electricity due to an ECM range from 90 to 372 kWh/y (1% to 3% of total house use), increases in natural gas are 8 to 29 m^3/y (less than one percent of total house use), and net savings are \$4 to \$20 per year. Based on coal-fired electricity, net reductions of GHG emissions are 81 to 360 kg CO_2/y, and based on the provincial fuel mix, increases in GHG emissions are 6 to 32 kg CO_2/y. Results for the other cities are similar. The savings in electricity range from 90 kWh/y in a row house with ⅓ HP motor and no air conditioner in Toronto to 434 kWh/y (4% of total) in a typical existing house with air conditioning in Winnipeg. Increases in natural gas use go from 8 m^3/y in a row house with ⅓ HP motor and no air conditioning in Toronto, to 29 m^3/y (0.7% of total) in a typical existing house with air conditioning in Toronto. Net savings are smallest (\$2 per year) in a row house with ⅓ HP fan motor in Winnipeg, and largest (\$20) in typical existing houses in Toronto and Ottawa. Based on coal-fired electricity, net GHG emissions reductions range from 81 kg CO_2/y in the row house with ⅓ HP motor and no air conditioner in Toronto, to 424 kg CO_2/y in a typical existing house with air conditioning in Winnipeg. Based on provincial fuel mixes, the largest increase in

GHG emissions is 50 kg CO_2/y in the existing house with air conditioning in Winnipeg, and the largest decrease is 25 kg CO_2/y in a typical existing house with air conditioning in Moncton

Thus, whether ECM furnace fan motors will have significant benefits depends critically on whether the furnace fan is run in continuous mode for at least a significant part of the year.

4.3.3 "Free" Continuous Circulation with an ECM

A house with a PSC motor and no circulation mode that changed to an ECM with continuous circulation would see only a very small increase, or a small saving, in its utility bills. This can be seen by comparing the projections for ECMs with continuous circulation (Section 4.3.1) with those for PSC motors with no circulation mode in the previous section, as shown in Table 7. This table shows the projected total amounts of electricity and natural gas use for houses in Toronto. A comparison of the costs for all four cities shows that the maximum extra

House Type	ECM w/Circulation			PSC w/out Circulation			Cost of ECM Circ
	(kWh/y)	m^3/y	$/y	(kWh/y)	m^3/y	$/y	$/y
R2000 with A/C	11736	2,038	$1,783.14	11661	2,040	$1,778.00	$5.14
R2000 without A/C	9855	2,038	$1,634.48	9841	2,040	$1,634.23	$0.25
Typical New with A/C	11773	2,886	$2,142.05	11787	2,883	$2,142.22	-$0.17
Typical New without A/C	9962	2,886	$1,998.92	10037	2,883	$2,003.95	-$5.04
Typical Existing with A/C	10820	4,055	$2,557.78	10959	4,058	$2,569.99	-$12.21
Typ. Existing without A/C	9372	4,055	$2,443.38	9564	4,058	$2,459.81	-$16.43
Typical Row with A/C	9631	2,008	$1,604.20	9566	2,013	$1,601.19	$3.01
Typical Row without A/C	8003	2,008	$1,475.60	7994	2,013	$1,477.07	-$1.47
Row, 1/3 HP with A/C	9197	2,018	$1,574.26	9114	2,024	$1,570.13	$4.14
Row, 1/3 HP without A/C	7915	2,018	$1,472.98	7890	2,024	$1,473.43	-$0.45
Average Cost of ECM Circulation:							-$2.32

Table 7. Operating Costs of an ECM with Continuous Circulation Compared with a PSC motor without Continuous Circulation.

utility bill for continuous circulation with an ECM would be $5.14 in an R-2000 with air conditioning in Toronto. The greatest reduction would be $19.09/y in a typical existing house without air conditioning in Ottawa. For all cities and houses, the average result is a saving of $3.51/y. Thus, having made the initial purchase of an ECM, occupants could enjoy the health and comfort benefits of continuous circulation for virtually no cost, or even a small saving in their utility bills.

4.4 Conclusions from the Projections

ECMs have significant potential benefits in houses that operate their furnace fans in continuous ventilation mode. These benefits apply across the entire range of locations, house types and furnace types. Cost savings to occupants depend on the relative costs of electricity and natural gas, but they are positive in all the projections, and significant in many of them. Net reductions in greenhouse gas emissions depend on how the electricity saved by ECMs is generated, but a comparison of the two methods used here indicates that ECMs should cause significant net reductions in GHGs under most conditions. ECMs will definitely reduce the demand for electricity, and should reduce peak loads during both the heating and cooling seasons. ECMs will increase the use of natural gas, which is a benefit from the point of view of gas utilities.

For houses that do not operate furnace fans in continuous mode, the benefits of ECMs are not significant. But most houses could have improved comfort and indoor air quality if they did use continuous circulation. Continuous circulation provides the benefits of more even distribution of fresh air and temperatures throughout the house. This is especially true of newer houses in which the fresh air from the heat recovery ventilator is distributed through the house by the furnace fan and ducts. Since ECMs provide continuous circulation with no increase in utility bills – as compared to PSC fan motors without continuous circulation, ECMs can be part of a package promoting better circulation, health and comfort.

5.0 Summary & Conclusions

Electronically commutated motors (ECM™) are significantly more efficient than the permanently split capacitor (PSC) motors used in most residential furnaces. This is especially true at the lower speeds used for continuous circulation in many new houses. In order to quantify the effects of an ECM on electricity and gas consumption, we installed an ECM in one of the two identical houses of the Canadian Centre for Housing Technology (CCHT), and observed the amounts of furnace natural gas, furnace fan electricity, air conditioner compressor electricity, and all internal electricity in the two houses.

Prior to installing the ECM, the two houses were benchmarked, i.e., run under the same conditions with the original PSC furnace motors in both. This confirmed that the daily electricity and gas consumption of the two houses were nearly identical. Furnace air flows, and supply flows to each room of the house, were measured in both the Test and Reference House. The ECM was installed in the Test House and programmed to have the same heating and air conditioning air flows, and a smaller, but still adequate, circulation air flow, compared to the PSC motor that remained in the Reference House. The ECM was programmed to a lower circulation flow in order to take advantage of its wider range, and the fact that its electrical consumption continues to drop significantly at lower flows. Air flows to each room were measured at the lower circulation flow, and found to be very acceptable.

With the ECM and PSC motors operating side by side, the differences in both electrical and natural gas consumption were clear. During the space heating test period, the ECM reduced the average furnace electrical consumption from 9.29 to 2.38 kWh/day, a 74% saving. Electrical consumption for the entire house was reduced from 25.9 to 19.1 kWh/day, which is a 26% saving in a house with a typical electrical load. Reducing the use of electricity by the furnace motor reduces the amount of heat it adds to the house, and thus increases the use of natural gas for heating. This increase was from an average of 213.7 to 243.4 MJ/day, or 14%. As shown in Figure 5, this secondary effect is very clear, i.e., the plots of daily gas consumption during ECM testing and during benchmarking are quite distinct. This demonstrates a unique fuel switching opportunity associated with ECMs, by which natural gas used at close to 90% efficiency can displace significant amounts of electrical energy. This efficiency is at least twice the efficiency with which electricity could be generated from gas by any known technology.

The air conditioning benchmark was not as exact as the heating benchmark, and there were differences in the amounts of condensate in both benchmarking and testing, so the air conditioning results are not as straightforward as the heating ones. Nevertheless, the difference between electricity use for air conditioning is clear, as shown in Figure 10. The differences in benchmarking and condensate can be factored out, showing that the ECM saved the following percentages: 48% of the fan energy, 4% of the compressor energy, 21% of the air conditioner (fan plus compressor) energy, and 14% of the electricity used by the entire house. The ECM also resulted in slightly lower average relative humidity in the house, which could lead to further savings because occupants could feel cooler and thus set the thermostat to a slightly higher temperature.

The characteristics of the types of ECM and PSC motors, and of the furnace blower used at the CCHT were studied in detail at the Advanced Combustion Technology Lab (ACT). Their CMHC fan test rig was used to measure electricity use, air flow, and aerodynamic efficiency of the motor-blowers across their ranges, and confirmed the fact that ECMs are more efficient, especially at low flow rates. The ACT results also indicate that there is a large potential for savings from better designed motor-blower assemblies. The results from the CCHT were compared with a numerical analysis and found to be in close agreement. An examination of deviations from the analytical results at low gas use confirms the occurrence of wasted, or non-utilizable, internal gains in the house with the PSC motor. This was confirmed by both house temperatures and total (gas plus electric) furnace heat in the two houses.

The HOT2000 house energy simulation model was used to project the CCHT results to a complete year, and also to combinations of other houses, furnaces and climates. For a complete year at the CCHT without air conditioning, the projection shows a saving of 1,574 kWh (14 % of total use for the house), and increased natural gas use of 184 m^3 (7% of the house total, including use for domestic hot water). The net savings on both electricity and natural gas would be $50 per year. If saved electricity is generated from coal, then the net reduction in greenhouse gas emissions would be 1,379 kg of CO_2 equivalent. If the saved electricity were generated from the provincial mix of generating fuels, then GHG emissions would be increased by 236 kg CO_2. With airconditioning, electrical savings are 2,854 kWh (18% of the house total), and net savings are $158 per year. On the coal-electric basis GHG emissions are reduced by 2,786 kg CO_2, and based on the provincial mix they increase by 142 kg CO_2.

For houses that operate furnace fans in continuous circulation mode, the projections to other cities, houses and furnaces show similar benefits over a wide range of conditions, and indicate that ECMs would have significant benefits as a demand side management tool for reducing electrical demand, and as a way of increasing natural gas sales. For houses with ½ HP motors, electrical savings range from 1,535 to 2,911 kWh/y, and increased use for gas is between 152 and 222 m^3/y. They would also reduce net utility bills by amounts that are significant in some locations. Net savings range from $14 to $180 per year, and except in Winnipeg, all are $38/y or greater. Currently, wholesale prices of ECMs are about US$170 resulting in increased consumer costs of around C$450. Prices are expected to come down, and properly applied incentives could reduce or eliminate the additional cost to the consumer. The largest variation among the cities is in the effects on GHG emissions based on provincial mixes of generating fuels. These vary from significant increases in Winnipeg, where electricity is mainly hydro electric with zero GHG intensity, to a range from small increases to significant decreases in Moncton, where electricity is more GHG intensive than natural gas. When GHG emissions are calculated on the basis of electricity from coal, then all locations show significant reductions. Since it is most likely that electrical savings displace some form of fossil fuel generated electricity, actual net GHG emissions would probably be reduced significantly in all cases.

For houses without continuous circulation, the benefits of ECMs are not very significant. But, ECMs would allow such houses to switch to continuos circulation with no significant increase in utility bills. In fact, in most cases utility bills would be reduced slightly. Continuous circulation provides benefits of more even distribution of fresh air and temperatures, and is especially important in houses which use the furnace fan to distribute fresh air to the house. Thus, ECMs can be part of a package promoting better circulation, comfort and health.

Thus, this project demonstrated two important results. The key result is the demonstration of the benefits of the use of ECMs as furnace fan motors and the associated unique fuel switching opportunity of displacing electrical energy with gas. From the point of view of a natural gas utility promoting ECMs as a demand-side management program, the benefits would include increased gas sales. From the consumer's point a view, they include net savings on utility bills, and from a wider perspective, they include significant reductions in greenhouse gas emissions from houses. The greenhouse gas reductions are due to the unique fuel switching that uses extra gas in place of electricity at an efficiency that is at least twice that of any know gas-electric generating technology. The second result is the demonstration of the ability of the CCHT to be used as a valuable research facility for examining energy saving opportunities, by accurately measuring secondary and tertiary effects of a relatively small change in one of the houses.

Further study to define the potential impacts of ECMs could include:

- A statistically significant study of the percentages of houses that use continuous circulation, including analysis by province and house age, and by those in which the furnace ducts supply fresh air to the house. The study should include questions as to whether people would use continuous circulation if they thought it would improve comfort and health, and how much they would be willing to pay for it, either in utility bills or increased cost of their next furnace.

- A study of the costs of ECM and similar motors, including wholesale costs for various quantities, and resulting costs to consumers. This could include the effects of incentives to furnace manufactures, utilities and/or consumers.

- Surveys of utilities to determine what their usual swing fuels are. If possible, this would include imports and export of electricity and their effects, and seasonal variation, if any. This would allow the actual GHG effects of saving electricity to be calculated much more accurately for each region.

The results of this report indicate that there are significant potential benefits from ECMs. Further study would better define these benefits, and help to determine the most cost-effective incentive programs to promote them.

References

1. Phillips, B., 1997. "Residential Furnace Blower Efficiency and Power Requirements", International Appliance Technical Conference, Columbus, Ohio.

2. Proskiw, G., Personal communication, September, 2002.

3. Edwards, P., Personal communication, November, 2002.

4. Manufacturer's data sheet, inside compressor housing.

5. Sachs, Harvey M. and Sandy Smith, 2003. *Saving Energy with Efficient Residential Furnace Air Handlers: A Status Report and Program Recommendations*. Report Number A033. American Council for an Energy-Efficient Economy, Washington.

6. Edwards, P., Personal communication, June, 2003.

7. General Electric Co., 2001. "Energy Savings with GE ECM™ Variable Speed Motors." Issued October 30th. Contact: ECM.marketing@indsys.ge.com.

8. Grinbergs, P., Personal communication, July, 2003.

9. Gusdorf, J, *et. al.*, 1999. *Revised Canadian Housing Archetypes for Greenhouse Gas Forecasts*, The Buildings Group, Natural Resources Canada, Ottawa.

10. National Energy Use Database, 1997. *Survey of Houses built in Canada in 1994*. Natural Resources Canada, Ottawa.

11. GHG intensities were calculated for HOT2000 by Anil Parekh of NRCan's Buildings Group from *Canada's Emissions Outlook: An Update*, Prepared by Natural Resources Canada. August 2000.

12. Bradley, B. Personal communication, June, 2003.

Appendix A: Daily Data Tables

Date	Furnace Natural Gas Consumption (MJ)				Furnace Electrical Consumption (kWh)			
	Ref	Test	Ref - Test	Diff	Ref	Test	Ref-Test	Diff
19-Jan-02	563.91	558.47	5.44	-1.0%	11.14	11.18	-0.04	-0.4%
20-Jan-02	422.48	417.78	4.70	-1.1%	10.40	10.41	-0.01	-0.1%
21-Jan-02	349.44	355.94	-6.50	1.9%	10.08	10.12	-0.04	-0.4%
22-Jan-02	312.58	309.89	2.69	-0.9%	9.57	9.84	-0.27	-2.8%
23-Jan-02	334.23	322.46	11.78	-3.5%	9.84	9.94	-0.11	-1.1%
24-Jan-02	342.21	331.54	10.67	-3.1%	9.82	10.12	-0.30	-3.1%
25-Jan-02	427.81	433.31	-5.49	1.3%	10.31	10.56	-0.25	-2.5%
26-Jan-02	260.46	263.68	-3.22	1.2%	9.50	9.63	-0.13	-1.3%
27-Jan-02	320.35	311.68	8.66	-2.7%	9.84	9.94	-0.10	-1.1%
28-Jan-02	319.98	323.30	-3.33	1.0%	9.80	9.98	-0.18	-1.9%
29-Jan-02	384.19	384.30	-0.11	0.0%	10.11	10.20	-0.09	-0.9%
27-Mar-02	275.09	286.02	-10.93	4.0%	9.64	9.80	-0.15	-1.6%
2-May-02	193.65	203.11	-9.45	4.9%	9.20	9.35	-0.15	-1.6%
3-May-02	157.59	160.28	-2.69	1.7%	9.01	9.11	-0.10	-1.1%
4-May-02	77.84	83.18	-5.33	6.9%	8.66	8.69	-0.03	-0.4%
5-May-02	31.90	30.26	1.64	-5.1%	8.39	8.35	0.04	0.4%
6-May-02	5.97	3.49	2.48	-41.6%	8.27	8.24	0.02	0.3%
Minimum:	5.97	3.49	-10.93	-41.6%	8.27	8.24	-0.30	-3.1%
Mean:	281.16	281.10	0.06	0.0%	9.62	9.73	-0.11	-1.2%
Maximum:	563.91	558.47	11.78	6.9%	11.14	11.18	0.04	0.4%

Table A1: Benchmarking, Space Heat Period: Daily values of Furnace Gas and Electricity Consumption. Differences are (Test - Ref)/Ref. The Mean row shows the differences between the means.

Date	Fan Motor (kWh)				Compressor (kWh)				A/C (fan + compressor) (kWh)			
	Ref	Test	Ref - Test	Diff	Ref	Test	Ref - Test	Diff	Ref	Test	Ref - Test	Diff
27-Jun-02	10.489	11.023	-0.534	-5.1%	14.741	14.788	-0.047	-0.3%	25.231	25.811	-0.581	-2.3%
28-Jun-02	10.703	11.324	-0.620	-5.8%	16.249	16.693	-0.444	-2.7%	26.953	28.017	-1.064	-3.9%
29-Jun-02	10.934	11.612	-0.678	-6.2%	17.636	18.410	-0.775	-4.4%	28.570	30.023	-1.453	-5.1%
30-Jun-02	11.304	12.181	-0.877	-7.8%	21.283	22.501	-1.219	-5.7%	32.587	34.682	-2.095	-6.4%
1-Jul-02	12.023	13.108	-1.085	-9.0%	28.201	29.723	-1.522	-5.4%	40.225	42.831	-2.606	-6.5%
2-Jul-02	12.557	13.684	-1.127	-9.0%	33.248	34.564	-1.316	-4.0%	45.805	48.248	-2.443	-5.3%
3-Jul-02	12.695	13.896	-1.201	-9.5%	33.442	34.931	-1.489	-4.5%	46.137	48.827	-2.690	-5.8%
4-Jul-02	12.028	13.069	-1.041	-8.7%	27.318	28.500	-1.182	-4.3%	39.346	41.569	-2.223	-5.6%
5-Jul-02	9.995	10.499	-0.503	-5.0%	10.506	11.155	-0.649	-6.2%	20.501	21.654	-1.153	-5.6%
6-Jul-02	10.301	10.874	-0.574	-5.6%	13.435	14.203	-0.767	-5.7%	23.736	25.077	-1.341	-5.6%
7-Jul-02	10.804	11.696	-0.892	-8.3%	17.623	18.774	-1.151	-6.5%	28.427	30.470	-2.043	-7.2%
8-Jul-02	10.625	11.228	-0.604	-5.7%	15.673	16.004	-0.331	-2.1%	26.297	27.232	-0.935	-3.6%
9-Jul-02	10.984	11.776	-0.792	-7.2%	17.903	18.866	-0.964	-5.4%	28.886	30.642	-1.756	-6.1%
10-Jul-02	9.951	10.372	-0.421	-4.2%	9.986	10.173	-0.187	-1.9%	19.937	20.545	-0.608	-3.0%
11-Jul-02	9.819	10.144	-0.325	-3.3%	9.421	9.378	0.043	0.5%	19.240	19.522	-0.282	-1.5%
12-Jul-02	10.355	10.860	-0.505	-4.9%	13.792	14.058	-0.266	-1.9%	24.147	24.918	-0.771	-3.2%
13-Jul-02	10.538	11.215	-0.677	-6.4%	15.249	16.205	-0.956	-6.3%	25.787	27.421	-1.633	-6.3%
14-Jul-02	11.165	11.963	-0.799	-7.2%	20.200	21.050	-0.851	-4.2%	31.364	33.014	-1.649	-5.3%
28-Aug-	10.139	10.603	-0.463	-4.6%	11.045	11.542	-0.497	-4.5%	21.185	22.145	-0.960	-4.5%
29-Aug-	10.221	10.802	-0.581	-5.7%	12.116	13.177	-1.061	-8.8%	22.337	23.980	-1.642	-7.4%
17-Sep-02	9.902	10.397	-0.494	-5.0%	10.244	11.066	-0.823	-8.0%	20.146	21.463	-1.317	-6.5%
18-Sep-02	10.090	10.610	-0.521	-5.2%	11.247	12.062	-0.815	-7.2%	21.337	22.672	-1.336	-6.3%
19-Sep-02	10.270	10.923	-0.653	-6.4%	13.323	14.690	-1.367	-10.3%	23.593	25.613	-2.020	-8.6%
20-Sep-02	10.604	11.354	-0.751	-7.1%	15.910	17.422	-1.512	-9.5%	26.513	28.776	-2.263	-8.5%
21-Sep-02	10.667	11.412	-0.745	-7.0%	16.021	17.431	-1.410	-8.8%	26.687	28.843	-2.155	-8.1%
22-Sep-02	10.165	10.731	-0.566	-5.6%	11.917	12.930	-1.013	-8.5%	22.081	23.661	-1.580	-7.2%
24-Sep-02	9.353	9.694	-0.340	-3.6%	6.637	7.237	-0.600	-9.0%	15.990	16.930	-0.940	-5.9%
5-Oct-02	8.808	8.907	-0.099	-1.1%	2.980	3.002	-0.022	-0.7%	11.788	11.909	-0.121	-1.0%
6-Oct-02	8.888	9.050	-0.162	-1.8%	3.063	3.423	-0.360	-11.8%	11.951	12.473	-0.522	-4.4%
Minimum	8.808	8.907	-1.201	-9.5%	2.980	3.002	-1.522	-11.8%	11.788	11.909	-2.690	-8.6%
Mean:	10.565	11.207	-0.642	-6.1%	15.531	16.343	-0.812	-5.2%	26.096	27.551	-1.455	-5.6%
Maximum	12.695	13.896	-0.099	-1.1%	33.442	34.931	0.043	0.5%	46.137	48.827	-0.121	-1.0%

Table A2. Benchmarking, Air Conditioning Period, Daily values of A/C Electricity Consumption. Differences are (Test - Ref)/Ref. The Mean row shows the differences between the means.

