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# MONITORING AND INVESTIGATION OF A MULTI-SUITE RESIDENTIAL COMPLEX IN WHITEHORSE, YUKON, FROM 1988 To 1992

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Energy, Mines and Resources Canada
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The goal of this study reported here was to advance our understanding of multi-residential buildings. Closeleigh Manor is EMR's first involvement in building and monitoring a multi-residential dwelling to the equivalence of the R-2000 performance standard for houses.

This work was performed for CANMET's Buildings Group as part of its commercial-buildings research activities. These activities are distinct from but complementary to the Buildings Group's Advanced Commercial Buildings Program (C-2000).

For more information on this project, contact CANMET's Frank Szadkowski, the project manager, at (613) 995-9043. For further information about C-2000 or the Buildings Group's other commercial-building research activities, contact Nils Larsson, MRAIC, the C-2000 Program Manager, at (613) 943-2263, 580 Booth St. Ottawa Ontario, K1A 0E4.

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## Executive Summary

Closeleigh Manor is a 3-storey, 3140 m², 30-suite apartment building with 340 m² of commercial space. It is located in Whitehorse, Yukon, situated at latitude 60.7°North at an elevation of 637 m. Whitehorse has a 97½% design temperature of -41°C and 6988 Celsius heating degree-days. The complex, which opened in 1988, was designed for senior citizens and represents the first building of its kind to be constructed to the equivalence of the R-2000 performance standard developed for houses. Energy efficient features incorporated into Closeleigh Manor include increased wall and ceiling insulation levels, upgraded windows, a vapour diffusion retarder and continuous air barrier system, and a ventilation system with heat recovery.

The purpose of this project was to learn more about the cold climate operation of a multi-suite residential complex that had been built using R-2000 standards. The results and findings were to be used to assist in providing answers to common questions and concerns about large buildings in the areas of design, envelope durability, the operation, effectiveness and efficiency of mechanical systems, and indoor air quality. The project's conclusions and recommendations were to provide guidelines for the design and operation of future buildings of this type. This report documents information relating to:

- the monitoring investigation which commenced in the fall of 1988;
- the original building design;
- the issues which arose and the problems which occurred in the ensuing years;
- the manner in which issues and problems were addressed and resolved;
- system changes which were implemented and their effect on building performance;
- recommendations for further system changes;
- the use of building energy analysis tools such as the DOE2 computer program; and
- guidelines and recommendations for the design and operation of future buildings.

To evaluate the performance of Closeleigh Manor and to analyse the applicability of R-2000 standards to apartment buildings of this type, a study of the building was initiated in the fall of 1988. A computer monitoring system was installed to continuously gather the data required to assess actual building performance and to determine the effectiveness of the energy efficient features. The system consisted of approximately 120 sensors located throughout the building and measured heating fluid flow rates and temperatures, supply and exhaust air flow rates and temperatures, energy consumption, interior space conditions and weather. In addition to the computerized monitoring, a series of ventilation related manual measurements were conducted to gather detailed information on the air distribution system and the indoor environment and an independent engineering evaluation of the building was carried out.

A detailed analysis of the computerized and manually measured monitored data from Closeleigh Manor was carried out in the following areas:

- the building envelope;
- the design heating requirement;
- the envelope air leakage;
- the heat recovery system;
- the ventilation air distribution system;
- the boiler system
- the space heating system;
- the domestic hot water system;
- the cooling system; and
- the electrical system.

The findings showed that the main factors which impacted on Closeleigh Manor's heating requirement were the ventilation rate, the envelope air leakage, the overall heat recovery effectiveness and the windows. The effect of these factors on the building's energy performance was studied using a calibrated energy analysis model. The analysis included Closeleigh Manor as it was originally constructed, the building after numerous changes were implemented, and the building's potential if it were being constructed today. The following annual space and ventilation requirements were determined.

- The original building configuration required 68.5 kJ/m²/HDD or 1503 GJ;
- After numerous changes, the current requirement is 49.0 kJ/m²/HDD or 1075 GJ/yr;
- With the technology advances in recent years, if Closeleigh Manor was constructed today, it would be possible to attain an annual space and ventilation load as low as 23.6 kJ/m²/HDD or 574 GJ.

On the basis of the findings of this project, the principal conclusions were:

- If systems in energy efficient buildings are to be properly sized and their performance is to be optimized, more sophisticated energy analysis tools must be used during the design process. Standards and guidelines which have served as accepted practices for a number of years may no longer apply to energy efficient buildings. Optimization must include the full range of operating conditions and not just design conditions.
- Buildings of this nature must be commissioned over a full range of operating conditions if their performance and operation are to be optimized. This will require monitoring the energy performance of the whole building and the HVAC components. The more complex the building, the more important the commissioning process becomes. Annual system operation specifications and maintenance schedules must be developed and fully documented as part of the commissioning.
- Every attempt should be made to keep building systems as simple as possible. This is especially true in the north due to the harshness of the climate, the remoteness of the location and the lack of skilled service people required to maintain these systems.
- Building operators must be trained to properly operate the building and make the seasonal adjustments required to optimize performance. The building operator must then educate the occupants so that they do not operate their suites in a manner that will undermine the efforts to optimize building performance throughout the year.

The report includes recommendations and guidelines for additional changes at Closeleigh Manor which will improve the energy performance and ensure that the building is operated in a manner that will maximize its performance.

Recommendations are also presented which will serve as guidelines for the design, specification and operation of building systems in future buildings of this type.

**Résumé**

Closeleigh Manor est un immeuble de trois étages mesurant 3140 $m^2$. Il abrite 30 appartement et contient 340 $m^2$ d'espace à bureaux. Il est situé à Whitehorse, au Yukon, à une latitude de 60,7° nord et à une altitude de 637 m. Dans 971/2% des cas, Whitehorse a une température de calcul de -41° et il y a 6 988 degrés-jours de chauffage Celsius. L'immeuble, qui a été ouvert en 1988, a été conçu pour les personnes âgées et c'est le premier du genre à être construit selon des normes de rendement équivalentes à celles élaborées pour les maison R-2000. Des niveaux d'isolation plus élevés pour les murs et les plafonds, des fenêtres plus étanches, un retardateur de diffusion de la vapeur, un pare-air en continu et un ventilateur récupérateur de chaleur sont parmi les éléments qui contribuent à accroître l'efficacité énergétique de Closeleigh Manor.

Ce projet devait nous permettre d'en savoir plus sur l'entretien en climat froid d'un immeuble d'habitation de plusieurs appartements construit selon les normes R-2000. Les résultats nous ont fourni des réponses et des solutions aux questions et aux problèmes que posent habituellement la conception, la durabilité de l'enveloppe, l'entretien, l'efficacité et l'efficience des systèmes mécaniques et la qualité de l'air, lorsqu'il s'agit de grands bâtiments.

Les conclusions et les recommandations émises à l'issue du projet devaient servir à établir des lignes directrices pour la conception et l'entretien des bâtiments du même genre qui seraient construits par la suite. Ce rapport inclut des données sur les points suivants :

- surveillance commencée en automne 1988;
- conception originale du bâtiment;
- questions et problèmes qui se sont posés dans les années qui ont suivi;
- manière dont les questions et les problèmes ont été étudiés et régles;
- modifications apportées au système et incidence sur le rendement de l'immeuble;
- recommandations de nouveaux changements à apporter au système;
- utilisation d'outils d'analyse énergétique, tels que le programme informatisé DOE2;
- directives et recommandations pour la conception et l'entretien des bâtiments qui seront construits dans l'avenir.

Pour évaluer le rendement de Closeleigh Manor et analyser l'applicabilité des normes R-2000 aux bâtiments de ce genre, on a entrepris une étude du bâtiment à l'automne 1988. On a installé un système de surveillance informatisé afin de recueillir en permanence les données nécessaires pour évaluer le rendement réel du bâtiment et pour déterminer l'efficacité des équipements qui influent sur son rendement énergétique. Le système de surveillance - environ 120 détecteurs installés partout dans le bâtiment - mesurait le débit et la température du liquide calorifère, le débit d'air en circulation, la consommation énergétique, les conditions intérieures et la température extérieure. En plus de ce moyen de surveillance informatisé, on a mesuré manuellement la ventilation pour obtenir de l'information précise sur le système de distribution de l'air et le milieu intérieur. Enfin, une évaluation technique du bâtiment a été effectuée par une entreprise indépendante de génie-conseil.

Un anayse précise des données obtenues à l'aide des outils informatisés ou manuels a été effectuée sur les aspects suivants :

- enveloppe du bâtiment;
- besoins théoriques en chauffage;
- chaudière;
- système de chauffage des locaux;

- infiltration d'air dans l'enveloppe;
- système de récupération de la chaleur;
- système de distribution de l'air de ventilation;
- système de chauffage de l'eau;
- système de refroidissement;
- système électrique.

D'après les résultats obtenus, on a découvert que c'était surtout la ventilation, les fuites d'air dans l'enveloppe, l'efficacité de l'ensemble du système de récupération de la chaleur et l'étanchéité des fenêtres qui influaient sur les besoins en chauffage. On a étudié la façon dont ces facteurs intervenaient dans le rendement énergétique du bâtiment au moyen d'un modèle étalonné d'analyse de l'énergie. L'analyse portait sur le bâtiment tel qu'il avait été construit à l'origine, sur le bâtiment après ses nombreuses modifications et sur les capacités du bâtiment s'il avait été construit aujourd'hui. Les besoins annuels en espace et en ventilation ont été déterminés :

- pour le bâtiment tel qu'il était configuré à l'origine, il fallait 68,5 kJ/m$^2$/degrés-jours de chauffage ou 1 503 GJ:
- après les nombreux changements, les besoins actuels sont de 49,0 kJ/m$^2$/degrés-jours de chauffage ou 1 075 GJ/année;
- Si Closeleigh Manor était construit aujourd'hui, avec les progrès technologiques réalisés au cours des dernières années, aussi peu que 23,6kJ/m$^2$/degrés-jours de chauffage ou 574 GJ suffiraient pour le chauffage et la ventilation.

Le projet a permis de tirer les conclusions suivantes :

- dans les bâtiments à haut rendement énergétique, pour installer des équipements de taille adéquate et optimiser leur rendement dans, il faut utiliser des outils d'analyse énergétique plus sophistiqués durant la phase de la conception. Les normes et les directives utilisées depuis de nombreuses années peuvent ne plus s'appliquer aux bâtiments à haut rendement énergétique. Si l'on veut optimiser le rendement, on ne doit pas tenir compte seulement des conditions théoriques mais de toute la gamme des conditions réelles de fonctionnement.

- Pour la mise en service de bâtiments de ce genre, on doit tenir compte de toutes les conditions de fonctionnement. Il faudra pour cela surveiller le rendement énergétique de tout le bâtiment et des éléments du système CVC. Plus le bâtiment est complexe, plus le processus de mise en service devient important. Il faut fixer les spécifications annuelles pour l'exploitation du système et les dates d'entretien, puis documenter toutes les mesures prises.

- Il faut tout faire pour que les systèmes demeurent aussi simples que possible, et c'est encore plus nécessaire pour les bâtiments construits dans le Nord en raison de la rigueur du climat, de l'éloignement et du manque de personnel d'entretien qualifié sur place.

- Les responsables des bâtiments doivent recevoir la formation nécessaire pour faire fonctionner adéquatement le bâtiment et faire les ajustements saisonniers nécessaires afin d'optimiser son rendement. Le responsable doit ensuite montrer aux occupants comment bien utiliser l'équipement de façon à ne pas nuire aux efforts déployés durant une année pour optimiser le rendement du bâtiment.

Le rapport comprend des recommandations et des lignes directrices relatives aux changements supplémentaires à apporter pour améliorer le rendement énergétique de Closeleigh Manor et utiliser le bâtiment de manière à optimiser son rendement.

On présente aussi des recommandations qui serviront de directives pour la conception, les spécifications et l'entretien de l'équipement dans des bâtiments du même type qui seront construits par la suite.

# 1. Background

Closeleigh Manor, located in Whitehorse, Yukon, is a multi-suite residential and commercial building designed for senior citizens. This 3-storey complex, which opened in 1988, represents the first building of its kind to be constructed to the R-2000 performance standard developed for houses constructed in cold climates. Energy efficient features incorporated into Closeleigh Manor included increased wall and ceiling insulation levels, upgraded windows, a vapour diffusion retarder and continuous air barrier system, and a ventilation system with heat recovery. The residential area consists of 19 single- and 11 two-bedroom suites with a lounge area on each floor. A commercial area houses the Whitehorse Housing Authority, which manages the building, and the Yukon College Downtown Learning Center, which holds classes for up to 30 students at a time. Elevation views of the building are presented in Figures 1 to 4 and the floor plans are shown in Figures 5 and 6.

In order to evaluate the performance of Closeleigh Manor and to analyse the applicability of R-2000 standards to multi-level apartment buildings, a study of the building was initiated in the fall of 1988. A computer monitoring system was installed to continuously gathered the data used to assess actual building performance and to determine the effectiveness of the energy efficient features. The system consisted of approximately 120 sensors located throughout the building which measured heating fluid flow rates and temperatures, supply and exhaust air flow rates and temperatures, energy consumption, interior space conditions and weather conditions.

The investigation carried out during the 1988/89 heating season included an analysis of the design of the building, a comparison of the simulated and monitored building performance using the U.S. Department of Energy building energy analysis program, DOE2.1C, and a parameter sensitivity study to optimize the thermal design and performance of the building. The report on this investigation [13] detailed the building design and the design of the monitoring system, presented the findings of the work carried out and made a number of recommendations for reducing energy consumption and improving overall performance. From the findings, it was evident that the building's heating and ventilation systems had not been optimally designed and that a number of changes could be carried out which would improve the building's overall performance.

As a result, in December 1989, a technical meeting involving representatives from Besant Consulting (BEC), Howell-Mayhew Engineering (HME), Energy, Mines and Resources Canada (EMR), the Canada Housing and Mortgage Corporation (CHMC), the National Research Council (NRC), the Yukon Housing Corporation (YHC), and the Whitehorse Housing Association (WHA) took place in Whitehorse to discuss the performance and operation of Closeleigh Manor and to formulate recommendations for optimizing performance. Changes were recommended in four areas - heating and ventilation, electrical energy use, system redesign, and operating manuals and tenant education. The recommendations were documented in reports by BEC [12], CMHC [17], and NRC [7] and submitted to YHC and EMR for evaluation and implementation. A summary of all of these recommendations was included in a 1991 monitoring proposal to YHC by HME [10].

Monitoring continued in January 1990 to evaluate building changes which were to be implemented before the end of the heating season. In March 1990, five of the ten boilers initially installed in the building were shut down and isolated from the boiler loop, and the supply and exhaust ventilation rates were reduced to approximately 0.5 air changes per hour (ACH) from the design value of 1.0 ACH. Monitoring continued through April 1990 and the results of this investigation were presented in four monthly reports submitted to EMR and YHC by BEC [12].

In June 1990, as part of their commitment to optimizing the performance of Closeleigh Manor, YHC engaged J.M. Bean & Co. (JMB), a Vancouver-based engineering firm, to carry out an engineering evaluation of the building. One of JMB's tasks was to review recommendations which had emerged from the monitoring investigations and make decisions regarding building modifications which should be implemented.

In the fall of 1990, HME assumed responsibility for the analysis of the monitored data from BEC. In anticipation of the completion of additional building system changes during the 1990/91 heating season, EMR provided additional support for YHC to evaluate building performance and HME carried out a monitoring investigation from November 1990 through April 1991. Unfortunately, heating system problems encountered during this time prevented the implementation of additional changes and a comparative analysis evaluating the effects of proposed changes could not be carried out. However, the *R-2000 Data Processing Program,* developed for processing data from the R-2000 Level B houses, was customized for use in processing the data from Closeleigh Manor. The detailed information provided by the processed output resulted in a greater understanding of the performance of the heating and ventilating systems and provided YHC and JMB with the technical data and information necessary to evaluate proposed changes. In addition, a number of areas were studied in greater detail because of their importance to building performance, and the acquired database provided the base of information required to conduct an in-depth comparative analysis and evaluation of proposed building changes. The results of the 1990/91 investigation were documented in a report submitted to EMR and YHC by HME [11].

The JMB engineering evaluation [16] and the plans for the proposed *Heat Reclaim System Renovation* were completed in August 1991 [19]. The renovation commenced in December 1991 and was completed in February 1992. A monitoring investigation was carried out from November 1991 through July 1992 in order to evaluate the changes implemented. In February 1992, the Saskatchewan Research Council (SRC) conducted a series of ventilation related measurements for comparison to the work conducted by NRC in December 1989. Also in February, a meeting was held at Closeleigh Manor and attended by representatives from YHC, WHA, JMB, HME, SRC and Arctech Associates. The purpose of the meeting was to review progress on changes to the building and to identify additional issues which should be addressed. As a result of this meeting, Arctech Associates of Whitehorse was hired to investigate a number of issues for YHC. A report on their findings [18] was submitted to YHC.

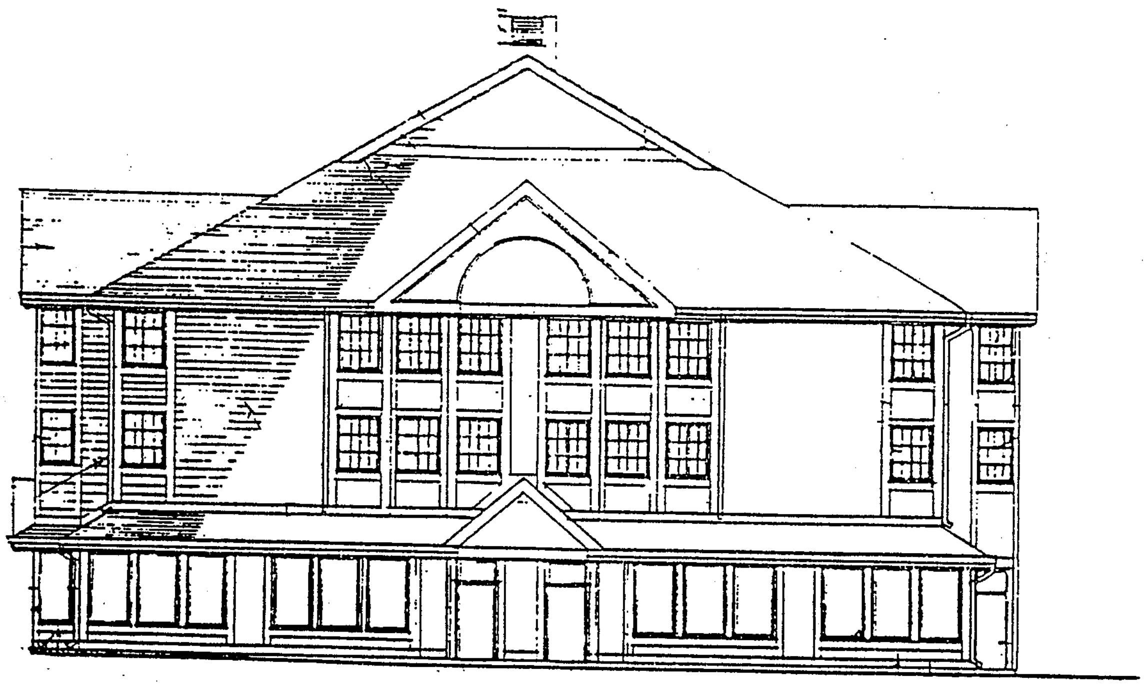

Figure 1: North Elevation of Closeleigh Manor

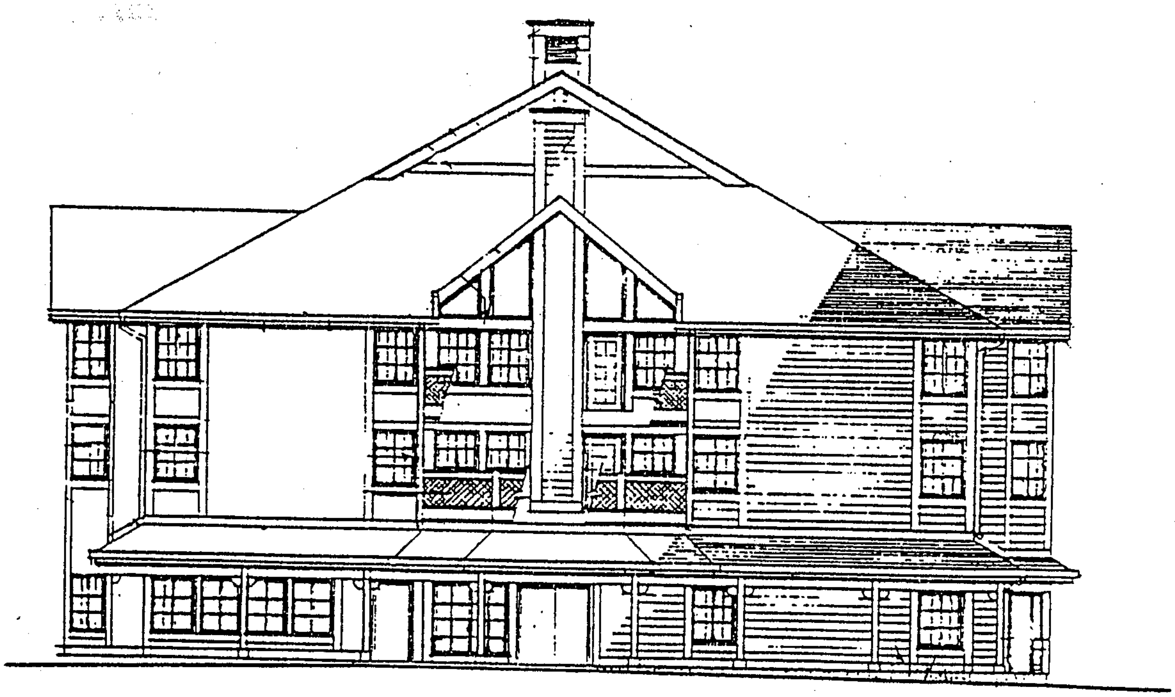

Figure 2: South Elevation of Closeleigh Manor

Figure 3: East Elevation of Closeleigh Manor

Figure 4: West Elevation of Closeleigh Manor

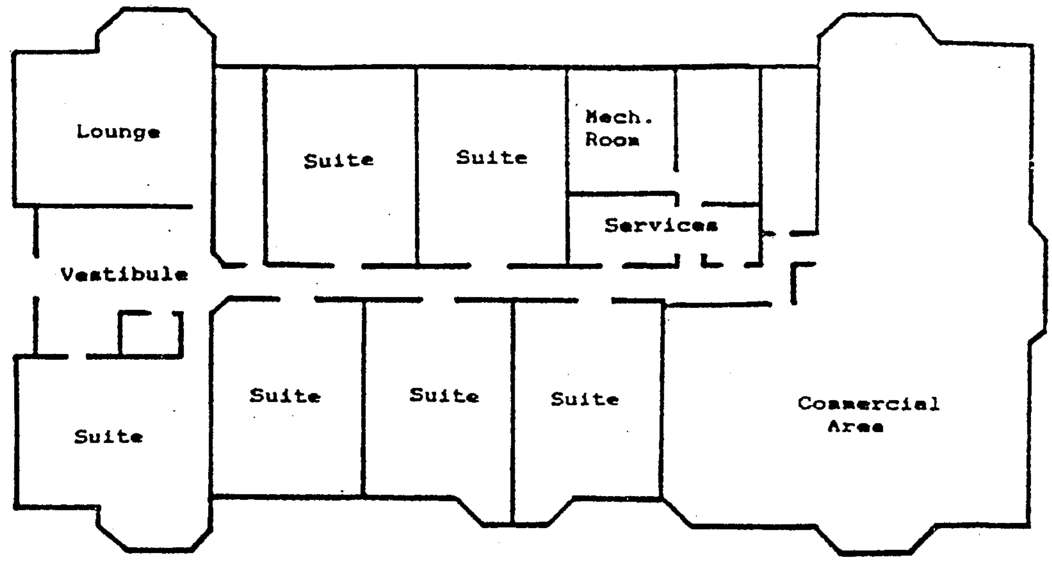


Figure 5: First Floor Layout of Closeleigh Manor

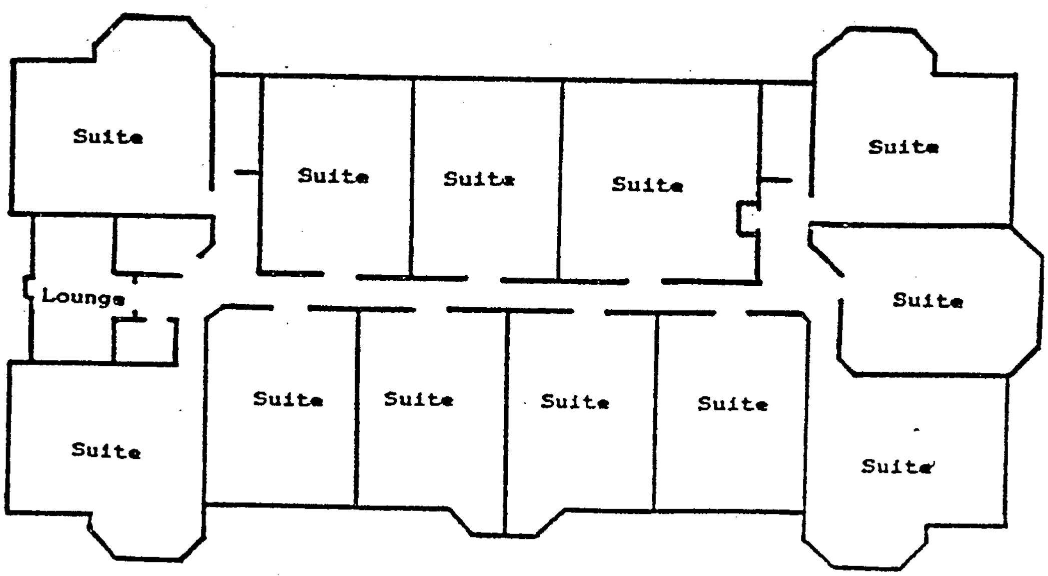


Figure 6: Second and Third Floor Layout of Closeleigh Manor

## 1.1. Introduction

The purpose of the project was to learn more about the cold climate operation of a multi-suite residential complex that had been built using R-2000 standards. The results and findings were to be used to assist in providing answers to common questions and concerns about large buildings in the areas of design, envelope durability, the operation, effectiveness and efficiency of mechanical systems, and indoor air quality. The project's conclusions and recommendations were to provide guidelines for the design and operation of future buildings of this type.

The purpose of this report is to present the results of each of the completed investigations in a manner which will allow them to serve as a guide to the design and operation of future buildings of this type. It documents information relating to:

- the monitoring investigation which commenced in the fall of 1988;
- the original building design;
- the issues which arose and the problems which occurred in the ensuing years;
- the manner in which issues and problems were addressed and resolved;
- the system changes implemented and their effect on building performance;
- recommendations for additional system changes;
- the use of energy analysis tools such as the DOE2 computer program; and
- guidelines and recommendations for future buildings of this type.

The results, conclusions and recommendations presented in this report may differ from those reported previously because, with each year of monitoring, a greater understanding of the building and its systems was achieved. This report supersedes all previously published and unpublished reports and, where differences occur, this document shall be deemed to be correct. Every attempt has been made to clearly indicate the source of all of the information presented in this report. This should assist the reader in understanding differences encountered among existing reports.

The following acronyms appear frequently throughout this report.

