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RESEARCH REPORT

FINAL REPORT

CORRIDOR AIR VENTILATION SYSTEM ENERGY USE IN MULTI-UNIT RESIDENTIAL BUILDINGS

CMHC SCHL

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FINAL REPORT

CORRIDOR AIR VENTILATION SYSTEM ENERGY USE IN MULTI-UNIT RESIDENTIAL BUILDINGS

Prepared for

RESEARCH DIVISION
CANADA MORTGAGE AND HOUSING CORPORATION

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UNIES LTD.

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Abstract

A field test protocol to assess the heating season energy impact of operating corridor ventilation systems was developed and successfully applied to five multi-unit residential buildings (MURBs) in Winnipeg. The protocol was straightforward and inexpensive to apply. The data analyses, done in a spreadsheet computer program, revealed a similar relationship between energy use and operation of the corridor ventilation system for all five MURBs. Operating corridor ventilation systems resulted in increases in heating season energy use equivalent to the energy needed to heat 60 to 90% of the amount of air supplied by the corridor ventilation systems. This increase was considerably more than had been anticipated, indicating that operating corridor ventilation air supply systems does not displace as much infiltration as had been expected.

Acknowledgements

This study was prepared for the Research Division of Canada Mortgage and Housing Corporation. The project team acknowledges the support of Duncan Hill, P.Eng., Project Manager, for his significant contributions to the direction of the project and for his useful editorial and technical comments on project reports.

The project team also acknowledges the support provided by Harry Schroeder, P.Eng., and the Manitoba Housing Authority, for identifying candidate buildings with cooperative and capable staff and for providing introductions to those staff. The project team would like to thank Anna Perreault, Anton Zakrewsky, Glen Grotke, Jean Paul and Rose Rousset, building operators whose cooperation in operating the corridor ventilation systems and recording meter readings made this project possible.

Bert Phillips, P.Eng. of UNIES Ltd., project manager and principal researcher, developed field test protocols, performed building investigations and analysis, managed data collection and prepared project reports.

Executive Summary

Canada Mortgage and Housing Corporation (CMHC) funded this study to expand knowledge about the energy impact of operating ventilation systems that pressurize corridors in multi-unit residential buildings (MURBs). In the winter of 1997/98, a field test protocol to assess the impact of corridor ventilation system operation was developed and tested on a MURB. Building energy use was monitored with the corridor ventilation system operating one winter night and off the following night. This process was repeated over a range of temperatures. The tests provided real data on the energy impact of operating corridor ventilation systems. Monitoring data were compared with predictions from a computer model. The computer model proved not to be a useful tool for assessing the impacts of corridor ventilation on infiltration or building energy use. In the winter of 1998/99, the field protocol was tested on another four buildings to assess its applicability to buildings with different energy systems.

Data analysis focussed on time periods between midnight and early morning, when the impacts of solar gains and day-to-day variation in DHW loads and occupant activities (cooking, cleaning, clothes drying, weekends, holidays, etc.) were assumed to be minimized. Linear regression was applied to each data set (i.e., the fans-on data and the fans-off data) to mathematically define the relationships between outdoor temperature and energy use in each building.

The field protocol was relatively straightforward and inexpensive to apply and could be done without use of expensive or high-tech monitoring equipment. The data analyses, done in a spreadsheet computer program, showed very good correlation between outdoor temperature and whole-building energy use and distinct relationships for the "fan on" and "fan off" operating condition. Observations made on the five study buildings were sufficiently similar to allow for general conclusions to be drawn about the impact of operating corridor ventilation systems on building energy use and whole-building air change rates.

The observed increase in whole building energy use when the corridor ventilation systems were operated in the study buildings ranged from 60 to 90% of energy that would be required to condition the corridor ventilation system air flow. This energy increase was much bigger than expected, based on a fundamental analysis of the buildings. This leads to the conclusion that operating corridor ventilation systems does not appreciably increase indoor-to-outdoor pressure differentials across suite walls so does not displace significant amounts of infiltration.

Turning the corridor ventilation system off did not result in complaints about air quality during cold weather, but did when temperatures were above freezing. As such, turning corridor ventilation systems off may be an effective strategy for reducing energy consumption and peak energy demand during very cold weather.

Résumé

La Société canadienne d'hypothèques et de logement (SCHL) a financé cette recherche dans le but d'en savoir davantage sur l'incidence en matière de consommation d'énergie du fonctionnement des systèmes de ventilation qui pressurisent les corridors des bâtiments résidentiels collectifs. Au cours de l'hiver 1997-1998, un protocole d'essais sur place visant à évaluer l'incidence du fonctionnement du système de ventilation des corridors a été élaboré et testé dans des bâtiments résidentiels collectifs. La consommation énergétique des bâtiments a fait l'objet d'un contrôle, alors que le système fonctionnait une nuit d'hiver sur deux. Cette procédure a été répétée à des températures différentes. Les essais ont permis de recueillir des données réelles sur l'incidence énergétique du fonctionnement de systèmes de ventilation des corridors. Les données de contrôle ont été comparées aux prévisions d'un modèle informatique. Par contre, le modèle informatique ne s'est pas révélé un outil très utile pour évaluer l'incidence de la ventilation des corridors sur les infiltrations ou la consommation énergétique des bâtiments. Au cours de l'hiver 1998-1999, le protocole d'essais sur place a été testé sur quatre autres bâtiments pour vérifier son adaptabilité à des bâtiments équipés de différents systèmes énergétiques.

L'analyse des données a porté sur des périodes s'étendant de minuit jusqu'à tôt le matin, alors que l'on présumait que l'incidence des gains solaires et les fluctuations quotidiennes de la charge des chauffe-eau domestiques et des activités des occupants (cuisson, nettoyage, séchage des vêtements, fins de semaine, jours fériés, etc.) était réduite. Une équation de régression linéaire a été appliquée à tous les jeux de données (alors que les ventilateurs fonctionnaient et alors qu'ils ne fonctionnaient pas) pour définir par une formule mathématique les rapports existant entre la température extérieure et la consommation énergétique de chaque bâtiment.

Le protocole d'essais sur place était assez simple et peu coûteux à appliquer, de sorte qu'il pouvait être exploité sans devoir recourir à du matériel de contrôle de haute technologie coûteux. Les analyses de données, effectuées à l'aide d'un tableur électronique, ont permis d'établir d'excellentes corrélations entre la température extérieure et la consommation énergétique dans l'ensemble du bâtiment de même que des rapports distincts selon que le ventilateur fonctionnait ou pas. Les observations faites à l'égard des cinq bâtiments à l'étude se ressemblaient suffisamment pour permettre de tirer des conclusions générales quant à l'incidence du fonctionnement des systèmes de ventilation des corridors sur la consommation énergétique du bâtiment et le renouvellement d'air dans l'ensemble du bâtiment.

L'accroissement observé de la consommation globale d'énergie alors que les systèmes de ventilation des corridors fonctionnaient dans les bâtiments à l'étude variait entre 60 et 90 % de la quantité requise pour conditionner le mouvement d'air des systèmes de ventilation des corridors. Cette augmentation de la consommation d'énergie était beaucoup forte que ce qui avait été prévu, d'après une analyse fondamentale des bâtiments. Cela porte à conclure que le fonctionnement des systèmes de ventilation des corridors ne fait pas augmenter de façon appréciable les différences de pression entre l'intérieur et l'extérieur agissant sur les murs des appartements, pas qu'il qu'il n'entraîne d'infiltrations importantes.

Le fait de ne pas faire fonctionner le système de ventilation du corridor n'a pas donné lieu à des plaintes au sujet de la qualité de l'air par temps froid, mais ce fut différent alors que les températures voisinaient le point de congélation. Ainsi, fermer le système de ventilation des corridors peut constituer une mesure efficace d'économie d'énergie et de réduction de la demande d'énergie de pointe par temps très froid.

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Table of Contents

List of Figures

List of Tables

Introduction

Ventilation systems that pressurize corridors in multi-unit residential buildings (MURBs) probably reduce infiltration and increase exfiltration; however, we do not have the understanding necessary to fully evaluate the impact of operating corridor ventilation systems on design condition energy loads or annual energy use. Canada Mortgage and Housing Corporation (CMHC) funded the development of a protocol to assess the impact of the operation of building corridor ventilation systems on energy consumption in MURBs and to utilize this protocol to characterize the relative impacts of mechanical ventilation and related infiltration on energy consumption in MURBs.

The normally considered factors which influence infiltration, exfiltration and related building energy usage are wind, stack effect (i.e., indoor-to-outdoor temperature difference), flue effect, mechanical ventilation system operation, and envelope airtightness. Also important but often overlooked is the degree of compartmentalization in the building (i.e., corridor-to-suite airtightness, suite-to-suite airtightness and floor-to-floor airtightness, referred to as the thermal draft coefficient), the operation of windows and local exhausts by occupants, the distribution of air leakage paths between compartments and through the exterior envelope, the flow characteristics of air leakage through the envelope, the location of the neutral pressure plane, the impact of the dynamic wall effect on heat loss, the distribution of outdoor temperatures during the heating (and cooling) seasons (not just degree days) and internal heat gains.

A complicating factor to estimating the annual impact of corridor ventilation on whole-building energy use is the fact that the balance point temperature for the building varies with wind, solar heat gains and occupant activities, and it will be different with the corridor ventilation system on than it is with the corridor ventilation system off.

In order to be effective, a protocol to assess the impact of corridor ventilation on energy use in MURBs must factor in all these influences. Two approaches to study the impact of corridor ventilation on overall building energy usage were proposed. The first involved monitoring building energy use during a series of corridor ventilation system fan-on/fan-off tests. The fan-on/fan-off tests provided real data on the energy impact of operating corridor ventilation in the study building.

The second method proposed the use of a computer model to estimate the impact of corridor ventilation on building energy use. An effective computer model would be faster and less costly to apply than field monitoring and its application would not be weather dependent. As such, it could be an effective tool for Heating, Ventilating and Air-Conditioning (HVAC) system designers and decision makers trying to evaluate the economics of air sealing MURBs and operating corridor (or other) ventilation systems.

This project was undertaken in two phases. In the first phase, a field test protocol to assess the impact of the operation of building corridor air ventilation systems on energy consumption was developed and tested on a single building. The field monitoring results were compared with predictions from a computer model in order to assess the usefulness of the computer model. In the second phase, the protocol was applied to four other buildings to assess its applicability to other building sizes and with other fuel sources. Computer modelling done for the first building indicated that the computer model was not a useful tool for assessing the impact of corridor ventilation on either infiltration or building energy use, so computer modelling was not done in the second phase.

Field Test Protocol for Assessing the Energy Impact of Corridor Ventilation in MURBs

1. Overview

The objective of the protocol was to gather information which would facilitate an assessment of the impact of the operation of building corridor ventilation systems on energy consumption in MURBs.

In this method, building energy use was monitored with the corridor ventilation system operating one winter night and with it turned off the following night. This process was repeated over a range of temperatures. Data analysis focussed on time periods when the impact of occupant activity and solar loads on energy use are minimized, that is between midnight and early morning, when it can be reasonably assumed that the impacts of solar gains and day-to-day variation in DHW loads and occupant activities (cooking, cleaning, clothes drying, weekends, holidays, etc.) are minimized and that almost all other energy used in the building offsets space heating. Linear regression was applied to each data set (i.e., the fans-on data and the fans-off data) to mathematically define the relationships between outdoor temperature and energy use. The following is a more detailed description of the tasks involved in applying the protocol to any given building.

1.1 Task 1 - Qualify the Test Building

Building attributes must be evaluated to ensure there is a reasonable probability that the data gathered will be meaningful. The building evaluation should include the following:

- assess the building's energy systems to ensure systems are functioning properly. Check that corridor ventilation system intake air dampers close properly;
- ensure that necessary energy consumptions can be measured or estimated for each monitoring period. Necessary energy consumptions: are used within the building; vary with outdoor temperatures; and impact space heating loads;
- check for factors which may negate the validity of test results (e.g., other buildings operated on the same heating systems or served by the same energy meters);
- measure corridor ventilation air flows at the supply fan and to each floor and exhaust air flows from the building. Compare these to design air flows and estimate corridor ventilation heat loads;
- based on a review of building plans and specs, estimate design condition skin heat losses. If corridor ventilation heating load is estimated to be less than 10% of skin losses, corridor ventilation load may get lost in the noise of the whole-building energy use;
- assess occupant schedules to determine when occupant activities and other variable, diurnal energy loads are minimized (i.e., time of night, days of week).

1.2 Task 2 - Select and Apply Data Acquisition Method

Select a data acquisition method appropriate for the application. Acceptable methods range from manually reading building energy meters at the start and end of each monitoring period, through to application of fully automated data acquisition systems. Essential to the success of the method is the ability to measure whole-building energy use and average outdoor temperatures during time periods when all energy being used in the building offsets (but does not exceed) space heating loads and there are no solar heat gains.

It is necessary to account for energy loads included in the measured readings which do not contribute to heating the building. Non-contributing loads may include, but are not restricted to, outdoor lighting, parking plugs, heated parking or out-buildings, and combustion equipment flue losses.

DHW which goes to a drain is a non-contributing load which does not readily lend itself to measurement. However, by selecting test periods between late night and early morning, it may be assumed that DHW heat loss variations from test period to test period are modest. In buildings with central DHW heating, water or energy use by the DHW system may be monitored and day-to-day variations in use factored into the energy calculations.

Determining energy use in all-electric, resistance-heated buildings is straightforward as there is no need to account for energy conversion efficiencies. If the objective is to estimate the impact of corridor ventilation on purchased energy costs or quantities (i.e., quantification of actual heat losses is not critical), assessing the impact of corridor ventilation on purchased energy use can be done without accounting for equipment performance characteristics. Estimating infiltration from energy use requires estimating heat delivery rates so performance parameters of heat pumps, heat exchangers and fuel-fired heating appliances must be known or estimated to accommodate infiltration calculations.

Data should be recorded in a format that can be averaged over intervals of not less than four hours. Short-term energy use is highly variable; longer averaging periods smooth out short-term variations and reduce the relative magnitude of meter reading errors, but they hide demand peaks.

1.3 Task 3 - Monitor Building

Operate the corridor ventilation system one night on, one night off. This procedure is repeated over a temperature range of at least 20°C, starting at temperatures near typical winter lows, but not extending above average temperatures of +10°C. Somewhere above +5°C, appliance loads will exceed heat losses. Above this temperature, the linear relationship between outdoor temperature and building energy use observed at lower temperatures is no longer valid.

Appropriate monitoring periods may vary with the nature of building occupants' schedules. In seniors' residences, occupants may shut down before midnight and rise after dawn. In apartments serving mill towns, a significant fraction of the occupants may be active before and after shift changes. Weekend schedules may differ from weekday schedules. Monitoring periods (i.e., the time between start and finish times for the meter readings) need to reflect the particularities of the schedules of the building's occupants.

Periodically check to ensure the data acquisition system and fans are operating correctly. The minimum information required for each monitoring period is start and stop times, energy use (or a means of estimating energy use), and average outdoor temperatures.

1.4 Task 4 - Analyse Data

The primary intent of this project was to develop a method to estimate the impact of operating corridor ventilation systems on net air change rates and hence on annual heating costs. Energy demand with corridor ventilation system operating and with corridor ventilation system turned off is plotted against outdoor temperature to determine an appropriate upper limit for outdoor temperature. At temperatures above the balance point outdoor temperature, building energy use is not related to outdoor temperature. Linear regression analysis is used on the data below the balance point temperature to identify the relationships between energy use and outdoor temperature with the corridor ventilation system operating and with the corridor ventilation system off.

The difference between these two relationships (i.e., temperature versus energy demand with the corridor ventilation system fans on and with them off) represents the impact of corridor ventilation on whole-building energy use. The relationships or the difference between relationships can be used in conjunction with outdoor temperature data to estimate the impact on overall air change rates and to provide a conservative estimate of the annual impact of corridor ventilation on heating costs. A procedure for doing this is outlined below. This procedure is described in more detail and demonstrated with an example in Appendix C. The results from applying this procedure to the five project test buildings are presented in the section of the report titled Data Analysis.

2. Estimating the Impact on Ventilation

Step 1) Determine equations which define the relationship between outdoor temperatures and nighttime energy use for the "fan-on" and "fan-off" operating condition, for each heating source used in the building.