71

Date	Furnace Electrical Consumption (kWh)				Furnace Natural Gas Consumption (MJ)				Total Furnace Heat (MJ)		
	Ref	Test	Ref - Test	Test/Ref	Ref	Test	Test - Ref	Diff	Ref	Test	Diff
15-Feb-02	9.73	2.68	7.04	27.6%	297.21	327.74	30.52	10.3%	263.86	263.74	0.0%
16-Feb-02	9.38	2.30	7.08	24.5%	231.62	262.78	31.16	13.5%	211.71	211.97	0.1%
17-Feb-02	9.87	2.74	7.13	27.7%	325.31	337.14	11.83	3.6%	286.15	271.21	-5.2%
03-Mar-02	9.73	3.22	6.51	33.1%	311.53	359.85	48.32	15.5%	274.97	290.50	5.6%
05-Mar-02	10.41	3.92	6.49	37.7%	440.38	474.02	33.64	7.6%	377.40	381.58	1.1%
20-Mar-02	9.82	3.06	6.76	31.2%	327.00	362.22	35.22	10.8%	287.31	291.82	1.6%
21-Mar-02	10.01	3.48	6.53	34.8%	373.58	405.63	32.06	8.6%	324.14	326.95	0.9%
22-Mar-02	10.33	3.81	6.53	36.9%	432.09	461.24	29.15	6.7%	370.71	371.28	0.2%
23-Mar-02	10.02	3.34	6.68	33.4%	370.09	385.25	15.16	4.1%	321.47	310.65	-3.4%
24-Mar-02	9.65	2.90	6.75	30.1%	290.61	317.49	26.88	9.2%	258.45	256.51	-0.7%
25-Mar-02	10.04	3.28	6.76	32.7%	361.11	376.64	15.53	4.3%	314.57	303.75	-3.4%
21-Apr-02	9.08	2.09	6.99	23.0%	164.93	193.87	28.94	17.5%	158.86	157.71	-0.7%
22-Apr-02	9.44	2.64	6.80	28.0%	244.99	273.93	28.94	11.8%	222.31	221.79	-0.2%
23-Apr-02	9.07	2.12	6.95	23.4%	160.54	198.35	37.81	23.6%	155.43	161.30	-3.8%
24-Apr-02	8.71	1.60	7.11	18.4%	92.68	122.57	29.89	32.3%	101.49	100.66	-0.8%
25-Apr-02	8.98	1.96	7.02	21.9%	143.91	172.37	28.46	19.8%	142.20	140.58	-1.1%
26-Apr-02	9.11	2.31	6.80	25.4%	175.12	226.87	51.75	29.6%	166.89	184.11	10.3%
27-Apr-02	8.94	1.91	7.03	21.3%	136.20	163.82	27.62	20.3%	136.08	133.74	-1.7%
28-Apr-02	9.44	2.64	6.79	28.0%	250.21	275.19	24.98	10.0%	226.35	222.77	-1.6%
29-Apr-02	9.20	2.27	6.92	24.7%	198.57	218.26	19.70	9.9%	185.40	177.28	-4.4%
30-Apr-02	9.00	2.13	6.87	23.6%	156.05	196.24	40.19	25.8%	151.70	159.67	5.3%
14-May-02	9.31	2.46	6.85	26.5%	217.84	246.20	28.36	13.0%	200.76	199.63	-0.6%
15-May-02	8.82	1.77	7.05	20.1%	112.22	146.65	34.43	30.7%	117.03	119.94	2.5%
16-May-02	8.67	1.50	7.17	17.3%	83.02	105.14	22.13	26.7%	93.83	86.78	-7.5%
17-May-02	8.55	1.48	7.07	17.3%	55.24	101.08	45.84	83.0%	71.84	83.54	16.3%
18-May-02	8.96	1.93	7.03	21.6%	132.66	167.62	34.96	26.4%	133.39	136.78	2.5%
21-May-02	8.56	1.39	7.17	16.2%	58.94	89.41	30.47	51.7%	74.77	74.17	-0.8%
22-May-02	8.48	1.21	7.27	14.3%	47.85	64.43	16.58	34.7%	65.88	54.15	-17.8%
25-May-02	8.27	0.95	7.32	11.5%	6.76	27.83	21.07	311.7%	33.25	24.85	-25.3%
Minimum:	8.27	0.95	6.49	11.5%	6.76	27.83	11.829	3.6%	33.25	24.85	-25.3%
Mean:	9.30	2.38	6.91	25.6%	213.73	243.44	29.710	13.9%	197.52	197.22	-0.2%
Maximum:	10.41	3.92	7.32	37.7%	440.38	474.02	51.754	311.7%	377.40	381.58	16.3%

Table A3. ECM Testing, Space Heat Period: Daily Furnace Electrical & Gas Consumption and Total Furnace Heat.

The Electrical Difference is Test/Ref. The Gas Difference is (Test - Ref)/Ref.
Total Furnace Heat is the sum of Electrical x 94% plus Gas x 77.7%.

Date	Fan Motor (kWh)				Compressor (kWh)				A/C (fan + compressor) (kWh)			
	Ref	Test	Ref - Test	Diff	Ref	Test	Ref - Test	Diff	Ref	Test	Ref - Test	Diff
1-Aug-02	12.186	9.146	3.040	24.9%	28.202	29.516	-1.315	-4.7%	40.388	38.663	1.725	4.3%
2-Aug-02	11.797	8.456	3.341	28.3%	24.041	25.794	-1.753	-7.3%	35.838	34.250	1.588	4.4%
3-Aug-02	11.564	7.292	4.272	36.9%	22.121	22.202	-0.082	-0.4%	33.685	29.495	4.190	12.4%
4-Aug-02	10.609	5.441	5.168	48.7%	14.642	15.112	-0.470	-3.2%	25.252	20.554	4.698	18.6%
5-Aug-02	11.018	6.482	4.537	41.2%	17.995	18.649	-0.654	-3.6%	29.013	25.130	3.883	13.4%
6-Aug-02	9.728	3.563	6.165	63.4%	8.531	8.272	0.259	3.0%	18.259	11.835	6.424	35.2%
7-Aug-02	10.106	4.267	5.839	57.8%	11.368	11.014	0.353	3.1%	21.473	15.281	6.193	28.8%
8-Aug-02	10.363	4.727	5.636	54.4%	13.120	12.851	0.269	2.0%	23.483	17.578	5.905	25.1%
9-Aug-02	10.768	5.436	5.332	49.5%	16.316	15.865	0.451	2.8%	27.084	21.301	5.783	21.4%
10-Aug-02	11.417	6.914	4.502	39.4%	21.618	21.461	0.157	0.7%	33.035	28.375	4.660	14.1%
11-Aug-02	11.527	7.439	4.088	35.5%	23.863	23.980	-0.117	-0.5%	35.390	31.419	3.971	11.2%
12-Aug-02	12.016	8.512	3.505	29.2%	27.811	28.238	-0.427	-1.5%	39.827	36.749	3.077	7.7%
13-Aug-02	12.086	8.828	3.258	27.0%	27.068	28.054	-0.986	-3.6%	39.154	36.882	2.272	5.8%
14-Aug-02	11.836	8.424	3.412	28.8%	26.649	27.601	-0.952	-3.6%	38.485	36.025	2.459	6.4%
15-Aug-02	11.501	7.623	3.878	33.7%	22.036	23.114	-1.078	-4.9%	33.538	30.737	2.801	8.4%
16-Aug-02	11.273	7.139	4.134	36.7%	20.755	21.608	-0.853	-4.1%	32.029	28.747	3.281	10.2%
17-Aug-02	11.347	6.886	4.461	39.3%	21.369	20.912	0.457	2.1%	32.716	27.798	4.918	15.0%
18-Aug-02	11.692	8.026	3.665	31.4%	23.287	24.377	-1.090	-4.7%	34.979	32.403	2.576	7.4%
19-Aug-02	9.877	3.810	6.067	61.4%	9.939	9.362	0.577	5.8%	19.816	13.172	6.644	33.5%
20-Aug-02	10.447	4.964	5.482	52.5%	14.041	13.543	0.499	3.6%	24.488	18.507	5.981	24.4%
21-Aug-02	10.571	5.213	5.359	50.7%	15.016	14.863	0.153	1.0%	25.588	20.076	5.512	21.5%
22-Aug-02	9.193	2.403	6.790	73.9%	5.326	4.787	0.539	10.1%	14.519	7.190	7.330	50.5%
31-Aug-02	10.885	5.913	4.972	45.7%	16.219	16.730	-0.512	-3.2%	27.103	22.643	4.460	16.5%
1-Sep-02	10.831	5.978	4.853	44.8%	16.510	17.146	-0.636	-3.9%	27.341	23.125	4.217	15.4%
4-Sep-02	10.187	4.888	5.299	52.0%	12.278	12.945	-0.667	-5.4%	22.465	17.833	4.631	20.6%
5-Sep-02	9.940	4.129	5.811	58.5%	9.923	10.085	-0.162	-1.6%	19.863	14.214	5.649	28.4%
6-Sep-02	9.917	3.845	6.072	61.2%	10.241	9.930	0.311	3.0%	20.158	13.775	6.383	31.7%
7-Sep-02	11.077	6.354	4.723	42.6%	19.170	19.591	-0.421	-2.2%	30.247	25.945	4.302	14.2%
8-Sep-02	11.584	7.373	4.210	36.3%	23.090	23.921	-0.831	-3.6%	34.674	31.295	3.379	9.7%
9-Sep-02	12.056	8.759	3.297	27.3%	28.088	29.220	-1.132	-4.0%	40.144	37.979	2.165	5.4%
10-Sep-02	11.850	8.420	3.430	28.9%	25.592	26.468	-0.875	-3.4%	37.442	34.888	2.554	6.8%
11-Sep-02	9.216	2.636	6.580	71.4%	5.501	5.289	0.212	3.9%	14.717	7.925	6.792	46.2%
12-Sep-02	9.403	2.677	6.727	71.5%	6.569	5.716	0.853	13.0%	15.973	8.393	7.580	47.5%
13-Sep-02	10.072	4.441	5.630	55.9%	11.826	11.903	-0.077	-0.6%	21.898	16.344	5.554	25.4%
14-Sep-02	9.733	3.666	6.067	62.3%	9.304	9.272	0.032	0.3%	19.037	12.938	6.099	32.0%
15-Sep-02	10.091	4.589	5.502	54.5%	11.072	11.332	-0.260	-2.4%	21.163	15.922	5.242	24.8%
26-Sep-02	9.781	3.807	5.974	61.1%	9.392	9.556	-0.164	-1.7%	19.174	13.363	5.810	30.3%
27-Sep-02	8.378	0.809	7.569	90.3%	0.703	0.142	0.562	79.9%	9.082	0.951	8.131	89.5%
28-Sep-02	9.402	2.945	6.457	68.7%	6.326	6.051	0.275	4.4%	15.728	8.996	6.733	42.8%
1-Oct-02	9.613	3.227	6.386	66.4%	8.926	8.052	0.874	9.8%	18.539	11.279	7.260	39.2%
3-Oct-02	9.181	2.444	6.736	73.4%	4.874	4.528	0.346	7.1%	14.055	6.973	7.082	50.4%
Minimum:	8.378	0.809	3.040	24.9%	0.703	0.142	-1.753	-7.3%	9.082	0.951	1.588	4.3%
Mean:	10.637	5.558	5.079	47.7%	15.871	16.074	-0.203	-1.3%	26.508	21.633	4.875	18.4%
Maximum	12.186	9.146	7.569	90.3%	28.202	29.516	0.874	79.9%	40.388	38.663	8.131	89.5%

Table A4. ECM Testing, Air Conditioning Period, Air Conditioner Electrical Consumption. Differences are (Test - Ref)/Ref. The Mean row shows the differences between the means.

Date	House Internal Electrical Consumption (kWh)			
	Ref	Test	Ref - Test	Diff
15-Feb-02	26.31	19.55	6.76	74.3%
16-Feb-02	25.88	19.07	6.81	73.7%
17-Feb-02	26.50	19.51	6.99	73.6%
3-Mar-02	26.50	19.51	6.99	73.6%
5-Mar-02	27.62	21.26	6.37	76.9%
20-Mar-02	26.35	20.02	6.33	76.0%
21-Mar-02	26.69	20.53	6.16	76.9%
22-Mar-02	27.33	21.20	6.13	77.6%
23-Mar-02	26.70	20.31	6.39	76.1%
24-Mar-02	26.31	19.91	6.40	75.7%
25-Mar-02	27.08	20.59	6.48	76.1%
21-Apr-02	25.88	18.78	7.10	72.6%
22-Apr-02	26.21	19.38	6.82	74.0%
23-Apr-02	25.84	18.93	6.91	73.3%
24-Apr-02	25.22	18.16	7.06	72.0%
25-Apr-02	25.26	18.63	6.63	73.8%
26-Apr-02	25.51	19.09	6.42	74.8%
27-Apr-02	25.47	18.54	6.92	72.8%
28-Apr-02	25.83	19.19	6.64	74.3%
29-Apr-02	25.70	18.89	6.81	73.5%
30-Apr-02	25.46	18.79	6.66	73.8%
14-May-02	25.70	18.99	6.71	73.9%
15-May-02	25.62	18.37	7.25	71.7%
16-May-02	25.09	17.96	7.14	71.6%
17-May-02	25.09	18.07	7.02	72.0%
18-May-02	25.65	18.44	7.21	71.9%
21-May-02	25.48	17.92	7.56	70.3%
22-May-02	25.21	17.79	7.43	70.5%
25-May-02	24.76	17.51	7.25	70.7%
Minimum:	24.76	17.51	6.13	70.3%
Mean:	25.94	19.13	6.81	73.8%
Maximum:	27.62	21.26	7.56	77.6%

Table A5. ECM Testing, Space Heat Period: Daily House Internal Electrical Consumption. Internal consumption is the reading of the main meter minus those of the control room, external and air conditioning meters.

Date	Internal (without compressor) (kWh)				Total (Internal plus compressor (kWh)			
	Ref	Test	Ref - Test	Diff	Ref	Test	Ref - Test	Diff
1-Aug-02	28.651	25.675	2.976	10.4%	56.853	55.192	1.661	2.9%
2-Aug-02	28.261	25.033	3.228	11.4%	52.302	50.827	1.475	2.8%
3-Aug-02	28.115	24.007	4.109	14.6%	50.236	46.209	4.027	8.0%
4-Aug-02	27.088	22.016	5.072	18.7%	41.731	37.128	4.603	11.0%
5-Aug-02	27.566	23.057	4.510	16.4%	45.561	41.705	3.856	8.5%
6-Aug-02	26.071	20.044	6.028	23.1%	34.602	28.316	6.286	18.2%
7-Aug-02	26.570	20.777	5.794	21.8%	37.938	31.791	6.147	16.2%
8-Aug-02	26.879	21.244	5.636	21.0%	40.000	34.095	5.905	14.8%
9-Aug-02	27.229	21.974	5.255	19.3%	43.545	37.840	5.705	13.1%
10-Aug-02	27.938	23.528	4.409	15.8%	49.556	44.989	4.567	9.2%
11-Aug-02	27.932	23.873	4.060	14.5%	51.796	47.853	3.943	7.6%
12-Aug-02	28.769	24.982	3.787	13.2%	56.579	53.219	3.360	5.9%
13-Aug-02	28.432	25.350	3.082	10.8%	55.500	53.404	2.096	3.8%
14-Aug-02	28.130	24.995	3.135	11.1%	54.779	52.596	2.183	4.0%
15-Aug-02	27.997	24.154	3.844	13.7%	50.033	47.267	2.766	5.5%
16-Aug-02	27.746	23.738	4.009	14.4%	48.502	45.346	3.156	6.5%
17-Aug-02	27.682	23.366	4.316	15.6%	49.051	44.278	4.773	9.7%
18-Aug-02	27.989	24.574	3.415	12.2%	51.276	48.951	2.325	4.5%
19-Aug-02	26.292	20.272	6.020	22.9%	36.231	29.634	6.597	18.2%
20-Aug-02	26.899	21.458	5.441	20.2%	40.940	35.000	5.940	14.5%
21-Aug-02	26.948	21.497	5.451	20.2%	41.965	36.361	5.604	13.4%
22-Aug-02	25.610	18.800	6.809	26.6%	30.936	23.587	7.349	23.8%
31-Aug-02	27.355	23.658	3.697	13.5%	43.573	40.388	3.185	7.3%
1-Sep-02	27.253	23.650	3.603	13.2%	43.763	40.796	2.967	6.8%
4-Sep-02	26.323	21.202	5.122	19.5%	38.601	34.147	4.454	11.5%
5-Sep-02	26.296	20.483	5.813	22.1%	36.219	30.568	5.651	15.6%
6-Sep-02	26.372	20.245	6.127	23.2%	36.613	30.175	6.437	17.6%
7-Sep-02	27.575	22.790	4.785	17.4%	46.745	42.381	4.364	9.3%
8-Sep-02	27.831	23.811	4.020	14.4%	50.921	47.732	3.189	6.3%
9-Sep-02	28.475	25.220	3.256	11.4%	56.564	54.440	2.124	3.8%
10-Sep-02	28.313	24.970	3.343	11.8%	53.905	51.437	2.468	4.6%
11-Sep-02	25.639	19.029	6.610	25.8%	31.140	24.318	6.822	21.9%
12-Sep-02	25.696	19.080	6.616	25.7%	32.265	24.796	7.469	23.1%
13-Sep-02	26.479	20.870	5.609	21.2%	38.305	32.773	5.533	14.4%
14-Sep-02	26.159	20.053	6.106	23.3%	35.463	29.325	6.138	17.3%
15-Sep-02	26.464	21.109	5.356	20.2%	37.536	32.441	5.095	13.6%
26-Sep-02	26.030	20.182	5.848	22.5%	35.422	29.738	5.684	16.0%
27-Sep-02	24.754	17.185	7.570	30.6%	25.457	17.326	8.131	31.9%
28-Sep-02	25.706	19.234	6.472	25.2%	32.032	25.285	6.748	21.1%
1-Oct-02	25.957	19.648	6.308	24.3%	34.883	27.700	7.183	20.6%
3-Oct-02	25.464	18.764	6.700	26.3%	30.338	23.292	7.046	23.2%
Minimum:	24.754	17.185	2.976	10.4%	25.457	17.326	1.475	2.8%
Mean:	27.047	22.088	4.960	18.3%	42.918	38.162	4.756	11.1%
Maximum:	28.769	25.675	7.570	30.6%	56.853	55.192	8.131	31.9%

Table A6. ECM Testing, Air Conditioning Period, House Internal & Total Electrical Consumption.

Appendix B: Factoring Out the A/C Benchmark Offset

B.1 Electricity Use: Furnace Fan, Compressor, and Air Conditioning

As noted in Section 3.1.2, the benchmarking for air conditioning is not as close to perfect as it was for heating. This appendix details the method of factoring out the A/C benchmark offset so that the effects of the ECM can be determined as accurately as possible. As in the main text, the following terms are used:

- *A/C* is used to refer to the air conditioner or to air conditioning.
- Electricity used by the *furnace fan*, or simply the *fan*, is electricity used by the furnace to move air, either during A/C or in circulation mode when the A/C is not operating. It includes the electricity used by the fan motor itself, plus a small amount for the furnace controls.
- Electricity used by the *compressor* is the electricity used by the A/C compressor unit located outside the house.
- Electricity used for *air conditioning* (A/C) is the sum of electricity used for the fan and for compressor. This is the amount of electricity used to air condition the house.

Electricity use by the fan during both benchmarking and ECM testing is shown in Figure B1 (Figure 8 in the main text). The benchmark line shows that the fan in the Test House uses significantly more energy than the one in the Reference House, especially at the high (A/C) speed. This explains part of difference in the A/C benchmark (Figure 2). There was no such difference during the benchmarking for the space heat period, and handling of the fan and blower during frequent motor changes is a suspected cause of this increased electricity use by the PSC motor. Despite this benchmarking difference, the change due to the ECM motor is very clear. During benchmarking the average fan electrical use in the Test House was 11.250 kWh/day, and during ECM testing it was 5.558, a reduction of 5.692 kWh/day or 51%. This is a smaller difference than the 74% observed in the space heating period because the A/C was on for a greater percentage of time than the furnace was, so the fan ran more often in high speed where the difference between the PSC and ECM power draws is smaller. In any case, the fan benchmark difference is irrelevant to the ECM testing because the PSC motor in the Test House was replaced by the ECM. Thus, fan energy savings due to the ECM should be based on the fan energies in the two houses during ECM testing. Then the average fan use with the PSC motor is 10.637 kWh/day, and with the ECM it is 5.558. The difference of 5.079 kWh/day is 48% of the PSC fan energy.

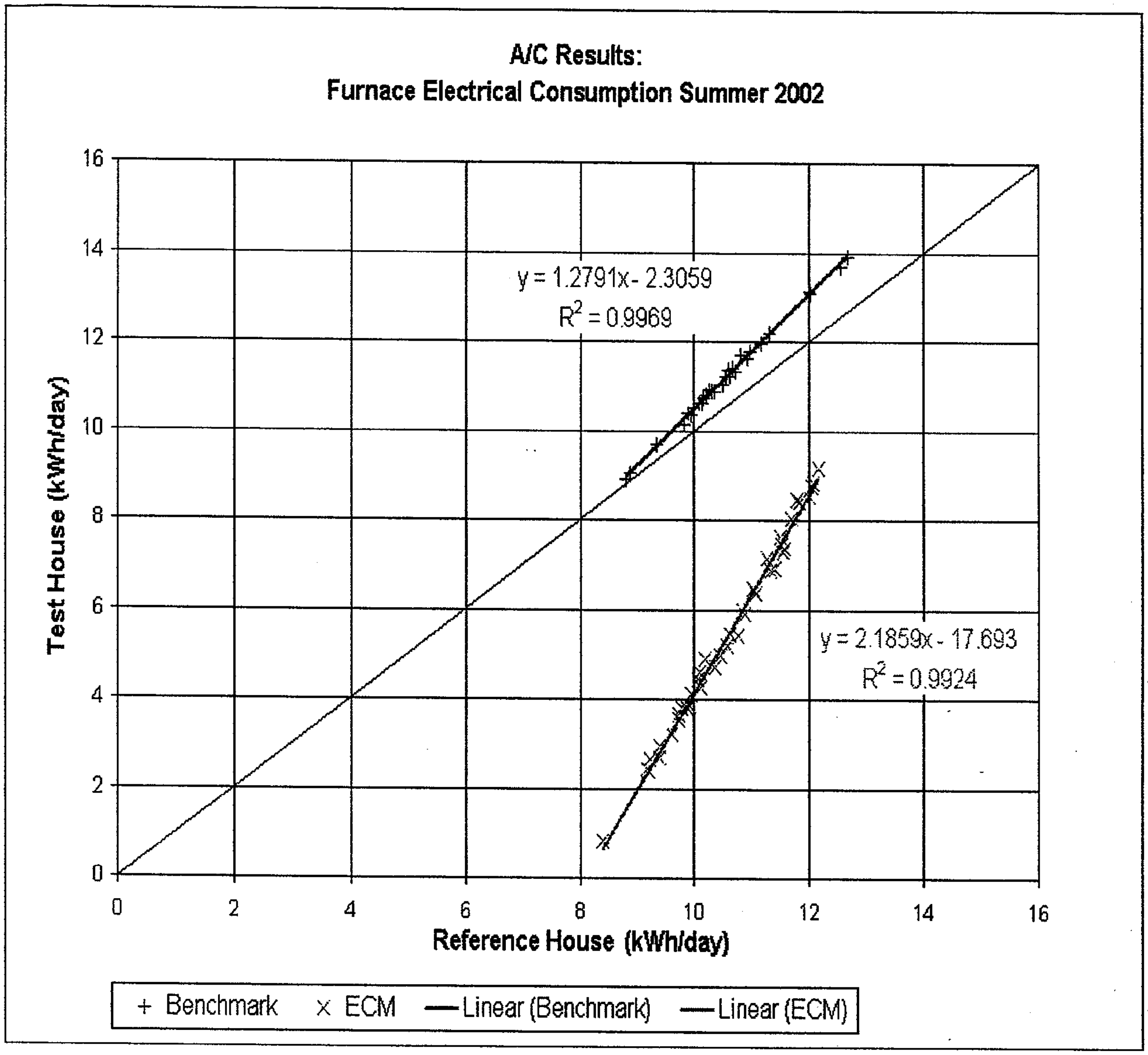


Figure B1. Electricity Use by the Fans during the A/C Period: Benchmarking & ECM Testing.

