SUMMARY REPORT ON THE FLAIR HOMES ENERGY DEMO/CHBA MARK XIV PROJECT

PREPARED FOR:

Energy Efficiency Division
Energy Technology Branch
CANMET - Energy Sector
Department of Natural Resources Canada
Ottawa, Ontario
December, 1995

PREPARED BY:

G. PROSKIW, P. Eng.
Proskiw Engineering Ltd.
1666 Dublin Avenue
Winnipeg, Manitoba
R3H 0H1
(204) 633-1107 ; FAX: (204) 633-1442

SCIENTIFIC AUTHORITY:

Tim Mayo
Energy Efficiency Division
Energy Technology Branch/CANMET
Department of Natural Resources Canada
580 Booth Street
Ottawa, Ontario
K1A 0E4

CITATION

G. PROSKIW, P. Eng., Proskiw Engineering Ltd., *Summary Report on the Flair Homes Energy Demo/CHBA Mark XIV Project (Contribution Agreement)*. Energy Technology Branch, CANMET - Energy Sector, Department of Natural Resources Canada, Ottawa, Ontario, 1995, (35 pages).

Copies of this report may be obtained through the following:

Energy Technology Branch, CANMET
Department of Natural Resources Canada
580 Booth Street, 7th Floor
Ottawa, Ontario
K1A 0E4

or

Intellectual Property and Technical Information Management (IPTIM)
Library and Documentation Services Division, CANMET
Department of Natural Resources Canada
555 Booth Street, 3rd Floor, Room 341
Ottawa, Ontario
K1A 0G1

DISCLAIMER

NOTE

Funding for this project was provided by the Government of Canada.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the members of the project's National Steering Committee, Technical Advisory Committee and the resource individuals who provided valuable insight, review and advice in the preparation of this report.

NATIONAL STEERING COMMITTEE

Mr. W. Bryant; Energy, Mines and Resources Canada (Chairman)
Dr. J. Kenward; Canadian Home Builders Association
Mr. W. McDonald; Manitoba Energy and Mines

TECHNICAL ADVISORY COMMITTEE

Mr. M. Riley; Energy, Mines and Resources Canada (Chairman)
Mr. T. Akerstream; Manitoba Energy and Mines
Mr. G. Barthels; R-2000 Program of Manitoba
Mr. R. Cardinal; Dow Chemical Canada Inc.
Mr. J. Dewil; Fiberglas Canada Inc.
Dr. D. Figley; Saskatchewan Research Council
Mr. D. Geddes; Heating, Refrigerating and Air-Conditioning Institute of Canada
Mr. D. Goodman; Greentree Homes Ltd.
Mr. D. Greeley; Dow Chemical Canada Inc.
Mr. W. Heeley; Heating, Refrigerating and Air-Conditioning Institute of Canada
Mr. R. McGrath; Fiberglas Canada Inc.
Mr. T. Mayo; Energy, Mines and Resources Canada
Dr. J. Meranger; Health and Welfare Canada
Mr. L. Nakatsui; Lincolnberg Homes
Mr. P. Piersol; ORTECH International
Mr. T. Robinson; Canada Mortgage and Housing Corp.
Dr. J. Timusk; University of Toronto

RESOURCE INDIVIDUALS

Mr. O. Drerup; Canadian Home Builders Association
Mr. T. Hamlin; Canada Mortgage and Housing Corp.
Mr. B. Maybank; Flair Homes (Manitoba) Ltd.
Dr. D. Onysko; Forintek Canada Corp.
Mr. N. Shymko; Today Homes (East) Ltd.
Mr. R. Slasor; Energy, Mines and Resources Canada
Mr. B. Sloat; Canadian Home Builders Association
Mr. D. Verville; Manitoba Home Builders Association

OVERVIEW OF THE FINDINGS

THE FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

The Flair Homes Energy Demo/CHBA Flair Mark XIV Project was a multi-year demonstration and monitoring project carried out in Winnipeg to study the performance of residential, low-energy design concepts under real-world conditions. Twenty-four single-detached bungalows, utilizing over 100 energy-conserving components, systems and design features, were constructed and monitored for up to three years. The performance of the conservation measures was assessed and compared to equivalent systems used in conventional construction. Issues such as performance degradation and incremental costs were also addressed. The major findings of the project are summarized below.

BUILDING ENVELOPE PERFORMANCE

The performance of both energy efficient and conventional building envelope systems was assessed using wood moisture content measurements, thermographic examinations and airtightness testing. The results showed that while both the energy efficient and conventional building envelope systems performed in a satisfactory manner, fewer problems were observed in the energy efficient houses. In particular, no evidence was found of envelope degradation, interstitial condensation or other problems which could threaten a house's useful life, particularly one constructed with high levels of thermal insulation and a well-sealed air/vapour barrier.

AIRTIGHTNESS

Airtightness testing showed that both the energy efficient and conventional houses displayed stable airtightness characteristics; no significant evidence of air barrier degradation could be found in either. With respect to air barrier systems, two basic types were used in the project houses: polyethylene and the Airtight Drywall Approach. Both systems were judged to have performed in a satisfactory fashion. However, the study concluded that a significant opportunity exists to improve the performance of residential air barrier systems through a systematic analysis of the performance and costs of alternative methods of sealing each envelope component.

INDOOR AIR QUALITY

The concentrations of various indoor pollutants were monitored on a regular basis in 20 of the project houses. In general, the air quality in the energy efficient houses was found to be superior to that in the conventional structures. An analysis of pollutant concentrations and air change rates was also carried out. This identified the limitations of relying upon mechanical ventilation as the sole control measure for achieving indoor air quality. While pollutant levels generally increased at lower air change rates, the benefits of higher ventilation rates became marginal once the total air change rate (mechanical and natural) exceeded approximately 0.30 air changes per hour. It was concluded that greater emphasis should be placed on alternative control strategies including source removal and isolation, pollutant entry control and improved ventilation system efficiency/effectiveness. Homeowner intervention with the ventilation system (for example, by turning the system off for extended periods) was also a common problem. The study recommended that design rates for ventilation systems should be established both on the ability of the system to remove pollutants, as well as the effect the ventilation rate will have on the homeowner's utilization of the system.

MECHANICAL VENTILATION SYSTEMS

The study found that the subject of homeowner interaction with the mechanical ventilation system operation has not been adequately addressed. For example, utilization of ventilation systems varied dramatically depending on the type installed. Central-exhaust systems, ostensibly intended for continuous operation, were only used an average of 37 minutes per day whereas the utilization of Heat Recovery Ventilators exceeded 19 hours per day. Several of the systems in the project houses were also subjected to detailed tracer gas testing and flow rate measurements to evaluate their ability to comply with CSA F326 "Residential Mechanical Ventilation Systems". It was found that the ventilation systems in houses with forced air or baseboard heating systems were both able to satisfy the standard's requirement for a Minimum Ventilation Capacity for Dwelling Units. Further, the ventilation systems in houses with forced air heating met the standard's requirement for a Minimum Ventilation Capacity for Rooms, because of the furnace's high air recirculation rates. However, the ventilation systems in houses with baseboard heating systems were unable to meet this latter requirement, which resulted in under-ventilation of several zones, particularly those in the main living areas. This finding was viewed as support for the argument that houses with baseboard or radiant heating systems require dedicated ventilation ductwork, or equivalent, to meet the distribution requirements of CSA F326.

ENERGY PERFORMANCE

Twenty-three of the project houses were energy-metered and monitored for periods of 16 to 39 months. This data was compared to predicted energy usage using HOT2000 6.0, modified with various enhancements to allow greater resolution of inputs (actual weather, occupancy, usage patterns and other inputs estimated from measured data). The analysis found that HOT2000 6.0 was able to predict the total annual energy consumption with an accuracy of about ±10%. Several areas were identified in which the model could be changed to improve its accuracy. The impact of lifestyle was found to be highly unpredictable and responsible for significant variation in the total energy consumption.

COOLING

A field study and theoretical analysis were conducted of a removable exterior solar shade screen system for windows, as an alternative to mechanical cooling. This analysis concluded that these screens have a significant potential to reduce summer cooling loads and thereby lessen the amount of energy needed for air-conditioning and may, in some cases, permit the cooling system to be eliminated. The shade screens were calculated to reduce the design cooling load by approximately one-third for a new house located in Winnipeg, Montreal or Toronto.

NOISE

Interior noise, produced by the house's mechanical system or transmitted from the outdoors through the building envelope, was also explored. Sound levels generated by the mechanical system were found to generally exceed acoustical design goals in those rooms located directly above the equipment. Transmission of outdoor noise into the house occurred mainly through windows and through ductwork which ran through exterior walls.

INCREMENTAL COSTS OF ENERGY CONSERVATION SYSTEMS

Based on the construction experiences with the 24 project houses, the incremental costs of over 100 energy conservation components and systems were analyzed and documented using data collected from local suppliers and trades. In addition, general conclusions were developed on the relative cost-effectiveness of many of these measures. Finally, guidelines were developed for prioritizing energy conservation alternatives which could be applied regardless of location, climate or energy cost.

APERÇU DES CONCLUSIONS

LE PROJET « *FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV* »

Le projet « *Flair Homes Energy Demo/CHBA Flair Mark XIV* » est un projet de surveillance pilote portant sur plusieurs années, qui a été mené à Winnipeg et a permis d'étudier le rendement des concepts résidentiels éconergétiques dans les conditions réelles. On a construit et on a surveillé pendant des périodes pouvant atteindre trois ans, vingt-quatre maisons unifamiliales de type bungalow, équipées de plus de cent composants et systèmes éconergétiques. On a évalué le rendement des systèmes éconergétiques adoptés et on l'a comparé à celui de systèmes équivalents utilisés dans la construction ordinaire. On a également étudié des questions telles que la diminution de ce rendement et les coûts additionnels occasionnés par les mesures éconergétiques. Nous avons résumé ci-après les principales conclusions auxquelles a abouti ce projet.