Step 2) Determine corridor ventilation system air flows and any other air flows which are switched on and off as part of the application of the field test protocol.

Step 3) Use the equations which define the relationship between outdoor temperatures and nighttime energy use to estimate energy use rates for each energy source for the "fans-on" and "fans-off" operating conditions for each temperature (or temperature bin) of interest.

Step 4) Correct for energy system conversion efficiency and heat recovery system contributions in order to estimate heat delivery from each energy source for each temperature bin.

Step 5) Assuming the changes in heat delivery calculated in Step 4 are related to changes in the air change rate in the building, estimate the changes in air change rate in each temperature bin by applying and solving one of the following equations:

Heat flow rate (watts) = 1.2 x temperature difference (°C) x air flow rate (L/s)
Heat flow rate (Btuh) = 1.08 x temperature difference (°F) x air flow rate (cfm)

Step 6) To express the change in air change rate as a fraction of corridor ventilation, calculate the ratio of the net change in air change rate calculated in Step 5 relative to the measured air flow rate for the corridor ventilation system determined in Step 2.

3. Impact on Energy Use and Energy Costs

Step 1) See Step 1 in Estimating Impact on Ventilation above.

Step 2) Obtain Annual Temperature Data - temperature bin data was used in this study. Hourly or average daily temperatures would also be suitable for this application.

Step 3) Estimate Energy Requirements at Temperatures of Interest - at each temperature which is of interest, use the energy use equations to estimate heat flow rates for each energy form for the fans-on and the fans-off operating conditions.

Step 4) Estimate Heating Season Energy Impact - for temperatures below the cutoff temperature, the products of energy use at specific outdoor temperatures, determined in Step 1, and time spent at that temperature, determined from the temperature data referenced in Step 2, are summed to determine the total for the heating season. Separate calculations should be done for each energy source if the cost impact is of interest.

Step 5) Apply Energy Cost to Determine Energy Cost Impact - apply unit energy prices to the estimated annual energy changes to estimate the cost impact of operating the corridor ventilation system. This was done in Table 3.

Considerations in Applying the Field Test Protocol

The application of the protocol indicated that the energy impact of corridor ventilation can be defined from whole-building energy demand or consumption and outdoor temperatures if solar heat gains and occupant impacts on energy use are small and outdoor temperatures are below the balance point temperature for the building. Fan-on and fan-off performance equations can be determined by applying linear regression to the field data.

Data acquisition systems can collect energy use data at very small time intervals. The result is a huge volume of highly scattered data. In this study, longer (e.g., overnight) recording intervals proved to be practical. Analysis of hourly data in this project indicated that monitoring periods starting between 11 pm and midnight, and ending at 7 am, worked as well or better than four-hour monitoring periods. Shorter monitoring periods resulted in more highly scattered data. Thus, manually recording energy meter readings and times at the start and end of each monitoring period is a practical alternative to using automated data acquisition systems.

Outdoor or extraneous energy use (e.g., car plugs, heated parking, site lighting, etc.) and heating equipment performance characteristics should be taken into account in the calculations.

It appears that this procedure is only applicable in cold weather. As such, its application is restricted to winter months and so will be geographically restricted (e.g., it may not be applicable in areas such as the BC lower mainland). The data collected can be utilized to estimate the impact of corridor ventilation on heating energy, but it may be quite complex to estimate the impact of corridor ventilation on air-conditioning costs. Estimating the impact of the operation of corridor ventilation systems on air-conditioning energy use was beyond the scope of this study.

1. The Impact of Heating Balance Point Temperature

A very significant complication to estimating the annual impact of corridor ventilation on whole-building energy use is the fact that the balance point temperature for the building varies with wind, solar heat gains and occupant activities, and will be different with the corridor ventilation system on than it is with the corridor ventilation system off. (Balance point temperature is the outdoor temperature at which internal and solar gains offset heating requirements for a building, that is the lowest temperature at which heat from the building's space heating system is not required to maintain space temperatures.)

Figure 1 shows overnight average energy demand versus outdoor temperature for 505 Munroe, the first test building. Figure 2 shows average energy demand for four-hour time blocks over the entire monitoring period (i.e., day and night). The highest energy demands recorded at an outdoor temperature around -20°C were about double those depicted in Figure 1. Given that daytime energy demand was usually much higher than overnight demand, it may be assumed that some

FIGURE 1

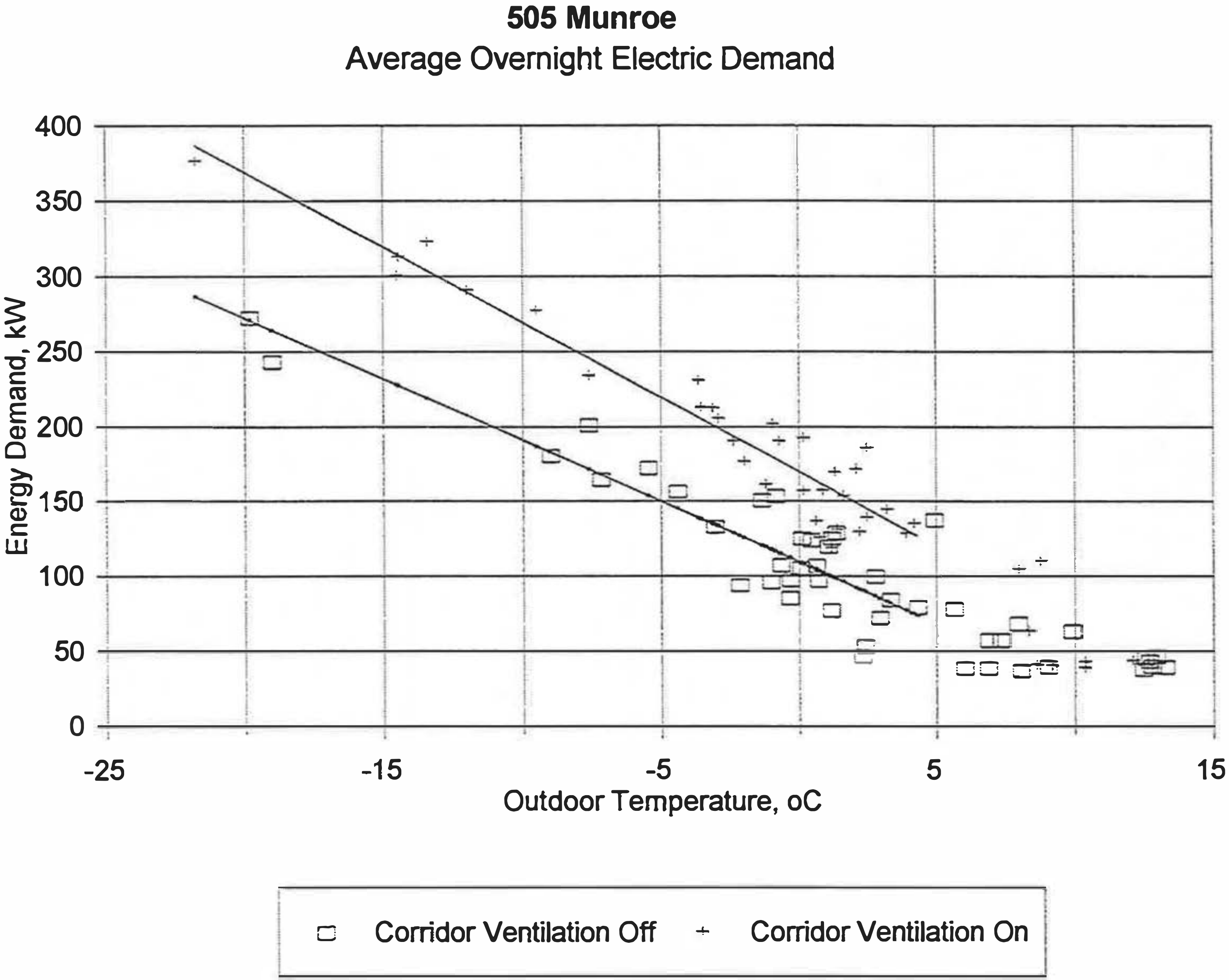
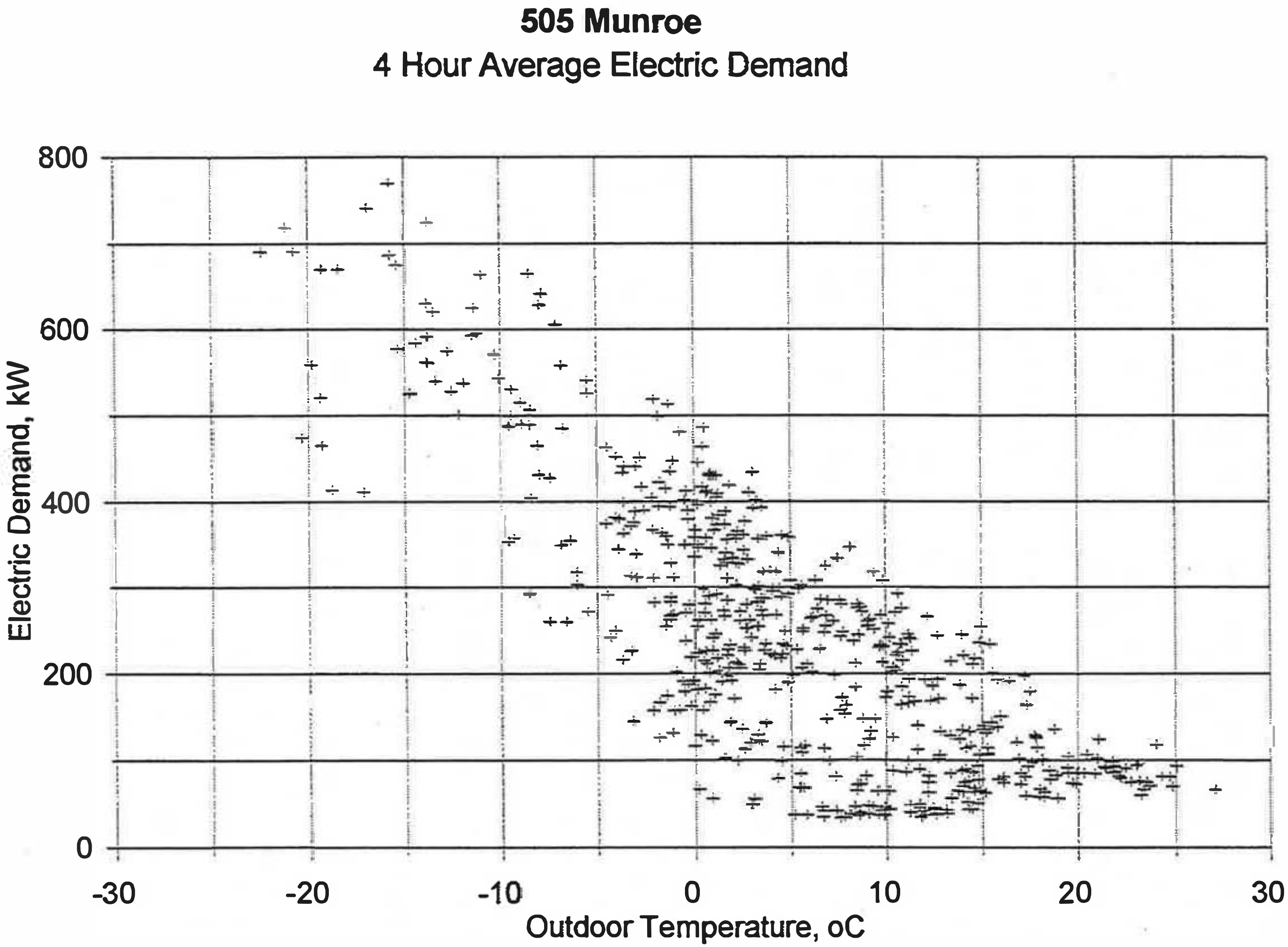

505 Munroe
Average Overnight Electric Demand
Energy Demand, kW
400
350
300
250
200
150
100
50
0
-25
-15
-5
5
15
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

FIGURE 2


505 Munroe
4 Hour Average Electric Demand
Electric Demand, kW
0
200
400
600
800
-30
-20
-10
0
10
20
30
Outdoor Temperature, oC

fraction of daytime energy consumption is converted into useful internal gains, offsetting building heating loads.

Internal heat gains are generally available to offset heating loads due to skin losses and infiltration. In a situation in which internal heat gains significantly exceed whole-building heating requirements, infiltration may be heated by internal gains, if the infiltration occurs in an area of the building with excess heat available. In this situation, heating infiltration air does not represent an added energy cost, and reducing infiltration (e.g., by air sealing the building or by operating the corridor ventilation system) will not provide an energy cost saving. During such times, the energy cost impact of operating the corridor ventilation system will equal the cost of energy directly consumed by the corridor ventilation system to operate the fan motor and heat the ventilation air.

At temperatures below the heating balance point temperature, the fraction of building heat loss (infiltration/exfiltration and envelope heat losses) met by internal heat gains decreases as the outdoor temperature decreases and heat losses increase. The relationships determined for outdoor temperature versus energy consumption on winter nights will under-predict incremental energy costs during periods when internal gains exceed the heating loads from skin losses and infiltration.

2. Impact on Air-Conditioning Loads

Above the balance point heating temperature, internal and solar heat gains can cause buildings to overheat. Ventilation may be used to provide free cooling when outdoor air temperatures are below space temperatures. At outdoor temperatures (or enthalpies) above the thermostat set point for cooling, the whole-building cost of corridor ventilation will be the cost of cooling the corridor ventilation air from outdoor conditions to the thermostat cooling set point temperature less the savings from not cooling infiltration air which is displaced by operating the corridor ventilation system. The relationship between air-conditioning energy use and operation of the corridor ventilation system was beyond the scope of this study, and as such is not dealt with in detail.

3. Defining Balance Point Temperatures

Discussions of balance point temperatures often appear to assume that it is a well-defined point. In fact, most buildings consist of a variety of zones, each with its own balance point temperature at a given point in time. For example, an upper level, south facing apartment in which the occupants are cooking on a sunny day, may have a heating balance point temperature of -25°C; while a ground level, north facing suite, may have a balance point temperature of +10°C. Changing occupant activity levels, appliance loads, adjusting curtain position, a cloud passing in front of the sun, and so on, can alter the balance point of a zone.

Thus, one cannot precisely define a single balance point temperature for an apartment building, even for a very specific outdoor weather condition or at a precise point in time. The excess gains in an upper level suite will not benefit a ground level suite, unless the building has an energy system which is capable of transferring energy from zones with excess gains to those able to use the excess energy. Thus, one cannot precisely estimate the energy impact of operating a corridor ventilation system on a seasonal or annual basis, but one can utilize the above-defined protocol to develop conservative estimates.

Balance point temperature may also be different for different energy systems or energy sources in a building. For example, data collected for the all-electric building at 505 Munroe indicated a nighttime balance point temperature of around 10°C. A balance point temperature was not apparent for gas usage in the three buildings with gas corridor ventilation air heating.

Computer Model

Utilization of a simple air leakage model to predict the impact of corridor ventilation on infiltration and exfiltration patterns and related heating costs was explored in the first phase of the project. The purpose of this task was to determine if the computer model could be easily calibrated to predict the energy impact of operating the corridor ventilation system at 505 Munroe. If agreement between the model and monitored results was reasonable, and the effort to calibrate the model and run the simulations was modest compared to the time and effort required to undertake a series of fan-on/fan-off tests, computer modelling may be a more effective way to study the impact of corridor ventilation systems on building energy use in the future.

The proposed computer routine was developed to estimate the energy benefit of improving air barriers in big buildings from the status quo to levels recommended in the 1995 National Building Code. It is a Basic program, which estimates air leakage for buildings with various characteristics, at various outdoor temperatures. Inputs include building height, width, length, number of storeys, envelope air leakage characteristics, resistance to air flow between floors, annual temperature distribution, windspeed and wind angle. The model goes through an iterative process to close in on the building envelope pressure profiles which balance infiltration, exfiltration and mechanical air flow rates.

1. Calibrating and Running the Model

Calibration of the model required collecting data regarding pressure differentials between floors, air flow capacity of the corridor ventilation system, the impact of the corridor ventilation system on building pressures and location of the neutral pressure plane, and so on, at specific indoor and outdoor conditions. The degree of pressurization and the shift in the level of the neutral pressure plane were interpreted as indicators of building airtightness. Based on these observations, estimates were made for the normalized leakage area of the building at 505 Munroe. After the model was calibrated, energy estimates from simulations were compared to specific results from the fan-on/fan-off tests.