Figure B2 (9) shows electricity use by the compressor during both benchmarking and ECM testing. As with the fan, the compressor in the Test House uses more electricity than the one in the Reference House, and the difference increases with increasing daily use. Thus, both the fan and the compressor contribute to the difference in the A/C benchmark (Figure 2). The change in compressor energy due to the ECM is small, as would be expected since the difference in motor heat is divided by the COP of the compressor. The difference between average use of the PSC and ECM is 5.079 kWh/day. Divided by the compressor COP at typical conditions (3.60), this yields an average expected difference of 1.41 kWh/day for the compressor. During benchmarking

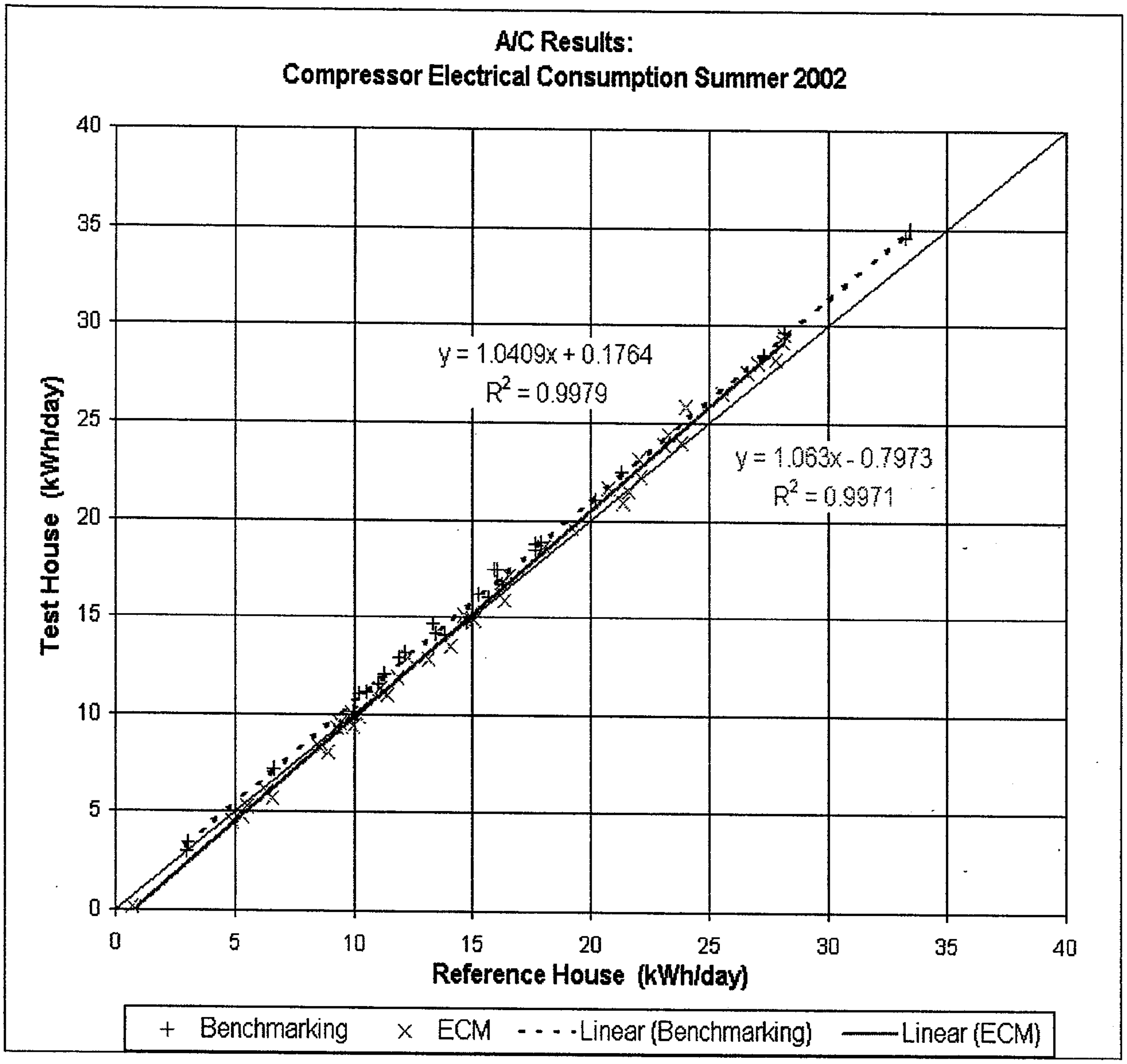


Figure B2. Electricity Use by the Compressors during the A/C Period: Benchmarking & ECM Testing.

the Reference House compressor used an average of 15.777 kWh/day while the Test House use 16.575 or 0.798 kWh/day more. During ECM testing, the corresponding figures are 15.871, 16.074 and 0.203. Thus, the net change in compressor energy due to the ECM is 0.798 - 0.203 = 0.595 kWh/day or 3.7% of the average compressor use in the Reference House. The difference between that change and the one based on motor energies and COP (1.41 kWh/day) may be due

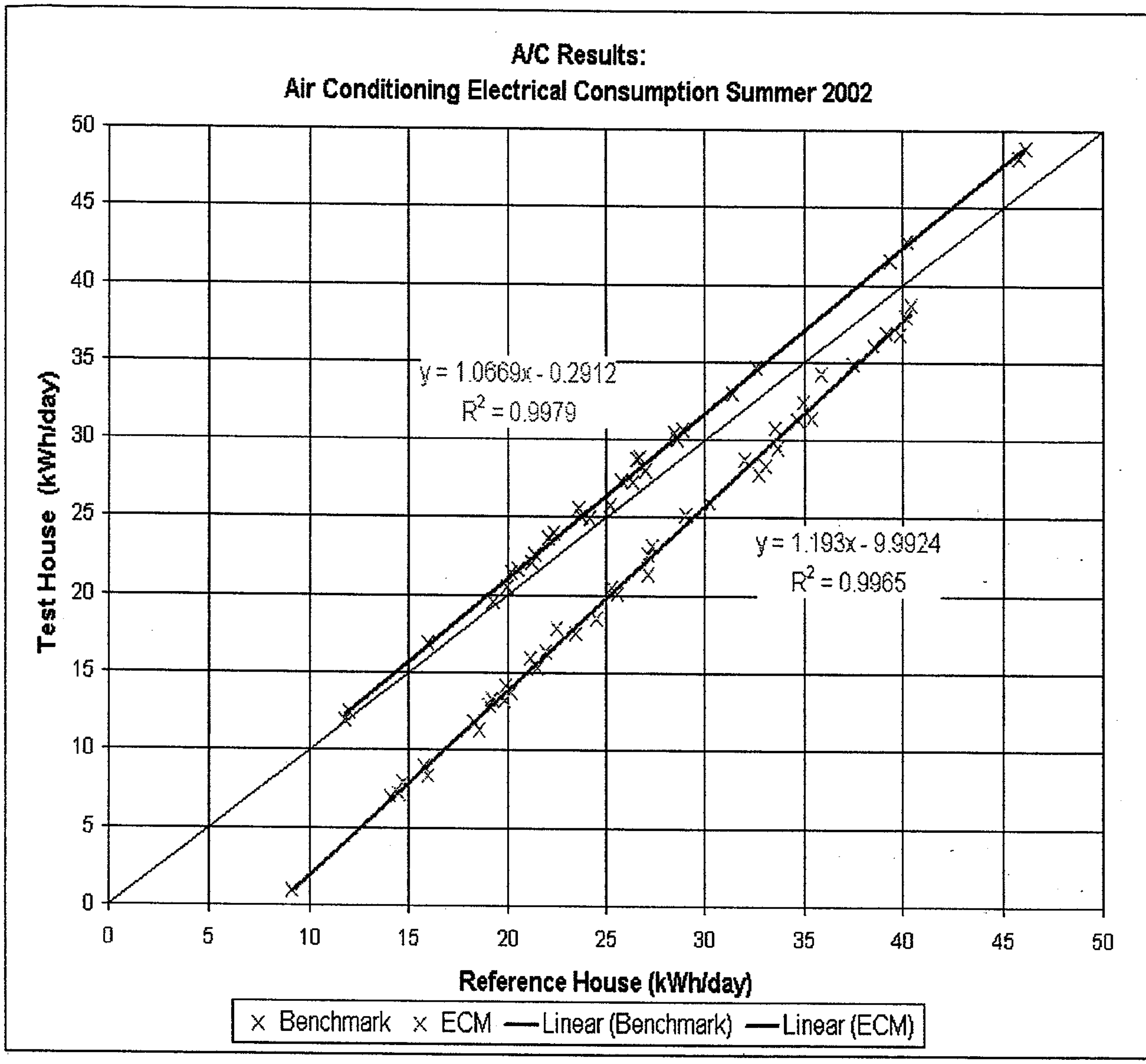


Figure B3. Electricity Use by the Air Conditioners during the A/C Period: Benchmarking & ECM Testing.

to the increased amount of condensate with the ECM (see Section 3.3.2). With the ECM in the Test House, its compressor uses less energy than the Reference House's for loads below 12.66 kWh/day; above that, the Test House compressor uses more.

Figure B3 (10) shows electrical use for the A/C (compressor plus fan) during both benchmarking and ECM testing. As previously discussed, the benchmark is significantly above the 1:1 line due to differences in energy use by both the fan motors and compressors. Despite the imperfect benchmark, the differences caused by the ECM are clear. However, not all of the difference between the A/C benchmark and results is due to the effect of the ECM. Some of it is due to the fact that the PSC motor in the Test House used more than the one in the Reference House, and this difference is not relevant to the ECM results, as discussed above. The difference between the PSC motors can be factored out of the difference between the benchmarking and results as follows:

A/C energy use in the Test House during benchmarking B can be calculated as a function of A/C energy use in the Reference House x according to the upper regression in Figure B3.

$$B = 1.0669x - 0.2912.$$

Similarly, A/C energy use in the Test House during ECM testing T can be calculated from the lower regression in Figure B3.

$$T = 1.193x - 9.9924.$$

Then the difference between them is

$$B - T = -0.1261x + 9.7012. \qquad (1)$$

The higher energy use by the PSC motor in the Test House increased the energy use by the compressor. Since the COP of the compressor is 3.6, the difference in total A/C use for a given day due to the different PSC motors ΔM will be the difference between the PSC motors times $1 + 1/3.6 = 1.278$. When ΔM is plotted as a function of A/C energy use in the Reference House the result is

$$\Delta M = 0.0386x - 0.1882.$$

ΔM can be factored out of B - T as

$$(B - T) - \Delta M = -0.1647x + 9.8894. \qquad (2)$$

Figure B4 (11) shows the results of these calculations. The difference between the 1:1 line and the dotted line shows the difference between the benchmark and ECM results in Figure B3 as defined by Eqn. (1). (This difference is subtracted from the 1:1 line to show what the results would look like if the benchmark were on the 1:1 line). The difference between the 1:1 line and the solid line has the difference between the energy use of the PSC motors factored out (Eqn (2)), and is a calculation of what the results would have been if the A/C benchmark had been exactly on the 1:1 line. That is, the solid line is the best estimate of what the results would have looked like if the benchmark had not been affected by either the motor or compressor differences, and therefore of the true difference that an ECM can make to air conditioning energy use. The solid line can be directly defined as

$$y = 1.1647x - 9.8894 \qquad (3)$$

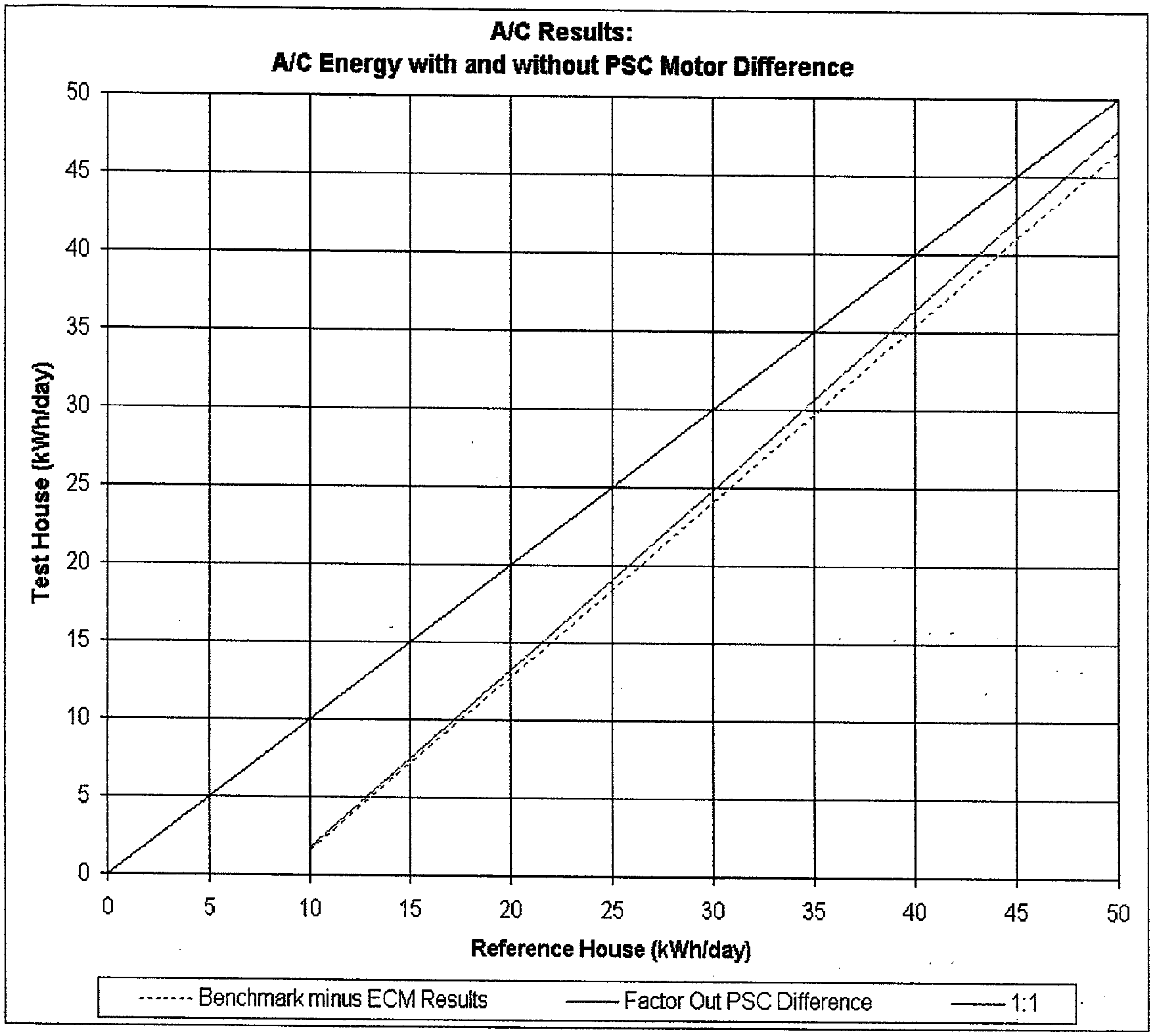


Figure B4. A/C Benchmark minus ECM Results, with and without PSC Difference.

where x is the electricity used by the A/C with the PSC motor on a given day, and y is the electricity used by the A/C with the ECM on the same day, both in kWh/day. The difference between the two lines in very small at low A/C loads, e.g., 0.198 kWh/day at a load of 10 kWh/day, and grows to 1.742 at a load of 50. Looked at as a percentage of the A/C use in the Reference House, the difference is 13% when the Reference House uses 10 kWh/day, and 4% when it uses 50.

The effect of the difference between the PSC motors can also be factored out of the average daily A/C electricity use as follows: During benchmarking the A/C in the Reference House used an average of 26.387 kWh/day, and the Test House used 27.825 which is 1.447 kWh/day more. Of this difference, 0.649 kWh/day is directly due to the higher consumption the PSC motors in the Test House. But this difference would also have resulted in higher consumption by the compressor, i.e., the difference divided by the compressor's COP of 3.60, or 0.180 kWh per day. So the Test House's higher energy use with the PSC difference factored out is 1.447 - 0.649 - 0.180 = 0.618 kWh/day. During ECM testing the Reference House A/C averaged 26.508 kWh/day, and the Test House averaged 21.633 or 4.875 kWh/day less. Thus, the net A/C difference due to the ECM is 4.875 + 0.618 = 5.493 kWh/day or 20.7% of the average Reference House A/C use.

The two methods of factoring out the PSC motor difference agree quite well. One can apply equation (1) to each of the daily measurements of A/C consumption in the Reference House during ECM testing. The result is an estimate of A/C consumption in the Test House with the PSC difference factored out. The difference between the averages of the A/C consumptions is then 5.523 kWh/day. This difference is only 0.5% larger than the one calculated at the end of the last paragraph.

B.2 Electrical, House

During benchmarking the use of electricity (internal plus compressor) by the Reference House averaged 42.393 kWh/day while the Test House averaged 44.010, which is 1.617 kWh/day or 3.8% more. This difference is due mainly to the extra use by the Test House PSC motor (0.649 kWh/day) and compressor (0.798 kWh/day). During ECM testing the Reference House used an average of 42.056 kWh/day and the Test House used 37.181 which is 4.875 kWh/day or 11.6% less. The net effect of the ECM can be calculated by taking the total difference between benchmarking and ECM testing (4.875 + 1.617), and subtracting the difference due to the Test House PSC motor (0.649). The result is 5.843 kWh/day or 13.9% of the electricity used by the Reference House. Thus, using an ECM during A/C results in a substantial saving on the total electrical use for a house with a typical consumption.

Appendix C:
Inter-House Temperature Differences in Benchmarking and ECM Tests

An Investigation into Circulation Differences
with the Reduced ECM Circulation Rate.

As mentioned in Section 2.6, the ECM's air flow rate in circulation mode is 45% of that of the PSC motor. In order to investigate the possibility that the reduced flow results in inadequate air circulation to parts of the house, temperatures at a number of points in the Test House are compared with those at the same points in the Reference House. The difference between a given point, e.g., master bedroom ceiling in the Test House, and the same point in the Reference House at a given time is called an inter-house (temperature) difference. Significantly larger inter-house difference during ECM tests could be considered evidence that the ECM's circulation mode air flow was not adequate, while a lack of such differences would indicate that the ECM's flow is adequate.

Three five-day periods during which there where significant temperature variations within each house were selected, as follows:

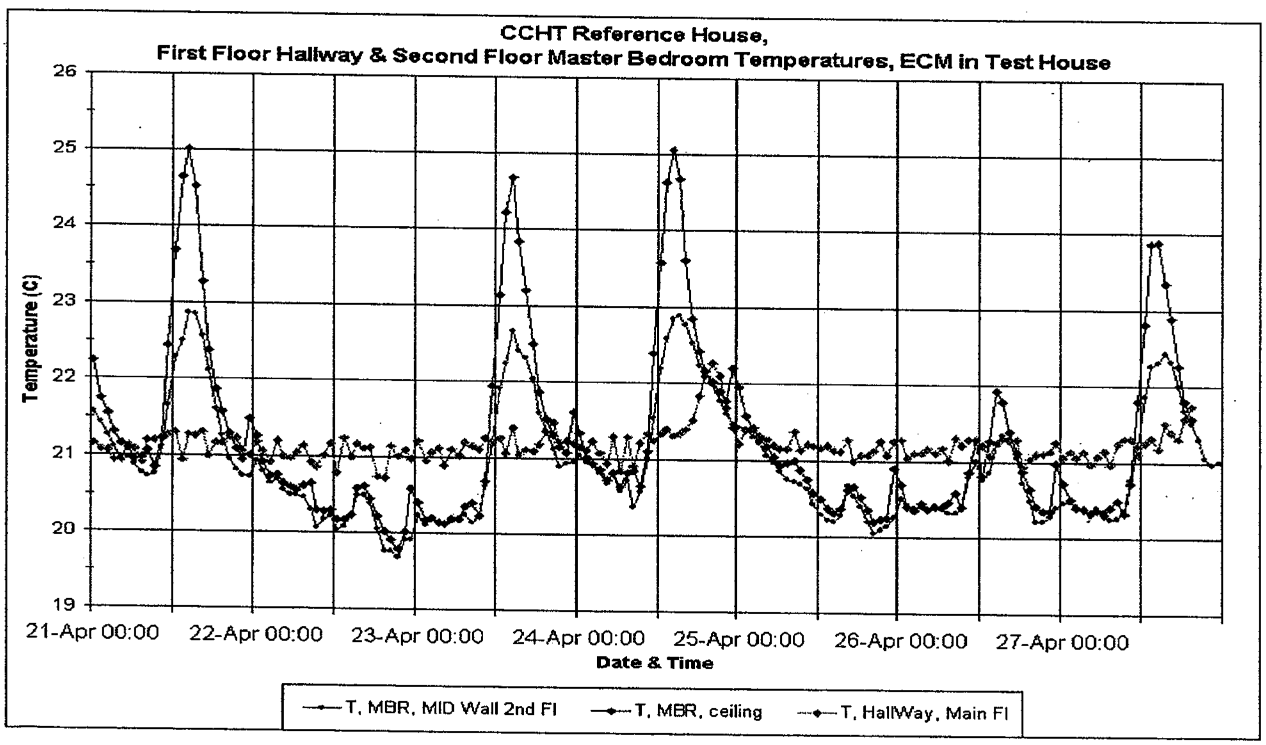


Figure C-1. Representative temperature variations, ECM Testing, 21 - 25 April.