<u>Organizations</u>

| | | | |
|---|---|---|---|
| BEC | Besant Consulting | SRC | Saskatchewan Research Council |
| CMHC | Canada Mortgage & Housing Corp. | UOS | University of Saskatchewan |
| HME | Howell-Mayhew Engineering | WHA | Whitehorse Housing Authority |
| JMB | J.M. Bean & Co. | YHC | Yukon Housing Corporation |
| NRC | National Research Council | | |

<u>Technical Terms</u>

| | | | |
|---|---|---|---|
| ACH | air changes per hour | L/s | litres per second |
| DHW | domestic hot water | MJ/h | megajoules per hour |
| GJ | gigijoules | TMY | typical meteorological year |
| HDD | Celsius heating degree days | | |
| HVAC | heating, ventilation and air conditioning | | |

# 2. Monitoring Investigation

## 2.1. Data Collection

The computerized monitoring system installed at Closeleigh Manor consisted of over 120 sensors which continually measured primary and secondary heating system fluid-flow rates and temperatures, supply and exhaust air flow rates and temperatures, the electrical consumption of various building components, interior space conditions including air quality, and weather conditions. A complete list of the monitored parameters and the monitoring equipment is presented in Appendix A.

In addition to computerized data collection, ventilation related measurements were carried out by the NRC in December 1989 [8] and by SRC in February 1992 [5].

Problems encountered with the building systems and with the monitoring system that affected data collection are detailed in the reports on the investigation conducted during each of the heating seasons from 1988 to 1991. Problems encountered during the 1990/91 and 1991/92 heating seasons are footnoted on the processed data sheets. In this way, as the processed data is reviewed, the reader can immediately evaluate the effects of these problems on the data.

## 2.2. Data Processing

Investigations during the first two years of building operation presented only a portion of the data collected due to the lack of a data processing tool capable of processing the large amount of monitoring data in a reasonable amount of time.

A similar problem was encountered during EMR's R-2000 house monitoring program and solved with the development of the *R-2000 Level B Data Processing Program,* designed using the spreadsheet software, Microsoft Excel. One of the tasks carried out as part of the 1990/91 investigation, was the customizing of this program for use in processing the data from Closeleigh Manor. The processed data output comprised daily summaries for each month and consisted of 16 pages of detailed information on approximately 140 different parameters, and a one page summary sheet which highlighted the main parameters of the detailed output. Presented in this manner, the output served the needs of those interested in only an overview of the data as well as those interested in more detailed information.

The processed data sheets were streamlined for the 1991/92 investigation and reorganized to better suit the needs of the individuals using the information. Processed data is available for November 1991 through July 1992 and is included in Appendix E. The output comprises both monitored data and calculated values. The equations used to determine the calculated values are presented in Appendix B. Details about events which affected the data and additional information about specific parameters are footnoted on each sheet.

## 2.3. Data Analysis

Throughout the project, it was often difficult to use the monitored data to analyse the performance of the building from one heating season to the next because of:

- the numerous building changes which occurred at irregular times throughout the monitoring period;
- the partial months of data that resulted from down-time caused by various monitoring and building system component failures;
- the different number of monitored months during each heating season; and
- the significant differences in the amount of energy reclaimed by the recovery system from one year to the next.

The original intent of the 1991/92 investigation was to use the processed database from the 1990/91 heating season to carry out a comparative analysis with the 1991/92 processed data in order to evaluate the major mechanical system changes took that place during the *Heat Reclaim System Renovation.* The 1990/91 processed data was considered to be the most reliable and useful database for conducting a comparative analysis since it had been thoroughly checked by HME and few building changes had been carried out during this monitoring period.

This changed, however, when the *Heat Reclaim System Renovation,* which was originally scheduled for completion in November 1991, was not completed until February 1992. Establishing a database for this heating season was further hampered when faulty controls prevented the reclaim system from operating correctly until the middle of April. By this time, the heating season was almost over and the time required to collect the data necessary for the proposed comparative analysis had passed.

To assist in overcoming these problems, the U.S. Department of Energy's building energy analysis program, DOE2, was used extensively in the analysis of the data from the 1988/89 and the 1991/92 investigations. The investigation carried out during the 1988/89 heating season used DOE2.1C to assist in an analysis of the design of the building, a comparison of the simulated and monitored building performance, and a parameter sensitivity study to optimize the thermal design and performance of the building [13].

In the 1991/92 investigation, DOE2.1D, was calibrated by the University of Saskatchewan (USO) using the 1990/91 and 1991/92 databases and used for the final project analysis. A comparison of the monitored and simulated heating requirements for Closeleigh Manor for November 1991 and February/March 1992 is shown in Figures 7 and 8. The graphs show good tracking between the actual monitored data and the DOE simulated data and indicated that the calibrated model could accurately simulate the performance of Closeleigh Manor. All of the parameters used by USO to calibrate the DOE model are listed in Appendix C.

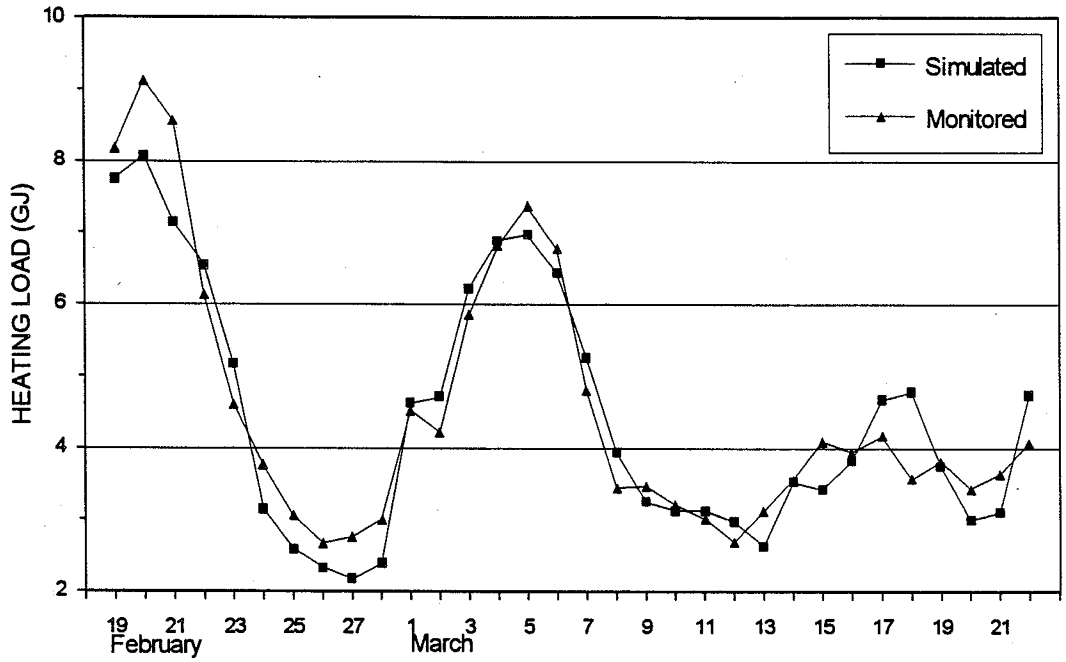


**Figure 7: Comparison of February and March Heating Requirements**

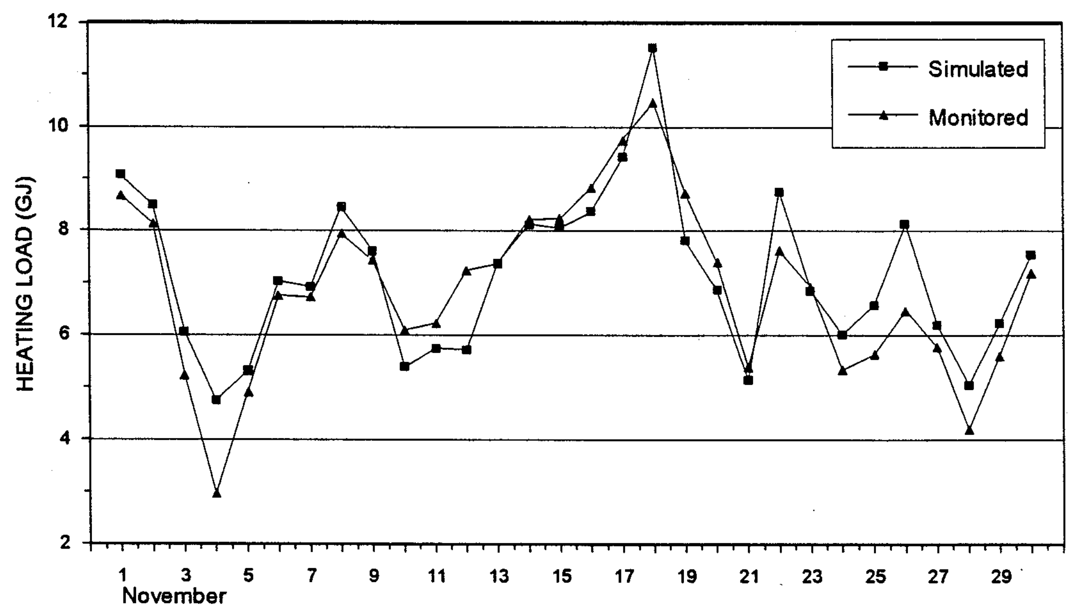


**Figure 8: Comparison of November Heating Requirements**

With assistance from USO researchers, the DOE model was used extensively by HME in the analysis to investigate and evaluate the effects of building system changes on the overall energy performance of Closeleigh Manor.

# 3. Results of the Monitoring Investigation

This section describes the building systems as they were originally specified, the subsequent changes which were implemented to improve the performance of the building and the results of the monitoring investigation which comprised:

- the computerized monitoring conducted by Howell-Mayhew Engineering (HME);
- the manual measurements carried out by the National Research Council (NRC) [8] and the Saskatchewan Research Council (SRC) [5]; and
- the engineering evaluation completed by J.M. Bean & Co. (JMB) [16].

The subjects addressed in this section include:

- the building description;
- the design heating requirement;
- the building envelope air leakage;
- the heat recovery system;
- the ventilation air distribution system;
- the boiler system
- the space heating system;
- the domestic hot water system;
- the cooling system; and
- the electrical system.

## 3.1. Building Description

Closeleigh Manor is a 3-storey, 3140 m², 30-suite apartment building which includes 340 m² of main floor commercial area at the north end of the building. It is located in Whitehorse, Yukon, which is situated at latitude 60.7°North, at an altitude of 637 m above sea level. Whitehorse has a 97½% design temperature of -41°C and 6988 Celsius heating degree-days (HDD) for a typical meteorological year (TMY), indicating a significant heating requirement. The total volume of Closeleigh Manor is 10,988 m³ and comprises a residential volume of 8,542 m³, a commercial volume of 1,339 m³ and a crawl space volume of 1,117 m³.

The building envelope is wood-frame construction with the residential area built over a crawl space and the commercial and service areas built on a slab-on-grade foundation. The upgrades incorporated into the building envelope in order for it to meet the R-2000 performance requirements included:

- blown-in fiberglass in the ceiling - RSI 7.0 (R 40.0);
- fiberglass batt insulation and sheathing in above grade walls - RSI 4.7 (R 26.5);
- fiberglass sheathing in below grade walls - RSI 3.1 (R 17.5);
- a continuous air barrier system; and.
- and upgraded windows.

The windows had the following features:

- triple-glazed, sealed units with a center-of-glass conductance of 1.82 W/m²·°C in suites at the north end of the building (all remaining windows were double glazed sealed units with a conductance of 2.82 W/m²·°C);
- all glazing units had 13 mm air spaces between each lite to reduce heat loss;
- all window types were fixed or casement to reduce air leakage; and
- all window frames were made of wood to reduce heat loss.

With these upgraded features, DOE calculated the effective RSI value of the windows, including the frame, to be 0.46 (R 2.6) compared to conventional metal sliding units at RSI 0.25 (R 1.4). The windows comprise 24 percent of the above grade envelope area which resulted in an effective insulation value of RSI 1.4 (R 8.1) for the above grade envelope and RSI 1.65 (R9.4) for the entire envelope, including the crawl space and slab-on-grade foundation.

## 3.2. Design Heating Load

The mechanical systems in Closeleigh Manor were sized and specified to meet design, or peak loading, conditions. Design conditions for the space heating system, for example, occur when the building is subjected to the coldest winter day and there are no external gains, such as solar energy, and no internal gains, such as occupant and electrical energy. None of the original design calculations were available and this report will reference only the engineering evaluation conducted by JMB and the DOE simulations carried out by the UOS.

The engineering evaluation of the building conducted by JMB included heat loss calculations using in-house software. Their software is based on engineering design practices which are in accordance with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines. A design analysis was also conducted by UOS using DOE2.1D. The building inputs used by JMB and UOS were determined independently using the original building specifications. The results of their design day analyses are presented in Table 1.

The design conditions used for their calculations included an indoor design temperature of 24°C, an outdoor design temperature of -40°C and a design ventilation rate of 1.0 air change per hour (ACH), based on the residential volume of the building. In the *JMB Revised Heating Load* shown in Table 1, the *Window glazing* heat loss has been calculated for a wood frame, instead of a metal frame, and the *Ventilation Air Heating Load* has been corrected for a pressure of 91.5 kPa. Once these corrections were made, the major difference between the *DOE Heating Load* and the *JMB Revised Heating Load* was the domestic hot water (DHW) load. This difference is discussed in Section 3.8.3.

### Table 1: Design Day Heating Loads

| Building System | JMB Initial Heating Load (MJ/h) | DOE Heating Load (MJ/h) | JMB Revised Heating Load (MJ/h) |
|---|---|---|---|
| **Building Envelope Heat Loss:** | | | |
| Roof | *32* | *39* | *32* |
| Walls, doors and floor | *108* | *118* | *108* |
| Window glazing | *241* | *145* | *189* |
| Envelope Leakage | *136* | *118* | *136* |
| | **517** | **420** | **465** |
| **Ventilation Air Heating Load: At 1.0 ACH** | **658** | **612** | **603** |
| *At 0.4 ACH* | *(263)* | *(245)* | *(241)* |
| **Domestic Hot Water Load** | **522** | **245** | **522** |
| **DESIGN HEATING LOAD: At 1.0 ACH** | **1,697** | **1,277** | **1,590** |
| *At 0.4 ACH* | *(1,302)* | *(910)* | *(1,228)* |

The building is currently operating at an average daily ventilation rate of approximately 1,200 L/s, which is equivalent to 0.4 ACH based on the combined residential and commercial volume. The volume of the commercial area was included with the residential volume because no additional ventilation was added in the commercial area once it became occupied in August 1989. All ventilation air is supplied by the central system. When the current flow rate was used as the design ventilation rate, the ventilation heating requirement and, therefore, the design heating load was reduced significantly. As shown in Table 1, the DOE design heating load for 0.4 ACH was reduced 29% to 910 MJ/h.

## 3.3. Envelope Air Leakage

Both uncontrolled and controlled air leakage occur across the building envelope. The amount of uncontrolled air leakage is dependent upon the integrity of the envelope's continuous air barrier system while controlled air leakage occurs through open windows and is dependent upon the number of open windows.

### 3.3.1. Continuous Air Barrier System

An air leakage test of the building envelope conducted in December 1989 by NRC [8] using the blower door method and conforming to CGSB 149.10-M86 test procedures, determined that the infiltration rate at 50 Pascals (Pa) was 0.76 ACH for the total building volume. This result satisfied the R-2000 envelope leakage requirement of a maximum of 1.5 ACH at 50 Pa and verified the integrity of the continuous air barrier system. The DOE simulations indicated that the building's natural uncontrolled envelope air leakage rate was approximately 0.1 ACH.

Neutral pressure level (NPL) testing was also carried out in December 1989 to determine the distribution of envelope leakage points. If leakage points are uniformly distributed vertically and there is no internal air flow resistance, the NPL is typically at the mid-height of the building. NRC determined the NPL to be at 6.1 meters, or 0.67 times the height of the building which indicated that, although the leakage was fairly well distributed throughout the building, there were more air leakage locations in the upper parts of the building. According to ASHRAE, the NPL in tall buildings varies from 0.3 to 0.7 of the total building height.

### 3.3.2. DOE Simulated Envelope Air Leakage

A comparison of the monitored building heating requirements[1] with the heating requirements determined using the DOE calibrated model, indicated that the monthly monitored space heating requirements were consistently higher than the DOE simulated space heating requirements. It was believed that the difference was due to variations in the air leakage rates across the building envelope from the first floor to the third floor, and from month to month during the year, caused by the opening of windows throughout the building. In order to determine the amount of air leakage

[1] Building heating loads were determined using the monitored data from the 1990/91 and 1991/92 heating seasons.

that would account for the differences in the space heating requirements, the infiltration rate specified in the DOE model was adjusted until the monitored and DOE loads were equal. Figure 9 compares a number of monthly heating requirements and indicates the envelope air leakage rate which was determined for each month.

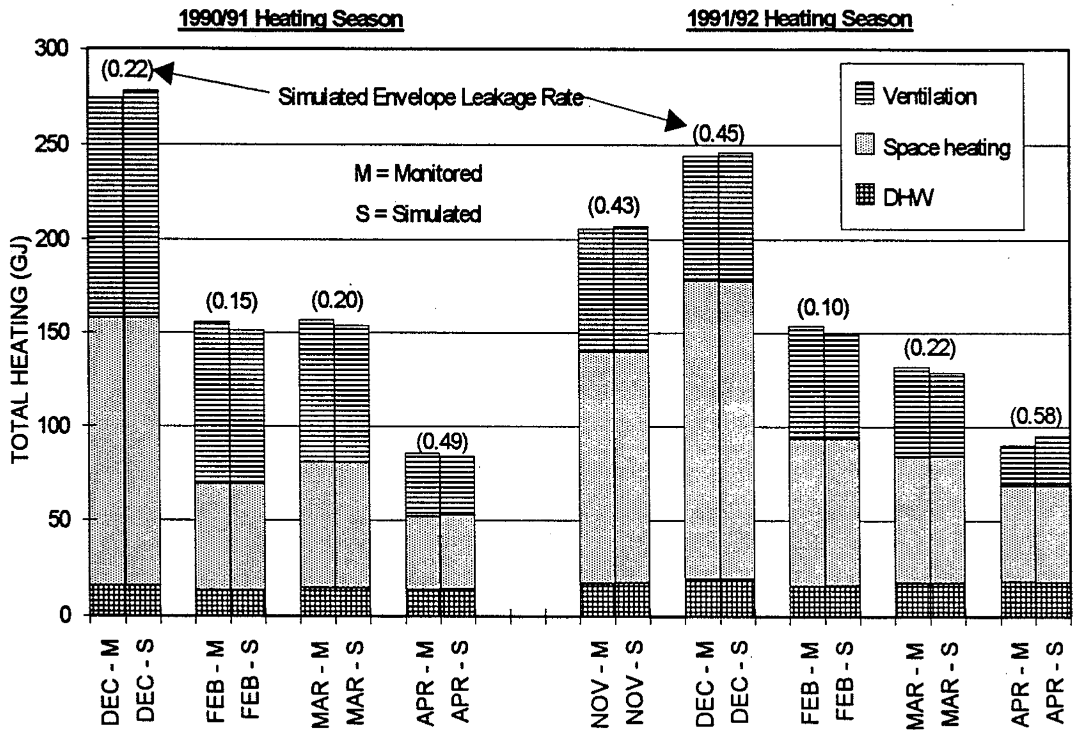


**Figure 9: DOE Simulated Envelope Leakage Rates**

The following points should be noted about this graph:

- The January 1991 data could not be used because monitoring system interference resulted in unreliable data.
- The January 1992 data was not used since the heat recovery system renovation was in progress and systems were not operating normally.
- In November and December 1991, the ventilation system was operating at 1.0 ACH whereas in all of the other months it was operating at approximately one-half of this value. It is not clear if the increased leakage rate was due to the increased air circulation, a greater number of open windows in the building, or a combination of both.
- During the first week of February 1992, all of the windows in the building were closed in order to conduct ventilation system balancing and ventilation system measurements by SRC. The leakage rate of 0.1 ACH for this month provides an indication of the rate that can be achieved in Closeleigh Manor if windows are kept closed.
- The higher leakage rates in April are an indication that, with the milder weather, more windows are being opened for longer periods of time.

The DOE simulation work indicated that, with the advanced R-2000 envelope air barrier system, the building had the capability of achieving an uncontrolled leakage rate of 0.1 ACH[2]. The rate that was typically achieved at Closeleigh Manor, however, appeared to vary significantly from 0.1 ACH and, at times, there was as much outside air leaking across the envelope as there was being supplied by the central ventilation system. From Figure 10, it can be seen that the variations caused notable increases in space heating requirements. For example, November and February 1992 had HDD of 816 and 860 respectively. The space heating required in November, however, with a simulated envelope leakage rate of 0.43 ACH, was 122.5 GJ compared to 77.7 GJ, an increase of 58%.

In order to verify that the DOE simulated leakage rates were correct, monitored data from the individual suites was analysed to determine if the space heating requirements in the suites varied with changes in the simulated air leakage rates, which had been determined using monitored data for the entire building. The analysis was conducted by comparing variations in the effective UA-values[3] of the monitored suites with the variations in the building's leakage rate. The results of this comparison, which are presented in Figure 10, showed a strong relationship between the envelope air leakage rate and the space heating requirement and confirmed that the simulated rates were a clear indication of the actual leakage rate which was occurring in the building.

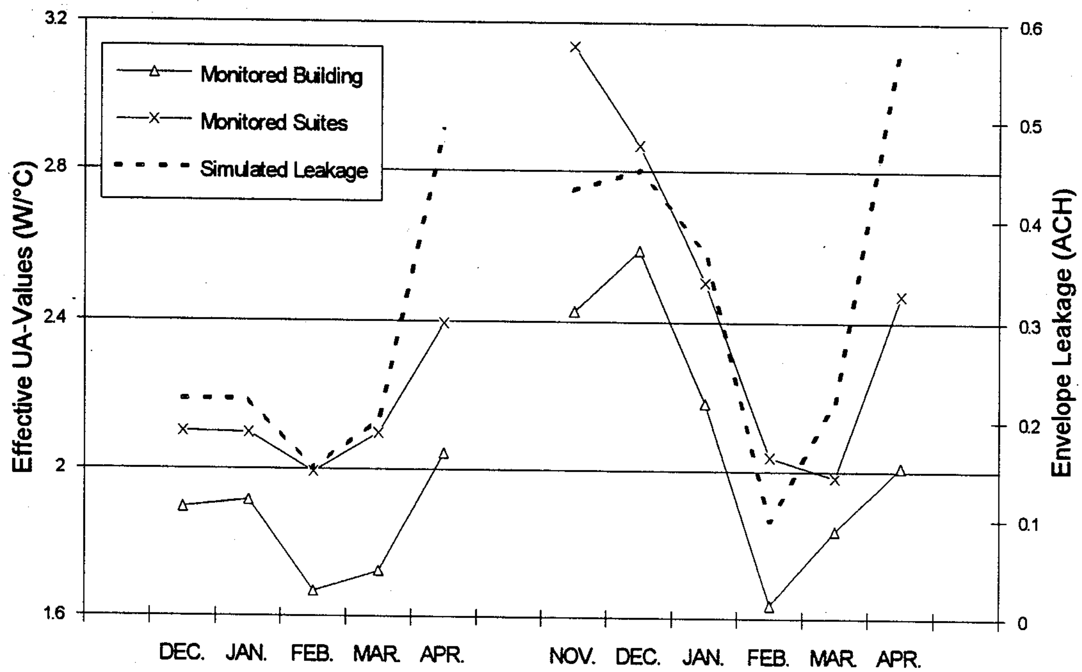


**Figure 10: Effective UA-Values and Envelope Leakage**

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[2] A rate of 0.25 to 0.35 ACH is considered normal for conventional buildings.
[3] The effective UA-value is the net space heating load, including electrical gains, divided by the average temperature difference.

### 3.3.3. Reducing Controlled Envelope Air Leakage

Having established the validity of the DOE envelope leakage rates, the calibrated DOE model was run with different rates. The results indicated that an increase of 0.1 ACH in the average annual envelope rate caused an increase in energy consumption of 91 GJ. This significant increase indicated that it would be worthwhile to reduce envelope leakage rates as much as possible. The integrity of the continuous air barrier system had been verified by testing carried out by NRC [8] and it appeared that increased air leakage variations were due to a greater amount of controlled air leakage through the large number of openable windows in Closeleigh Manor. This was supported by the DOE simulation results which showed the lowest air leakage occurring in February 1992 after all of the windows had been closed (Figure 9).

In order to develop solutions for reducing controlled air leakage rates, the driving forces which cause this leakage were investigated further. It was known that the infiltration and exfiltration rates across the building envelope were dependent upon:

- the temperature differences between the inside and outside;
- the pressure differences induced by the stack effect, the building's air circulation system and the prevailing winds; and
- the number of windows that were open at any one time.

<u>Effects of Temperature Difference</u>

Higher suite temperatures result in higher temperature differences across the building envelope and a subsequent increase in leakage rates. The average temperature in the monitored suites during the 1991/92 heating season was 23°C and ranged from 20°C to 26°C. The average temperature of the building, based on the exhaust air flow temperature during this same period, was 24°C. These temperatures, which are relatively high and reflect the elderly population in the building, are occupant controlled and, therefore, not likely to be reduced.

<u>Effects of Pressure Differences</u>

The building's natural stack effect and the amount of HVAC supply and exhaust air determine the position of the neutral pressure level (NPL) and the distribution of pressure differences across the building envelope. In December 1989, NPL measurements were carried out by NRC [8] under three operating conditions, with the following results:

- Under normal operating conditions, the NPL was 7.9 metres, or 0.86 of the inside building height above grade.
- With the ventilation system turned off, the NPL was 7.5 metres, or 0.82 of the inside building height. There was a slight excess of exhaust flow (1732 L/s) over supply flow (1670 L/s) and turning the ventilation system off caused the NPL to drop about 0.4 metres.

- With the ventilation system off and all of the windows in the building closed, the NLP was 6.1 metres, or 0.67 of the inside building height. In the previous tests, eleven windows in the building were found to be open on the upper floors. Closing the windows caused the NPL to drop 1.4 metres.
- Finally, by compensating for the flow of exhaust air up the boiler chimneys (the boilers had not been turned off during testing), it was determined that the NPL for the building, with no mechanical systems operating would be 6.1 metres, or 0.67 of the inside building height.

With the NPL above the second floor level, the tendency would be for cold outside air to infiltrate into the first and second floor suites and for warm inside air to exfiltrate from the third floor suites. Under these conditions, the space heating requirements for the first and second floor suites would increase during the winter months compared to third floor suites. The greatest effect would occur on the first floor where infiltration would be the greatest. Air that exfiltrates from third floor suites is replaced by heated building air from the hallway and, therefore, does not affect the space heating requirement. Figure 11 shows the effective UA-values for Suites 105, 205, and 305, three suites of identical size, and indicates that this is exactly what is happening. It is known that the occupant of Suite 105 liked to keep a window open at night.