The model was run for three ventilation strategies: i) no corridor make-up air (i.e., exhaust only); ii) 2596 L/s (5500 cfm) corridor make-up air (i.e., similar to the as-operated condition for this building), and; iii) 5191 L/s corridor make-up air (i.e., balanced ventilation). Each strategy had 5191L/s (11 000 cfm) net exhaust, five windspeeds (5, 10, 15, 20 and 30 kph), and seven outdoor air temperatures (-25, -20, -15, -10, -5, 0 and +5°C). The results from the simulations are presented in Table 1. Leakage In and Leakage Out are infiltration and exfiltration across the building envelope (the minus sign indicates exfiltration). Total ACR, the total air change rate in the building, is equal to the sum of the infiltration plus make-up air, which is equal to the sum of exfiltration plus exhaust. Slight differences can be attributed to rounding.

TABLE 1

Exhaust Rate 5191 L/s all cases

Make-up Air Rate		5191 L/s			2596 L/s			0 L/s		
		Balanced Mechanical Ventilation			Ventilation Similar to "As Operated"			Exhaust Only Ventilation		
Wind (KPH)	Temp. (C)	Leakage Out (L/s)	Leakage In (L/s)	Total ACR (L/s)	Leakage Out (L/s)	Leakage In (L/s)	Total ACR (L/s)	Leakage Out (L/s)	Leakage In (L/s)	Total ACR (L/s)
5	-25	-1967	1966	7157	-841	3437	6033	-106	5298	5298
5	-20	-1814	1813	7004	-709	3305	5901	-45	5237	5237
5	-15	-1660	1660	6851	-577	3172	5768	0	5191	5191
5	-10	-1504	1504	6695	-434	3031	5627	0	5191	5191
5	-5	-1345	1345	6536	-310	2906	5502	0	5191	5191
5	0	-1182	1182	6373	-182	2779	5375	0	5191	5191
5	5	-1012	1012	6203	-73	2669	5265	0	5191	5191
10	-25	-1986	1986	7177	-880	3456	6052	-129	5319	5319
10	-20	-1832	1832	7023	-718	3314	5910	-47	5238	5238
10	-15	-1678	1678	6869	-570	3166	5762	-11	5202	5202
10	-10	-1522	1521	6712	-451	3047	5643	0	5191	5191
10	-5	-1362	1362	6553	-315	2911	5507	0	5191	5191
10	0	-1198	1198	6389	-196	2792	5388	0	5191	5191
10	5	-1026	1026	6217	-84	2680	5276	0	5191	5191
15	-25	-2003	2002	7193	-873	3469	6065	-141	5331	5331
15	-20	-1847	1847	7038	-737	3333	5929	-93	5284	5284
15	-15	-1690	1690	6881	-609	3205	5801	-42	5232	5232
15	-10	-1529	1529	6720	-474	3070	5666	-1	5192	5192
15	-5	-1375	1376	6567	-345	2941	5537	0	5191	5191
15	0	-1223	1223	6414	-241	2837	5433	0	5191	5191
15	5	-1059	1059	6250	-161	2757	5353	0	5191	5191
20	-25	-2026	2026	7217	-919	3515	6111	-224	5414	5414
20	-20	-1881	1881	7072	-780	3376	5972	-152	5343	5343
20	-15	-1733	1733	6924	-658	3254	5850	-101	5292	5292
20	-10	-1581	1581	6772	-532	3128	5724	-43	5235	5235
20	-5	-1426	1426	6617	-428	3025	5621	-4	5195	5195
20	0	-1276	1276	6467	-358	2955	5551	0	5191	5191
20	5	-1130	1131	6322	-279	2874	5470	0	5191	5191
30	-25	-2166	2166	7357	-1113	3709	6305	-459	5650	5650
30	-20	-2036	2036	7227	-1014	3610	6206	-388	5579	5579
30	-15	-1903	1903	7094	-943	3539	6135	-314	5505	5505
30	-10	-1772	1772	6963	-869	3465	6061	-236	5427	5427
30	-5	-1667	1667	6858	-793	3389	5985	-169	5360	5360
30	0	-1568	1567	6758	-714	3310	5906	-99	5290	5290
30	5	-1524	1524	6715	-633	3228	5824	-42	5233	5233

2. Analysis of Results

Predictions by the model conformed to intuitive logic. At warmer temperatures and mild windspeeds, a high net exhaust flow rate places the model predicted under a negative pressure and infiltration would predominate. When make-up air was added, it primarily displaced infiltration. Operating the building's corridor ventilation system was predicted to increase Total ACR (air change rate) of the building by about 3% of the increase in corridor ventilation air flow at 5°C and mild winds. Increasing corridor ventilation to equal building exhaust was predicted to increase Total ACR by about 20% over that for the exhaust-only simulation.

At cold temperatures or strong winds or both, stack or wind pressures or both alter pressure regimes, and even at high rates of exhaust, significant portions of the building were predicted to be under positive (exfiltration) pressures. Adding make-up air was predicted to have a more significant impact on Total ACR under these conditions (the increase in Total ACR predicted for 505 Munroe was about 25 to 30% of the increase in corridor ventilation air flow at -25°C, regardless of wind speed, and almost 25% of the increase in corridor ventilation air flow at a windspeed of 30 kph, regardless of outdoor temperature).

Whereas the model conformed to intuitive logic, field monitoring results did not. Compared to the field monitoring results for 505 Munroe, the program underestimated the energy impact of operating the corridor ventilation system. The field monitoring results indicated an average increase in whole-building energy use equivalent to heating 60 to 65% of the corridor ventilation air flow rate, as opposed to the 3 to 30% predicted by the model for that range of outdoor conditions. (An underlying assumption in the analysis in this report is that observed changes in actual building energy use are primarily the result of changes in the air change rate in the building.) We believe that the building is highly compartmentalized, resulting in actual air change rate increases and thus energy use being higher than the model predicted.

These very significant differences between predicted and measured results imply that the current model is not a suitable tool for predicting the impact of corridor ventilation on whole-building air change rates. It may have some use as a research or teaching tool, but would need multi-zone capabilities and very sophisticated inputs and calibration in order to accurately model the energy impact of corridor ventilation in multi-zone buildings. For this reason, the model was not applied to the four buildings tested in the second phase of the project.

Test Building Descriptions

The Manitoba Housing Authority provided apartment buildings from its portfolio for inclusion in this study. The following includes a brief description of each building. Photographs can be found in Appendix A.

1. 505 Munroe

505 Munroe, a 125-suite, 15-storey, all-electric (i.e., electric space heating, DHW heating and corridor ventilation air heating), seniors' building in Winnipeg, was used for the initial application of this protocol. A preliminary assessment of the building was undertaken in early February, 1998. This was the first study building, as such the preliminary assessment was very rigorous. Monitoring was done from February 16 until May 25, 1998.

Building envelope pressures measured with the corridor ventilation fan on and then off indicated that the corridor ventilation system had a significant impact on corridor pressures. At an outdoor temperature of -8°C, the neutral pressure plane between the corridor and the outdoors was near the roof of the building with the ventilation system off and exhaust fans running; corridor-to-outdoor pressure differentials at the second floor level were in the order of 30 Pa infiltrating. With the corridor ventilation fan on, corridor-to-outdoor pressure differentials were 9 Pa exfiltrating near the roof and 21 Pa infiltrating at the second floor level. Suite-to-outdoor pressure differentials with the corridor ventilation system on and with the corridor ventilation system off were about a quarter of the observed corridor-to-outdoor pressure differentials. Suite pressures lower than corridor pressures were expected because the corridor ventilation system pressurizes the corridors while the suites are depressurized by exhaust.

Air flow calculated from a pitot traverse at the corridor ventilation fan was 7100 cfm. Corridor ventilation system air flows measured on each floor using a flow hood varied from 300 to 650 cfm, totalling 5500 cfm, compared to a design supply rate of 700 cfm per floor. Air flow from nine exhaust fans on the roof of the building (measured using a flow hood) totalled 11 100 cfm.

Data loggers were installed on the building's two main power supplies (i.e., a three-phase, 416-volt supply for heating and a three-phase, 208-volt supply which met appliance, lighting and parking plug loads), the parking lot plug circuits and the corridor ventilation system power supply. Winnipeg Airport weather data was used for this building. The building caretaker was contracted to manually turn the corridor ventilation system on and off on alternate nights.

2. Oak Tree Towers

Oak Tree Towers in Portage la Prairie, is a seven-storey, all-electric (i.e., electric space heating, DHW heating and corridor ventilation air heating), seniors' apartment building with 65 suites. The preliminary assessment was done in mid-December and monitoring commenced January 11, 1999.

The corridor ventilation system in this building was slated for a gas retrofit which commenced earlier than expected. Data acquisition ended February 25, 1999 when the retrofit began.

Air flow calculated from a pitot traverse at the corridor ventilation fan was 4226 cfm, after a new fan belt was installed. Prior to belt replacement, air flow was measured at 1543 cfm. Corridor ventilation system air flows measured on each floor using a flow hood totalled 3100 cfm. Air flow from six exhaust fans on the roof of the building (measured using a pitot tube) was estimated at 4350 cfm.

At an outdoor temperature of -12°C, corridor-to-outdoor pressure differentials with the corridor ventilation fans off and building exhausts running were about 6 Pa infiltrating at the seventh floor level and 20 Pa infiltrating at the third floor level. Operating the corridor ventilation system increased corridor-to-outdoor pressure differentials to about 9 Pa exfiltrating at the seventh floor level and 7 Pa infiltrating at the third floor level.

Data loggers were installed on the building's main power supply, the corridor ventilation system power supply and to record outdoor temperatures. The building caretaker was contracted to turn the corridor ventilation system on and off on alternate nights.

3. 185 Smith

185 Smith is a 21-storey, 370-suite apartment building with 18 storeys of residences and three storeys of offices (1, 2 and 21). Gas-fired boilers provide perimeter heat to the building and a gas-fired rooftop make-up air unit provides corridor ventilation to the residential floors. DHW was also heated by gas. Ventilation and cooling for the office floors is provided by all-electric air handling units.

Air flow calculated from a pitot traverse at the corridor ventilation fan was 13 571 cfm. Corridor ventilation system air flows measured on suite floors using a flow hood totalled 9620 cfm. Air flow from thirteen exhaust fans on the roof of the building (measured using a pitot tube) was estimated at 23 740 cfm. The exhaust fans operated continuously.

This building was equipped with a pulse output on the gas meter. A data logger/pulse counter was installed on the gas meter. As well, a live-in building maintenance person was contracted to turn the corridor ventilation system on and off and to record gas and electric meter readings each night and morning. This allowed a comparison of manual and automated data collection alternatives. Manual meter reading was started February 3 and automated data acquisition began February 12, 1999. Meter reading continued through April 30, 1999 except for a one-week period during which the gas meter failed.

4. 388 Kennedy

388 Kennedy is an eight-storey, 54-suite apartment building with electric baseboard heating in suites, gas-fired corridor ventilation systems with heat recovery and gas fired DHW. It has two penthouse mechanical rooms, one serving the north end of the building, the other serving the south. Each mechanical room contained a corridor ventilation fan system, a kitchen and a bathroom fan exhausting continuously from the suites in that wing.

Air flow calculated from pitot traverses for the two corridor ventilation fans was 4983 cfm. Air flow calculated from pitot traverses for the four exhaust fans was 3756 cfm.

The electric service meter in the building has built-in data logging capabilities. The electric utility offered to provide electric energy use data to the project. The gas meter, located outside the building, was not equipped for pulse metering. The caretaker/maintenance man was contracted to switch the corridor ventilation system and manually read the gas and electric meter for this project. Energy monitoring was done on this building between January 13 and April 30, 1999.

5. 303 Goulet

303 Goulet is a 10-storey, 163-suite, seniors' apartment building with gas hot water space heating and a gas-fired rooftop corridor ventilation heating system. The rooftop corridor ventilation system had been recently installed. A recent air balance report for the corridor system was provided by Manitoba Housing. The sum of air flows from the rooftop system delivered to floors 2 through 10 was 6930 cfm. Design air flow for the system was 7965 cfm. Air flow calculated from pitot traverses for nine exhaust fans located on the roof of the building was 9215 cfm. Exhaust fans operated continuously.

Neither the gas nor the electric meters in this building had pulse metering capabilities. The building caretaker was contracted to read the gas meter and switch the corridor ventilation system. Monitoring was done between February 8 and April 30, 1999.

Problems Encountered in Protocol Application

Monitoring in Phase 1 proceeded smoothly. The first building identified by the Manitoba Housing Authority was suitable for the project and identification of what and where to monitor was straightforward. Phase 2 of the project was somewhat more challenging. The study was to include gas/gas and gas/electric heating systems and a mix of building sizes. Much of Manitoba Housing Authority's stock is all-electric. Several candidate buildings were rejected. Some shared energy metering with other buildings; some were judged to be too similar to other study buildings; in others, corridor ventilation system or building characteristics were considered unsuitable for this study.

Delays encountered in qualifying and initiating monitoring in Phase 2 buildings resulted in the November/December, 1998 monitoring window being missed. Winter of 1998/99 in Manitoba was very mild, so there was no very cold weather test data for the buildings. Each Phase 2 building also presented some challenges to the application of the protocol. Discussion of those challenges is presented in Appendix B.

Data Analysis

1. Relationships Between Outdoor Temperature and Energy Use

Average energy usage was plotted against average temperature for the fans-on and fans-off conditions. A visual examination of the electric consumption for 505 Munroe, the first building evaluated, indicated that the relationship between energy use and outdoor temperature started to flatten out to the base load at temperatures above +5°C (see Figure 3). Graphs of gas consumption for the three buildings with gas heat did not demonstrate this trend (see Figures 4 through 8). There was no data for outdoor temperatures above 0°C for Oak Tree, the all-electric building tested in the second phase of the project (see Figure 4).

Hourly weather data from the Winnipeg Airport was utilized to determine outdoor temperatures for the four buildings located in Winnipeg. An outdoor temperature sensor and data logger were used to obtain outdoor temperatures for Oak Tree, the test building in Portage la Prairie. Average outdoor temperatures for each monitoring period (typically 11 pm until 8 am) were matched against the corresponding average hourly energy demand. Best-fit lines for average overnight energy use versus outdoor temperature were generated using the linear regression analysis feature of a spreadsheet computer program.

The data and best fit lines for the test buildings are shown in Figures 3 through 8. Best-fit equations and correlation coefficients (r) are presented below. Energy use by the corridor ventilation system was separately monitored in the all-electric buildings, but not separately monitored in buildings with gas heated corridor ventilation. As such, best-fit equations relating corridor ventilation system energy use and outdoor temperature were only generated for the all-electric buildings.