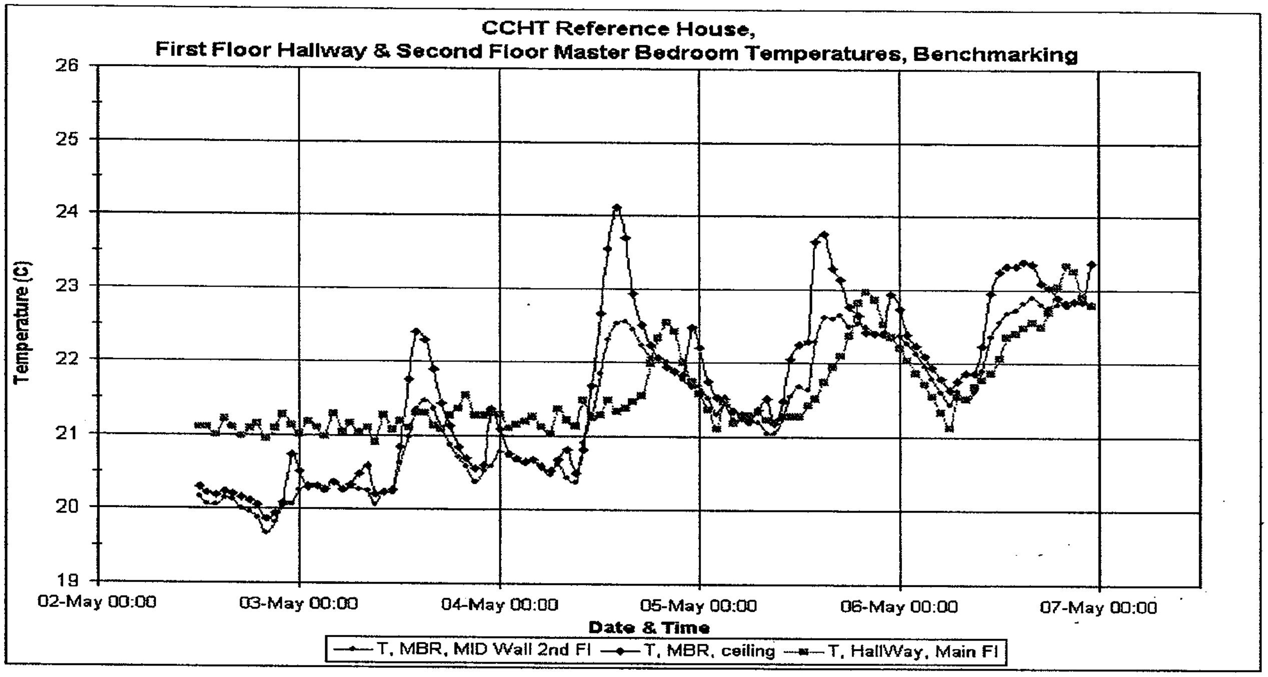


Figure C-2. Representative temperature variations, Benchmarking, 2 - 6 May.

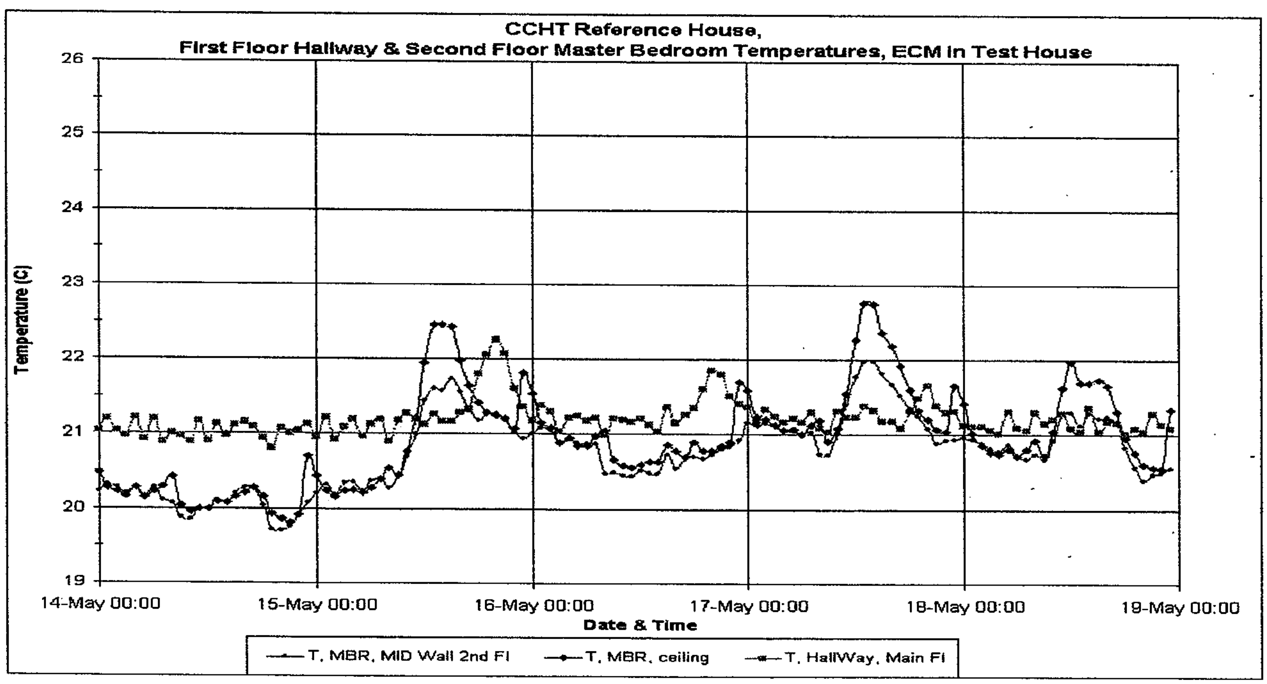


Figure C-3. Representative temperature variations, ECM Testing, 14 -18 May.

ECM Testing, 21 - 25 April 2002

Benchmarking, 2 - 6 May 2002

ECM Testing, 14 - 18 May 2002

Figures C-1 to C-3 illustrate the amount of temperature variation within the Reference House. The variation includes significant solar warming on some days, and some cooling below the set-point during both days and nights. The maximum amount of cooling (~1 °C) is the same in all three periods, but the maximum heating varies significantly, being greatest (~4 °C) in the first period, and decreasing in each of the following periods. Thus, the amount of variation in the benchmarking period is between those in the two ECM testing periods.

Table C-1 shows the minimum, mean and maximum inter-house temperature differences for the three periods for nine points in three rooms. It shows inter-house differences on the main floors of -0.73 to +1.08 °C, with an average of 0.21 °C. The basement differences range from

	ECM, 21 - 25 April			Benchmark, 2 - 6 May			ECM, 14 - 18 May		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Master Bedroom									
Ceiling	-0.12	0.40	1.01	-0.12	0.36	0.91	-0.18	0.41	0.98
Mid-height	0.20	0.54	0.78	0.17	0.41	0.66	0.30	0.48	0.69
Bedroom #4									
Ceiling	-0.47	0.10	0.64	-0.42	0.04	0.76	-0.73	0.01	1.08
Mid-height	-0.02	0.30	0.85	0.01	0.32	0.65	-0.01	0.30	0.67
Floor	0.14	0.34	0.61	-0.26	0.03	0.49	-0.27	0.01	0.47
Living Room									
Ceiling	-0.31	-0.01	0.36	-0.35	-0.01	0.32	-0.27	0.00	0.26
Mid-height	-0.31	0.20	0.61	-0.54	-0.02	0.34	-0.40	0.13	0.60
Floor	-0.32	0.02	0.43	-0.18	0.24	0.68	-0.20	0.05	0.39
Basement	-1.19	-0.52	0.11	-0.73	-0.18	0.36	-1.01	-0.37	0.29

Table C-1. Inter-house temperature variations.

	ECM, 21 - 25 April			ECM, 14 - 18 May		
	Min	Mean	Max	Min	Mean	Max
Master Bedroom						
Ceiling	0.00	0.04	0.10	0.06	0.05	0.07
Mid-height	0.03	0.13	0.12	0.13	0.07	0.03
Bedroom #4						
Ceiling	0.05	0.06	0.12	0.31	0.03	0.32
Mid-height	0.03	0.02	0.20	0.02	0.02	0.02
Floor	0.40	0.31	0.12	0.01	0.02	0.02
Living Room						
Ceiling	0.04	0.00	0.04	0.08	0.01	0.06
Mid-height	0.23	0.22	0.27	0.14	0.15	0.26
Floor	0.14	0.22	0.25	0.02	0.19	0.29
Basement	0.46	0.34	0.25	0.28	0.19	0.07

Table C-2. Deviations in inter-house temperature differences during ECM testing.

–1.19 to +0.36, and average –0.36. These inter-house differences occur during both benchmarking and ECM testing. To determine whether the differences are larger during ECM testing, the absolute differences between the inter-house differences are calculated as shown in Table C-2. The differences between inter-house differences are referred to as deviations. All of the deviations have absolute values of less than 0.5 °C, and except for one in the basement, all are less than 0.4 °C. Only 4 out of 48 non-basement points (or 5 of 54 total points) have deviations greater than 0.3 °C. The great majority of points (79% of non-basement and 74% including the basement) have deviations of less than 0.2 °C, close to the level of accuracy of the thermocouples. Thus, there is no evidence that the ECM's lower circulation flow rates have a significant effect on house temperatures.

The possible exception is in the basement where 67 % of the measurements have deviations greater than 0.2 °C, and the only deviation of 0.4 °C occurs. The larger basement deviations could be explained by the fact that duct flows in the basement, as indicated by bag tests (Section 2.5), are reduced by more than those on the main floors. This may be due to the lack of sufficient air return in the basement. In any case, in the rooms that are designed for habitation, this comparison of temperatures does not indicated that the lower ECM circulation flow rates results in inadequate air circulation.

Appendix D: Numerical Analysis of Gas Consumption for Furnaces with ECM and PSC Fan Motors.

The theoretical values of the line defining the daily gas consumption of the furnace with the ECM vs the furnace with the PSC motor (Figure 4) can be calculated as follows. For a day in which one of the furnaces runs for a given number of hours in heating mode, one calculates the total amount of space heat it should deliver to the house. This amount is the sum of:

1. The hours the given furnace runs in heating mode, times the rate at which the furnace consumes gas, times the efficiency with which it converts gas to space heat,

2. The hours the given furnace runs in heating mode, times the electrical consumption of its motor in heating speed, times the "efficiency" with which motor electricity is converted to space heat, and

3. The hours the given furnace runs in circulation mode, times the electrical consumption of its motor in circulation speed, times the "efficiency" with which motor electricity is converted to space heat.

One then solves two equations in two unknowns to get the time that the other furnace runs in heating speed. The gas consumption of each furnace for that day is then the number of hours it runs in heating mode times its rate of gas consumption.

Defining some terms:

t	=	Time in heating or circulation mode (hours/day) (h/d),
H	=	Total Furnace Heat (Gas and Electric) delivered to the house (MJ/d),
G	=	Gas Consumption Rate of the Furnaces (MJ/h),
M	=	Electrical Consumption Rate of a Motor (MJ/h),
E	=	Efficiency of a Furnace or Motor as a Heat Source (decimal percent), and
C	=	Daily Gas Consumption by a Furnace (MJ/d).

Subscripts are used to qualify the above terms as follows:

f	=	furnace,
m	=	motor,
P	=	PSC motor or furnace with the PSC motor,
E	=	ECM or furnace with the ECM,
h	=	heating mode, and
c	=	circulation mode.

Thus, t_{Ph} is the hours per day that the furnace with PSC motor spends in heating mode. M_{Ec} is the MJ/d of electricity consumed by the ECM in circulation speed. $C_E(t_{Ph} = x)$ is the gas consumption of the furnace with the ECM producing the same H as the furnace with the PSC motor running in heating mode for x hour. Since both furnaces must deliver the same amount of total space heat $H_P = H_E$, and both are simply written H.

The total furnace heat generated by the furnace with the PSC motor running t_{Ph} hours per day is

$$H = t_{Ph}\,(G \cdot E_f + M_{Ph} \cdot E_m) + t_{Pc}\,(M_{Pc} \cdot E_m) \qquad (1)$$

where $t_{Pc} = 24\ \text{h/d} - t_{Ph}$

The times that the furnace with the ECM must run to deliver the same H are defined by

$$t_{Eh}\,(G \cdot E_f + M_{Eh} \cdot E_m) + t_{Ec}\,(M_{Ec} \cdot E_m) = H, \text{ and} \qquad (2)$$

$$t_{Eh} + t_{Ec} = 24\ \text{h/d}. \qquad (3)$$

Substituting 24 - t_{Eh} for t_{Ec}

$$t_{Eh}\,(G + M_{Eh} \cdot E_m) + (24 - t_{Eh})\, M_{Ec} \cdot E_m = H$$

$$t_{Eh}\,(G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m) = H - 24 \cdot M_{Ec} \cdot E_m$$

$$t_{Eh} = \frac{H - 24 \cdot M_{Ec} \cdot E_m}{G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m}. \qquad (4)$$

Similarly, if heating time is given and H is calculated for the furnace with the ECM

$$t_{Ph} = \frac{H - 24 \cdot M_{Pc} \cdot E_m}{G \cdot E_f + M_{Ph} \cdot E_m - M_{Pc} \cdot E_m}. \qquad (5)$$

Now, given one of t_{Ph}, t_{Eh} or H, the remaining terms can be calculated, and the gas consumptions for the furnaces with the PSC and ECM are:

$$C_P = t_{Ph} \cdot G, \text{ and} \qquad (6)$$
$$C_E = t_{Eh} \cdot G. \qquad (7)$$

This pair of numbers are the coordinates of one point on the line defining the daily gas consumption of the furnace with the ECM vs the furnace with the PSC motor.

The high end of the normal conditions (Section 3.4.2) line is defined by the point at which the furnace with the ECM can just supply the needed space heat by running in heating mode 24 hours per day, i.e., $t_{Eh} = 24$ h/d. The intercept is defined by the point at which the furnace with the PSC motor can just supply the needed space heat by running in circulation speed 24 hours per day, i.e, t_{Ph} = zero. This is the point at which the PSC motor in circulation speed can just supply the required heat. Thus, the intercept and slope can be defined as

$$\text{Intercept} = C_E(t_{Ph} = 0), \text{ and} \tag{8}$$

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}} = \frac{C_E(t_{Eh} = 24) - C_E(t_{Ph} = 0)}{C_P(t_{Eh} = 24) - C_P(t_{Ph} = 0)}. \tag{9}$$

Since $C = t \cdot G$, each of the terms in Eqn (9) can be found by solving for the appropriate t. For the intercept and the second term in the slope, $C_E(t_{Ph} = 0)$, first find H for $t_{Ph} = 0$ from Eqn (1)

$$H = t_{Ph}(G \cdot E_f + M_{Ph} \cdot E_m) + t_{Pc} \cdot M_{Pc} \cdot E_m)$$

$$= 24 \cdot M_{Pc} \cdot E_m.$$

Then substitute for H in Eqn (4)

$$t_{Eh} = \frac{24 \cdot M_{Pc} \cdot E_m - 24 \cdot M_{Ec} \cdot E_m}{G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m}$$

and

$$\text{Intercept} = C_E(t_{Ph} = 0) = G \cdot t_{Eh} = \frac{24G(M_{Pc} \cdot E_m - M_{Ec} \cdot E_m)}{G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m}. \tag{10}$$

For $C_E(t_{Eh} = 24)$

$$C_E = 24G. \tag{11}$$

Similarly, for $C_P(t_{Eh} = 24)$ from Eqns (2 & 5)

$$C_P(t_{Eh} = 24) = \frac{24(G \cdot Ef + M_{Ph} \cdot E_m - M_{Pc} \cdot E_m)}{G \cdot E_f + M_{Ph} \cdot E_m - M_{Pc} \cdot E_m}. \qquad (12)$$

Finally,

$$C_P(t_{Ph} = 0) = \quad 0G \quad = 0. \qquad (13)$$

Substituting Eqns(10 - 13) into Eqn (9)

$$\text{Slope} = \frac{24G - \dfrac{24G\,(M_{Pc} \cdot E_m - M_{Ec} \cdot E_m)}{G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m}}{\dfrac{24G\,(G \cdot E_f + M_{Eh} \cdot E_m - M_{Pc} \cdot E_m)}{G \cdot E_f + M_{Ph} \cdot E_m - M_{Pc} \cdot E_m} - 0}$$

$$= \frac{1 - \dfrac{M_{Pc} \cdot E_m - M_{Ec} \cdot E_m}{G \cdot E_f + M_{Eh} \cdot E_m - M_{Ec} \cdot E_m}}{\dfrac{G \cdot E_f + M_{Eh} \cdot E_m - M_{Pc} \cdot E_m}{G \cdot E_f + M_{Ph} \cdot E_m - M_{Pc} \cdot E_m}}. \qquad (14)$$

From the equation for the intercept (Eqn(10)), it is clear that the intercept increases as the difference between the electrical consumption of the two motors in circulation speed ΔM_c increases. The intercept will increase slightly as the rate of gas consumption G increases, and will decrease significantly as furnace efficiency E_f increases. (But see the comments on the effect of higher fan power in high-efficiency furnaces in Section 4.2). From the equation for the slope, one can say that since $G \cdot E_f$ is much larger than any of the $E \cdot E_m$ terms, and since the result of subtracting one $E \cdot E_m$ term from another will be even smaller, both the numerator and denominator will be close to one, and the slope is likely to be close to one. Table D-1 shows the effects on slope and intercept of varying some parameters by plus or minus 10%. None of these variations has a significant effect on the slope which varies by only 0.6% from its minimum to its maximum. Changing one of E_f, E_m or ΔM_c has an approximately proportional change in the intercept. As E_f increases from 73.8% to 82%, the intercept decreases by 9.8%, and decreasing E_f another 10% decreases the intercept by another 8.9%. Decreasing E_m by 10% decreases the intercept by 9.8%. Increasing ΔM_c by 10% (by raising M_{pc} from 1.134 to 1.250) increases the intercept by 12.6%; a further 10% increase results in a further 10.6% increase in the intercept. Changing the difference between the motor powers in heating mode ΔM_h makes little or no difference. Increasing M_{Eh} from 1.2442 to 1.3824 results in a 0.5% intercept increase, while a further 10% increase results in a 0.2% intercept decrease. Changing ΔM_h by changing M_{Ph} has no effect on the intercept. The last statement follows logically and mathematically. At intercept conditions, the PSC motor does not run in heating speed, and M_{Ph} is not found in the intercept equation.

Since none of the parameters has a significant effect on the slope, the way to increase electrical savings (and gas consumption) is to vary the parameters that increase the intercept. However, decreasing furnace efficiencies and using larger (oversized) furnaces are clearly not valid methods since their increased costs and gas consumptions would be much larger than electrical savings.* Thus, the only valid and significant way to use ECMs to maximize gas consumption within overall energy savings is to maximize the difference between the electricity consumption by the two motors in circulation speed. This conclusion is not surprising.

The mathematics presented here should be useful for comparing the theory with the results of the CCHT study or other studies, and for projecting these results to other furnaces, houses and climates. For a given daily space heat load H, a given furnace, and ECM and PSC motors with known electrical uses, the changes in electrical and gas consumption that the ECM can achieve can be calculated easily. A range of H's can be used to define an annual space heat load for a given house and climate, or used to model monthly energy consumption of electricity and gas using HOT2000's bin method. However, as shown in Section 3.2.4, for low gas consumption rates, less extra gas is required by a furnace with an ECM , even though the percentage of extra gas can be very large. For the particular conditions of the CCHT houses, low gas consumption means less than 50 MJ/day, but this may be different for other houses, furnaces and climates. Therefore, the HOT2000 modelling used in Section 5 may be a better way of projecting results to other conditions.

* Oversizing furnaces increase their capital cost. For mid-efficiency (non-condensing) furnaces it also lowers their seasonal efficiency by making run times shorter. High-efficiency (condensing) furnaces maintain their efficiency with short run times, but their cost is still an issue.

Furnace Efficiency E_f (%)	Furnace Capacity G (MJ/h)	Motor "Efficiency" E_m (%)	PSC in Circulation M_{Pc} (MJ/h)	EMC in Circulation M_{Ec} (MJ/h)	PSC in Heating M_{Ph} (MJ/h)	EMC in Heating M_{Eh} (MJ/h)	Slope	Intercept (MJ/d)
82%	71.2125	100%	1.260	0.0594	1.764	1.3824	0.98629	34.3610
73.8%	71.2125	100%	1.260	0.0594	1.764	1.3824	0.98480	38.0852
90.2%	71.2125	100%	1.260	0.0594	1.764	1.3824	0.98751	31.3003
82%	**64.091**	100%	1.260	0.0594	1.764	1.3824	0.98480	34.2766
82%	71.2125	**90%**	1.260	0.0594	1.764	1.3824	0.98763	30.9936
82%	71.2125	100%	**1.386**	0.0594	1.764	1.3824	0.98418	37.9677
82%	71.2125	100%	**1.134**	0.0594	1.764	1.3824	0.98849	30.5149
82%	71.2125	100%	1.260	0.0594	**1.5876**	1.3824	0.98333	34.3610
82%	71.2125	100%	1.260	0.0594	**1.940**	1.3824	0.98924	34.3610
82%	71.2125	100%	1.260	0.0594	1.764	**1.2442**	0.98857	34.4407
82%	71.2125	100%	1.260	0.0594	1.764	**1.5206**	0.98401	34.2817
77.7%	71.2125	**94%**	1.260	0.0594	1.764	1.3824	0.98639	34.0929

Table D-1. Sensitivity of Slope & Intercept to various parameters. The parameter that is varied in each row is shown in bold. Parameters are varied by ±10%, except in the last row which shows the closest fit of the intercept to the data.

Appendix E: Numerical Analysis of Electricity Consumption of Air Conditioners with ECM and PSC Fan Motors.

The numerical analysis of electricity use by the CCHT air conditioners is similar to the analysis of furnace gas consumption in Appendix D, but is complicated by two factors. First, the energy use and COP of the compressors vary with outside dry-bulb temperature, and with inside dry-bulb and wet bulb temperature as shown in Table E-1 and Figure E-1. The following analysis will use constant values that are typical of operating conditions during this project, and will not attempt to deal with the variations. Second, it would be desirable to do the analysis for the total air conditioning (A/C) load (compressor and fan) for comparison with the "factored out" results in Figure 11. However, that analysis soon becomes much too complex and "messy," so the following deals with energy use by the compressor alone. Numerical values for typical operating conditions are then used for comparison with total A/C results.