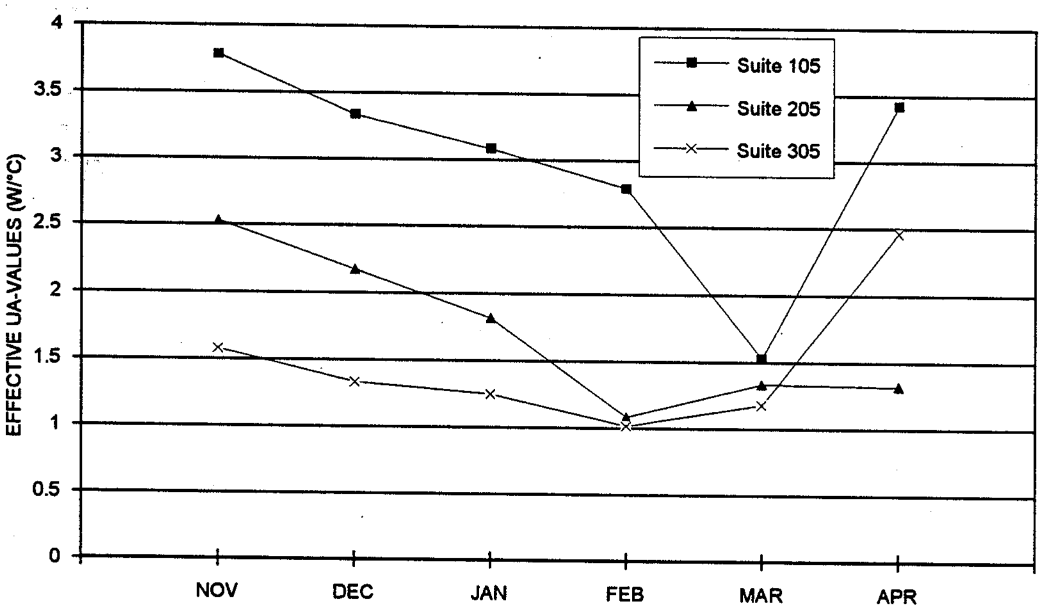


**Figure 11: Effective UA Values of Individual Suites**

The position of the NPL is also affected by the quantity of supply and exhaust air flow to the building and the locations in the building where this air is supplied and exhausted. A balanced ventilation system supplies and exhausts an equal amount of air and the NPL is not affected. In November 1990, the air handling system in Closeleigh Manor, was balanced and the results indicated that the net supply air flow rate was 230 L/s greater than the net exhaust air flow. This would tend to drive the NPL down and increase the surface area for exfiltration. Although the supply and exhaust flows to the second and third floor levels were approximately equal, the supply to the third floor was 170 L/s greater than the exhaust flow. This pressurization would cause increased exfiltration, especially when windows were open. It is important, therefore, that the supply and exhaust rates to both the building and to each floor are balanced.

The dominant wind directions during the winter months in Whitehorse are south and east. As a result, opening windows on the north and west sides of the building will only serve to increase exfiltration rates and will fail to provide the occupant with the desired ventilation. Once opened, these windows tend to be left open causing increased leakage rates and space heating requirements.

Number of Open Windows

By understanding the factors which increase controlled air leakage, a program can be developed to educate the building occupants in the proper use of the windows. If the number of open windows, and the length of time window are left open, can be reduced, the controlled leakage rate will be kept as low as possible and space heating requirements will be minimized. Efforts to ensure that windows are kept closed during the coldest months, when temperature differences are the highest, would reduce temperature driven infiltration and exfiltration.

## 3.4. Heat Recovery System

The purpose the heat recovery system investigation was to evaluate its performance and assess its impact on overall energy consumption. Monitored parameters included heat recovery system fluid flows and temperatures and ventilation air distribution system air flows and temperatures.

### 3.4.1. Design and Specification

The design ventilation air heating requirement determined by JMB was 603 MJ/h at an assumed air flow rate of 2,360 L/s with no heat recovery. The DOE calibrated model determined this design load to be 612 MJ/h. To handle this load, the run-around heat exchanger system originally specified utilized a 637 MJ/h capacity preheat coil and exhaust air reclaim coil, and a boiler-fed tube-in-shell heat exchanger located in the recovery loop between the reclaim coil and the preheat coil.

The purpose of the heat exchanger was to supplement the heat supplied by the reclaim coil in order to provide the preheating necessary to raise the incoming outside air to the setpoint temperature of the supply air to the building. The use of one coil to serve as both the preheat and the heating coil was a relatively new concept and the effect on heat recovery efficiency was evaluated as part of this project. The system was designed for a constant supply air temperature of 15.5°C for both heating and cooling.

A schematic of the system is shown in Figure 12.

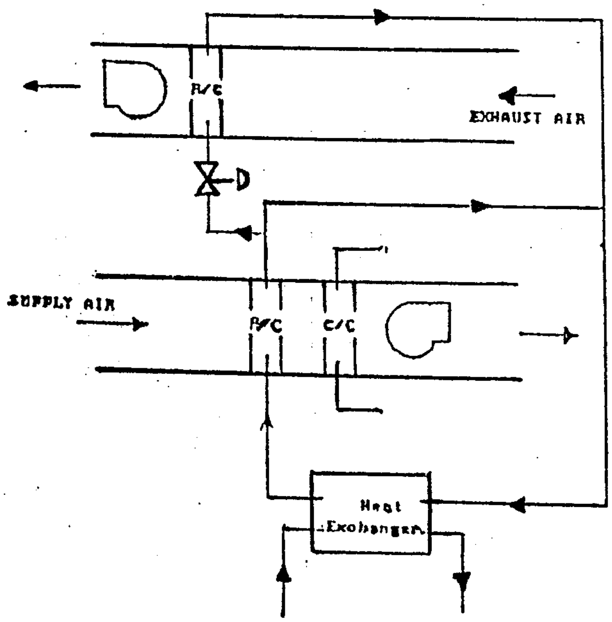


**Figure 12: Original Heat Recovery System**

### 3.4.2. Problems Encountered and Changes Implemented

As a result of the monitoring investigation, the following problems were uncovered which resulted in changes to the heat recovery system:

- **December 30, 1988** - Flow through a manually operated bypass valve in the recovery loop was decreased to improve recovery coil effectiveness. This valve was shown to have such a significant effect on reducing the effectiveness of the recovery coil that it was eventually replaced with a temperature controlled, three-way valve.
- **February 1992** - The *Heat Reclaim System Renovation* was completed. The changes which were implemented are detailed in Section 3.4.3.
- **March 1992** - The monitoring investigation indicated that the recovery system was not operating properly. The problem was caused by flow through the three-way valve that should not have been occurring. It was determined that some of the controls were faulty.
- **April 1992** - The three-way valve controls were changed and the recovery system was operating correctly.

### 3.4.3. Heat Recovery System Renovation

Early in the monitoring investigation, it became apparent that heat recovery system efficiencies were low and that the cause of the problem was the tube-in-shell heat exchanger. As a result of recommendations by BES and CMHC, and the engineering evaluation by JMB, YHC initiated the *Heat Reclaim System Renovation [21]* which was carried out between December 1991 and February 1992. The renovation implemented the following changes to the HVAC system:

- The tube-in-shell heat exchanger was removed from service.
- The manually operated bypass valve in the recovery loop was replaced with a three-way mixing valve controlled by the air temperature leaving the reclaim coil and the supply air temperature to the building.
- Filters were installed before the reclaim coil.
- Two new heating coils were installed in the ventilation supply air duct.
- The glycol concentration in the boiler loop was raised from 20% to 35% to provide added freeze protection for the heating coils.
- Adjustable speed drives were installed on the ventilation supply and exhaust fans, and on the space heating and boiler fluid loop pumps.

A schematic of the renovated heat recovery system is shown in Figure 13.

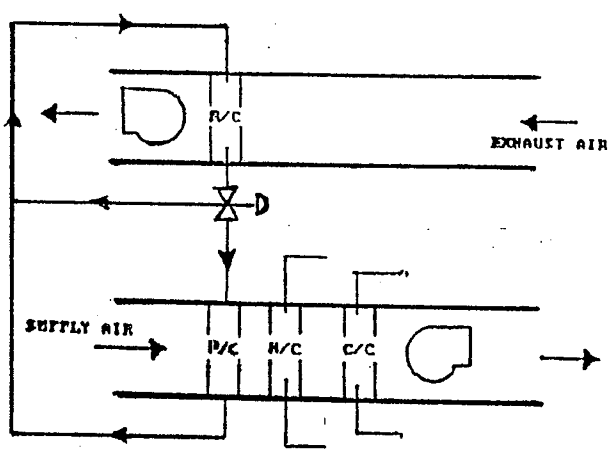


**Figure 13: Heat Recovery System After Renovation**

The purpose of the three-way mixing valve was to ensure that the heat recovery system operates within set limits. Heat recovery is controlled to prevent freezing of the reclaim coil by maintaining the temperature of the exhaust air flow leaving the reclaim coil above the low limit setpoint temperature of 2°C. Supply air preheating is controlled to prevent the temperature to the building from exceeding the high limit setpoint temperature of 20°C. The recovery loop circulation pump is de-energized when the outside temperature rises above the setpoint temperature.

### 3.4.4. Heat Recovery Effectiveness and Efficiency

The two parameters which reflect how well a heat recovery system is operating are the overall loop effectiveness and heat recovery efficiency. The overall loop effectiveness is the combined effectiveness of the preheat and the reclaim coils[4]. It provides an indication of the overall heat transfer capability of the system but does not indicate the amount of heat recovered. The heat recovery efficiency indicates the amount of heat recovered relative to the amount of heat available for recovery. Sensible recovery efficiency was used in this study and is based on the supply air temperature entering the preheat coil[5]. When system operation has been optimized, the overall effectiveness and the recovery efficiency are equal.

The sensible recovery efficiency of the system initially installed was low because of the large amount of heat supplied by the tube-in-shell heat exchanger. The 1990/91 project report [11], which details the analysis of the tube-in-shell heat exchanger, concluded that increasing the recovery efficiency would make the single largest contribution to improving building energy performance and recommended that major changes be made to the heat recovery system. This recommendation was supported by JMB and resulted in the *Heat Reclaim System Renovation* discussed in Section 3.4.3. Figure 14 shows the actual amount of heat recovered during the 1990/91 and 1991/92 heating seasons and DOE prediction of the heat which will be recovered for a TMY with the renovation completed.

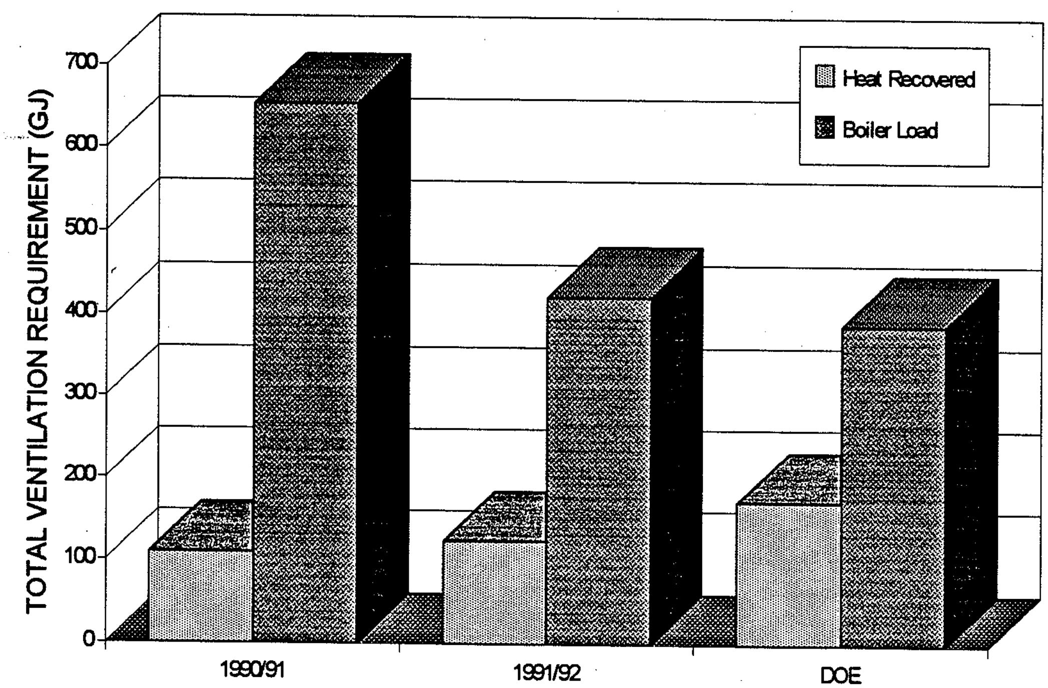


**Figure 14: Changes in Amount of Heat Recovered**

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4 The equation for determining the overall effectiveness is given in Appendix B.

5 The apparent efficiency does include the effects of tempering before the preheat coil and is based on the outside temperature.

Performance monitoring after the renovation was completed indicated that the heat recovery system was achieving its full potential and providing 40% of the ventilation heating requirement compared to less than 20% before the renovation. The processed data showed that the heat recovery efficiency was approximately equal to the overall loop effectiveness indicating that system performance had been optimized.

Cold weather performance monitoring of the renovated recovery system could not be conducted because the system was not operating properly until the middle of April. As a result, the effect on heat recovery performance of recycling fluid through the three-way valve to prevent ice buildup on the reclaim coil was not investigated. This matter was discussed with Bob Besant, a researcher at the UOS, who indicated that, based on his experience with similar systems in Saskatoon, and because of the low winter humidity levels in Whitehorse, freezing of the reclaim coil was not likely to occur.

<u>High Performance Heat Recovery Systems</u>

Run-around heat exchanger systems typically have an overall field effectiveness of 40% or less, depending on their size. Recent research at the University of Saskatchewan [9] [4] has shown that overall field effectiveness of 60% can be obtained by optimizing the systems according to the overall savings. The optimization adjusts such coil parameters as fluid flow rate, tube size, coil size, tube spacing, fin thickness, fin spacing and the depth of the fin wave. It takes into account the cost of running the system, the initial capital cost, and the heat recovery savings. Results of these studies indicated that it would be possible to increase the net financial savings derived from the run-around system by 20 per cent for a typical year in Saskatoon.

## 3.5. Ventilation Air Distribution System

The purpose of the air distribution system investigation was to assess the system's ability to reliably provide adequate ventilation. This was accomplished by monitoring air flow rates, temperatures, and carbon dioxide and relative humidity levels within the distribution system and throughout the building.

### 3.5.1. Design and Specification

A constant-volume air distribution system supplies 100 per cent outside ventilation air to the residential and commercial areas 24 hours-a-day and exhausts all return air outdoors. Each suite has a fully ducted supply and exhaust system as follows:

- The design supply air flow rate to the one bedroom suites was 20 L/s while the two bedroom suites were to receive 30 L/s. Supply ducts were located in the bedroom and living room.
- The design exhaust flow rate from each suite was 40 L/s. Exhaust grilles were located in the bathroom and kitchen area.
- The balance of the supply air was supplied from the pressurized corridor which also served to control odour movement.

The design supply air requirement for the residential volume of the building was 2,360 L/s, or 1.0 ACH, with a design exhaust flow rate of 1,900 L/s. A remote system in the garbage room was designed to exhaust an additional 110 L/s. Design specifications also called for an exhaust fan in the commercial area to balance supply and exhaust air flow rates. This fan was never installed. Initially, the commercial area was to consist of a number of small businesses to serve the needs of the seniors at Closeleigh Manor. From the original plans and specifications, it is not clear how the ventilation and exhaust requirements of these businesses were to be addressed. The original business plan was never realized, however, and, in the fall of 1989, the commercial area became occupied by the Whitehorse Housing Association (WHA) and Yukon College Downtown Learning Center. The existing ventilation system was used to supply their ventilation requirements.

### 3.5.2. Problems Encountered and Changes Implemented

As a result of the monitoring investigation, the following problems were uncovered and resulted in a number of changes to the system:

- **January 13, 1989** - The outside supply and exhaust hoods were directed away from each other in order to prevent cross-contamination of the supply air. A cross-contamination test conducted in June 1988 and based on CSA Standard C349-M1985, *Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators,* determined that the measured exhaust air transfer ratio ranged from 34% to 60% with an overall average of 41% for the duration of a one hour test.
- **December 18-23, 1989** - The investigation carried out by NRC [8] uncovered the following problems:
  - A damper in the left side supply duct was improperly set and provided only 170 L/s when the design flow was 630 L/s. This was the reason for occupant complaints of poor ventilation in suites supplied by this duct.
  - A damper on the right side supply duct had become disconnected and lodged at an angle in the duct and was no longer operating properly. In addition, it was blocking the air flow in front of the flow measuring station, impairing its ability to measure accurately.
  - A number of suites had obvious air flow problems including one with a reverse flow in the kitchen exhaust grille, and another with zero air flow in the bedroom indicating a blocked damper or a duct not connected to the grille.
  - A significant amount of noise was coming from the ductwork in the suite adjacent to the boiler room.
  - In the main floor lounge, the distribution of the supply air was poor. The ceiling diffusers were poorly located and one of the diffusers was adjacent to the exhaust grille causing short circuiting of the flow. By moving the diffusers further away from the exhaust grille, ventilation efficiency was improved.

- **March 30, 1990** - New belts and pulleys were installed on the ventilation system supply and exhaust air fans and the resulting air flow was approximately 1300 L/s or 0.47 ACH. The system was not rebalanced at this time.
- **January 1990 to November 1990** - Repairs and alterations to existing dampers and ductwork were carried out based on the NRC findings [8].
- **November 29, 1990** - The ventilation system was rebalanced. It was noted that the reclaim coil was extremely dirty and significantly restricting the exhaust flow rate. The coil had to be cleaned before balancing could be carried out. The total supply air measured at the supply outlets throughout the building, including the commercial area, was 1,445 L/s while the measured exhaust air flow rate was 1283 L/s.
- **June 1991** - The flow rate was returned to its full capacity in order to operate the cooling equipment and remained at this level until the *Heat Reclaim System Renovation* was carried out.
- **January 1992** - Heating coils were added to the supply air duct and adjustable controllers were installed to regulate fan and pump speeds.
- **January 1992** - The ventilation system air flow rates were set, using the adjustable fan controllers installed during the renovation, to deliver 1520 L/s, or 0.55 ACH, from 0700h to 2400h and 760 L/s, or 0.28 ACH, from 0000h to 0700h. The air change rates are based on the combined volume of the residential and commercial area which is 9881 $m^3$.
- **February 1992** - The investigation conducted by SRC [5] indicated that the suites and rooms close to the mechanical room had excessive flows while those remote from the mechanical room had insufficient flow. The balancing contractor indicated that the balancing dampers in the system were not adequate to properly balance this type of system. For example, when the dampers for suites adjacent to the mechanical room were fully closed, air flows in excess of the recommended values were measured in the suites. In addition, the supply ducts to the second and third floor hallways did not have dampers or any other means of flow adjustment. As a result, the third floor receives an excess of flow.
- **November 1992** - The interior doors to the commercial area and the doors to the washrooms for this area were undercut to provide a 30 mm opening at the bottom of each door and improve air movement. The commercial area is exhausted through the washrooms.

### 3.5.3. Ventilation Air Heating Coils

The heating coils installed during the renovation were designed to have sufficient capacity to provide all of the building's space heating requirements. Under operating conditions, however, they provide only enough heat to raise the temperature of the air leaving the preheat coil to 20°C[6] which provides ventilation air to the suites at a temperature which

[6] This is the setpoint temperature of the ventilation supply air to the building.

should not be perceived as a draft. The baseboard heaters in each suite are used to satisfy individual temperature preferences. The average daily temperature maintained in the monitored suites ranged from 20°C to 26°C.

Using the monitored data, the balance point temperature difference for Closeleigh Manor was determined to be 8C°[7]. At a temperature difference of 8C° across the building envelope, the internal gains, which do not include solar gains, equal the heat loss from the building and no additional space heating is required. Ideally, therefore, with the exhaust air temperature indicating that the average temperature inside the building during the heating season is 24°C, the setpoint of the supply air temperature to the building should not be set greater than 16°C. In this way, heated ventilation air will not be delivered to the building when it is not required. The investigation has shown, however, that because of the type and location of the supply air grilles in the suites, supplying 16°C air to the building has resulted in tenant complaints of drafts. In some suites, the supply ducts were taped over. As a result, the building operator has established the setpoint temperature at 20°C.

### 3.5.4. Ventilation System Air Flow Rates

The initial supply air flow rate to the building was approximately 2100 L/s. Using the ASHRAE Standard 62-1989 [2], NRC determined the flow rates for the different areas of the building. Suite flows were based on 0.5 ACH resulting in a recommended supply air flow rate of 22 L/s for the one bedroom suites and 30 L/s for the two bedroom suites. The recommended suite exhaust flow rate was 5 L/s more than the supply flow rate in order to control the movement of odours to the hallways. The kitchen exhaust flow rate was 12 L/s for all suites. The recommended air flow for the occupied volume of the building, including the commercial and service areas, was 1520 L/s or 0.50 ACH. Although ASHRAE recommendations allow the air change rate to be as low as 0.35 ACH, continuous flow rates lower than 0.5 ACH were not recommended due to the high number of smokers in the building. As a result of these recommendations, new belts and pulleys were installed on the ventilation system supply and exhaust air fans and the resulting air flow was approximately 1300 L/s or 0.47 ACH.

### 3.5.5. Detailed Ventilation System Investigation

A detailed investigation of the ventilation air distribution system was conducted through two studies - the December 1989 investigation by NRC [8] and the follow-up study by SRC in February 1992 [5].

During the December 1989 investigation, NRC measured supply and exhaust flows in individual suites, lounges and hallways and uncovered numerous damper and ducting problems in the system. Details of these problems and the changes implemented are detailed in Section 3.5.2. The extent and nature of the problems indicated that the system had not been

[7] Using the DOE model it was determined to be 9C°.

balanced properly. Once a number of the problems had been addressed, the system was rebalanced in November 1990. The results of the balancing contractor's measurements taken at each supply and exhaust register throughout the building are presented in Table 2. The monitored supply and exhaust air flow rates for the building agreed to within 7% of the balancing contractor's measurements.

**Table 2: Actual and Design Air Flow Rates**

| Location | Supply Air (L/s) | | Exhaust Air (L/s) | |
|---|---|---|---|---|
| | Nov. 90 | Design | Nov. 90 | Design |
| **Third Floor** | | | | |
| Suites | 361 | 304 | 397 | 364 |
| Lounge | 0 | 0 | 22 | 25 |
| Hallway | 126 | 155 | 81* | 70* |
| Total | 487 | 459 | 500 | 459 |
| **Second Floor** | | | | |
| Suites | 362 | 304 | 389 | 364 |
| Lounge | 0 | 0 | 21 | 25 |
| Hallway | 95 | 155 | 78* | 70* |
| Total | 457 | 459 | 488 | 459 |
| **First Floor** | | | | |
| Suites | 122 | 140 | 153 | 170 |
| Lounge | 87 | 150 | 71 | 155 |
| Hallway | 37 | 90 | 54** | 55** |
| Commercial | 188 | 222 | 108 | 222 |
| Total | 434 | 602 | 386 | 602 |
| **TOTALS** | **1,378** | **1,520** | **1,374** | **1,520** |

* Intermittent exhaust of 60 L/s for 2 clothes dryers, 50% duty cycle is included
** Intermittent exhaust of 30 L/s for 1 clothes dryer, 50% duty cycle, is included

Arctech Associates in Whitehorse analysed the information in this balancing report for YHC and determined that thirteen of the suites had supply air volumes which exceeded 110% of design. They noted that this likely had contributed to occupant discomfort and the overall perception of the effectiveness of the ventilation in the building. Eight suites had exhaust volumes which were less than 90% of design and although it may not have been perceived as discomfort, this deficiency, combined with the hallway imbalance, likely accounted for suite odours entering the hallways.

In February 1992, SRC measured supply and exhaust flows throughout the building. All flows in all suites were not measured. The monitored data at this time indicated that the supply air flow rate was 1605 L/s and the exhaust flow was 1545 L/s. One of the main findings reported by SRC was that the suites and rooms closest to the mechanical room had excessive flows while suites and rooms remote from the mechanical room had insufficient flow. Suite 104, for example, which is adjacent to the mechanical room, had a measured supply flow rate of 28 L/s and the recommended rate was 22 L/s. The measured exhaust flow rate was 52 L/s and the recommended value was 27 L/s. The first floor lounge, however, which is at the opposite end of the building, had a measured supply flow rate of 103 L/s and an exhaust rate of 78 L/s while the recommended values are 150 and 155 L/s respectively. The balancing contractor on site during this time noted that the balancing dampers in the system were not adequate to do a proper job of balancing. Some dampers, when fully closed, still allowed flows in excess of the recommended values.

SRC also investigated the pressure differences between the hallways and the individual suites. In general, it is desirable to have a positive pressure between the hallways and the suites so as to control odour movement. Although odor control is the primary function of these differentials, they also assist in ensuring that the recommended design supply and exhaust rates to the suites are achieved. SRC noted that only 60% of the suites had a positive differential:

- On the first floor, 3 out of 6 suites had a positive differential.
- On the second floor, 5 out of 12 suites had a positive differential.
- On the third floor, 10 out of 12 suites had a positive differential.

The third floor had the best pressure differentials and also the highest supply flow, with the hallway receiving 254 L/s while the recommended value is only 155 L/s. The first floor, on the other hand, was receiving only one-half of its recommended value of 90 L/s. Once again, the dampers necessary to balance the system had not been installed. It is not know if this deficiency was reported to the mechanical contractor when the building was initially balanced since the original reports were not available.

### 3.5.6. Air Quality and Comfort

Air quality and comfort were monitored in order to evaluate the effect of occupancy, building characteristics, mechanical systems and outside conditions on the indoor environment.

Carbon Dioxide ($CO_2$) Levels

The ASHRAE 62-1989 Standard [2] suggests that $CO_2$ levels above 1000 ppm are considered to be a sign of inadequate ventilation. Continuous monitoring of $CO_2$ levels in 6 suites, the lounges and the building exhaust air stream indicated that adequate ventilation was being provided.

In January 1992, the operation of the ventilation system was set using the adjustable fan controllers installed during the reclaim system renovation to deliver 1520 L/s, or 0.55 ACH, from 0700h to 2400h and 760 L/s, or 0.28 ACH, from 0000h to 0700h. The air change rate was based on the volume of both the residential and commercial area which totals 9881 $m^3$.

This night setback allowed the ventilation heating requirement to be reduced without reducing ventilation requirements during the occupant's most active hours. The setback also addresses occupant complaints of cool air in the bedrooms at night where the supply grille is often located over the beds, and should reduce, if not eliminate, occurrences of occupants covering over these grilles. This operating schedule provides an average daily ventilation rate of approximately 0.4 ACH and meets the ASHRAE standard requirement of 7.5 L/s for each occupant. This is the lowest ventilation rate at which the building has been operated.

During the first week of February 1992, SRC conducted ventilation measurements in the building. Prior to conducting its testing, all windows in the building were closed. The DOE analysis showed that this month had the lowest amount of envelope leakage during the 1991/92 heating season. In this month, therefore, the building was operating at the lowest ventilation and leakage rates since the monitoring had started. Table 3 shows the maximum hourly averaged $CO_2$ levels which were recorded

**Table 3: Maximum $CO_2$ Levels During February 1992**

| Suite | 105 | 205 | 305 | 311 | 308 | AVG | PR | SA | XA |
|---|---|---|---|---|---|---|---|---|---|
| Max. PPM | 699 | 1001 | 552 | 573 | 756 | 685 | 915 | 365 | 567 |

during this month. The highest levels recorded were 1001 ppm in Suite 205 and 915 ppm in the Pioneer Room (PR) which indicated that adequate ventilation was being provided in the monitored areas. The concentration of $CO_2$ in the exhaust air stream (XA) of 567 ppm indicated that the entire building was receiving adequate ventilation. The supply air (SA) concentrations were considered normal for outside air entering a building.