505 Munroe (all-electric)

Whole-building energy use with corridor fans on (kW) = 169.92 - 9.98 T, r = 0.96
Whole-building energy use with corridor fans off (kW) = 109.54 - 8.16 T, r = 0.91
Corridor ventilation system energy use (kW) = 79.54 - 3.23 T, r = 0.94

Oak Tree (all-electric)

Whole-building energy use with corridor fans on (kW) = 115.682 - 3.11 T, r = 0.94
Whole-building energy use with corridor fans off (kW) = 71.09 - 1.92 T, r = 0.85
Corridor ventilation system energy use (kW) =47.35 - 1.28 T, r = 0.98

185 Smith (all-gas heat)

Whole-building gas consumption with corridor fans on (m^3/hour) = 76.192 - 2.747 T, r = 0.95
Whole-building gas consumption with corridor fans off (m^3/hour) = 55.254 - 2.676 T, r = 0.97

FIGURE 3

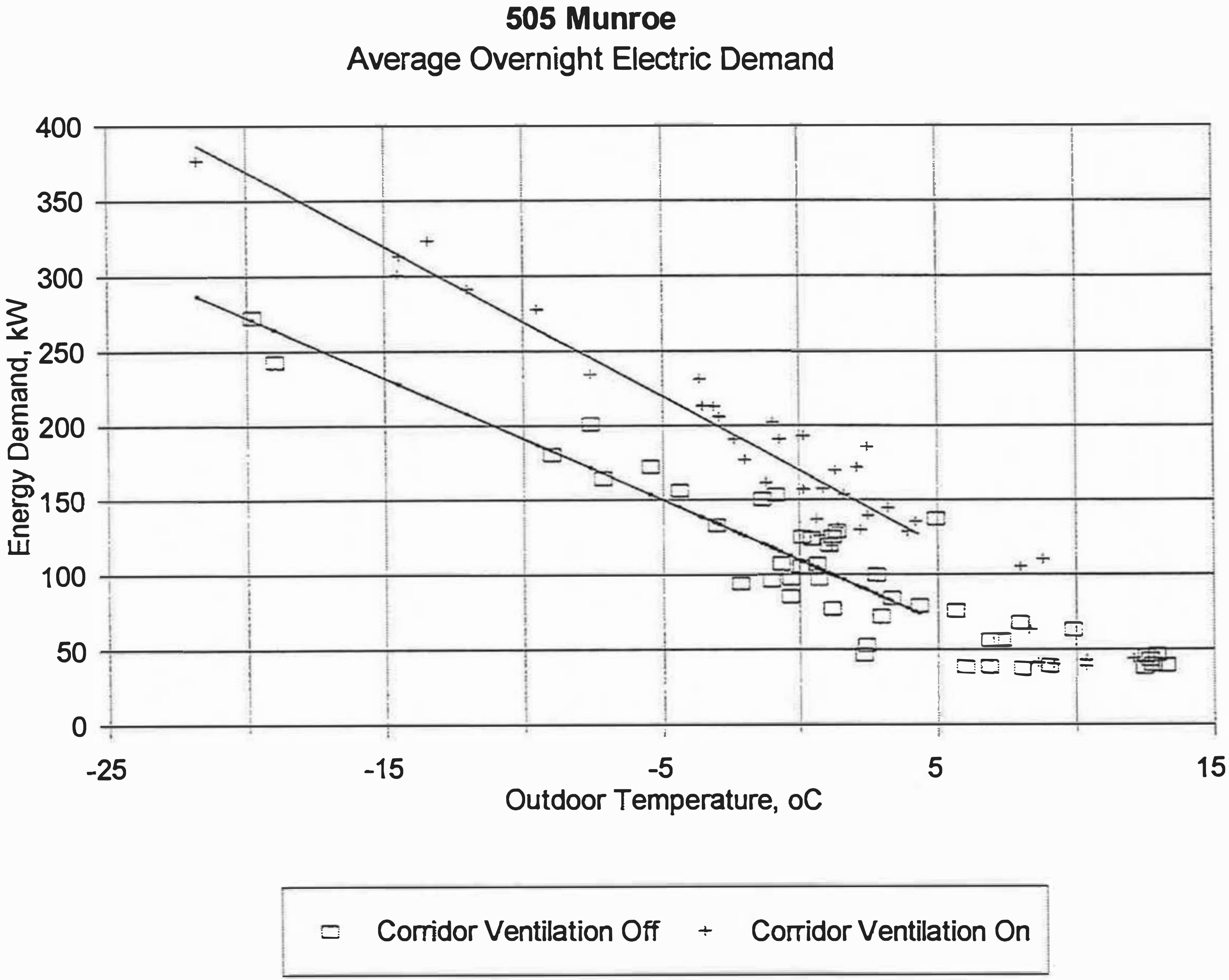

505 Munroe
Average Overnight Electric Demand
Energy Demand, kW
400
350
300
250
200
150
100
50
0
-25
-15
-5
5
15
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

FIGURE 4

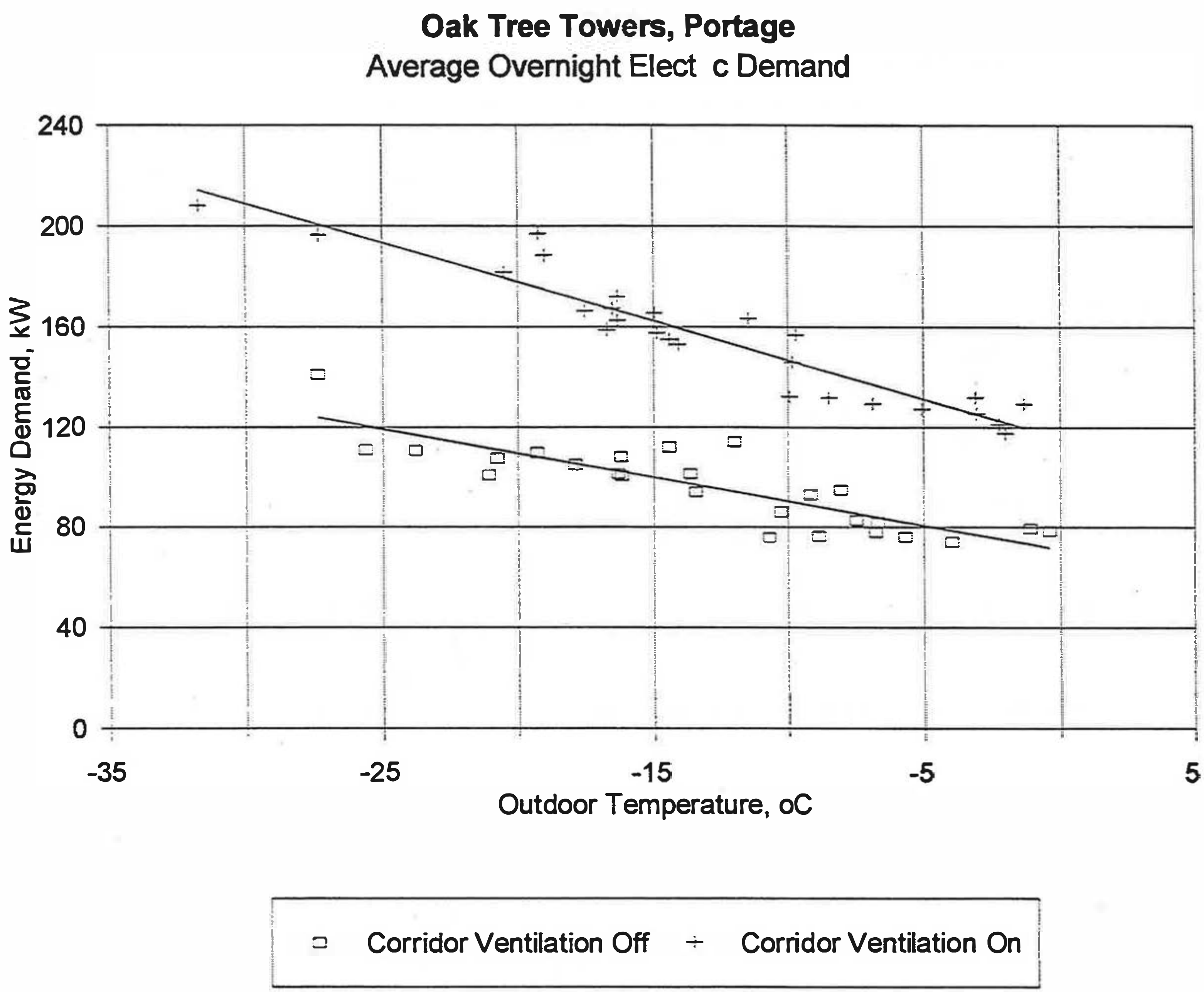

Oak Tree Towers, Portage
Average Overnight Elect c Demand
Energy Demand, kW
240
200
160
120
80
40
0
-35
-25
-15
-5
5
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

FIGURE 5

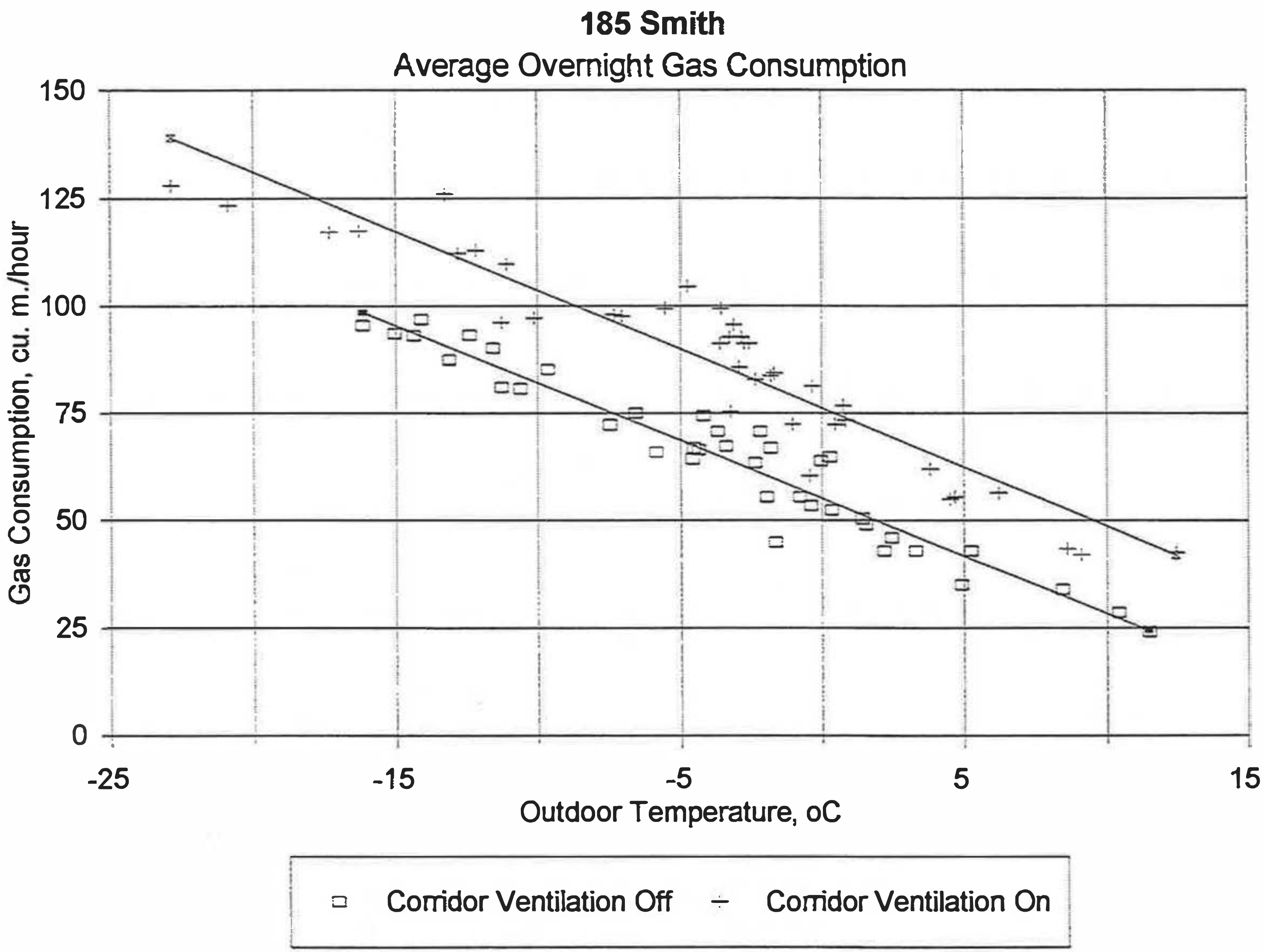
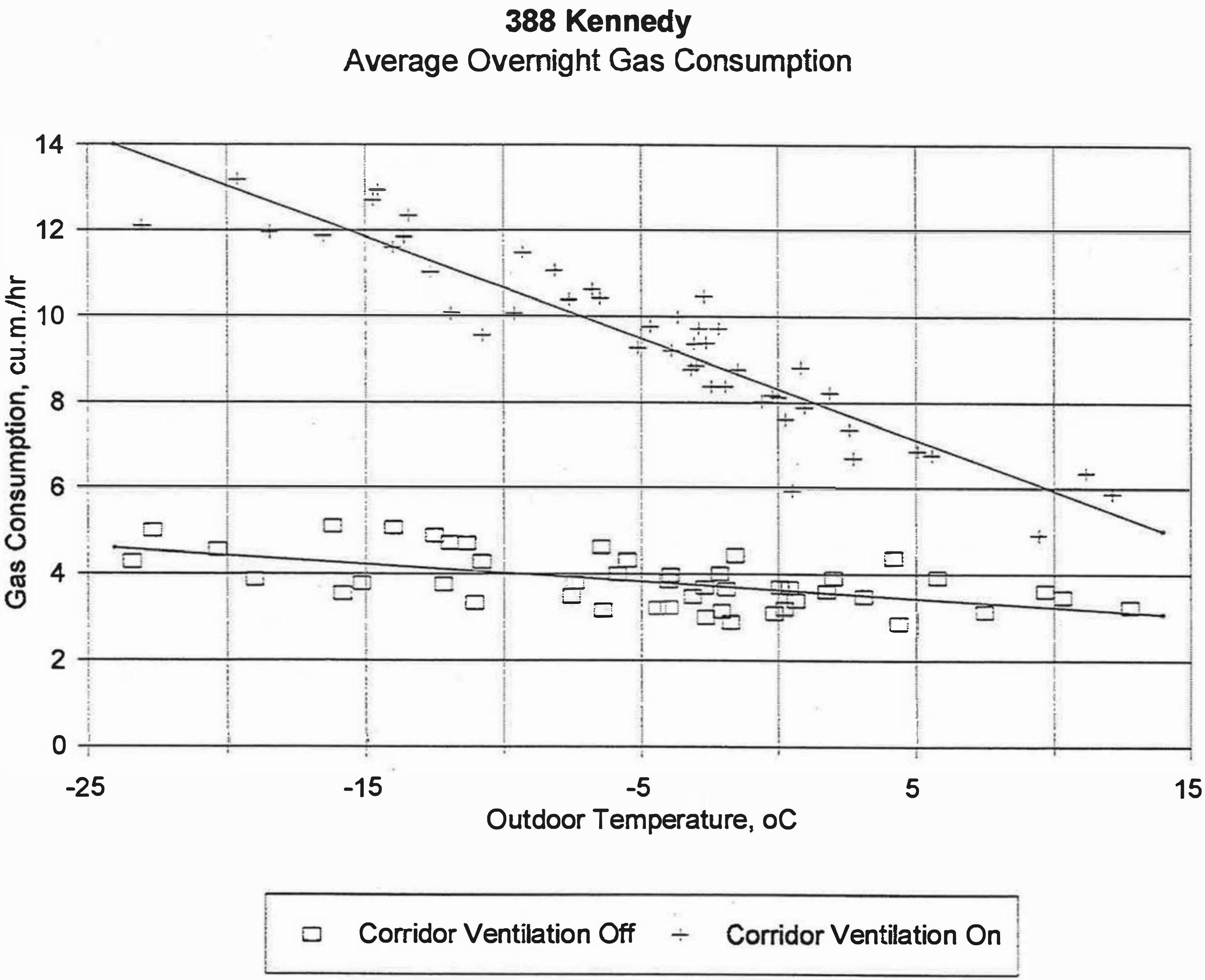

185 Smith
Average Overnight Gas Consumption
Gas Consumption, cu. m./hour
150
125
100
75
50
25
0
-25
-15
-5
5
15
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

FIGURE 6



388 Kennedy
Average Overnight Gas Consumption
Gas Consumption, cu.m./hr
14
12
10
8
6
4
2
0
-25
-15
-5
5
15
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

