Vancouver Healthy House Monitoring Results

Final Report

for the
Canada Mortgage and Housing Corporation

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by

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DISCLAIMER

SUMMARY

The Canada Mortgage and Housing Corporation (CMHC) sponsored the Healthy Housing Design Competition to demonstrate to the Canadian public and housing industry that it is possible to design houses for the Canadian climate which are in keeping with the principles of sustainable development, which offer healthy indoor environments, and which remain affordable.

The CMHC Vancouver Healthy House demonstrates several important features:

- the viability of building compact, infill housing in an urban environment,
- the use of low emission materials to create a healthy indoor air environment,
- the use of low-flow faucets, and low water use appliances to make it **possible to reduce** overall and hot water usage,
- energy efficient envelope,
- energy efficient heating system.

The Vancouver Healthy House was monitored, in an occupied condition, from 12 February, 1994 through 30 April, 1995. Over this period of time there were two sets of occupants - a couple who had a baby during their stay, and two to four adults, from August, 1994 onward.

Continuous hourly data, as well as monthly meter readings were obtained over the whole period. In particular, monthly hot and cold water use was obtained for the kitchen, each bathroom and laundry. The hourly monitoring covered indoor and outdoor environment, and energy use.

Description:

The Vancouver Healthy House is a 2.5 storey infill, with a heated area of 136.7 square metres. The truss ceiling has an RSI 8.1 insulating value, while the walls are RSI 4.4. The floor slab is insulated at the perimeter and under the full slab. Windows are double glazed, single low-E coated and argon filled (RSI 0.51). Heated volume is 334 cubic metres and air tightness was tested at 3.4 air changes at 50 Pascals pressure differential (ELA of 582 square centimetres).

Space and water heating are provided by a condensing natural gas water heater plus fan-coil. A single core, cross-flow heat recovery ventilator provides continuous ventilation.

Environment:

From August, 1994 to April, 1995, the house site averaged 0.8C warmer than the Vancouver International airport, which averaged 0.7C warmer than long-term. Heating Degree Days at the airport were 7% less than long-term for the same period.

Indoor temperatures and indoor air quality of the occupied houses were generally within acceptable comfort ranges.

However, the house overheated during the period from April to June, 1994 due to a combination of:

- solar heat gain,
- lack of opening windows in the third storey,
- heating system circulation when no heat called for, and
- heat recovery by the HRV on hot days.

An electric check valve in the heating system loop, along with foil over the south clerestory windows and shutting the HRV off eliminated the overheating reported by the first occupants. The second set of occupants reported no significant overheating (and removed the foil from the south windows), except that the loft area was excessively warm on some occasions.

From August, 1994 to April, 1995, temperatures in the living room were typically in the 22C to 26C range in the summer and 20C to 24C in winter. The ground floor master bedroom was 0.6C cooler in summer and 1.9C cooler in winter.

Winter relative humidity averaged 40%, ranging from 15% to 89% (latter with the HRV off).

Carbon dioxide concentration averaged about 485 ppm with only 3% of hours having concentrations in excess of 950 ppm (maximum 1,400 ppm, with the HRV off). Carbon dioxide concentrations with the HRV off were typically 300 to 400ppm higher than with the unit operating.

One week indoor air quality tests showed formaldehyde concentrations, within six months of completion of construction, of about 0.04 ppm - below the Health and Welfare recommended value of 0.05 ppm. Formaldehyde source strength at the same time was about 9 mL/h.

Mechanical Systems:

The integrated space and water heating system operated with an average efficiency of 91%. The space heating circulation fan used a continuous 211W.

The single core, cross-flow, heat recovery ventilator operated with a sensible core efficiency of 53% under typical winter conditions. The HRV used 115W, while delivering approximately 70 L/s balanced air flow.

Water and Energy Use:

Depending on occupancy, hot water usage varied from approximately 87% to 116% of typical usage of about 68 L/person/day in B.C., pointing to the need for more consumer education.

Depending on the occupancy, total water usage varied from 64% to 117% of the predicted 212 L/person/day.

Electrical energy use by the second set of occupants amounted to:

- utilities (appliances, indoor lighting) averaged 17.0 kWh per day,
- fan energy use was 7.7 kWh per day,
- outdoor energy use varied from 2.1 kWh per day in the summer to 4.8 KWh per day in winter - the latter due to the operation of an electric heater in the garage.

The total energy usage amounted to approximately 23,500 kWh, or 172 kWh per square metre of heated floor area. Annual space heating demand (delivered to the space) amounted to 26.1 GJ, or 7,260 kWh.

RÉSUMÉ

La Société canadienne d'hypothèques et de logement (SCHL) a parrainé le Concours de modèles de maisons saines afin de montrer au public et au secteur du logement du Canada qu'il est possible de concevoir des habitations pour le climat canadien qui respectent les principes du développement durable et qui offrent un milieu intérieur sain tout en demeurant abordables.

La maison saine de Vancouver de la SCHL présente plusieurs caractéristiques importantes :

- viabilité inhérente à la construction intercalaire de maisons compactes en milieu urbain;
- utilisation de matériaux à faible émissivité pour procurer un air intérieur de qualité;
- emploi de robinets à faible débit et d'appareils sanitaires à faible consommation d'eau permettant de réduire l'utilisation d'eau totale, y compris de l'eau chaude;
- enveloppe éconergétique;
- installation de chauffage éconergétique.

Une fois habitée, la maison saine de Vancouver a fait l'objet de contrôles entre le 12 février 1994 et le 30 avril 1995. Pendant cette période, la maison a été occupée par deux types d'occupants : un couple qui a eu un enfant durant son séjour et des adultes (de deux à quatre), à compter du mois d'août 1994.

Pendant toute la période de contrôle, des données horaires ont été recueillies en continu et des lectures ont été prises mensuellement sur des appareils de mesure. On a notamment enregistré les données mensuelles de consommation d'eau froide et d'eau chaude dans la cuisine, les salles de bains et la buanderie. Les contrôles horaires ont porté sur les milieux extérieur et intérieur ainsi que sur la consommation énergétique.

Description :

La maison saine de Vancouver est une habitation de deux étages et demi construite en intercalaire dont la surface de chauffage est de 136,7 m². Le toit en solives ajourées possède une valeur de résistance thermique RSI de 8.1, tandis que celle des murs est de 4.4. La dalle de plancher est isolée sur son périmètre et sur toute sa surface inférieure. Les fenêtres sont à double vitrage, possèdent une pellicule à faible émissivité ainsi qu'une lame d'argon (RSI de 0.51). Le volume à chauffer est de 334 m³ et l'étanchéité à l'air a été mesurée à 3,4 renouvellements d'air à une différence de pression de 50 pascals (surface de fuite équivalente de 582 cm²).

L'eau et les locaux sont chauffés par un chauffe-eau à condensation fonctionnant au gaz naturel et doté d'un ventilo-convecteur. Un ventilateur-récupérateur de chaleur à noyau simple et à courants croisés procure une ventilation continue.

Environnement :

De août 1994 à avril 1995, l'emplacement de la maison a connu des températures moyennes supérieures de 0,8 °C à celles enregistrées à l'aéroport international de Vancouver, lesquelles étaient elles-mêmes 0,7 °C plus chaudes que la normale à long terme. Les degrés-jours de chauffage à l'aéroport ont été de 7 % inférieurs à la normale à long terme durant la même période.

Les températures intérieures et la qualité de l'air intérieur de la maison occupée sont demeurées à un niveau de confort généralement acceptable.

Toutefois, la maison a subi une surchauffe durant la période comprise entre avril et juin 1994 en raison des facteurs suivants :

- gain de chaleur solaire;
- absence de fenêtres ouvrantes au dernier étage;
- circuit de chauffage en fonction à des moments où la chaleur n'était pas requise;
- récupération de la chaleur par le VRC par temps chaud.

L'ajout d'une soupape d'arrêt électrique sur la boucle de l'installation de chauffage et d'une pellicule opaque sur les lanterneaux sud ainsi que la mise hors service du VRC ont permis d'éliminer la surchauffe signalée par les premiers occupants. Le deuxième groupe d'occupants n'a observé aucune surchauffe (et a enlevé la pellicule couvrant les lanterneaux), sauf que l'attique devenait excessivement chaud par moments.

De août 1994 à avril 1995, les températures du séjour oscillaient habituellement entre 22 °C et 26 °C en été et entre 20 °C et 24 °C en hiver. La chambre principale située au rez-de-chaussée était 0,6 °C plus fraîche en été et 1,9 °C plus froide en hiver.

En hiver, l'humidité relative a atteint en moyenne 40 %, variant de 15 % à 89 % (cette dernière valeur a été obtenue lorsque le VRC était hors service).

Les concentrations de dioxyde de carbone ont atteint en moyenne 485 mg/L. Des concentrations de 950 mg/L et plus n'ont été enregistrées que dans 3 % du temps (valeur maximale de 1 400 obtenue lorsque le VRC était hors service). Les concentrations de dioxyde de carbone mesurées lorsque le VRC était hors service étaient normalement de 300 à 400 mg/L plus élevées que lorsque l'appareil était en service.

Des essais de qualité de l'air intérieur menés durant une semaine ont révélé la présence de formaldéhyde, six mois avant la fin des travaux, à des concentrations d'environ 0,04 mg/L, soit une valeur inférieure à la concentration de 0,05 mg/L recommandée par Santé et Bien-être. Durant la même période, la source a émis du formaldéhyde à un rythme d'environ 9 mL/h.

Installations mécaniques :

Le système intégré de chauffage de l'eau et des locaux a fonctionné à une efficacité moyenne de 91 %. Le ventilateur de circulation utilisé pour le circuit de chauffage des locaux a consommé 211 W en continu.

Le ventilateur-récupérateur de chaleur à noyau simple et à courants croisés fonctionne avec une efficacité raisonnable de 53 % dans des conditions hivernales typiques. Consommant 115 W, le VRC a fourni un débit d'air équilibré d'environ 70 L/s.

Consommation d'eau et d'énergie :

Selon l'occupation, la consommation d'eau chaude a varié suivant une plage approximative comprise entre 87 % et 116 % de l'utilisation typique établie à environ 68 L/personne/jour en C.-B., un signe que les consommateurs doivent être sensibilisés davantage.

Selon l'occupation, la consommation totale d'eau a varié de 64 % à 117 % de la consommation prévue de 212 L/personne/jour.

L'utilisation de l'énergie électrique par le second groupe d'occupants s'est élevée à :

- appareils et éclairage intérieur : 17,0 kWh par jour en moyenne;
- ventilateur : 7,7 kWh par jour;
- utilisation d'énergie à l'extérieur : de 2,1 kWh par jour en été à 4,8 kWh par jour en hiver (à cause de l'emploi d'un radiateur électrique dans le garage durant l'hiver).

La consommation totale d'énergie s'est élevée à environ 23 500 kWh, ou 172 kWh par mètre carré de surface de plancher chauffée. Les besoins annuels de chauffage (des locaux) ont totalisé 26,1 GJ, soit 7 260 kWh.

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1 BACKGROUND

1.1 General

The Canada Mortgage and Housing Corporation (CMHC) sponsored the Healthy Housing Design Competition[1] to demonstrate to the Canadian public and housing industry that it is possible to design houses for the Canadian climate which are in keeping with the principles of sustainable development, which offer healthy indoor environments, and which remain affordable. The competition was a means to encourage innovation in products and services in the Canadian construction industry.

CMHC's vision of sustainable development includes environmental, economic and social dimensions. Under this view, a "systems approach" to housing is required, one which takes into account the global environment, the indoor environment, and afforability.

The Healthy Housing Design Competition included three categories:

- Suburban detached,
- Older home retrofit, and
- Urban infill

The Vancouver Healthy House proposal[2] was a winner in the competition in the category of urban infill housing.

Monitoring of the Vancouver Healthy House was based on a reduced version of the "Level B" approach developed for the R-2000 Program[3]. In this approach, data collection addresses issues of energy use, occupancy, ventilation and air quality, performance of mechanical systems and the building envelope, and environmental concerns. A combination of continuous, short-term and manual measurements were used to obtain the required data.

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[1] competition partially funded by the Panel for Energy Research and Development (PERD).

[2] Design proposal submitted by Habitat Design + Consulting, Greg Johnson Architecture/Engineering and Archemy Consultants.

[3] Originally, the Level B method of monitoring was used in the SERI program in the U.S. and in the NRC Solar Energy Program. Briefly, Level C monitoring consists of reading sub-meters on a monthly basis, with only minimal knowledge of what is happening inside the house; Level B monitoring typically uses a computer-based system to monitor conditions inside and outside the house, as well as to monitor energy use of various sub-systems; and Level A monitoring goes beyond Level B to monitor conditions inside various sub-systems in an attempt to understand there operation. The monitoring program used in the Vancouver Healthy House, while primarily Level B, had elements of Levels A and C as well.

1.2 Technical Requirements

The Healthy Houses had to meet specified technical requirements.[4] The following issues were considered in the Healthy House Design Competition (the underlined items were deemed essential or important in the evaluation process, while the others were desirable factors to incorporate):

1. **Occupant Health:** Indoor air quality, Water quality, and Light, sound and radiation,

2. **Energy Efficiency**: Embodied energy, Design heat loss, Heating, cooling and ventilation, Renewable energy, and Electrical consumption and Peak demand,

3. **Resource Efficiency:** Materials, Management of construction waste, Water conservation, Durability and Longevity,

4. **Environmental Responsibility**: Emissions and combustion by-products, Waste water and sewage, Community planning and Site planning issues, and Hazardous materials (landfill and disposal), and

5. **Affordability and Economic Viability**: Affordability, Viability for the construction industry, Adaptability, and Marketability.

A HOT-2000 energy performance simulation was a requirement, however there was no specific energy target. For reference, the NRCan Advanced Houses are targeted to use between 30 and 70 kWh/m2 of total energy consumption per year whereas houses built to the 1975 National Building Code of Canada are using approximately 200 to 300 kWh/m2 per year.

The monitoring discussed here was primarily concerned with item 1 - Indoor air quality, item 2 - all aspects of operating energy use and item 3 - water conservation.

[4] *"CMHC's Healthy Housing Design Competition Guide and Technical Requirements"*, CMHC., 1991

2 MONITORING OBJECTIVES

CMHC required that the monitoring be able to:

- determine the energy use (utilities, outside, space and water heating) over a full year
- determine the outdoor environment
- determine the indoor environment - temperature, relative humidity and carbon dioxide concentration on a continuous basis; other pollutants with spot measurements
- determine a breakdown of water use (monthly)

3 METHODOLOGY

3.1 Defining the Monitoring Program

The basis of Level B monitoring is to measure house parameters in sufficient detail so as to derive a heat balance for the house such that all losses and all energy inputs are characterized.

Analysis of the heat load for a house includes calculating heat losses associated with above grade components (ceilings, walls, windows), below grade components (floor slab), infiltration and mechanical ventilation. Space heating gains are made up of three principal components - free heat generated from appliances and occupants, passive solar gains, and purchased space heat.

The space heating consumption for this house was put into context with respect to other loads in the house, including domestic hot water energy consumption, and base electric energy consumption (lights and appliances). The performance of two specific sub-systems, the domestic hot water and ventilation systems, were also examined.

The indoor air quality performance of this house was examined through analysis of over one year's worth of data with respect to indoor temperatures, relative humidity and carbon dioxide concentration. In addition, two one week tests determined levels of formaldehyde, volatile organic compounds and particulates.

The CMHC monitoring program objectives required that the following be determined, on an hourly basis:

- outdoor operating conditions
  - temperature
  - horizontal insolation
- indoor operating conditions
  - temperatures
  - relative humidity

- carbon dioxide concentration
- energy use over a one year period, broken down by end use (space heating, water heating, utilities) - demand and supply
- peak power use

Monthly values of the following were required:

- outside electrical energy use,
- water use, broken down, hot and cold, and by end use:
  - bathrooms
  - kitchen
  - laundry
  - outdoor

In addition, spot values were required for the following:

- indoor air quality -
  - formaldehyde
  - volatile organic compounds (total)
  - radon
  - particulates
- air-change rate (concurrent with indoor air quality test)
- fan depressurization air-tightness test

3.2 Detailing the Monitoring Program

The monitoring program was comprised of three components:

- analysis,
- monitoring system design, and
- sensor, software and equipment.

3.2.1 Analysis

The analysis software was developed, using Microsoft Excel (version 5.0) linked spreadsheets. All of the hourly data was input into this set of spreadsheets for analysis and graphing.

After checking the results and putting in comments, the results were output as monthly reports (see Appendix C). If necessary, questionable data was deleted, and meter calibration factors input as required.

The results were linked to provide the summary outputs used in this report. Monthly summaries of utilities energy use, inside temperature, outside temperatures and horizontal insolation were determined and input to HOT-2000 for a series of calibrated simulations to determine energy balances.

3.2.2 Monitoring

Data was typically collected at 60 second intervals and accumulated into hourly averages or sums. Data collected included:

- on-time of specific mechanical systems and sub-systems,
- energy consumption (electricity and natural gas),
- water flows and temperatures,
- solar radiation,
- indoor and outdoor ambient temperatures,
- relative humidity, and
- carbon dioxide concentration

3.2.3 Software and Monitoring Equipment

Two computerized data loggers[5] were set up in the house to automatically collect data from 16 sensors.

Error checking and preliminary processing were performed on the data and the results stored hourly.

The data was later analysed using Excel spreadsheet-based software.

Manual readings of the main house meters (electrical, gas and water) as well as of meters on several water-use areas were taken monthly. Total electrical, gas and hot water readings were used to check the hourly logged values.

[5] Campbell Scientific CR21 data loggers.

4 RESULTS

The results presented in this report cover the Vancouver Healthy House from the outside to inside, from general to more detailed. The report begins by describing the house and the conditions around it.

The summary tables are generally divided into A and B sections to reflect the fact that the house had two sets of occupants over the monitored period.

The summary tables and figures in this report reference summary tables in Appendix C, which in turn reference the processed hourly data.

4.1 Monitoring Status

The Vancouver Healthy House was monitored, in an occupied condition, from 12 February, 1994 through 30 April, 1995. Data is essentially complete, except for the following:

- hourly inside space conditions and hot water flow data missing from 16 May through 11 July, 1994
- hourly carbon dioxide concentrations missing from 9 August to 3 November, 1994
- hourly gas consumption missing up to 3 November, 1994 (monthly data available, however)

4.2 Description

The house has a total heated floor area of 136.7 square metres plus 32.8 square metres of garage (see Appendix A for floor plans and section).

The house has a variety of features:

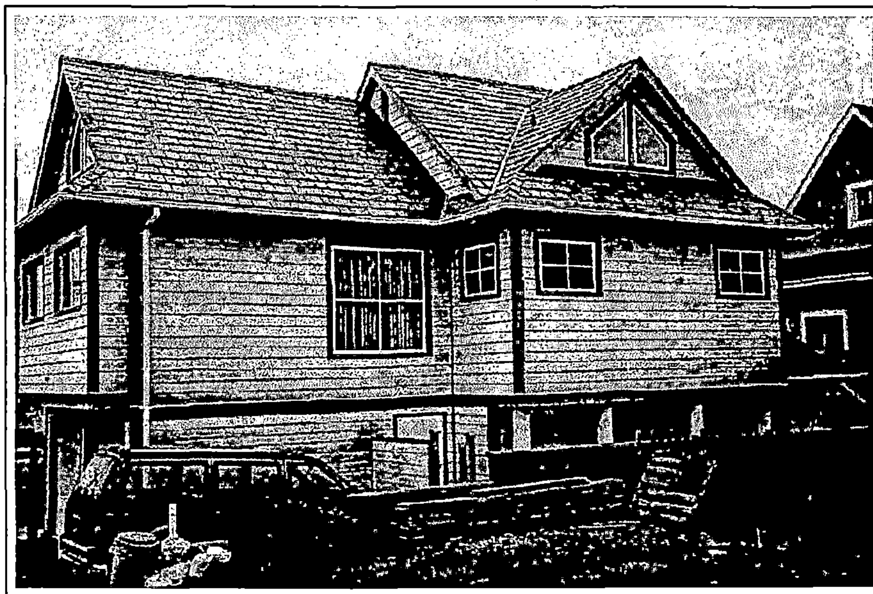
- Infill construction, to increase housing density,
- Innovative wall construction -
  - non-combustible fibre-cement lapped siding board,
  - 1x3 vertical strapping to create a rain screen cavity,
  - 38mm rigid fibreglass insulation with integral, taped, polyolefin wind barrier,
  - 2x6 advanced framing stud wall, with let-in steel cross-bracing; filled with cellulose insulation, and
  - fibre-reinforced GWB with lowtox sealer and lowtox vapour barrier paint
- "Live-in" attic open-plan roof construction -
  - non-combustible fibre-cement roof tiles,
  - building paper,
  - 2x4 strapping,
  - 337mm deep open-web joists, with blown-in RSI 7.0 cellulose insulation (50mm air space), and
  - fibre-reinforced GWB with lowtox sealer and lowtox vapour barrier paint
- Slab-on-grade construction -
  - 100mm concrete floor slab,
  - 6 mil polethylene moisture barrier,
  - 75mm high density expanded polystyrene insulation,

- 150mm crushed drain rock, and
- perimeter foundation walls with 75mm rigid fiberglass insulation to footing (for drainage and insulation).