<u>Relative Humidity Levels</u>

At an outside temperature of -35°C, the moisture content in the air is very low. Even if the air is 100% saturated, the absolute humidity is only about 0.0001 kg of moisture/kg of dry air. When outside air with that amount of moisture content is heated to 24°C without any moisture being added, the corresponding relative humidity (RH) is about 1%.

The ventilation air supply has a 20 kW, electrically driven humidifier providing the option of supplying humidified ventilation air to each suite. The monitoring investigation has indicated that, to approach the Health and Welfare Canada air quality guidelines of 30% RH, the central humidifier would have to operate continuously at full capacity throughout the heating season. The question arises, however, as to whether or not the cost of the humidification can be justified. For example, the processed data for November 1990, indicated that the humidifier operated 75% of the time and provided an average RH in the monitored suites of 23%. In providing this level of humidification, the humidifier consumed 26% of the total amount of electricity used in the building. The RH level of 23% was not perceived as a greater comfort level by the tenants and, in fact, the humidifier had to be shut down in December due to tenant complaints of window condensation on the double glazed windows. With the humidifier off, although RH levels dropped below 15% within a few days, the tenants did not complain. It appeared that the only noticeable effect of the humidifier operation was the window condensation in colder weather.

Whitehorse has a design temperature of -41°C, and an average January temperature of -20°C. To avoid serious frost buildup at -20°C with double glazed windows, the relative humidity should be below 25% when the room air temperature is 23°C. With triple glazed windows, however, the humidity can rise to 45% without serious window frosting at -20°C[8].

In addition to the high electrical costs of operating the humidifier, the maintenance costs were very high. The average cylinder filter life was 60 days and the estimated cost of changing it was $285. Used throughout the year, the maintenance cost could be as high as $1700.

The humidifier has operated since April 1991 and there were no discomfort complaints from the tenants. There are no plans to operate the humidifier in the future. If the humidifier is run, however, its operation should be monitored to ensure that excessive window condensation does not occur.

<u>Space Temperatures</u>

An analysis of space temperatures throughout the building over the period from November 1988 to April 1989 was conducted by NRC [6] using data from the 6 monitored suites. A summary of their results are as follows:

- The accuracy of the monitored outside temperature was checked using weather data from the Whitehorse Airport Atmospheric Environmental Station. Despite some differences between the two locations, agreement between the two sets of readings was generally within 1°C.
- A plot of the outside air temperatures indicated that the minimum temperature recorded during this period was -39.7°C while the warmest temperature was 20.2°C. The average temperature was -9.8°C.
- Periodic daily swings which did not occur in the period up to January 30, occurred after this date. Whitehorse is located in a valley and, around the winter solstice, receives few sunlight hours. The period after January 30 was characterized by many clear days during which the air temperature fluctuated due to solar radiation. The data shows that the magnitude of the daily temperature swings increased as the day length increased.
- In Suites 105, 205, 308 and 311, temperatures were quite constant with the standard deviation being less than 1°C.

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[8] These figures depend upon the presence of window coverings which can lower the window surface temperature causing increased condensation.

- Suite 302, a corner unit with both south and west facing windows, was more prone to overheating than some of the other suites. The data indicated that the temperature in this suite varied more than some of the other suites on a daily basis, possibly because of the larger windows.
- Suite 308, which is an internal suite with west facing windows, showed larger internal fluctuations starting in April due to increased solar gains.

Table 4 shows the hours of bright sunshine during this period compared to a normal year. With the exception of November, the monitored period had

**Table 4: Hours of Bright Sunshine**

| Month | Hours of Bright Sunshine | |
|---|---|---|
| | 1988/89 | TMY |
| November | 29 | 58 |
| December | 23 | 23 |
| January | 53 | 46 |
| February | 165 | 91 |
| March | 174 | 153 |
| April | 280 | 230 |

an equal, or greater, number of hours of bright sunshine compared to a TMY indicating that the information from this analysis should be representative of what would typically happen in this building during the heating season.

## 3.6. Boiler System

The purpose of monitoring the boiler system was to determine how efficiently it was operating and to better understand the requirements for sizing. The boiler loop in the Closeleigh Manor system provides heating fluid:

- to the heating coils in the ventilation supply air duct through a three-way valve;
- to the space heating loop through three-way valve; and
- directly to the heat exchanger of the DHW heater.

The heating coils were discussed in Section 3.5.3, the space heating system will be Section 3.7 and DHW heating system will be discussed in Section 3.8. This section will deal mainly with the boiler system components and their operation.

### 3.6.1. Design and Specification

Boiler Sizing

The original design drawings specified two banks of five hot water, oil-fired boilers with each boiler providing a design output of 294 MJ/h[9]. In view of the fact that one-half of the boilers were removed from service and the remaining five boilers had no difficulty in meeting the heating demands of the building, JMB carried out an investigation to verify that the original

[9] This value is corrected for the Whitehorse elevation of 636 m above sea level.

design was in accordance with good engineering practice and not excessively oversized.

The *JMB Revised Heating Load* was 1,590 MJ/h. It is customary engineering practice to increase the design load by a minimum of 50% to provide for building pick-up which may be required to restore the building temperature after night setback or after temperature loss due to power failure. The pick-up factor also ensures adequate capacity in the event of the failure of one or more boiler modules. Allowing for a 50% pick-up factor, the boiler heating capacity requirement would be 2,385 MJ/h or 8.1 of the originally specified boilers. At this point, it would become a design decision whether to meet the capacity with 8 boilers or to be more conservative and install 9 or 10 modules. The selection of 10 boilers for Closeleigh Manor suggests the more conservative route was chosen which provided a design output equivalent of 2,936 MJ/h. It is also possible, however, that the original selection resulted from design calculations based on different assumptions regarding the air infiltration rate, the design indoor and outdoor air temperatures, or incorporated a higher safety factor justified by the nature of the building occupancy and the building's location. The net result was that the actual building pick-up factor was 85% greater than the design load calculated by JMB.

<u>Circulation Temperature</u>

The boiler controller, which senses the boiler fluid supply temperature, step-fires each boiler to maintain either the design circulation temperature or a preset temperature determined by the building operator. The design circulation temperature chosen for Closeleigh Manor was 93°C and, according to JMB, is a value based on common engineering practices and experience and is commonly used in buildings of this type. The circulation temperature must be high enough to satisfy the ventilation air preheating requirements supplied by the heating coil, the space heating needs of each individual suite supplied by the baseboard heaters, and the DHW heating needs, when the building is subjected to design conditions. Variations from the design temperature are generally set manually at the discretion of the building operator to deal with the range of operating conditions encountered during the year.

<u>Circulation Flow Rate</u>

Based on the use of 10 boiler modules, the boiler fluid circulating pump capacity was specified at 17.1 L/s in order to achieve a 12.8C° temperature rise across the boilers at rated capacity. The manufacturer's specifications rate peak boiler efficiency at 78% with a temperature rise of 11C°. A second pump with the same capacity was installed as a backup unit. The flow through each pump was controlled with a manually operated valve. During commissioning, this valve is used to adjust the circulation rate. The rate is determined by measuring the temperature drop across the boilers at the prevailing outside temperature.

Control Strategy

The boiler controls also have the capability of resetting the boiler circulation temperature based on outside temperature. However, this feature is currently disabled because the heating coil loop, the space heating loop and the DHW heat exchanger are all dependent on the boiler loop. Therefore, it is not possible to optimize performance for partial loading during other than design day conditions. If it were possible to use this feature, the boiler fluid circulation temperature could be decreased during the milder months of the year. With the current mechanical configuration, any strategy utilizing this control capability must maintain circulation temperatures sufficiently high to satisfy ventilation air and DHW heating requirements.

### 3.6.2. Problems Encountered and Changes Implemented

As a result of the monitoring investigation, the following problems were uncovered and changes to the boiler system carried out:

- **November 30, 1988** - The burner nozzle sizes were changed from 10.4 L/hr (2.75 US GPH) to 7.6 L/hr (2.0 US GPH) in order to improve the efficiency of the boilers.
- **December 1989** - Several litres of soot had accumulated at the base of the chimney indicating inefficient boiler operation.
- **March 02, 1990** - One bank of five boilers was shut down and isolated from the boiler loop leaving 5 functioning boilers in the building with a design output capacity of 1,468 MJ/h. Fuel nozzles were replaced and it was discovered that one boiler had a 10.4 L/hr (2.75 US GPH) nozzle and another had a 8.5 L/hr (2.25 US GPH) nozzle. All units were serviced, 7.6 L/hr (2.0 US GPH) nozzles were installed and boiler combustion efficiencies were measured.
- **October 23, 1990** - The boiler system was flushed and the system recharged with appropriate levels of an aqueous glycol solution.
- **January 1992** - Adjustable speed drives were installed for the space heating and boiler fluid circulation pumps as part of the recovery system renovation. Circulation flow rates were adjusted during commissioning.

### 3.6.3. Removal of Five Boilers

It was possible to remove five of the 10 boilers because:

- The building's ventilation rate was reduced to 0.55 ACH at the same time that the boilers were removed. The current rate is 0.4 ACH.
- Boiler sizing was originally based on a design heating load which included the ventilation heating requirement for 1.0 ACH, and allowed for a 50% pick-up capacity. With the system sized to include a ventilation requirement, additional pick-up capacity is automatically built into the system. For example, if extra capacity was required to recover from a significant temperature drop or because one or more

boiler modules have failed, the ventilation rate could be reduced by the building operator until the extra capacity was no longer required.

- On the basis of the monitored data, the design DHW requirement was about 50% larger than necessary.

Using the *JMB Revised Heating Load* at 0.4 ACH of 1,228 MJ/h (Table 1), the design output capacity of the remaining 5 boilers (1,468 MJ/h) would provide a pick-up factor of 20%. Without the *Ventilation Air Heating Load*, the pick-up factor would be 49%. Using the *DOE Heating Load* of 910 MJ/h, which is adjusted for DHW system oversizing, the building pickup factor would be 61%. Without the ventilation requirement, it would be 121%.

### 3.6.4. Circulation Temperature and Flow Rate

The monitored data indicated that the initial boiler circulation temperature was approximately 85°C. The highest circulation temperature recorded in the space heating loop during the project was 77°C. It occurred during the 1990-91 heating season at an outside temperature of -44°C, which is colder than the design temperature. This temperature indicated that the space heating loop would rarely, if ever, have a need for the 85°C fluid available in the boiler loop. As a result, the boiler circulation temperature was lowered to 78°C after the recovery system renovation was completed. This temperature maintained the domestic hot water at 55°C.

In addition, at the outside temperature of -44°C and with all boilers firing, the temperature rise across the boilers was only 6.4C° (optimal is 11C°) indicating that the boiler fluid flow rate was too fast. Following the recovery system renovation, the boiler fluid circulation pump had to be set at 35% rotation speed to achieve a 10.0°C rise in boiler fluid temperature when the system was on full demand. The pump capacity measured at the monitoring flow meter was 5.0 L/s. When the heating system was returned to a controlling mode, excessive boiler cycling was noticed (on and off every 30 seconds). To stop the rapid cycling, the pump was increased to 65% rotation speed which resulted in a flow rate of 7.0 L/s and a temperature rise across the boilers of 9.9C°. This indicated that the system was operating at close to its optimal performance.

The monitored data also revealed that the backup circulation pump was operating at a different speed and providing a flow rate of 13.5 L/s. The backup pump had not been commissioned.

### 3.6.5. Efficiency and Operation

On the basis of the manufacturer's specifications, the peak boiler efficiency is 78% with an 11°C temperature rise across the boiler. The DOE model, which included manufacturer's part-load performance curves for other than peak conditions, indicated that the five boilers are capable of achieving an annual boiler efficiency of 66% for a TMY. The boiler manufacturer supports the DOE predictions.

The lowest recorded efficiencies occurred during the first year of operation. The building system changes which had a major effect on the operating efficiency of the boiler system were:

- the removal of 5 boilers and the reduction of the ventilation rate to 0.5 ACH in March 1990;
- the completion of the recovery system renovation in February 1992.

The effect of these changes on boiler efficiency can be seen in Table 5.

**Table 5: Boiler Efficiencies for Each Heating Season**

| Month | 1988/89 | | 1989/90 | | 1990/91 | | 1991/92 | | DOE | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Effcy (%) | HDD | Effcy (%) | HDD | Effcy (%) | HDD | Effcy (%) | HDD | Effcy (%) | HDD |
| NOV | 58 | 774 | | | 70 | 1114 | 70 | 816 | 69 | 804 |
| DEC | 57 | 887 | | | 69 | 1103 | 62 | 904 | 71 | 1073 |
| JAN | 56 | 1231 | 52 | 1113 | 68 | 1141 | 44 | 812 | 71 | 1200 |
| FEB | 59 | 998 | 55 | 1084 | 63 | 712 | 57** | 830 | 70 | 883 |
| MAR | 48 | 928 | 61* | 665 | 64 | 782 | 56 | 662 | 68 | 811 |
| APR | 31 | 444 | 62 | 458 | 61 | 462 | 52 | 536 | 67 | 532 |
| MAY | | | | | | | 45 | 383 | 66 | 352 |
| JUN | | | | | | | 36 | 218 | 65 | 209 |
| JUL | | | | | | | 35 | 124 | 65 | 124 |

*Bank of 5 boilers removed
**Heat reclaim system renovation completed

The *Degree-Day (HDD)* columns indicate the heating requirements for each month. The removal of the five boilers in March 1990 immediately improved boiler efficiency, especially during warmer months such as April when efficiency increased 27%. With fewer boilers, the operating time of each boiler increased, resulting in higher efficiencies. The *Heat Reclaim System Renovation* in February 1992, however, appears to have decreased the efficiency. With the improved heat recovery capability, the heating load on the boilers was decreased, the operating time of each boiler was reduced, and the overall boiler efficiency decreased. From Table 6 it can be seen that, after the renovation, the boilers cycled more frequently and operated for shorter periods of time. The month of April is

**Table 6: Average Boiler On/Off Cycling**

| Month | Boiler Number | 1 | 3 | 5 | 7 | 9 |
|---|---|---|---|---|---|---|
| APR 91 | Cycle length (minutes/cycle) | 3.3 | 3.3 | 3.3 | 5.0 | 1.3 |
| | Cycle frequency (cycles/hour) | 7.5 | 2.7 | 2.2 | 0.9 | 0.5 |
| APR 92 | Cycle length (minutes/cycle) | 2.4 | 2.4 | 2.6 | 2.5 | 3.0 |
| | Cycle frequency (cycles/hour) | 9.0 | 5.0 | 3.0 | 1.4 | 1.2 |

shown since it was this month that recovery loop performance was optimized. Note that the table values are derived from daily totals.

## 3.7. Space Heating System

The purpose of the space heating system investigation was to determine the system's effectiveness and to better understanding sizing requirements.

### 3.7.1. Design and Specification

Baseboard Sizing

Hydronic baseboard heaters were installed in the suites, commercial areas and lounges. Unit heaters were used in stairwells, vestibules and service areas. An investigation by JMB of the individual rooms within the building indicated a total installed capacity of 1,278 MJ/hr. Based on the *Revised JMB Heat Load* (Table 1) which indicated a design day space heating requirement of 465 MJ/hr, and allowing for 50% pick-up factor, the total installed heating capacity would normally have been 698 MJ/hr which is 45% smaller than what was actually installed. The reasons for this are unclear since original design calculations were not available and it is not clear how the heat recovery system and the tube-in-shell heat exchanger were accounted for in the calculations. It was speculated that, with the ventilation system designed to operate at a supply air temperature of 15.5°C, additional capacity may have been designed into the system to ensure adequate heating over and above the room heat loss. With the current ventilation system configuration, JMB stated that they would have no reservations about specifying a baseboard capacity of 698 MJ/hr

Circulation Temperature

The circulation temperature of the fluid in the space heating loop is controlled by an outside temperature sensor and a space heating fluid sensor. System design specified that the temperature of the space heating fluid would vary from a maximum of 93°C for ambient temperatures below -34°C, to a minimum of 38°C for ambient temperatures above 21°C. The circulation temperature is varied by introducing fluid from the boiler loop into the space heating loop through a three-way valve. The lower the outside temperature, the greater the amount of boiler fluid that will be introduced. Below -34°C, the three-way valve would be fully open and the temperature of the space heating fluid would be the same as the boiler fluid. By reducing the circulation temperature under milder conditions, the heating capacity installed in each room more closely matches the heat loss and will, consequently, operate with the heating valve open a greater percentage of the time. This increases the pump circulating rate through the individual suites at any given time and avoids the frequent cycling that would occur if 93°C water was supplied whenever a suite thermostat was calling for heat.

Circulation Flow Rate

The space heating loop circulation pump was sized with a design capacity of 11.3 L/s which included 7.2 L/s to supply the building heating radiators and 4.1 L/s to supply the recovery loop tube-in-shell heat exchanger. This rate was designed to produce an 11C° temperature drop across the radiators. These rates were confirmed by JMB for the installed radiation capacity. The design flow rate is set during commissioning by adjusting manually operated balancing valves associated with the pump. Information on the original balancing of the system was not available. As with the boiler system, the backup pump was providing a different flow rate indicating that it had not been commissioned.

Thermostat and Valve Control

Room temperature control exists for the baseboard heaters only and not for the ventilation air supply. When the system is controlling, the flow to the individual suites is controlled by the suite thermostat. At any given time, depending upon solar and internal heat gain, a significant number of suites could be satisfied and the thermostats would close the heating control valves for those suites. This has the effect of increasing the flow rate through the suites that have the zone control valve open while reducing the total system flow and causing the pump to operate at a higher pressure. At some point, if too many control valves are closed, the velocity through the remaining valves that are open is too high and excessive valve wear and noise can result.

### 3.7.2. Problems Encountered and Changes Implemented

- **February 07, 1991** - The thermostats throughout the building were retrofitted with temperature controls that could be easily seen and adjusted by the occupants.
- **January 1992** -As part of the *Heat Reclaim Renovation,* an adjustable speed controller was installed to regulate the main space heating circulation pump speed and a pressure bypass regulator was installed on the discharge side of the pump.

### 3.7.3. Circulation Temperature and Flow Rate

Circulation Temperature

The lowest recorded space heating fluid supply temperature was 55.3°C at a flow rate of 1.85 L/s. It occurred on June 30, 1992 when the outside temperature was 32°C. JMB indicated that the original design supply temperature of 38°C at outside air temperatures above 21°C should result in acceptable heating conditions. They suggested that the controls contractor lower the temperature controller setpoint as much as possible while still providing sufficient heat to all areas of the building.

Circulation Flow Rate

System balancing carried out after the renovation, indicated that, at 100% rotation speed, the space heating pump capacity through the monitoring flow meter was 10.7 L/s with the system calling for full heat and 4.6 L/s with the system controlling. Using the adjustable controller, a 65% pump rotation speed resulted in a flow rate of 7.7 L/s with a call for full heat and a 9C° temperature drop across the baseboard heaters tested. The monitored data indicated that, with the system controlling, the pump flow rate was 1.8 L/s. JMB indicated that the pump speed reduction to 65% would result in a 70% pumping energy saving.

It is not known if the backup pump flow rate was adjusted to match the main pump rate. JMB indicated that, if the backup pump is used, the flow rate should be reduced since the tube-in-shell heat exchanger is no longer requiring some of the pump flow. This will reduce the likelihood of excess noise in the suites. It will not, however, significantly reduce the energy consumption as the flow reduction is being created by adding pressure drop to the system, not by reducing the pump speed and horsepower requirements.

The pressure bypass regulator was added during the renovation because of evidence that a premature unit heater coil failure was caused by excessive water velocity through the coil tubes. The regulator opens if the discharge pressure exceeds a setpoint, and bypasses some of the flow back into the suction side of the pump. It will also prevent excessive wear and noise of thermostat control valves when fewer areas of the building are calling for heat and circulation pressures are higher.

### 3.7.4. Suite Temperature Control

As part of the February 1992 investigation conducted by SRC [5], a number of suite temperatures were once again tested. One of the objectives of this investigation, was to compare the thermostat temperature set by the occupant to the actual suite temperature. The thermostats throughout the building had been retrofitted in February 1991 with temperature setting controls that could be more easily seen and adjusted by the occupants. On the basis of the data from their report on the work, the agreement between the thermostat setpoint temperature and the suite temperature indicated on the thermostat was generally good, with the following exceptions:

- In Suite 203, the thermostat was set at 27°C and the measured reading was 22°C. In Suite 307, the thermostat was set at 25°C and the reading was 18°C. These suites should be checked to determine if the thermostat and control valve are operating correctly.
- In Suites 206, 207, 212, 303, 306 and 309, the thermostats were set to 18°C while the actual suite temperatures were 23, 22, 26, 21, 23 and 22°C respectively. All interior suite surfaces are sound-proofed with a material providing an insulation value of RSI 2.1 (R-12). It is suspected that high internal gains from appliances and lighting are causing the higher temperatures. If this is happening, the occupants only recourse would be to open windows which is unfortunate since, as discussed in Section 3.3.3, open windows are a major cause of increased envelope leakage which results in increased space heating.

  It should be noted that Suite 2l2 may also have a defective thermostat or control valve, since the actual temperature was 26°C. It is also possible that the thermostat temperature sensor was out of calibration.

## 3.8. Domestic Hot Water System

The purpose of monitoring the DHW system was to determine how effectively the system operated and to better understand DHW tank sizing requirements.

### 3.8.1. Design and Specification

Sizing

A 145 kW boiler-fed heat exchanger in a 680 L storage tank provides DHW for Closeleigh Manor. Design calculations carried out by JMB in accordance with ASHRAE and the American Society of Plumbing Engineers (ASPE) recommendations, determined that, to meet ASPE guidelines with a 680 L storage tank, the recommended heating capacity would be 200 kW. The DHW capacity may have been reduced to below the recommended level for an apartment building in recognition of the fact that seniors have a lower DHW usage. On the basis of their evaluation, JMB was confident that the system had been sized correctly in accordance with good engineering practice.

Control and Operation

The hot water tank is heated by means of a boiler-fed heat exchanger and requires that the boiler system, including the boilers and circulating pumps, operates continuously, even when space heating is not required. A controller, which senses the tank water temperature, maintains the tank at the design temperature of 60°C by energizing a boiler water circulation pump and an intra-tank circulating pump. The building DHW circulation system consists of a pump which circulates DHW continuously throughout the building at a rate of 0.5 L/s. In this way, hot water may be obtained almost instantaneously at any given plumbing fixture.

### 3.8.2. Problems Encountered and Changes Implemented

With the manufacturer's design output of each boiler rated at 297 MJ/h, two boilers would be required to handle the installed DHW system capacity of 576 MJ/h. It is not known why this type of system was chosen over a stand-alone DHW system. The company supplying the boilers indicated that the initial capital cost of two boilers plus the DHW system now installed would be significantly greater than the cost of a dedicated DHW system. In addition, operating the system in this manner, means that the boiler system must always be circulating boiler fluid in order to meet the DHW tank requirements. As a result, the opportunity for shutting down the boiler loop when space heating is not required is lost.

No changes were made to the DHW system during this project.

### 3.8.3. Sizing Criteria for DHW Systems

Table 7 presents a comparison of various parameters relating to the DHW system including the installed capacity and the DOE simulated capacity.

## Table 7: Domestic Hot Water System Parameters

| | 1988/89 Heating Season | 1990/91 Heating Season | 1991/92 Heating Season |
|---|---|---|---|
| Installed Capacity | 576 MJ/h | 576 MJ/h | 576 MJ/h |
| OE Simulated Capacity | 243 MJ/h | 243 MJ/h | 243 MJ/h |
| Peak Demand | 195 MJ/h | 115 MJ/h | 147 MJ/h |
| Daytime Average | 46 MJ/h | 30 MJ/h | 27 MJ/h |
| Supply Temperature | 60°C | 58°C | 55°C |
| Consumption | 2,100 L/d | 2,500 L/d | 2,800 L/d |

The installed capacity of the DHW exchanger was 576 MJ/h, and was verified by JMB. The DHW design heat load determined using the DOE model, however, was less than one-half of this value. An investigation by HME revealed that the difference was due to the source of data used by JMB and UOS. Whereas JMB used the ASPE and ASHRAE guidelines based on fixture demands, UOS used daily water usage from Table 8.1-101 in the *Means Assemblies Cost Data 1989* [14]. The data in Table 7 indicates that capacity based on daily water usage results in a more accurate figure. The highest hourly peak demand recorded at Closeleigh Manor was 195 MJ/h.

JMB indicated, however, that it is characteristic of senior citizen's complexes to have lower DHW consumption than typical apartment buildings. The DHW heating capacity published by ASPE and ASHRAE is based on short term peak loading which occurs in apartment buildings, for example, when the tenants are all getting up and showering at approximately the same time in the morning. A senior citizen's building would not have the same morning demands. Even the demand around dinner time, when dish washing is occurring, would be less than an average apartment building. JMB was not able to find published design information nor recommendations for derating or downsizing system capacity for senior's housing. Nor were they able to find any accepted design publications, including engineering information published by hot water tank manufacturers, which used Table 8.1-101 for sizing equipment. They stated that the use of this table may be a "rule of thumb" for contractor-designed, minimum-budget developments, but it is not used for sizing "engineered" systems.

The decrease in the DHW supply temperature from 60°C to 55°C shown in Table 7 was due to a corresponding decrease in the boiler fluid circulation temperature. Although this temperature may not be considered by the manufacturer to be hot enough for dishwater use, it is deemed a safer temperature considering the elderly nature of the building occupants and the potential for scalding. The increase in the consumption shown in Table 7 is related to the change in the mixing ratio of hot and cold water due to the lower supply temperature.

## 3.9. Cooling System

The cooling of supply air to the building is handled by a 155 MJ/h capacity, direct expansion cooling coil installed between the preheat coil and the supply fan. A 50 kW, air-cooled condenser/refrigeration unit supplies cooling fluid to the cooling coil. The commercial area is equipped with three 700 L/s air handling units which provide additional air circulation. Although the original tender drawings indicate space for future cooling coils and compressors on these three fans, they were never installed.

When the outdoor temperature rises above the setpoint temperature of the supply air to the building, the heating coil pump is de-energized and the supply and exhaust fans run at maximum speed. The supply air temperature to the building is then maintained at 16°C by a separate controller which cycles the refrigeration unit. The cooling unit has a temperature setpoint controller which determines the outdoor temperature at which the cooling is initiated.

The monitoring data indicated that the cooling system was not operating properly. JMB was advised of the problems (Appendix D) and will work with YHC to correct them and then commission the system. An evaluation of the effectiveness of the cooling should be conducted once system operation has been verified. Since the building has operated since 1989 without the cooling system, the value of using the refrigeration unit to cool Closeleigh Manor is questionable. As with the humidifier, an evaluation may determine that the limited benefits do not justify the operating and maintenance costs.

## 3.10. Electrical System

Monitoring electrical use was limited to total building consumption, the total consumption of each of the six monitored suites, the block heaters, the ventilation supply and exhaust fans, the humidifier and the air-conditioning unit. Consumption data for the total building and the ventilation fans were used directly in the DOE model along with appliance and pump specifications and lighting schedules.