RENDEMENT DE L'ENVELOPPE DE BÂTIMENT

On a évalué le rendement des enveloppes de bâtiment éconergétiques et celui des enveloppes de bâtiment ordinaires en se basant sur des mesures de la teneur en eau du bois, des examens thermographiques et des essais d'étanchéité à l'air. Les résultats ont montré que les installations à enveloppe de bâtiment éconergétique et celles à enveloppe ordinaire se comportaient toutes deux de manière satisfaisante, mais que les maisons éconergétiques présentaient moins de problèmes. En particulier, on n'a constaté ni dégradation de l'enveloppe, ni condensation interstitielle ni quelque autre problème susceptible de raccourcir la durée de vie utile de la maison, surtout lorsque le niveau d'isolation thermique de celle-ci était élevé et qu'elle présentait une étanchéité renforcée à l'air et à la vapeur.

ÉTANCHÉITÉ À L'AIR

Les essais d'étanchéité à l'air ont montré que les maisons éconergétiques et les maisons ordinaires présentaient des caractéristiques stables dans ce domaine et que leurs pare-vent ne se dégradaient pas. Deux types de pare-vent ont été utilisés dans les maisons du projet : l'un en polyéthylène et l'autre en panneaux de mur secs, étanches à l'air. Le rendement s'est avéré satisfaisant dans les deux cas. Cependant, l'étude a révélé qu'il y a moyen d'améliorer sensiblement le rendement des systèmes d'étanchéité à l'air des maisons par une analyse systématique du rendement et du coût des différentes méthodes qui permettent d'assurer l'étanchéité de chaque élément de l'enveloppe.

QUALITÉ DE L'AIR INTÉRIEUR

On a vérifié régulièrement la concentration des différents polluants intérieurs dans les vingt maisons du projet. La qualité de l'air était en général meilleure dans les maisons éconergétiques que dans les maisons ordinaires. On a également étudié la concentration des différents polluants et les taux de renouvellement d'air. Cette analyse a révélé les limites de la ventilation mécanique lorsqu'elle est seule à assurer la qualité de l'air intérieur. Si, d'une part, le niveau des polluants a tendance à augmenter lorsque le taux de renouvellement d'air diminue, d'autre part, l'avantage inhérent à des débits de ventilation plus élevés devient marginal lorsque le taux total - mécanique et naturel - de renouvellement d'air dépasse environ 0,30 renouvellement d'air par heure. On en a conclu qu'il faudrait attacher plus d'importance aux autres stratégies de contrôle, entre autres l'élimination de la source de polluants et l'isolation ainsi que le contrôle de l'entrée des polluants et l'amélioration de l'efficacité des installations de ventilation. L'intervention du propriétaire (qui arrête, par exemple, le système de ventilation pendant des périodes prolongées) constitue fréquemment une source de problèmes. L'étude recommande que l'on évalue les systèmes de ventilation en se basant à la fois sur la capacité du système à éliminer les polluants et sur l'effet du taux de ventilation quant à l'utilisation du système par le propriétaire.

SYSTÈMES DE VENTILATION MÉCANIQUE

L'étude a montré que le problème relatif à l'action du propriétaire sur le fonctionnement du système de ventilation mécanique n'avait pas été envisagé de manière adéquate. Par exemple, l'utilisation des systèmes de ventilation varie énormément selon le type de ventilation installé. Les systèmes à évacuation centrale, qui sont manifestement conçus pour fonctionner continuellement, ne sont utilisés en moyenne que pendant 37 minutes par jour tandis que la durée d'utilisation des ventilateurs échangeurs de chaleur dépasse 19 heures par jour. On a également évalué plusieurs systèmes installés dans les maisons du projet quant à leur capacité à se conformer à la norme CSA F326, intitulée « Ventilation mécanique des habitations », en les soumettant à des essais approfondis de gaz traceurs et à des mesures de débit. On a trouvé que les installations de ventilation des maisons équipées de systèmes de chauffage à air pulsé ou celles des maisons équipées de chauffage à plinthes satisfaisaient toutes deux les exigences de la norme en ce qui concerne la capacité minimale de ventilation des habitations. De plus, grâce aux taux élevés de recirculation d'air inhérents à leur appareil de chauffage, les systèmes de ventilation des maisons équipées d'installations de chauffage à air pulsé répondaient aux exigences de la norme en ce qui concerne la capacité minimale de ventilation des pièces, tandis que les installations de ventilation des maisons équipées de systèmes de chauffage à plinthes ne répondaient pas à ces exigences et, plusieurs endroits étaient insuffisamment ventilés, en particulier dans les salles de séjour principales. Cette conclusion appuie l'argument selon lequel les maisons équipées de systèmes de chauffage à plinthes ou de chauffage radiant doivent posséder un réseau de gaines spécifiques, ou l'équivalent, qui réponde aux exigences de distribution de la norme CSA F326.

RENDEMENT ÉNERGÉTIQUE

Parmi les maisons du projet, vingt-trois ont été équipées de compteurs d'énergie et ont été surveillées durant des périodes allant de 16 à 39 mois. Les données recueillies ont été comparées aux prévisions de consommation énergétique au moyen du logiciel HOT2000 6.0 auquel on a apporté des améliorations pour accroître la résolution des entrées (conditions atmosphériques réelles, taux d'occupation, modèles d'utilisation et autres entrées tirées des données mesurées). L'analyse a montré que le logiciel HOT2000 6.0 pouvait prévoir la consommation énergétique totale annuelle à ± 10 p. 100 près. On a relevé plusieurs secteurs dans lesquels on pouvait modifier le modèle de manière à le rendre plus précis. On a trouvé que l'influence du style de vie sur la consommation totale d'énergie était imprévisible mais considérable.

REFROIDISSEMENT

Une étude sur le terrain et une analyse théorique ont été menées dans le but de comparer le refroidissement mécanique à un système de pare-soleil extérieurs amovibles pour fenêtres. L'analyse a conclu que ces pare-soleil peuvent réduire sensiblement les charges de refroidissement estivales - ce qui diminue la quantité d'énergie nécessaire au conditionnement de l'air - et qu'ils permettent, dans certains cas, d'éliminer complètement le système de refroidissement. Les pare-soleil ont été calculés pour réduire environ d'un tiers la charge de refroidissement prévue par le calcul effectué lors de la conception d'une nouvelle maison située à Winnipeg, Montréal ou Toronto.

NIVEAU SONORE

On a également étudié le bruit produit par le système mécanique de la maison et celui transmis de l'extérieur par l'enveloppe de bâtiment. Le bruit produit par le système mécanique dépasse généralement les niveaux acoustiques visés dans les pièces situées juste au-dessus de l'équipement. La transmission dans la maison des bruits extérieurs est principalement due à l'existence des fenêtres et au réseau de gaines qui parcourt les murs extérieurs.

COÛTS ADDITIONNELS DES SYSTÈMES ÉCONERGÉTIQUES

En se basant sur l'expérience de la construction des vingt-quatre maisons du projet, on a rassemblé de la documentation concernant les coûts additionnels de plus de 100 systèmes et composants éconergétiques, en utilisant les données obtenues auprès des fournisseurs et des corps de métiers locaux, et on a procédé à l'analyse de ces coûts additionnels. De plus, on a tiré des conclusions générales concernant l'économie relative de bon nombre de ces mesures éconergétiques. Enfin, on a dégagé des lignes directrices destinées à favoriser les méthodes d'économie d'énergie applicables indépendamment de l'endroit, du climat et du coût de l'énergie.

SECTION 1

THE FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

INTRODUCTION

This report summarizes the major findings of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project. It was prepared from information contained in a series of 12 technical reports which detail the monitoring, testing and analysis elements of the project. A full list of these reports, complete with summaries and information on obtaining copies can be found in Appendix A.

OVERVIEW OF THE PROJECT

The Flair Homes Energy Demo/CHBA Flair Mark XIV Project was initiated in 1985 to demonstrate energy efficient residential construction technologies. Twenty-four houses were constructed in Winnipeg, Manitoba by a major tract builder and monitored for periods of up to three years by an independent engineering firm. The field work was completed in 1990.

Financial support for the project was provided by Energy, Mines and Resources Canada with additional assistance from Manitoba Energy and Mines. The project was given the Mark XIV designation by the Technical Research Committee of the Canadian Home Builders Association (CHBA). Project management was the responsibility of Flair Homes (Manitoba) Ltd. Monitoring, analysis and reporting were performed by UNIES Ltd., Consulting Engineers, of Winnipeg.

PROJECT HOUSES

The 24 project houses were all standard, detached bungalows with cast-in-place concrete basements and (interior) main floor areas ranging from 60 m^2 to 85 m^2 (646 ft^2 to 915 ft^2). Their energy conservation levels ranged from those of conventional houses to those which met, or exceeded, the R-2000 Standard. Approximately 100 different types of energy-conserving components, systems and design features were used in the building envelopes and mechanical systems of the project houses.

OBJECTIVE

The primary objective of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project was to study the performance of commonly used energy efficient, residential building envelopes and mechanical systems under real-world conditions.

REPORT ORGANIZATION

The remaining sections of this report summarize the findings of the study and the performance of the project houses according to the following categories:

- Building Envelope Performance
- Airtightness
- Indoor Air Quality
- Mechanical Ventilation Systems
- Energy Performance
- Cooling
- Noise
- Incremental Costs of Energy Conservation Components and Systems

At the end of each section there is a list of the applicable technical reports which can be pursued for more information.

SECTION 2

BUILDING ENVELOPE PERFORMANCE

ISSUES INVESTIGATED
In the last decade, Canadian builders have made a dramatic shift towards energy efficient construction methods. These typically combine high levels of thermal insulation in the building envelope with a well-sealed air/vapour barrier. Since the envelope is such a critical component of a house, the use of these new techniques has raised questions about their adequacy. For example, how do energy efficient building envelope systems compare to conventional methods? Does degradation occur over time? Are framing materials exposed to greater risks from moisture generated within the house? How does the polyethylene air/vapour barrier system perform relative to the Airtight Drywall Approach? And finally, how do building envelopes perform under real-world conditions when built in any type of weather, with non-laboratory exposure conditions and with actual people living in the houses?

THE BUILDING ENVELOPE MONITORING PROGRAM
The evaluation of the building envelope systems in the 24 houses commenced at their time of completion and extended for periods which ranged up to three years. A comprehensive monitoring program was developed which utilized measurements of the wood moisture content (WMC) of wall, attic and floor joist components, detailed thermographic examinations of the envelopes and regular airtightness testing of the houses. This resulted in over 13,000 WMC measurements, the production of 1013 thermographic images and the completion of 167 airtightness tests.