- Windows are double-glazed, single low-E coated and argon filled with thermally broken aluminum frames.
- Improved indoor air quality through the use of low off-gassing interior finishes such as water-dispersion urethanes and low-toxicity drywall fillers, for example.
- heat recovery ventilation system to exhaust stale air and supply fresh air. Integrated, condensing natural gas, space and water heating system.

Figure 4.1 South Elevation

Figure 4.2 East elevation



The Vancouver healthy house shares its lot with the house to the right in

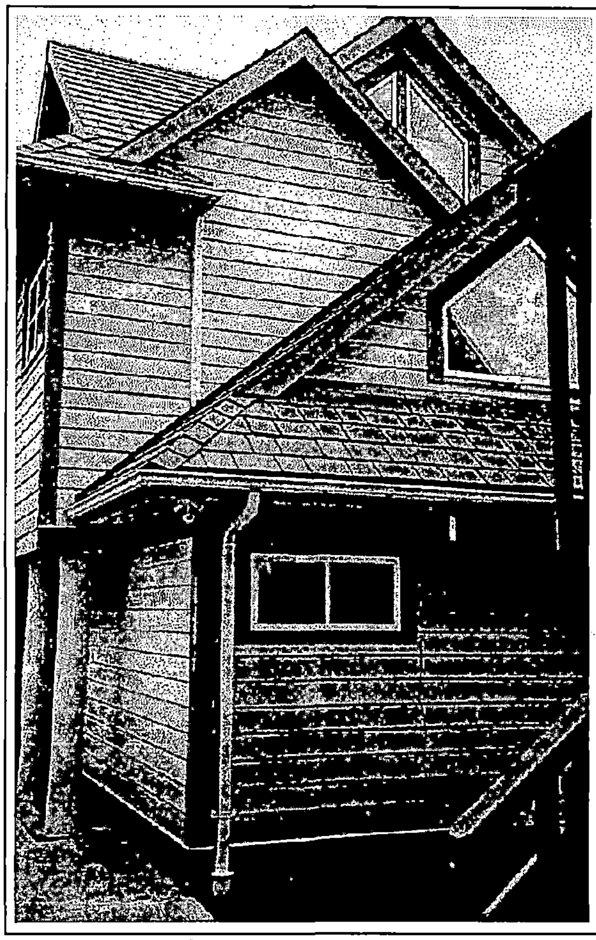
Figure 4.2 (infill housing). Table 4.1 contains some of the details regarding insulation levels and occupancy.

Table 4.1 House Description

House located in Vancouver, B.C.

Form: 2 storey, on slab		
Heated Floor Area	(m^2)	136.7
Volume	(m^3)	334
Envelope area	(m^2)	357
Insulation Levels		
Ceiling	(RSI)	8.10
Walls	(RSI)	4.40
Floor slab - perimeter	(RSI)	3.87
- centre	(RSI)	1.94
Floor over garage	(RSI)	4.64
Windows (south)	(RSI)	0.51
Air tightness at 50 Pa	(ac/h)	3.40
ELA	(cm^2)	582
NLA	(cm^2/m^2)	1.63
Window area	(m^2)	30.1
South	(m^2)	7.6
Fraction of floor area	(%)	5.6%
Shading		~30%
Occupants: adults, teens		2+
children		0
Monitoring average power	(W)	<5 (battery)

Figure 4.3 North elevation



4.3 Environment

4.3.1 Outdoor Conditions

In order to relate the monitored performance of the Vancouver Healthy House to long-term performance, the outdoor conditions for the monitored period were compared to long-term values (see Appendix B).

From February to July, 1994 (first occupants), the house site averaged 1.5C warmer than the airport. Airport temperatures for the period averaged 0.8C warmer than long-term. Degree Days at the airport totalled 1,188 (base 18C), 10% less than long-term for the same period. Site measured horizontal insolation averaged 18% less than long-term for U.B.C., while hours of bright sun at the airport averaged 4% more than long-term. Airport winds averaged 12% higher than long-term.

From August, 1994 to April, 1995 (second occupants), the house site averaged 0.8C warmer than the airport. Airport temperatures for the period averaged 0.7C warmer than long-term. Degree Days at the airport totalled 2,505 (base 18C), 7% less than long-term for the same period. Site measured horizontal insolation averaged 20% less than long-term for U.B.C., while hours of bright sun at the airport averaged 10% more than long-term. Airport winds averaged 7% higher than long-term.

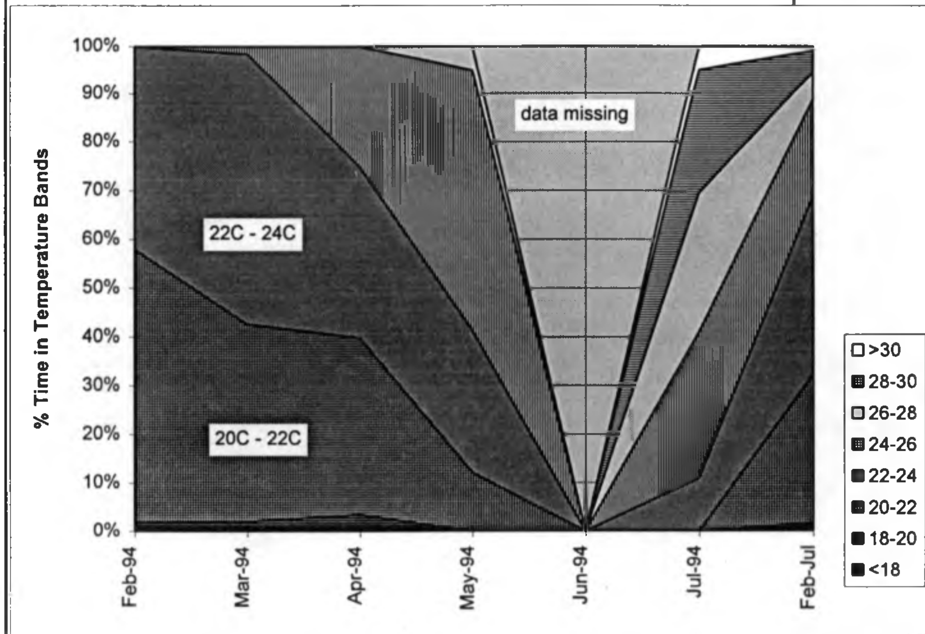
4.3.2 Indoor Temperatures

Frequency histograms (graphs and tables) are shown in the following figures for the living room and ground floor master bedroom.

They show the percentage frequency of hours within each temperature band. The tables also show the average temperature for the period as well as the extreme minimum and extreme maximum. At the bottom of each table are values that indicate the completeness of the data, as a percentage.

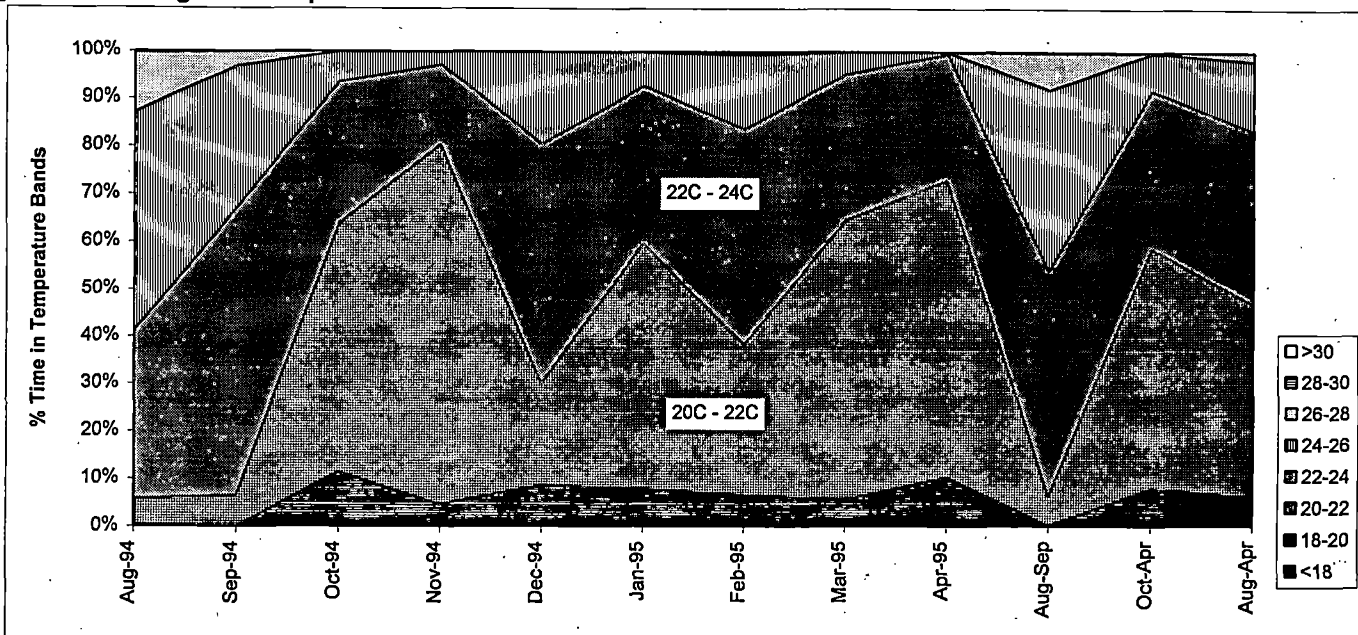
For the period from February to July, 1994, the living room temperature was between 20C and 26C for 88% of the monitored hours (data 66% complete). The ground floor master bedroom temperatures were in the same temperature range for only 58% of the hours, with temperatures between 18C and 20C for 33% of the hours. The occupants complained of overheating, due to a combination of a malfunction in the space heating controls (corrected 20 June, 1994) and solar gains through the upper level clerestory windows.

Figure 4.4A Living room temperature



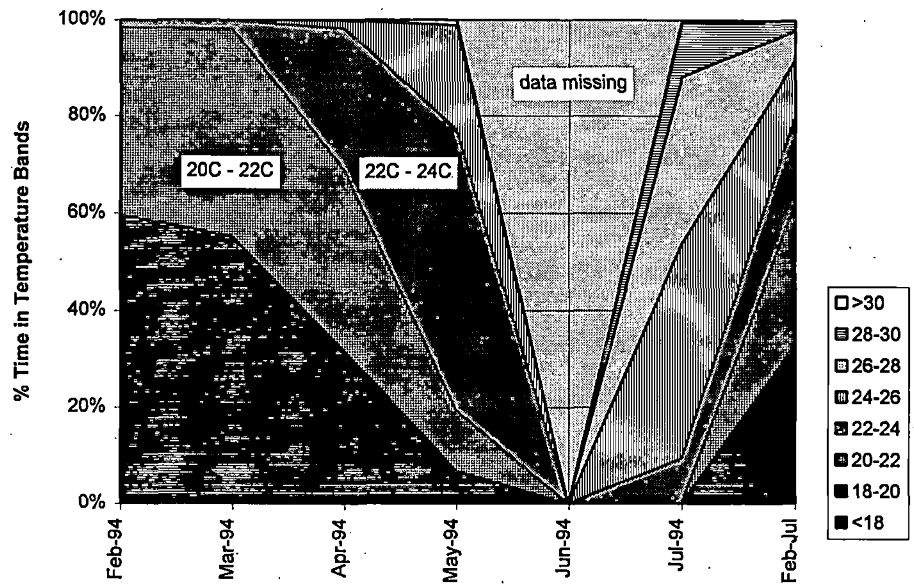
Living room temperature		Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	Feb-Jul
Maximum	C	23.8	24.3	25.8	27.0		30.9	30.9 max
Average	C	**21.8**	**22.1**	**22.6**	**24.1**		**26.7**	**23.5 avg**
Minimum	C	19.5	19.4	19.6	20.4		22.6	19.4 min
Time in temp. bands:								
<18	%	0%	0%	0%	0%		0%	0% wtd.
18-20	%	2%	2%	3%	0%		0%	2% wtd.
20-22	%	56%	41%	36%	12%		0%	31% wtd.
22-24	%	42%	56%	35%	29%		11%	37% wtd.
24-26	%	0%	2%	25%	54%		30%	20% wtd.
26-28	%	0%	0%	0%	5%		29%	6% wtd.
28-30	%	0%	0%	0%	0%		26%	5% wtd.
>30	%	0%	0%	0%	0%		5%	1% wtd.
Hours of data/month		390	742	720	363	0	490	2,705 sum
							complete:	66.3%

Figure 4.4B Living room temperature



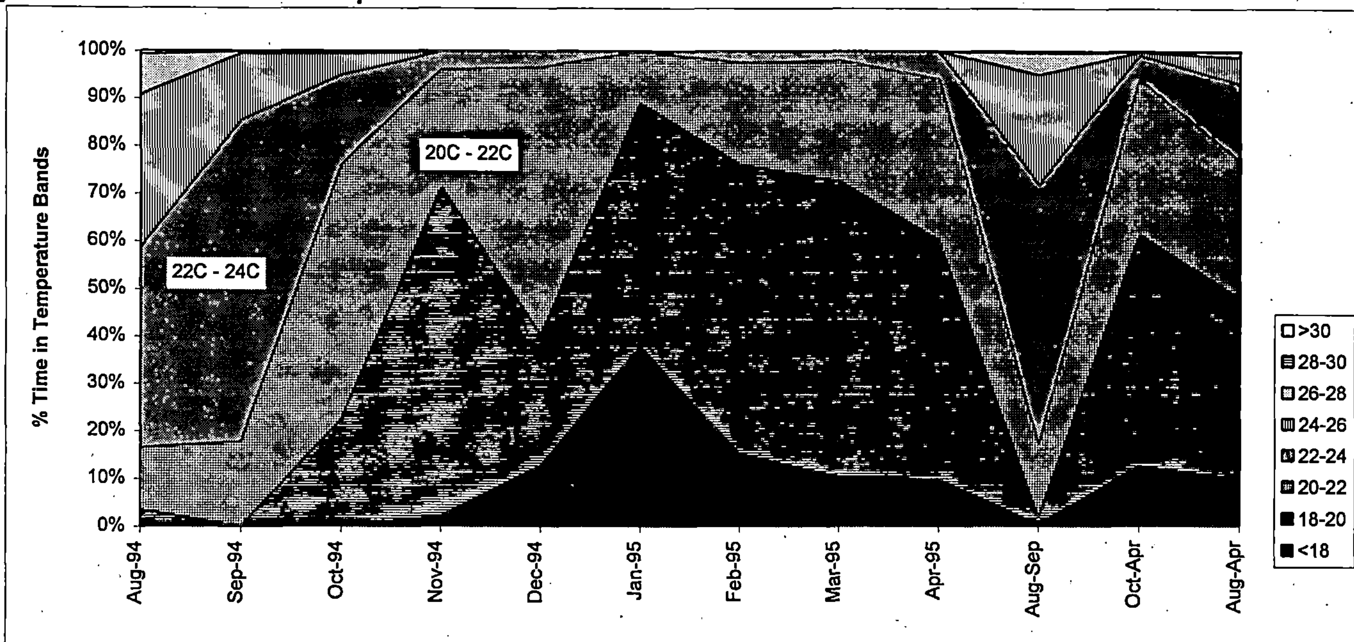
Living room temperature		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	Aug-Sep	Oct-Apr	Aug-Apr
Maximum	C	28.7	26.5	25.3	25.5	25.4	25.4	26.6	24.9	24.2	28.7	26.6	28.7 max
Average	C	**24.4**	**23.5**	**21.7**	**21.4**	**22.7**	**21.8**	**22.3**	**21.8**	**21.4**	**23.9**	**21.9**	**22.3 avg**
Minimum	C	19.9	20.3	18.7	18.5	16.1	18.0	18.6	18.6	18.9	19.9	16.1	16.1 min
Time in temp. bands:													
<18	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0% wtd.
18-20	%	0%	0%	11%	5%	8%	8%	7%	6%	10%	0%	8%	6% wtd.
20-22	%	6%	7%	52%	76%	21%	52%	32%	59%	63%	6%	51%	41% wtd.
22-24	%	35%	60%	30%	17%	51%	33%	45%	31%	27%	48%	33%	36% wtd.
24-26	%	46%	30%	6%	3%	19%	7%	16%	5%	0%	38%	8%	15% wtd.
26-28	%	13%	3%	0%	0%	0%	0%	1%	0%	0%	8%	0%	2% wtd.
28-30	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0% wtd.
>30	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0% wtd.
Hours of data/month		743	720	744	717	744	736	672	739	718	1,463	5,070	6,533 sum
										complete:	99.9%	99.6%	99.7%

Figure 4.5A Master bedroom temperature



		Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	Feb-Jul
Maximum	C	22.2	22.6	24.7	26.5		30.3	30.3 max
Average	C	**19.9**	**20.0**	**21.0**	**23.0**		**26.0**	**21.9 avg**
Minimum	C	17.9	17.7	18.1	18.9		21.7	17.7 min
Time in temp. bands:								
<18	%	0%	1%	0%	0%		0%	0% wtd.
18-20	%	59%	55%	32%	7%		0%	33% wtd.
20-22	%	39%	43%	37%	12%		0%	29% wtd.
22-24	%	2%	2%	29%	58%		9%	18% wtd.
24-26	%	0%	0%	2%	22%		44%	11% wtd.
26-28	%	0%	0%	0%	1%		34%	6% wtd.
28-30	%	0%	0%	0%	0%		11%	2% wtd.
>30	%	0%	0%	0%	0%		0%	0% wtd.
Hours of data/month		390	743	720	363	0	489	2,705 sum
							complete:	66.3%

Figure 4.5B Master bedroom temperature



		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	Aug-Sep	Oct-Apr	Aug-Apr
Maximum	C	28.8	26.6	26.6	23.9	23.3	21.9	23.4	23.0	24.0	28.8	26.6	28.8 max
Average	C	**23.6**	**22.9**	**21.1**	**19.7**	**20.0**	**18.3**	**19.3**	**19.4**	**19.7**	**23.3**	**19.6**	**20.4 avg**
Minimum	C	17.0	20.5	17.5	17.3	15.6	14.2	16.3	16.3	16.7	17.0	14.2	14.2 min
Time in temp. bands:													
<18	%	1%	0%	0%	2%	13%	38%	15%	10%	10%	0%	13%	10% wtd.
18-20	%	3%	0%	22%	69%	28%	51%	61%	62%	50%	2%	49%	38% wtd.
20-22	%	13%	18%	54%	25%	56%	11%	22%	26%	34%	15%	33%	29% wtd.
22-24	%	42%	68%	19%	4%	3%	0%	2%	2%	6%	55%	5%	16% wtd.
24-26	%	32%	14%	5%	0%	0%	0%	0%	0%	0%	23%	1%	6% wtd.
26-28	%	9%	0%	1%	0%	0%	0%	0%	0%	0%	5%	0%	1% wtd.
28-30	%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0% wtd.
>30	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0% wtd.
Hours of data/month		743	720	744	717	741	741	672	739	718	1,463	5,072	6,535 sum
										complete:	99.9%	99.7%	99.7%

For the period from August, 1994 to April, 1995, the living room temperature was between 20C and 24C for 77% of the monitored hours (data 99.7% complete). The ground floor master bedroom temperatures were in the same temperature range for only 45% of the hours, with temperatures between 18C and 20C for 38% of the hours.

4.3.3 Indoor Relative Humidity

For the period from February to July, 1994, the HRV exhaust relative humidity (collecting from kitchen and bathrooms) averaged 40%, ranging from a low hourly value of 18% to a high of 56% (the latter with the HRV off to reduce overheating).

For the period from August, 1994 to April, 1995, relative humidities averaged 43% (52% in summer and 40% in winter), ranging from a low of 15% to a high of 89%,[6] (the latter with the HRV off). Turning the HRV on resulted in a decrease in average relative humidity from about 50% to 35%.