The theoretical values of the line defining the daily electical consumption of the compressor with the ECM vs the compressor with the PSC motor (Figure 9) can be calculated as follows: For a day in which one of the compressors runs for a given number of hours, one calculates the net amount of cooling it should deliver to the house. This amount is the difference between:

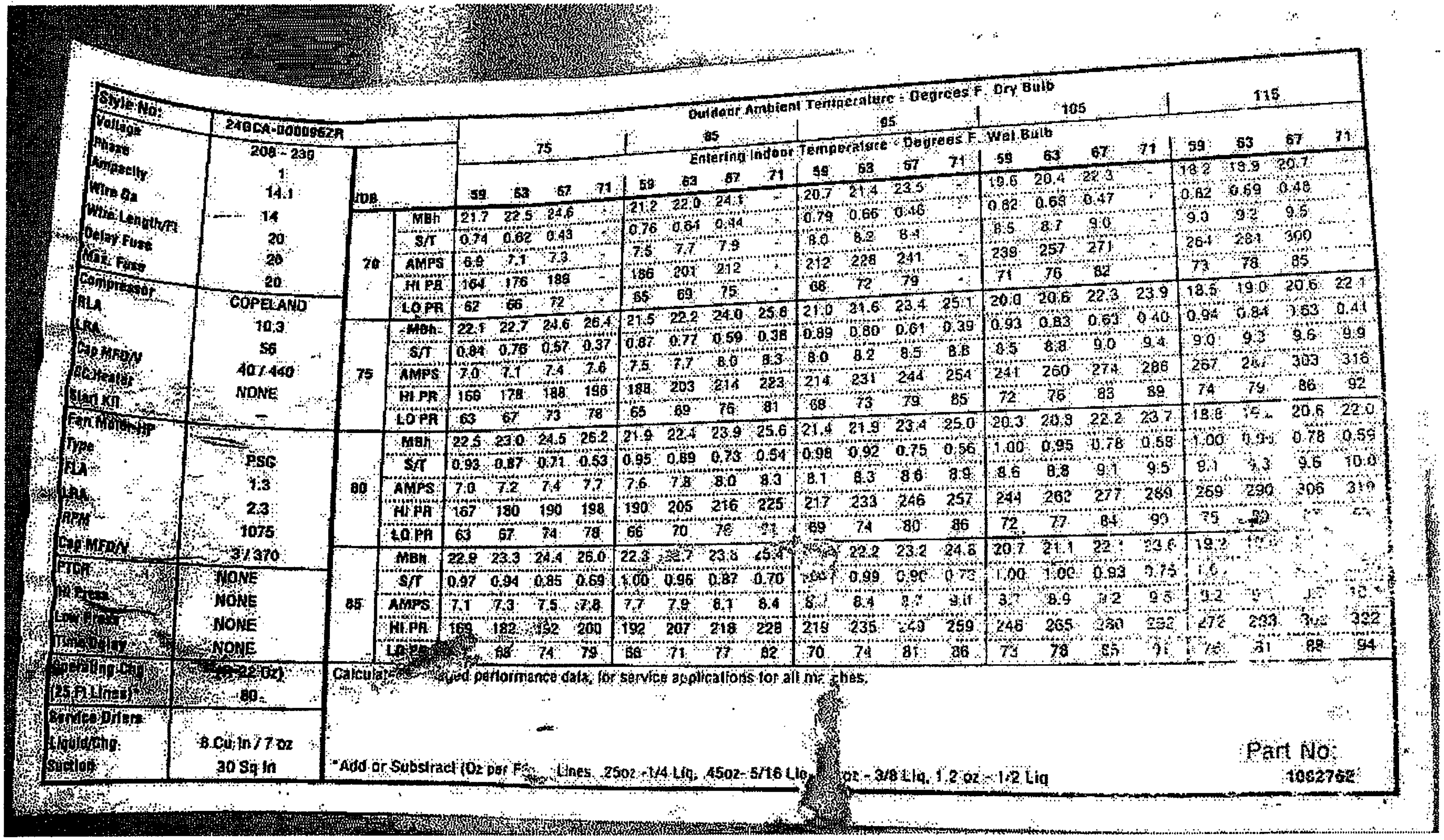
1. The hours the given compressor runs, times the rate at which it consumes electicity, times the efficiency with which it converts electricity to cooling (the COP of the compressor alone), minus

2. The hours the given compressor runs, times the electrical consumption of the fan motor in A/C speed, times the "efficiency" with which motor electricity is converted to heat in the duct, minus

3. The hours the compressor does not run, times the electrical consumption of the fan motor in circulation speed, times the "efficiency" with which motor electricity is converted to heat in the duct.

One then solves two equations in two unknowns to get the time that the other compressor runs. The electrical consumption of each compressor for that day is then the number of hours it runs times its rate of electrical consumption (power).

Defining some terms, consistently with Appendix D:



Style No:	240CA-000095ZR
Voltage	208 - 230
Phase	1
Ampacity	14.1
Wire Ga	14
Wire Length/Ft	—
Delay Fuse	20
Max. Fuse	20
Compressor	COPELAND
RLA	10.3
LRA	56
Cap MFD/V	40/440
Crc Heater	NONE
Start Kit	—
Fan Motor HP	
Type	PSC
FLA	1.3
LRA	2.3
RPM	1075
Cap MFD/V	3/370
PTCR	NONE
Hi Press	NONE
Low Press	NONE
Time Delay	NONE
Operating Chg (25 Ft Lines)	[illegible]-22 Oz) 80
Service Driers	
Liquid/Chg	8 Cu In / 7 oz
Suction	30 Sq In

Outdoor Ambient Temperature - Degrees F Dry Bulb; Entering Indoor Temperature - Degrees F Wet Bulb

IDB		75: 59	75: 63	75: 67	75: 71	85: 59	85: 63	85: 67	85: 71	95: 59	95: 63	95: 67	95: 71	105: 59	105: 63	105: 67	105: 71	115: 59	115: 63	115: 67	115: 71
70	MBh	21.7	22.5	24.6	-	21.2	22.0	24.1	-	20.7	21.4	23.5	-	19.6	20.4	22.3	-	18.2	18.9	20.7	-
	S/T	0.74	0.62	0.43	-	0.76	0.64	0.44	-	0.79	0.66	0.46	-	0.82	0.68	0.47	-	0.82	0.69	0.48	-
	AMPS	6.9	7.1	7.3	-	7.5	7.7	7.9	-	8.0	8.2	8.4	-	8.5	8.7	9.0	-	9.0	9.2	9.5	-
	HI PR	164	176	188	-	186	201	212	-	212	228	241	-	239	257	271	-	264	281	300	-
	LO PR	62	66	72	-	65	69	75	-	68	72	79	-	71	76	82	-	73	78	85	-
75	MBh	22.1	22.7	24.6	26.4	21.5	22.2	24.0	25.8	21.0	21.6	23.4	25.1	20.0	20.6	22.3	23.9	18.5	19.0	20.6	22.1
	S/T	0.84	0.76	0.57	0.37	0.87	0.77	0.59	0.38	0.89	0.80	0.61	0.39	0.93	0.83	0.63	0.40	0.94	0.84	0.63	0.41
	AMPS	7.0	7.1	7.4	7.6	7.5	7.7	8.0	8.3	8.0	8.2	8.5	8.8	8.5	8.8	9.0	9.4	9.0	9.3	9.6	9.9
	HI PR	169	178	188	196	188	203	214	223	214	231	244	254	241	260	274	286	267	[illegible]	303	316
	LO PR	63	67	73	78	65	69	76	81	68	73	79	85	72	76	83	89	74	79	86	92
80	MBh	22.5	23.0	24.5	26.2	21.9	22.4	23.9	25.6	21.4	21.9	23.4	25.0	20.3	20.9	22.2	23.7	18.8	[illegible]	20.6	22.0
	S/T	0.93	0.87	0.71	0.53	0.95	0.89	0.73	0.54	0.98	0.92	0.75	0.56	1.00	0.95	0.78	0.58	1.00	[illegible]	0.78	0.59
	AMPS	7.0	7.2	7.4	7.7	7.6	7.8	8.0	8.3	8.1	8.3	8.6	8.9	8.6	8.8	9.1	9.5	9.1	9.3	9.6	10.0
	HI PR	167	180	190	198	190	205	216	225	217	233	246	257	244	262	277	289	269	290	306	319
	LO PR	63	67	74	78	66	70	76	[illegible]	69	74	80	86	72	77	84	99	75	80	[illegible]	[illegible]
85	MBh	22.9	23.3	24.4	26.0	22.3	22.7	23.8	25.4	[illegible]	22.2	23.2	24.8	20.7	21.1	22.[illegible]	23.6	19.2	[illegible]	[illegible]	[illegible]
	S/T	0.97	0.94	0.85	0.69	1.00	0.96	0.87	0.70	[illegible]	0.99	0.90	0.73	1.00	1.00	0.93	0.75	[illegible]	[illegible]	[illegible]	[illegible]
	AMPS	7.1	7.3	7.5	7.8	7.7	7.9	8.1	8.4	[illegible]	8.4	[illegible]	9.0	[illegible]	8.9	9.2	9.5	9.2	[illegible]	[illegible]	[illegible]
	HI PR	169	182	192	200	192	207	218	228	219	235	249	259	248	265	280	292	272	293	[illegible]	322
	LO PR	[illegible]	68	74	79	68	71	77	82	70	74	81	86	73	78	85	91	[illegible]	81	88	94

Calcula[illegible] [illegible]ayed performance data, for service applications for all m[illegible]ches.

*Add or Substract (Oz per F[illegible] Lines. 25oz - 1/4 Liq, 45oz - 5/16 Liq, [illegible]oz - 3/8 Liq, 1.2 oz - 1/2 Liq

Part No: 1092762

Table E-1. A/C Manufacturers data sheet from inside the Compressor Housing. Showing that compressor power (AMPS), and cooling capacity (MBh) vary with outside dry bulb, inside web bulb, and inside dry bulb (IDB) temperatures.

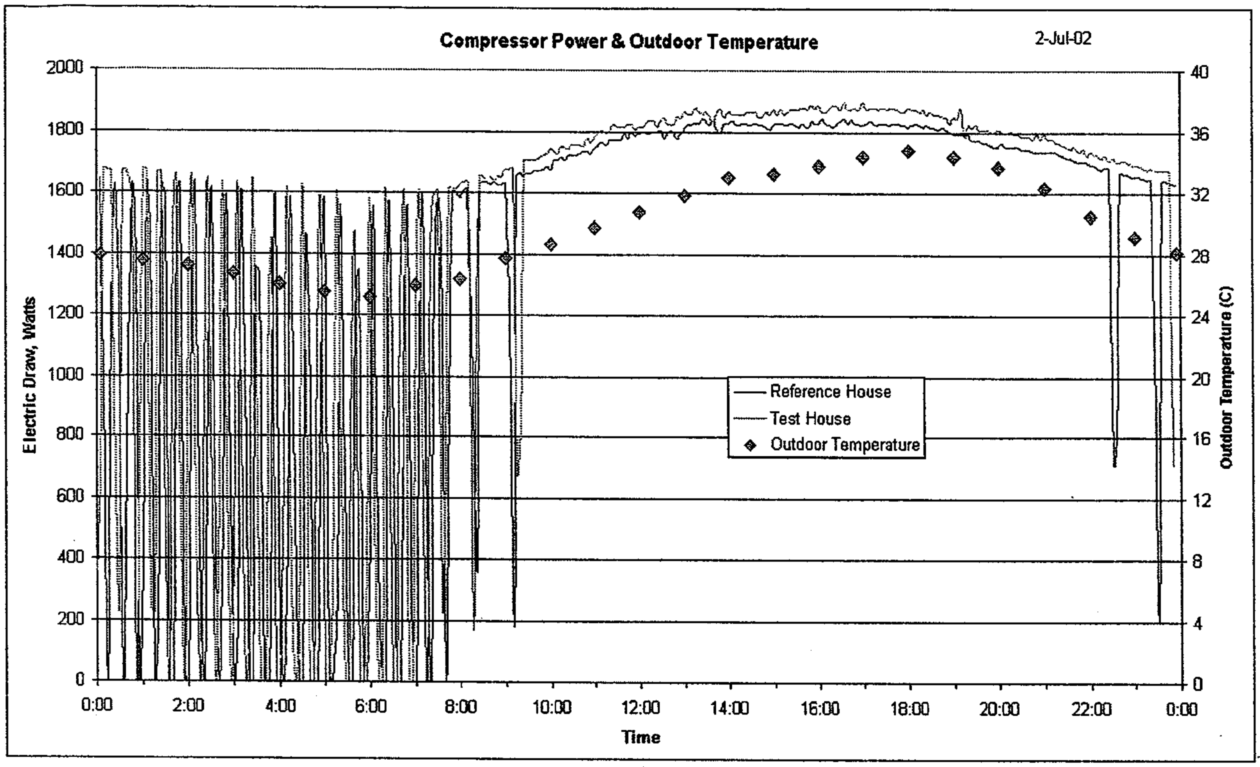


Figure E-1. A Typical Daily Graph of Compressor Power vs. Time. Illustrating the Relationship between Compressor Power and Outdoor Temperature.

t	=	Time in air conditioning or circulation mode (hours/day) (h/d),
F	=	Net Cooling (compressor cooling minus motor heat) delivered to house (MJ/d),
E	=	Electrical Consumption Rate (power) of a compressor (MJ/h),
M	=	Electrical Consumption Rate of a Motor (MJ/h),
η	=	(Eta) Efficiency of a Compressor (COP) or of a Motor as a Heat Source (decimal percent),
Σ	=	(Sigma) Daily Electrical Consumption by a Compressor (MJ/d), and
S	=	Daily Electrical Consumption by an A/C System (compressor plus fan).

Subscripts are used to qualify the above terms as follows:

P	=	PSC motor,
E	=	ECM,
a	=	A/C mode, and
c	=	circulation mode.

Thus, t_{Pa} is the hours that the compressor with the PSC fan motor runs in a given day. M_{Ec} is the MJ/h of electricity consumed by the ECM in circulation speed. $\Sigma_E(t_{Ph} = x)$ is the electrical consumption of the compressor with the ECM producing the same F as the compressor with the PSC motor running for x hours. Since both compressors must deliver the same amount of net cooling $F_P = F_E$, and both can be simply written as F. For the compressor, η_a is the COP, and $E\eta_a$ is its cooling capacity. The following substitutions for net motor heat are made in order to simplify the equations:

$$N_{Pa} = M_{Pa}\eta_m,$$
$$N_{Pc} = M_{Pc}\eta_m,$$
$$N_{Ea} = M_{Ea}\eta_m, \text{ and}$$
$$N_{Ec} = M_{Ec}\eta_m.$$

For the compressor with the ECM fan motor running t_{Ea} hours per day, the net cooling is

$$F_E = t_{Ea}(E\eta_a - N_{Ea}) - (24 - t_{Ea})N_{Ec}. \quad (1)$$

Similarly, for the compressor with the PSC fan motor running t_{Pa} hours per day, the net cooling is

$$F_P = t_{Pa}(E\eta_a - N_{Pa}) - (24 - t_{Pa})N_{Pc}. \quad (2)$$

The time that the compressor with the ECM must run to produce the same net cooling as in Eqn (2) is, from Eqn (1)

$$F = t_{Ea}(E\eta_a - N_{Ea}) + t_{Ea}N_{Ec} - 24N_{Ec}, \text{ so}$$

$$t_{Ea} = \frac{F + 24N_{Ec}}{E\eta_a - N_{Ea} + N_{Ec}}. \quad (3)$$

Similarly, the time that the compressor with the PSC motor must run to produce the same F is

$$t_{Pa} = \frac{F + 24N_{Pc}}{E\eta_a - N_{Pa} + N_{Pc}}. \quad (4)$$

The daily electricity consumption by a compressor is then a simple function of its on-time:

$$\Sigma_P = t_{Pa}E, \text{ and} \quad (5)$$

$$\Sigma_E = t_{Ea}E. \quad (6)$$

The entire theoretical graph of daily electrical consumption by the two compressors can be defined by the high and low points of the line. The high point is defined by the amount of compressor energy required to produce the net cooling of the A/C with the PSC motor running 24 hours per day. Then

$$t_{Pa} = 24 \text{ h/d},$$

$$\Sigma_p(t_{Pa} = 24) = 24E \text{ MJ/d, and} \qquad (7)$$

$$F = 24(E\eta_a - N_{Pa} \text{ MJ/d.}$$

The number of hours the compressor with the ECM must run is found by substituting F into Eqn (3).

$$t_{Ea} = \frac{24(E\eta_a - N_{Pa} + N_{Ec})}{E\eta_a - N_{Ea} - N_{Ec}},$$

and the electrical consumption by that compressor is found by substituting t_{Ea} into Eqn (6).

$$\Sigma_E(t_{Pa} = 24) = \frac{24E(E\eta_a - N_{Pa} + N_{Ec})}{E\eta_a - N_{Ea} + N_{Ec}}. \qquad (8)$$

So Eqns (7) & (8) respectively define the x and y coordinates of the high point of the line.

The low point is defined by the amount of compressor energy required to produce the net cooling of the A/C with the ECM when its compressor does not run for the entire day. (This is a negative net cooling, but the compressor with the PSC motor is required to run in order to match it).

$$t_{Ea} = 0,$$

$$\Sigma_E(t_{Ea} = 0) = 0, \text{ and} \qquad (9)$$

$$F = -24N_{Ec}.$$

Then the compressor with the PSC motor must run

$$t_{Pa} = \frac{-24(N_{Ec} - N_{Pc})}{E\eta_a - N_{Pa} - N_{Pc}},$$

and the energy used by its compressor is

$$\Sigma_P(t_{Ea} = 0) \quad = \quad \frac{-24E(N_{Ec} - N_{Pc})}{E\eta_a - N_{Pa} + N_{Pc}} . \qquad (10)$$

So Eqns (9) & (10) respectively define the y and x coordinates of the low point of the line.

The slope of the line can now be defined in terms of the x and y coordinates of its two points.

$$\text{slope} \quad = \quad \frac{\text{rise}}{\text{run}} \quad = \quad \frac{\Sigma_E(t_{Pa} = 24) \ - \ \Sigma_E(t_{Pc} = 0)}{\Sigma_P(t_{Pa} = 24) \ - \ \Sigma_E(t_{Ec} = 0)} .$$

Substituting from Eqns (7), (8), (9) & (10),

$$\text{slope} \quad = \quad \frac{\dfrac{24E(E\eta_a - N_{Pa} + N_{Ec})}{E\eta_a - N_{Ea} + N_{Ec}} \ - \ 0}{24E \ - \ \dfrac{-24E(N_{Ec} - N_{Pc})}{E\eta_a - N_{Pa} + N_{Pc}}} \qquad (11)$$

$$= \quad \frac{\dfrac{E\eta_a - N_{Pa} - N_{Ec}}{E\eta_a - N_{Ea} + N_{Ec}}}{1 \ - \ \dfrac{N_{Pc} - N_{Ec}}{E\eta_a - N_{Pa} + N_{Pc}}} . \qquad (12)$$

The intercept can now be calculated from any (x,y) point as

$$\text{Intercept} \quad = \quad y - x \cdot \text{slope}.$$

Using the low point of the line,

$$\text{Intercept} \quad = \quad 0 - x \cdot \text{slope}$$

$$= \quad - \Sigma_E(t_{Ec} = 0) \cdot \frac{\Sigma_E(t_{Pa} = 24) \ - \ \Sigma_E(t_{Pc} = 0)}{\Sigma_P(t_{Pa} = 24) \ - \ \Sigma_E(t_{Ec} = 0)} .$$

Then substituting from Eqn (11)

$$\text{Intercept} = \frac{\dfrac{24E(E\eta_a - N_{Pa} + N_{Ec})}{E\eta_a - N_{Ea} + N_{Ec}}}{\dfrac{E\eta_a - N_{Pa} + N_{Pc}}{N_{Pc} - N_{Ec}} - 1} \qquad (13)$$

The following values taken from this project can now be used in the above equations:

E = 1.7 kW = 6.12 MJ/h,
η_a = 3.60,
η_m = 0.94,
M_{Pc} = 0.344 kW, N_{Pc} = 1.1641 MJ/h,
M_{Pa} = 0.569 kW, N_{Pa} = 1.9255 MJ/h,
M_{Ec} = 0.0316 kW, N_{Ec} = 0.1069 MJ/h, and
M_{Ea} = 0.508 kW, N_{Ea} = 1.7191 MJ/h.

From Eqns (7) & (8), the coordinates of the high point in MJ/d are (146.880, 145.395), and from Eqns (9) & (10), the low point is (7.3003, 0). The slope of the line (Eqn (12)) is 1.042, and the intercept (Eqn (13) is -7.6044 MJ/d. For comparison with the graphs in the report, the coordinates and intercept can be converted into kWh/day:

High point = (40.800, 40.388),
Low point = (2.028, 0), and
Intercept = 2.112.

The daily consumption of electricity by an entire A/C system (compressor plus furnace fan) can be calculated from the amount of time the compressor runs in a day. For the high point, t_{Pa} = 24 h/d, and the electricity used by the system S_p is

$$S_P = t_{Pa}(E + M_{Pa}) + (24 - t_{Pa})M_{Pc} = 24 \text{ h/d} (1.7 \text{ kW} + 0.569 \text{ kW}) = 54.456 \text{ kWh/d}.$$

Also for the high point, t_{Ea} = 23.757 h/d, and S_E = 52.464 kWh/day. For the low point, t_{Ea} = 0, S_E = 0.758 kWh/day, t_{Pa} = 1.1928 h/d, and S_P = 10.552 kWh/d. The slope of the line defined by these points is 1.178, and the intercept is -11.669 kWh/d. Thus, the equation for the line of system, or A/C, electrical consumption is

$$y = 1.18x - 11.7$$

and the equation of the line produced by the project results with the difference between the PSC motors factored out (Figure 11) is

$$y = 1.16x - 9.9.$$

Given the uncertainties generated by the variable compressor power and COP, and by the differences in the amounts of condensation in the two houses, this can be considered a very close fit.

Savings due to an ECM correspond to decreases of the intercept and/or the slope. Either decrease will increase the difference between the energy consumption of the A/C with the PSC motor (which corresponds to the 1:1 line in Figure 11) and the A/C with the ECM (which corresponds to the "factored out" line).* The implications of the numerical analysis are similar to those for the analysis of heating. From the equation for the intercept (Eqn (13)), one can see that increasing the difference between the two motors in circulation speed ΔM_c will decrease the intercept and increase ECM savings. Table E-2 shows the effects of varying the parameters by plus or minus 10%. In all cases, cases the effect on the intercept is the opposite of the effect on the slope, so the last column shows the energy consumption of the A/C with the ECM producing the same net cooling as the A/C with the PSC consuming 26.5 kWh/d, the average A/C consumption of the Reference House. When this value is less than the standard value in the first row, that indicates an increased benefit from the ECM, i.e., a larger difference between the consumption of the A/Cs with the PSC and ECM.

As is the case with furnace efficiency, increasing the COP of the compressor decreases the benefits of an ECM, but the decrease is rather small: 0.9% for a 10% increase in COP. Increasing the compressor power (and thus cooling capacity) by 10% decreases the ECM benefit by 1.1%, so – in contrast to furnaces – oversizing A/Cs decreases ECM benefits. The largest increase in ECM benefits comes from increasing the difference between the circulation wattages of the two motors; a 10% increase in ΔM_c results in a 3.6% increase in ECM benefits. Increasing the difference between the motors in A/C speed ΔM_a by 10% results in a very small (0.5%) increase in ECM benefits. Lowering the efficiency of the motors as duct heaters η_m by 10% decreases ECM benefits by 1.0%. Thus, as with furnaces, the best way to increase the benefits of an ECM motor is by maximizing the difference between the wattages of the PSC motor and the ECM in circulation mode. This can be done by setting the ECM circulation speed as low as is compatible

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* This is the opposite of the analysis for space heat in Appendix D in which gas consumption was analysed, and increases in either intercept or slope corresponded to increased gas consumption and electrical savings.

with good air distribution and indoor air quality.

As noted above, the compressor power and COP of the particular air conditioners installed at the CCHT vary with outside and inside temperature and inside humidity. This is true of most or all air conditioners, and is modelled by HOT2000 and other common simulation programs. (Brian Bradley, personal communication, July, 2003).