### 3.10.1. Problems Encountered and Changes Implemented

- **March 30, 1990** - New belts and pulleys were installed on the ventilation system supply and exhaust air fans to reduce the building air change rate to 0.5 ACH.
- **January 1992** - During the recovery system renovation adjustable speed drives were installed on the ventilation supply and exhaust fans, and on the space heating and boiler fluid circulation pumps.
- **January 1992** - Continuously operating 60 Watt, incandescent bulbs outside each suite were replaced with 13 Watt compact fluorescents.

### 3.10.2. Fans and Pumps

SRC reported that the rated power of the central supply fan when supplying 2360 L/s was 5.6 kW while the rated power of the exhaust fan was 2.25 kW. This provided a combined rated power consumption of 3.3 W/(L/s). The ASHRAE Standard 90.1-1989 [1] states that the maximum allowable fan power in a constant volume system shall not exceed 2.6 W/(L/s) which is 21% lower than Closeleigh Manor. The monitored data indicated that the initial fan consumption was 2.8 W/(L/s) while the current consumption 1.8 W/(L/s).

The calibrated DOE model determined that reducing the ventilation rate from 1.0 ACH to 0.4 ACH would reduce the fan electrical load 58%. JMB indicated that the pump speed reductions would result in a 70% pumping energy saving.

# 4. Building Energy Performance

The purpose of monitoring building energy performance was to aid in understanding the impact of the individual building systems on overall energy performance.

## 4.1. Heating Requirement

The main factors which impact on Closeleigh Manor's heating requirement are:

- the ventilation rate;
- the envelope air leakage;
- the overall heat recovery effectiveness; and
- the windows.

The effect of these factors on building performance was investigated using the calibrated DOE model. With the originally specified ventilation rate of 1.0 ACH, the model predicted that Closeleigh Manor's total heating requirements for a typical meteorological year (TMY) having 6988 HDD would be 1,739 GJ. Table 8 shows the specific heating requirements which comprise the total heating.

**Table 8: Heating Requirements of Original Design**

| Total (GJ) | Ventilation (GJ) | Space Heating (GJ) | DHW (GJ) |
|---|---|---|---|
| 1,739 | 674 | 829 | 236 |

### 4.1.1. Ventilation Rate

Figure 15 shows the annual energy consumption at the original design ventilation rate of 1.0 ACH and with the ventilation rate reduced to its

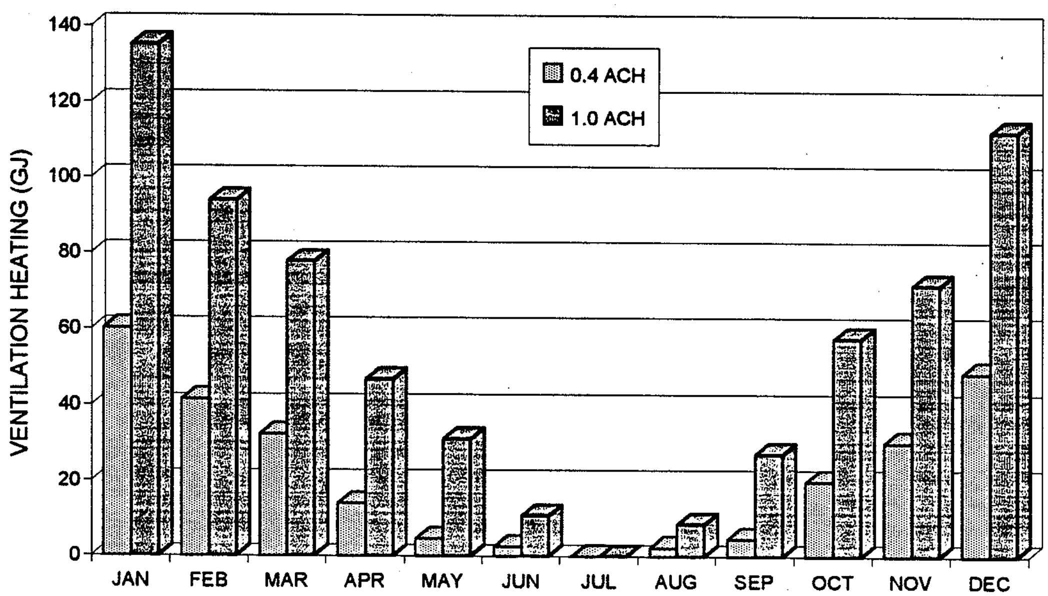



**Figure 15: Effect of Reduced Ventilation Rate on Ventilation Heating**

current operating value of 0.4 ACH. The values shown assume an overall heat recovery efficiency of 40%. By reducing the ventilation rate to 0.4 ACH, the ventilation heating requirement was reduced 64% to 246 GJ. The overall energy consumption would be reduced 25% to 1311 GJ.

### 4.1.2. Controlled Envelope Air Leakage

The continuous air barrier system installed as part of the R-2000 enhancements, provided the building envelope with a potential for reducing uncontrolled envelope air leakage to as low as 0.1 ACH. The controlled envelope leakage rate is primarily affected by occupants opening windows and, as indicated in Section 3.3.3, has a significant impact on space heating. Figure 16 shows the space heating requirement for the building with a controlled leakage rate of 0.4 ACH and 0.15 ACH.

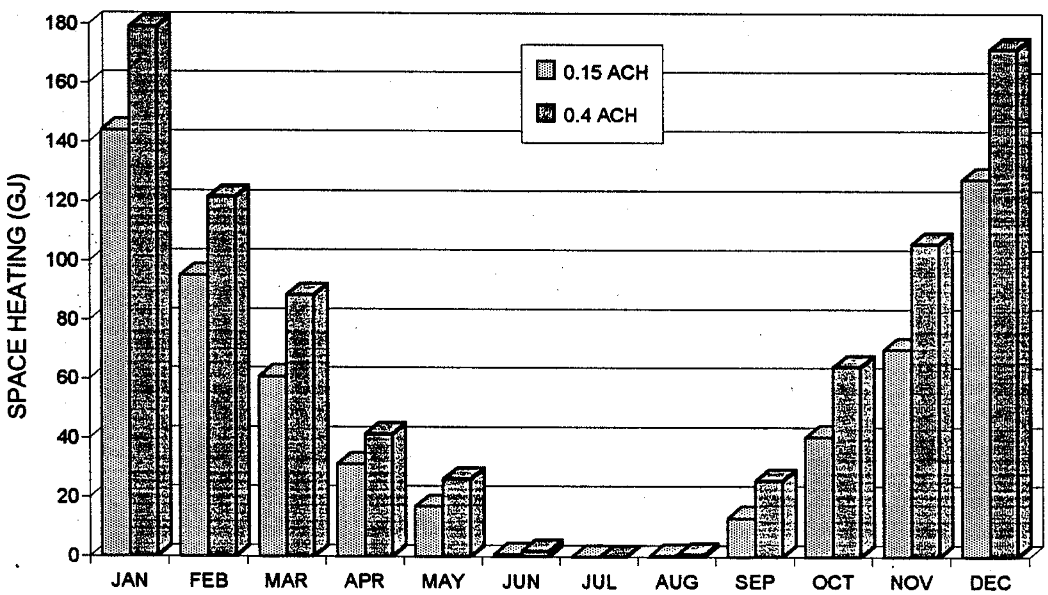



**Figure 16: Effect of Reduced Envelope Leakage on Space Heating**

The DOE model, which assumes a wind speed of 16 km/h, predicted that the space heating requirement for a TMY would be reduced 28% to 601 GJ and the overall energy consumption reduced 17% if the controlled leakage was reduced to 0.15 ACH.

The combined effect of reducing both the ventilation rate to 0.4 ACH and the envelope leakage rate to 0.15 ACH would reduce the original building's energy requirement by 38% to 1,083 GJ.

### 4.1.3. Improved Overall Heat Recovery Effectiveness

The overall effectiveness of the heat recovery system is the combined effectiveness of the preheat and reclaim coils. The monitored data indicated that, with the coils that are currently installed, the heat recovery system has the capability of recovering approximately 40% of the available heat. Section 3.4.4 discussed the advances which now make it possible to achieve an installed overall field effectiveness of 60%.

Figure 17 shows the energy requirements for a building with a heat recovery system having an overall effectiveness of 40%, and for one with an effectiveness of 60%, and assumes a ventilation rate of 0.4 ACH and an envelope air leakage rate of 0.15 ACH.

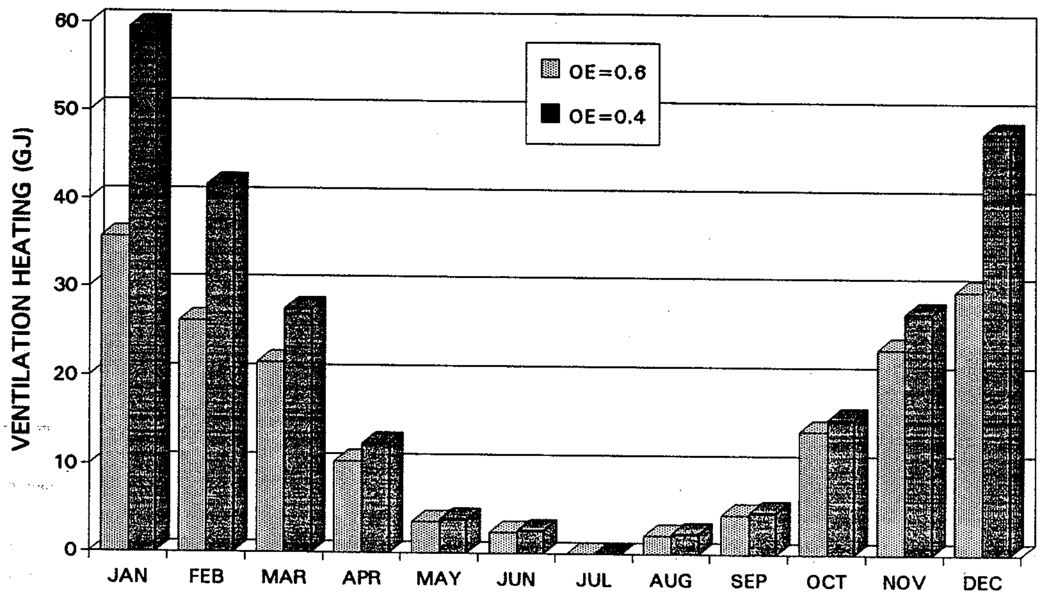



**Figure 17: Effect of Improved Heat Recovery on Ventilation Heating**

The DOE model predicted that the ventilation heating requirement for a TMY would be reduced 29% to 174 GJ if the heat recovery system had an overall effectiveness of 60%. The overall energy consumption would be reduced an additional 7%.

The combined effect of reducing the ventilation rate to 0.4 ACH, the envelope leakage rate to 0.15 ACH, and increasing the effectiveness of the heat recovery system to 60%, would decrease the original building's energy requirement 42% to 1,004 GJ.

### 4.1.4. Windows

Windows have typically been the "holes" in the building envelope because of their relatively low thermal resistance. Window technology has advanced significantly in recent years, however, and high performance windows are now available for which resistance values of RSI 1.4 are being reported. Figure 18 shows the space heating requirements for Closeleigh Manor with the existing windows, with triple-glazed windows and with high performance window technology (Super-R).

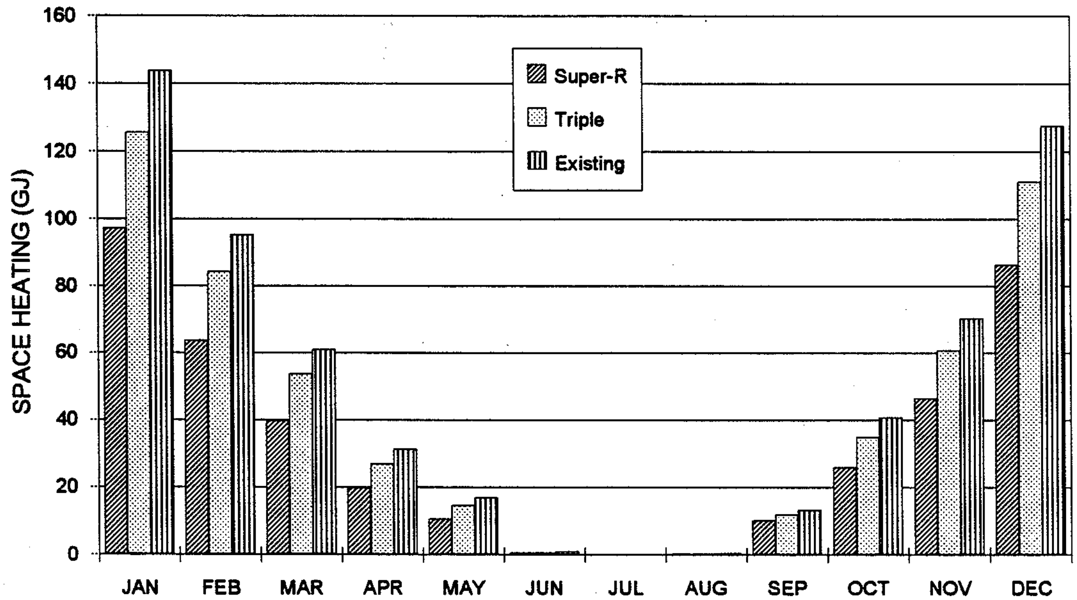



**Figure 18: Effect of Upgraded Windows on Space Heating**

The DOE model predicted that the space heating requirement for a TMY would be reduced 13% if triple-glazing was used throughout the building and by 33% if high performance window technology (RSI 1.4) was used.

The combined effect of reducing the ventilation rate to 0.4 ACH, the envelope leakage rate to 0.15 ACH, increasing the effectiveness of the heat recovery system to 60% and adding high performance technology, decreased the original building's energy requirement 53% to 810 GJ.

## 4.2. Optimized Heating Performance

Table 9 presents the space, ventilation and domestic hot water (DHW) heating requirements predicted by the calibrated DOE model for a TMY. Results are shown for Closeleigh Manor as it was originally constructed, for the building after numerous changes were implemented, and for a potential configuration based on the findings of this project.

**Table 9: Heating Requirements for Different Building Configurations**

| Code | BUILDING CONFIGURATION | Space Heating (GJ) | Ventilation (GJ) | DHW (GJ) | Total (GJ) |
|---|---|---|---|---|---|
| O | Original configuration (see Figure 19) | 829 | 674 | 236 | 1739 |
| C | Current configuration (see Figure 19) | 829 | 246 | 236 | 1311 |
| CE | "C" plus reducing controlled envelope leakage | 601 | 246 | 236 | 1083 |
| CTH | "CE" plus triple glazing and 60% heat recovery | 524 | 174 | 236 | 934 |
| P | "CTH" with high efficiency windows (see Figure 19) | 400 | 174 | 236 | 810 |

Figure 19 shows a monthly comparison of the space, ventilation and DHW energy consumption of the original building configuration (O), the current configuration (C) and a potential configuration (P) for a TMY. The values presented in this figure were predicted by the calibrated DOE model.

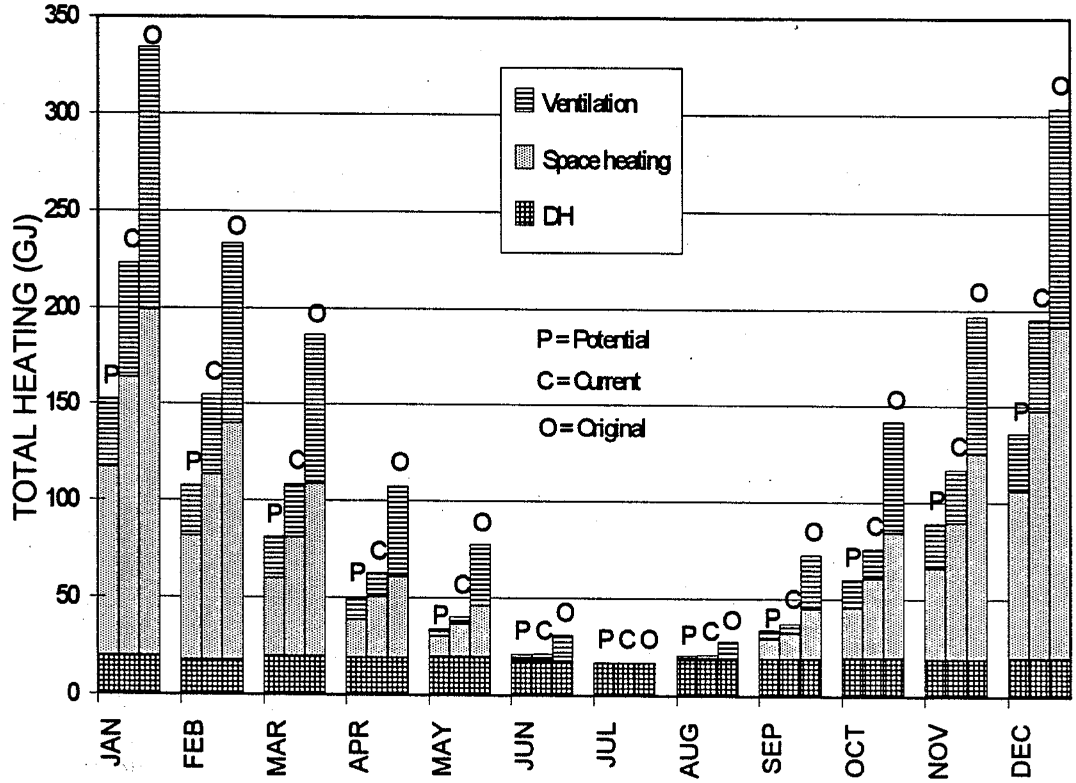



**Figure 19: Comparison of Optimized, Existing and Original Building**

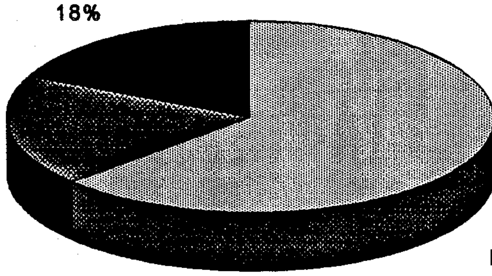
Using values from Table 9, the following combined annual *Space Heating* and *Ventilation* ( DHW is not included) heating requirements can be determined:

- the original building configuration required 68.5 kJ/m²/HDD or 1503 GJ/yr;
- the building currently requires 49.0 kJ/m²/HDD or 1075 GJ/yr;
- if envelope leakage can be reduced by educating occupants to keep windows closed during the winter months, the building requirement can be reduced to 34.8 kJ/m²/HDD or 847 GJ/yr; and
- with technology advances in recent years, if Closeleigh Manor was constructed today, it would be possible to attain an annual space and ventilation requirement as low as 23.6 kJ/m²/HDD or 574 GJ/yr.

These annual space and ventilation requirements can be compared to the findings of the Level B monitoring program for R-2000 houses, which reported 56 kJ/m²/HDD or 1229 GJ/yr.

## 4.3. Fuel Oil Consumption

Figure 20 shows the distribution of fuel oil consumption for Closeleigh Manor as it is currently operating and is based on the values in Table 9 and DOE simulations.



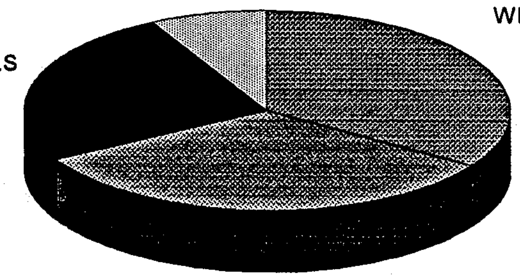




**Figure 20: Fuel Oil Consumption**

The amount of fuel oil consumed to provide space, ventilation air and DHW heating depends upon boiler efficiency. Table 10 shows the average monthly boiler efficiencies of the existing system and the efficiencies predicted by the DOE model using part load curves provided by the manufacturer.

**Table 10: Existing and Optimized Boiler Efficiencies**

| | | Avg | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Existing | % | **56** | 65 | 57 | 56 | 52 | 45 | 36 | 35 | 36 | 45 | 52 | 57 | 65 |
| Optimized | % | **67** | 71 | 72 | 68 | 67 | 66 | 65 | 65 | 65 | 66 | 68 | 69 | 73 |

Simulations of Closeleigh Manor as it is currently operating indicated that improving the average annual boiler efficiency from 56% to 67% would result in a reduction of fuel oil consumption of 449 GJ for a TMY. This amount of energy translates into 11,648 litres of #2 fuel oil (38.54 MJ/L) and an annual savings of

$3,494, using a fuel oil rate of $0.30/L. The boiler manufacturer confirmed that it should be possible to attain the DOE predicted efficiencies.

## 4.4. Electricity Consumption

Electrical consumption figures for Closeleigh Manor are shown in Table 11. Two points should be noticed about these figures:

- A very large amount of electricity is being consumed at Closeleigh Manor and little or no attention was given to electrical conservation when the building was initially designed.
- The February to April data from 1990 to 1992 indicates that simple measures such as reducing fan and pump speeds, converting thirty, continuously burning, 60 Watt incandescent bulbs to 13 Watt compact fluorescents, and limiting the use of the humidifier have reduced electrical consumption 15%.

**Table 11: Annual Electricity Consumption**

| Year | Total (kWh/yr) | Feb - Apr (kWh/day) |
|---|---|---|
| 1988/89 | 390,480 | na |
| 1989/90 | 395,451 | na |
| 1990/91 | 405,156 | 1,257 |
| 1991/92 | 362,585 | 972 |
| 1992/93 | *(326,326)* | 874 |

Figure 21 shows the DOE predicted electrical consumption for the current building configuration. It is interesting to note that consumption targets were not initially specified for the two largest users, the appliances and the lights. The calibrated DOE model determined that reducing the ventilation rate from 1.0 ACH to 0.4 ACH reduced the fan electrical load 58%. JMB indicated that the pump speed reductions resulted in a 70% pumping energy saving.

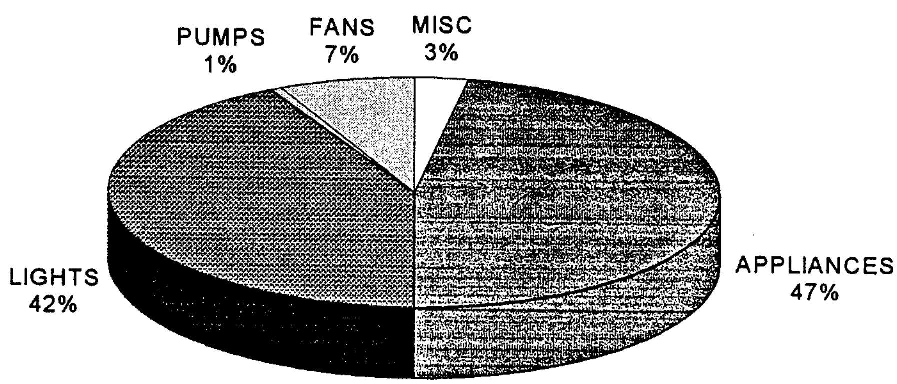



**Figure 21: Total Building Electrical Consumption**

## 4.5. Annual Fuel Oil and Electricity Cost Savings

Table 12 shows the potential cost savings by implementing various system changes. This is the type of information that is required in order to determine the payback period of the investment required to incorporate specific design features into a building. The energy savings have been taken from Table 9.

**Table 12: Annual Fuel Oil and Electricity Cost Savings**

| FUEL OIL SAVINGS | System Change | Furnace Efficiency | Energy Savings (GJ) | Cost Savings @ $0.30/L ($7.78/GJ) |
|---|---|---|---|---|
| Windows | Existing to Triple Glazing | 0.56 | 77.2 | $1,073 |
| | | 0.67 | | $897 |
| | Existing to High Performance | 0.56 | 200.8 | $2791 |
| | | 0.67 | | $2,333 |
| Ventilation | 1.0 ACH to 0.4 ACH | 0.56 | 428.1 | $5,951 |
| | | 0.67 | | $4,974 |
| Envelope Leakage | 0.4 ACH to 1.5 ACH | 0.56 | 227.1 | $3,157 |
| | | 0.67 | | $2,638 |
| Heat Recovery | Effectiveness from 0.4 to 1.6 | 0.56 | 72.0 | $1001 |
| | | 0.67 | | $837 |
| **ELECTRICITY SAVINGS** | **System Change** | | **Energy** (kWh) | **Savings @ $0.09/kWh** |
| Ventilation Fans | 1.0 ACH to 0.4 ACH (Savings predicted by DOE) | | 29,000 | $2,610 |
| Lighting | Convert all fluorescent to low wattage | | 5,072 | $456 |
| | Convert suite entry light to fluorescent | | 12,352 | $1,112 |

When determining cost savings it is important to consider the effect of energy subsidies and utility rate structures. In addition, note that energy savings do not accumulate in a linear manner and cannot simply be added together. Buildings work as an interactive system and should be modeled the same manner.

# 5. Energy Performance Simulations

This project has demonstrated the value of an energy simulation program as a design tool and in predicting the performance of the building. The value of these programs has also been recognized by a number of utility companies who provide design assistance to their customers free of charge. The following information has been taken directly from the publication by Northeast Utilities, *Energy and Economics: Strategies for Office Building Design [15]*. Although the publication deals with buildings larger than Closeleigh Manor, most of the design principles it discusses are relevant to all buildings.

*A computerized energy performance simulation can give architects, engineers, developers and owners an estimate of how much energy a proposed building will consume under actual operation and weather conditions. This whole building energy performance, in quantitative terms, is important information for predicting and for demonstrating that a proposed building will meet any standards of energy and comfort performance that might be set for it. A program such as DOE-2 reduces both the cost and time barriers that have prevented many design professionals from including energy analysis as a routine part of the design process.*

*Energy performance simulations can be performed at any time during the design of a new building and on existing buildings, but research and experience have shown that the usefulness of the simulation is greatest at the conceptual and schematic design process, when energy-saving concepts and strategies can be explored inexpensively, and when the greatest potential energy savings can be achieved for the building.*

*New projects need assistance during the early planning and design phase where energy-saving strategies can not only be more effective, but also the most economical. The work carried out in this project demonstrates that:*

1. *Energy efficiency is not always more expensive. There are many energy saving strategies that can be very effective without necessarily increasing the construction cost or design time.*
2. *Energy-saving strategies must be designed into the building in the very first planning and schematic design stages of a project*
3. *There are no magic energy-saving formulas that will work in every situation. Since many factors interact and influence energy performance - including orientation, configuration, load characteristics, patterns of use, type of mechanical system and so on - some strategies will be more effective on some buildings than others.*
4. *The only way to know how a particular strategy will perform on a specific building is to run a computerized simulation of it.*

# 6. Conclusions and Recommendations

The building system problems and issues addressed during this investigation, and the conclusions and recommendations regarding the performance and operation of Closeleigh Manor and future buildings of this type, can be related to:

- system design and specification;
- system commissioning; and
- building operator training and tenant education.

System Design and Specification

The various building systems originally installed in Closeleigh Manor appeared to have been designed and specified according to what are generally accepted as good engineering practices for conventional buildings. The investigation indicated, however, that the potential benefit of some of the innovative design concepts used in Closeleigh Manor was not realized due to the conservative nature of the practices used to specify equipment, and to the absence of guidelines for specifying system operating parameters over a full range of conditions. The use of conventional design practices resulted in oversized equipment and system operating specifications that did not allow the potential performance of the building to be achieved.

If systems in energy efficient buildings are to be properly sized and their performance is to be optimized, more sophisticated energy analysis tools must be used during the design phase. Although building simulations can be performed at any time during the design process, research and experience have shown that the usefulness of the simulation is greatest at the conceptual and schematic design stages, when energy-saving concepts and strategies can be explored inexpensively, and when the greatest potential energy savings can be achieved for the building.