SUMMARY OF THE FINDINGS
The study found that the energy efficient building envelope systems provided a satisfactory method of construction for residential construction and, in fact, exhibited fewer problems than conventional envelope systems built with leakier air barriers and lower levels of insulation.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

ENERGY EFFICIENT AND CONVENTIONAL BUILDING ENVELOPES

Both the energy efficient and conventional building envelope systems performed in a satisfactory manner although fewer problems were found with the energy efficient houses. Average wood moisture content levels in the wall and attic framing members were lower in the energy efficient houses and fewer excursions above 19% were observed (Fig. 1); 19% is the WMC level at which wood is generally considered to be "dry" and above which it starts to become susceptible to decay. The energy efficient houses also displayed fewer thermographic anomalies, particularly those of a severe nature. Anomalies were defined as irregularities in the thermographic image caused by air infiltration/exfiltration, interstitial air movement, condensation, insulation defects or thermal bridging. Figure 2 shows the percentage of envelope locations which displayed severe thermographic faults. No evidence of interstitial condensation was found in either type of construction.

DEGRADATION OF ENERGY EFFICIENT BUILDING ENVELOPES

The energy efficient building envelopes did not display any evidence of envelope degradation. Both the polyethylene air barrier and ADA houses exhibited predominately stable WMC levels, thermographic characteristics and airtightness rates during the monitoring period.

MOISTURE LEVELS IN THE ENERGY EFFICIENT BUILDING ENVELOPES

No significant evidence was found of elevated WMC levels in the walls, attics and floor joist/header areas of the energy efficient houses. Those houses built with sandwiched polyethylene air/vapour barriers (i.e. double walls and walls with interior strapping) did not exhibit elevated WMC levels or display signs of interstitial condensation.

POLYETHYLENE AIR BARRIERS vs. ADA

The building envelopes constructed with polyethylene air barriers generally performed superior to those which used the Airtight Drywall Approach; WMC levels were slightly lower in the polyethylene houses and fewer thermographic anomalies were found. Both systems however, were judged as having provided acceptable performance for residential construction.

PROBLEM AREAS

Although the envelope systems performed quite well, some problem areas were identified during the thermographic examinations which could not be attributed to faulty workmanship, poor materials or other non-design causes. They were found in both the energy efficient and conventional houses.

<u>Bow Windows</u> - The framed portions of wall sections containing bow windows frequently displayed evidence of significant interstitial air movement. This was most evident in the ADA houses which suggests that leakage may have occurred past the bottom gasket.

FIGURE 1

MEAN WALL WMC

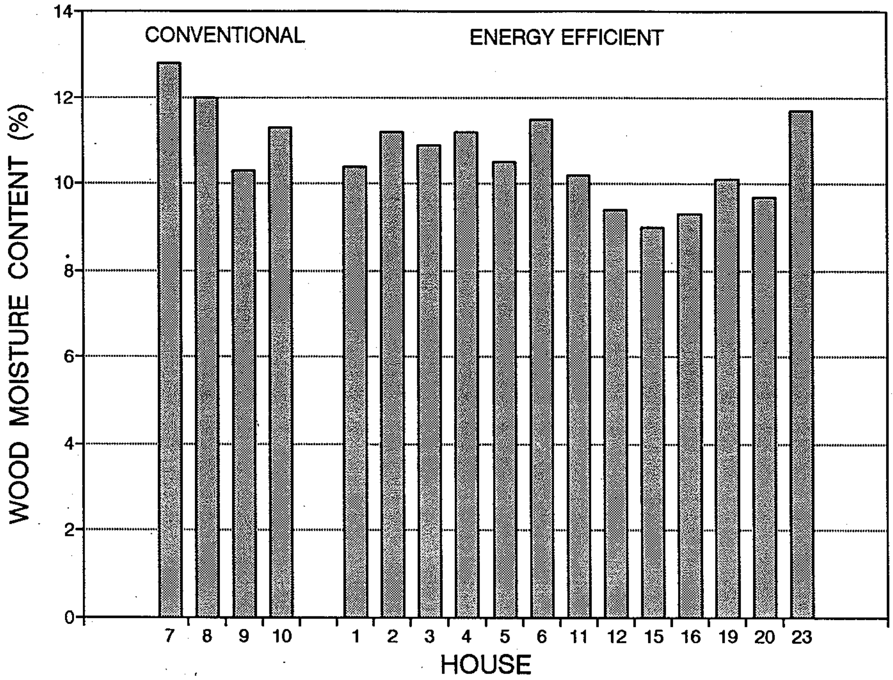
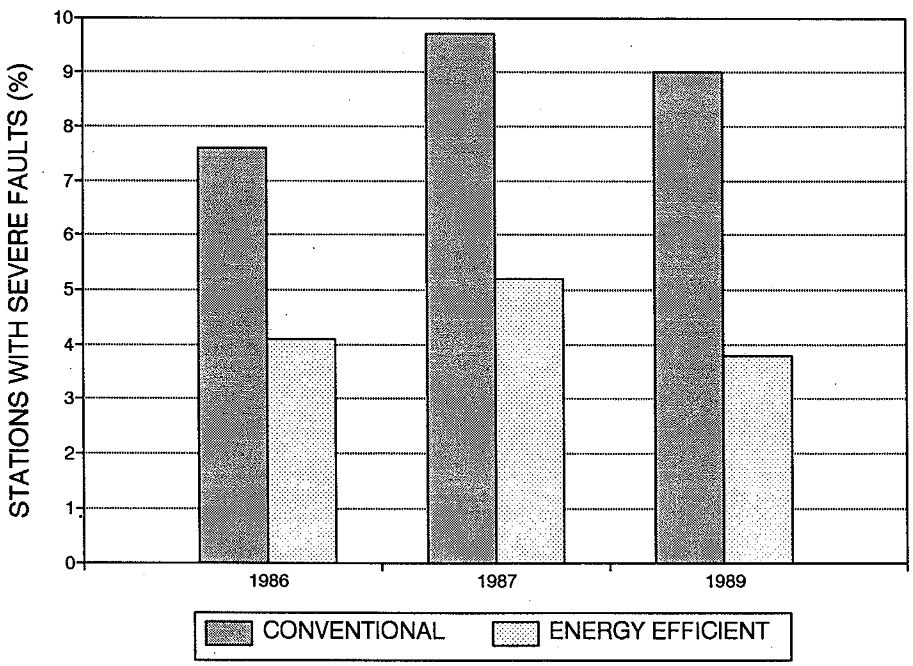


FIGURE 2

THERMOGRAPHIC FAULTS



Vertical Walls Exposed to Attic Spaces on One Side - Massive thermal anomalies were often found over most or all of the interior surfaces of vertical walls separating vaulted and non-vaulted portions of the ceiling. It is believed that due to the absence of exterior sheathing on the cold (attic) side of these walls, the cavity insulation separated from the drywall surface and permitted cold air to circulate between the drywall and the insulation.

Plumbing Stacks - Significant interstitial air movement was found at the tops of plumbing walls separating the bathroom and kitchen. This anomaly may have been created by air leaking around the plumbing stack due to inadequate sealing at the top plate or by air flow or air leakage taking place down the stack.

Exterior Doors/Entrance Ways - Interstitial air movement was frequently observed in the exterior wall in the vicinity of the entrance door. Anomalies were also noted near short divider walls which intersected the exterior wall near the entrance door. This problem was found with all wall types to varying degrees and intensities.

FOR MORE INFORMATION:
"Field Performance of Energy Efficient Residential Building Envelope Systems"

SECTION 3

AIRTIGHTNESS

ISSUES INVESTIGATED
A fundamental component of an energy efficient house is a well-sealed air barrier. Fortunately, building tight houses has not proven to be difficult for the Canadian home building industry; thousands have been designed to, and met, the rigorous airtightness requirements of the R-2000 Program. However, some important questions remain to be answered. What is the long-term performance of different types of air barrier systems? Are they durable or will their airtightness degrade with time? How does the polyethylene air barrier system compare with the Airtight Drywall Approach? Do opportunities exist to improve residential air barrier systems?

THE AIRTIGHTNESS MONITORING PROGRAM
Airtightness tests were performed on the 24 project houses commencing at their time of completion and continuing on a regular basis for periods of up to three years. Testing was performed using the fan depressurization method in accordance with CAN/CGSB-149.10-M86. Regular site visits were also made to the houses to insure that no major physical alterations occurred during the monitoring period. A complementary study was also performed to measure the air leakage characteristics of various methods of sealing the rough-openings around doors and windows.

SUMMARY OF THE FINDINGS
Both the polyethylene and ADA houses displayed stable airtightness characteristics over their respective monitoring periods; no significant evidence of air barrier degradation was found. With one exception, all of the houses were able to meet the airtightness requirements of the R-2000 Program at the end of their monitoring periods. However, the study concluded that a significant opportunity exists to improve the performance of residential air barrier systems through a systematic analysis of the performance and costs of alternative methods of sealing each component of the building envelope.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

STABILITY OF POLYETHYLENE AIR BARRIERS

The airtightness of the 10 houses constructed with polyethylene air barriers remained stable over their monitoring periods, which ranged up to three years. Although two of the houses demonstrated possible, albeit slight, evidence of airtightness degradation, the magnitude of the changes was small and judged to not be of practical significance. For example, all but one of the ten houses met the airtightness requirements of the R-2000 Program at the end of the monitoring period, as shown in Figs. 3 and 4. The houses with the lowest measured airtightness rates were those constructed using the double wall technique and polyethylene air barriers.

STABILITY OF ADA AIR BARRIERS

The airtightness of the 14 ADA houses (constructed using an early version of the system) also remained stable over their monitoring periods - which ranged up to three years. Although six of the houses displayed possible, but slight, evidence of airtightness degradation, the magnitude of the changes was small and judged not to be of practical significance. All 14 houses were able to meet the airtightness requirements of the R-2000 Program at the end of the monitoring periods.

DOOR AND WINDOW ROUGH-OPENING AIR LEAKAGE

The air leakage characteristics of eight different methods of sealing, or otherwise treating, the rough-openings (R/O) around doors and windows were measured under laboratory conditions using a wood frame window installed in a 38x140 (2x6) wall section.