4.3.4 Indoor Air Quality

For the period from February to July, 1994, carbon dioxide concentration in the master bedroom averaged 452ppm, with concentrations in the range from 350ppm to 650ppm for 86% of the monitored hours (data 66% complete). In July, concentrations were over 950ppm for 1% of the hours - with a maximum of 1,400ppm (HRV off).

For the period from August, 1994 to April, 1995, carbon dioxide concentration in the master bedroom averaged 485ppm, with concentrations in the range from 350ppm to 650ppm for 68% of the monitored hours (data 74% complete). In November, with the HRV off, concentrations were over 950ppm for 27% of the hours - with a maximum of 1,407ppm. Turning on the HRV resulted in a decrease in carbon dioxide concentration of approximately 300 to 400 ppm (average and maximum).

No consistent correlation between carbon dioxide concentration and bedroom door open or closed was found, however we were not monitoring whether the room was occupied or not.

One week tests for indoor air quality were performed - one test in December, 1994/January, 1995 prior to occupancy and one post-occupancy. The results shown in Table 4.2 are from an ORTECH report[7]. Perfluorocarbon tests were also performed in order to determine overall air change rates during the tests.

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[6] Note that the relative humidities are for the HRV exhaust and are not necessarily representative of the whole house.

[7] *"Indoor Air Quality Monitoring Results - Vancouver Healthy Home"*, by Peter Piersol, ORTECH Corporation for SAR engineering ltd.. 31 March, 1994

Overall formaldehyde source strengths were determined from the following relationship:

$$S = C \times V \times ac$$

S = source strength (mL/h)
C = pollutant concentration (ppm)
V = house volume (m^3)
ac = PFT determined air change rate (h^{-1})

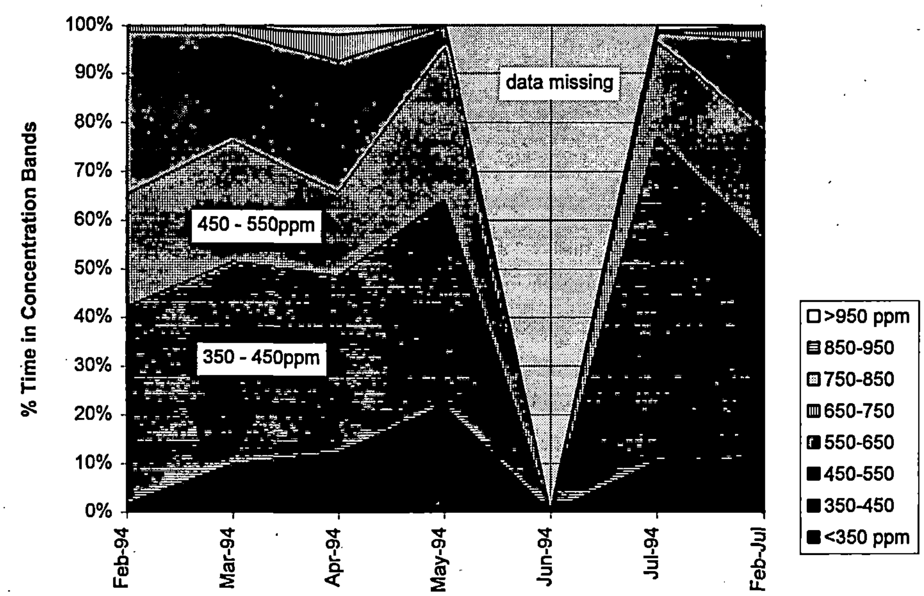
The January, 1994 formaldehyde whole house source strength of 9 mL/hr equals the average for the NRCan Advanced houses[8] (ranging from 2 to 21 mL/hr) for approximately the same time after construction. Both tests were well below the health & welfare goals of 0.05 ppm.

Table 4.2 Indoor Air Quality Test Results

		Units	Test period 27-Dec-93 to 3-Jan-94	Test period 11 May-95 to 21-May-95
Test Conditions	Occupants		Unoccupied	~3
	Outside temperature	C	2.0	~14
	Living room temp.	C	21.2	~21
	Master bedroom temp.	C	17.8	~21
	Relative humidity	%	31	
CONCENTRATIONS:				
TVOC	living room	mg/m3	0.57	
Formaldehyde	master bdrm	ppm	0.04	0.02
	living room	ppm	0.04	0.02
Xylenes	living room	mg/m^3	0.04	
Benzene	living room	mg/m^3	0.01	
Aliphatic Hydrocarbons	living room	mg/m^3	0.52	
Radon	living room	mWL	1	
Particulates	living room	ug/m^3	<10	
AIR CHANGE RATE:				
Volume		m^3	334	334
Total Air change rate	(PFT)	ac/h	0.69	1.61
SOURCE STRENGTH:				
Formaldehyde	master bedroom	mL/h	8.8	10.8
	living room	mL/h	9.2	10.8
Average		mL/h	9.0	10.8

[8] Note, however, that the NRCan Advanced houses were about twice the size of the Vancouver Healthy House, therefore the latter should have had a lower whole house source strength (for comparable construction).

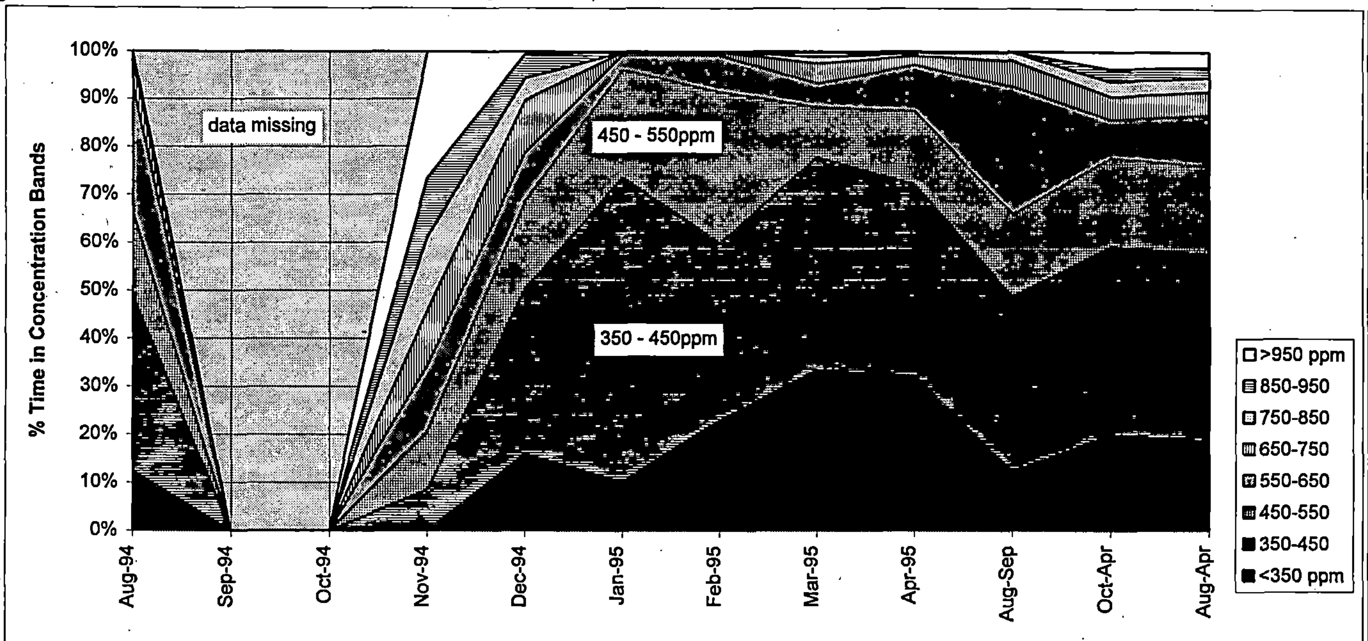
Figure 4.6A Master bedroom CO2 concentration



		Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	Feb-Jul	
Maximum	ppm	694	716	812	608		1,400	1,400	max
Average	ppm	**483**	**461**	**482**	**418**		**418**	**452**	**avg**
Minimum	ppm	346	325	317	310		330	310	min
Time in conc. bands:									
<350 ppm	%	2%	10%	12%	22%		10%	11%	wtd.
350-450	%	41%	42%	36%	42%		67%	45%	wtd.
450-550	%	23%	25%	17%	31%		19%	22%	wtd.
550-650	%	33%	22%	27%	5%		2%	19%	wtd.
650-750	%	1%	1%	6%	0%		0%	2%	wtd.
750-850	%	0%	0%	2%	0%		0%	1%	wtd.
850-950	%	0%	0%	0%	0%		0%	0%	wtd.
>950 ppm	%	0%	0%	0%	0%		1%	0%	wtd.
Hours of data/month		390	743	720	363	0	485	2,701	sum
							complete:	66.2%	
Relative Humidity (HRV exhaust)									
Maximum	%	41%	44%	56%	56%		56%	56%	max
Average	%	**34%**	**37%**	**42%**	**39%**		**45%**	**40%**	**avg**
Minimum	%	18%	27%	35%	26%		40%	18%	min

HRV on >>>>>>>>>>>>>>> | HRV off >>>>>>>>>>>>>>

Figure 4.6B Master bedroom CO2 concentration



		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	Aug-Sep	Oct-Apr	Aug-Apr	
Maximum	ppm	721			1,407	1,009	693	737	1,029	855	721	1,407	1,407	max
Average	ppm	**441**			**781**	**504**	**420**	**427**	**412**	**411**	**441**	**492**	**485**	**avg**
Minimum	ppm	318			351	289	306	282	281	258	318	258	258	min
Time in conc. bands:														
<350	%	12%			0%	16%	10%	23%	33%	32%	12%	20%	19%	wtd.
350-450	%	36%			8%	34%	63%	37%	44%	40%	36%	39%	39%	wtd.
450-550	%	17%			12%	18%	23%	32%	11%	15%	17%	18%	18%	wtd.
550-650	%	27%			14%	10%	3%	8%	5%	10%	27%	8%	11%	wtd.
650-750	%	6%			11%	11%	1%	1%	4%	2%	6%	5%	5%	wtd.
750-850	%	2%			15%	5%	0%	0%	1%	1%	2%	3%	3%	wtd.
850-950	%	0%			12%	5%	0%	0%	1%	0%	0%	3%	2%	wtd.
>950	%	0%			27%	1%	0%	0%	0%	0%	0%	4%	3%	wtd.
Hours of data/month		719	0	0	542	744	742	669	739	718	719	4,154	4,873	sum
										complete:	49.1%	81.6%	74.4%	

Relative Humidity (HRV exhaust)

		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	Aug-Sep	Oct-Apr	Aug-Apr	
Maximum	%	62%	65%	77%	89%	86%	64%	57%	50%	48%	65%	89%	89%	max
Average	%	**50%**	**54%**	**49%**	**53%**	**37%**	**35%**	**37%**	**34%**	**37%**	**52%**	**40%**	**43%**	**avg**
Minimum	%	38%	39%	28%	30%	20%	17%	15%	19%	24%	38%	15%	15%	min

HRV off >>>>>>>>>>>>>>>>>>>>>> | HRV on from Dec. 4 >>>>>>>>>>>>>>>>>>>

4.4 Mechanical Systems

A condensing gas water heater provided both domestic hot water and space heat (the latter through a fan-coil unit).

4.4.1 Domestic Water Heating

Monthly space and water heating system efficiency averaged about 91% over the period from September, 1994 to April, 1995 (see Table 4.3B).

Hot water use for the first set of occupants averaged 118 L/day from February to April of 1994 - about 13% less than is typical for B.C. (about 68 L/person/day[9]). With the arrival of a baby in early May, hot water use increased to an average of about 210 L/day (May to July - including a two week absence for holidays) - about average for a family of three. Hot water temperature averaged 46C. Hot water averaged 49% of total water use (see Table 4.4A).

Hot water use for the second set of occupants averaged 315 L/day for the period from August, 1994 to April, 1995. Even with four occupants (number varied from two to four), this would be 16% greater than is typical for B.C.. Hot water temperature was increased from 46C to 56C in October, 1994 (occupants complained there was insufficient hot water at the lower set point). Hot water averaged 42% of total water use (see Table 4.4B).

4.4.2 Heat Recovery Ventilation

A spot measurement of air flow[10] and fan power in December, 1994 showed a balanced flow of approximately 70 L/s with a fan power of 115W (0.91 power factor). A second power reading, in March, 1995, of 104W (0.91 power factor) showed good agreement.

The first set of occupants turned the HRV off in May, 1994 to reduce overheating (solar gains and malfunctioning heating system).

The HRV sensible efficiency averaged 53% for a period in January with typical winter conditions[11] (see Appendix C, Figure C12.5) - fairly typical for a single core, cross-flow unit.

4.4.3 Space Conditioning

The first set of occupants reported overheating, in part due to the fact that hot water was circulating through the space heating fan-coil unit, even when no heat was required. An electric valve in the space heating supply line, installed in June, 1994, eliminated this problem.

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[9] B.C. Hydro

[10] Obtained with a flow traverse, using a hot-wire anemometer

[11] For the period from January 6th to 10th, 1995: Average outside temperature was 5.1C - equal to the average temperature for November, 1994 to January, 1995.

Winter heating system efficiency averaged 91% (space and water heating)[12]. This equals the 91% efficiency from CANMET tests on a similar heating system[13].

4.5 Power and Energy Use

4.5.1 Peak Power

Peak electrical power for the period from August, 1994 to April, 1995 was 6.3 kW (in January) - with monthly peak values ranging to as low as 4.2 kW in March.

4.5.2 Energy Use Breakdown

Electrical energy use for the period from February to July, 1994 averaged 18.5 kWh/day inside and 1.1 kWh/day outside.

Electrical energy use for the summer period from August to September, 1994 averaged 22.1 kWh/day inside and 2.1 kWh/day outside. For the winter period from October, 1994 to April, 1995, inside electrical use averaged 24.0 kWh/day and outside use was 4.8 kWh/day. The high outside use was due to the operation of an electrical baseboard heater in the garage.

The continuously operating furnace fan consumed about 5.1 kWh/day and the HRV fans about 2.6 kWh/day. Excluding fans, inside electrical energy use averaged **17.0 kWh/day**[14] from August, 1994 to April, 1995.

During the period from August, 1994 to April, 1995, gas energy supply averaged 1,341 kWh/month for space and water heating. If the **August - September period is assumed to be typical of summer consumption** (536 kWh/month), then annual consumption would amount to 13,677 kWh (**49.2 GJ**) for space and water heating.

Measured **space heating demand**[15] averaged 111 kWh/month for August and September, and 959 kWh/month for the winter period from October to April - amounting to an annual total of approximately 7,268 kWh (26.1 GJ) or 53 kWh per square metre of heated floor area.

Measured **water heating demand**[16] averaged 388 kWh/month for August and September, and 468 kWh/month for the winter period from October to April - amounting to an annual total of approximately 5,216 kWh (18.8 GJ).

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[12] Efficiency determined from total of domestic water heating and space heating demands, divided by gas energy fuel equivalent.

[13] *"Performance Testing of Integrated Space/Water Heating System in the INNOVA Advanced House - Ottawa"*, by A. Hayden et al. Note that the efficiency they quote includes electrical energy for igniter, controls and induction fan.

[14] Seven R-2000 houses used 25.7 kWh/day, *"R-2000 Monitoring Program Data Processing Results"* by K. Cooper.

[15] Space heating demand was determined from water flow (one-time measurement of 7.7 gallons/minute, or 35 L/minute times measured on-time) times temperature difference across fan-coil.

[16] Water heating demand was determined from continuously monitored water flow times temperature increase.

Table 4.3A Energy and Power

		Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	TOTAL Feb-Jul
Electric power:								
Maximum	kW		6.4	6.1	5.5		0.5	6.4 max
Average	kW		1.1	0.9	0.6		0.1	**0.7 avg**
Minimum	kW		0.0	0.0	0.0		0.0	0.0 min
Electric energy:								
Inside	kWh	549	628	512	564	565	565	564 avg
Outdoor	kWh		58	31	16	17	40	32 avg
Total	kWh		686	542	580	582	605	599 avg
Utilities	kWh/d		12.6	9.4	13.1	13.7	13.1	12.4 avg
Fans	kWh/d		7.7	7.7	5.1	5.1	5.1	6.1 avg
Inside total	kWh/d		20.3	17.1	18.2	18.8	18.2	18.5 avg
Outside	kWh/d		1.9	1.0	0.5	0.6	1.3	1.1 avg
Total	kWh/d		22.1	18.1	18.7	19.4	19.5	19.6 avg
Gas energy:								
Supply	kWh	1,323	705	505	964	225	218	657 avg

Notes: Electric power, space & water heat demand values are from data acquisition system - pro-rated to cover any missing data. Electric and gas energy supply values are from manual meter readings - pro-rated to cover calendar months

Table 4.4A Water Use

		Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	TOTAL Feb-Jul	
Cold water -									
OUTSIDE	L/d	0	0	7	0	0	0	1.3 avg	
Upstairs bath	L/d	20	33	27	44	20	66	35 avg	
Dwnstairs bath	L/d	66	63	67	65	43	100	68 avg	
Kitchen	L/d	7	10	10	18	17	32	16 avg	
Laundry	L/d	44	35	51	56	51	81	53 avg	
TOTAL COLD	L/d	137	140	162	184	132	280	173 avg	
Hot water -									
Upstairs bath	L/d	2	1	1	8	1	10	3.8 avg	
Dwnstairs bath	L/d	86	73	63	143	47	122	89.3 avg	
Kitchen	L/d	41	34	26	115	68	57	56.8 avg	
Laundry	L/d	9	10	9	19	9	30	14.3 avg	
TOTAL HOT	L/d	138	118	99	285	125	219	164.1 avg	
hot / total water	%	50%	46%	38%	61%	49%	44%	49% avg	
Dishwasher	L/d	12.8	11.1	9.1	10.3	4.7	6.4	9.1 avg	
% of kitchen hot water		31%	33%	35%	9%	7%	11%	16%	
Total water -									Predicted
Outside	L/d	0	0	7	0	0	0	1.3	1.2
Bathroom	L/d	175	170	158	261	112	299	196	206
Kitchen	L/d	48	44	36	134	85	90	73	146
Laundry	L/d	52	44	59	75	61	111	67	71
TOTAL	L/d	276	258	261	470	257	499	337	423
		couple moved in 12-Feb-94			baby arrived				

Table 4.3B Energy and Power

		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	SUMMER Aug-Sep	WINTER Oct-Apr	TOTAL Aug-Apr
Electric power:													
Maximum	kW	5.8	5.2	6.2	4.9	5.9	6.3	5.9	4.2	4.5	5.8	6.3	6.3 max
Average	kW	1.0	1.1	1.1	0.9	1.4	1.5	1.2	1.2	1.1	**1.0**	**1.2**	**1.2 avg**
Minimum	kW	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0 min
Electric energy:													
Inside	kWh	658	690	746	631	927	778	623	590	787	674	726	715 avg
Outside	kWh	57	70	54	36	218	250	234	222	4	63	145	127 avg
Total	kWh	715	760	800	667	1145	1028	857	812	791	738	871	842 avg
Utilities	kWh/d	16.1	17.9	18.9	15.9	22.2	17.4	14.6	11.3	18.5	**17.0**	**17.0**	**17.0 avg**
Fans	kWh/d	5.1	5.1	5.1	5.1	7.7	7.7	7.7	7.7	7.7	**5.1**	**7.0**	**6.5 avg**
Inside total	kWh/d	21.2	23.0	24.0	21.0	29.9	25.1	22.3	19.0	26.2	**22.1**	**23.9**	**23.5 avg**
Outside	kWh/d	1.8	2.3	1.7	1.2	7.0	8.1	8.3	7.2	0.1	**2.1**	**4.8**	**4.2 avg**
Total	kWh/d	23.1	25.3	25.8	22.2	36.9	33.2	30.6	26.2	26.4	**24.2**	**28.8**	**27.7 avg**
Gas energy:													
Supply	kWh	352	720	1,454	1,753	2,279	1,776	1,771	1,190	771	**536**	**1,571**	**1,341 avg**
Demand -													
Space heat	kWh	0	221	970	904	1563	1183	1026	767	299	**111**	**959**	**770 avg**
Water heat	kWh	354	421	441	482	447	483	480	494	452	**388**	**468**	**450 avg**
TOTAL	kWh	354	642	1411	1386	2009	1666	1506	1260	751	**498**	**1,427**	**1,221 avg**
Efficiency	%		87%	97%	83%	90%	87%	87%	88%	95%		91%	91% avg