FIGURE 7

388 Kennedy
Average Overnight Electric Demand

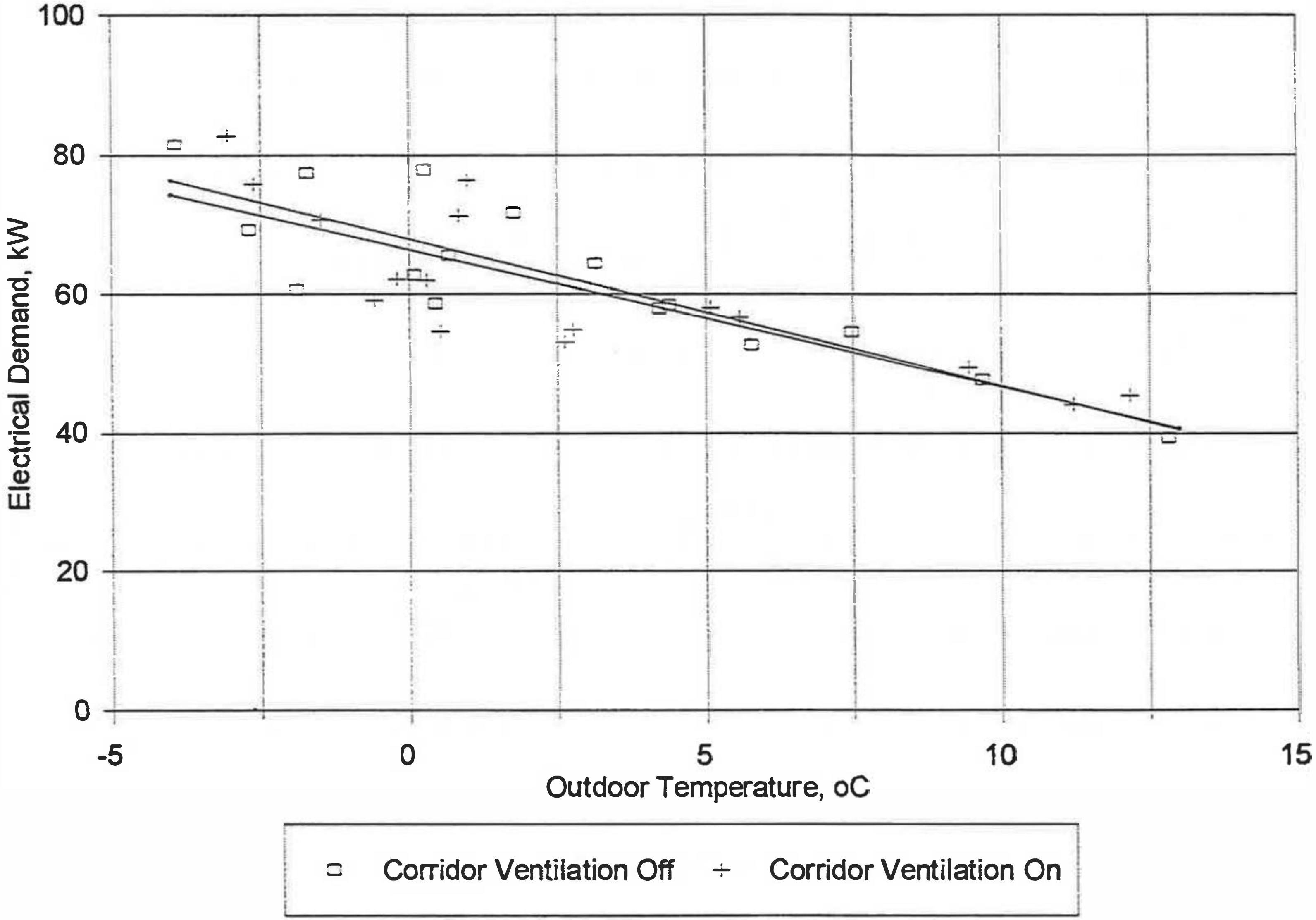
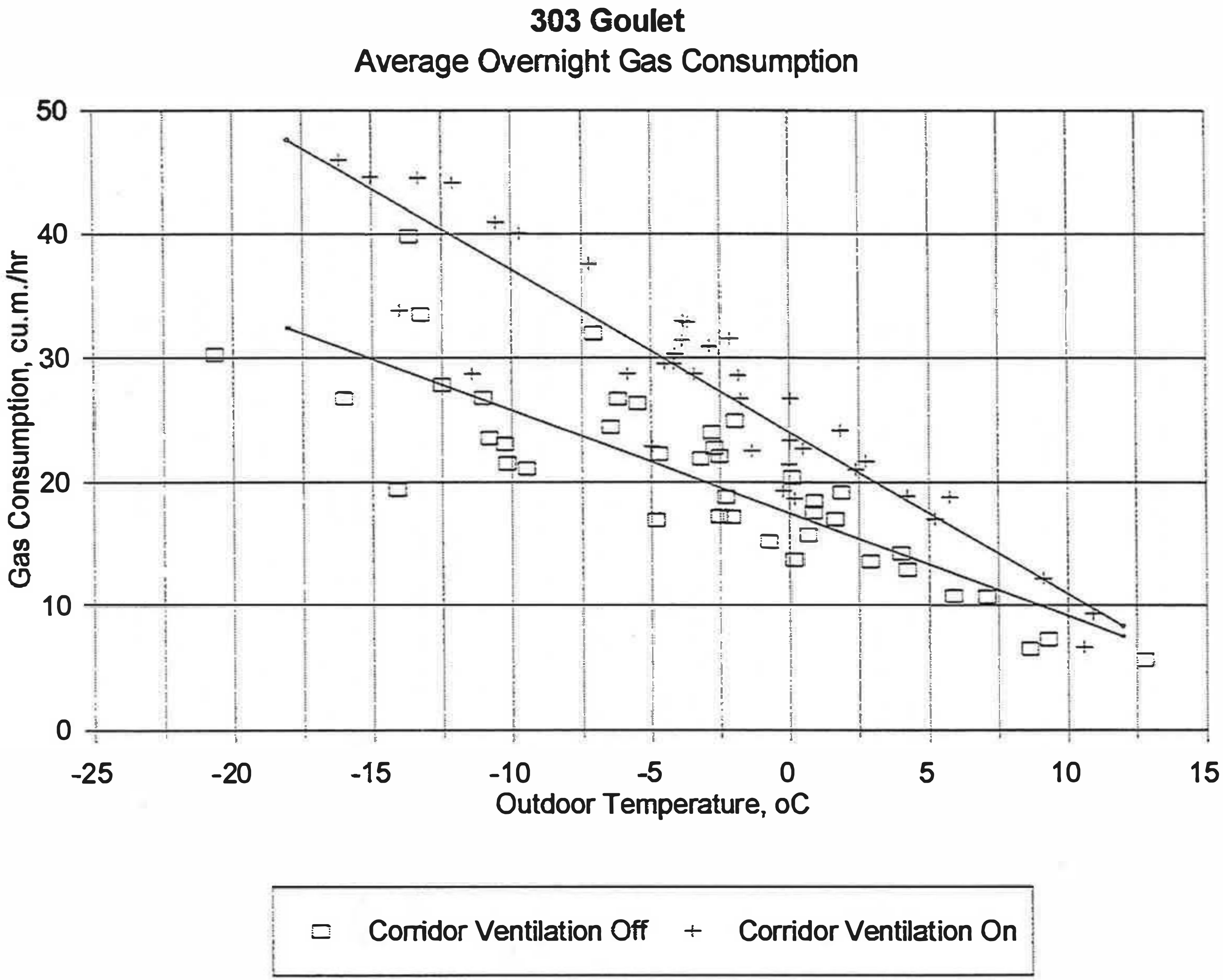


FIGURE 8


303 Goulet
Average Overnight Gas Consumption
Gas Consumption, cu.m./hr
50
40
30
20
10
0
-25
-20
-15
-10
-5
0
5
10
15
Outdoor Temperature, oC
Corridor Ventilation Off
Corridor Ventilation On

388 Kennedy (gas heated corridor ventilation and DHW, electric space heating)

Whole-building gas consumption with corridor fans on (m^3/hour) = 8.315 - 0.237 T, r = 0.92
Whole-building gas consumption with corridor fans off (m^3/hour) = 3.623 - 0.040 T, r = 0.56

Whole-building electric energy use with corridor fans on (kW) = 66.449 - 1.975 T, r = 0.82
Whole-building electric energy use with corridor fans off (kW) = 67.935 - 2.107 T, r = 0.86

303 Goulet (all-gas heat)

Whole-building gas consumption with corridor fans on (m^3/hour) = 24.035 - 1.311 T, r = 0.92
Whole-building gas consumption with corridor fans off (m^3/hour) = 17.493 - 0.830 T, r = 0.84

where T is the outdoor temperature in °C.

2. Estimated Impact of Corridor Ventilation on Air Change Rate

In all cases, the data clearly show that operating the corridor ventilation system has a significant impact on whole-building energy use and that there is a good correlation between outdoor temperature and energy use. Based on the outdoor air temperature/building energy use equations, the impact of operating the corridor ventilation system on building energy use is presented below.

505 Munroe - the impact of operating the corridor ventilation system at 505 Munroe was to increase electric demand by about 100 kW at -20°C. The equation derived for the corridor ventilation system indicates its heating load would be 144 kW at -20°C. Thus, the impact of operating the corridor ventilation system at 505 Munroe at -20°C on whole-building energy use was equivalent to 69% of the energy used directly by the corridor ventilation system.

Typical interior temperature readings taken in 505 Munroe were 22°C during site visits. If all air entering the building is heated to 22°C and the increase in energy use when the corridor ventilation system operated was the result of increased ventilation, then the 100 kW increase in whole-building energy use when operating the corridor ventilation system at -20°C would be equivalent to heating about 1960 L/s of outside air. Air flow measured for the corridor ventilation system was 3350 L/s at the fan, 2595 L/s in the corridors. Thus, the net impact of operating the corridor ventilation system at 505 Munroe at -20°C appears to equal the energy required to heat about 59% of the air flow measured at the corridor ventilation system fan or 76% of the ventilation air flow measured in the corridors.

Oak Tree - the impact of operating the corridor ventilation system at Oak Tree on electric demand was about 68.5 kW at -20°C, equivalent to heating about 1340 L/s of outside air to 22°C. Corridor ventilation air flows to the building were measured at 1993 L/s at the fan. Thus, the net impact of operating the corridor ventilation system in Oak Tree at -20°C is equal to the energy required to heat about 67% of air provided by the corridor ventilation system.

185 Smith - the impact of operating the corridor ventilation system on whole-building gas consumption at 185 Smith was about 22.35 m^3/h at -20°C. Assuming a combustion efficiency of 80%, this is equivalent to a heat delivery rate of 185 kW which would heat about 3630 L/s of outside air to 22°C. Corridor ventilation air flows to the building were measured at 6400 L/s at the fan. Thus, the net impact of operating the corridor ventilation system in 185 Smith at -20°C is equal to the energy required to heat about 57% of air provided by the corridor ventilation system.

388 Kennedy - the impact of operating the corridor ventilation system at 388 Kennedy was to increase gas consumption by about 8.62 m^3/h and to reduce electric consumption by about 4.1 kW at -20°C. Gas meets corridor ventilation heating loads, space heating is electric. Assuming a conversion/delivery efficiency of 75% for the corridor ventilation system (including heat losses from the outdoor glycol loop between mechanical rooms), the gas consumption is equal to a delivered heat rate of 66 kW. If the heat recovery system effectiveness is 50%, the heat provided by the corridor ventilation system would be equal to 106 kW (including a correction for unbalanced air flows through the heat recovery apparatus), which is sufficient to heat about 2200 L/s of outside air to 20°C. Corridor ventilation air flows to the building were measured at 2350 L/s. The 4.1 kW decrease in electric consumption for space heating is equal to a reduction in infiltration of 80 L/s (170 cfm). Thus, the net impact of operating the corridor ventilation system at 388 Kennedy at -20°C is equal to the energy required to heat about 90% of air provided by the corridor ventilation system. This impact would fall to 80% if heat recovery effectiveness were 40% and 55% without any heat recovery.

303 Goulet - the impact of operating the corridor ventilation system on whole-building gas consumption was about 16.16 m^3/h at -20°C. Assuming a combustion efficiency of 80%, this is equivalent to a heat delivery rate of 134 kW which would heat about 2620 L/s of outside air to 22°C. From a balance report for the building, corridor ventilation system air flows were 3270 L/s at the fan. Thus, the net impact of operating the corridor ventilation system in 303 Goulet at -20°C is equal to the energy required to heat about 80% of air provided by the corridor ventilation system.

Based on computer modelling of 505 Munroe, there was an expectation that operation of corridor ventilation systems in the test buildings would result in smaller increases in total air change rate (i.e., considerably less than 30% of the corridor ventilation system air flow rates) or stated another way, that operation of the corridor ventilation system would displace a greater portion of other heating loads. The measured energy data for all five study buildings indicate that the increase in whole-building air change rate was in the range of 60% to 90% of the corridor ventilation system flow rate. The difference between expected and observed results indicates the walls between the suites and corridors are quite airtight, and air supplied to the corridors finds more direct paths to the outdoors (e.g., via elevator shafts, garbage chutes, stairwells, pipe chases, corridor windows, etc.). As such, corridor ventilation does not significantly impact the pressure in suites, and so does not significantly impact air movement across exterior suite walls, which dominate building envelope surface area. As such, the impact of corridor ventilation on the overall building infiltration is small.

3. Estimated Impact of Corridor Ventilation on Energy Use and Energy Costs

The impact of operating the corridor ventilation system on building energy use and energy costs was estimated using the method presented in Appendix C. The data show that operating the corridor ventilation system had the effect of increasing heating season energy consumption in all five buildings and that there was a good correlation between outdoor temperature and energy use. The estimated impact on energy use and energy cost are presented in Tables 2 and 3. The cost estimates are based on energy costs at 1998 Manitoba utility rates of $0.1885/m^3$ for gas and $0.0212/kWh for electricity. Electric demand savings are not estimated.

Table 2

Estimated Impact of Corridor Ventilation on Five Study Houses

a) Estimated Impact of Corridor Ventilation on Electric Energy Use at 505 Munroe

Temperature Bin °C	Hours in Bin	Fans On	Electric kW Fans Off	Difference	Bin Totals Electric kWh
8	717	90.1	44.3	45.82	32853
4	640	130.0	76.9	53.10	33984
0	596	169.9	109.5	60.38	35986
-4	578	209.8	142.2	67.66	39107
-8	564	249.8	174.8	74.94	42266
-12	536	289.7	207.5	82.22	44070
-16	467	329.6	240.1	89.50	41797
-20	351	369.5	272.7	96.78	33970
-24	223	409.4	305.4	104.06	23205
-28	126	449.4	338.0	111.34	14029
-32	66	489.3	370.7	118.62	7829
-36	33	529.2	403.3	125.90	4155
-40	15	569.1	435.9	133.18	1998
Totals	4912 hours				355249 kWh/year

b) Estimated Impact of Corridor Ventilation on Electric Energy Use at Oak Tree

Temperature Bin °C	Hours in Bin	Fans On	Electric kW Fans Off	Difference	Bin Totals Electric kWh
8	717	90.8	55.7	35.07	25147
4	640	103.2	63.4	39.83	25492
0	596	115.7	71.1	44.59	26577
-4	578	128.1	78.8	49.35	28525
-8	564	140.6	86.5	54.11	30519
-12	536	153.0	94.1	58.87	31555
-16	467	165.4	101.8	63.63	29716
-20	351	177.9	109.5	68.39	24006
-24	223	190.3	117.2	73.15	16313
-28	126	202.8	124.9	77.91	9817
-32	66	215.2	132.5	82.67	5456
-36	33	227.6	140.2	87.43	2885
-40	15	240.1	147.9	92.19	1383
Totals	4912 hours				257392 kWh/year

Table 2 continued

c) Estimated Impact of Corridor Ventilation on Gas Consumption at 185 Smith

Temperature Bin °C	Hours in Bin	Gas m³/h Fans On	Gas m³/h Fans Off	Difference	Bin Totals Gas m³
8	717	54.22	33.85	20.37	14605
4	640	65.20	44.55	20.65	13219
0	596	76.19	55.25	20.94	12479
-4	578	87.18	65.96	21.22	12266
-8	564	98.17	76.66	21.51	12129
-12	536	109.16	87.37	21.79	11679
-16	467	120.14	98.07	22.07	10309
-20	351	131.13	108.77	22.36	7848
-24	223	142.12	119.48	22.64	5049
-28	126	153.11	130.18	22.93	2889
-32	66	164.10	140.89	23.21	1532
-36	33	175.08	151.59	23.49	775
-40	15	186.07	162.29	23.78	357
Totals	4912 hours				105136 m³/year

d) Estimated Impact of Corridor Ventilation on Energy Use at 388 Kennedy

Temperature Bin °C	Hours in Bin	Gas m³/h Fans On	Gas m³/h Fans Off	Gas m³/h Diff	Electric kW Fans On	Electric kW Fans Off	Electric kW Diff	Bin Totals Gas m³	Bin Totals Electric kWh
8	717	6.42	3.31	3.12	50.6	51.1	-0.43	2234	-308
4	640	7.37	3.47	3.90	58.5	59.5	-0.96	2497	-613
0	596	8.31	3.63	4.69	66.4	67.9	-1.49	2794	-886
-4	578	9.26	3.79	5.48	74.3	76.4	-2.01	3165	-1164
-8	564	10.21	3.95	6.26	82.2	84.8	-2.54	3532	-1434
-12	536	11.15	4.11	7.05	90.1	93.2	-3.07	3778	-1646
-16	467	12.10	4.27	7.83	98.0	101.6	-3.60	3659	-1680
-20	351	13.05	4.42	8.62	105.9	110.1	-4.13	3026	-1448
-24	223	13.99	4.58	9.41	113.8	118.5	-4.65	2098	-1038
-28	126	14.94	4.74	10.19	121.7	126.9	-5.18	1285	-653
-32	66	15.89	4.90	10.98	129.6	135.4	-5.71	725	-377
-36	33	16.83	5.06	11.77	137.5	143.8	-6.24	388	-206
-40	15	17.78	5.22	12.55	145.4	152.2	-6.77	188	-101
Totals	4912 hours							29396 m³/year	-11554 kWh/yr