As expected, the maximum air leakage occurred with an empty R/O, (see "1." in Fig. 5). An analysis showed that if this method were used on a typical 1040 ft^2 bungalow with an overall house airtightness of 1.5 ac/hr_{50}, the rough-opening leakage would account for 39% of the total house leakage. With the conventional sealing method of packing pieces of fibreglass insulation into the R/O cracks, the contribution of R/O leakage to total house leakage would drop to 14%.

However, four of the methods (5, 6, 7 and 8) were able to reduce R/O leakage to less than 1% of the reference bungalow's total house leakage. This was seen as an important finding since the costs of the eight sealing methods varied widely. For example, although their ability to control leakage was identical, the poly-wrap approach was five times as expensive as the foamed-in-place urethane method.

OPPORTUNITIES TO IMPROVE THE PERFORMANCE OF RESIDENTIAL AIR BARRIER SYSTEMS

The study of rough-opening air leakage, combined with the cost analysis of air leakage sealing methods (discussed in Section 9) demonstrated the benefits which could be achieved from a comprehensive program to evaluate alternative methods of sealing the building envelope. The same cost/performance analysis procedure used to evaluate R/O sealing methods could be used to optimize methods for sealing other parts of the envelope. The proposed program should include laboratory and field testing of component air leakage along with an analysis of the incremental costs of each system. It should study all major building envelope joints

FIGURE 3

CHANGE IN AIRTIGHTNESS

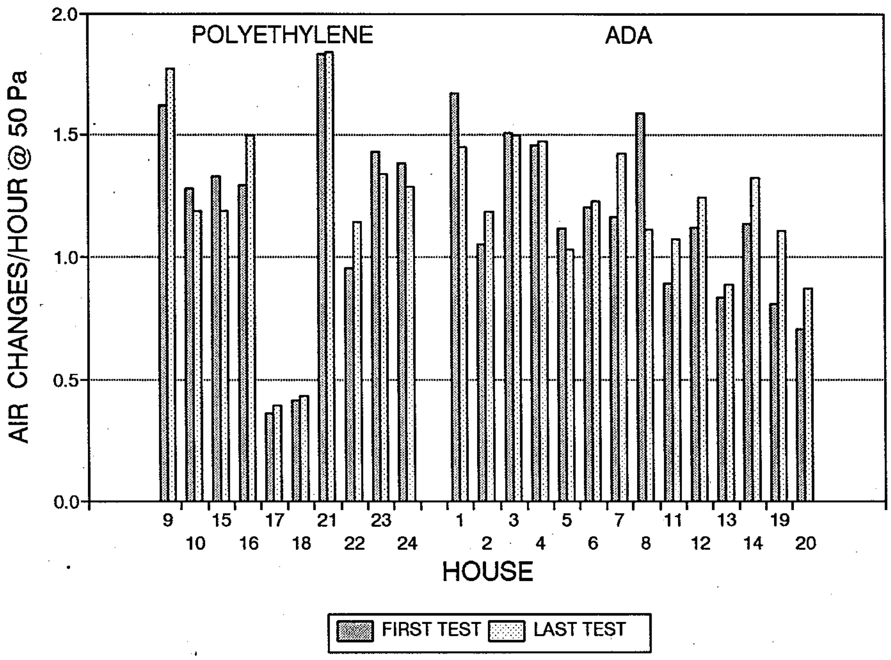


FIGURE 4

TYPICAL VARIATION IN AIRTIGHTNESS

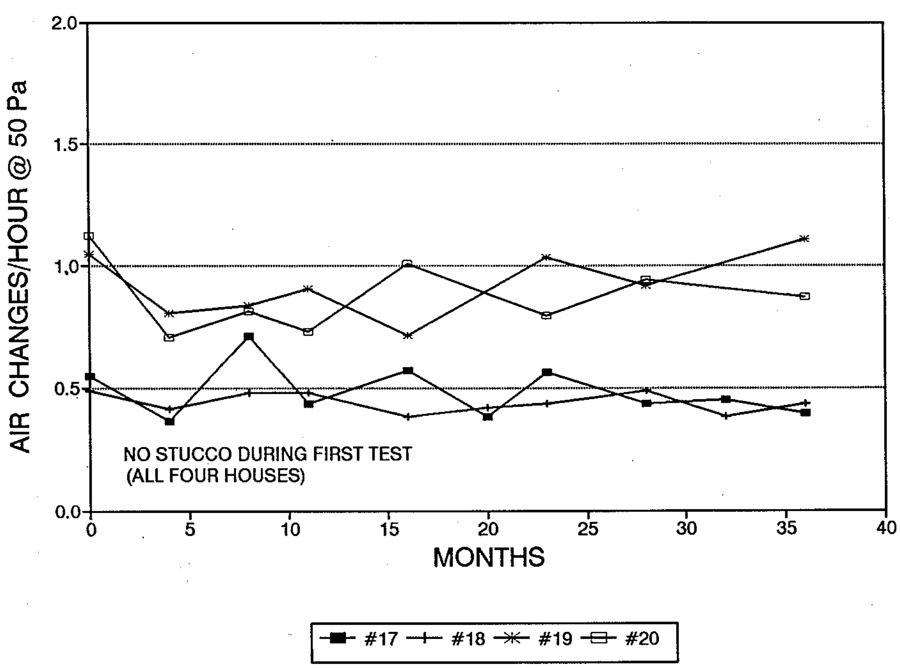
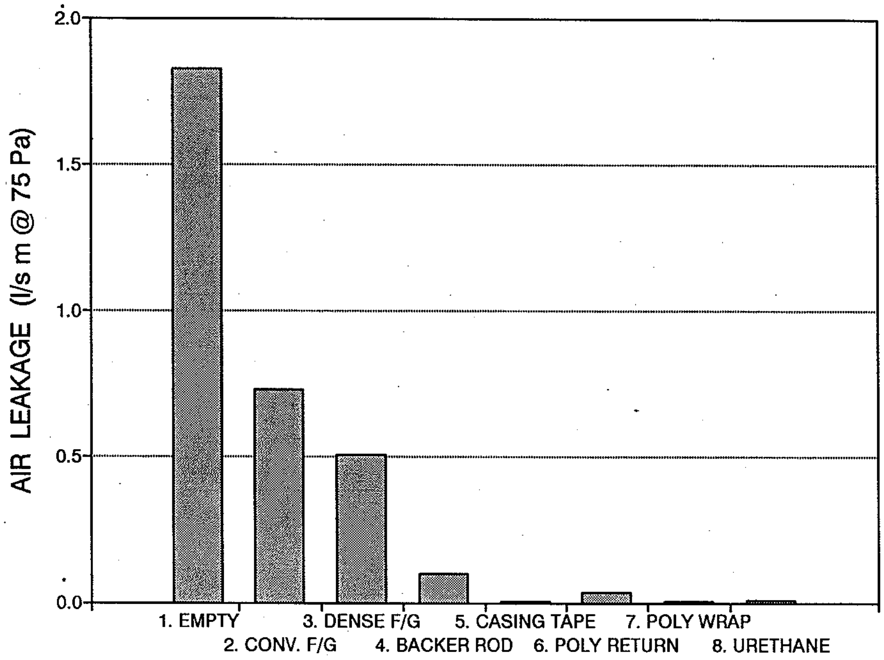


FIGURE 5

ROUGH-OPENING AIR LEAKAGE



1. EMPTY - No sealing of rough-opening spaces.
2. CONV. F/G - Pieces of fibreglass batt jammed into rough-opening spaces.
3. DENSE F/G - Pieces of fibreglass batt jammed into rough-opening spaces to twice the density as method 2.
4. BACKER ROD - Appropriately-sized backer rod jammed into rough-opening spaces.
5. CASING TAPE - Sheathing tape applied across rough-opening spaces between drywall and window frame and covered by casing.
6. POLY-RETURN - Polyethylene on walls returned and sealed to outer face of window frame.
7. POLY-WRAP - Separate polyethylene skirt sealed to window frame and mated to wall polyethylene.
8. URETHANE - Single component urethane foam injected into rough-opening spaces.

and intersections including those at the: floor/main wall, foundation/floor, interior partition walls/ceiling as well as cantilevers, plumbing, heating and electrical penetrations and below grade penetrations. The outcome of this work would be a valuable data base of performance/cost information on air leakage control measures which would benefit builders and renovation contractors.

FOR MORE INFORMATION:
"Measured Airtightness of Twenty-Four Detached Houses Over Periods of Up to Three Years"

"Air Leakage Characteristics of Various Rough-Opening Sealing Methods for Windows and Doors"

"Incremental Costs of Residential Energy Conservation Components and Systems"

SECTION 4

INDOOR AIR QUALITY

ISSUES INVESTIGATED
Indoor air quality is a concern in all houses, although perhaps more so in energy efficient houses since their natural leakage is so small. In R-2000 construction, special measures are mandated to protect air quality including high quality mechanical ventilation systems and restrictions on the use of spillage-susceptible combustion appliances. Although much research has been conducted, many issues remain. For example, how does the air quality in R-2000 houses compare to that in comparable, conventional structures? How important is mechanical ventilation and what is the impact of the homeowner on the ventilation system?

THE INDOOR AIR QUALITY MONITORING PROGRAM
Twenty of the project houses were monitored over a three year period to assess their indoor air quality. Formaldehyde, radon, particulate, nitrogen dioxide, carbon dioxide and relative humidity concentrations were measured on a regular basis. Total air change rates were also measured and correlated to the observed pollutant concentrations.

SUMMARY OF THE FINDINGS
The indoor air quality in the R-2000 houses was judged to have been superior to that in the conventional houses. Increased mechanical ventilation rates were found to improve air quality although this improvement became marginal once the total air change rate (mechanical and natural) exceeded roughly 0.30 ac/hr (air changes per hour). Homeowner intervention with the ventilation system (such as turning the system off for extended periods) was found to be a common problem. It was concluded that design ventilation rates should be established both on the ability of the system to remove pollutants as well as the effect the ventilation rate will have on homeowner utilization of the system.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

FORMALDEHYDE CONCENTRATIONS AND HEALTH GUIDELINES

The formaldehyde Action Level of 0.10 ppm (parts per million) established by the Federal-Provincial Advisory Committee on Environmental and Occupational Health was found to be readily achievable while the Target Level of 0.05 ppm could not be reached on a consistent basis. Note that the only formaldehyde control measure employed in the houses was mechanical ventilation.