Notes: Electric power, space & water heat demand values are from data acquisition system - pro-rated to cover any missing data
Electric and gas energy supply values are from manual meter readings - pro-rated to cover calendar months
Heating efficiencies are based on data acquisition system based gas supply and demand
High values of outside energy use from December to March due to electric space heater in garage

Table 4.4B Water Use

		Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	SUMMER Aug-Sep	WINTER Oct-Apr	TOTAL Aug-Apr	Predicted
Cold water -														
OUTSIDE	L/d	0	0	0	0	0	0	0	0	0	0	0	0 avg	
Upstairs bath	L/d	144	196	162	104	125	160	126	111	273	170	152	156 avg	
Dwnstairs bath	L/d	128	167	131	164	151	127	145	143	138	148	143	144 avg	
Kitchen	L/d	44	50	51	45	53	62	71	73	77	47	62	58 avg	
Laundry	L/d	77	129	92	114	47	13	45	46	62	103	60	69 avg	
TOTAL COLD	L/d	394	542	437	427	376	362	387	373	550	468	416	428 avg	
Hot water -														
Upstairs bath	L/d	32	49	32	17	20	39	31	23	38	41	28	31 avg	
Dwnstairs bath	L/d	198	216	167	169	166	147	169	146	188	207	165	174 avg	
Kitchen	L/d	74	49	96	71	59	78	91	89	89	62	82	78 avg	
Laundry	L/d	54	26	45	38	36	24	32	14	26	40	31	33 avg	
TOTAL HOT	L/d	358	340	339	296	281	288	323	273	341	349	306	315 avg	
% hot water	%	48%	39%	44%	41%	43%	44%	46%	42%	38%	43%	42%	42% avg	
Dishwasher	L/d	12.4	7.3	16.1	10.0	6.2	1.8	0.0	0.0	1.6	9.9	5.1	6.2 avg	
% of kitchen hot water		17%	15%	17%	14%	11%	2%	0%	0%	2%	16%	6%	8% avg	
Total water -														
Outside	L/d	0	0	0	0	0	0	0	0	0	0	0	0	1.2
Bathroom	L/d	503	627	492	455	462	473	471	423	637	565	487	505	206
Kitchen	L/d	118	100	148	116	112	140	162	163	166	109	144	136	146
Laundry	L/d	131	155	137	152	84	37	77	60	88	143	91	102	71
TOTAL	L/d	752	882	776	723	657	650	710	646	891	817	722	743	423

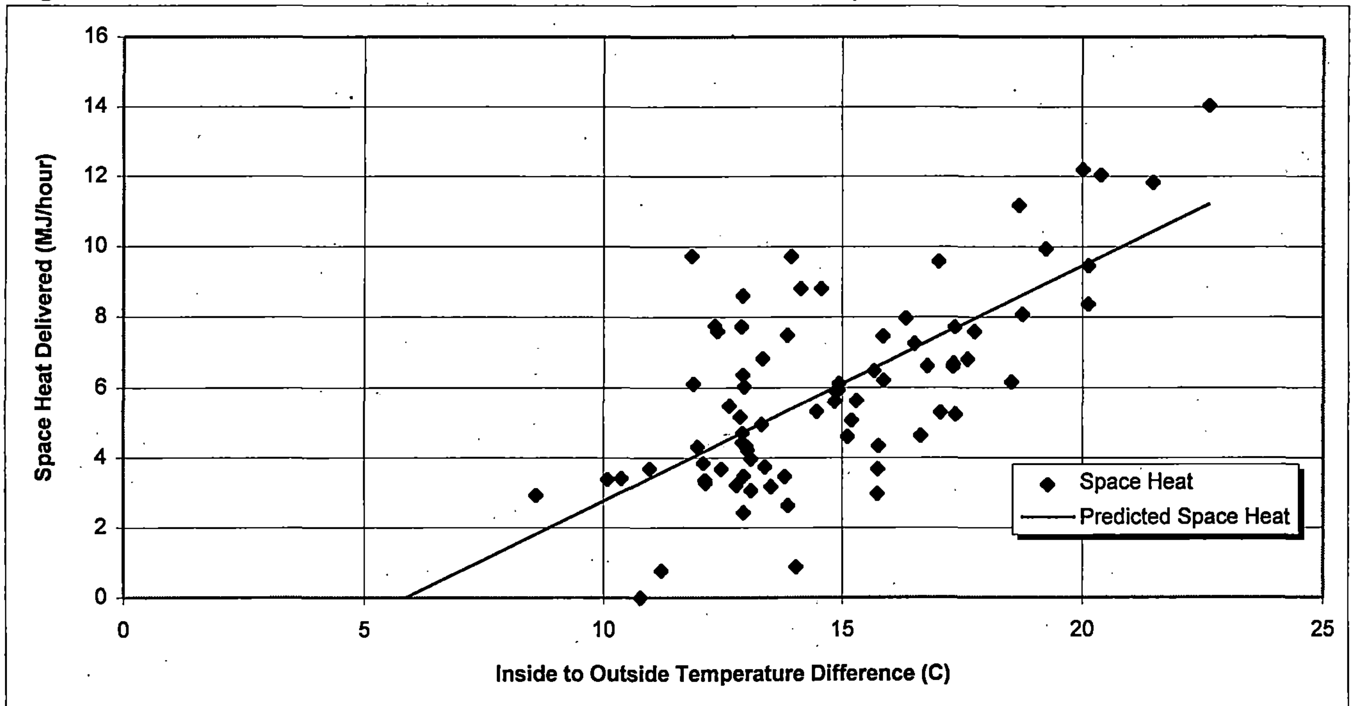
Two adults moved in (typically 2 to 4 occupants)
1-Aug-95

4.5.3 Heat Loss Coefficient and Balance Point Temperature

A linear regression of space heat delivered versus inside to outside temperature difference, for days with insolation less than 3 MJ/m^2.day, had a slope, or Heat Loss Coefficient of about 186 W/C.

The zero space heat requirement intercept occurred at 5.9C temperature difference. The average inside temperature was 20.7C for the period, so the balance point temperature is 14.8C for days with low solar input. This equals an average usable internal gains (utilities, people and minimal solar) for the period of 1092W (utilities alone averaged 1025W)

Figure 4.7 Heat Loss Coefficient and Balance Point Temperature



For the period from 4 November, 1994 to 28 February, 1995:							90% confidence limits	
Conditions:		Minimum	Maximum	**Results:**			Lower	Upper
Outside temperature	5.3 C average			Heat loss coefficient	**186**	**W/C**	148	224
Inside temperature	20.7 C average			Balance point temp.	**14.8**	**C**		
Temperature difference	14.8 C average	8.6	22.6	'Free heat'	5.9	C		
Occupants	2 to 4				26.2	kWh/day		
Utilities	24.6 kWh/day				1,092	W average		
	1,025 W average	0	6,307					
Criteria:				Sample	77	days		
Horizontal Insolation	< 3.0 MJ/m^2day	(cloudy days)		Regression coeff. (r^2)	0.47			

Notes: The heat loss coefficient shown here is an **equivalent heat loss to air**, but incorporates the total losses and gains - including losses through the floor slab to ground.

The relatively high scatter in the data (low regression coefficient) means that the resulting heat loss coefficient is in the range from 148 W/C to 224 W/C with 90% confidence. Some of the scatter is due to the variability of internal heat gains from utilities - average of 1,025W, but varying from 0 W to 6,307 W, on an hourly basis.

4.5.4 Energy Use Comparisons

Annual space heating demand[17], calculated from flow times temperature difference, was approximately 26.1GJ, or 53 kWh per square metre of heated floor area (section 4.5.2). A HOT-2000 run predicted 20.2 GJ using long-term Vancouver weather and 18.8 GJ using measured on-site weather[18]. Note that HOT-2000 predicted 7.7 GJ of useful solar contribution - with no allowance for the estimated 30% solar shading.

From Table 4.3B, if the August-September, 1994 period is assumed typical of summer electrical use, total annual electrical use amounts to 9,800 kWh. Annual total gas energy supplied was about 13,700 kWh for water and space heating. Total energy consumed therefore amounted to about 23,500 kWh[19] or 172 kWh per square metre of floor area.

4.6 Water Use

Predicted total water use was 423 L/day for two adult occupants[20], or 212 L/person/day. Actual water use was quite variable, depending on the occupants.

With the first occupants, total water use for the couple averaged 265 L/day (February to April), or 132 L/person/day, but increased to 409 L/day with the arrival of their baby, or 136 L/person/day - both about 36% less than originally predicted.

The second set of occupants (two to four adults), used a total of 743 L/day of water. Assuming an average of three adult occupants, this would amount to 248 L/person/day, or about 17% more than predicted. Kitchen water use was slightly less than predicted, laundry water use somewhat more than predicted, and bathroom water use over twice predicted (Table 4.4B).

In order to purge the fresh water in the fire extinguisher system's pipes, it was connected to the downstairs toilet. Work on the fire extinguishing system in October, 1994 resulted in the toilet being connected to full mains pressure (before the house pressure reducer). The resulting high pressure into the toilet caused it to leak continuously, at a rate of of about 1,000 L/day - more than the water use for the entire household. The situation was finally corrected in February, 1995.

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[17] Measured for the winter period October to April, but extrapolating August-September results to the May to September period (the prediction showed no space heating demand for the period from May to September, while the extrapolated measurements showed 2.0 GJ)

[18] Note that on-site outside temperatures were measured with a shielded thermistor under the north eave of the house. This measurement does not meet AES standards as there may have been some warming of the air next to the house. Therefore, predicted energy use could be somewhat higher than indicated if AES standard temperatures had been used - this would require a Stephenson screen located some distance from the house (not feasible in the built-up environment of the healthy house).

[19] HOT-2000 predicted a total energy requirement (utilities, outside, space and water heating) of 23,475 kWh per year.

[20] *"Healthy Housing Project Final Report"* by C. Mattock, G. Johnson, and D. Rousseau, for CMHC, 6 January, 1994

5 CONCLUSIONS and RECOMMENDATIONS

The CMHC Vancouver Healthy House demonstrates several important features:

- the viability of building compact, infill housing in an urban environment,
- the use of low emission materials to create a healthy indoor air environment,
- the use of low-flow faucets, and low water use appliances to make it **possible to reduce** overall and hot water usage,
- energy efficient envelope,
- energy efficient heating system.

Some design aspects were not as succesful:

- the lack of any opening windows on the third floor (loft), contributed to overheating,
- the lack of an easily implemented, purely ventilation mode of operation (without heat recovery), contributed to overheating and also resulted in the HRV being left off during the fall (non heat recovery mode is implemented by replacing the core of the unit). Note that this is a common fault in HRV equipped houses,
- the lack of an electric valve in the space heating loop contributed to overheating in the spring of 1994.

The integrated space and water heating system operated with an average natural gas to delivered heat conversion efficiency of 91%. The space heating circulation fan used a continuous 211W with a 0.97 power factor.

The single core, cross-flow, heat recovery ventilator operated with a sensible core efficiency of 53%. The HRV used 115W with a 0.91 power factor, while delivering approximately 70 L/s balanced air flow.

Depending on occupancy, hot water usage varied from approximately 87% to 116% of typical usage of about 68 L/person/day in B.C., pointing to the need for more consumer education.

Depending on the occupancy, total water usage varied from 64% to 117% of the predicted 212 L/person/day.

Electrical energy use by the second set of occupants amounted to:

- utilities (appliances, indoor lighting) averaged 17.0 kWh per day,
- fan energy use was 7.7 kWh per day,
- outdoor energy use varied from 2.1 kWh per day in the summer to 4.8 KWh per day in winter - the latter due to the operation of an electric heater in the garage.

There was no specific energy budget, however, the total energy usage amounted to approximately 23,500 kWh, or 172 kWh per square metre of heated floor area. Annual space heating demand (delivered to the space) amounted to 26.1 GJ, or 7,260 kWh.

6 ACKNOWLEDGEMENTS

We wish to express our appreciation to the following, whose assistance made this report possible:

- Peter Piersol, Ortech
- Chris Ives, CMHC, and
- last but not least, the occupants of the monitored houses who put up with us.

7 REFERENCES

1. *"Indoor Air Quality Monitoring Results - Advanced Houses"*, by Peter Piersol, ORTECH Corporation for the Saskatchewan Research Council and NRCan. 18 July, 1994: Lab reports

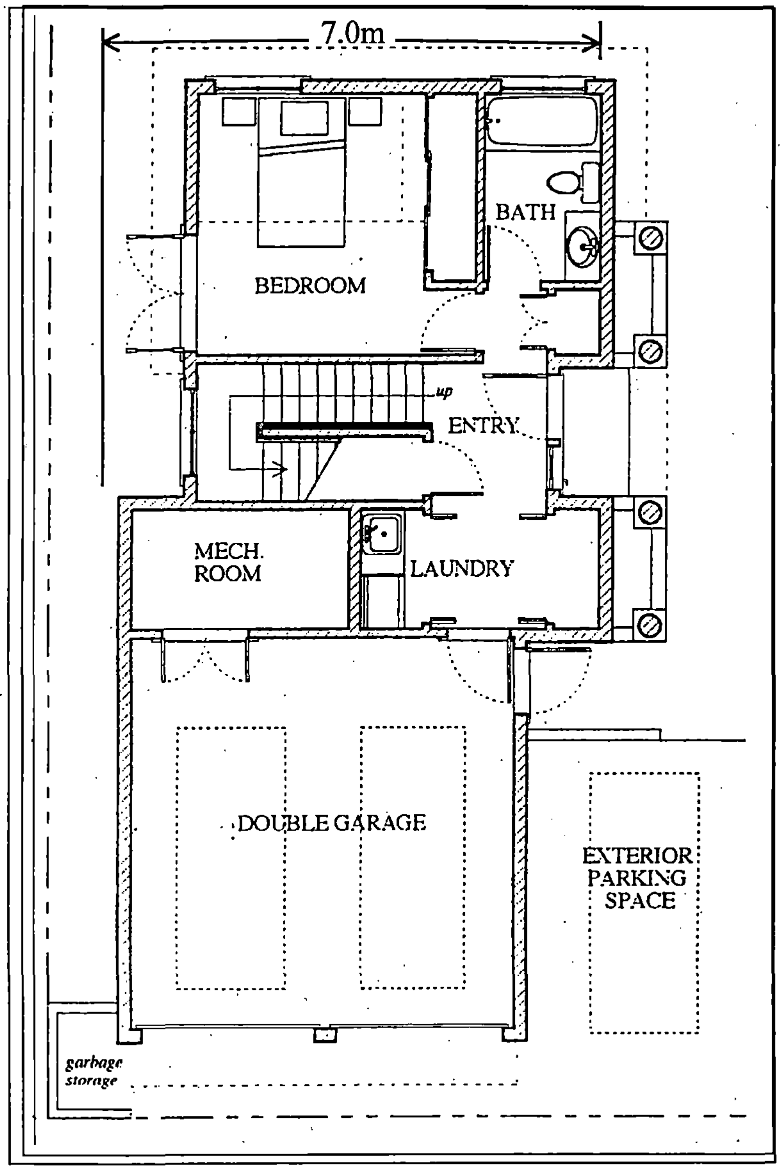
2. *"R-2000 Monitoring Program Data Processing Results"* by K. Cooper of SAR engineering ltd. for CANMET, NRCan. 31 March, 1995

3. Status and processed data reports by K. Cooper of SAR engineering (February, 1994 to April, 1995) for CMHC.

4. *"Healthy Housing Project Final Report"* by C. Mattock, G. Johnson, and D. Rousseau, for CMHC, 6 January, 1994

A APPENDIX: House Description

Figure A.1 Ground Floor Plan[1] (Scale approx. 1:100)



[1] Courtesy Habitat Design + Consulting Ltd./Greg Johnson Architecture/Engineering

Figure A.2 Main Floor Plan (Scale approx. 1:100)

Note: the covered inset balcony was enclosed and glazed.

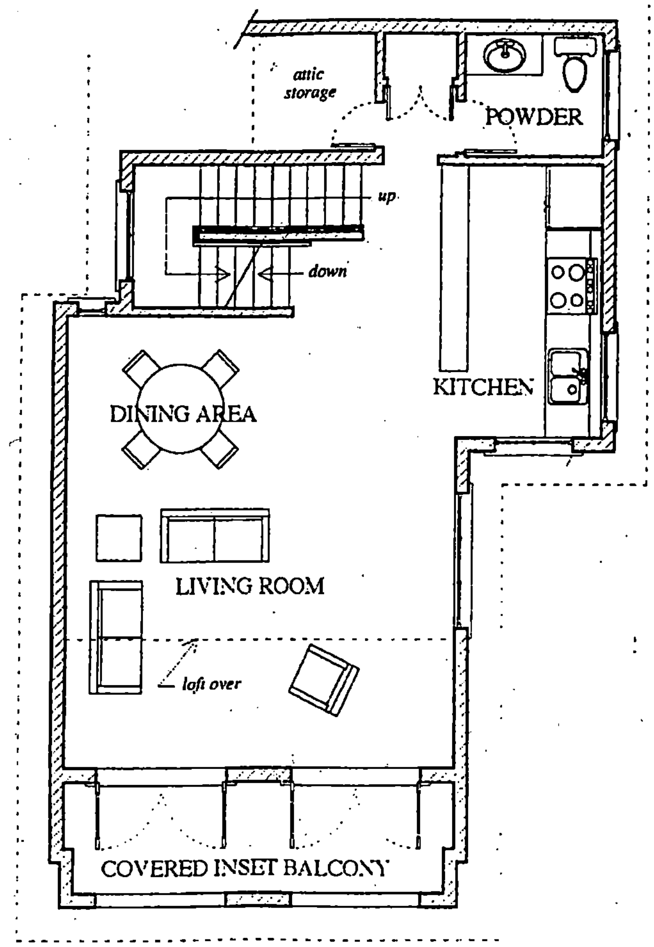


Figure A.3 Upper Floor Plan (Scale approx. 1:100)

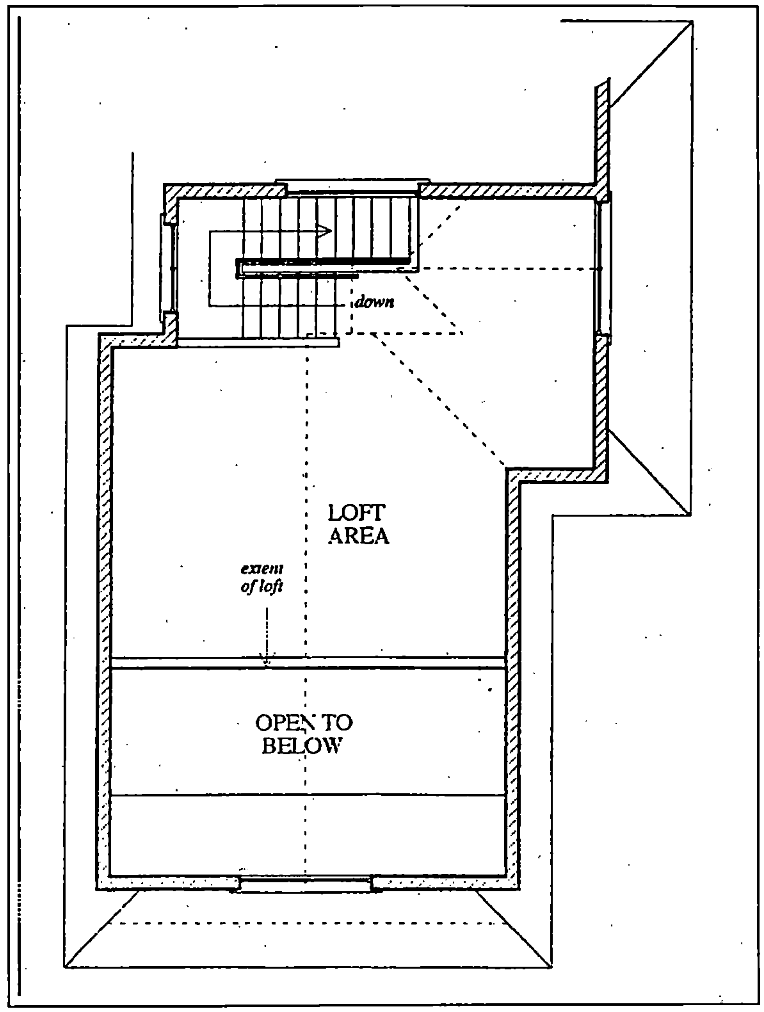
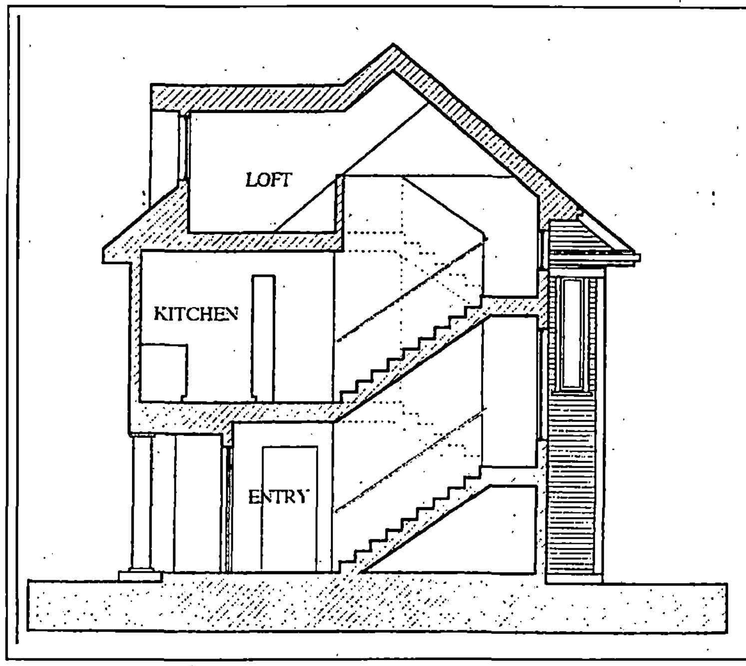


Figure A.4 Section through House



B APPENDIX: Outdoor Conditions

The tables following summarize outdoor conditions at the site of the Vancouver Healthy house and at nearby climatological stations - University of British Columbia (U.B.C.) - located approximately 13 km west, and the Vancouver International Airport - located approximately 13 km southwest.