Table 2 continued

e) Estimated Impact of Corridor Ventilation on Gas Consumption at 303 Goulet

Temperature Bin °C	Hours in Bin	Gas m^3/h Fans On	Fans Off	Difference	Bin Totals Gas m^3
8	717	13.55	10.85	2.69	1932
4	640	18.79	14.17	4.62	2956
0	596	24.04	17.49	6.54	3899
-4	578	29.28	20.81	8.47	4893
-8	564	34.52	24.13	10.39	5860
-12	536	39.77	27.45	12.31	6600
-16	467	45.01	30.77	14.24	6649
-20	351	50.26	34.09	16.16	5673
-24	223	55.50	37.41	18.09	4033
-28	126	60.74	40.73	20.01	2521
-32	66	65.99	44.05	21.93	1448
-36	33	71.23	47.37	23.86	787
-40	15	76.48	50.69	25.78	387
Totals	4912 hours				47638 m^3/year

Table 3

Estimated Cost of Operating Corridor Ventilation

Building	Electric kWh/year	Electric $/year	Gas m³/year	Gas $/year
505 Munroe	355 249	$7 531		
Oak Tree	257 392	$5 457		
185 Smith			105 136	$19 818
388 Kennedy	-11 554	($ 245)	29 369	$ 5 536
303 Goulet			47 638	$ 8 980

Assessment of the Methodologies for Estimating Seasonal Impact of Corridor Ventilation

The methodologies presented above and detailed in Appendix C should give a reasonable approximation of the changes in whole-building air change rates and energy use related to operation of corridor ventilation systems. For buildings which do not use electricity to heat corridor ventilation air, the air change rate calculations do not properly account for fan motor energy. However, the example below indicates this is not significant.

In 388 Kennedy, the corridor ventilation system supply fans would draw about 2 kW, which would help heat ventilation air. Adding this energy to the corridor ventilation system energy rate used in Step 5 of the air change rate procedure would increase the estimated air flow through the corridor ventilation system by 42 L/s at -20°C. Electricity used by the corridor ventilation system needs to be subtracted from space heating loads. For 388 Kennedy, operating the corridor ventilation system at -20°C was estimated to reduced electric consumption by 4.1 kW, which was attributed to a change in space heating due to changes in infiltration. This reduction in space heating energy should be further reduced by the 2 kW used by the corridor fans. Factoring this energy into the space heating/infiltration air flow calculated in Step 5 of the air change procedure would increase the impact on infiltration rates by about 40 L/s at -20°C.

The overall result of factoring fan energy into the calculations for 388 Kennedy would be to increase the estimated air flow heated by the corridor ventilation system from 1980 L/s to 2022 L/s and to reduce the infiltration load met by electric space heating by an estimated 120 L/s at -20°C (it was 80 L/s). The net change in air flow to the building when operating the corridor ventilation system at -20°C is an increase of ((1980+42) - (80+40)) 1902 L/s. As can be seen, the change in estimated corridor ventilation system air flows is offset by a similar change in estimated infiltration air flows. The slight difference is because the delivery temperature selected for corridor ventilation air is lower than the temperature assumed for air infiltrating into suites.

In buildings with all-gas heat, if fan energy is not accounted for, the impact on overall building ventilation rates and energy cost will be slightly understated. In all-electric buildings, the procedure correctly accounts for energy use without the adjustments discussed above.

The procedure to estimate the impact of corridor ventilation on air change rates does not consider the dynamic wall effect. It is possible that changes in infiltration and exfiltration affect conduction heat loss rates through exterior walls. If so, the impact on infiltration rates estimated above could be over or understated.

Although the procedure provides a quantified estimate of the impact of corridor ventilation on whole-building air change rates, it does not provide a quantified estimate of the change in ventilation rates in suites.

Based on the energy impact in the five test buildings, it appeared that operating the corridor ventilation systems had a proportionally large impact on whole-building air change rates. The implication of this is that operating the corridor ventilation system did not appreciably increase indoor-to-outdoor pressure differentials across suite walls so did not displace significant amounts of infiltration. (Suite walls comprise the dominant portion of the building envelope and probably the vast majority of air leakage paths.) This was supported by measurements taken in 505 Munroe, which indicated that pressure changes across exterior suite walls resulting from operation of the corridor ventilation system were about one quarter of the pressure changes across corridor-to-exterior walls. As such, it may be assumed that not much of the corridor ventilation air in the five test buildings reached the suites.

Using the nighttime energy use versus outdoor temperature equations for buildings may result in an under-prediction of the energy impact of operating corridor ventilation systems. This is because solar and internal heat gains will generally be higher during the day than late at night. When internal or solar heat gains or both exceed heating requirements for a suite, an increase (or decrease) in infiltration will not increase (or decrease) space heating requirements for the suite. As such, corridor ventilation which displaces infiltration in the suite will not reduce space heating requirements for the suite during these times, although the nighttime energy use may predict changes. As such, the procedure for estimating the energy impact of operating corridor ventilation systems should be considered to provide conservative estimates (i.e., understate savings).

Conclusions and Recommendations

1. The Field Monitoring Protocol Worked

The field test protocol, data analyses and calculations applied in this project appear to have been successful in providing information on the energy impact of operating corridor ventilation systems in apartment buildings. The field protocol was straightforward, relatively inexpensive to apply and could be done without use of expensive or high-tech monitoring equipment. The data analyses were done in a spreadsheet computer program. The results for the five test buildings were sufficiently similar to allow for general conclusions about the impact of operating corridor ventilation systems on building energy use and whole-building air change rates. Those conclusions are discussed below.

2. The Simple Computer Model Was Not a Useful Tool

The simple computer model applied in the first phase of this project did not provide useful predictions for this project. A much more complex model with detailed inputs would be required to reasonably predict the impact of mechanical ventilation on total air change rate or whole-building energy use. If there is a desire to identify a computer tool to predict the impact of corridor ventilation on air change rates, advanced energy prediction models such as BLAST and DOE or detailed indoor air quality programs such as CONTAM or COMIS, should be explored to determine if they are adaptable for this application.

Accurately predicting the full impact of corridor ventilation system operation on building energy use is not simple. Any computer model is likely to require extensive and detailed inputs if it is to be precise. Unless detailed (e.g., zone-by-zone) outputs are desired, estimates based on field testing, as done in this project, may be the most economical method to predict the impact of corridor ventilation on overall energy use, and tracer gas or PFT-type sampling may be most appropriate for predicting air change rates in buildings.

3. Impact of Corridor Ventilation was Greater than Anticipated

Increasing mechanical exhaust from a building will increase infiltration and decrease exfiltration. Adding corridor ventilation will increase exfiltration and decrease infiltration. The sum of exfiltration and mechanical exhaust must equal the sum of infiltration and mechanical supply. Infiltration and mechanical supply air must be conditioned to maintain thermal comfort in the building.

The relationship between mechanical air flows, infiltration and exfiltration means that:

- increasing mechanical exhaust or mechanical supply or both will result in an increase in the building's total ventilation rate (i.e., the sum of infiltration and mechanical supply), in most circumstances;

- the energy required to condition an increase in mechanical ventilation air supply will be partially offset by a reduction in energy needed to condition infiltration air, but the result will be a net increase in energy use, in most circumstances, i.e., there is not a 1:1 relationship between mechanical ventilation air supply and infiltration;

- some of the infiltration reductions (and thus energy savings) that may be expected by reducing mechanical exhaust from a building will be lost to increases in exfiltration, in most circumstances;

- the inverse of the above statements is true.

If the exhaust flow rate from a building is large relative to mechanical supply, infiltration will occur over most or all of the building envelope and there will be little or no exfiltration. In this situation, for a building without compartments, one would expect that increasing corridor ventilation would primarily displace infiltration and any resulting increase in exfiltration would be small. Thus, the energy needed to condition corridor ventilation supply air would be largely offset by a reduction in the energy required to condition infiltration air.

During the fan-off tests in the test buildings, building exhaust fans continued to operate. The observed location of building envelope pressure profiles when the corridor ventilation supply fans were off, led to the expectation that operation of the corridor ventilation air supply system would primarily displace infiltration; and any increases in exfiltration would be small. As such, it was expected that the impact on whole-building energy use of operating corridor ventilation systems would be small.

Based on a simplistic analysis, there was an expectation that operation of the corridor ventilation systems would result in energy use increases equivalent to the energy required to condition an air flow rate of less than 30% of the corridor ventilation system air flow rate. (Computer modelling done for 505 Munroe suggested increases in total air change rate of considerably less than 30%.) The measured energy data indicated that the increase was equivalent to the energy needed to condition 60 to 90% of the corridor ventilation system flow rate.

It is believed that the primary cause of the difference between expected and observed results is that the walls between the suites and corridors are quite airtight. As a result, air supplied by the corridor ventilation system flows out of the building through more direct leakage paths such as garbage chutes, elevator shafts, stairwells, corridor windows and exposed corridor walls, without significantly impacting the pressure in suites, and so does not significantly impact air movement across exterior suite walls. (Measurements taken in 505 Munroe support this conclusion.) The corridor ventilation system's primary impact is to exfiltrate in areas of the building where infiltration was modest, so only modest amounts of infiltration are displaced while exfiltration is increased significantly.

Other possible explanations for the discrepancy between the expected and observed results include:

- inaccurate air flow or energy measurements taken in the field;
- loss of air from the corridor ventilation system before it reached the core of the building;
- loss of the dynamic wall effect when infiltration is reduced results in an increase in conductive heat loss through exterior walls when the corridor ventilation system is operated.

Whereas each of these may have had an impact, it is not expected that any one of them could account for a significant portion of the full discrepancy.

4. Corridor Air Quality and Corridor Ventilation

There was a concern at the beginning of this project that turning off the corridor ventilation system could generate complaints about indoor air quality in test buildings. For this reason, the caretaker contracted to manually turn the corridor ventilation system off and on at 505 Munroe was advised to turn it off late in the evening and back on early in the morning. Over the course of the project, the times at which the fan was turned off and on shifted to suit the caretaker's schedule. On some occasions, corridor ventilation was off for more than 24 consecutive hours.

There were no complaints about air quality when the fans were off at night in any of the study buildings, even during warmer weather. This may be attributed to two factors: pollutant loading is low at night; and very few tenants use the corridors at night.

When outdoor temperatures were above freezing and the fans at 505 Munroe were off throughout the day, some tenants complained to the caretaker about odours or stuffiness in the corridors. The lack of complaints about air quality when the corridor ventilation system was off may be in part due to the fact building exhausts operated during the fan-off trials, and stack driven air leakage was sufficient in the cold weather to control odours. Had the central exhaust fans been turned off as well, there may have been complaints about air quality at nights and during cold weather.

5. Load Shedding Corridor Ventilation Could be Beneficial

Turning the corridor ventilation system off during cold weather did not result in complaints about air quality. Energy can be saved by turning the corridor ventilation system off at night during cold weather. Turning the corridor ventilation system off could also be used to reduce peak electrical demand during very cold weather, in electrically heated buildings. For example, in 505 Munroe, turning the corridor ventilation system off at outdoor temperatures below -15°C could result in demand reductions of more than 100 kVA in December, January and February.

In buildings with space heating provided by electricity and corridor ventilation provided by fossil fuel, turning off the corridor ventilation system may increase space heating (i.e., electricity) loads. (This was not significant in the building at 388 Kennedy.) Whereas turning off corridor ventilation systems will reduce energy consumption, an assessment should be made in buildings with different fuel mixes to ensure that they will also reduce energy costs.