Throughout the project, changes were implemented that significantly improved the energy performance of Closeleigh Manor. Renovation, however, is often not practical and always expensive, and additional changes that could further improve the building's energy performance will not be carried out. The positive effects of the changes that were completed indicated that some of engineering practices which may be applicable to conventional buildings of this type are clearly not the practices that should be applied to the same buildings built to an R-2000 level of performance.

System Commissioning

There was no indication that the HVAC system initially installed in Closeleigh Manor had been adequately commissioned. The investigation revealed, for example, that:

- the ventilation system was never properly balanced;
- the boiler system was not operating to its full potential; and
- that the cooling system had never functioned properly.

One may question how the trades were held accountable for their installations when proper operation had not been verified.

The monitoring investigation, and observations of the commissioning carried out upon completion of the recovery system renovation, indicated that the purpose of commissioning was to ensure only that system components were functioning. System operation was not verified over the full range of operating conditions. For example, the heat recovery system installed during the renovation was commissioned by the design engineer and appeared to operating correctly. Monitoring revealed, however, that of a three-way bypass valve was not functioning properly under certain operating conditions because of faulty controls. Without the monitoring system, this problem might never have been discovered and the heat recovery capability of the system would have been significantly diminished.

Furthermore, commissioning at Closeleigh Manor made no attempt to define system operating parameters for other than design conditions. System optimization from season-to-season was the sole responsibility of the building operator, who did not have sufficient information or training to carry out this task. As a result, building performance is optimized for only a narrow range of operating conditions.

Building Operator Training and Tenant Education

Adequate building operator training and tenant education has never been carried out at Closeleigh Manor. The development and documentation of the operating and maintenance schedules required by the building operator to carry out the seasonal system adjustments required to maximize building performance were never completed. Moreover, the tenants were never instructed regarding the proper use of the windows, and the heating and ventilation system in the suites. This information is essential if buildings such as Closeleigh Manor are to be operated effectively and efficiently.

Principle Conclusions

On the basis of the findings of this project, the principal conclusions were as follows:

- If systems in energy efficient buildings are to be properly sized and their performance is to be optimized, more sophisticated energy analysis tools must be used during the design process. Standards and guidelines which have served as accepted practices for a number of years may no longer apply to energy efficient buildings. Optimization must include the full range of operating conditions and not just design conditions.
- Buildings of this nature must be commissioned over a full range of operating conditions if their performance and operation are to be optimized. This will require monitoring the energy performance of the whole building and the HVAC components. The more complex the building, the more important the commissioning process becomes. Annual system operation specifications and maintenance schedules must be developed and fully documented as part of the commissioning.
- Every attempt should be made to keep building systems as simple as possible. This is especially true in the north due to the harsh climate, the remote location and the lack of local skilled service people required to maintain these systems.
- Building operators must be trained to properly operate the building and make the seasonal adjustments required to optimize performance. The building operator must then educate the occupants so that they do not operate their individual suites in a manner that will undermine the efforts to optimize building performance.

The remainder of this section presents specific conclusions and recommendations for the areas discussed in detail in Sections 3. A number of recommendations presented in this section have been taken directly from the reports prepared by NRC and SRC. All of their recommendations are supported by HME.

## 6.1. Building Envelope

### 6.1.1. Envelope Air Leakage

The continuous vapour barrier installed in Closeleigh Manor is effective in reducing uncontrolled leakage across the building envelope. The amount of controlled leakage which occurs through the openable windows, however, was shown to have a significant impact on the space heating requirements of individual suites and the whole building. Although the DOE simulations indicated that air leakage across the building envelope with all of the windows closed can be reduced to 0.1 ACH, this number was seen to increase as much as four-fold when windows were opened. Therefore, the building operator must attempt to educate the occupants to open windows only when necessary and for as short a time as possible. The building must then be operated in a manner that will reduce the tenants' need to open windows.

### 6.1.2. Windows

The design load calculations and the DOE simulation work demonstrated that the upgraded window system chosen for Closeleigh Manor was effective in improving the overall energy performance of the building. The DOE simulation also showed, however, that the effective insulation value of the entire building envelope was reduced to RSI 1.65. On the basis of the DOE work and observations regarding window condensation during colder weather, it was concluded that, if this building was designed today, the window system should include triple glazing at a minimum, and high performance window technology should be considered.

### 6.1.3. Recommendations for Closeleigh Manor

1. Tenant seminars regarding the proper use of the windows should be held twice a year at the beginning of the heating and cooling seasons.
2. The use of the central humidifier should be limited, and possibly not used at all, in order to prevent condensation build-up on the windows during cold weather.

### 6.1.4. Recommendations for Future Buildings

1. All windows, and not just north facing units, should have a minimum of triple glazing and high performance window should be seriously considered:
   - Research conducted by NRC's Division of Building Research [3] has shown that, in regions with heating degree-days as low as Whitehorse, there is a positive net window heat loss during the

heating season on all orientations including the south. The net window heat loss is the design loss minus the solar gains.

- Triple glazed and high performance units have a higher interior surface temperature than double glazed units which allows higher relative humidity (RH) levels to be maintained throughout the building without having condensation problems. The Canadian Federal-Provincial Advisory Committee on Environmental and Occupational Health recommends winter RH levels in the range of 30-55%. In Whitehorse, this is not possible in dwellings with double glazing.
- The warmer window surface temperature will reduce drafts and provide greater comfort to the occupants.
- The space between glazing surfaces should be a minimum of 13 mm and advanced spacer technology should be used to reduce heat loss at the window edge. All metal frames should be thermally broken.

2. Instead of casement windows, windows should be specified with a fixed unit on the top and an awning window on the bottom. The smaller openable window reduces the amount of leakage area.

## 6.2. Heat Recovery and Ventilation

### 6.2.1. Heat Recovery System

The heat recovery system initially installed in Closeleigh Manor is not recommended for future applications of this type. The operation of the run-around heat exchanger system currently installed has been optimized and cannot be improved upon further without a complete redesign of the system. For future buildings, however, a high performance system capable of achieving an overall field effectiveness of 60% can now be designed and specified. System designers should account for the incremental electrical energy required to power the supply and exhaust fans and the recovery loop circulation pump when assessing cost effectiveness.

### 6.2.2. Ventilation Air Distribution System

The air distribution system was evaluated using manually gathered information. It was concluded that, in order for this type of ventilation system to operate effectively, it is imperative that the design of the system include a sufficient number of high quality dampers strategically located throughout the building which will make it possible to balance the supply and exhaust air flows required in each area. This was not done in Closeleigh Manor and, even with all the retrofit work and repairs that were carried out, the building is still not at a point where it can be properly balanced. The investigation carried out during this project indicated that the problems encountered were the result of a combination of incomplete design specifications, inexpensive and poorly installed dampers and inadequate system balancing when the building was commissioned. An air distribution system with separate supply and exhaust ducts to individual suites is not recommended for future buildings of this type.

### 6.2.3. Air Quality and Comfort

The $CO_2$ levels monitored throughout the building indicated that, with the operating schedule which provides a ventilation rate of 0.4 ACH, adequate indoor air quality is being maintained. There was no indication of a need for the original design specification of 1.0 ACH. A ventilation rate of this magnitude served only to increase the ventilation heating requirement and the electrical consumption of the ventilation fans.

Although building humidity levels were generally low by Health and Welfare standards, this was not a common complaint expressed by the tenants. In addition, maintaining relative humidity levels above 20% during the colder months resulted in condensation problems on the double glazed windows. As a result, if the humidifier is operated, it must be monitored by the building operator and adjusted regularly based on outside conditions. Humidifier operation is not recommended, however, because of the high operating and maintenance costs compared to the limited benefits.

If future evaluation of humidity levels indicate that additional humidity should be added to the building with this humidifier, changes to the unit should be carried out so that it is supplied with domestic hot water, which is maintained at 55°C, rather than cold municipal water which is approximately 5°C during the winter months. By doing this, the humidifier would only need to raise the water temperature 45 C° and the electrical consumption would be reduced by almost one-half. With the price of electricity over three times the price of fuel oil in Whitehorse, the savings would be substantial.

Thermal comfort in Suites 206, 207, 212, 303, 306 and 309 appeared to be difficult to attain. SRC reported [5] that the thermostats were set to 18°C while the actual suite temperatures were 23, 22, 26, 21, 23 and 22°C respectively. Since all interior suite surfaces are sound-proofed with a material providing an insulation value of RSI 2.1 (R-12), it is suspected that high internal gains from appliances and lighting are causing the higher temperatures.

### 6.2.4. Recommendations for Closeleigh Manor

1. The boiler and space heating circulation pumps should be set to operate at the same speed as the principle pumps.
2. SRC noted that Suite 104, which is adjacent to the mechanical room, experienced excessively high noise levels from the supply air system and recommended that a sound absorbing duct section be added to the supply ducts for this room. It was noted that Suite 102 also had a significant amount of noise from the ductwork.
3. SRC recommended that several existing dampers in the air system be retrofitted to provide superior flow control. The key dampers are those located close to the mechanical room. At present, even with these dampers fully closed, the required flows cannot be achieved.

4. SRC and Arctech recommended that balancing dampers be installed behind the supply air grilles in the second and third floor hallways. At present, there are no dampers on these grilles and the third floor receives an excess flow while the second floor receives a deficit. The estimated cost of the dampers, installed and balanced, was $400.
5. Arctech recommended that supply diffusers, such as the Whisper Grill Type VLT-100, be installed in those suites where air flows exceed design tolerances. If they prove successful, consideration should be given to installing them in all of the suites. The estimated cost for 10 or more diffusers, installed and balanced, is $75 each.
6. If better diffusers are installed, the building operator should experiment with lowering the setpoint temperature of the supply air to the building to its balance point temperature of 16°C. This will minimize the delivery of heated ventilation air to the building when it is not required.
7. The building operator at Closeleigh Manor noted that the Yukon is normally considered as a semi-arid climate and Yukoners are conditioned to lower relatively humidity levels. He recommends that the humidifier not be used and suggests that tenants requiring additional humidity should supply their own room units.
8. The tenants in Suites 206, 207, 212, 303, 306 and 309 should be interviewed to determine if regulating the suites' temperature is a problem and if windows are opened as a result. It may be necessary to supply these suites with more energy efficient appliances and lighting in order to reduce overheating.

### 6.2.5. Recommendations for Future Buildings

1. An alternative heat recovery and ventilation strategy to the one used in Closeleigh Manor should be considered for future buildings of this type. Any strategy considered should incorporate:
   - supply and exhaust air flow rates based on ASHRAE Ventilation Standard 62-1989;
   - high performance heat recovery; and
   - energy efficient motors and pumps.
2. NRC recommended that the air intake should not be located at the ground floor level as is the case at Closeleigh Manor. Car and service vehicle exhaust, and wood smoke have all entered the building at various times because of the location of the air intake. On one occasion, fumes and smoke from a "weed eater" activated the smoke detector in the supply duct and set off the fire alarm resulting in a full evacuation of the building. The distance between the air intake and the air exhaust should also be carefully considered. At Closeleigh Manor, the air intake had to be redirected because a high percentage of air exhausted outside that was re-entering the building.
3. NRC recommended that the ductwork be properly sealed to minimize air leakage. The 1989 ASHRAE Handbook of Fundamentals recommends that "a leakage class of 3 (corresponding to less than 1.5% leakage) is

attainable by careful selection of joints and sealing methods and by good workmanship. Where less leakage is required, designers should understand that less experienced contractors may have difficulty; meeting their requirements." At Closeleigh Manor, the longitudinal seams in the ductwork were not sealed and the durability of the sealing compound used on the transverse seams is not known.

4. NRC recommended that the adjustment mechanism for the air flow to each room be located in each suite. In the Closeleigh Manor duct system, almost all of the air dampers that control the room air supply and exhaust flows to all three floors are located in the space above the first floor. Consequently a two person crew with 2-way radios is required to efficiently set the correct air flows in the building.
5. A sufficient number of high quality dampers must be installed if a reasonable attempt is to be made at balancing the supply and exhaust flows to the building and to each individual suite.
6. Supply grilles should be located away from commonly used areas to prevent drafts in the immediate area. They could be located above closets, on short unusable walls or in hallways. Moreover, a diffuser grille should be used to ensure that supply air is delivered in a manner that will allow for greater tempering and mixing with existing room air.
7. The use of more efficient appliances and lighting is recommended to reduce overheating in individual suites which may be well insulated due to the thermal resistance of sound proofing materials.

## 6.3. Boiler System

The boiler system in Closeleigh Manor was designed so that the boiler loop provides heating fluid to:

- the heating coils in the ventilation supply air duct;
- the space heating loop; and
- the heat exchanger of the domestic hot water (DHW) heater.

The investigation has shown this to be inefficient because, although DHW is required throughout the year, ventilation air heating and space heating requirements are reduced during the spring and fall seasons and are often not required at all during the summer months. The current configuration requires that the boilers operate throughout the year in order to meet DHW requirements. These three functions could be separated into two sub-systems with a boiler system dedicated to space heating and a ventilation air/DHW system dedicated to DHW needs and reduced space heating requirements. In this way, when space heating requirements were small, the boiler system could be shut down.

The analysis of the boiler operation and boiler efficiency data indicated that the operation and performance of the boiler system has still not been optimized. The data indicated that, throughout the year, the boilers operate in much the same manner. All five boilers are used to satisfy the boiler requirement, whether it is large or small, resulting in frequent cycling and short firing times. According to the manufacturer, this is not how the system should be operating. HydroTherm

Canada has offered to work directly with YHC and WHA to resolve this matter. HydroTherm recommended that the boiler/nozzle firing capacity and the overall control strategy be returned to the manufacturer's recommended specifications and settings. Then, their technical support staff will work with the building operator over the phone to assess step-by-step what exactly is causing the boilers to cycle rapidly. Proper operation of the boilers will result in lower operation and maintenance costs, higher efficiencies, reduced standby and chimney losses and increased boiler life.

### 6.3.1. Recommendations for Closeleigh Manor

1. It is recommended that YHC and WHA work closely with the boiler manufacturer to resolve the boiler problems which have been identified.

### 6.3.2. Recommendations for Future Buildings

1. The boiler system in a building like Closeleigh Manor should be dedicated to space heating and not linked to DHW heating. In addition, serious consideration should be given to combining the ventilation air heating with the DHW system and not the boiler system.
2. The pick-up capacity provided by reducing the ventilation rate should be considered when designing the system. This will allow the design engineer to take a less conservative approach when sizing and result in a heating plant more closely matched to the actual heating requirement of the building.

## 6.4. Space Heating System

The JMB engineering evaluation of Closeleigh Manor determined that the space heating system had twice the installed capacity of what was actually required. The reasons for this are unclear since the original design calculations were not available. Although the added capacity had not adversely affected the operation and performance of the system, the initial capital cost of a properly sized system would have been significantly lower.

The monitoring data indicated that the controller which allows the temperature of space heating fluid to drop to 38°C when the outside temperature is above 21°C was not set properly. During periods when no space heating was required, the fluid temperature did not drop below 55°C. The hotter fluid increases piping losses to the building during periods when cooling is required.

### 6.4.1. Recommendations for Closeleigh Manor

1. The setpoint of the controller should be adjusted to the original design specification of 38°C by the controls contractor.
2. SRC noted that there were large differences between the suite temperature and the thermostat temperature in Suites 203, 212 and 307. The thermostats and control valves in these suites should be examined to verify the calibration of the temperature sensor on the thermostat and the proper operation of the thermostat and control valve.

### 6.4.2. Recommendations for Future Buildings

1. Space heating should be provided with a dedicated system which is independent of the DHW system. Reduced space heating needs should be provided by the ventilation air heating system which should possibly be combined of the DHW system.

2. A multiple speed motor should be considered for the space heating circulation pump because of the different flow rates and pressures caused by the varying number of control valves calling for heat.

## 6.5. Domestic Hot Water System

Since monitoring commenced in 1988, the peak hourly DHW demand system has been 195 MJ/h. This demand is only one-third of the system's installed capacity and would appear to be oversized. It is recognized that the system was originally sized using what are considered good engineering practices. However, given the magnitude of the oversizing, these practices may have to be challenged and adjustments made for future buildings, especially those designed for seniors. In addition, current guidelines are not available for water saving devices which are part of the conservation strategy in an energy efficient building. It is not sufficient to accept that, because a system is "engineered", it is sized correctly.

The study also concluded that a dedicated DHW system should have been installed instead of a boiler fed system. A stand-alone system would allow both the DHW and space heating systems to operate more efficiently and effectively.

### 6.5.1. Recommendations for Closeleigh Manor

1. Equipco, the boiler representative in Vancouver, indicated that controllers are available which will allow the existing DHW system to emulate a dedicated system. This should be further investigated.

### 6.5.2. Recommendations for Future Buildings

1. Consideration must be given to the fact the low-flow fixtures and low-usage appliances are more frequently being used in all types of dwellings. It is no longer acceptable to merely pull a number from a chart or to accept "good engineering practice" without question. This can only be done if there is no concern for optimizing building performance and reducing capital and operating costs. ASPE water consumption rates should be reviewed since there are many low-flow fixtures and appliances now on the market.

2. In a building like Closeleigh Manor, a dedicated DHW system should be specified. Whereas the DHW system is required year round, there will be a number of months when space heating is not required, or is greatly reduced. If the space heating system is not tied to the DHW system, it becomes easier to optimize the performance of both the space heating and the DHW system. The advantages of a dedicated oil-fired water heater are that it comes as a packaged unit, there are no pumping or

heat losses between the combustion source and the tank, and the controls are much simpler.

## 6.6. Cooling System

The monitored data indicated that the system was not operating properly and would have to be repaired and commissioned. The building has operated without the cooling system since 1989 and the benefit of providing cooling to Closeleigh Manor is questionable. As with the humidifier, a cooling system evaluation may determine that limited benefits will not justify the operating cost.

### 6.6.1. Recommendations for Closeleigh Manor

1. An evaluation of the effectiveness of the cooling system should be conducted once system operation has been verified and an operating schedule has been determined.
2. The temperature at which cooling is initiated must be chosen such that the 16°C air delivered to the building is not perceived by the elderly tenants as a draft. Otherwise, they are likely to revert to covering over supply ducts and lodging complaints with the building operator, as has occurred in the past,.
3. In order to minimize, or eliminate, the use of the refrigeration unit, a cooling system evaluation should consider a strategy which would utilize the ventilation system and the cool summer evenings that are typical in Whitehorse. If ventilation rates as minimized during the hot part of the day, and maximized when it is cooler, it may be possible to provide adequate cooling without using the refrigeration unit.

### 6.6.2. Recommendations for Future Buildings

1. It should not be assumed that, like conventional buildings, energy efficiency ones will require a cooling system. As with other components of the HVAC system, the design, equipment selection and operation settings should be selected with the aid of simulation studies.

## 6.7. Electrical System

The project emphasized the importance of having electrical consumption targets established at the design phase and specifying the equipment necessary to meet these targets.

### 6.7.1. Recommendations for Closeleigh Manor

1. Arctech recommended that the 36 hallway fluorescent fixtures should immediately be retrofitted with 32 Watt tubes. Replacing 72 tubes will save an estimated 5046 kWh per year. In addition, retrofitting the reflector and electronic ballast in each fixture should be investigated.
2. Arctech noted that the vehicle plug-ins could be effectively controlled by time-of-day switching or temperature-controlled switching. Temperature-control sensors can be added to existing receptacles for $10 each. Programmable controllers can be added to the existing breaker panel to

combine both time-of-day and temperature functions and include demand limiting and load shedding. The cost of these units is approximately $2000. Energy savings of 60% to 80% are typical for temperature-control sensors. From December 3, 1991 to November 28, 1992, 16,883 kWh were used for block heaters at a cost of $1,519.

The building supervisor noted that any change regarding the plug-ins should be reviewed with the tenants. Some tenants are apparently quite adamant about not having to call an ambulance or wake up a neighbour to take them to the hospital during normal sleeping hours. They believe their car should not only start any time of day or night, but should also be also kept warm with an in-car heater.

### 6.7.2. Recommendations for Future Buildings

1. SRC recommended that more emphasis be placed on the efficient use of electricity.
   - Fixed lighting, particularly lighting which is run continuously, should not be incandescent.
   - The electrical appliances chosen should be in the higher efficiency ranges. In Closeleigh Manor, the refrigerators chosen were frost-free units, with an Energuide rating of 149 kWh/month. Similarly sized refrigerators are commonly available that use less than 90 kWh/month.
   - All electric motors should be in the high efficiency range.

## 6.8. Building Operation and Maintenance

In order to optimize building performance over a full range of operating conditions, detailed commissioning must be carried out and complete operating procedures must be prepared. The building operator must then be trained to properly operate the building and make the seasonal adjustments required to optimize performance. This individual must then educate the building occupants so that they do not undermine efforts to maximize building performance.

### 6.8.1. Recommendations for Closeleigh Manor

1. Operating guidelines that will allow the building operator to easily determine mechanical system operating conditions and the changes that should be implemented during different operating conditions should be identified and posted in the mechanical room.
2. A preventative maintenance manual including procedures for seasonal switchovers should also be developed.
3. Twice a year, preferably at the beginning of the heating and the cooling seasons, a short seminar should be given to the tenants on the operation of the ventilation system and the proper use of thermostats and windows. The outside of the building should be checked during the cold winter months to determine where windows are being opened. The reasons for these openings should be investigated.

### 6.8.2. Recommendations for Future Buildings

1. Twice a year, preferably at the beginning of the heating and the cooling seasons, information should be given to the tenants on the operation of the heating and ventilation systems and on the proper use of windows.
2. An manual identifying different operating conditions and specifying the building system settings for each different condition should be developed as part of the commissioning process.
3. A preventative maintenance manual complete with schedules and procedures should be also be developed.

## 6.9. Recommendations for Further Research

1. With the advances in high performance window technology, there may now be a significant benefit to upgrading windows rather than insulation in order to increase the effective RSI value of the building envelope. A study should be initiated to evaluate the building science, construction and cost implications of this design concept.
2. The methods used for sizing DHW systems should be reviewed and guidelines be established for buildings incorporating water conservation strategies and for low-usage buildings such as senior's complexes.
3. In regions where fossil fuels are relatively inexpensive compared to electricity, detailed research should be carried out on heat recovery systems to determine the cost effectiveness of heat recovery when additional electrical loads are considered. These loads include the additional fan power resulting from the pressure drops across the preheat, heating and reclaim coils, and the recovery loop circulation pump. The effect of freezing on the overall effectiveness should also be considered. Ongoing heat recovery system research at the University of Saskatchewan will be addressing issue such as these.
4. Research on simplified building monitoring systems to assist in commissioning and system operation should be carried out. If actual system efficiency could be determined and compared to predicted values for given conditions, the building operator could more easily optimize building performance and ascertain when problems were developing.

## References

NOTE: All of the documents and reports produced as a result of this project are designated with an asterisk (*) and included in Appendix F.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# APPENDIX A:

## List of Monitored Parameters and Monitoring Sensors

## List of Monitored Parameters

**A. Apartments #105, 205, 305**

1. Flow of heating water
2. Temperature of heating water supply
3. Temperature of heating water return
4. Relative humidity of living room
5. Temperature of living room
6. Temperature of master bedroom
7. CO2 concentration in exhaust ventilation air
8. Electricity consumption of suite
9. Pressure difference across exterior wall

**B. Apartments #302, 308, 311**

1. Flow of heating water
2. Temperature of heating water supply
3. Temperature of heating water return
4. Relative humidity of living room
5. Temperature of living room
6. Temperature of master bedroom
7. CO2 concentration in exhaust ventilation air
8. Electricity consumption of suite

**C. Outdoors/Miscellaneous**

1. Temperature of outdoor air
2. Horizontal solar radiation
3. Sol-air temperature
4. Temperature of crawl space
5. Electricity consumption of building
6. Electricity consumption of car block heaters

**D. Commercial Areas: East, North, West**

1. Flow of heating water
2. Temperature of Heating water supply
3. Temperature of heating water return

**E. Common Lounges: Pioneer, Library, Exercise**

1. Relative humidity of room
2. Temperature of room
3. CO2 concentration in exhaust ventilation air
4. Fireplace status in second-floor lounge

## F. Boiler Room

*HRV air sensors*

1. Flow of supply air
2. Flow of exhaust air
3. Temperature of supply air entering building
4. Temperature of supply air leaving building
5. Temperature of exhaust air entering building
6. Temperature of exhaust air leaving building
7. $CO_2$ concentration in supply air
8. $CO_2$ concentration in exhaust air
9. Electricity consumption of supply air fan
10. Electricity consumption of exhaust air fan

*HRV fluid sensors* (50% glycol)

11. Flow of HRV fluid
12. Temperature of fluid entering pre-heat coil
13. Temperature of fluid leaving pre-heat coil
14. Temperature of fluid leaving recovery coil

*Boiler fluid sensors* (20% glycol)

15. Flow of boiler fluid
16. Temperature of fluid inlet
17. Temperature of fluid outlet
18. On-time of boiler 1
19. On-time of boiler 2
20. On-time of boiler 3
21. On-time of boiler 4
22. On-time of boiler 5
23. On-time of boiler 6
24. On-time of boiler 7
25. On-time of boiler 8
26. Fuel oil consumption

*Space heating fluid sensors* (20% glycol)

27. Flow of space heating fluid
28. Temperature of supply fluid
29. Temperature of return fluid

*Domestic hot water sensors*

30. Flow of cold water to DHW heater
31. Temperature of cold water supply
32. Temperature of hot water delivery
33. Flow of DHW heat exchanger fluid
34. Temperature of heat exchanger supply fluid
35. Temperature of heat exchanger return fluid

## Monitoring Sensors

Space and Fluid Temperatures

Manufacturer: Yellow Springs Instrument Co.
Model: YSI 46030, 46034, 46032
Interchangeability: ±0.1°C

Ventilation Supply and Exhaust Air Temperatures

Manufacturer: Alltemp Sensors Instrument Co.
Model: Custom made, 9-point, T type thermocouple grids
Accuracy: ±0.1°C

Fluid Flow Rate Meters

Location: Space heating in suites
Manufacturer: Valmet Meter Works
Model: Valmet NS 20 3/5 hot water meter with pulse transmitter
Accuracy: ±2% above 250 L/hr

Location: Heat recovery loop, domestic hot water
Manufacturer: Valmet Meter Works
Model: Valmet NS 40 20/30 hot water meter with pulse transmitter
Accuracy: ±2% above 250 L/hr

Location: Boiler loop and space heating loop
Manufacturer: Cosmos Meters
Model: Cosmos WP100 and WP 80
Accuracy: ±2% above 4000 L/hr and 3000 L/hr

Relative Humidity

Manufacturer: General Eastern
Model: RH-2 Bulk Polymer Sensor
Accuracy: At 25°C, ±2% RH, 20 - 95% RH

Carbon Dioxide

Manufacturer: Nova Analytical Systems
Model: 300D
Range: 0 - 2000 ppm
Calibration: On air using $CO_2$ scrubber
Accuracy: Not stated.

## Monitoring Equipment

1. Sanyo 286-based computer with hard disk.
2. Sciemetric Instruments 8082A Electronic Measurement Systems
3. Sciemetric Instruments RB01 Relay Board
4. Sciemetric Instruments PC8 Pulse Counters
5. Scanivalve pressure and air sampling multiplexing valve
6. Air Research Micro-manometer pressure sensor
7. Howell-Mayhew Engineering Watchdog Timer

# APPENDIX B:

## Data Processing Equations

## DATA PROCESSING EQUATIONS

As part of the 1991-92 investigaton, the equations used to calculate various system parameters were incorporated into the monitoring task and now appear online. The more involved equations are detailed below in the order in which they appear in the processed data sheets. The page numbers refer to the specific processed data sheet.