Generally, the weather at the site was slightly warmer than at the airport (metropolitan "heat island" effect), which in turn experienced weather slightly warmer than long-term (7% fewer degree days). This should result in a lower than average space heating requirement.

While hours of bright sun at the airport averaged slightly higher than long-term, horizontal insolation measured at the site was about 20% less than long-term measured at U.B.C.. This could be a result of a combination of different instrumentation and metropolitan pollution. This would result in lower than average solar contribution and consequently higher than average space heating requirement.

Winds averaged higher than long-term (7% higher for the period from August, 1994 to April, 1995). This would contribute to higher than average air change rates and space heating requirement for the house.

Table B.1A Outside Conditions

	Units	First occupants: Feb-94	Mar-94	Apr-94	May-94	Jun-94	Jul-94	TOTAL Feb-Jul
Outdoor site temperature								
Maximum	C	11.2	20.8	20.8	24.3		32.9	32.9 max
Average	C	**5.3**	**8.5**	**11.6**	**14.8**		**21.6**	**12.4 avg**
Minimum	C	-1.2	0.4	4.4	6.6		14.2	-1.2 min
Vancouver airport								
Actual average	C	3.7	7.2	10.9	13.8	15.0	18.5	11.5 avg
Long-term average	C	4.7	6.3	8.8	12.1	15.2	17.2	10.7 avg
Site avg. - airport	C	1.6	1.3	0.7	1.0		3.1	1.5 avg
Degree Days (18C base)								
Actual		400	335	213	131	91	18	1,188 sum
Long-term		376	363	276	183	89	40	1,327 sum
Actual/Long-term	%	106%	92%	77%	72%	102%	45%	90% avg
Insolation								
Horizontal, at site	MJ/m²d	3.1	9.6	11.3	17.6	16.0	21.4	**13.2 avg**
Maximum	W/m²	458	622	754	865	887	822	**735 avg**
U.B.C. long-term	MJ/m²d	5.7	10.0	14.9	20.5	21.7	23.0	16.0 avg
Site meas./U.B.C.	%	54%	96%	76%	86%	74%	93%	82% avg
Vancouver airport								
Hours bright sun	hr/d	65	167	152	257	205	365	1,211 sum
Long-term	hr/d	87	132	172	237	242	296	1,166 sum
Actual/Long-term	%	74%	127%	88%	108%	84%	123%	104% avg
Vancouver airport								
Actual Wind	km/h	15.0	14.2	13.4	13.6	11.7	12.6	13.4 avg
Long-term	km/h	12.0	13.5	13.3	11.0	11.0	11.0	12.0 avg
Actual/Long-term	%	125%	105%	101%	124%	106%	115%	112% avg

Table B.1B Outside Conditions

	Units	Aug-94	Sep-94	Oct-94	Nov-94	Dec-94	Jan-95	Feb-95	Mar-95	Apr-95	SUMMER Aug-Sep	WINTER Oct-Apr	TOTAL Aug-Apr
		Second occupants:											
Outdoor site temperature													
Maximum	C	28.9	24.7	21.5	11.0	11.0	14.3	13.2	21.3	22.6	28.9	22.6	28.9 max
Average	C	**19.6**	**16.8**	**10.9**	**5.0**	**4.8**	**5.3**	**6.4**	**8.0**	**10.8**	**18.2**	**7.3**	**9.7 avg**
Minimum	C	12.5	10.5	5.2	-1.2	-6.2	-3.4	-3.5	-0.7	3.3	10.5	-6.2	-6.2 min
Vancouver airport													
Actual average	C	18.5	15.7	10.2	5.0	4.4	4.5	5.3	7.1	9.6	17.1	6.6	8.9 avg
Long-term average	C	17.4	14.3	10.0	5.9	3.5	3.0	4.7	6.3	8.8	15.9	6.0	8.2 avg
Site avg. - airport	C	1.1	1.1	0.7	0.0	0.4	0.8	1.1	0.9	1.2	1.1	0.7	0.8 avg
Degree Days (18C base)													
Actual		10	71	242	391	423	419	356	339	254	81	2,424	2,505 sum
Long-term		36	113	248	363	451	466	376	363	276	149	2,543	2,692 sum
Actual/Long-term	%	28%	63%	98%	108%	94%	90%	95%	93%	92%	54%	95%	93% avg
Insolation													
Horizontal, at site	MJ/m²d	17.1	10.8	5.8	1.9	1.6	2.4	3.7	7.8	11.9	**13.9**	**5.0**	**7.0 avg**
Maximum	W/m²	770	638	507	286	246	273	421	561	712	**704**	**429**	**490 avg**
U.B.C. long-term	MJ/m²d	18.6	13.4	7.3	3.5	2.3	2.9	5.7	10.0	14.9	16.0	6.7	8.7 avg
Site meas./U.B.C.	%	92%	80%	81%	54%	71%	83%	65%	78%	80%	87%	76%	80% avg
Vancouver airport													
Hours bright sun	hr/d	294	191	117	67	46	84	93	143	224	485	774	1,259 sum
Long-term	hr/d	265	189	121	69	54	55	87	132	172	454	689	1,143 sum
Actual/Long-term	%	111%	101%	97%	97%	86%	152%	107%	109%	130%	107%	112%	110% avg
Vancouver airport													
Actual Wind	km/h	12.0	10.3	11.2	17.6	14.6	11.0	11.6	13.4	12.5	11.2	13.1	12.7 avg
Long-term	km/h	11.0	10.0	11.2	12.2	12.0	12.0	12.0	13.5	13.3	10.5	12.3	11.9 avg
Actual/Long-term	%	109%	103%	100%	144%	122%	92%	97%	99%	94%	106%	107%	107% avg

C APPENDIX: Monthly Result Summaries

Summaries for the following months are included

- February, 1994 (first occupants moved in),
- March, 1994
- April, 1994
- May, 1994
- June, 1994: hourly data missing,
- July, 1994
- August, 1994 (second occupants moved in),
- September, 1994
- October, 1994
- November, 1994
- December, 1994
- January, 1995
- February, 1995
- March, 1995
- April, 1995

Each monthly summary includes a table of inside temperature distributions, as well as average, hourly minimum and hourly maximum outside and inside temperatures, relative humidity and carbon dioxide concentrations. Hourly graphs show outside and inside temperatures, horizontal insolation, inside relative humidity and carbon dioxide concentration.

February, 1994

The first occupants, a professional couple, moved in on February 12th.

The monitoring systems was functioning normally. The statistics in the table below are for the occupied period only.

Temp. (C)	Living rm.	M. Bdrm	CO2 concentration (ppm)	% of time
	% of time in each bin			
<18C	0%	0%	<350	2%
18-20	2%	59%	350-450	41%
20-22	56%	39%	450-550	23%
22-24	42%	2%	550-650	33%
24-26	0%	0%	650-750	1%
26-28	0%	0%	750-850	0%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	390	390		390

	Outside (C)	Inside Conditions: Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	11.2	23.8	22.2	41%	694
Average	**5.3**	**21.8**	**19.9**	34%	483
Minimum	-1.2	19.5	17.9	18%	346

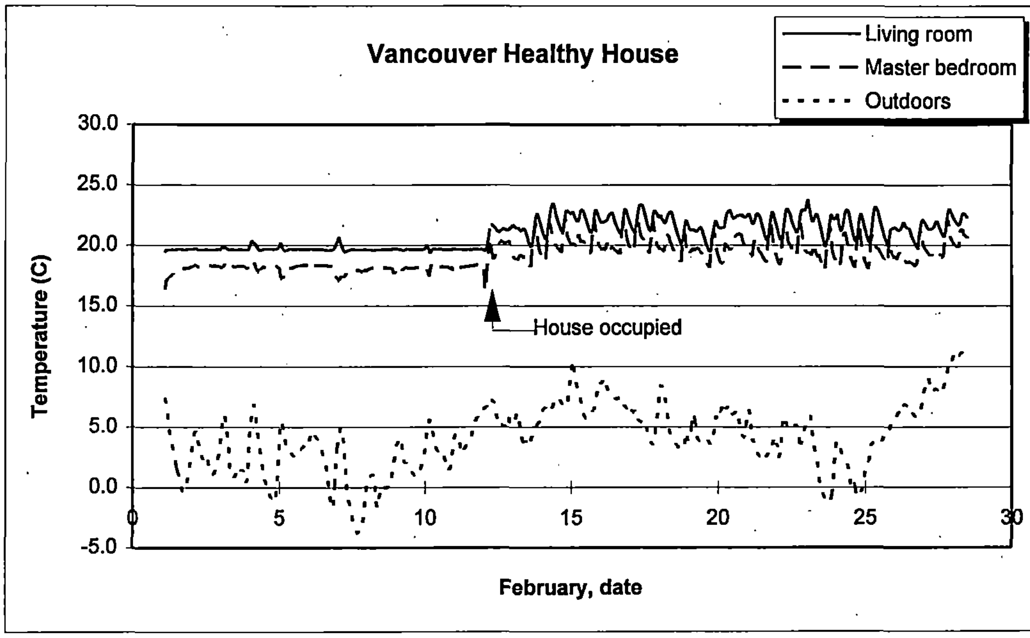


Figure C1.1
Inside & Outside Temperatures

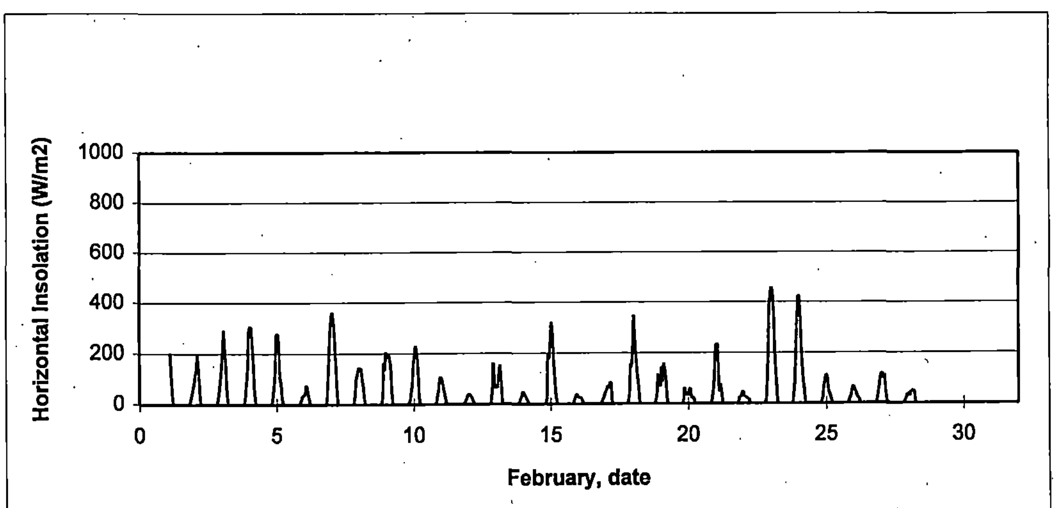


Figure C1.2
Horizontal Insolation

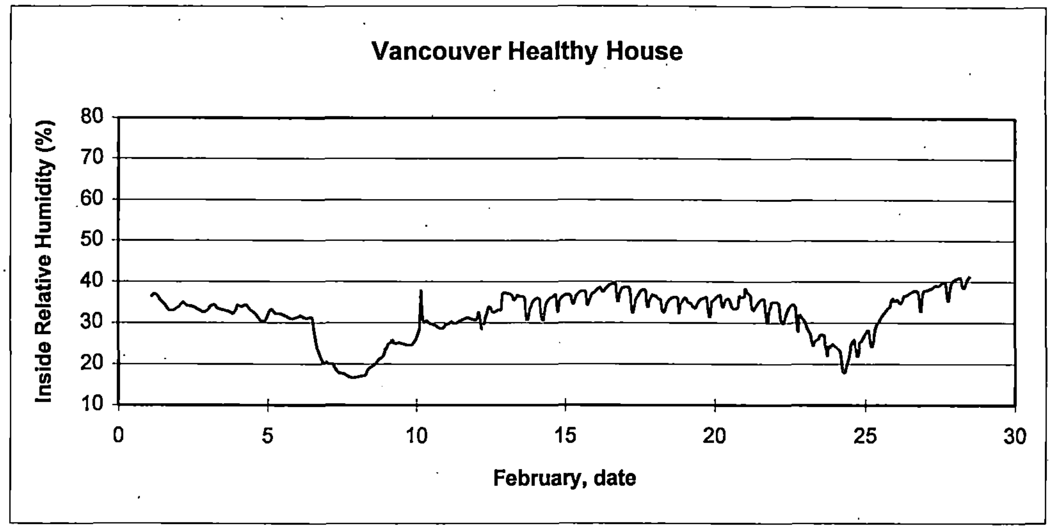


Figure C1.3
Inside Relative Humidity

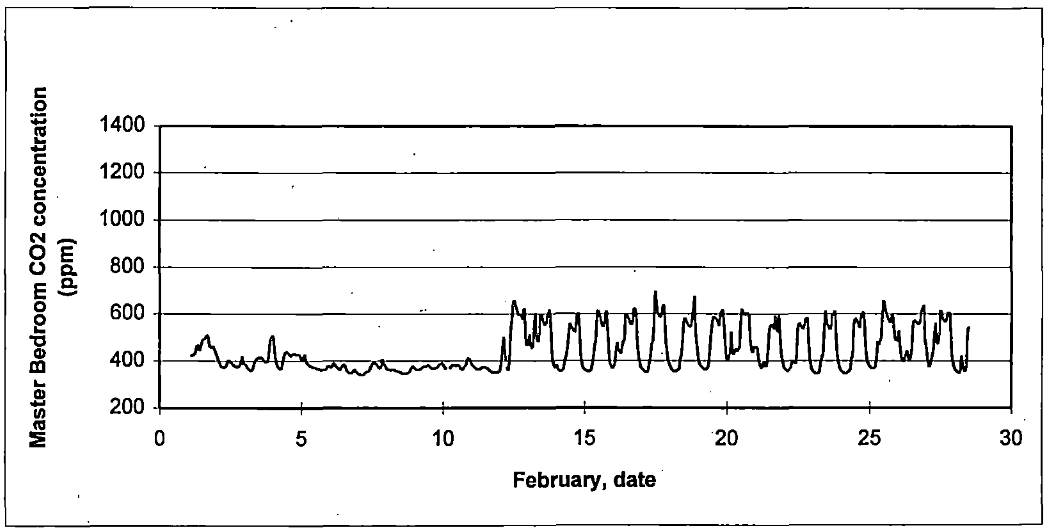


Figure C1.4
Carbon Dioxide Concentration

March, 1994

No news reported by occupants.

Monitoring system functioning normally.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm % of time in each bin	CO2 concentration (ppm)	% of time		Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
<18C	0%	1%	<350	10%	Maximum	20.8	24.3	22.6	44%	716
18-20	2%	55%	350-450	42%	**Average**	**8.5**	**22.1**	**20.0**	37%	461
20-22	41%	43%	450-550	25%	Minimum	0.4	19.4	17.7	27%	325
22-24	56%	2%	550-650	22%						
24-26	2%	0%	650-750	1%						
26-28	0%	0%	750-850	0%						
28-30	0%	0%	850-950	0%						
>30	0%	0%	>950	0%						
Total hours:	742	743		743						