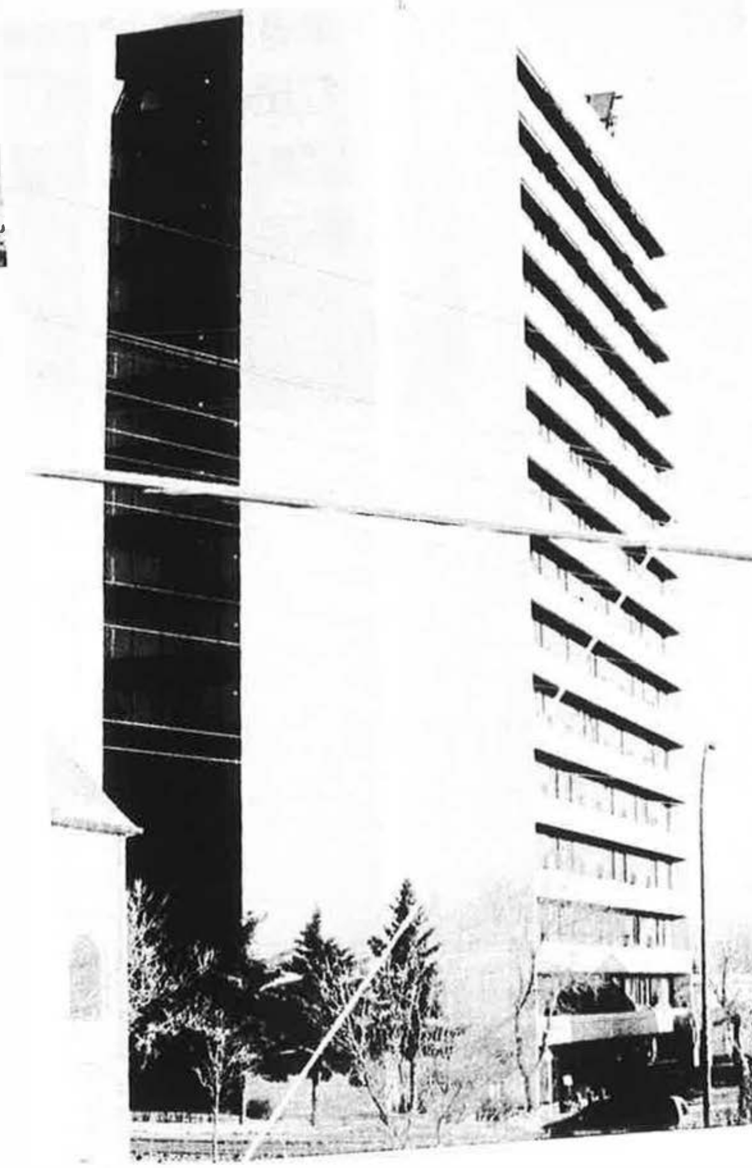
Appendix A

Photographs

505 Munroe Avenue
WNW Elevation
Facing Watt Street

505 Munroe Avenue

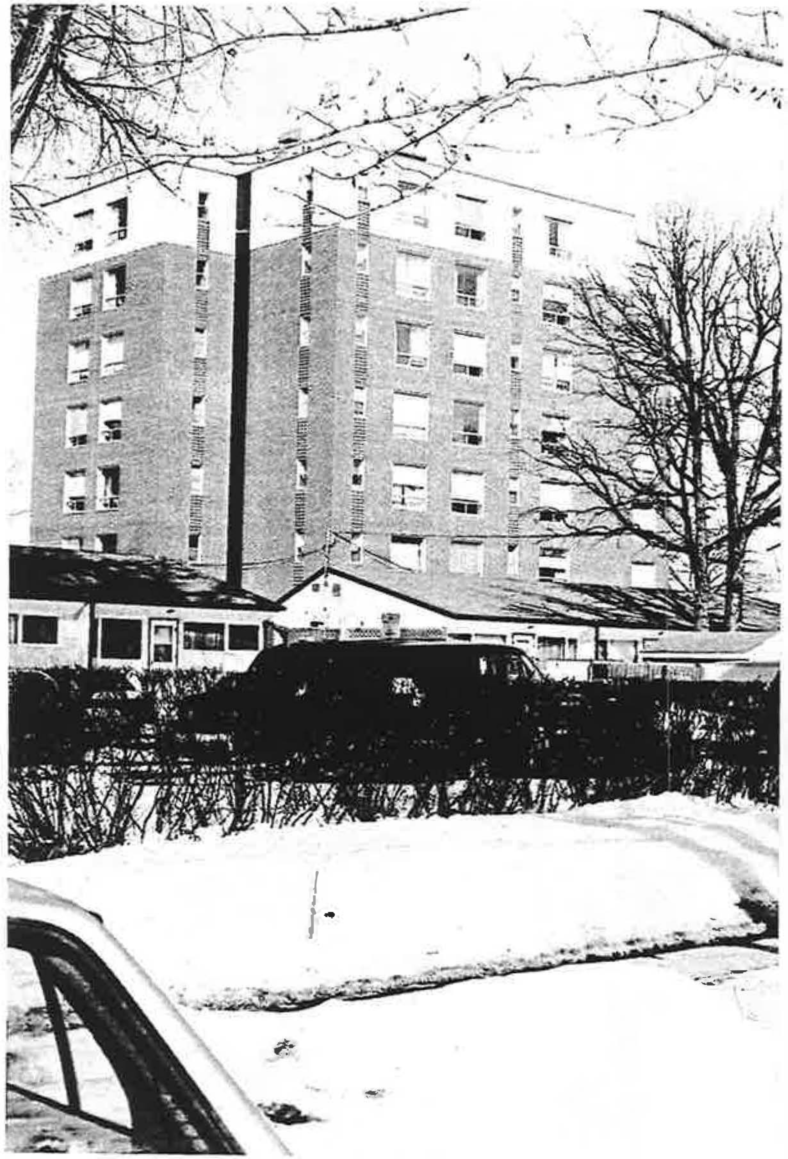
NNE Elevation



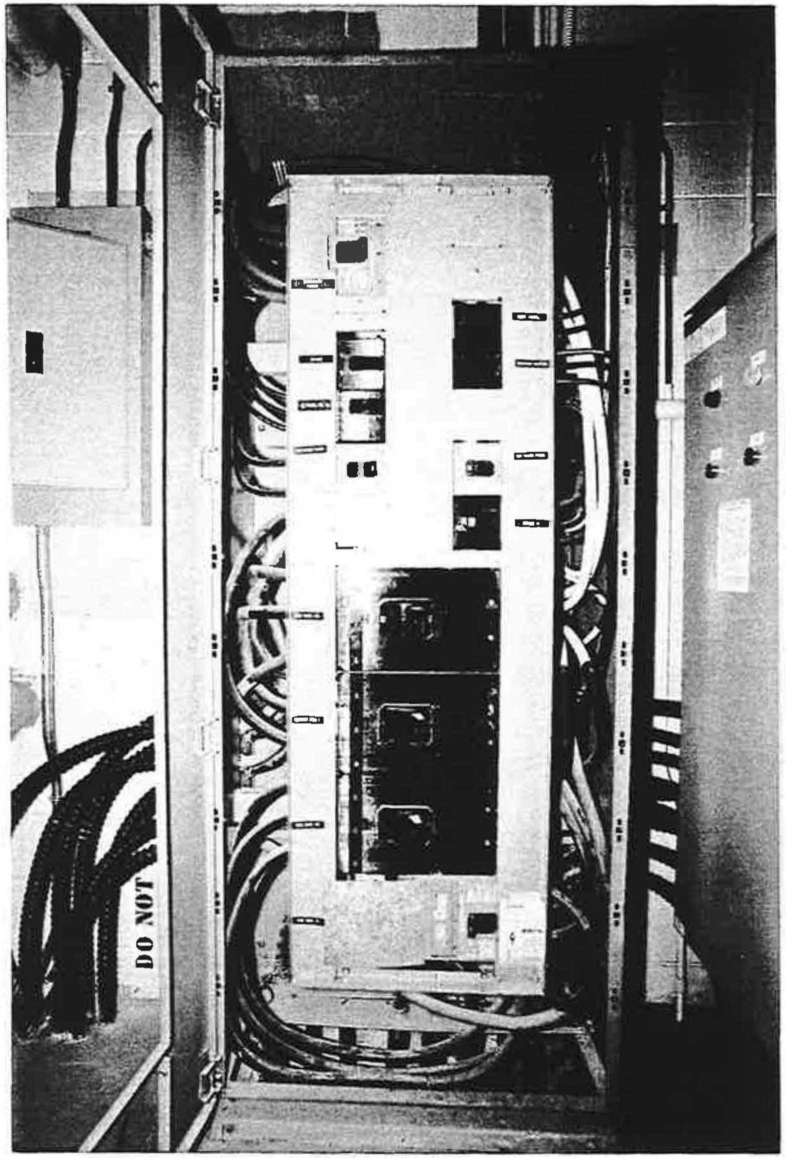
SSW Elevation

Facing Munroe

Oaktree Towers



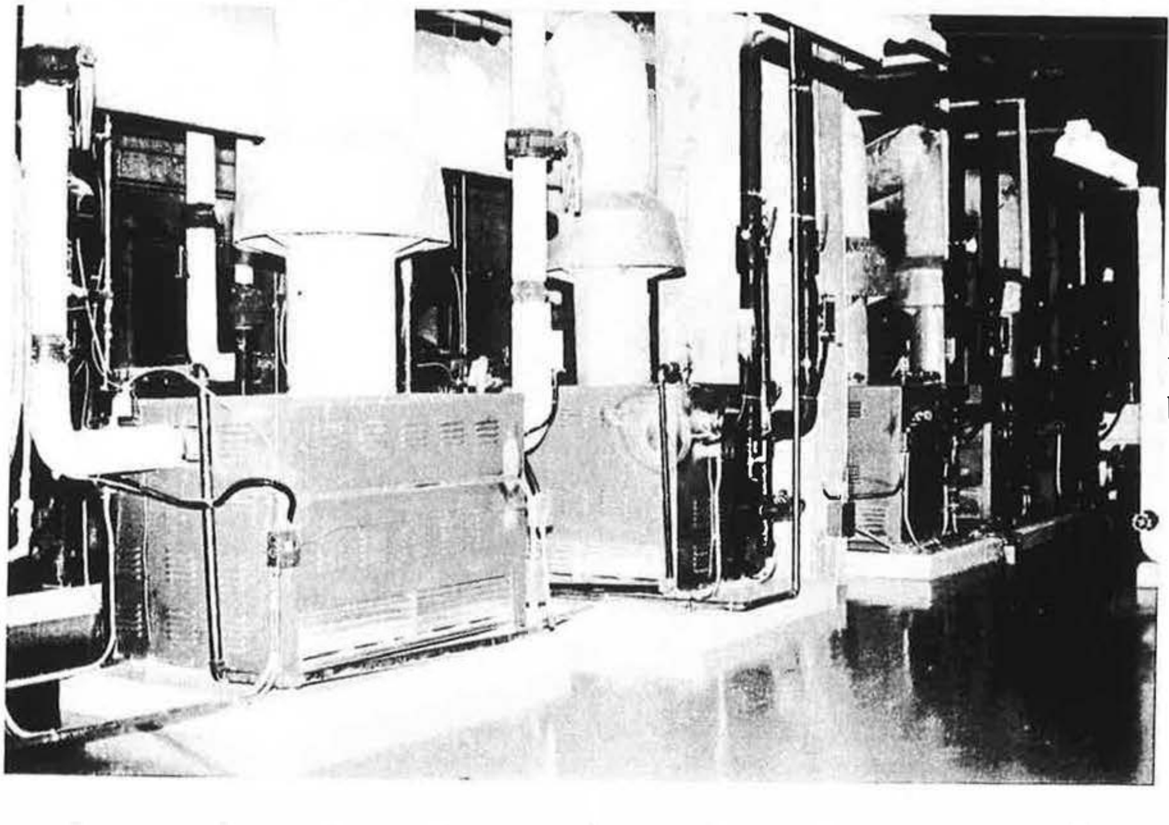
West and South Elevations



Main Power Distribution Panel

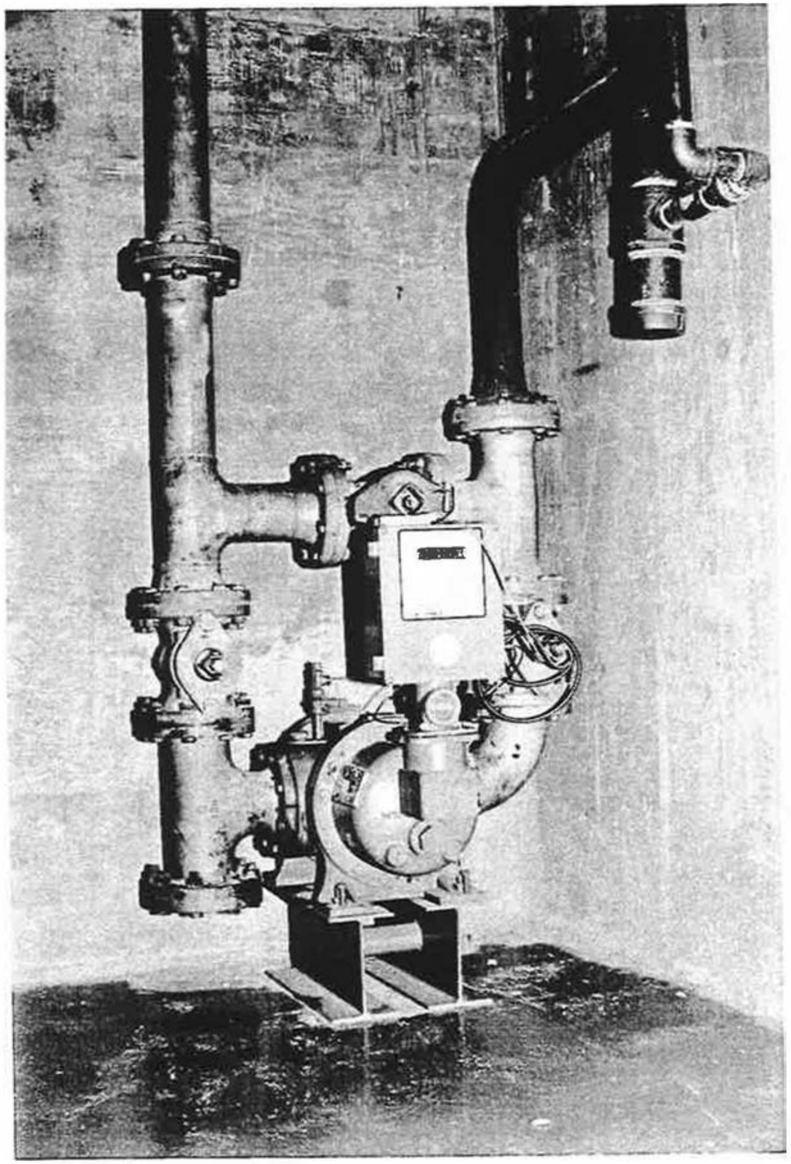
185 Smith

West Elevation

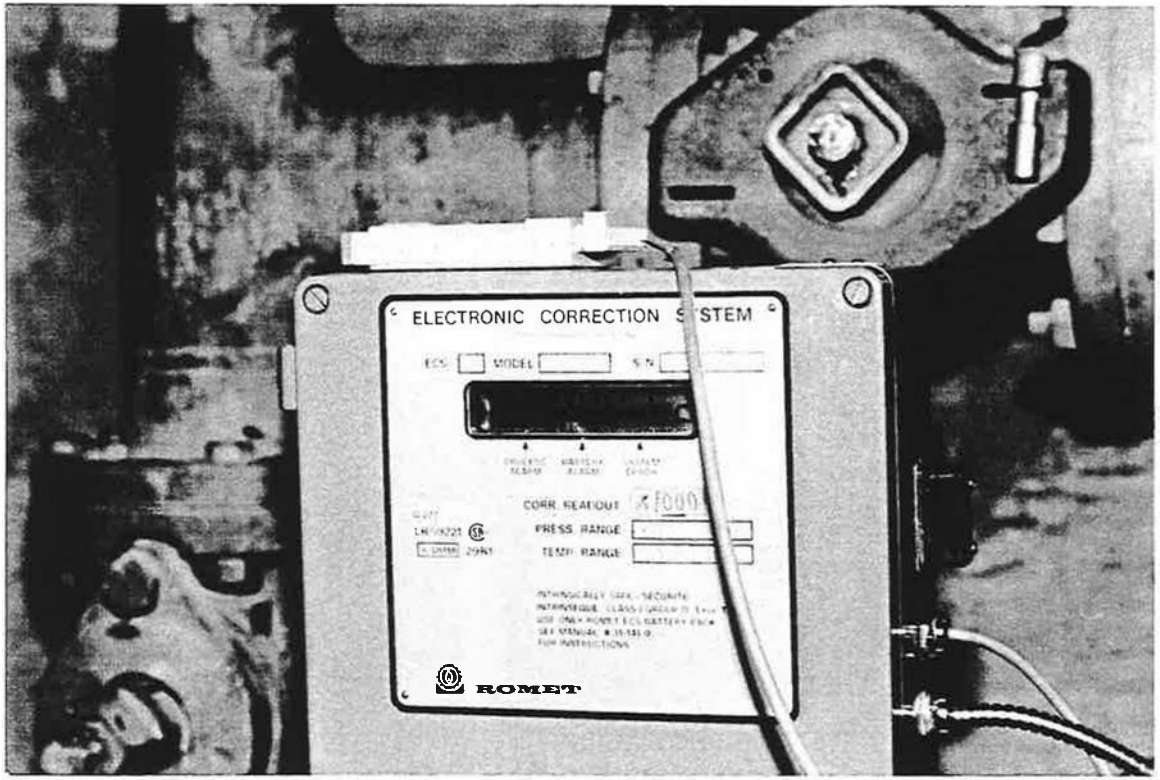


Boilers were submerged during recent watermain break in building basement.

185 Smith



Gas meter in boiler room was damaged during basement flood.



Correction system on gas meter corrects gas flows to standard pressure and temperature conditions. This correction system contains the pulse metering contacts. The white case on top of the correction system housing is the data logger. Digital read out is in thousands of cubic feet.

388 Kennedy

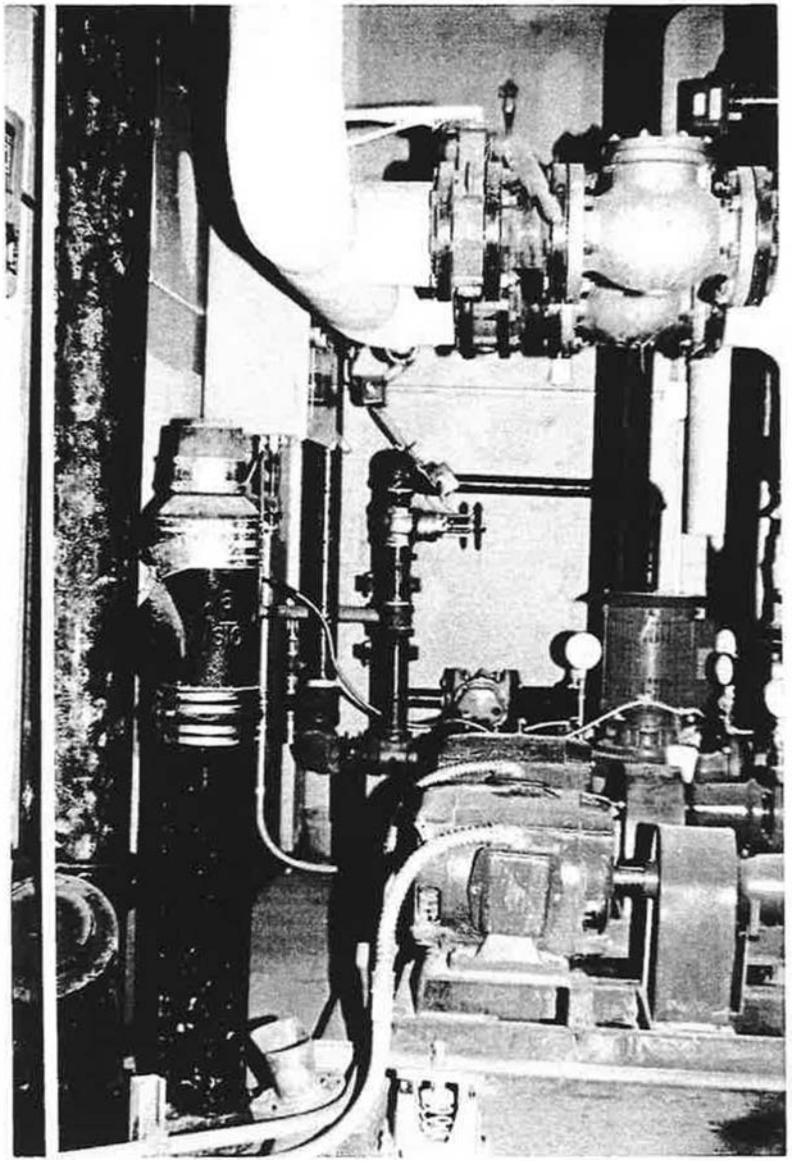
East Elevation

West and South Elevations

303 Goulet

South and East Elevations

Gas meter location: grey module just above the red pumps



Appendix B

Challenges to Application of the Protocol

Problems Encountered in Protocol Application

Monitoring in Phase 1 proceeded smoothly. The first building identified by the Manitoba Housing Authority was suitable for the project and identification of what and where to monitor was straightforward. The on-call electrician had been involved in the construction of the building and was very knowledgeable with all the electrical services and systems in this all-electric building.