### Page 7: Boiler Energy Supplies

***Recovery Loop Heat Exchanger (used prior to renovation)***

$$Q_{hx} = (pC_p)_{gly50} * V_{hrvf} * (T_{rcfm} - T_{pcfi})$$

where: $(pC_p)_{gly50}$ = density * specific heat of a 50% propylene glycol solution
$V_{hrvf}$ = volume of fluid through the heat recovery loop
$T_{rcfm}$ = mixed temperature of the recovery coil and bypass loop fluids
$T_{pcfi}$ = inlet temperature to the preheat coil

***Heating Coil (used after renovation)***

$$Q_{hc} = (pC_p)_{glyBL} * V_{hcf} * (T_{hcfs} - T_{hcfr})$$

where: $(pC_p)_{glyBL}$ = density * specific heat of the aqueous glycol in the boiler loop
$V_{hcf}$ = volume of fluid through the heating coil
$T_{hcfs}$ = supply temperature to heating coil
$T_{hcfr}$ = return temperature from heating coil

***Space Heating***

$$Q_{space} = (pC_p)_{gly20} * V_{shf} * (T_{shfs} - T_{shfr})$$

where: $(pC_p)_{gly20}$ = density * specific heat of 20% propylene glycol solution
$V_{shf}$ = volume of fluid through the space heating loop
$T_{shfs}$ = supply temperature of space heating fluid
$T_{shfr}$ = return temperature to space heating fluid

***Space Heating (Energy Balance)***

$$Q_{space} = Q_{boiler} - Q_{dhw} - Q_{hx} (Q_{hc})$$

where: $Q_{boiler}$ = boiler output energy
$Q_{dhw}$ = energy for domestic hot water heating
$Q_{hx}$ = energy provided by recovery loop heat exchanger (before renovation)
$Q_{hc}$ = energy provided by heating coil (after renovation)

***Domestic Hot Water***

$$Q_{dhw} = (pC_p)_{H_2O} * V_{dhw} * (T_{dhw} - T_{cws})$$

where: $(pC_p)_{H_2O}$ = density * specific heat of a water at
$V_{dhw}$ = building hot water consumption
$T_{dhw}$ = temperature of the domestic hot water delivered to the suites
$T_{cws}$ = temperature of cold water supply to building

***Boiler Output Energy***

$$Q_{boiler} = (pC_p)_{gly20} * V_{bf} * (T_{bfs} - T_{bfr})$$

where: $(pC_p)_{gly20}$ = density * specific heat of a 20% propylene glycol solution
$V_{bf}$ = volume of fluid through the boiler loop
$T_{bfs}$ = supply temperature of boiler fluid
$T_{bfr}$ = return temperature to boiler fluid

***Boiler Output Energy (Energy Balance)***

$$Q_{output} = Q_{space} + Q_{dhw} + Q_{hx} (Q_{hc})$$

***Boiler Input Energy***

$$Q_{input} = Q_{fuel}$$

$$Q_{fuel} = V_{fuel} * 38.54, \quad (MJ)$$

where: $V_{fuel}$ = volume of #2 fuel oil used by the boilers
38.54 = energy value of #2 fuel oil in MJ/L

***Boiler Efficiency***

$$n = \frac{Q_{output}}{Q_{input}}$$

***Fuel Oil Consumption***

$$V_{fuel} = v_{\#2} * O_b, \quad (L)$$

where: $v_{\#2}$ = flow of fuel through a #2 nozzle = 0.00210301 L/s
$O_b$ = boiler ontime

## Page 10: Ventilation Air Supply

### *Tempering of Supply Air*

$$Q_{tsa} = (pC_p)_{amb} * V_{sa} * (T_{amb} - T_{sae})$$

where: $(pC_p)_{amb}$= density times specific heat of supply air entering the building
$V_{sa}$ = volume of supply air entering the building
$T_{amb}$ = outdoor temperature measured on the building's north side
$T_{sae}$ = temperature of the supply air entering the preheat coil

### *Preheat Coil Heat Transfer*

$$Q_{pc} = (pC_p)_{glyRL} * V_{hrvf} * (T_{pcfs} - T_{pcfr})$$

where: $(pC_p)_{glyRL}$ = density*specific heat of aqueous glycol in recovery loop
$V_{hrvf}$ = volume of fluid through the heat recovery loop
$T_{pcfs}$ = supply temperature of preheat coil fluid
$T_{pcfr}$ = return temperature to preheat coil fluid

### *Heating Coil Heat Transfer*

$$Q_{hc} = (pC_p)_{glyBL} * V_{hcf} * (T_{hcfs} - T_{hcfr})$$

where: $(pC_p)_{glyBL}$ density * specific heat of propylene glycol solution in boiler loop
$V_{hcf}$ = volume of fluid through the heating coil
$T_{hcfs}$ = supply temperature of heating coil fluid
$T_{hcfr}$ = return temperature to heating coil fluid

### *Total Energy to Supply Air*

$$Q_{sa} = Q_{hc} + Q_{tsa} + Q_{pc} + Q_{sm}$$

where: $Q_{hc}$ = heating coil heat transfer
$Q_{tsa}$ = heat transfer due to tempering
$Q_{pc}$ = preheat coil heat transfer
$Q_{sm}$ = heat transfer from supply motor

## Page 11: Ventilation Exhaust Air

### *Recovery Coil Heat Transfer*

$$Q_{rc} = (pC_p)_{glyRL} * V_{hrvf} * (T_{rcfs} - T_{rcfr})$$

where: $(pC_p)_{glyRL}$ = density*specific heat of aqueous glycol in recovery loop
$V_{hrvf}$ = volume of fluid through the heat recovery loop
$T_{rcfs}$ = supply temperature of recovery coil fluid
$T_{rcfr}$ = return temperature to recovery coil fluid

***Exhaust Temperature from Recovery Coil***

$$T_{xalc} = T_{xal} - \frac{Q_{xm}}{(pC_p)_{xal} * V_{xa}}$$

where: $T_{xal}$ = temperature of the exhaust air leaving the building
$Q_{xm}$ = energy from exhaust motor
$(pC_p)_{xal}$ = density * specific heat of exhaust air leaving the building
$V_{xa}$ = volume of exhaust air

**Page 12: Efficiency and Effectiveness**

***DHW Heat Exchanger Effectiveness***

$$e_{dhw} = \frac{T_{dhw} - T_{cws}}{T_{hxs} - T_{cws}}, \qquad C_c = C_{min} = C_{dhw}$$

where: $T_{hxs}$ = supply temperature to the hot water heat exchanger
$C_c$ = fluid capacity rate of the cold fluid
$C_{min}$ = minimum fluid capacity rate

***Preheat Coil Effectiveness***

$$e_{pc} = \frac{T_{sal} - t_{sm} - T_{sae}}{T_{pcfi} - T_{sae}}, \qquad C_c = C_{min} = C_{sae}$$

where: $T_{sal}$ = temperature of the supply air to the building
$t_{sm}$ = temperature rise due to the supply motor
$T_{sae}$ = temperature of the supply air entering the preheat coil
$T_{pcfi}$ = temperature of the aqueous glycol mixture entering the preheat coil

Note: The temperature of the supply air leaving the preheat coil is measured after the supply fan motor so that the temperature rise due to the motor energy must be subtracted from the temperature of the supply air to the building.

$$t_{sm} = \frac{Q_{sm}}{(pC_p)_{sal} * V_{sa}}$$

where: $Q_{sm}$ = energy from supply motor
$(pC_p)_{sal}$ = density * specific heat of supply air to the building
$V_{sa}$ = volume of supply air

***Recovery Coil Effectiveness***

$$e_{rc} = \frac{T_{xae} - T_{xalc}}{T_{xae} - T_{rcfi}}, \qquad C_h = C_{min} = C_{xae}$$

where: $T_{xae}$ = temperature of the exhaust air entering the recovery coil
$T_{xalc}$ = temperature of the exhaust air leaving the core
$T_{rcfi}$ = temperature of fluid entering the recovery coil

Note: In Closeleigh Manor, the exhaust fan motor is located after the recovery coil so that the fan motor energy is lost directly to the outside and does not pass through the recovery coil.

***Overall Loop Effectiveness***

$$\frac{1}{e_o} = \frac{C_{mino}}{e_{rc} * C_{mine}} + \frac{C_{mino}}{e_{pc} * C_{mins}} - \frac{C_{mino}}{C_L}$$

where: $C_{mino}$ = minimum fluid capacity rate of the two air streams
$C_{mine}$ = minimum fluid capacity rate of the fluid and air stream across the recovery coil
$C_{mins}$ = minimum fluid capacity rate of the fluid and air stream across the preheat coil
$C_L$ = fluid capacity rate of the aqueous glycol
$e_{rc}$ = effectiveness of the recovery coil
$e_{pc}$ = effectiveness of the preheat coil

***Apparent Heat Recovery Efficiency***

$$Eff_a = \frac{(pC_p)_{sa} * V_{sa} * (T_{sal} - T_{amb}) - Q_{sm} - Q_{hc}}{V_{max} * (pC_p)_{max} * (T_{xae} - T_{amb})}$$

where: $(pC_p)_{sa}$ = density times specific heat of supply air to the building
$V_{sa}$ = volume of supply air entering the building
$T_{sal}$ = temperature of supply air to building
$T_{amb}$ = outdoor temperature measured on the building's north side
$Q_{sm}$ = energy from the supply motor
$Q_{hc}$= energy from the heating coil
$V_{max}$ = maximum of the two air streams
$T_{xae}$ = temperature of the exhaust air entering the recovery coil

***Sensible Heat Recovery Efficiency***

The equation is similar to the *Apparent Heat Recovery Efficiency* except $T_{sae}$, the temperature supply air entering the preheat coil, replaced $T_{amb}$.

# APPENDIX C:

## List of Parameters Used to Calibrate DOE2.1D

## DOE-2.1D MODEL PARAMETERS USED FOR CLOSELEIGH MANOR

Design specifications for wall construction, space conditions including the levels and scheduling of people, lighting and equipment, primary and secondary heating and ventilation equipment, and operating strategies were used to model the building's operation. Measured building data and hourly weather data supplied by the building monitoring system were used to calibrate the model and to verify the building simulation. Hourly typical meteorological year (TMY) data obtained from the weather office at the Whitehorse airport was used for yearly simulation studies. Monitored data from the 1990/91 and 1991/92 heating seasons was used to calibrated the model.

### PARAMETERS USED TO CONSTRUCT THE DOE MODEL

- latitude, longitude, altitude
- construction materials and their associated parameters (including windows)
- lighting types and levels
- equipment types and sizes
- blueprints to input space areas and volumes

### PARAMETERS USED TO CALIBRATE THE DOE MODEL:

- actual hourly weather date including:
  -dry bulb temperature
  -wet bulb temperature
  -pressure
  -cloud cover and type
  -rain/snow indication
  -wind direction and speed
  -humidity ratio
  -air density
  -air enthalpy
  -horizontal and direct normal solar radiation

- domestic hot water consumption*
- space temperatures*
- supply and exhaust air flow rates#
- boiler efficiency#
- HRV overall loop effectiveness#
- supply and exhaust fan electrical consumption

*typical or average values were used year round for the typical year runs
#values for the typical year runs were input as requested

# APPENDIX D:

## Cooling System Evaluation

howell-mayhew
engineering, inc.

15006 · 103 AVENUE
EDMONTON · ALBERTA · T5P 0N8
(403) 484-0476

February 8, 1993

Mr. Bob Overland , P.Eng.
JM Bean & Company Ltd.
201, 1661 West 2nd Avenue
Vancouver, BC V6J 1H3

Dear Bob:

I have reviewed the data for Closeleigh Manor regarding the operation of the refrigeration unit. I have enclosed the original *Sequence of Operation* and a number of graphs which will assist you in assessing the operation of the system when cooling is required. From the monitored data, it certainly does not appear that the system is operating in the manner intended. The following points should be noted:

- the graphs for June 30 and July 1 show system operation on two of the hottest days;
- the remaining graphs show three days of continuous operation towards the end of July;
- the *Sequence of Operation* indicates that the heat recovery circulating pump, P-11, will be de-energized when the outdoor air temperature rises above 19.5°C. All of the graphs indicate that this is not happening. As a result, heating and cooling are occurring at the same time.
- NOTE: The *Flow of HRV fluid* shown on the graphs is the flow through the preheat coil. When this flow decreases it indicates that bypass flow through the 3-way valve is occurring
- the lower flows which occur when preheating is required are correct and indicate that the bypass valve is operating properly by limiting the amount of preheating and maintaining the discharge air temperature below the setpoint.
- the *Sequence of Operation* also indicates that the discharge air temperature, or the supply air temperature to the building, will be maintained at 15.5°C by a separate controller cycling the refrigeration unit. The graphs for July 22 - 24 show this temperature to be consistently lower than this value.

It would seem that if cooling is to be used, the system will have to be thoroughly commissioned and its operation during the cooling season verified. If you have any questions, of if you require additional information, please do not hesitate to contact me.

Sincerely,

Wil Mayhew

Wil Mayhew, P.Eng.

cc: Dan Boyd
Art Haber

DECEMBER 16, 1991

SEQUENCE OF OPERATION

JOB NAME: WHITEHORSE CLOSELEIGH MANOR

JOB NUMBER: 51-1908

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HEAT RECOVERY TEMPERATURE CONTROL

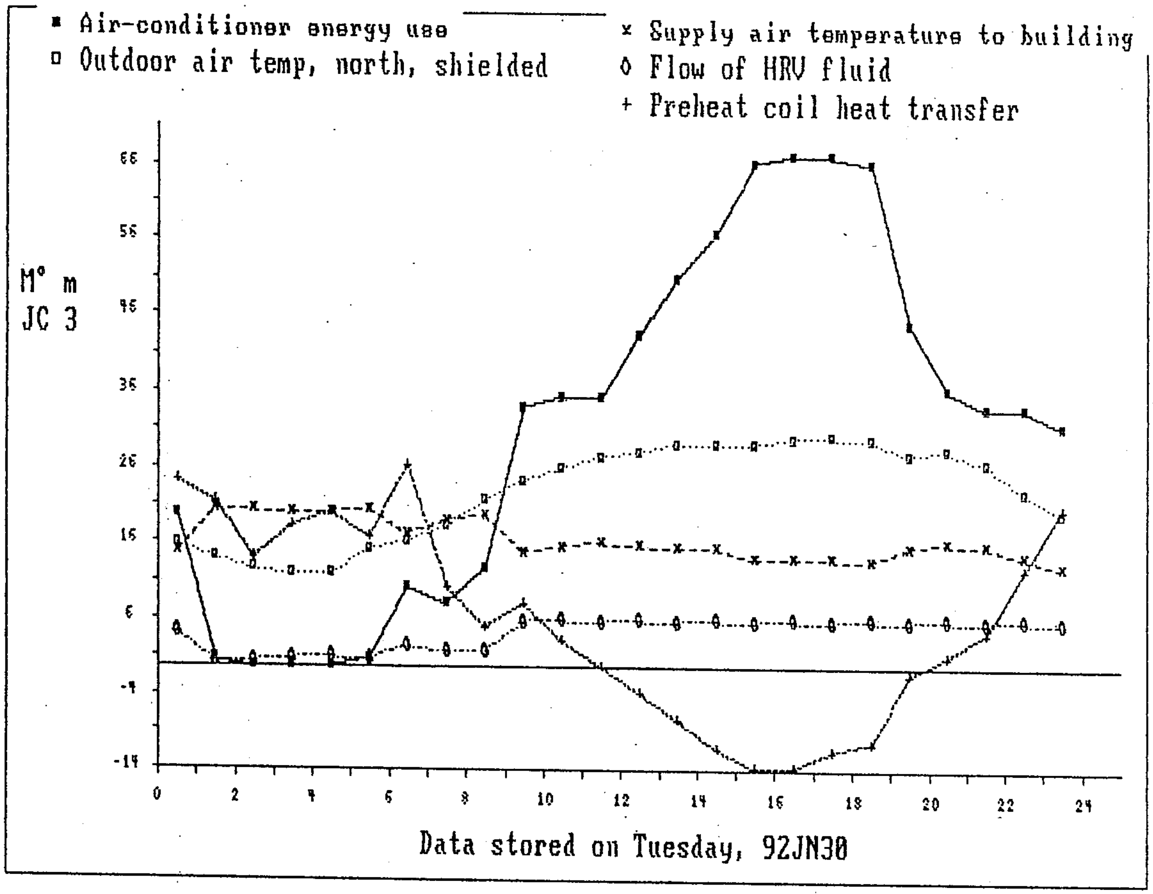
A THREE WAY MIXING VALVE WILL BE POSITIONED TO MAINTAIN THE LEAVING AIR TEMPERATURE AT ~~8°C~~ 2°C. A HIGH LIMIT CONTROLLER WILL PREVENT THE SUPPLY AIR TEMPERATURE FROM EXCEEDING THE DISCHARGE AIR TEMPERATURE SETPOINT. THE CIRCULATING PUMP P-11 WILL BE DE-ENERGIZED WHEN THE OUTDOOR AIR TEMPERATURE RISES ABOVE 19.5°C.

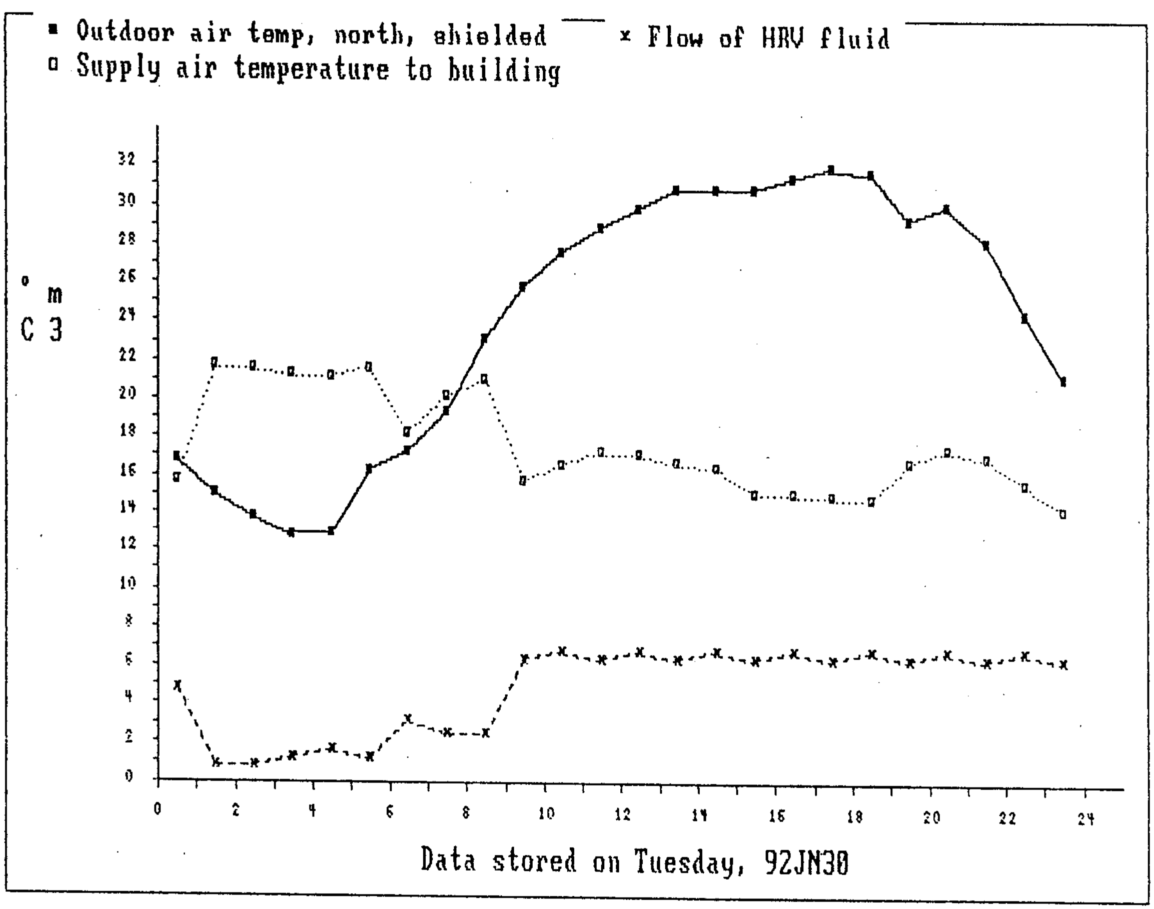
SUPPLY AIR TEMPERATURE CONTROL

A THREE WAY MIXING VALVE TO THE HEATING COIL WILL MAINTAIN THE DISCHARGE AIR TEMPERATURE ACCORDING TO THE RESET SCHEDULE. WHEN THE OUTDOOR AIR TEMPERATURE RISES ABOVE 19.5°C, THE CIRCULATING PUMP P-12 WILL BE DE-ENERGIZED AND THE SUPPLY AND EXHAUST FANS WILL RUN AT MAXIMUM SPEED. THE DISCHARGE AIR TEMPERATURE WILL BE MAINTAINED AT 15.5°C BY A SEPARATE CONTROLLER CYCLING THE REFRIGERATION UNIT. (locked out by outdoor temp)

A FLOW SWITCH AND A LOW LIMIT CONTROLLER WILL OPEN THE OUTDOOR AIR DAMPERS WHEN THE CIRCULATING PUMP P-12 IS RUNNING AND THE DISCHARGE AIR TEMPERATURE IS ABOVE 4°C. WHEN BOTH DAMPERS ARE FULLY OPEN, THE FANS ARE ENABLED BY THE END SWITCHES CONNECTED TO THE DAMPERS. WHEN THE SYSTEM IS IN THE COOLING MODE, THE FLOW SWITCH WILL BE BYPASSED TO ENABLE THE FANS TO OPERATE. THE OUTDOOR AIR DAMPERS WILL CLOSE AND BOTH FANS WILL SHUTDOWN WHEN THE DISCHARGE AIR TEMPERATURE DROPS BELOW 4°C.

WHEN THE OUTDOOR AIR TEMPERATURE IS BELOW 19.5°C, THE SUPPLY AND EXHAUST FANS WILL RUN AT 50% DURING THE DAY AND 25% AS NIGHT AT SCHEDULED BY THE TIME CLOCK.


■ Air-conditioner energy use
□ Outdoor air temp, north, shielded
× Supply air temperature to building
◊ Flow of HRV fluid
+ Preheat coil heat transfer
M° m
JC 3
66
56
46
36
26
16
6
-4
-14
0
2
4
6
8
10
12
14
16
18
20
22
24
Data stored on Tuesday, 92JN30


■ Outdoor air temp, north, shielded
□ Supply air temperature to building
× Flow of HRV fluid
° m
C 3
32
30
28
26
24
22
20
18
16
14
12
10
8
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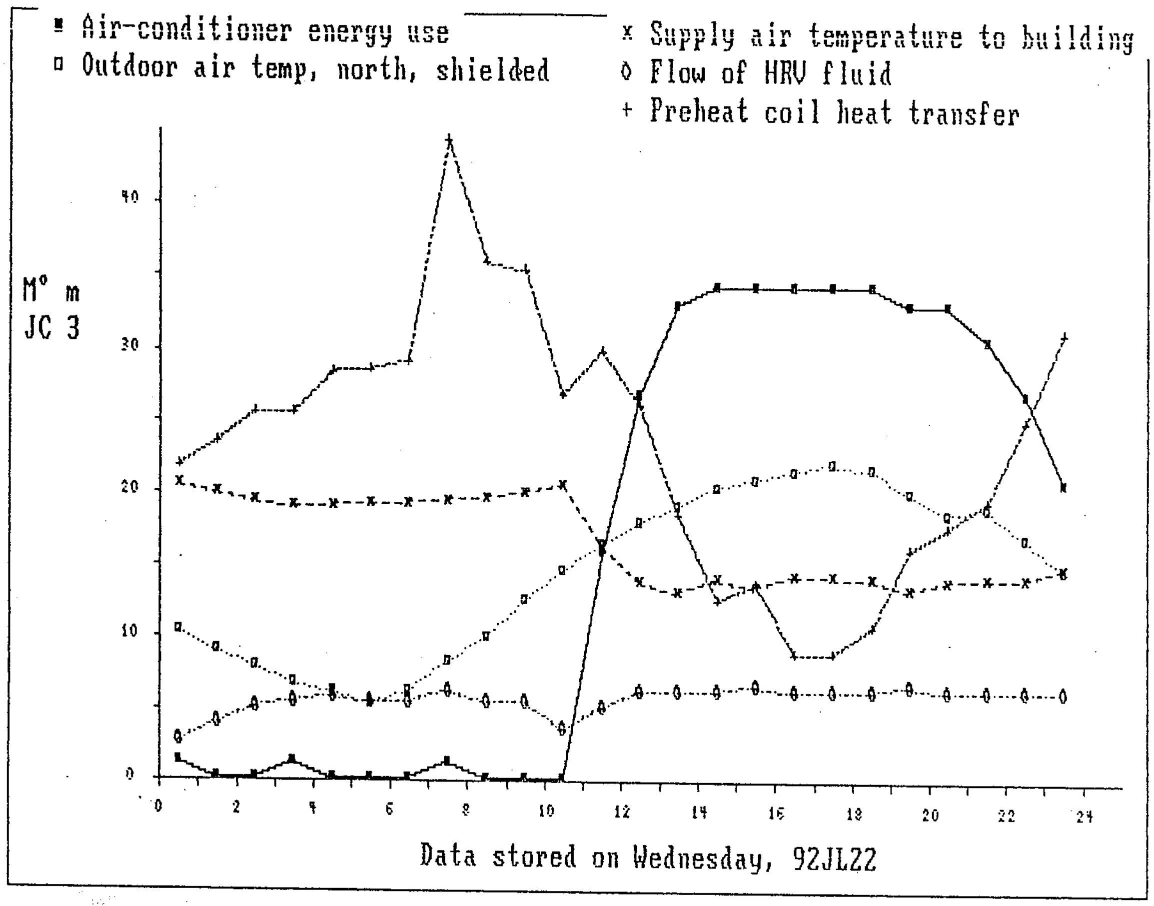
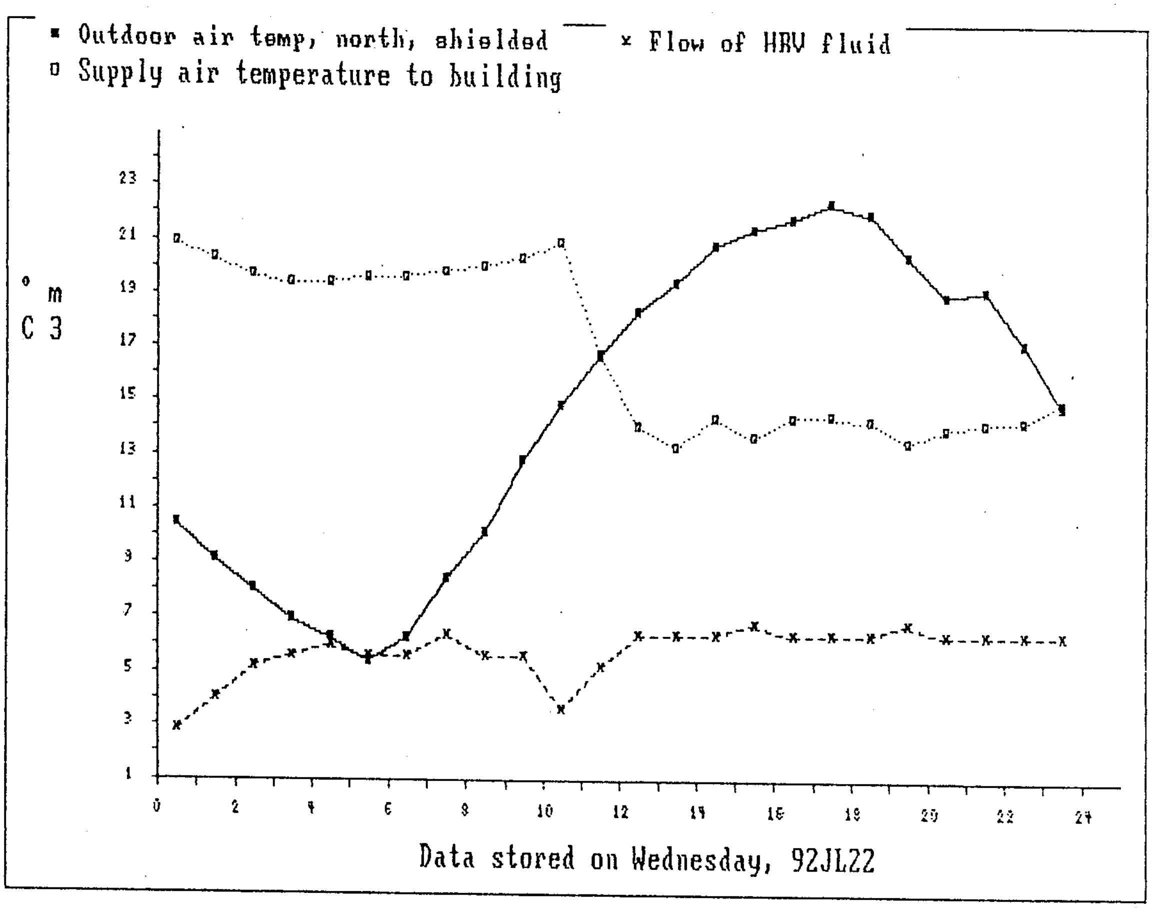
Data stored on Tuesday, 92JN30