FORMALDEHYDE CONCENTRATIONS AND R-2000 VENTILATION GUIDELINES

Significantly higher formaldehyde levels were measured in those R-2000 houses which were not operated in accordance with the R-2000 Ventilation Guidelines, relative to those which were operated in compliance with the Guidelines.

FORMALDEHYDE CONCENTRATIONS AND SMOKING

Formaldehyde levels in houses containing smokers were found to be slightly higher than those without smokers, although the difference was not statistically significant. However, higher air change rates were also observed in the houses containing smokers.

FORMALDEHYDE SOURCE STRENGTH

The formaldehyde source strength was measured in a sub-group of seven houses for three consecutive winters and found to decline by 48% over the period. The formaldehyde source strength was found to be poorly correlated to indoor temperature and absolute humidity.

RADON DAUGHTER LEVELS

Radon daughter levels were generally quite low with only one out of 123 measurements exceeding the action level guideline, published by the Federal-Provincial Advisory Committee on Environmental and Occupational Health. Radon daughter levels were nearly twice as high in houses which used baseboard heating systems compared to those with forced air heating systems.

PARTICULATE LEVELS AND SMOKING

Particulate levels were nearly 60% higher in houses which contained smokers relative to those which did not, even though air change rates were higher in the houses with smokers.

CARBON DIOXIDE CONCENTRATIONS

Spot measurements of carbon dioxide concentrations were made on 1065 occasions and only one reading was found to exceed the recommended exposure guideline of 3500 ppm. In fact, 94% of the measurements were below 1000 ppm.

COMPARISON OF THE INDOOR AIR QUALITY IN R-2000 AND CONVENTIONAL HOUSES

The air quality in the R-2000 houses was found to be superior to that in the conventional houses. Average concentrations of formaldehyde, particulates and nitrogen dioxide were lower, although not to statistically significant degrees. The R-2000 houses also experienced lower radon daughter and carbon dioxide concentrations, while relative humidity levels were more frequently within the recommended exposure range.

MECHANICAL VENTILATION AND INDOOR AIR QUALITY

The study highlighted the limitations of using mechanical ventilation as the sole means of achieving acceptable indoor air quality. Correlations between pollutant levels and total air change rates were generally weak, demonstrating that ventilation was not the sole factor determining pollutant concentrations. Figures 6 and 7, which relate formaldehyde and relative humidity to total air change rates, illustrate that little benefit was achieved by operating the houses at total air change rates (mechanical and natural) which exceeded about 0.30 ac/hr. The study concluded that, as an alternative to relying solely on mechanical ventilation for IAQ control, greater emphasis should be placed on other measures including source removal and/or isolation, pollutant entry control and improved ventilation system efficiency.

HOMEOWNER INTERVENTION

Homeowner intervention with the mechanical ventilation systems was a common problem and often resulted in lower than expected utilization rates and average air change rates. Central-exhaust systems were seldom used by the homeowners while HRVs (Heat Recovery Ventilators) were frequently turned off or had their air flow rates reduced to levels well below the design values. The study concluded that design rates for mechanical ventilation systems should be established both on the ability of the system to remove pollutants as well the effect the rate will have on homeowner intervention since higher design rates may result in decreased utilization.

FOR MORE INFORMATION:

"Indoor Air Quality Monitoring of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project"

"Utilization of Residential Mechanical Ventilation Systems"

FIGURE 6

FORMALDEHYDE vs. AIR CHANGE RATE

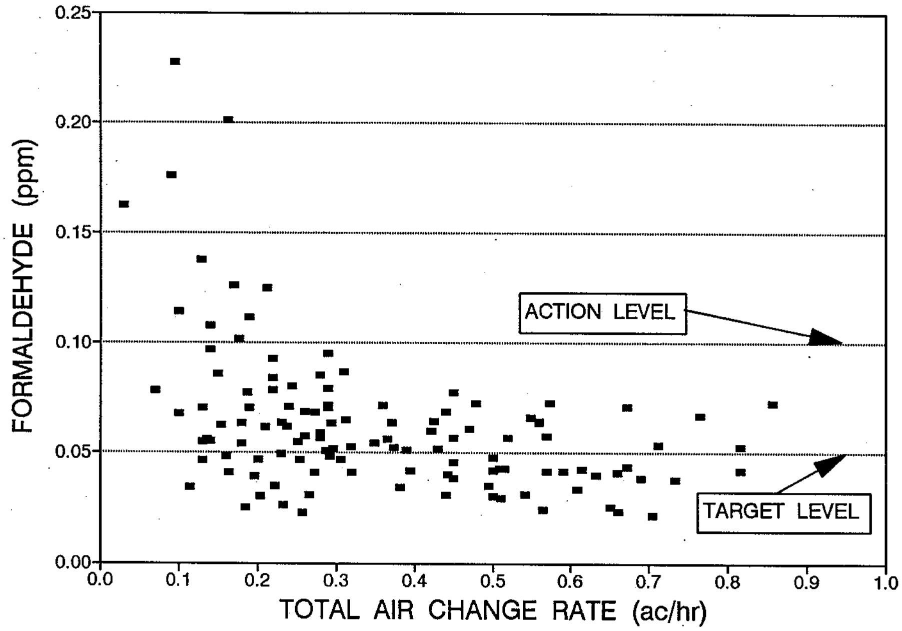
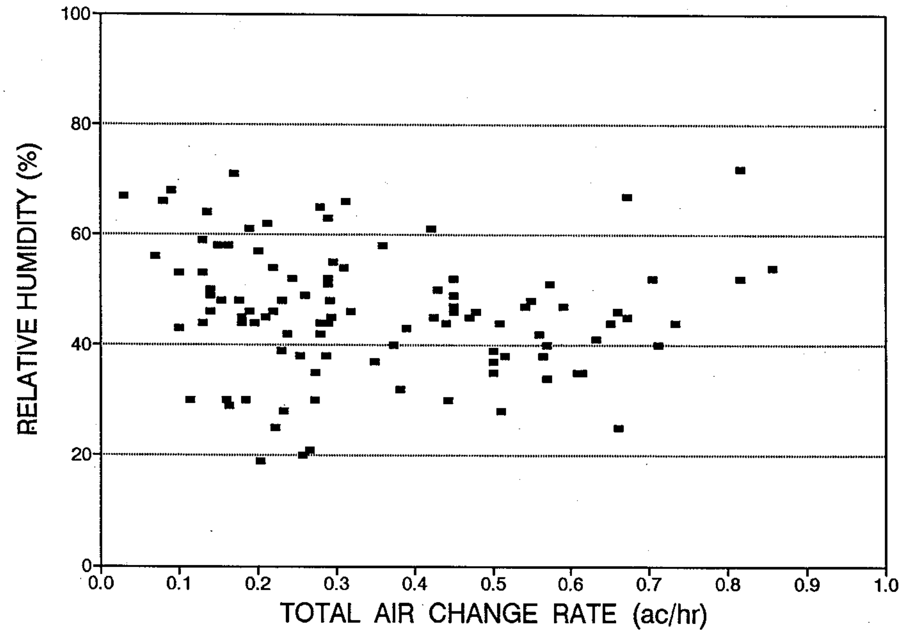


FIGURE 7

RELATIVE HUMIDITY vs. AIR CHANGE RATE



SECTION 5

MECHANICAL VENTILATION SYSTEMS

ISSUES INVESTIGATED
Residential ventilation system design has evolved rapidly in recent years with more stringent requirements being introduced in National and Provincial Building Codes, the R-2000 Program and CSA F326 "Residential Mechanical Ventilation Systems". These changes have raised questions as to whether currently used ventilation systems meet the new requirements, in particular CSA F326. Also, whether current design methods reasonably predict actual system performance. And, whether mechanical ventilation systems are properly utilized by homeowners - an important issue given that most research has focused on the ventilation system and not its usage by the occupants.

DESCRIPTION OF THE MONITORING PROGRAM
Long-term performance data was collected on the mechanical ventilation systems in 17 of the project houses equipped with various types of HRVs and central-exhaust systems. Additional studies, which utilized tracer gas testing and flow rate measurements, were also performed in a select group of the project houses.

SUMMARY OF THE FINDINGS
The study found that the effect of homeowner interaction with the mechanical ventilation system operation has not been adequately addressed. Homeowner utilization of the ventilation systems varied dramatically, depending on the type of system. Central-exhaust systems, intended for continuous operation, were only used an average of 37 minutes per day whereas HRVs were operated in excess of 19 hours per day. With respect to CSA F326, tracer gas testing of the ventilation systems in houses with forced air and baseboard heating systems found that both types were able to satisfy the standard's Minimum Ventilation Capacity for Dwelling Units requirement. Also, ventilation systems in the houses with forced air heating systems met the standard's Minimum Ventilation Capacity for Rooms requirement, because of their high recirculation rates. In contrast, the ventilation systems in houses with baseboard heating systems did not meet the requirement. This finding supports the argument that houses with baseboard or radiant heating systems will need dedicated ventilation ductwork, or equivalent, to meet the distribution requirements of CSA F326.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

UTILIZATION OF CENTRAL-EXHAUST SYSTEMS

Average utilization of the central-exhaust systems by the occupants was found to be very low, averaging only 37 minutes per day (or 3% of the time), see Fig. 8, despite the fact they were designed for continuous operation and equipped with convenient-to-use controls (dehumidistats or manual switches).

UTILIZATION OF HEAT RECOVERY VENTILATORS

HRVs in the project houses were two speed models designed for continuous operation. Their utilization was much higher than the central-exhaust systems, averaging over 19 hours per day (or 80% of the time) - equivalent to an average annual mechanical ventilation rate of 0.33 ac/hr. However, large variations in utilization were found among houses, with some units being rarely used. Seasonal variations also occurred with slightly higher usage in the winter.

MECHANICAL VENTILATION AND THE HOMEOWNER

The study concluded that to achieve the intent of ventilation standards such as CSA F326 or the requirements of the National Building Code, additional effort must be devoted to homeowner education and ventilation system operation and control. The central-exhaust systems used in the study met the basic requirements of CSA F326 yet had very low utilizations, well below that normally considered necessary to maintain indoor air quality. It was also concluded that ventilation system controls need to be improved to make them easier for homeowners to understand and operate. For example, dehumidistats function in a counter-intuitive fashion (relative to heating thermostats) in which the setting represents the upper, rather than the lower, limit of the desired range.