Compressor COP	Compressor Power (kW)	Motor Eff η_m (%)	PSC in Cric. M_{Pc} (W)	ECM in Circ. M_{Ec} (W)	PSC in A/C M_{Pa} (W)	ECM in A/C M_{Ec} (W)	Slope	Intercept (kWh/d)	ECM A/C Energy at average Ref House A/C Energy (kWh/d)
3.60	1.700	94%	344	31.6	569	508	1.1777	-11.6690	19.540
3.24	1.700	94%	344	31.6	569	508	1.1834 (+0.5%)	-12.0429 (-3.2%)	19.317 (-1.1%)
3.96	1.700	94%	344	31.6	569	508	1.1731 (-0.4%)	-11.3677 (+2.6%)	19.719 (+0.9%)
3.60	**1.530**	94%	344	31.6	569	508	1.1966 (+1.6%)	-11.9155 (-2.1%)	19.794 (+1.3%)
3.60	**1.870**	94%	344	31.6	569	508	1.1621 (-1.3%)	-11.4676 (+1.7%)	19.328 (-1.1%)
3.60	1.700	94%	**375.2**	31.6	569	508	1.2030 (+2.1%)	-13.0491 (-11.8%)	18.830 (-3.6%)
3.60	1.700	94%	**312.8**	31.6	569	508	1.1532 (-2.1%)	-10.3328 (+11.5%)	20.277 (+3.5%)
3.60	1.700	94%	344	31.6	**575.1**	508	1.1728 (-0.4%)	-11.6288 (+0.3%)	19.450 (-0.5%)
3.60	1.700	94%	344	31.6	**562.9**	508	1.1826 (+0.4%)	-11.7093 (-0.3%)	19.630 (+0.5%)
3.60	1.700	**84.6%**	344	31.6	569	508	1.1727 (-0.4%)	-11.3378 (+2.8%)	19.739 (+1.0%)
3.60	1.700	**100%**	344	31.6	569	508	1.1810 (+0.3%)	-11.8831 (-1.8%)	19.413 (-0.6%)

Table E-2. Sensitivity of Slope, Intercept and A/C (compressor plus fan) Energy to various parameters. The parameter that is varied in each row is shown in bold. Parameters are varied by ±10%, except that motor wattage is varied so that ΔM changes by 10%, and η_m can only be increased by 6.4%.

Appendix F: Use of HOT2000 for Projections

F.1 Suitability of HOT2000 for Projections

HOT2000 is a building energy simulation program developed by Natural Resources Canada. It produces annual and monthly predictions of a variety of quantities including space heat fuel consumption and electrical use by furnace fans and air conditioners. It was recently modified to include dual speed (circulation and heating) furnace fans. An existing HOT2000 model of the CCHT Reference House was modified to simulate the test conditions of this project. The modifications included setting the efficiency of the furnace to 77.7%, and the air flows through the heat recovery ventilator to 33 L/s. One version of the model has the circulation, heating and air conditioning speed wattages of the PSC motor, and the other has the wattages of the ECM.

F.1.1 CCHT & HOT2000 Results for Heating

The empirical results from the CCHT houses show that the house with the ECM used an average of 13.9% more furnace gas than the house with the PSC motor during the test days. According to the HOT2000 models of the houses, the ECM house should use 7.0% more furnace gas during a complete heating season. The difference between the CCHT and HOT2000 average gas consumptions is due to the difference between the HOT2000 weather file for Ottawa and the actual weather conditions on the days during which ECM testing occurred. Above 50 MJ/day of Reference House furnace gas consumption, the difference between the consumptions of the two houses is a relatively constant 30.52 MJ/day. Thus, as the daily consumption increases, the percentage difference gets smaller. Since HOT2000 has a higher average Reference House gas consumption than was experienced during the ECM test period, it predicts a lower average percentage difference..

In order to eliminate the effect of different weather in the CCHT results and HOT2000 runs, the data is separated in three categories:

1. All heating days, defined as all days with Reference House furnace gas consumption greater than zero for the CCHT, and the months of September through May for HOT2000. (There is no furnace gas consumption in HOT2000 for June, July and August).

2. Days of low gas use, defined as days with Reference House furnace gas consumption between zero and 50 MJ/day for the CCHT, and the months of April, May, September and October for HOT2000.

3. Days of high gas use, defined as days with Reference House furnace gas consumption over 50 MJ/day for the CCHT, and December, January and February for HOT2000.

	Daily Gas Consumption					
	All Heating Days		Low Gas Use		High Gas Use	
	Ref House	Test - Ref	Ref House	Test - Ref	Ref House	Test - Ref
CCHT Results	213.73	29.71	27.3	18.83	227.54	30.52
HOT2000	270.04	25.63	62.92	20.01	525.58	30.11
Difference		-13.7%		6.3%		-1.3%

Table F1. Comparison of CCHT and HOT2000 Furnace Gas Consumption.
All values are MJ/day except percentages.

	Daily Furnace Electrical Energy					
	Low Gas Use			High Gas Use		
	Ref House	Test House	Ref - Test	Ref House	Test House	Ref - Test
CCHT Results	8.378	1.081	7.297	9.363	2.480	6.883
HOT2000	8.868	1.039	7.829	9.664	2.590	7.073
Difference	5.8%	-3.9%	7.3%	3.2%	4.4%	2.8%

Table F2. Comparison of CCHT and HOT2000 Furnace Fan Energy.
All values are kWh/day except percentages.

The results of this separation are shown in Table F1. For all heating days, the Reference House furnace used an average of 213.73 MJ/day, and the Test House averaged an additional 29.71 MJ/day. The HOT2000 model of the Reference House used an average of 270.04 MJ/day, with an additional 25.63 MJ/day in the Test House. Thus, HOT2000's additional gas consumption due to the ECM is 13.7% smaller than the CCHT's. For low gas use, this difference is reduced to 6.3%, and for high gas use it is -1.3%. Thus, separating the data according to gas use shows that the large apparent difference between HOT2000 and the CCHT result is due to differences in weather, and that HOT2000 actually follows the CCHT results quite closely. Although HOT2000 will overestimate the difference in gas use during low gas use, it will slightly underestimate it during high gas use. The far greater number of days with high gas use should lead to a close balancing of the two.

Table F2 compares CCHT results and HOT2000 simulations of furnace electrical energy use. During low gas use, HOT2000 overestimates electrical savings 7.3%, but during the more frequent days of high gas use, HOT2000 overestimates the savings by only 2.8%. Thus, on an annual basis, HOT2000's simulations of changes in both gas and electrical consumption due to the ECM are probably well within ±5%. Thus, HOT2000 is considered an adequate tool for projecting the CCHT gas and electrical use to an entire heating season, and to other furnaces, houses and climates.

F.1.2 CCHT & HOT2000 Results for Cooling

When the air conditioning results from the CCHT are compared with a HOT2000 run for an entire year, the two are not very close for three reasons. First, as with the heating results, the weather conditions during the particular days of air conditioner testing are not the same as the average HOT2000 weather for Ottawa. Second, the HOT2000 output table showing air conditioner fan energy does not include the fan energy used in circulation mode during the air conditioning season. However, it can be shown that HOT2000 does calculate this energy internally, and its amount can be determined from other information in the output. Third, the CCHT results need to be corrected for the difference in air conditioner compressor energy during the benchmark. These factors can be corrected for by analysing a single month of HOT2000 results, and comparing them to a period of CCHT data with a similar average outdoor temperature with the compressor and total air conditioner energy corrected for the benchmark offset.. The results of three such comparisons are shown in Table F3. HOT2000's predictions for fan motor energy are very close, both in absolute values and in the percentage by which an ECM reduces fan energy. HOT2000's predictions of air conditioner compressor energy are high both in absolute numbers and ECM savings. The HOT2000 predictions for total air conditioner energy (fan motor plus compressor) are high in absolute terms, but the percentage savings due to an ECM – the most important HOT2000 parameter for the projections – is reasonably close. Thus, HOT2000 is considered adequate for projection both the heating and air conditioning results.

Period	Time Period		Average T_{out}		Motor Energy				A/C Compressor Energy				Total A/C Energy			
	CCHT	H2K	CCHT	H2K	CCHT		H2K		CCHT		H2K		CCHT		H2K	
					PSC	ECM	PSC	ECM	PSC	ECM	PSC	ECM	PSC	ECM	PSC	ECM
1	1 - 22 & 31 August	July	22.9	20.6	11.03	6.39	10.76	5.03	18.75	18.21	23.61	21.38	29.79	24.6	34.37	26.41
2	1 - 15 September	Aug.	19.8	19.3	10.46	5.22	10.59	4.62	14.55	14.19	21.25	19.05	25.02	19.41	31.84	23.66
3	26 Sept. - 3 Oct	Sep.	14.7	14.3	9.28	2.64	9.44	2.60	6.04	5.13	10.66	8.75	15.32	7.77	20.10	11.35
Mean			19.1	18.1	10.26	4.75	10.26	4.08	13.12	12.51	18.51	16.39	23.37	17.26	28.77	20.47
ECM Saving						54%		60%		5%		11%		26%		29%

Table F3. Comparison of CCHT and HOT2000 Air Conditioning Results for Specific Time Periods.
All units are average kWh/d, except for outdoor temperature (°C) and percentages.

F.2 Projection Method

F.2.1 Projecting the CCHT Results to a Complete Heating Season

Projecting the results from the CCHT to an entire heating season consisted of:

1. Obtaining current residential prices for electricity and natural gas in Ottawa, and entering them in the HOT2000 fuel cost library. HOT2000 allows for monthly connect charges, and for rate structures.

2. Running HOT2000 and extracting the following information from the outputs for both PSC and ECM fan motors:

    2.1 The estimated annual fuel consumption summary, which includes the amounts of natural gas and electricity used for space heating, hot water heating, appliances and totals.

    2.2 The estimated annual fuel consumption costs for natural gas and electricity.

    2.3 The space heating system performance, which includes monthly and annual amounts of natural gas use for space heat, and of electricity for furnace fans.

    2.4 The air conditioning system performance, which includes monthly and annual amounts of electricity for the air conditioner and the furnace fans.

3. For the projection without air conditioning, subtracting the amount of electricity used by the furnace fan from mid-May through mid-September – when the furnace is not operating – from the fan and total uses of electricity. This is based on the assumption that windows will be open, and the fan will not be run during that period. For the projection without A/C, this subtraction was not made. Note that for the CCHT, projections were done for continuous circulation only.

4. Calculating the reduction in electricity use, and the increase in natural gas use, due to the ECM. The dollar values of these changes, and the net savings were then calculated.

5. Calculating the reduction in greenhouse gas emissions (GHGs) due to savings of electricity, the increase in emissions due to increased use of natural gas, and the net reduction. To calculate electrical GHG reduction based on coal-generated electricity, a GHG intensity of 1.1 kg CO_2 equivalent per kWh was used. To calculate electrical reductions based on the provincial mix of generating fuels, HOT2000's internal calculations were used. For natural gas, the standard value of 1.9124 kg CO_2 per cubic metre was used.

F.2.2 Projections to other Houses, Furnaces and Climates

In order to project the results to other furnaces, houses and climates, pairs of HOT2000 files for all combinations of the following had to be created:

1. Furnaces: Mid-efficiency (82% steady-state efficiency), and high-efficiency (92% efficiency).

2. House types: R-2000, typical new, typical existing, typical row housing, and typical row housing with a ⅓ horse power (HP) fan motor (the motors used in the tests, and in all other projections are ½ HP).

3. Cities: Toronto, Ottawa, Moncton and Winnipeg.

4. Furnace Fan Operation: With and without continuous, low-speed operation when the furnace or air conditioner is not on.

The house types for each city were based on housing archetypes previously developed by SAR Engineering Ltd. and the Buildings Group.[1] Each house type has different volumes, insulation levels, windows, and airtightness levels for each of the three provinces that the cities are found in. Thus, there were twelve significantly different HOT2000 files to be created: R-2000, typical new, typical existing, and typical row houses for Manitoba, Ontario and New Brunswick. The variations (furnace efficiencies, motor HP, Toronto & Ottawa, PSC & ECM, and with and without continuous circulation) brought the total number of HOT2000 files to 160. Each pair of files was used as described in the previous sub-section, including using current electrical and natural gas prices for each province.

The typical new house archetypes were based on the National energy Use Database (NEUD) *Survey of Houses Built in Canada in 1994.*[2] The R-2000 houses have the same volumes with improved airtightness, windows and insulation values to meet the current R-2000 standard. Typical existing houses were based on the archetypes for 1961 - 77, and typical row houses are typical existing houses reduced to a volume of 350 m^3, and with one-half the wall and window area. Standard values are used for temperature settings, hot water temperature and consumption, and electricity consumption for lights and appliances. (See Section F.3 for house details).

The results of projections with continuous circulation are shown in Tables F4 through F11, and the results without continuous circulation are in Tables F12 through F19.

F.3 House Archetypes Used in Projections.

Single Detached houses		Winnipeg, MA			Toronto, ON			Ottawa, ON			Moncton, NB		
Element	Units	Typical[1]	New2	R2000 3	Typical 1	New2	R2000 3	Typical 1	New2	R2000 3	Typical 1	New2	R2000 3
Main Floor Area	m^2	121.0	142.1	142.1	139.5	177.9	177.9	139.5	177.9	177.9	114.4	143.8	143.8
Basement Floor Area	m^2	98.1	113.8	113.8	99.6	101.7	101.7	99.6	101.7	101.7	102.4	98.3	98.3
Ceiling, Area	m^2	101.7	115.7	115.7	102.9	105.5	105.5	102.9	105.5	105.5	108.6	109.1	109.1
Thermal resistance	RSI	*4.70*	*7.20*	*8.92*	*3.80*	*5.59*	*7.00*	*3.80*	*5.59*	*7.00*	*3.80*	*6.15*	*6.93*
Main Walls, Area	m^2	175.4	187.2	187.2	223.7	197.5	197.5	223.7	197.5	197.5	166	190.2	190.2
Thermal resistance	RSI	*2.30*	*3.20*	*3.62*	*2.16*	*2.67*	*3.35*	*2.16*	*2.67*	*3.59*	*2.16*	*3.09*	*3.44*
Windows, Area	m^2	16.2	17.4	17.4	21.3	26.8	26.8	21.3	26.8	26.8	17.1	19.8	19.8
Thermal resistance	RSI	*0.35*	*0.41*	*0.53*	*0.36*	*0.42*	*0.49*	*0.36*	*0.42*	*0.49*	*0.34*	*0.41*	*0.53*
Doors, Area	m^2	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Thermal resistance	RSI	*0.60*	*1.39*	*1.50*	*0.50*	*1.54*	*1.54*	*0.50*	*1.54*	*1.54*	*0.54*	*1.54*	*1.54*
Overhanging flr., Area	m^2	3.6	1.9	1.9	3.3	3.7	3.7	3.3	3.7	3.7	6.2	10.8	10.8
Thermal resistance	RSI	*3.00*	*5.18*	*5.18*	*3.05*	*5.14*	*5.14*	*3.05*	*5.18*	*5.14*	*2.40*	*4.64*	*5.08*
Bsmt. walls, Area	m^2	128.0	134.5	134.5	155.6	112.1	112.1	155.6	112.1	112.1	126.3	122.8	122.8
Thermal resistance	RSI	*0.92*	*2.10*	*2.78*	*0.74*	*0.92*	*2.78*	*0.74*	*0.92*	*2.78*	*1.06*	*1.25*	*3.16*
Volume	m^3	536.4	650.6	650.6	590.4	720.5	720.5	590.4	720.5	720.5	526.6	616.8	616.8
Air tightness	ac/h_{50Pa}	3.70	2.00	1.50	6.80	3.60	1.50	6.80	3.60	1.50	5.70	2.90	1.50
ELA	cm^2	729	466	351	1487	935	389	1487	935	389	1098	659	333
Furnace output	kW	17.6	17.6	17.6	17.6	17.6	17.6	22.0	17.6	17.6	17.6	17.6	17.6
Design day[4]	kW	14.8	12.1	10.5	15.0	11.9	8.7	18.7	14.8	10.5	13.7	11.7	8.5
Ventilation - type		none	bal. fans	HRV	none	HRV	HRV	none	HRV	HRV	none	HRV	HRV
rate	ac/h	0	0.15	0.15	0	0.15	0.15	0	0.15	0.15	0	0.15	0.15
	L/s	0	27	27	0	30	30	0	30	30	0	25	25
Avg. Infiltration + Vent.	ac/h	0.196	0.253	0.246	0.298	0.301	0.220	0.307	0.306	0.223	0.305	0.312	0.229
Temperature - main	C	21	21	21	21	21	21	21	21	21	21	21	21
basement	C	20	20	20	20	20	20	20	20	20	20	20	20
Utilities - inside	kWh/d	20	20	20	20	20	20	20	20	20	20	20	20
outside	kWh/d	4	4	4	4	4	4	4	4	4	4	4	4
Hot water use	L/d	225	225	225	225	225	225	225	225	225	225	225	225
temperature	C	55	55	55	55	55	55	55	55	55	55	55	55

Row houses

Element	Units	Winnipeg, MA Typical[1]	Winnipeg, MA %SD typical	Toronto, ON Typical[1]	Toronto, ON %SD typical	Ottawa, ON Typical[1]	Ottawa, ON %SD typical	Moncton, NB Typical[1]	Moncton, NB %SD typical
Main Floor Area	m^2	85.9	71%	82.7	59%	82.7	59%	85.0	74%
Basement Floor Area	m^2	56.0	57%	59.0	59%	59.0	59%	57.0	56%
Ceiling, Area	m^2	58.4	57%	61.0	59%	61.0	59%	61.1	56%
Thermal resistance	RSI	*4.70*		*3.80*		*3.80*		*3.80*	
Main Walls, Exp.Area	m^2	88.2	50%	78.4	35%	78.4	35%	90.7	55%
Thermal resistance	RSI	*2.30*		*2.16*		*2.16*		*2.16*	
Windows, Area	m^2	11.5	71%	12.6	59%	12.6	59%	12.7	74%
Thermal resistance	RSI	*0.35*		*0.36*		*0.36*		*0.34*	
Doors, Area	m^2	3.6	100%	3.6	100%	3.6	100%	3.6	100%
Thermal resistance	RSI	*0.60*		*0.50*		*0.50*		*0.54*	
Overhanging flr., Area	m^2	2.4	67%	1.9	58%	1.9	58%	4.1	66%
Thermal resistance	RSI	*3.00*		*3.05*		*3.05*		*2.40*	
Bsmt. walls, Exp.Area	m^2	58.9	46%	58.4	38%	58.4	38%	61.4	49%
Thermal resistance	RSI	*0.92*		*0.74*		*0.74*		*1.06*	
Fdtn. attach adj. units	m	10.0		11.0		11.0		10.0	
Volume	m^3	350.5	65%	349.3	59%	349.3	59%	350.3	67%
Air tightness	ac/h_{50Pa}	3.7	100%	6.8	100%	6.8	100%	5.7	100%
ELA	cm^2	477	65%	880	59%	880	59%	730	66%
Furnace output	kW	17.6		17.6		17.6		17.6	
Design day[4]	kW	8.5	57%	7.6	51%	9.7	52%	8.3	61%
Ventilation - type		none		none		none		none	
rate	ac/h	0		0		0		0	
	L/s	0		0		0		0	
Avg. Infiltration + Vent.	ac/h	0.238	121%	0.34	114%	0.352	115%	0.327	107%
Temperature - main	C	21		21		21		21	
basement	C	20		20		20		20	
Utilities - inside	kWh/d	18.0	90%	18.0	90%	18.0	90%	18.0	90%
outside	kWh/d	3.0	75%	3.0	75%	3.0	75%	3.0	75%
Hot water use	L/d	185	82%	185	82%	185	82%	185	82%
temperature	C	55		55		55		55	

NOTES:

[1] REES 1961-1977 archetypes (based on 1993 SHEU study) and STAR database (Row houses same RSI values, reduced areas)
[2] REES new house (based on NEUD 1994 survey)
[3] Based on New house archetype, with air-tightness and R-values adjusted to meet R-2000 budget, including F326 ventilation.
Ventilation then adjusted to 0.15 ac/h
[4] HOT2000 calculated design day heat loss times 110% plus 0.5kw warmup (no credit for HRV)

Fans	Space heat	Circulation
PSC	505	365 W
ECM	299	32 W

Furnaces	Efficiency
Mid efficiency	82%
High efficiency	92%

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-	Nat	Net	Elec-	Nat	Net
						Fan	A/C	Total					Furn	Total			tricity	Gas		tricity	Gas	
R2000 with A/C	PSC	3477	1661	14676						1,147	1,868											
	ECM	835	1352	11736	2940	76%	18%	20%	$249	1,317	2,038	170	14%	9.1%	$76	$172	3,234	-325	2,909	217	-325	-108
R2000 without A/C	PSC	1938	-	11461						1,147	1,868											
	ECM	333	-	9855	1606	83%	N/A	14%	$136	1,317	2,038	170	14.8	9.1%	$76	$59	1766	-325	1441	119	-325	-207
Typical New with	PSC	3513	1595	14657						1,957	2,702											
A/C	ECM	908	1307	11773	2884	74%	18%	20%	$244	2,141	2,886	184	9.4%	6.8%	$83	$161	3172	-352	2820	213	-352	-139
Typical New without	PSC	2011	-	11533						1,957	2,702											
A/C	ECM	440	-	9962	1572	78%	N/A	14%	$133	2,141	2,886	184	9.4%	6.8%	$83	$50	1729	-352	1377	116	-352	-236
Typical Existing with	PSC	3563	1264	13628						3107	3853											
A/C	ECM	998	1,008	10820	2808	72%	20%	21%	$237	3309	4055	202	6.5%	5.2%	$91	$147	3089	-385	2704	208	-385	-178
Typical Existing	PSC	2156	-	10916						3107	3853											
without A/C	ECM	612	-	9372	1545	72%	N/A	14%	$131	3309	4055	202	6.5%	5.2%	$91	$40	1699	-385	1314	114	-385	-271
Typical Row with	PSC	3511	1400	12596						1183	1832											
A/C	ECM	869	1066	9631	2965	75%	23%	24%	$251	1359	2008	176	14%	9.6%	$79	$172	3261	-336	2925	219	-336	-117
Typical Row without	PSC	1942	-	9607						1183	1832											
A/C	ECM	338	-	8003	1604	83%	N/A	17%	$136	1359	2008	176	14%	9.6%	$79	$56	1764	-336	1428	119	-336	-217
Row with 1/3HP	PSC	2360	1098	11143						1249	1899											
motor with A/C	ECM	602	900	9197	1946	74%	18%	17%	$165	1369	2018	120	9.6%	6.3%	$54	$111	2141	-229	1912	144	-229	-85
Row with 1/3 HP	PSC	1324	-	8989						1249	1899											
motor without A/C	ECM	250	-	7915	1074	81%	N/A	12%	$91	1369	2018	120	9.6%	6.3%	$54	$37	1181	-229	952	79	-229	-149

Table F4. HOT2000 Projections of ECM Effects for Toronto: Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 $/kWh, Natural Gas: 0.4494 $/$m^3$, including taxes.