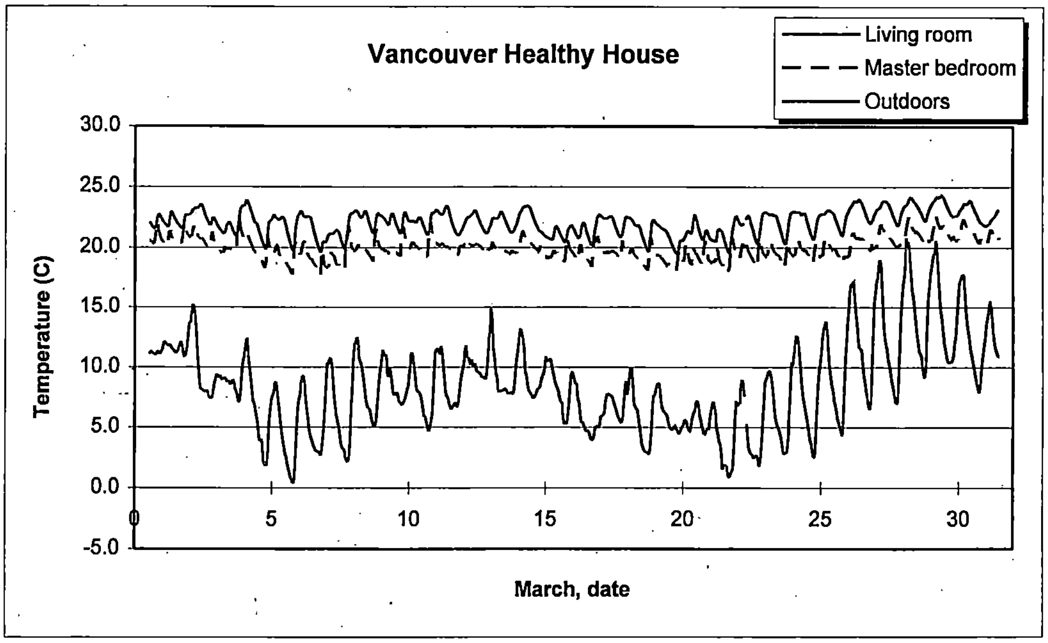


Figure C2.1
Inside & Outside Temperatures

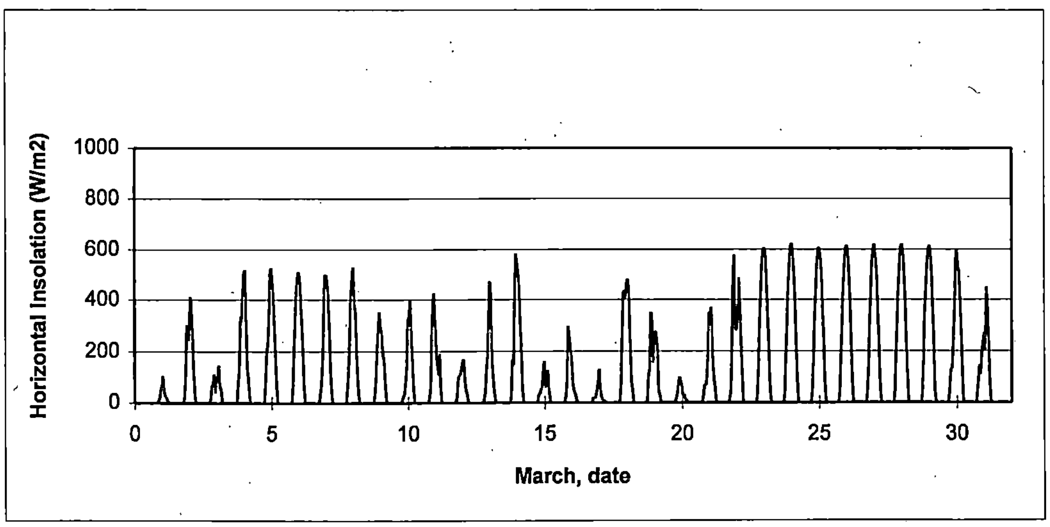


Figure C2.2
Horizontal Insolation

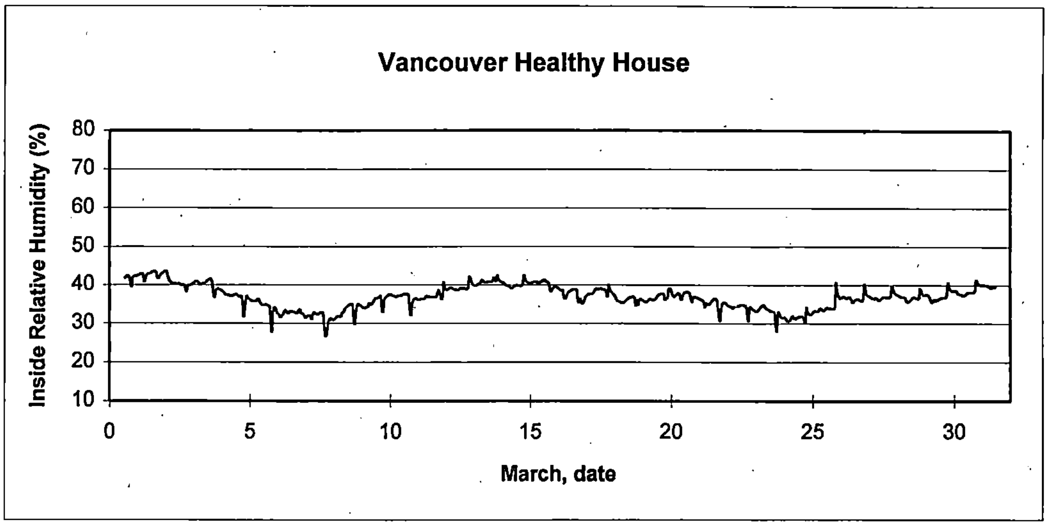


Figure C2.3
Inside Relative Humidity

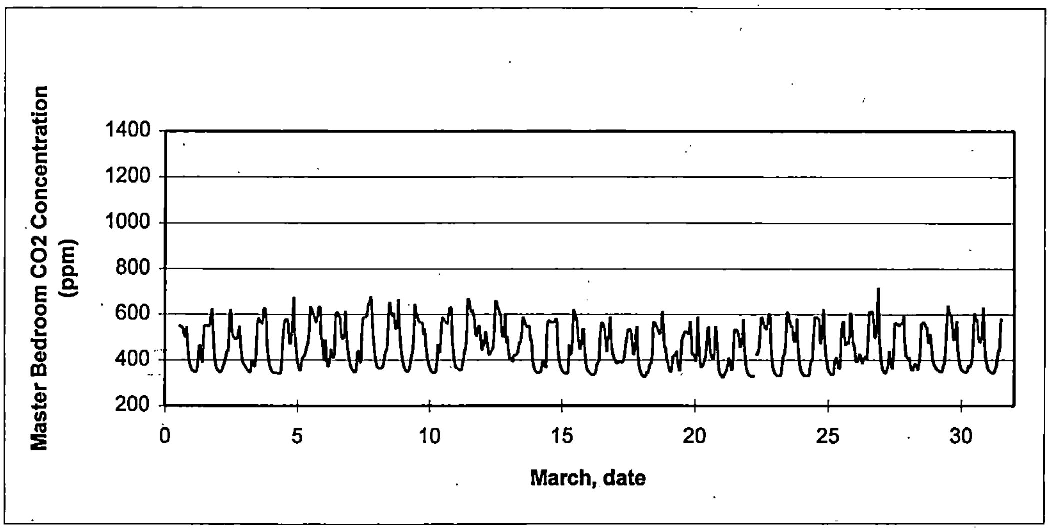


Figure C2.4
Carbon Dioxide Concentration

April, 1994

Occupants reported that the house was too warm on sunny days - causing them to leave the windows open when they were home in the evening. The wife went to the hospital on April 29th to deliver a baby.

Monitoring system functioning normally.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	0%	<350	12%
18-20	3%	32%	350-450	36%
20-22	36%	37%	450-550	17%
22-24	35%	29%	550-650	27%
24-26	25%	2%	650-750	6%
26-28	0%	0%	750-850	2%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	720	720		720

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	20.8	25.8	24.7	56%	812
Average	**11.6**	**22.6**	**21.0**	42%	482
Minimum	4.4	19.6	18.1	35%	317

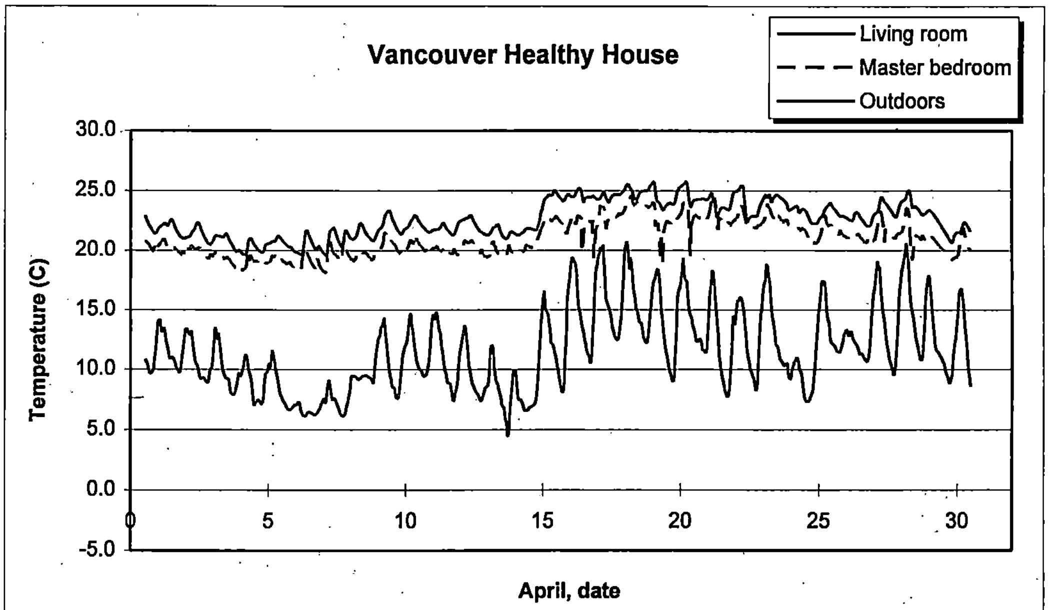


Figure C3.1
Inside & Outside Temperatures

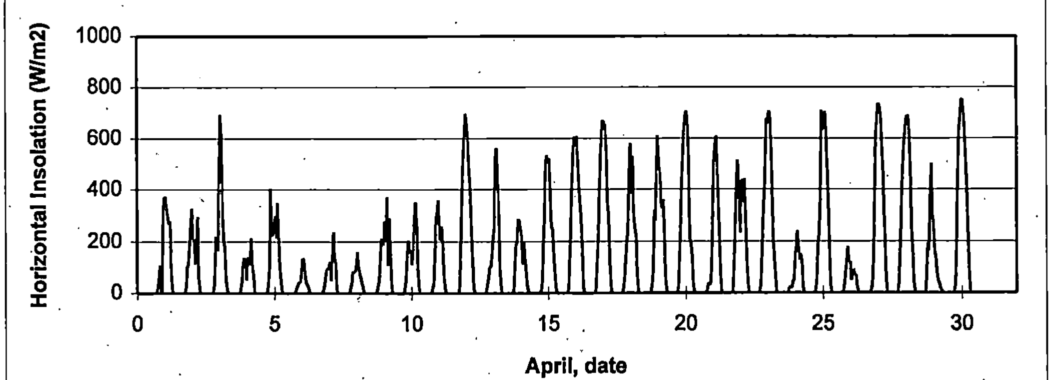


Figure C3.2
Horizontal Insolation

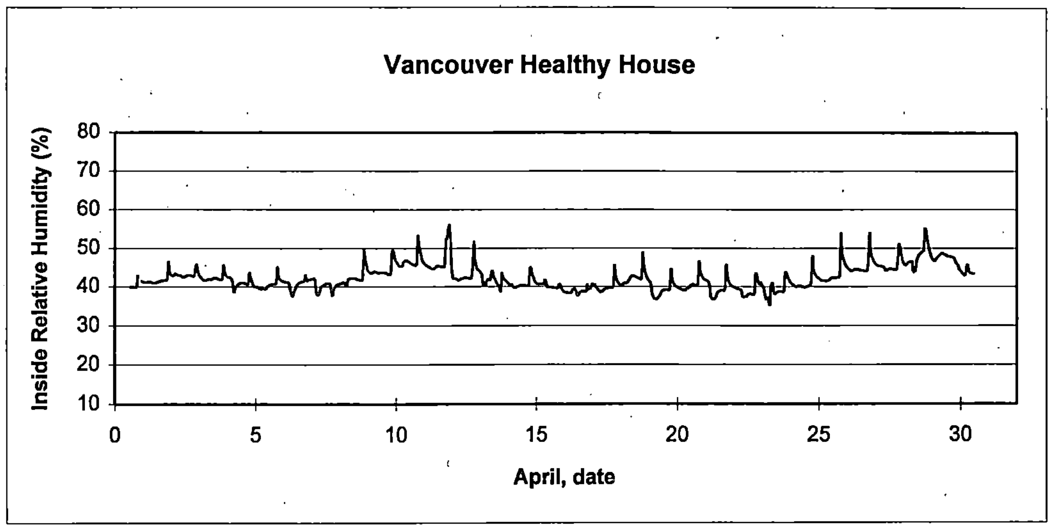


Figure C3.3
Inside Relative Humidity

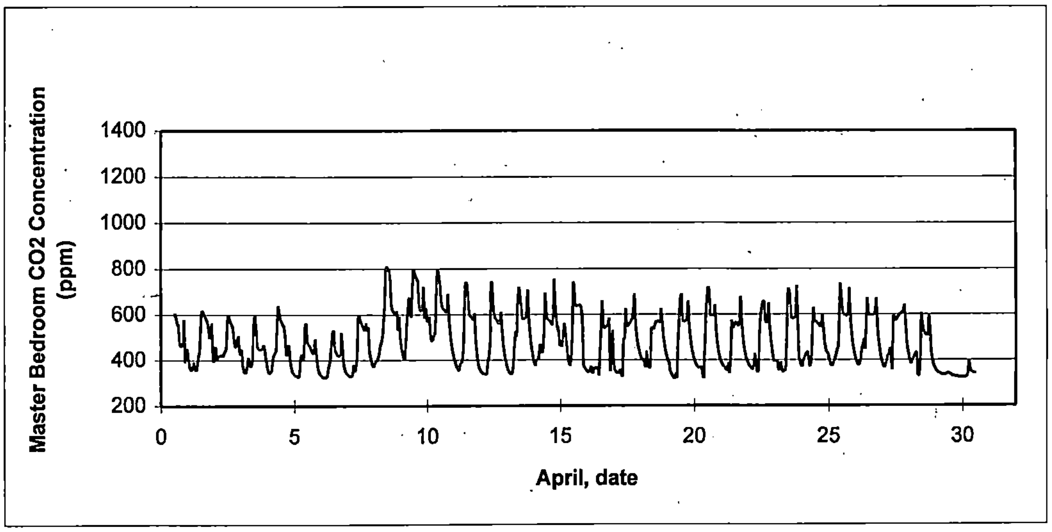


Figure C3.4
Carbon Dioxide Concentration

May, 1994

House overheating (space heating operating partial cause)
Wife returned from hospital with baby.
HRV turned off and foil covers south clerestory windows to reduce overheating.
Data logger #1 was down from May 16th to June 6th.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	0%	<350	22%
18-20	0%	7%	350-450	42%
20-22	12%	12%	450-550	31%
22-24	29%	58%	550-650	5%
24-26	54%	22%	650-750	0%
26-28	5%	1%	750-850	0%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	363	363		363

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	24.3	27.0	26.5	56%	608
Average	**14.8**	**24.1**	**23.0**	39%	418
Minimum	6.6	20.4	18.9	26%	310

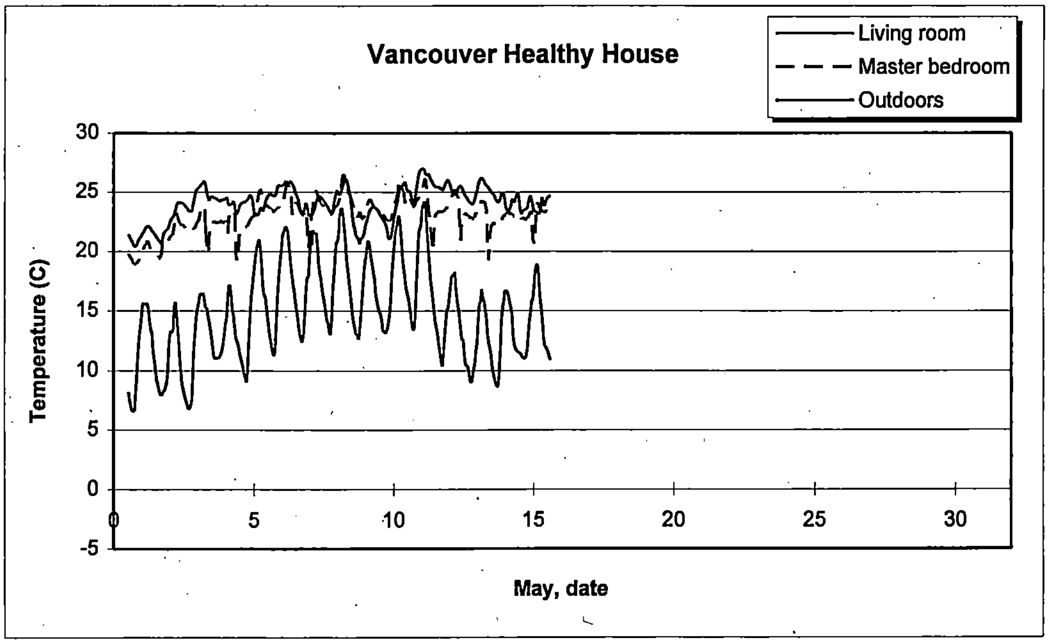


Figure C4.1
Inside & Outside Temperatures

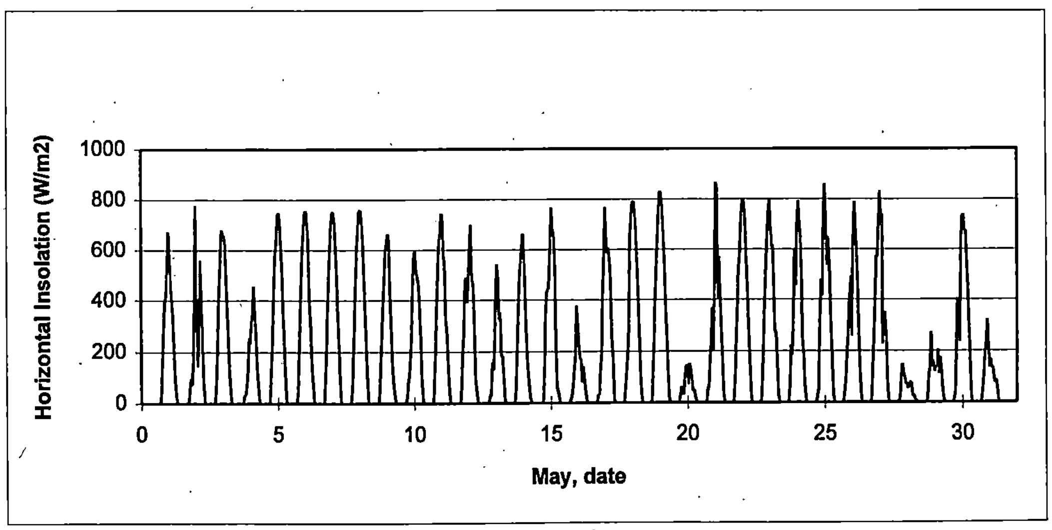


Figure C4.2
Horizontal Insolation

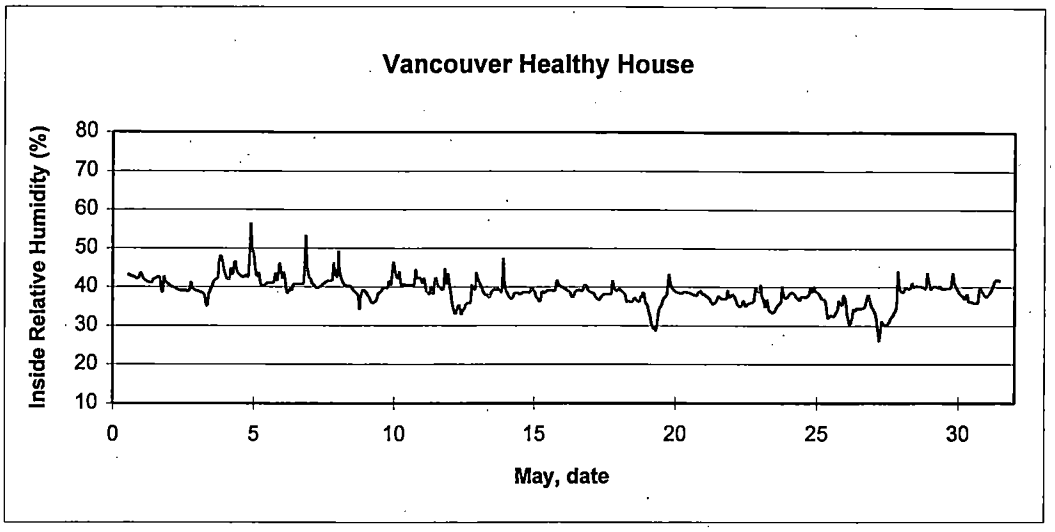


Figure C4.3
Inside Relative Humidity

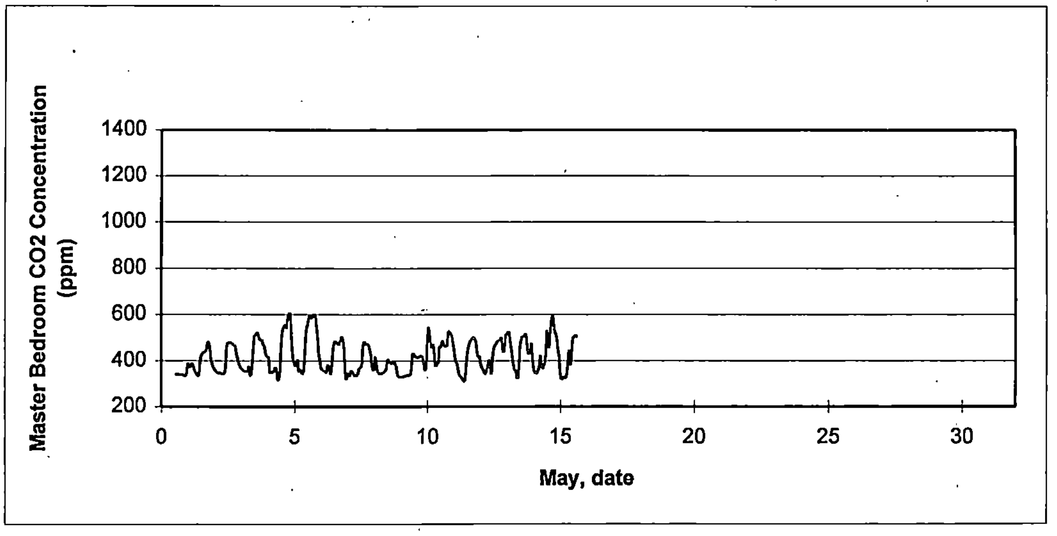


Figure C4.4
Carbon Dioxide Concentration

June, 1994

Overheating
Check valve installed in space heating loop on June 20th to reduce overheating.
Family away June 28th to July 12th.
Data logger #1 malfunctioned (no data available)

							Inside Conditions			
Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time		Outside (C)	Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
<18C			<350		Maximum				52%	
18-20			350-450		**Average**				43%	
20-22	data missing		450-550	data missing	Minimum		data missing		34%	
22-24			550-650							
24-26			650-750							
26-28			750-850							
28-30			850-950							
>30			>950							
Total hours:	0	0		0						

July, 1994

The occupants were away until July 12th. The occupants reported overheating reduced now that the check valve is installed in the space heating loop. They moved out of the house at the end of July.
HRV still off.
Data logger #1 was down until the 12th of July.