MEETING THE VENTILATION REQUIREMENTS OF CSA F326

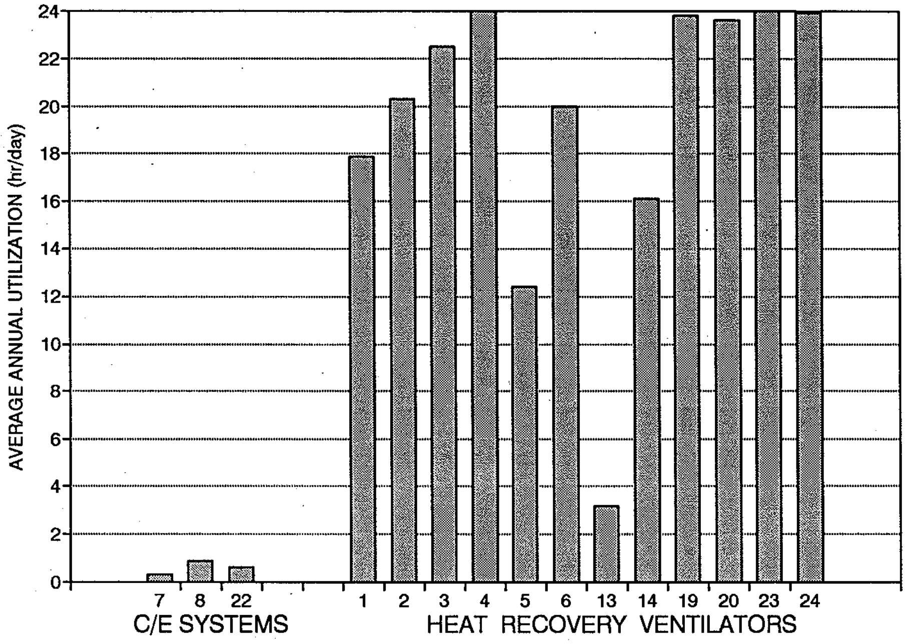
Two of the fundamental requirements of CSA F326 are the: 1) Minimum Ventilation Capacity for Dwelling Units and the 2) Minimum Ventilation Capacity for Rooms. Tracer gas tests were conducted on five types of mechanical systems to evaluate their ability to meet these two requirements:

a) Forced air heating system with exhaust-only ventilation
b) Forced air heating system with partially balanced ventilation
c) Baseboard heating system with exhaust-only ventilation
d) Baseboard heating system with partially balanced ventilation
e) Baseboard heating system with supply-only ventilation

The tracer gas testing confirmed that all five systems were able to satisfy the Minimum Ventilation Capacity for Dwelling Units requirement of CSA F326. The two systems intended for houses with forced air heating (a and b) were also able to meet the Minimum Ventilation Capacity for Rooms requirement because of the high recirculation rates produced by the furnace blowers. These recirculation

FIGURE 8

VENTILATION SYSTEM UTILIZATION



rates, and the excellent mixing they produced, also overcame the discrepancy between the design heating and ventilation load distributions. It was found that designing the ductwork system to meet the heating load resulted in an acceptable distribution of ventilation air to each zone.

In contrast, two of the three systems intended for baseboard heated houses (c and e) did not meet the room air flow requirement while the performance of the third (d) could not be confirmed, but was also suspected of not meeting the requirement. The failure of these systems was partially attributed to their reliance on envelope leakage and hence the need for an even distribution of leakage sites over the envelope area - an uncommon occurrence. The systems were also found to be susceptible to ventilation short-circuiting if a window or door were opened. The inability of these systems to meet the Minimum Ventilation Capacity for Rooms requirement supports the argument that houses with baseboard or radiant heating systems require dedicated ventilation ductwork, or equivalent, to meet CSA F326.

COMPARISON BETWEEN MEASURED AND DESIGN VENTILATION RATES

The actual, measured room air flow rates in baseboard heated houses with dedicated ductwork ventilation systems were found to vary significantly from their design values. Basements were found to be over-ventilated, because of excessive duct leakage, while main floor rooms received significantly less than their design flows. The imbalance could not be corrected by balancing or careful sealing of the exposed ductwork in the basement.

DUCT LEAKAGE

Air leakage from ventilation system ductwork was found to be significant, ranging from 13% to 35% of the total air flow despite the ductwork having been sealed to "contractor standards", i.e. major, obvious joints sealed. Very careful sealing of the HRV ductwork in one house reduced leakage from 22% to 13% on the supply side and from 35% to 23% on the exhaust side.

RECOMMENDATIONS TO IMPROVE THE PERFORMANCE OF VENTILATION SYSTEMS IN BASEBOARD HEATED HOUSES

To minimize problems with poor air distribution caused by duct leakage in houses with baseboard heating systems, the following measures were suggested:

- Reduce air flow rates to the basement, if it is not heavily used.
- Leave main floor supply dampers fully open and verify air delivery during commissioning. Even relatively small flow rates can be detected by a hand placed in front of a grille.
- Design for low system static pressure by using properly-sized ductwork and grilles (although the latter measure may create problems of achieving adequate throw on the supply air jet).
- Seal ductwork located in the basement, especially the ductwork between the outdoors and the main balancing dampers.

EFFECT OF INTERIOR DOOR POSITION UPON ROOM VENTILATION RATES

The performance of the ventilation systems was not seriously affected by the interior doors being closed in houses which used forced air heating systems with individual room returns, or in houses which used baseboard heating systems and relied on inter-zone leakage.

SUPPLY GRILLE LOCATIONS

The grille location and direction of throw were found to have a strong impact on the ability of ventilation air to mix with room air. Ventilation efficiency was seriously degraded when supply air grilles were located such that the air could short-circuit out of the room through open doorways.

INTEGRATED MECHANICAL SYSTEMS

An integrated mechanical system consisting of a self-contained heat pump, heat recovery ventilator, space and domestic hot water heater was monitored during the project. Although this model is no longer in production, some of the lessons learned are applicable to other integrated systems. For example, it was found that the system required specialized design and installation capabilities beyond those needed for conventional systems. This increased costs and created maintenance problems, particularly in finding service technicians familiar with the unit.

Due to the method used by the unit to mix outdoor air with the recirculation air, the ventilation rate could not be measured by the system installer which made it impossible to verify compliance with the design ventilation rate. Also, the heat pump significantly degraded the airtightness of the house because the evaporator was located inside the unit (i.e. indoors) and required outdoor air to be brought into the house through large capacity ductwork. Despite considerable efforts to seal them, both the ductwork and the heat pump case were found to be very leaky, thereby creating an easy path for outdoor air to enter the house.

A second type of integrated mechanical system consisting of an exhaust-only heat pump HRV was also studied. It was found to have difficulty achieving the required distribution of air because it relied on envelope leakage to supply the ventilation air. Case and internal leakage were also found to be a problem with the system which reduced its ability to achieve the desired ventilation rates.

FOR MORE INFORMATION:

"Design, Installation and Commissioning of the Ventilation Systems in the Flair Homes Energy Demo/CHBA Flair Mark XIV Project"

"Field Performance of Various Types of Mechanical Ventilation Systems"

"Utilization of Residential Mechanical Ventilation Systems"

SECTION 6

ENERGY PERFORMANCE

ISSUES INVESTIGATED
The designers of low-energy houses, as well as the developers of energy conservation programs and standards, frequently utilize computer models to evaluate design options. If the model is sound, then the designer or developer is able to make reasonable decisions regarding insulation levels, airtightness, mechanical system efficiencies, etc. In Canada, HOT2000 is the most widely used energy simulation model. Therefore, it is very important to know the accuracy of HOT2000, relative to actual, metered energy consumption data from occupied houses. Further, what opportunities exist to improve the accuracy of HOT2000? With respect to actual house modelling, are there significant variations in energy consumption created by differences in occupancy patterns? Finally, what are typical usage rates for appliances and domestic hot water consumption, since default values are used for R-2000 compliance evaluations?

DESCRIPTION OF THE MONITORING PROGRAM
Twenty-three of the project houses were sub-metered for energy consumption and monitored for periods of 16 to 39 months. This data was compared to predicted energy usage using HOT2000 6.0, modified with various enhancements to allow greater resolution of program inputs such as actual weather, occupancy and usage patterns and numerous other inputs estimated from measured data.

SUMMARY OF THE FINDINGS
HOT2000 6.0 was able to predict the total annual energy consumption with an accuracy of about ±10%. Several areas were identified in which future versions of the model could be changed to improve its accuracy. The impact of lifestyle was found to be highly unpredictable and responsible for a significant variation in total energy consumption. The average, daily consumption for appliances and hot water for the project houses was found to be 15 kWh/d (kilowatt-hours per day) and 164 litres per day, respectively.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

ACCURACY OF HOT2000 6.0

HOT2000 6.0, with enhanced weather and user inputs, was typically able to predict the total annual energy consumption to within about 2000 kWh, or around

10%, for the houses studied. Overall, there was a tendency for underprediction of total energy consumption in the occupied low-energy and conventional electrically heated homes in the project group, and for overprediction of energy use in the two conventional gas-heated houses.

IMPROVEMENTS TO HOT2000 6.0

Several areas were identified in which improvements could be made to increase the accuracy of HOT2000:

- o Expansion of the capability to input certain key variables on a month-by-month basis.
- o Provision to select appliance energy and domestic hot water usage rates based on occupancy patterns.
- o Improvement to the DHW model.
- o Improvement to the HRV model.
- o Review and improvement of the flue loss estimation algorithms and the interactions of the various contributing sources of air exchange.
- o Treatment of clothes dryers and other previously non-quantified energy losses.
- o Improvement to the characterization of the hourly outdoor temperature distribution for each month.

IMPACT OF OCCUPANCY PATTERNS

Occupancy patterns, family size and personal behaviour had a major impact on the overall, annual energy consumption. While general patterns could be established between occupant-induced energy consumption and certain key variables, such as the number and ages of occupants, significant variations were observed among ostensibly equivalent situations. This mitigates against making accurate predictions of the impact of a specific family on energy consumption.

AVERAGE APPLIANCE ENERGY CONSUMPTION

Average appliance energy consumption ranged between 5 kWh/d and 35 kWh/d, excluding the energy used in ventilation systems, space heating fans, clothes dryers and air conditioners, with an average of 15 kWh/d.