House Type	Furnace Motor	Electricity Fan kWh/y	Electricity A/C kWh/y	Electricity Total kWh/y	Savings due to ECM kWh/y	Savings % of Fan	Savings % of A/C	Savings % of Total	Savings $/y	Natural Gas Furnace m^3/y	Natural Gas Total m^3/y	Increase due to ECM m^3	Increase % of Furn	Increase % of Total	Increase $/y	Net Savings $/y	GHG Reductions ($kg\ CO_2/y$) Based on Coal Elec-tricity	Based on Coal Nat Gas	Based on Coal Net	Based on Prov. Mix Elec-tricity	Based on Prov. Mix Nat Gas	Based on Prov. Mix Net
R2000 with A/C	PSC	3477	1661	14676						1022	1743											
	ECM	835	1352	11736	2940	76%	18%	20%	$249	1174	1895	152	14%	8.7%	$68	$180	3234	-290	2944	217	-290	-73
R2000 without A/C	PSC	1938	-	11460						1022	1743											
	ECM	332	-	9855	1606	83%	N/A	14%	$136	1,174	1,895	152	14%	8.7%	$68	$68	1766	-290	1476	119	-290	-171
Typical New with A/C	PSC	3545	1595	14690						1744	2489											
	ECM	908	1307	11773	2916	74%	18.1	20%	$247	1909	2653	164	9.4%	6.6%	$74	$173	3208	-313	2894	216	-313	-98
Typical New without	PSC	2008	-	11530						1744	2489											
A/C	ECM	439	-	9961	1569	78%	N/A	14%	$133	1909	2653	164	9.4%	6.6%	$74	$59	1726	-313	1413	116	-313	-197
Typical Existing with	PSC	3563	1264	13628						2769	3516											
A/C	ECM	998	1008	10820	2808	72%	20%	21%	$237	2949	3695	180	6.5%	5.1%	$81	$157	3089	-343	2746	208	-343	-136
Typical Existing	PSC	2146	-	10906						2769	3516											
without A/C	ECM	612	-	9372	1535	72%	N/A	14%	$130	2949	3695	180	6.5%	5.1%	$81	$49	1688	-343	1345	113	-343	-230
Typical Row with A/C	PSC	3511	1400	12596						1054	1704											
	ECM	869	1066	9631	2965	75%	23%	24%	$251	1,211	1,860	157	14.%	9.2%	$71	$180	3261	-299	2962	219	-299	-80
Typical Row without	PSC	1941	-	9606						1054	1704											
A/C	ECM	338	-	8003	1604	83%	N/A	17%	$136	1211	1860	157	14%	9.2%	$71	$65	1764	-299	1464	119	-299	-181
Row with 1/3 HP	PSC	2360	1098	11143						1113	1763											
motor with A/C	ECM	602	900	9197	1946	74%	18%	17%	$165	1,220	1870	107	9.6%	6.1%	$48	$117	2141	-204	1937	144	-204	-60
Row with 1/3 HP	PSC	1323	-	8988						1113	1763											
motor without A/C	ECM	250	-	7915	1073	81%	N/A	12%	$91	1,220	1,870	107	9.6%	6.1%	$48	$43	1180	-204	977	79	-204	-125

Table F5. HOT2000 Projections of ECM Effects for Toronto: Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 \$/kWh, Natural Gas: 0.4494 \$/m³, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Electricity: Savings due to ECM kWh/y	Savings due to ECM %of Fan	Savings due to ECM %of A/C	Savings due to ECM %of Total	Savings due to ECM $/y	Natural Gas: Furnace m³/y	Natural Gas: Total m³/y	Increase due to ECM m³	Increase due to ECM %of Furn	Increase due to ECM %of Total	Increase due to ECM $/y	Net Savings $/y	GHG Reductions (kg C O₂/y) Based on Coal: Elec-tricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Elec-tricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	3486	1610	14637						1364	2115											
	ECM	853	1310	11711	2926	76%	19%	20%	$247	1535	2286	171	13%	8.1%	$77	$170	3218	-328	2890	216	-328	-112
R2000 without A/C	PSC	1952	-	11474						1364	2115											
	ECM	361	-	9883	1591	82%	N/A	14%	$135	1535	2286	171	12.6	8.1%	$77	$58	1751	-328	1423	118	-328	-210
Typical New with	PSC	3532	1524	14610						2,347	3,120											
A/C	ECM	944	1248	11753	2857	73%	18%	20%	$241	2534	3307	188	8.0%	6.0%	$84	$157	3142	-358	2784	211	-358	-147
Typical New	PSC	2037	-	11559						2,347	3,120											
without A/C	ECM	490	-	10012	1547	76%	N/A	13%	$131	2,534	3,307	188	8.0%	6.0%	$84	$46	1701	-358	1343	114	-358	-244
Typical Existing	PSC	3543	1209	13556						3,655	4,430											
with A/C	ECM	954	963	10731	2825	73%	20%	21%	$239	3,866	4,642	211	5.8%	4.8%	$95	$144	3107	-404	2703	209	-404	-195
Typical Existing	PSC	2152	-	10912						3,655	4,430											
without A/C		585	-	9345	1567	73%	N/A	14%	$132	3,866	4,642	211	5.8%	4.8%	$95	$38	1724	-404	1320	116	-404	-288
Typical Row with	PSC	3523	1352	12559						1,464	2,138											
A/C	ECM	890	1023	9611	2948	75%	24%	23%	$249	1642	2315	178	12%	8.3%	$80	$169	3243	-339	2904	218	-339	-121
Typical Row	PSC	1960	-	9625						1,464	2,138											
without A/C	ECM	374	-	8039	1586	81%	N/A	16%	$134	1642	2315	178	12%	8.3%	$80	$54	1744	-339	1405	117	-339	-222
Row, 1/3 HP with	PSC	2368	1058	11115						1533	2206											
A/C	ECM	616	864	9178	1936	74%	18%	17%	$164	1,654	2,327	121	7.9%	5.5%	$54	$109	2130	-231	1899	143	-231	-88
Row, 1/3 HP	PSC	1336	-	9001						1,533	2,206											
without A/C	ECM	275	-	7940	1061	79%	N/A	12%	$90	1,654	2,327	121	7.9%	5.5%	$54	$35	1167	-231	937	78	-231	-152

Table F6. HOT2000 Projections of ECM Effects for Ottawa: Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 $/kWh, Natural Gas: 0.4494 $/m³, including taxes.

House Type	Furnace Motor	Electricity Fan kWh/y	Electricity A/C kWh/y	Electricity Total kWh/y	Savings due to ECM kWh/y	Savings due to ECM % of Fan	Savings due to ECM % of A/C	Savings due to ECM % of Total	Savings due to ECM $/y	Natural Gas Furnace m³/y	Natural Gas Total m³/y	Increase due to ECM m³	Increase due to ECM % of Furn	Increase due to ECM % of Total	Increase due to ECM $/y	Net Savings $/y	GHG Reductions ($kg\ CO_2/y$) Based on Coal Electricity	Based on Coal Nat Gas	Based on Coal Net	Based on Prov. Mix Electricity	Based on Prov. Mix Nat Gas	Based on Prov. Mix Net
R2000 with A/C	PSC	3486	1610	14637						1,216	1,966											
	ECM	853	1310	11711	2926	76%	19%	20%	$247	1,368	2,119	153	13%	7.8%	$69	$179	3218	-292	2926	216	-292	-76
R2000 without A/C	PSC	1952	-	11474						1,216	1,966											
	ECM	360	-	9883	1591	82%	N/A	14%	$135	1,368	2,119	153	13%	7.8%	$69	$66	1750	-292	1458	118	-292	-174
Typical New with	PSC	3532	1524	14610						2,091	2,865											
A/C	ECM	944	1248	11753	2857	73%	18%	20%	$241	2,259	3,032	167	8.0%	5.8%	$75	$166	3142	-319	2823	211	-319	-108
Typical New without	PSC	2034	-	11557						2,091	2,865											
A/C	ECM	500	-	10022	1535	75%	N/A	13%	$130	2,259	3,032	167	8.0%	5.8%	$75	$55	1688	-319	1369	113	-319	-206
Typical Existing with	PSC	3543	1209	13556						3,257	4,033											
A/C	ECM	954	963	10731	2825	73%	20%	21%	$239	3,446	4,221	188	5.8%	4.7%	$85	$154	3107	-360	2747	209	-360	-151
Typical Existing	PSC	2141	-	10901						3,257	4,033											
without A/C	ECM	585	-	9345	1557	73%	N/A	14%	$132	3,446	4,221	188	5.8%	4.7%	$85	$47	1713	-360	1353	115	-360	-245
Typical Row with	PSC	3523	1352	12559						1,305	1,978											
A/C	ECM	890	1023	9611	2948	75%	24%	23%	$249	1,464	2,136	159	12%	8.0%	$71	$178	3243	-302	2941	218	-302	-84
Typical Row without	PSC	1960	-	9625						1,305	1,978											
A/C	ECM	374	-	8039	1585	81%	N/A	16%	$134	1,464	2,136	159	12%	8.0%	$71	$63	1744	-302	1442	117	-302	-185
Row, 1/3 HP with	PSC	2368	1058	11115						1,366	2,040											
A/C	ECM	616	864	9178	1936	74%	18%	17%	$164	1,474	2,147	108	7.9%	5.3%	$48	$115	2130	-205	1925	143	-205	-62
Row, 1/3 HP without	PSC	1335	-	9000						1,366	2,040											
A/C	ECM	274	-	7939	1061	79%	N/A	12%	$90	1,474	2,147	108	7.9%	5.3%	$48	$41	1167	-205	962	78	-205	-127

Table F7. HOT2000 Projections of ECM Effects for Ottawa: Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 \$/kWh, Natural Gas: 0.4494 \$/m³, including taxes.

House Type	Furnace Motor	Electricity Fan kWh/y	Electricity A/C kWh/y	Electricity Total kWh/y	Savings due to ECM kWh/y	Savings % of Fan	Savings % of A/C	Savings % of Total	Savings $/y	Natural Gas Furnace m³/y	Natural Gas Total m³/y	Increase due to ECM m³	Increase % of Furn	Increase % of Total	Increase $/y	Net Savings $/y	GHG Based on Coal Electricity	GHG Based on Coal Nat Gas	GHG Based on Coal Net	GHG Based on Prov. Mix Electricity	GHG Based on Prov. Mix Nat Gas	GHG Based on Prov. Mix Net
R2000 with A/C	PSC	3464	1158	14176						1181	1966											
	ECM	773	845	11187	2990	78%	27%	21%	$268	1,371	2,157	191	16%	9.7%	$97	$171	3289	-364	2924	636	-364	272
R2000 without A/C	PSC	1966	-	11488						1,181	1,966											
	ECM	341	-	9863	1625	83%	N/A	14%	$146	1,371	2,157	191	16%	9.7%	$97	$49	1787	-364	1423	346	-364	-18
Typical New with	PSC	3485	1025	14079						1,957	2,746											
A/C	ECM	821	742	11148	2932	76%	28%	21%	$263	2,167	2,956	210	11%	7.6%	$106	$156	3225	-402	2823	624	-402	223
Typical New without	PSC	2076	-	11598						1,957	2,746											
A/C	ECM	465	-	9988	1611	78%	N/A	14%	$144	2,167	2,956	210	11%	7.6%	$106	$38	1772	-402	1370	343	-402	-59
Typical Existing with	PSC	3515	820	13155						2,781	3,570											
A/C	ECM	880	581	10295	2860	75%	29%	22%	$256	3,003	3,792	222	8.0%	6.2%	$112	$144	3146	-425	2721	609	-425	184
Typical Existing	PSC	2345	-	11105						2,781	3,570											
without A/C	ECM	594	-	9354	1751	75%	N/A	16%	$157	3,003	3,792	222	8.0%	6.2%	$112	$44	1926	-425	1501	373	-425	-52
Typical Row with	PSC	3464	973	12133						1,318	2,003											
A/C	ECM	756	669	9143	2991	78%	31%	25%	$268	1,513	2,198	195	15%	9.7%	$99	$169	3290	-373	2917	637	-373	264
Typical Row without	PSC	2204	-	9869						1,318	2,003											
A/C	ECM	381	-	8046	1823	83%	N/A	18%	$163	1,513	2,198	195	15%	9.7%	$99	$64	2006	-373	1633	388	-373	16
Row, 1/3 HP with	PSC	2331	722	10758						1,392	2,077											
A/C	ECM	532	551	8801	1957	77%	24%	18%	$175	1,525	2,209	133	9.5%	6.4%	$67	$108	2153	-254	1899	417	-254	163
Row, 1/3 HP without	PSC	1505	-	9170						1,392	2,077											
A/C	ECM	282	-	7947	1222	81%	N/A	13%	$109	1525	2,209	133	9.5%	6.4%	$67	$42	1344	-254	1091	260	-254	6

Table F8. HOT2000 Projections of ECM Effects for Moncton: Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0896 \$/kWh, Natural Gas: 0.5073 \$/m³, including taxes.

GHG Reductions in kg CO_2/y.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Savings due to ECM: kWh/y	Savings due to ECM: % of Fan	Savings due to ECM: % of A/C	Savings due to ECM: % of Total	Savings due to ECM: $/y	Natural Gas: Furnace m^3/y	Natural Gas: Total m^3/y	Increase due to ECM: m^3	Increase due to ECM: % of Furn	Increase due to ECM: % of Total	Increase due to ECM: $/y	Net Savings $/y	GHG Reductions ($kg\ CO_2/y$) Based on Coal: Electricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Electricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	3464	1158	14176						1,052	1,838											
	ECM	773	845	11187	2990	78%	27%	21%	$268	1,222	2,008	170	16%	9.2%	$86	$182	3289	-325	2964	636	-325	312
R2000 without A/C	PSC	1962	-	11484						1,052	1,838											
	ECM	340	-	9862	1622	83%	N/A	14%	$145	1,222	2,008	170	16%	9.2%	$86	$59	1784	-325	1460	345	-325	21
Typical New with	PSC	3485	1025	14079						1,744	2,533											
A/C	ECM	821	742	11148	2932	76%	28%	21%	$263	1,931	2,720	187	11%	7.4%	$95	$168	3225	-358	2867	624	-358	266
Typical New without	PSC	2066	-	11588						1,744	2,533											
A/C	ECM	465	-	9987	1601	77%	N/A	14%	$143	1931	2,720	187	11%	7.4%	$95	$49	1761	-358	1403	341	-358	-17
Typical Existing with	PSC	3515	820	13155						2,479	3,268											
A/C	ECM	880	581	10295	2860	75%	29%	22%	$256	2,677	3,466	198	8.0%	6.0%	$100	$156	3146	-379	2768	609	-379	230
Typical Existing	PSC	2341	-	11101						2,479	3,268											
without A/C	ECM	594	-	9354	1747	75%	N/A	16%	$156	2,677	3,466	198	8.0%	6.0%	$100	$56	1921	-379	1543	372	-379	-7
Typical Row with	PSC	3464	973	12133						1,175	1,860											
A/C	ECM	756	669	9143	2991	78%	31%	25%	$268	1,349	2,033	174	15%	9.3%	$88	$180	3290	-332	2958	637	-332	305
Typical Row without	PSC	2204	-	9869						1,175	1,860											
A/C	ECM	381	-	8046	1823	83%	N/A	18%	$163	1,349	2,033	174	15%	9.3%	$88	$75	2006	-332	1674	388	-332	56
Row, 1/3 HP with	PSC	2331	722	10758						1,240	1,925											
A/C	ECM	532	551	8801	1957	77%	24%	18%	$175	1,359	2,044	118	9.5%	6.2%	$60	$115	2153	-226	1926	417	-226	190
Row, 1/3 HP without	PSC	1504	-	9169						1,240	1,925											
A/C	ECM	282	-	7947	1222	81%	N/A	13%	$109	1,359	2,044	118	9.5%	6.2%	$60	$49	1344	-226	1118	260	-226	34

Table F9. HOT2000 Projections of ECM Effects for Moncton: Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0896 \$/kWh, Natural Gas: 0.5073 \$/m^e, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	A/C kWh/y	Total kWh/y	Savings due to ECM: kWh/y	% of Fan	% of A/C	% of Total	$/y	Natural Gas: Furnace m^3/y	Total m^3/y	Increase due to ECM: m^3	% of Furn	% of Total	$/y	Net Savings $/y	GHG Reductions ($kg\ CO_2/y$) Based on Coal: Electricity	Nat Gas	Net	Based on Prov. Mix: Electricity	Nat Gas	Net
R2000 with A/C	PSC	3543	1459	14553						1,693	2,500											
	ECM	944	1144	11652	2901	73%	22%	20%	$162	1,884	2,691	191	11%	7.6%	$71	$92	3191	-365	2827	31	-365	-334
R2000 without A/C	PSC	1989	-	11511						1,693	2500											
	ECM	406	-	9928	1583	80%	N/A	14%	$89	1,884	2,691	191	11%	7.6%	$71	$18	1741	-365	1376	17	-365	-348
Typical New with	PSC	3577	1398	14535						2,508	3,314											
A/C	ECM	1017	1107	11695	2840	72%	21%	20%	$159	2,711	3,517	203	8.1%	6.1%	$75	$84	3124	-388	2736	30	-388	-357
Typical New without	PSC	2091	-	11614						2,508	3,314											
A/C	ECM	502	-	10024	1589	76%	N/A	14%	$89	2,711	3,517	203	8.1%	6.1%	$75	$14	1748	-388	1361	17	-388	-371
Typical Existing with	PSC	3586	1217	13602						3,103	3,914											
A/C	ECM	1036	961	10758	2844	71%	21%	21%	$159	3,314	4,124	211	6.8%	5.4%	$78	$81	3129	-402	2727	30	-402	-371
Typical Existing	PSC	2338	-	11098						3,103	3,914											
without A/C	ECM	613	-	9373	1725	74%	N/A	16%	$96	3,314	4124	211	6.8%	5.4%	$78	$19	1897	-402	1496	18	-402	-383
Typical Row with	PSC	3504	1237	12428						1,414	2,115											
A/C	ECM	856	934	9487	2941	76%	24%	24%	$164	1,592	2,294	179	13%	8.4%	$66	$98	3235	-342	2893	31	-342	-310
Typical Row without	PSC	1958	-	9623						1,414	2,115											
A/C	ECM	368	-	8033	1590	81%	N/A	17%	$89	1,592	2,294	179	13%	8.4%	$66	$23	1749	-342	1407	17	-342	-325
Row, 1/3 HP with	PSC	2372	1035	11096						1,482	2,184											
A/C	ECM	624	848	9169	1928	74%	18%	17%	$108	1,604	2,306	122	8.2%	5.6%	$45	$63	2120	-233	1888	21	-233	-212
Row, 1/3 HP without	PSC	1336	-	9000						1,482	2,184											
A/C	ECM	270	-	7935	1065	80%	N/A	12%	$60	1,604	2,306	122	8.2%	5.6%	$45	$15	1172	-233	939	11	-233	-222

Table F10. HOT2000 Projections of ECM Effects for Winnipeg: Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0559 \$/kWh, Natural Gas: 0.3696 $\$/m^3$, including taxes.

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m³/y	m³/y	m³	% of		$/y	$/y	Elec-	Nat	Net	Elec-	Nat	Net
						Fan	A/C	Total					Furn	Total			tricity	Gas		tricity	Gas	
R2000 with A/C	PSC	3543	1459	14553						1,509	2,316											
	ECM	944	1144	11652	2901	73%	22%	20%	$162	1,680	2,486	170	11%	7.3%	$63	$99	3191	-325	2866	31	-325	-294
R2000 without A/C	PSC	1987	-	11509						1,509	2,316											
	ECM	406	-	9928	1581	80%	N/A	14%	$88	1,680	2,486	170	11%	7.3%	$63	$26	1739	-325	1414	17	-325	-308
Typical New with	PSC	3577	1398	14535						2,235	3,042											
A/C	ECM	1017	1107	11695	2840	72%	21%	20%	$159	2,416	3,223	181	8.1%	5.9%	$67	$92	3124	-346	2778	30	-346	-315
Typical New	PSC	2084	-	11606						2,235	3,042											
without A/C	ECM	514	-	10036	1570	75%	N/A	14%	$88	2,416	3,223	181	8.1%	5.9%	$67	$21	1727	-346	1382	17	-346	-329
Typical Existing	PSC	3586	1217	13602						2,766	3,577											
with A/C	ECM	1036	961	10808	2795	71%	21%	21%	$156	2,954	3,764	188	6.8%	5.2%	$69	$87	3074	-358	2716	30	-358	-328
Typical Existing	PSC	2334	-	11094						2,766	3,577											
without A/C	ECM	612	-	9372	1722	74%	N/A	16%	$96	2,954	3,764	188	6.8%	5.2%	$69	$27	1894	-358	1536	18	-358	-340
Typical Row with	PSC	3504	1237	12428						1,260	1,962											
A/C	ECM	856	934	9487	2941	76%	24%	24%	$164	1,419	2,121	159	13%	8.1%	$59	$106	3235	-305	2930	31	-305	-273
Typical Row	PSC	1958	-	9623						1,260	1,962											
without A/C	ECM	368	-	8033	1590	81%	N/A	17%	$89	1,419	2,121	159	13%	8.1%	$59	$30	1749	-305	1444	17	-305	-288
Row with 1/3 HP	PSC	2372	1035	11096						1,321	2,023											
motor with A/C	ECM	624	848	9169	1928	74%	18%	17%	$108	1,430	2,131	109	8.2%	5.4%	$40	$68	2120	-208	1913	21	-208	-187
Row with 1/3 HP	PSC	1335	-	9000						1,321	2,023											
motor without A/C	ECM	270	-	7935	1065	80%	N/A	12%	$60	1,430	2,131	109	8.2%	5.4%	$40	$19	1171	-208	963	11	-208	-196

Table F11. HOT2000 Projections of ECM Effects for Winnipeg: Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0559 \$/kWh, Natural Gas: 0.3696 \$/m^e, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Electricity: Savings due to ECM kWh/y	Savings due to ECM % of Fan	Savings due to ECM % of A/C	Savings due to ECM % of Total	Savings due to ECM $/y	Natural Gas: Furnace m³/y	Natural Gas: Total m³/y	Increase due to ECM m³	Increase due to ECM % of Furn	Increase due to ECM % of Total	Increase due to ECM $/y	Net Savings $/y	GHG Reductions (kg CO_2/y) Based on Coal: Electricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Electricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	775	1337	11661						1,319	2,040											
	ECM	595	1325	11470	191	23%	0.9%	1.6%	$16	1,332	2,053	13	1.0%	0.6%	$6	$10	210	-25	185	14	-25	-11
R2000 without A/C	PSC	319	-	9841						1,319	2,040											
	ECM	191	-	9713	128	40%	N/A	1.3%	$11	1,332	2,053	13	1.0%	0.6%	$6	$5	141	-25	116	9	-25	-16
Typical New with	PSC	935	1291	11787						2,140	2,883											
A/C	ECM	679	1280	11521	266	27%	0.8%	2.3%	$23	2,160	2,904	20	0.9%	0.7%	$9	$14	293	-39	254	20	-39	-19
Typical New without	PSC	515	-	10037						2,140	2,883											
A/C	ECM	308	-	9830	207	40%	N/A	2.1%	$18	2,160	2,904	20	0.9%	0.7%	$9	$9	228	-39	189	15	-39	-24
Typical Existing with	PSC	1150	996	10959						3,313	4,058											
A/C	ECM	786	987	10587	372	32%	1%	3.4%	$31	3,342	4,087	29	0.9%	0.7%	$13	$19	409	-56	354	28	-56	-28
Typical Existing	PSC	804	-	9564						3,313	4,058											
without A/C	ECM	480	-	9240	324	40%	N/A	3.4%	$27	3,342	4,087	29	0.9%	0.7%	$13	$14	356	-56	301	24	-56	-32
Typical Row with	PSC	818	1053	9566						1,364	2,013											
A/C	ECM	627	1038	9361	205	23%	1.4%	2.1%	$17	1,378	2,027	14	1.0%	0.7%	$6	$11	225	-27	199	15	-27	-12
Typical Row without	PSC	329	-	7994						1,364	2,013											
A/C	ECM	197	-	7862	132	40%	N/A	1.7%	$11	1,378	2,027	14	1.0%	0.7%	$6	$5	146	-27	119	10	-27	-17
Row with 1/3 HP	PSC	532	887	9114						1,375	2,024											
motor with A/C	ECM	407	879	8982	132	23%	0.9%	1.4%	$11	1,384	2,034	9	0.7%	0.5%	$4	$7	145	-18	127	10	-18	-8
Row with 1/3 HP	PSC	225	-	7890						1,375	2,024											
motor without A/C	ECM	135	-	7800	90	40%	N/A	1.1%	$8	1,384	2,034	9	0.7%	0.5%	$4	$3	99	-18	81	7	-18	-12

Table F12. HOT2000 Projections of ECM Effects for Toronto: No Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 \$/kWh, Natural Gas: 0.4494 \$/m³, including taxes.