Identifying buildings for Phase 2 of the project was somewhat problematic. The buildings requested for Phase 2 were to include gas/gas and gas/electric heating systems and a mix of building sizes while much of Manitoba Housing Authority's stock is all-electric. Several candidate buildings identified by the Manitoba Housing Authority were rejected. Some shared energy metering with other buildings; some were judged to be too similar to other study buildings; in others, corridor ventilation system or building characteristics were considered unsuitable for this study.

Delays encountered in qualifying and initiating monitoring in Phase 2 buildings resulted in the November/December, 1998 monitoring window being missed. Winter of 1998/99 in Manitoba was very mild. Except for a brief period around New Year's, before buildings were being monitored, nighttime temperatures did not fall into the -30°C range. As such, there was no very cold weather test data for the buildings.

Each Phase 2 building also presented some challenges to the application of the protocol. Discussion of those challenges follows.

The qualification inspections for Oak Tree Towers were done in early December, 1998. This was an all-electric building. Manitoba Housing Authority staff responsible for the building were not familiar with the energy systems in the building, and could not identify anyone knowledgeable on its electrical systems. There were numerous cable entries into what appeared to be the main power distribution panel, but there was not one set larger than all others. Ammeter measurements indicated that there was not one cable set that carried sufficient power to supply the loads measured in all the other cables connected to the panel.

After the site visit, as-built electrical drawings were obtained from Manitoba Housing. The drawings showed that power was supplied to the main panel via three sets of cables (i.e., nine power and three common or grounding cables). Based on discussions with an electrical engineer, it was expected that the amperages in the three cables feeding a particular power phase in the panel would be balanced, but that there would be differences in total amperage between phases. Measurements of loads in the nine power feed cables indicated short-term monitoring of all nine cables was needed to assess which cables to monitor for the longer term. Analysis of the short-term data indicated loads in seven of the nine cables were similar in terms of magnitude and profile. Loads in the other two cables were distinctively different from the first seven, but similar to each other.

In the time between the qualification inspection and the initiation of short-term monitoring, a plumbing problem resulted in the electrical room being flooded with sewage. In February, a break in a water line resulted in the room being flooded again. Data logging equipment and the stored data survived the flood.

At the outset, we were advised that the corridor ventilation system in this building was slated for a gas retrofit in mid to late March, 1999. The corridor ventilation system retrofit commenced earlier than expected. As a result, data acquisition ended February 25, 1999 when the corridor ventilation system was removed.

The qualifying inspection at 185 Smith was done in early December, 1998. This building uses gas for both space and corridor ventilation air heating. After the inspection, the gas utility was contacted regarding pulse metering gas flows to the building. This was the first such request that the utility had received, but the utility had been studying the application of pulse metering as a customer service. It took approximately eight weeks from our initial request until the utility connected our data logger to the gas meter. During that eight-week period: a water main break flooded the basement of the building to the four-foot level (the gas meter was submerged); the gas utility contacted its meter suppliers for information regarding pulse metering; the gas utility's legal department drafted an agreement to define responsibilities for those wishing to connect data loggers to utility meters; and, we rewrote the gas utility's agreement to better define the limits of our liability. At the end of that time period, a gas utility meter technician visited the site and determined that the gas meter was equipped with a pulse metering head. Connecting the data logger involved attaching two wires from the data logger onto a terminal strip on the pulse metering head.

The meter pulses at intervals of 1000 cubic feet of gas. Whereas this is an appropriate pulse rate for monthly billing purposes on a large gas service, it is somewhat crude for the purposes of this study.

On February 25, the gas meter in the building ceased operating, a result of flood damage. The person contracted to switch the ventilation system was also contracted to read the gas meter, so was immediately aware of the failure. He had a personal financial interest in having the meter repaired (he only got paid for data collected), so he aggressively pursued the gas utility to repair the meter. The meter was repaired on March 4.

388 Kennedy has gas heating for corridor ventilation air and domestic hot water and electric baseboard heating in tenant suites. The gas meter, located outside the building, cannot be equipped for pulse metering. Automated monitoring of gas consumption in this building would have required meter replacement or opening a gas line to install a suitable metering/signalling device. If the gas meter were to be the monitored load, the data logger would either have to be located outdoors or wires would have to be strung across the parking lot from the meter to the data logger. Inquiries indicated upgrading the building gas meter or installing a sub-meter at the corridor ventilation unit boiler would be costly, so a decision was taken to manually read the gas

meter. Gas consumption had to be corrected for pressure and temperature. The gas company provided the correction multiplier.

The meter was located outside the building in the parking lot, so the reader needed to dress to read it during colder weather. The meter had to be read late at night and early in the morning, so required use of a flashlight. The gas meter had seven dial-type indicators. The plastic window over the dials was yellow with age. These factors complicated the meter reading and undoubtedly increased the frequency of meter reading errors. Thus, the data for this address was less precise than would have been the case with machine-read data. This problem would have been avoided if the meter reader had been asked to record analog data (i.e., the position of meter dials) rather than digital data.

Although some meter reading errors could be identified with absolute certainty and corrected, others could not. The fifth dial of seven on the gas meter was the level at which errors could be easily detected and corrected during data analysis. Fifth dial reading errors were detected in 31 out of 193 meter readings or 23 out of 96 overnight test cycles. Fortunately, the impact of a typical meter reading error on the fourth or other higher resolution dial would almost always be less than 10% of overnight gas consumption.

The electric service into this building was not easily accessible for connection of data logging apparatus. The electric service supply appeared to enter the primary electric distribution panel from below through a slab-on-grade. Opening the primary electric distribution panel in the building would require turning off the power to the building. The primary panel serviced several sub-panels located throughout the building. The readout on the electric service meter had low resolution; overnight changes in meter readings were typically between 1 and 4.

An inquiry to the electric utility revealed that the electric service meter had built-in data logging/ storage capabilities. The electric utility agreed to provide electric energy use data over the monitoring period. However, when the data was retrieved, data was only available from March 23 to April 30.

303 Goulet is an all-gas building. The building caretaker was contracted to switch the corridor ventilation system and read meters. The gas meter was located in the boiler room behind some pumps. Accessing it required climbing over the pumps. The gas meter was not equipped for pulse metering, but it did have a digital readout. Gas consumption had to be corrected for pressure and temperature. The gas company provided the correction multiplier.

Initially, the caretaker did not fully understand the protocol for the fan-on/fan-off tests. This was realized on the first follow-up visit, about a week after monitoring was initiated. The intended protocol was reviewed with her at that time. Subsequent visits led to the conclusion that she was following the intended protocol.

Appendix C

Procedures for Providing a Conservative Estimate of the Annual Impact of Corridor Ventilation on Heating Costs

Estimating Seasonal or Annual Impact of Corridor Ventilation

The primary intent of this project was to develop a method to estimate the impact of operating corridor ventilation systems on net air change rates and hence on annual heating costs. The energy use equations for fan-on/fan-off derived from application of the protocol can be utilized to estimate the impact on overall air change rates and to provide a conservative estimate of the annual impact of corridor ventilation on heating costs. Procedures for doing so are outlined and demonstrated below.

1. Impact on Building Air Change Rates

Step 1) Determine Energy Use Equations - plot and examine the field test data (nighttime energy use versus outdoor temperature) to determine an appropriate balance point/cut-off temperature. At temperatures above the balance point outdoor temperature, building energy use is not related to outdoor temperature. Linear regression analysis is used on the data below the balance point temperature to identify the relationships between nighttime energy use and outdoor temperature with the corridor ventilation system operating and with the corridor ventilation system off, for each heating energy source used in the building.

For example, for 388 Kennedy (gas-heated corridor ventilation and DHW, electric space heating), visual examination of the data indicated that 10°C was an appropriate cut-off temperature. Linear regression of average nighttime gas and electric energy use at outdoor temperatures below 10°C resulted in the following relationships:

Gas Consumption with corridor fans on (m^3/hour) = 8.315 - 0.237 T
Gas Consumption with corridor fans off (m^3/hour) = 3.623 - 0.040 T

Electric energy use with corridor fans on (kW) = 66.449 - 1.975 T
Electric energy use with corridor fans off (kW) = 67.935 - 2.107 T

where T is outdoor air temperature in °C.

Step 2) Determine Actual Air Flow Rates - measure or otherwise obtain corridor ventilation system air flows and any other air flows which are switched on and off as part of the application of the field test protocol.

For example, for 388 Kennedy, the air flow rate for the corridor ventilation system, measured in the mechanical rooms, was 4983 cfm (2350 L/s). The exhaust flow rate was 3756 cfm (1770 L/s).

Step 3) Estimate Energy Requirements at Temperatures of Interest - at each temperature which is of interest, use the energy use equations to estimate heat flow rates for each energy form for the fans-on and the fans-off operating conditions.

For example, for 388 Kennedy, at an outdoor temperature of -20°C:

Gas, fans on = 8.315 - 0.237 (-20°C) = 13.055 m^3/hour
Gas, fans off = 3.623 - 0.040 (-20°C) = 4.423 m^3/hour

Electric, fans on = 66.449 - 1.975 (-20°C) = 105.949 kW
Electric, fans off = 67.935 - 2.107 (-20°C) = 110.075 kW

Step 4) Estimate the Difference in Fans-on and Fans-off Heat Delivery Rates - apply energy system conversion efficiency and heat recovery system contributions to the energy requirements determined in Step 3 in order to estimate heat delivery rate from each energy source for the fans-on and the fans-off operating conditions. Use common units for each energy form (e.g., kW).

For example, for 388 Kennedy, assume the conversion of gas to useful heat is 75 percent efficient and the heat recovery system has an effectiveness of 40 percent at -20°C.

13.055 m^3/hour of gas (fans on) less 4.423 m^3/hour (fans off) is a difference of 8.63 m^3/h. At a 75 percent conversion efficiency, this equals a heat delivery rate of 66 kW.

At -20°C, operating the corridor ventilation system increases the building heat load met by gas by 66 kW. Heat recovery also meets part of the corridor ventilation heat load. The fraction met by heat recovery is less than the 40 percent effectiveness of the heat recovery device, because the exhaust air flow (1770 L/s) is about 75% of the supply air flow (2350). Thus, the fraction of heat provided by the heat recovery system is 30% (i.e., 40 percent heat exchanger effectiveness multiplied by the ratio exhaust to supply air). Therefore, the 66 kW increase in heating load that is met by the gas-fired unit would be 70% of the total corridor ventilation system heat load. If 70% of the load is 66 kW, the whole heating load, including the portion met by heat recovery, is 95 kW.

The estimated impact of operating the corridor ventilation system at -20°C is an increased energy load of 95 kW.

The estimated impact on electric demand of operating the corridor ventilation system at -20°C is a decreased energy load of (110.075 kW - 105.949 kW) 4.1 kW.

Step 5) Calculate Air Flows that Heat Delivery Rates can Temper - the changes in heat delivery rates calculated in Step 4 are assumed to be related to changes in the loads to heat outdoor air. The air flow rates can be estimated by applying and solving one of the following equations:

Heat flow rate (watts) = 1.2 x temperature difference (°C) x air flow rate (L/s)
Heat flow rate (Btuh) = 1.08 x temperature difference (°F) x air flow rate (cfm)

For example, operating the corridor ventilation system at 388 Kennedy appeared to:

increase the air flow heated by the corridor ventilation system by 1980 L/s (determined from (95 000 watts = 1.2 x (20°C - (-20°C)) x air flow), assuming the corridor ventilation system heats air to 20°C, and;

decrease the load met by electric space heating by an air flow equivalent to 80 L/s (determined from (4100 watts = 1.2 x (22°C - (-20°C)) x air flow), assuming this was infiltration air into suites heated to 22°C.

Thus, the apparent net change in air flow to the building when operating the corridor ventilation system at -20°C is an increase of (1980 - 80) 1900 L/s.

Step 6) Express Net Change in Ventilation as a Fraction of Corridor Ventilation - calculate the ratio of the net change in whole-building air flow calculated in Step 5 relative to the measured air flow rate for the corridor ventilation system determined in Step 2.

For example, at 388 Kennedy, the amount of air delivered by the corridor ventilation system was measured to be 2350 L/s. The apparent increase in whole-building air change rate when the corridor ventilation system operated was 1900 L/s. The apparent increase in whole-building ventilation rate expressed as a fraction of the measured corridor ventilation air flow rate is (1900/2350) 0.8 or 80%.

2. Impact on Energy Use and Energy Costs

Step 1) Determine Energy Use Equations - determine the relationship between outdoor temperature and nighttime energy use for each heating energy source used in the building, for fan-on and fan-off operating conditions, during the heating season, as described in Step 1 in Impact on Overall Ventilation Rates above.

Step 2) Obtain Annual Temperature Data - temperature bin data is suitable for this application as would be hourly or average daily temperatures.

Bin temperature data for Winnipeg is presented in Table 2 in the body of the report. In this table, there are 351 hours in the -20°C temperature bin (i.e., the temperature bin which includes time/ temperature data between -22°C and -18°C).

Step 3) Estimate Energy Requirements at Temperatures of Interest - at each temperature which is of interest, use the energy use equations to estimate heat flow rates for each energy form for the fans-on and the fans-off operating conditions.

For example, for 388 Kennedy, at an outdoor temperature of -20°C:

Gas, fans on = 8.315 - 0.237 (-20°C) = 13.055 m^3/hour
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Electric, fans on = 66.449 - 1.975 (-20°C) = 105.949 kW
Electric, fans off = 67.935 - 2.107 (-20°C) = 110.075 kW

Step 4) Estimate Heating Season Energy Impact - the methodology applied will depend on whether bin temperature data or time/temperature-based data is utilized. For temperatures below the cutoff temperature, the products of energy use at specific outdoor temperatures, determined in Step 1, and time spent at that temperature, determined from the temperature data referenced in Step 2, are summed to determine the total for the heating season. Separate calculations should be done for each energy source if the cost impact is of interest.

For example, for 388 Kennedy, in the -20°C temperature bin:

Gas, fans on	= 13.055 m^3/hour x 351 hours =	4582 m^3
Gas, fans off	= 4.423 m^3/hour x 351 hours =	1552 m^3
	Difference	3030 m^3

Electric, fans on	= 105.949 kW x 351 hours =	37 188 kWh
Electric, fans off	= 110.075 kW x 351 hours =	38 636 kWh
	Difference	- 1 448 kWh

The estimated impact, using the bin temperature data for the year (see Table 2 d) in the body of the report) estimates the annual impact of operating the corridor ventilation system as increasing gas consumption by 29 396 m^3 and decreasing electric consumption by 11 554 kWh.

Step 5) Apply Energy Cost to Determine Energy Cost Impact - apply unit energy prices to the estimated annual energy changes to estimate the cost impact of operating the corridor ventilation system. This was done in Table 3 in the body of the report.