AVERAGE DOMESTIC HOT WATER ENERGY CONSUMPTION

Average consumption of domestic hot water ranged from almost zero up to 450 litres per day with an average of 164 litres per day.

FOR MORE INFORMATION:

"Energy Monitoring Program & Validation of HOT2000 6.0"

SECTION 7

COOLING

ISSUE INVESTIGATED
What potential exists to minimize summer cooling loads in conventional and energy efficient houses using exterior window shade screens?

DESCRIPTION OF THE MONITORING PROGRAM
A preliminary field study and theoretical analysis were carried out to assess the ability of semi-transparent solar shade screens to reduce summer cooling loads.

SUMMARY OF THE FINDINGS
Solar shade screens were found to have a significant ability to reduce the cooling load and thereby lessen the amount of energy needed for air-conditioning and may, in some cases, permit the cooling system to be eliminated.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

BENEFITS OF SOLAR SHADE SCREENS

The study found that solar shade screens can significantly reduce the residential design cooling load, save energy, allow a smaller capacity air-conditioning system to be used and, if combined with other low-energy cooling systems, may permit the conventional air-conditioning system to be eliminated in locations with modest cooling loads. The estimated retail cost of the screens was $38/m² ($3.54/ft²) or roughly $275 to $750 for a typical new house, assuming quantity production by the window manufacturer.

IMPACT OF SOLAR SHADE SCREENS ON THE DESIGN COOLING LOAD

A preliminary analysis indicated that the design cooling load could be reduced by approximately one-third for a typical 147 m² (1584 ft²) bungalow equipped with shade screens. The impact of the shade screens on the design cooling load was analyzed for three geographic locations (Winnipeg, Montreal and Toronto) and found to be similar regardless of whether the screens were used on double or triple-glazed windows, or used on houses with solar-optimized or non-optimized window configurations.

FOR MORE INFORMATION:

"A Preliminary Assessment of the Solar Shade Screen System for Reducing Residential Cooling Loads"

SECTION 8

NOISE

ISSUES INVESTIGATED
Reduced noise levels are a significant feature of energy efficient houses. How do sound levels produced by mechanical systems compare to established acoustical design goals? What are the major pathways for outdoor noise to enter a house? What measures can be taken to reduce the entry of outdoor noise?

DESCRIPTION OF THE MONITORING PROGRAM
Sound level measurements were performed in four of the project houses along with a fifth control structure. Sound pressure levels produced by the mechanical systems were measured and compared to ASHRAE indoor design goals. Measurements were also made of the attenuation of outdoor noise by the different types of building envelopes used in the houses.

SUMMARY OF FINDINGS
The sound levels generated by the mechanical system generally exceeded acoustical design goals in those rooms located directly above the mechanical equipment. Transmission of outdoor noise into the house was found to mainly occur through windows and ductwork which penetrated the envelope.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

MECHANICAL SYSTEM NOISE

Sound levels generated by the mechanical systems varied significantly and generally exceeded the acoustical design goals in rooms located directly above the mechanical systems. This will increase the likelihood of homeowners turning off their ventilation systems to reduce noise, thereby adversely affecting the indoor air quality.

NOISE TRANSMISSION THROUGH WINDOWS

Windows were found to be the major pathway for noise transmission across the building envelope meaning that, from a noise control perspective, little benefit was realized by using thicker exterior wall systems. Since a significant portion of the airborne noise transmission occurs along the same pathways as air leakage, noise transmission can be reduced by using windows with low air leakage characteristics and by carefully sealing the rough-openings. Windows should also be located, as much as possible, away from significant sources of outdoor noise.

EXTERIOR NOISE TRANSMISSION THROUGH DUCTWORK PENETRATIONS

Ductwork running through exterior walls also created major acoustical pathways for noise transmission. This problem can be minimized by locating ductwork penetrations in walls which do not face significant sources of noise, such as streets or commercial establishments.

FOR MORE INFORMATION:

"A Survey of Sound Levels in Five Unoccupied Houses"

SECTION 9

INCREMENTAL COSTS OF ENERGY CONSERVATION COMPONENTS AND SYSTEMS

ISSUES INVESTIGATED
How much do various energy conservation components, systems and design features cost? Do systems which produce the same performance come with the same price tag? Are there opportunities to reduce costs? Can general recommendations be made about cost optimization?

OVERVIEW OF THE COSTING STUDY
Based on the construction experiences with the 24 project houses, the incremental costs of over 100 energy conservation measures were analyzed using data from local (Winnipeg) suppliers. In addition, general conclusions were developed on the relative cost-effectiveness of many of these systems using their incremental costs (relative to conventional practice) and the change in thermal performance. Costing data for the study was developed using a standard 97 m^2 (1040 ft^2) bungalow as a reference structure with the assumption that the builder was experienced with energy efficient construction techniques. Incremental costs were defined as the direct costs which the builder would incur beyond those normally encountered using conventional practices. To provide a consistent basis for comparison, no provisions were made for builder overhead, profit or learning time. Since the cost data was developed using information from a single location and with a specific set of assumptions, the reader is cautioned that the relative costs of competing systems are more important than their absolute values.

DETAILED CONCLUSIONS AND RECOMMENDATIONS

EXTERIOR WALL SYSTEMS

The most cost-effective upgrade from a conventional 38x89 (2x4) wall system was found to be standard 38x140 (2x6) construction, since labour costs were largely unchanged and only the material costs increased significantly. To improve a wall system's thermal performance beyond that of 38x140 (2x6) construction, the most cost-effective upgrade would be to use either a wall with exterior insulated sheathing or an interior strapped wall. The cost-effectiveness of double wall construction, compared to other types of wall systems, was poor.

The cost performance of walls with exterior insulated sheathing, and walls with interior strapping, were similar. It was concluded that the choice between the two should be made on the basis of other factors such as the effect upon useful interior floor area or the impact upon property taxes.

BASEMENTS

The cost-effectiveness of interior basement insulation systems was high while that of the exterior insulation systems was much lower, although exterior schemes have other advantages such as providing protection against moisture entry. The most cost-effective exterior insulation systems were those which used the maximum insulation thickness available, since a significant percentage of the total cost was independent of the thickness used, i.e. labour and cladding to the above-grade portions. The cost-effectiveness of exterior systems which used extruded polystyrene and rigid glass fibre insulation were found to be similar for equivalent material thicknesses. Under-floor slab insulation was often cost-effective.

CEILINGS

Due to the low incremental material and labour costs, the cost-effectiveness of adding ceiling insulation was high, despite the assumption that the conventional ceiling was insulated to RSI 7.04 (R-40).

WINDOWS

Window technology is evolving rapidly and the incremental costs of high performance options vary widely between manufacturers. The window cost data shown below was compiled in 1990 using information from three manufacturers, all of whom had considerable experience with high performance windows. Thirteen types of high performance windows were investigated. Incremental costs were developed using both double and triple-glazed units as a reference point. Window performance is expressed below using the thermal resistance and shading coefficient for the glazed portion of the window.

REFERENCE WINDOW: CONVENTIONAL DOUBLE-GLAZING

WINDOW SYSTEM	THERMAL RESISTANCE		SHADING COEFFICIENT	INCREMENTAL COST	
	(RSI)	(R)		(per m²)	(per ft²)
Conventional double, metal spacer, 13 mm (½") air space	0.34	1.91	0.89	0	0
Conventional triple, metal spacers, 13 mm (½") air spaces	0.48	2.71	0.79	$30.12 to $51.65	$2.80 to $4.80
Double-glazing, butyl/metal spacer, 13 mm (½") air space	0.35	1.96	0.89	$5.59	$0.52
Double-glazing, 1 low E film, metal spacer, 13 mm (½") argon space	0.55	3.12	0.74	$48.52	$4.51
Double-glazing, 1 low E film, butyl/metal spacer, 13 mm (½") argon space	0.61	3.47	0.74	$54.12	$5.03

REFERENCE WINDOW: CONVENTIONAL TRIPLE-GLAZING

WINDOW SYSTEM	THERMAL RESISTANCE		SHADING COEFFICIENT	INCREMENTAL COST	
	(RSI)	(R)		(per m²)	(per ft²)
Conventional triple, metal spacers, 13 mm (½") air spaces	0.48	2.71	0.79	$0	$0
Triple-glazing, butyl/metal spacers, 13 mm (½") air spaces	0.52	2.93	0.79	$11.19	$1.04
Triple-glazing, 1 low E film, metal spacers, 13 mm (½") air spaces	0.60	3.41	0.66	$19.37	$1.80
Triple-glazing, 2 low E films, metal spacers, 13 mm (½") air spaces	0.69	3.94	0.58	$38.74	$3.60
Triple-glazing, 1 low E film, metal spacers, 13 mm (½") argon spaces	0.67	3.79	0.66	$48.42 to $48.53	$4.50 to $4.51
Triple-glazing, 2 low E films, metal spacers, 13 mm (½") argon spaces	0.79	4.46	0.58	$58.10 to $97.06	$5.40 to $9.02
Triple-glazing, 1 low E film, butyl/metal spacers, 13 mm (½") argon spaces	0.78	4.44	0.66	$59.72	$5.55
Triple-glazing, 2 low E films, butyl/metal spacers, 13 mm (½") argon spaces	0.97	5.52	0.58	$108.52	$10.06

AIRTIGHTNESS

The conventional method employed to "seal" the air barrier was assumed to be 4 mil polyethylene, stapled in place, with pieces of insulation stuffed into major gaps around penetrations, etc. The incremental cost of a high quality air barrier, sufficient to meet R-2000 requirements, was analyzed in detail and estimated to range from $117 to $261 for a typical 97 m² (1040 ft²) bungalow. These values would, of course, vary depending on house size and the relative complexity of the design. Costs were found to be similar for the polyethylene air/vapour barrier system and the Airtight Drywall Approach (ADA).

The study found that a significant opportunity exists to improve the cost-effectiveness of residential airtightness systems by developing a hybrid system which utilizes elements of both the polyethylene and ADA systems. At present, the two systems are often treated as being mutually exclusive; however each has strengths which could be realized by a hybrid system. The latter could make use of the data on the air leakage characteristics of alternative methods of sealing individual building envelope components (see Section 3).

VENTILATION SYSTEMS

The estimated, installed costs of the various mechanical ventilation systems studied are shown below with both the total and incremental costs (beyond that of the reference system) identified.