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-tricity	Nat Gas	Net	Elec-tricity	Nat Gas	Net
						Fan	A/C	Total					Furn	Total								
R2000 with A/C	PSC	775	1337	11661						1,176	1,897											
	ECM	595	1325	11470	191	23%	0.9%	2%	$16	1,188	1,909	12	1.0%	0.6%	$5	$11	210	-23	187	14	-23	-9
R2000 without A/C	PSC	319	-	9841						1,176	1,897											
	ECM	191	-	9713	128	40%	N/A	1%	$11	1,188	1,909	12	1.0%	0.6%	$5	$6	141	-23	118	9	-23	-13
Typical New with	PSC	935	1291	11787						1,907	2,651											
A/C	ECM	679	1280	11521	266	27%	0.8%	2%	$23	1,925	2,669	18	0.9%	0.7%	$8	$15	293	-35	258	20	-35	-15
Typical New without	PSC	515	-	10037						1,907	2,651											
A/C	ECM	308	-	9830	207	40%	N/A	2%	$18	1,925	2,669	18	0.9%	0.7%	$8	$10	228	-35	193	15	-35	-19
Typical Existing with	PSC	1150	996	10959						2,953	3,698											
A/C	ECM	786	987	10587	372	32%	1%	3%	$31	2,978	3,724	26	0.9%	0.7%	$12	$20	409	-50	360	28	-50	-22
Typical Existing	PSC	804	-	9564						2,953	3,698											
without A/C	ECM	480	-	9240	324	40%	N/A	3%	$27	2,978	3,724	26	0.9%	0.7%	$12	$16	356	-50	307	24	-50	-26
Typical Row with	PSC	818	1053	9566						1,216	1,865											
A/C	ECM	627	1038	9361	205	23%	1.4%	2%	$17	1,228	1,877	12	1.0%	0.7%	$6	$12	225	-24	201	15	-24	-9
Typical Row	PSC	329	-	7994						1,216	1,865											
without A/C	ECM	197	-	7862	132	40%	N/A	2%	$11	1,228	1,877	12	1.0%	0.7%	$6	$6	146	-24	122	10	-24	-14
Row, 1/3 HP motor	PSC	532	887	9114						1,226	1,875											
with A/C	ECM	407	879	8982	132	23%	0.9%	1%	$11	1,234	1,883	8	0.7%	0.4%	$4	$7	145	-16	129	10	-16	-6
Row, 1/3 HP motor	PSC	225	-	7890						1,226	1,875											
without A/C	ECM	135	-	7800	90	40%	N/A	1%	$8	1,234	1,883	8	0.7%	0.4%	$4	$4	99	-16	83	7	-16	-9

Table F13. HOT2000 Projections of ECM Effects for Toronto: No Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 $/kWh, Natural Gas: 0.4494 $/m³, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Electricity: Savings due to ECM: kWh/y	Savings due to ECM: % of Fan	Savings due to ECM: % of A/C	Savings due to ECM: % of Total	Savings due to ECM: $/y	Natural Gas: Furnace m³/y	Natural Gas: Total m³/y	Natural Gas: Increase due to ECM: m³	Increase due to ECM: % of Furn	Increase due to ECM: % of Total	Increase due to ECM: $/y	Net Savings $/y	GHG Reductions (kg CO_2/y): Based on Coal: Electricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Electricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	814	1294	11657						1,537	2,287											
	ECM	615	1283	11447	210	24%	0.8%	1.8%	$18	1,551	2,302	15	1.0%	0.6%	$7	$11	231	-28	203	16	-28	-13
R2000 without A/C	PSC	372	-	9894						1,537	2,287											
	ECM	222	-	9744	150	40%	N/A	1.5%	$13	1,551	2,302	15	1.0%	0.6%	$7	$6	165	-28	136	11	-28	-17
Typical New with	PSC	1012	1230	11806						2,534	3,306											
A/C	ECM	720	1219	11503	303	29%	0.9%	2.6%	$26	2,555	3,328	22	0.9%	0.7%	$10	$16	333	-42	291	22	-42	-20
Typical New without	PSC	610	-	10132						2,534	3,306											
A/C	ECM	364	-	9886	246	40%	N/A	2.4%	$21	2,555	3,328	22	0.9%	0.7%	$10	$11	270	-42	228	18	-42	-24
Typical Existing with	PSC	1079	949	10845						3,882	4,656											
A/C	ECM	737	940	10495	350	32%	1%	3.2%	$30	3,905	4,680	23	0.6%	0.5%	$11	$19	385	-46	339	26	-46	-20
Typical Existing	PSC	751	-	9511						3,882	4,656											
without A/C	ECM	448	-	9207	304	40%	N/A	3.2%	$26	3,905	4,680	23	0.6%	0.5%	$11	$15	334	-46	288	22	-46	-23
Typical Row with	PSC	869	1009	9576						1,648	2,320											
A/C	ECM	653	995	9346	230	25%	1.4%	2.4%	$19	1,664	2,336	16	1.0%	0.7%	$7	$12	253	-31	223	17	-31	-14
Typical Row without	PSC	399	-	8064						1,648	2,320											
A/C	ECM	238	-	7903	160	40%	N/A	2.0%	$14	1,664	2,336	16	1.0%	0.7%	$7	$7	177	-31	146	12	-31	-19
Row, 1/3 HP with	PSC	567	851	9116						1,661	2,333											
A/C	ECM	425	844	8967	150	25%	0.9%	1.6%	$13	1,671	2,344	10	0.6%	0.4%	$5	$8	164	-20	144	11	-20	-9
Row, 1/3 HP without	PSC	272	-	7937						1,661	2,333											
A/C	ECM	163	-	7828	109	40%	N/A	1.4%	$9	1,671	2,344	10	0.6%	0.4%	$5	$5	120	-20	99	8	-20	-12

Table F14. HOT2000 Projections of ECM Effects for Ottawa: No Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 \$/kWh, Natural Gas: 0.4494 \$/m³, including taxes.

House Type	Furnace	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
	Motor	Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-	Nat	Net	Elec-	Nat	Net
						Fan	A/C	Total					Furn	Total			tricity	Gas		tricity	Gas	
R2000 with A/C	PSC	814	1294	11657						1,370	2,120											
	ECM	615	1283	11447	210	24%	0.8%	1.8%	$18	1,383	2,133	13	0.9%	0.6%	$6	$12	231	-25	206	16	-25	-10
R2000 without A/C	PSC	372	-	9894						1,370	2,120											
	ECM	222	-	9744	150	40%	N/A	1.5%	$13	1,383	2,133	13	0.9%	0.6%	$6	$7	165	-25	139	11	-25	-14
Typical New with	PSC	1012	1230	11806						2,258	3,031											
A/C	ECM	720	1219	11503	303	29%	0.9%	2.6%	$26	2,278	3,050	20	0.9%	0.6%	$9	$17	333	-38	295	22	-38	-16
Typical New without	PSC	610	-	10132						2,258	3,031											
A/C	ECM	366	-	9888	244	40%	N/A	2.4%	$21	2,278	3,050	20	0.9%	0.6%	$9	$12	268	-38	230	18	-38	-20
Typical Existing with	PSC	1079	949	10845						3,460	4,234											
A/C	ECM	737	940	10495	350	32%	0.9%	3.2%	$30	3,481	4,255	21	0.6%	0.5%	$9	$20	385	-41	344	26	-41	-15
Typical Existing	PSC	751	-	9511						3,460	4,234											
without A/C	ECM	447	-	9207	304	40%	N/A	3.2%	$26	3,481	4,255	21	0.6%	0.5%	$9	$16	334	-41	293	22	-41	-18
Typical Row with	PSC	869	1009	9576						1,469	2,141											
A/C	ECM	653	995	9346	230	25%	1.4%	2.4%	$19	1,483	2,155	14	1.0%	0.7%	$6	$13	253	-27	226	17	-27	-10
Typical Row without	PSC	399	-	8064						1,469	2,141											
A/C	ECM	238	-	7903	160	40%	N/A	2.0%	$14	1,483	2,155	14	1.0%	0.7%	$6	$7	176	-27	149	12	-27	-15
Row, 1/3 HP with	PSC	567	851	9116						1,480	2,152											
A/C	ECM	425	844	8967	150	25%	0.9%	1.6%	$13	1,490	2,162	9	0.6%	0.4%	$4	$9	164	-18	146	11	-18	-7
Row, 1/3 HP without	PSC	272	-	7937						1,480	2,152											
A/C	ECM	163	-	7828	109	40%	N/A	1.4%	$9	1,490	2,162	9	0.6%	0.4%	$4	$5	120	-18	102	8	-18	-10

Table F15. HOT2000 Projections of ECM Effects for Ottawa: No Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0845 \$/kWh, Natural Gas: 0.4494 \$/m^e, including taxes.

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-tricity	Nat Gas	Net	Elec-tricity	Nat Gas	Net
						Fan	A/C	Total					Furn	Total								
R2000 with A/C	PSC	703	827	11103						1377	2,162											
	ECM	525	815	10913	190	25%	1.4%	1.7%	$17	1,390	2175	13	0.9%	0.6%	$6	$10	209	-25	184	40	-25	15
R2000 without A/C	PSC	327	-	9850						1,377	2,162											
	ECM	196	-	9718	132	40%	N/A	1.3%	$12	1,390	2,175	13	0.9%	0.6%	$6	$5	145	-25	120	28	-25	3
Typical New with	PSC	834	728	11148						2,172	2,960											
A/C	ECM	585	718	10889	259	30%	1.4%	2.3%	$23	2,190	2,979	18	0.8%	0.6%	$9	$14	285	-35	249	55	-35	20
Typical New without	PSC	525	-	10047						2,172	2,960											
A/C	ECM	313	-	9836	212	40%	N/A	2.1%	$19	2,190	2,979	18	0.8%	0.6%	$9	$10	233	-35	198	45	-35	10
Typical Existing with	PSC	979	566	10384						3,010	3,798											
A/C	ECM	656	558	10052	332	33%	1%	3.2%	$30	3,037	3,825	26	0.9%	0.7%	$13	$16	365	-51	313	71	-51	19
Typical Existing	PSC	730	-	9490						3,010	3,798											
without A/C	ECM	436	-	9196	294	40%	N/A	3.1%	$26	3,037	3,825	26	0.9%	0.7%	$13	$13	323	-51	272	63	-51	11
Typical Row with	PSC	697	653	9069						1,521	2,205											
A/C	ECM	509	643	8872	198	27%	1.6%	2.2%	$18	1,536	2,220	15	1.0%	0.7%	$7	$10	217	-29	189	42	-29	13
Typical Row without	PSC	369	-	8034						1,521	2,205											
A/C	ECM	221	-	7886	148	40%	N/A	1.8%	$13	1,536	2,220	15	1.0%	0.7%	$7	$6	163	-29	134	32	-29	3
Row, 1/3 HP with	PSC	457	537	8714						1,533	2,217											
A/C	ECM	333	532	8585	129	27%	1.0%	1.5%	$12	1,543	2,227	10	0.6%	0.4%	$5	$7	142	-19	123	27	-19	8
Row, 1/3 HP without	PSC	252	-	7917						1,533	2,217											
A/C	ECM	151	-	7816	101	40%	N/A	1.3%	$9	1,543	2,227	10	0.6%	0.4%	$5	$4	111	-19	92	21	-19	2

Table F16. HOT2000 Projections of ECM Effects for Moncton: No Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0896 $/kWh, Natural Gas: 0.5073 $/m³, including taxes.

House Type	Furnace Motor	Electricity								Natural Gas						Net	GHG Reductions (kg CO_2/y)					
		Fan	A/C	Total	Savings due to ECM					Furnace	Total	Increase due to ECM				Savings	Based on Coal			Based on Prov. Mix		
		kWh/y	kWh/y	kWh/y	kWh/y	% of			$/y	m^3/y	m^3/y	m^3	% of		$/y	$/y	Elec-tricity	Nat Gas	Net	Elec-tricity	Nat Gas	Net
						Fan	A/C	Total					Furn	Total								
R2000 with A/C	PSC	703	827	11103						1227	2,012											
	ECM	525	815	10913	190	25%	1.4%	1.7%	$17	1,239	2,024	11	0.9%	0.6%	$6	$11	209	-22	186	40	-22	18
R2000 without A/C	PSC	327	-	9849						1,227	2,012											
	ECM	196	-	9718	132	40%	N/A	1.3%	$12	1,239	2,024	11	0.9%	0.6%	$6	$6	145	-22	122	28	-22	6
Typical New with	PSC	834	728	11148						1,936	2,724											
A/C	ECM	585	718	10889	259	30%	1.4%	2.3%	$23	1,952	2,740	16	0.8%	0.6%	$8	$15	285	-31	253	55	-31	24
Typical New without	PSC	525	-	10047						1,936	2,724											
A/C	ECM	313	-	9835	212	40%	N/A	2.1%	$19	1,952	2,740	16	0.8%	0.6%	$8	$11	233	-31	202	45	-31	14
Typical Existing with	PSC	979	566	10384						2,683	3,471											
A/C	ECM	656	558	10052	332	33%	1%	3.2%	$30	2,707	3,495	24	0.9%	0.7%	$12	$18	365	-46	319	71	-46	25
Typical Existing	PSC	730	-	9490						2,683	3,471											
without A/C	ECM	436	-	9196	294	40%	N/A	3.1%	$26	2,707	3,495	24	0.9%	0.7%	$12	$14	323	-46	278	63	-46	17
Typical Row with	PSC	697	653	9069						1,356	2,040											
A/C	ECM	509	643	8872	198	27%	1.6%	2.2%	$18	1,369	2,053	13	1.0%	0.6%	$7	$11	217	-26	192	42	-26	16
Typical Row without	PSC	369	-	8034						1,356	2,040											
A/C	ECM	221	-	7886	148	40%	N/A	1.8%	$13	1,369	2,053	13	1.0%	0.6%	$7	$7	163	-26	138	32	-26	6
Row, 1/3 HP with	PSC	457	537	8714						1,366	2,050											
A/C	ECM	333	532	8585	129	27%	1.0%	1.5%	$12	1,375	2,059	9	0.6%	0.4%	$4	$7	142	-17	125	27	-17	10
Row, 1/3 HP without	PSC	252	-	7917						1,366	2,050											
A/C	ECM	151	-	7816	101	40%	N/A	1.3%	$9	1,375	2,059	9	0.6%	0.4%	$4	$5	111	-17	94	21	-17	4

Table F17. HOT2000 Projections of ECM Effects for Moncton: No Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0896 \$/kWh, Natural Gas: 0.5073 \$/m³, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Electricity: Savings due to ECM kWh/y	Savings due to ECM % of Fan	Savings due to ECM % of A/C	Savings due to ECM % of Total	Savings due to ECM $/y	Natural Gas: Furnace m³/y	Natural Gas: Total m³/y	Natural Gas: Increase due to ECM m³	Increase due to ECM % of Furn	Increase due to ECM % of Total	Increase due to ECM $/y	Net Savings $/y	GHG Reductions (kg CO_2/y) Based on Coal: Electricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Electricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	956	1133	11652						1,886	2,692											
	ECM	713	1117	11394	258	25%	1.4%	2.2%	$14	1,903	2,710	17	0.9%	0.6%	$6	$8	284	-33	251	3	-33	-31
R2000 without A/C	PSC	452	-	9974						1,886	2,692											
	ECM	270	-	9792	182	40%	N/A	1.8%	$10	1,903	2,710	17	0.9%	0.6%	$6	$4	200	-33	167	2	-33	-32
Typical New with	PSC	1115	1096	11783						2,708	3,514											
A/C	ECM	797	1082	11451	333	29%	1.3%	2.8%	$19	2,733	3,540	25	0.9%	0.7%	$9	$9	366	-49	317	4	-49	-45
Typical New	PSC	653	-	10175						2,708	3,514											
A/C	ECM	389	-	9912	264	40%	N/A	2.6%	$15	2,733	3,540	25	0.9%	0.7%	$9	$6	290	-49	242	3	-49	-46
Typical Existing	PSC	1196	949	10957						3,325	4,133											
A/C	ECM	826	938	10523	434	31%	1.1%	4.0%	$24	3,352	4,161	27	0.8%	0.7%	$10	$14	477	-53	424	5	-53	-48
Typical Existing	PSC	802	-	9562						3,325	4,133											
without A/C	ECM	479	-	9239	323	40%	N/A	3.4%	$18	3,352	4,161	27	0.8%	0.7%	$10	$8	356	-53	303	3	-53	-50
Typical Row with	PSC	822	917	9442						1,600	2,300											
A/C	ECM	616	905	9223	219	25%	1.3%	2.3%	$12	1,615	2,315	15	0.9%	0.7%	$6	$7	241	-30	211	2	-30	-27
Typical Row	PSC	386	-	8051						1,600	2,300											
A/C	ECM	230	-	7895	155	40%	N/A	1.9%	$9	1,615	2,315	15	0.9%	0.7%	$6	$3	171	-30	141	2	-30	-28
Row, 1/3 HP with	PSC	572	833	9107						1,612	2,312											
A/C	ECM	432	825	8959	148	25%	1.0%	1.6%	$8	1,622	2,323	10	0.6%	0.4%	$4	$5	163	-20	143	2	-20	-18
Row, 1/3 HP	PSC	263	-	7928						1,612	2,312											
A/C	ECM	158	-	7823	105	40%	N/A	1.3%	$6	1,622	2,323	10	0.6%	0.4%	$4	$2	116	-20	96	1	-20	-19

Table F18. HOT2000 Projections of ECM Effects for Winnipeg: No Continuous Circulation with Mid-Efficiency Furnaces.
Energy Costs: Electricity: 0.0559 $/kWh, Natural Gas: 0.3696 $/m³, including taxes.

House Type	Furnace Motor	Electricity: Fan kWh/y	Electricity: A/C kWh/y	Electricity: Total kWh/y	Electricity: Savings due to ECM kWh/y	Savings due to ECM % of Fan	Savings due to ECM % of A/C	Savings due to ECM % of Total	Electricity $/y	Natural Gas: Furnace m³/y	Natural Gas: Total m³/y	Increase due to ECM m³	Increase due to ECM % of Furn	Increase due to ECM % of Total	Natural Gas $/y	Net Savings $/y	GHG Reductions (kg CO_2/y) Based on Coal: Electricity	Based on Coal: Nat Gas	Based on Coal: Net	Based on Prov. Mix: Electricity	Based on Prov. Mix: Nat Gas	Based on Prov. Mix: Net
R2000 with A/C	PSC	956	1133	11652						1,681	2,487											
	ECM	713	1117	11394	258	25%	1.4%	2.2%	$14	1,696	2,503	15	0.9%	0.6%	$6	$9	284	-30	254	3	-30	-27
R2000 without A/C	PSC	452	-	9974						1,681	2,487											
	ECM	270	-	9792	182	40%	N/A	1.8%	$10	1,696	2,503	15	0.9%	0.6%	$6	$5	200	-30	170	2	-30	-28
Typical New with	PSC	1115	1096	11783						2,414	3,220											
A/C	ECM	797	1082	11451	333	29%	1.3%	2.8%	$19	2,436	3,243	22	0.9%	0.7%	$8	$10	366	-43	323	4	-43	-40
Typical New without	PSC	653	-	10175						2,414	3,220											
A/C	ECM	390	-	9912	263	40%	N/A	2.6%	$15	2,436	3,243	22	0.9%	0.7%	$8	$6	289	-43	246	3	-43	-41
Typical Existing with	PSC	1196	949	10957						2,964	3,772											
A/C	ECM	826	938	10576	381	31%	1.1%	3.5%	$21	2,988	3,797	24	0.8%	0.6%	$9	$12	419	-47	372	4	-47	-43
Typical Existing	PSC	802	-	9562						2,964	3,772											
without A/C	ECM	479	-	9239	323	40%	N/A	3.4%	$18	2,988	3,797	24	0.8%	0.6%	$9	$9	356	-47	308	3	-47	-44
Typical Row with	PSC	822	917	9442						1,426	2,126											
A/C	ECM	616	905	9223	219	25%	1.3%	2.3%	$12	1,439	2,140	14	0.9%	0.6%	$5	$7	241	-27	214	2	-27	-24
Typical Row without	PSC	386	-	8051						1,426	2,126											
A/C	ECM	230	-	7895	155	40%	N/A	1.9%	$9	1,439	2,140	14	0.9%	0.6%	$5	$4	171	-27	144	2	-27	-25
Row with 1/3 HP	PSC	572	833	9107						1,436	2,137											
motor with A/C	ECM	432	825	8959	148	25%	1.0%	1.6%	$8	1,445	2,146	9	0.6%	0.4%	$3	$5	163	-18	145	2	-18	-16
Row with 1/3 HP	PSC	263	-	7928						1,436	2,137											
motor without A/C	ECM	158	-	7823	105	40%	N/A	1.3%	$6	1,445	2,146	9	0.6%	0.4%	$3	$3	116	-18	98	1	-18	-17

Table F19. HOT2000 Projections of ECM Effects for Winnipeg: No Continuous Circulation with High-Efficiency Furnaces.
Energy Costs: Electricity: 0.0559 \$/kWh, Natural Gas: 0.3696 \$/m³, including taxes.

References, Appendix F

1. Gusdorf, J, *et. al.*, 1999. *Revised Canadian Housing Archetypes for Greenhouse Gas Forecasts*, The Buildings Group, Natural Resources Canada, Ottawa.

2. National Energy Use Database, 1997. *Survey of Houses built in Canada in 1994.* Natural Resources Canada, Ottawa.