Temp. (C)	Living rm.	M. Bdrm	CO2 concentration (ppm)	% of time
	% of time in each bin			
<18C	0%	0%	<350	10%
18-20	0%	0%	350-450	67%
20-22	0%	0%	450-550	19%
22-24	11%	9%	550-650	2%
24-26	30%	44%	650-750	0%
26-28	29%	34%	750-850	0%
28-30	26%	11%	850-950	0%
>30	5%	0%	>950	1%
Total hours:	490	489		485

	Outside (C)	Inside Conditions: Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	32.9	30.9	30.3	56%	1400
Average	**21.6**	**26.7**	**26.0**	**45%**	418
Minimum	14.2	22.6	21.7	40%	330

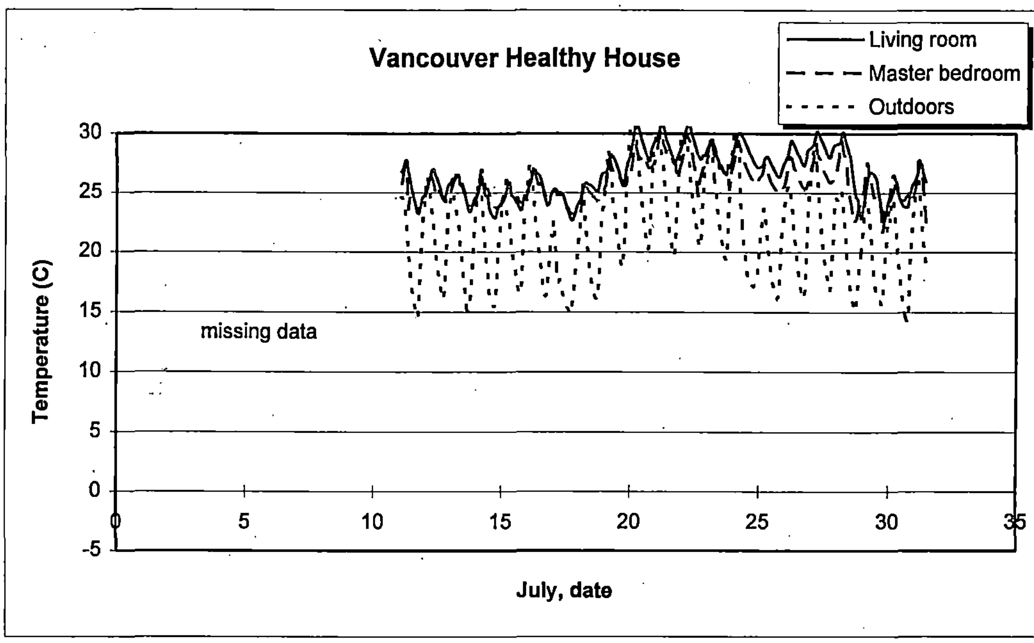


Figure C6.1
Inside & Outside Temperatures

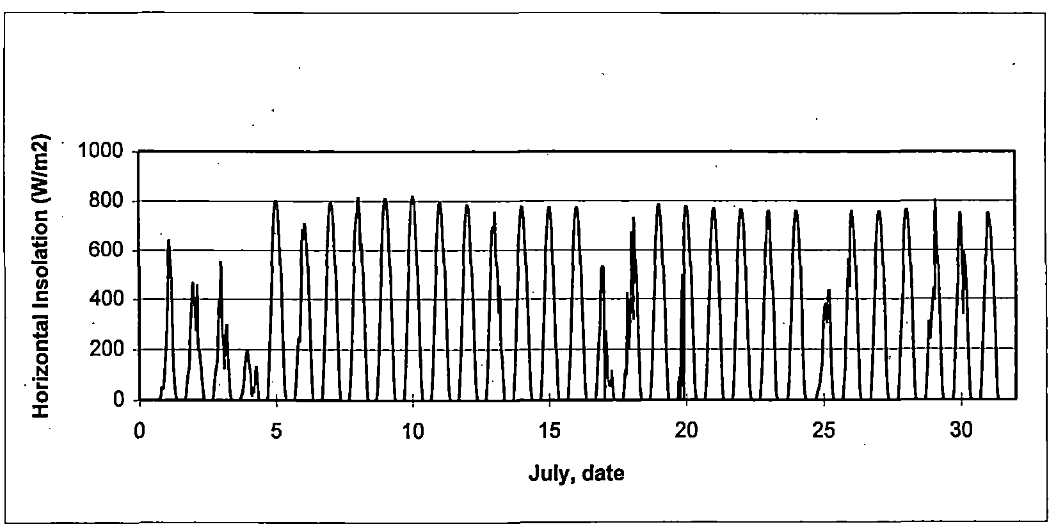


Figure C6.2
Horizontal Insolation

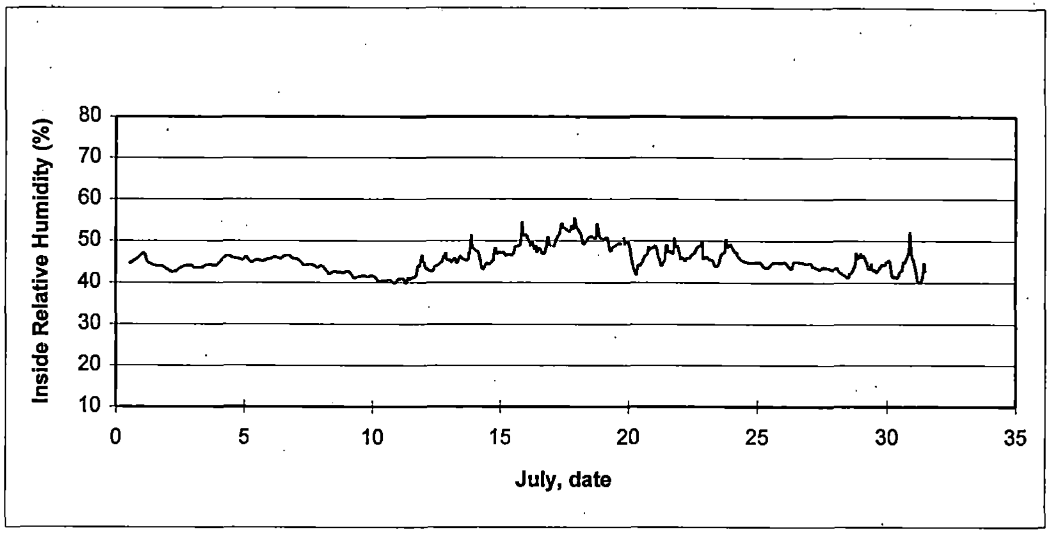


Figure C6.3
Inside Relative Humidity

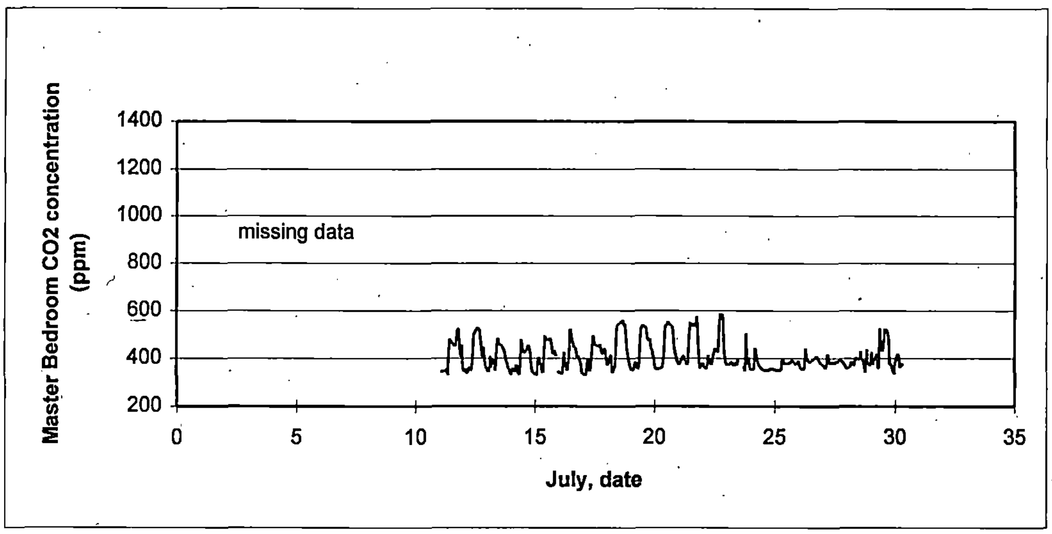


Figure C6.4
Carbon Dioxide Concentration

August, 1994

The second set of occupants - two single working women and three cats - moved in the first of August. They removed the foil from the south clerestory windows and report that they do not find the house too warm. HRV still off.
The monitoring system is functioning normally, except that the CO2 sensor is erratic.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	1%	<350	12%
18-20	0%	3%	350-450	36%
20-22	6%	13%	450-550	17%
22-24	35%	42%	550-650	27%
24-26	46%	32%	650-750	6%
26-28	13%	9%	750-850	2%
28-30	0%	1%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	743	743		719

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	28.9	28.7	28.8	62%	721
Average	**19.6**	**24.4**	**23.6**	50%	441
Minimum	12.5	19.9	17.0	38%	318

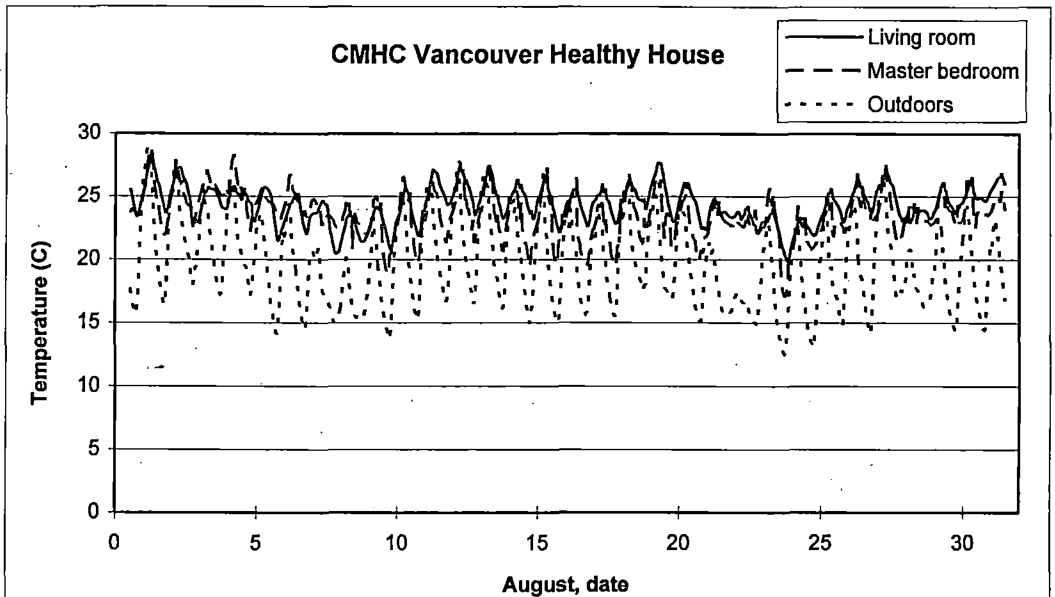


Figure C7.1
Inside & Outside Temperatures

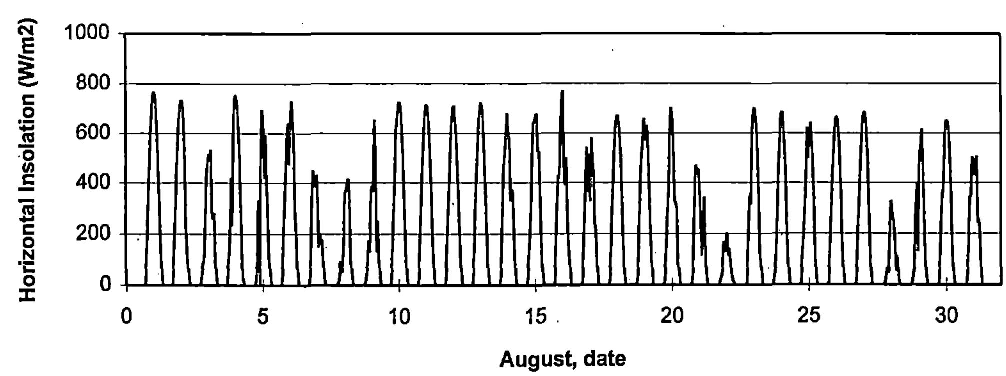


Figure C7.2
Horizontal Insolation

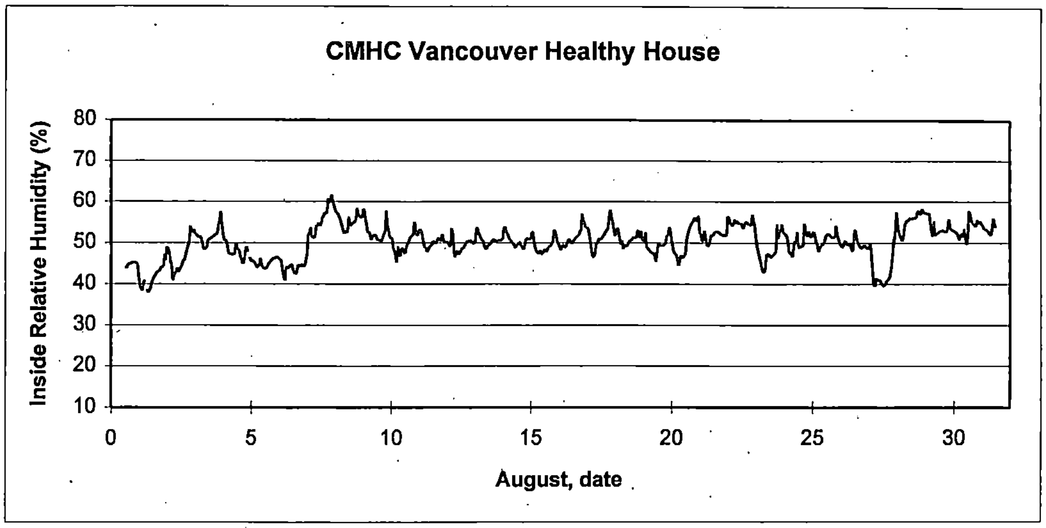


Figure C7.3
Inside Relative Humidity

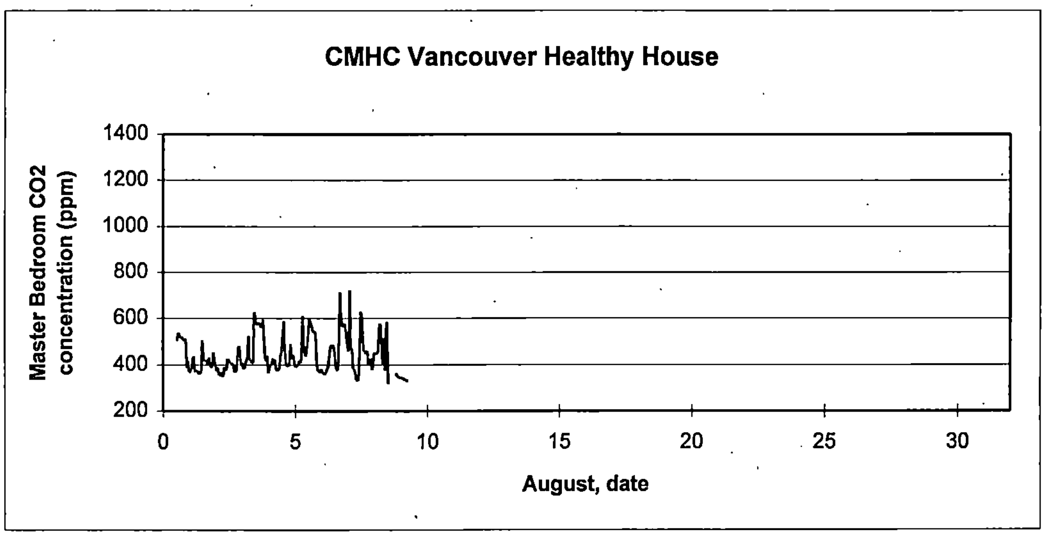


Figure C7.4
Carbon Dioxide Concentration

September, 1994

Relative humidity levels are quite high - possibly because the HRV is still off - owner advised.

Occupants report not enough hot water - water heater set-point increased from 120F to 140F (49C to 60C)
Monitoring system functioning normally, however still unable to get reliable readings from the CO_2 sensor

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time		Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
<18C	0%	0%	<350		Maximum	24.7	26.5	26.6	65%	
18-20	0%	0%	350-450		**Average**	**16.8**	**23.5**	**22.9**	54%	
20-22	7%	18%	450-550		Minimum	10.5	20.3	20.5	39%	
22-24	60%	68%	550-650							
24-26	30%	14%	650-750							
26-28	3%	0%	750-850							
28-30	0%	0%	850-950							
>30	0%	0%	>950							
Total hours:	720	720		0						

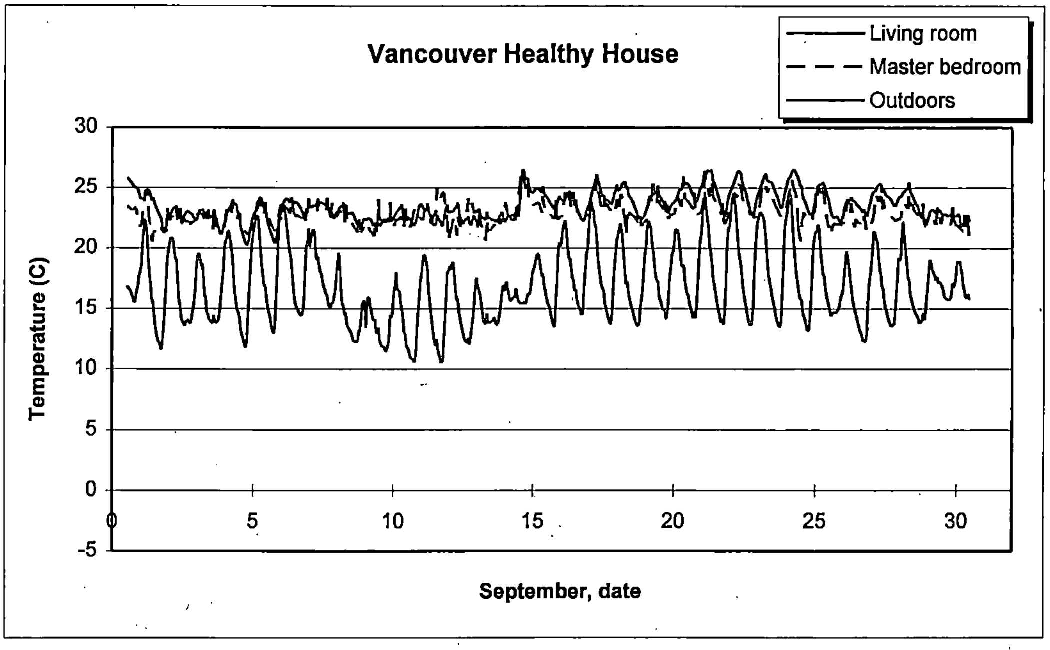


Figure C8.1
Inside & Outside Temperatures

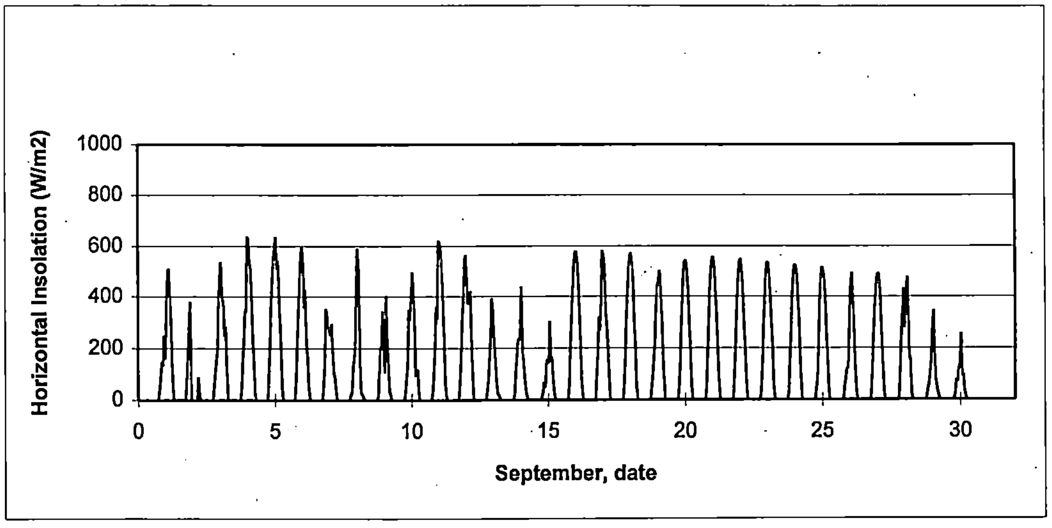


Figure C8.2
Horizontal Insolation

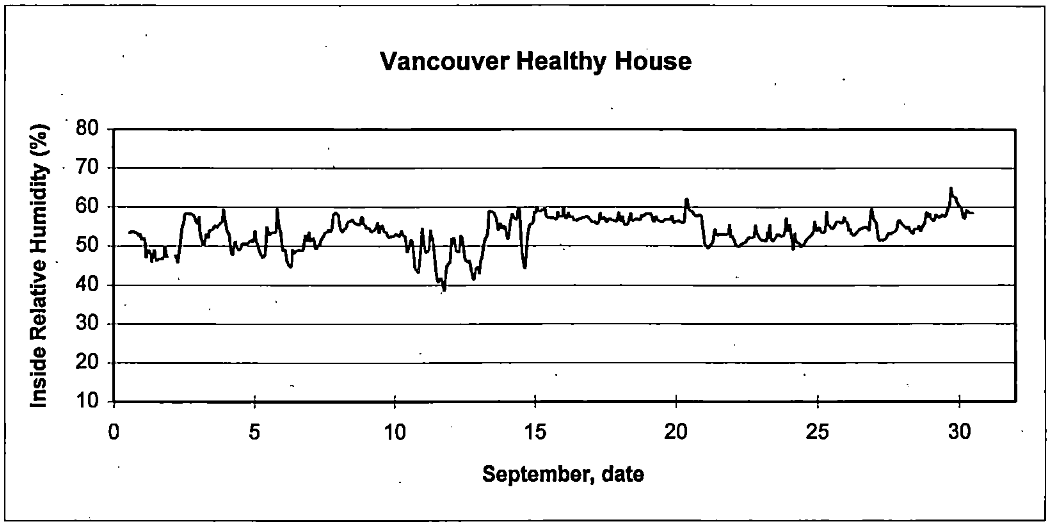


Figure C8.3
Inside Relative Humidity

October, 1994

One on holidays from October 4th.
HRV still off.
Carbon dioxide sensor erratic.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm % of time in each bin	CO2 concentration (ppm)	% of time
<18C	0%	0%	<350	
18-20	11%	22%	350-450	
20-22	52%	54%	450-550	
22-24	30%	19%	550-650	
24-26	6%	5%	650-750	
26-28	0%	1%	750-850	
28-30	0%	0%	850-950	
>30	0%	0%	>950	
Total hours:	744	744		0