REFERENCE SYSTEM: FRESH AIR INTAKE, KITCHEN AND BATHROOM EXHAUST FANS

SYSTEM	DESCRIPTION	TOTAL COST	INCREMENTAL COST
Conventional	o Fresh air intake o Kitchen exhaust fan o Bathroom exhaust fan	$257	$0
Central-Exhaust System	o Fresh air intake o Central-exhaust fan o Dehumidistat	$565	$308
HRV, Small Capacity for use with a Forced Air Heating System	o HRV, small capacity o Dehumidistat	$1,523	$1,266
HRV, Small Capacity for use with a Baseboard Heating System	o HRV, small capacity o Dedicated ventilation-only ductwork o Dehumidistat	$1,998	$1,741
HRV, Medium Capacity for use with a Forced Air Heating System	o HRV, medium capacity o Dehumidistat	$1,823	$1,566
HRV, Medium Capacity for use with a Baseboard Heating System	o HRV, medium capacity o Dedicated ventilation-only ductwork o Dehumidistat	$2,298	$2,041
Heat Pump HRV for use with a Forced Air Heating System	o Heat pump HRV	$2,698	$2,441
Heat Pump HRV for use with a Baseboard Heating System	o Heat pump HRV o Dedicated ventilation-only ductwork	$3,173	$2,916

HEATING SYSTEMS

The total and incremental installed costs of several, common space heating systems are shown on the next page.

REFERENCE SYSTEM: CONVENTIONAL, NATURALLY ASPIRATED GAS FURNACE

SYSTEM	TOTAL COST	INCREMENTAL COST
Conventional Naturally Aspirated Gas Furnace c/w Ductwork, 60% Seasonal Efficiency	$1,458	$0
Naturally Aspirated Gas Furnace with Spark Ignition and Vent Damper c/w Ductwork, 69% Seasonal Efficiency	$1,833	$375
Induced Draft Gas Furnace c/w Ductwork, 80% Seasonal Efficiency	$2,028	$570
Condensing Gas Furnace c/w Ductwork, 95% Seasonal Efficiency	$3,058	$1,600
10 kW Electric Furnace c/w Ductwork	$1,530	$72
8 kW Electric Baseboard Heating System	$756	-$702

It was concluded that high efficiency (i.e. 90% to 95%) heating systems are most cost effective in houses with large heating loads since the cost of the furnace is largely independent of house size and the extra cost of the unit can be applied against the larger heating load. In small and medium sized houses, an induced draft system would generally be the most appropriate upgrade from a conventional, naturally aspirated furnace. High efficiency furnaces are also best suited to larger houses which are poorly insulated and sealed.

INTEGRATED MECHANICAL SYSTEMS

Although integrated mechanical systems take many forms, some general guidelines on their cost performance can be made. First, integrated systems are most cost effective when they completely replace, rather than just augment, the systems used in conventional practice. For example, two of the systems analyzed in the Flair project provided a cooling capability in the summer. When this capacity was sufficient to meet the entire cooling load, the conventional air-conditioning system could be eliminated, thereby significantly reducing capital costs. Second, integrated systems need to be carefully matched to the load to ensure a good fit and prevent poor utilization of a potentially significant investment.

OPTIMIZATION OF ENERGY CONSERVATION PACKAGES

The incremental cost data developed in this study can be used by a designer to optimize the energy-related features of a house provided he also has access to a computerized energy analysis program such as HOT2000 and is prepared to evaluate a number of options. Unfortunately, this is not always possible due to time or budget constraints. However, using the data and recommendations of the cost study, some general optimization guidelines of energy features can be offered.

The table shown on the next page provides basic recommendations on upgrading a conventional house to the R-2000 Standard. Recommendations are presented for three house types and can be applied regardless of climate or energy costs. Each house type has a set of "Basic Requirements" which are either explicitly required to meet R-2000 requirements or will usually prove to be necessary to meet the R-2000 energy target. In some instances, the Basic Requirements alone are adequate, in other cases, additional measures will be needed. For the latter cases, the "Upgrade Options" should be considered. These are divided into groups containing one or more options. Each of the options within a group has roughly the same cost effectiveness and should be considered on an equal basis to others in that group. All options in a given group should be investigated before considering those in the following group.

It should be noted that in some cases, it may be appropriate to modify these general guidelines to reflect specific design needs since they were developed solely on the basis of energy cost effectiveness, with no consideration of other factors such as comfort, moisture protection, marketability, utility incentives, preferential mortgage rates, property taxes or the impact on the living space.

FOR MORE INFORMATION:
"Incremental Costs of Residential Energy Conservation Components and Systems"

GENERAL GUIDELINES FOR OPTIMIZING ENERGY CONSERVATION PACKAGES

	BUNGALOWS	SPLIT LEVELS, RAISED BUNGALOWS	1 1/2 and 2 STOREY HOUSES
BASIC REQUIREMENTS			
Walls	RSI 3.52 (R–20)	RSI 3.52 (R–20)	RSI 3.52 (R–20)
Basement Walls	RSI 3.52 (R–20)	RSI 4.23 (R–24)	RSI 3.52 (R–20)
Ceiling	RSI 7.04 (R–40)	RSI 7.04 (R–40)	RSI 7.04 (R–40)
Windows	Triple–glazing	Triple–glazing	Triple–glazing
Airtightness System	Polyethylene or ADA	Polyethylene or ADA	Polyethylene or ADA
Heating System	Induced draft (80%) or electric	Induced draft (80%) or electric	Induced draft (80%) or electric
DHW System	Induced draft or electric	Induced draft or electric	Induced draft or electric
Ventilation	Medium efficiency HRV (65%)	Medium efficiency HRV (65%)	High efficiency HRV (80%)
UPGRADE OPTIONS			
First Priority	Increase basement wall insulation Increase ceiling insulation Use high performance windows Use high efficiency HRV (80%)	Increase basement wall insulation Add slab perimeter insulation Use high performance windows Use high efficiency HRV (80%)	Increase basement wall insulation Increase ceiling insulation Use high performance windows
Second Priority	Add slab perimeter insulation	Increase ceiling insulation	Use high efficiency furnace (90%) Add slab perimeter insulation
Third Priority	Add slab centre insulation	Add slab centre insulation Use high efficiency furnace (90%)	Add slab centre insulation Increase wall insulation
Fourth Priority	Use high efficiency furnace (90%) Increase wall insulation	Increase wall insulation	

APPENDIX

APPENDIX A

FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT REPORTS

The following 12 technical reports have been prepared as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project. Copies can be obtained from:

Publications Dept.
The Buildings Group
CANMET
Energy, Mines and Resources Canada
9th Floor, 580 Booth St.
Ottawa, Ontario
K1A 0E4

"The Flair Homes Energy Demo/CHBA Flair Mark XIV Project: Description of the Project Houses, Monitoring Program and Data Base"
Provides a general background on the project and is intended to complement the other technical reports; it does not contain any results or analysis. The report provides an overview of the design of the 24 project houses including sample floor plans and elevations, cross-sections, air/vapour barrier details, window schedules and mechanical system schematics. It also summarizes the information contained in the project's data base.

"Field Performance of Energy Efficient Residential Building Envelope Systems"
Analyzes the performance of the building envelope systems used in the project houses using extensive measurements of the wood moisture content of framing members, thermographic examinations and airtightness test results. Comparisons are made between energy efficient and conventional houses and between the different air barrier systems.

"Measured Airtightness of Twenty-Four Detached Houses Over Periods of Up to Three Years"
Summarizes the results of the airtightness monitoring carried out on the 10 project houses constructed with polyethylene air barriers and the 14 built using the Airtight Drywall Approach. It analyzes the observed variations in airtightness and comments on the acceptability of each system.

"Air Leakage Characteristics of Various Rough-Opening Sealing Methods for Windows and Doors"
Describes the laboratory study of the measured air leakage characteristics of eight methods of sealing, or treating, the rough-openings around windows and doors. It includes an assessment of rough-opening leakage relative to the total house leakage.

"Indoor Air Quality Monitoring of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project"
Summarizes the results of the indoor air quality monitoring conducted over a three year period. Formaldehyde, radon daughter, particulate, nitrogen dioxide, carbon dioxide and relative humidity concentrations were compared to total air change rates. Comparisons are also made of the air quality in R-2000 and conventional houses.

"Design, Installation and Commissioning of the Ventilation Systems in the Flair Homes Energy Demo/CHBA Flair Mark XIV Project"
Summarizes tracer gas testing and balancing studies performed on ten of the project houses to determine their performance under actual operating conditions.

"Field Performance of Various Types of Residential Mechanical Ventilation Systems"
Describes the detailed tracer gas and air distribution measurements made on five types of mechanical ventilation systems to evaluate their compliance with CSA F326 "Residential Mechanical Ventilation Systems". Systems intended for houses with forced air and baseboard heating systems were considered.

"Utilization of Residential Mechanical Ventilation Systems"
Summarizes the utilization patterns of 12 conventional air-to-air HRVs, two exhaust-only HRVs and three central-exhaust systems. Monitoring periods ranged from 10 to 40 months, representing 45 house-years of field experience.

"Energy Monitoring Program & Validation of HOT2000 6.0"
Describes the detailed energy monitoring program conducted on 23 of the project houses. Actual, metered energy usage data was compared to values predicted using HOT2000 6.0, with enhanced inputs, to arrive at a commentary on the relative accuracy of the program. A number of areas were identified in which HOT2000 6.0 could be modified to improve its accuracy. Commentaries were also developed on the impact of occupancy upon energy consumption.

"A Preliminary Assessment of the Solar Shade Screen System for Reducing Residential Cooling Loads"
Describes a theoretical analysis which estimated the impact of residential window shade screens upon the design cooling load and air-conditioning system sizing requirements. Cost estimates are also included along with observations on the use of the shade screens on four of the project houses.

"A Survey of Sound Levels in Five Unoccupied Houses"
Summarizes field measurements conducted to study the sources and intensities of indoor noise in houses. Sound pressure levels generated by the heating and ventilation systems were measured along with attenuation of outdoor noise by different types of building envelope systems.

"Incremental Costs of Residential Energy Conservation Components and Systems"
Documents the incremental costs of over 100 energy conservation components and systems including building envelope, airtightness and mechanical system options. It also provides recommendations on prioritizing energy conservation options, based on their relative cost effectiveness.