Air-conditioner energy use
Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
Preheat coil heat transfer
M° m
JC 3
0
10
20
30
40
0 2 4 6 8 10 12 14 16 18 20 22 24
Data stored on Wednesday, 92JL22

Outdoor air temp, north, shielded
Flow of HRV fluid
Supply air temperature to building
° m
C 3
1
3
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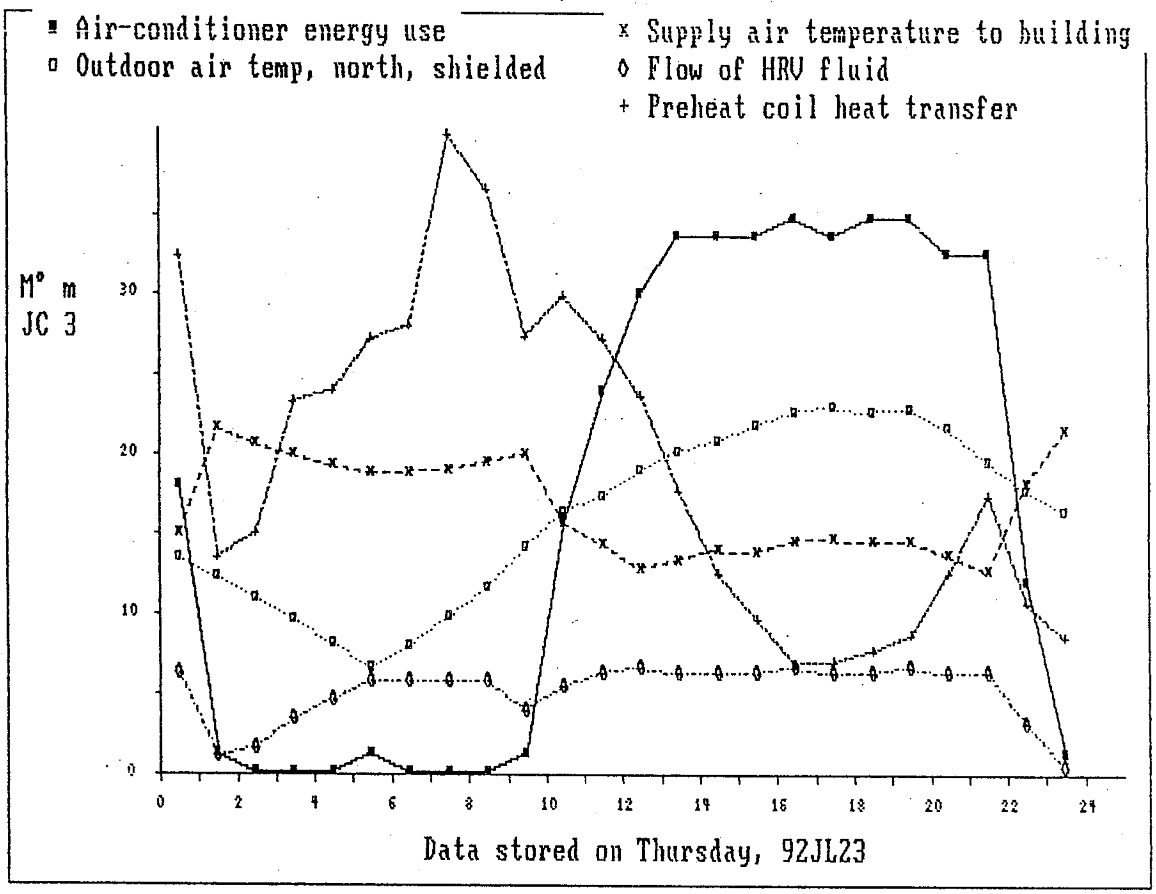
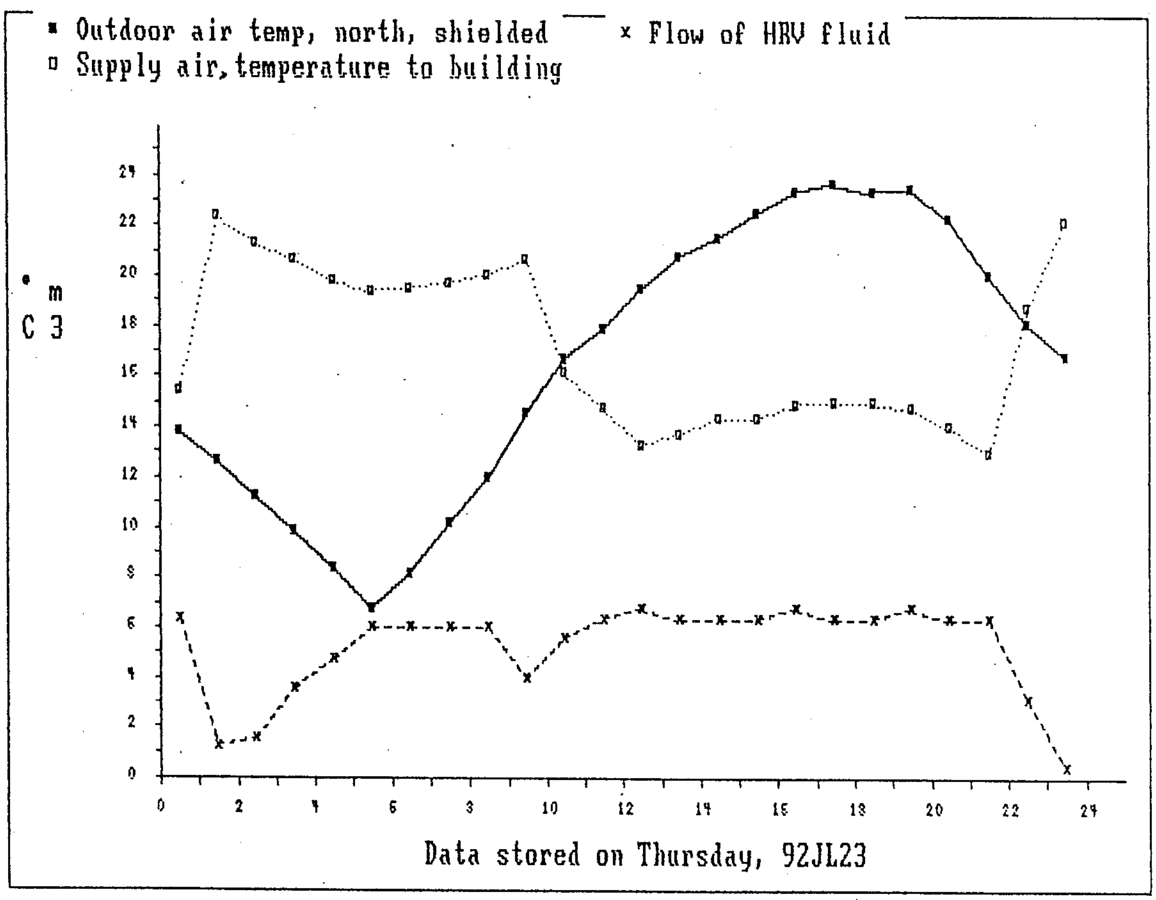
7
9
11
13
15
17
19
21
23
0 2 4 6 8 10 12 14 16 18 20 22 24
Data stored on Wednesday, 92JL22



Air-conditioner energy use
Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
Preheat coil heat transfer
M° m
JC 3
30
20
10
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Data stored on Thursday, 92JL23

Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
• m
C 3
24
22
20
18
16
14
12
10
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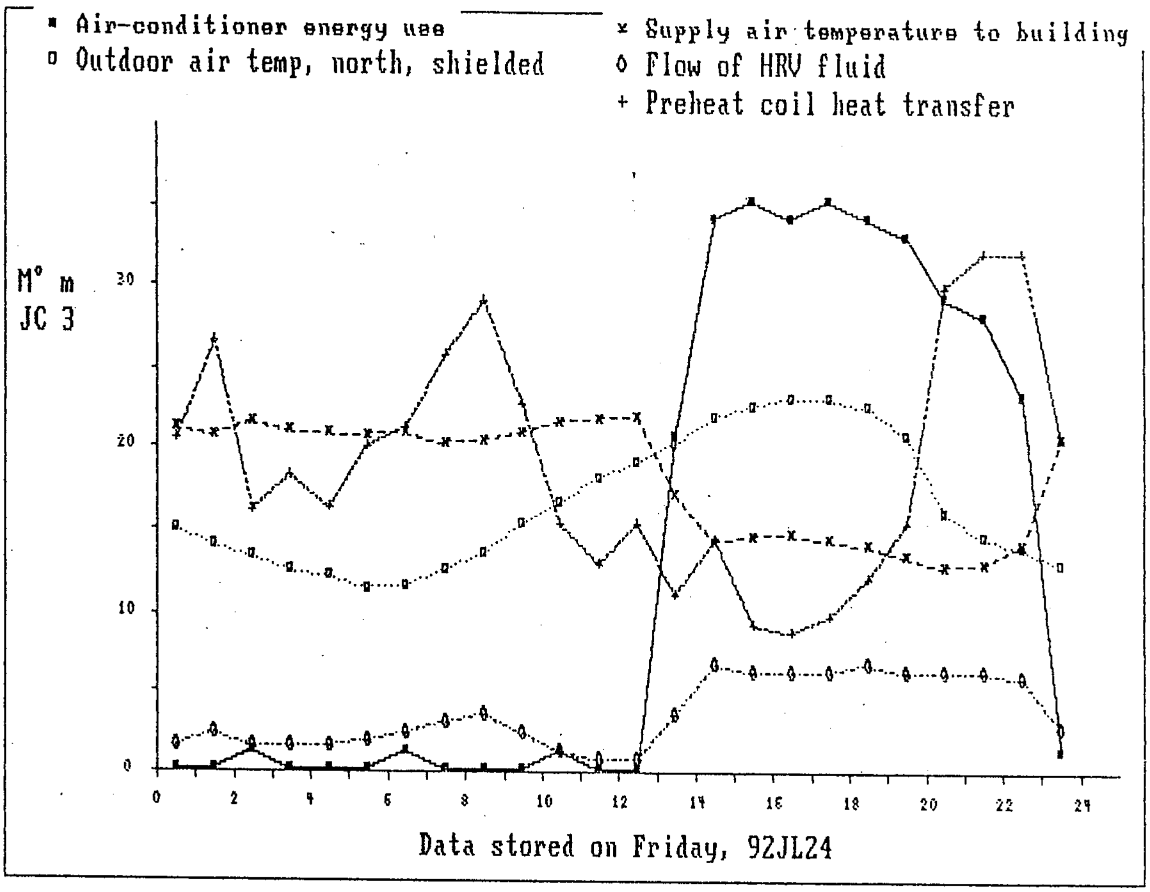
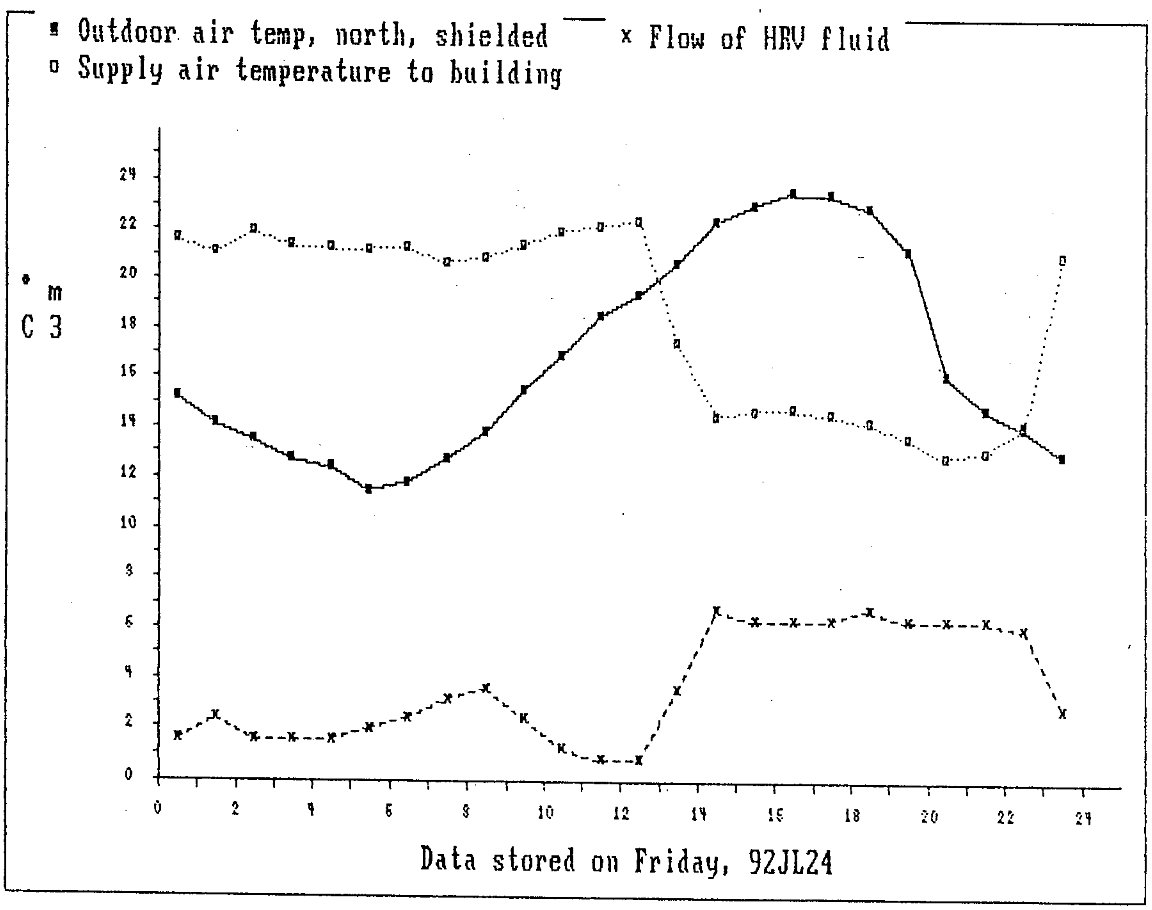
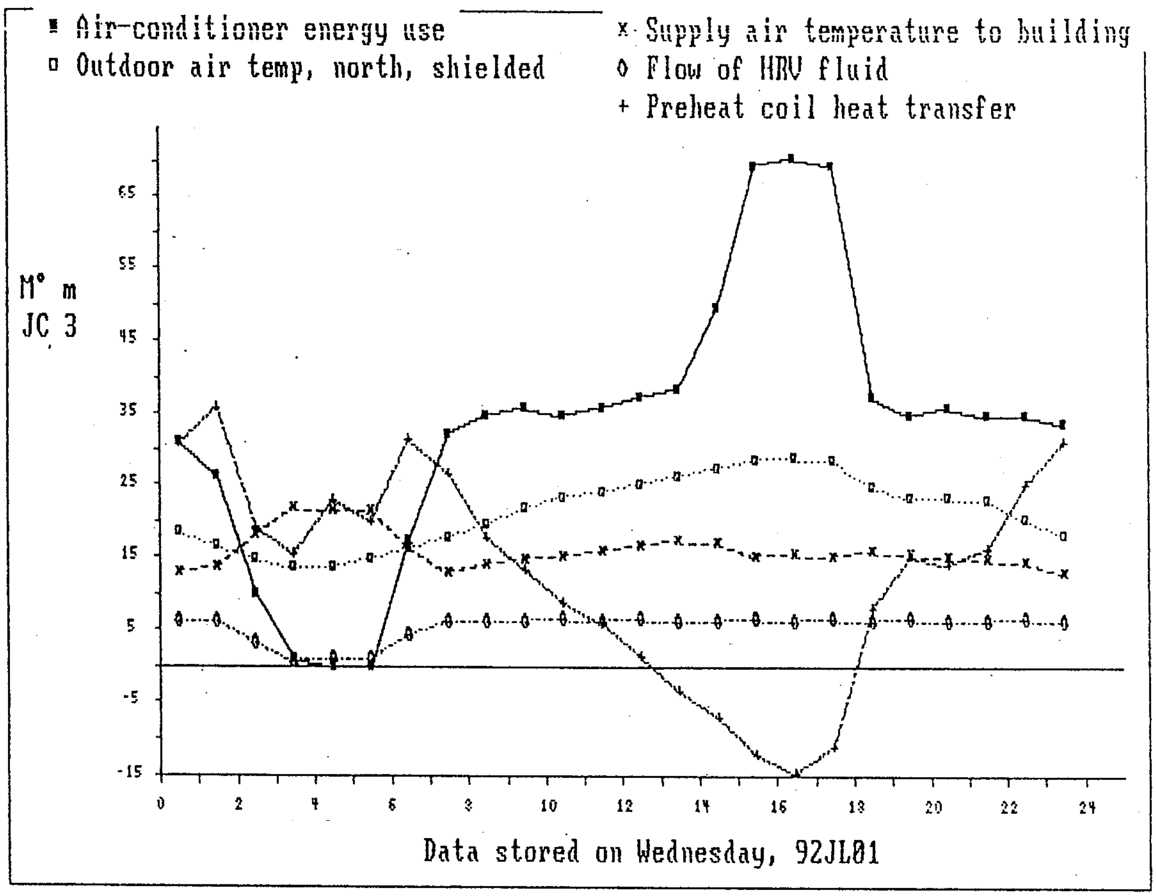
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Data stored on Thursday, 92JL23



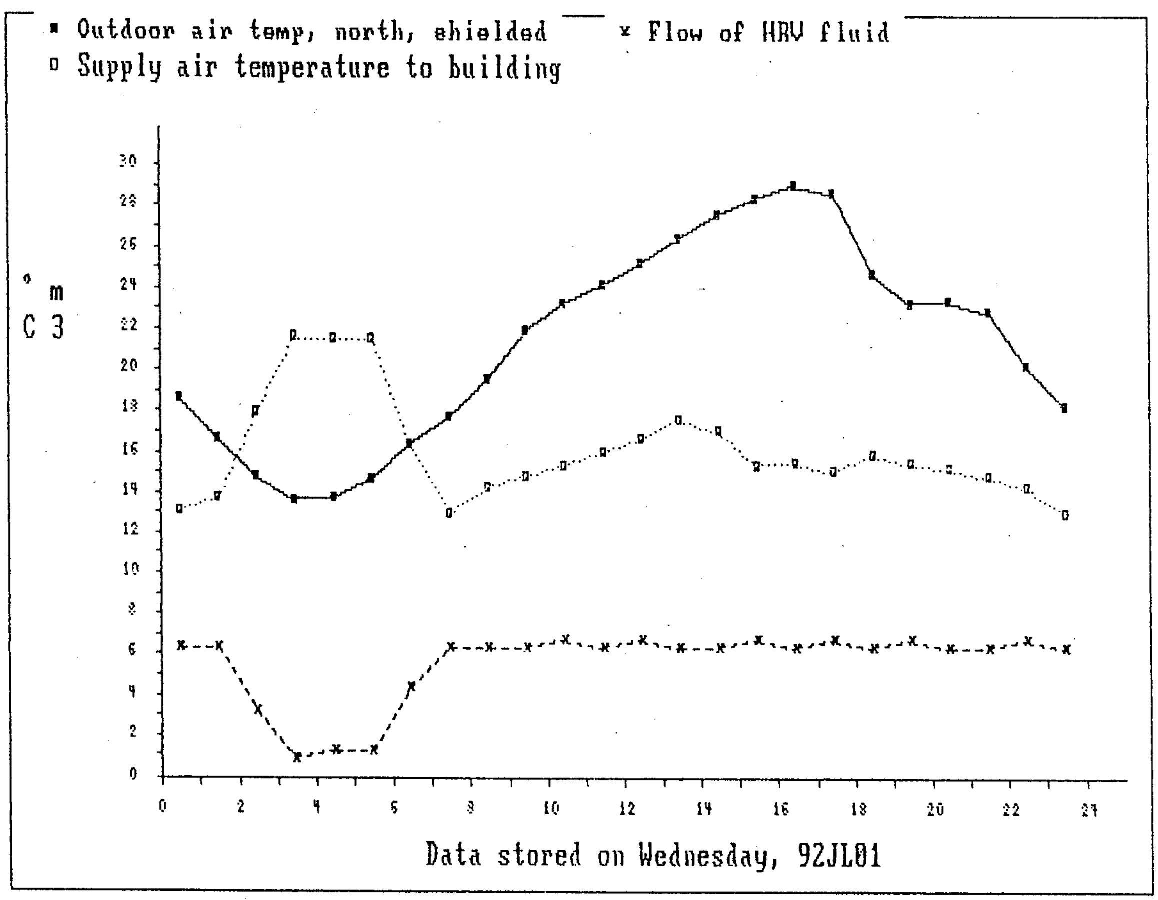
Air-conditioner energy use
Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
Preheat coil heat transfer
M° m
JC 3
0
10
20
30
0
2
4
6
8
10
12
14
16
18
20
22
24
Data stored on Friday, 92JL24

Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
° m
C 3
0
2
4
6
8
10
12
14
16
18
20
22
24
0
2
4
6
8
10
12
14
16
18
20
22
24
Data stored on Friday, 92JL24



Air-conditioner energy use
Outdoor air temp, north, shielded
Supply air temperature to building
Flow of HRV fluid
Preheat coil heat transfer
M° m
JC 3
65
55
45
35
25
15
5
-5
-15
0
2
4
6
8
10
12
14
16
18
20
22
24
Data stored on Wednesday, 92JL01

Outdoor air temp, north, shielded
Flow of HRV fluid
Supply air temperature to building
° m
C 3
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Data stored on Wednesday, 92JL01

MR 01

R. G. OVERLAND, P.ENG.
S. K. H. TAN, P.ENG.
J. M. BEAN, P.ENG.
D. M. JULIEN
D. T. PITTS

February 23, 1993

Kluane Mechanical Contractors Ltd.
P.O. Box 5576
Whitehorse, YUKON
Y1A 5H4

Attention: Mr. Dave Andrews

Dear Sirs:

Re: Closeleigh Manor
Our File No. 9001.15

I am enclosing a copy of a letter from Will Mayhew along with monitoring data which indicates that the 3-way mixing valve and circulating pump on the heat recovery circuit are still operating when the air conditioning unit is in operation.

This is contrary to the sequence of operations specified under the Controls and should be remedied as a contract deficiency.

The commissioning and inspection of the controls under cooling conditions was never carried out to the best of my knowledge.

Please investigate the situation and provide corrective action. The operation should be verified during next summer's cooling operation.

Please report back in writing to advise what corrective action is being planned and also advise me when the modification to the controls has been completed.

Yours very truly,

R.G. Overland, P. Eng.

cc: Honeywell Controls Ltd.
Yukon Housing Corporation - Mr. Dan Boyd
Howell-Mayhew - Mr. Will Mayhew, P.Eng.

J. M. BEAN & CO. LTD.
CONSULTING ENGINEERS
201 - 1661 WEST 2ND AVE. • VANCOUVER, B.C. V6J 1H3 • PHONE 736-6724 • FAX 736-6726

# APPENDIX E:

## Processed Data - 1991/92 Heating Season

The processed data is in a separate binder.

# APPENDIX F:

## Project Documentation and Reports

<u>**Project Documentation and Reports**</u>

Documentation and reports which are directly related to the work carried out at Closeleigh Manor are included in this appendix.

A. Dumont, R.S., *Ventilation Related Measurements at the Closeleigh Manor Project,* Building Science Division, Saskatchewan Research Council, March 1992.

B. Dumont, R.S., *Analysis of Temperature, Relative humidity and Carbon Dioxide Values, Closeleigh Manor,* Unpublished, 1990.

C. Dumont, R.S., *Recommended Changes to Mechanical and Electrical Systems at Closeleigh Manor,* Unpublished, 1990.

D. Dumont, R.S. and Snodgrass, L.J. *Indoor Environment Measurements at the Whitehorse Senior Citizens' Complex,* Institute for Research in Construction, National Research Council of Canada, 1990.

E. Howell-Mayhew Engineering, *Monitoring and Investigation of Closeleigh Manor During the 1990-1991 Heating Season*, Submitted to Energy Mines and Resources, Canada, August 1991.

F. Howell-Mayhew Engineering, *Continuation of the Monitoring of the Yukon Senior Citizen's Residence,* a proposal to Energy, Mines and Resources, Canada, 1990.

G. Johnson, C.A., *Whitehorse Senior Citizen's Building "Closeleigh Manor" Monitored Data Summary Reports,* submitted to Energy, Mines and Resources, Canada for January through April, 1990.

H. Johnson, C.A., and Besant, R.W., *Evaluation of the Design and Monitoring Data from the Whitehorse Senior Citizen's Building "Closeleigh Manor".* Submitted to Energy Mines and Resources, Canada, 1989.

I. Webster, W., *Recommendations re: Whitehorse Senior Citizens' Building,* CR File No: 6780, CMHC Research Division, Ottawa, Ontario, 1989.

J Youso, Micheal, *Update Report on Closeleigh Manor Tasks*, Letter to Yukon Housing Corporation, June 1992.

K Yukon Housing Corporation, *Renovation Schedule for Closeleigh Manor During the 1991/92 Heating Season,* September 1991.

A copy of these documents are in a separate binder.