	Outside (C)	Inside Conditions: Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	21.5	25.3	26.6	77%	0
Average	**10.9**	**21.7**	**21.1**	49%	#DIV/0!
Minimum	5.2	18.7	17.5	28%	0

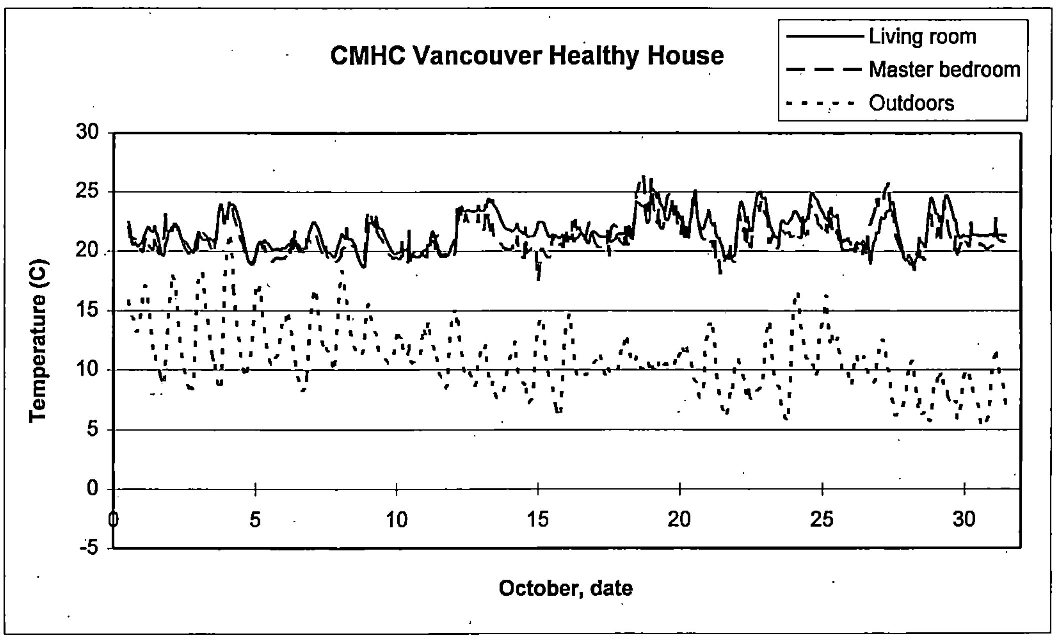


Figure C9.1
Inside & Outside Temperatures

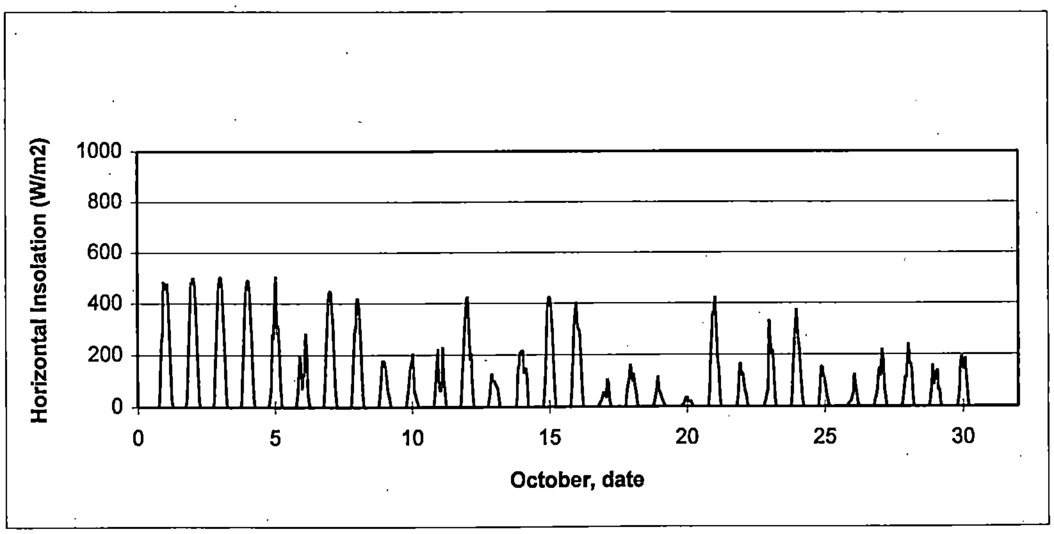


Figure C9.2
Horizontal Insolation

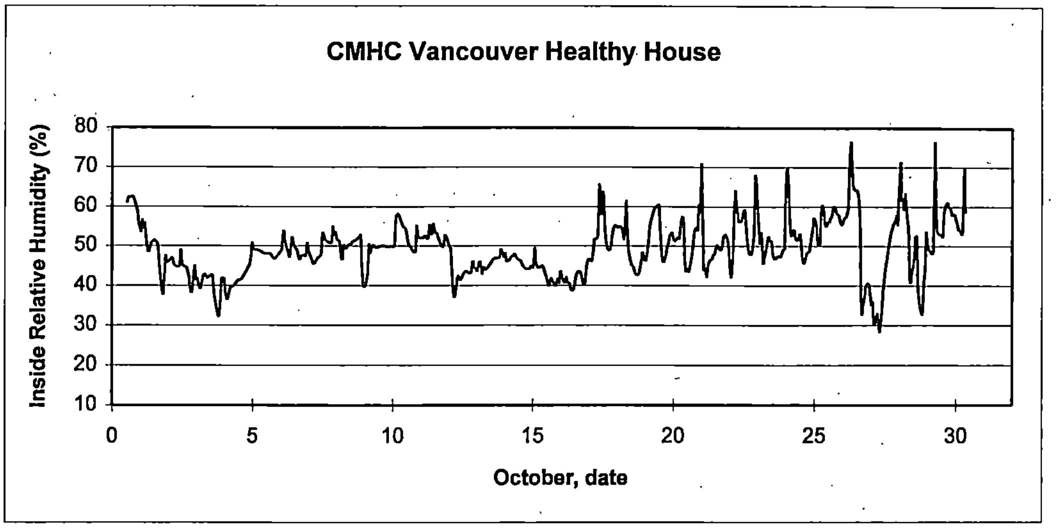


Figure C9.3
Inside Relative Humidity

November, 1994

Occasional overheating in loft
Three to four adults occupying house.
HRV still off.
House electrical and carbon dioxide concentration measurement restored November 3rd.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	2%	<350	0%
18-20	5%	69%	350-450	8%
20-22	76%	25%	450-550	12%
22-24	17%	4%	550-650	14%
24-26	3%	0%	650-750	11%
26-28	0%	0%	750-850	15%
28-30	0%	0%	850-950	12%
>30	0%.	0%	>950	27%
Total hours:	717	717		542

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	11.0	25.5	23.9	89%	1407
Average	**5.0**	**21.4**	**19.7**	53%	781
Minimum	-1.2	18.5	17.3	30%	351

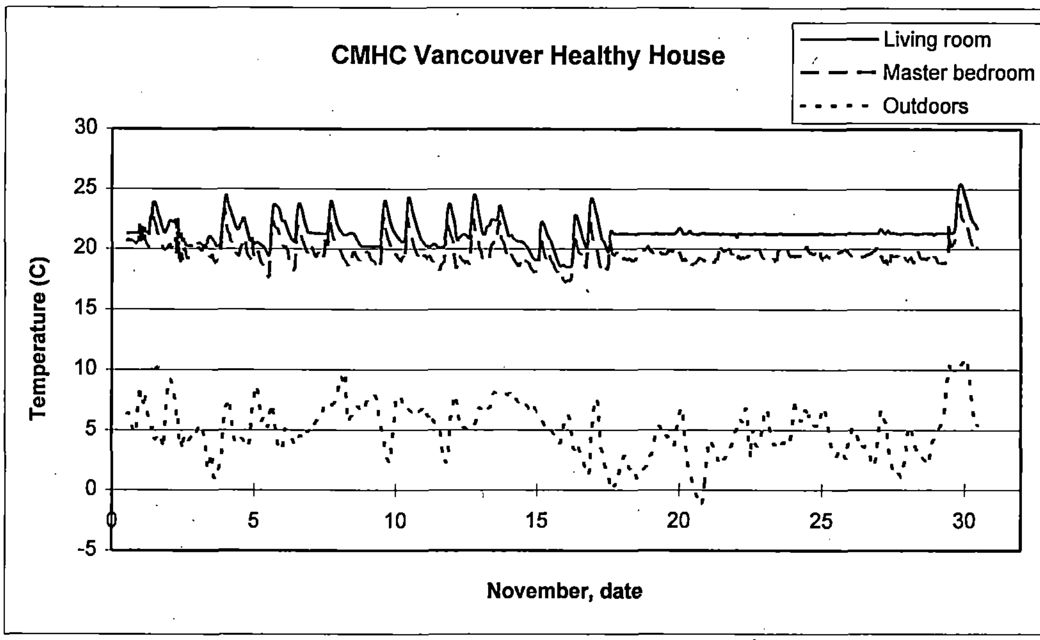


Figure C10.1
Inside & Outside Temperatures

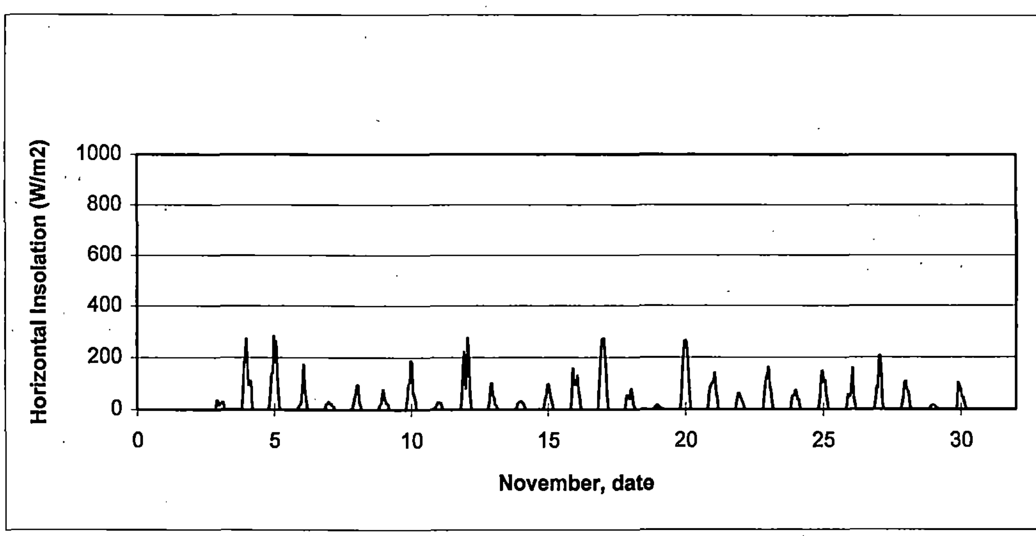


Figure C10.2
Horizontal Insolation

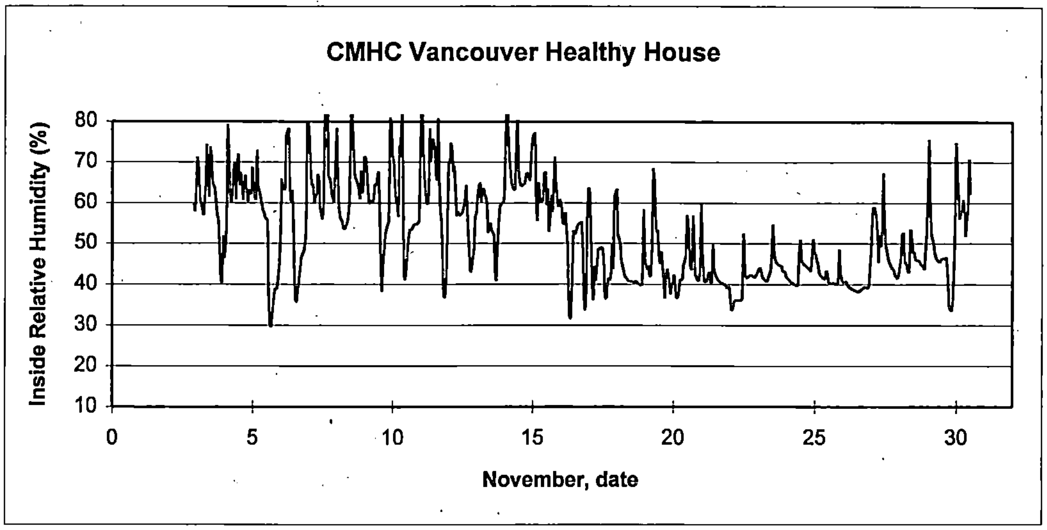


Figure C10.3
Inside Relative Humidity

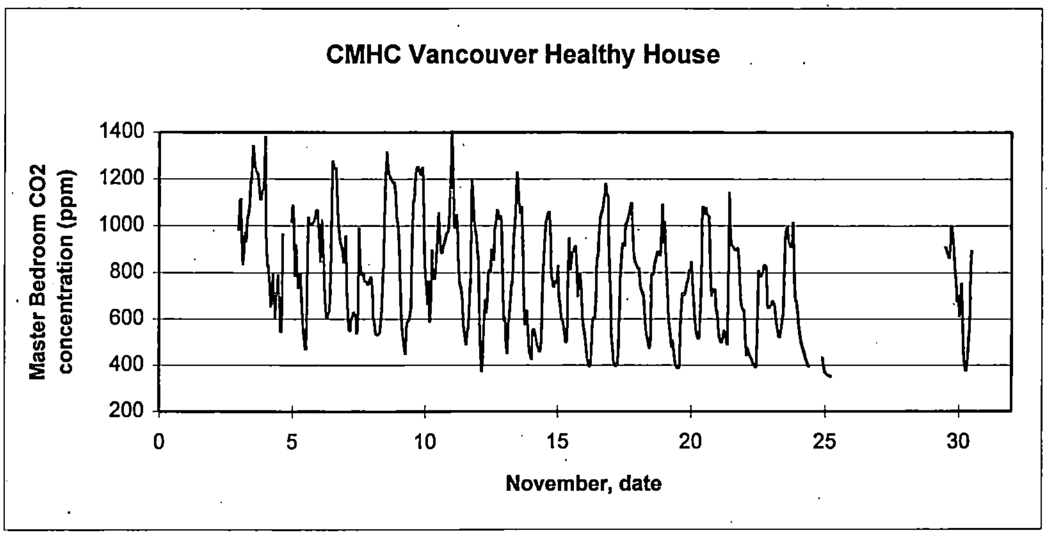


Figure C10.4
Carbon Dioxide Concentration

December, 1994

Two to three adults occupying house (on holidays from December 20th).
HRV turned on December 4th. (~70 L/s by hot-wire anemometer traverse)
Using 115W with 0.91power factor

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	13%	<350	16%
18-20	8%	28%	350-450	34%
20-22	21%	56%	450-550	18%
22-24	51%	3%	550-650	10%
24-26	19%	0%	650-750	11%
26-28	0%	0%	750-850	5%
28-30	0%	0%	850-950	5%
>30	0%	0%	>950	1%
Total hours:	744	741		744

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	11.0	25.4	23.3	86%	1009
Average	**4.8**	**22.7**	**20.0**	37%	504
Minimum	-6.2	16.1	15.6	20%	289

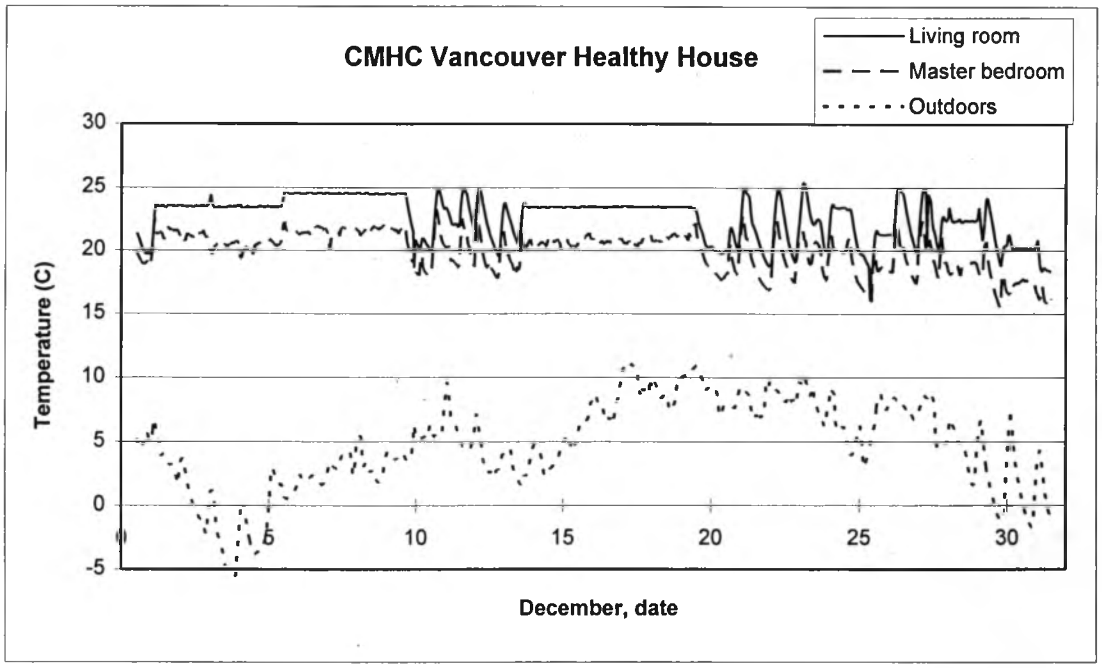


Figure C11.1
Inside & Outside Temperatures

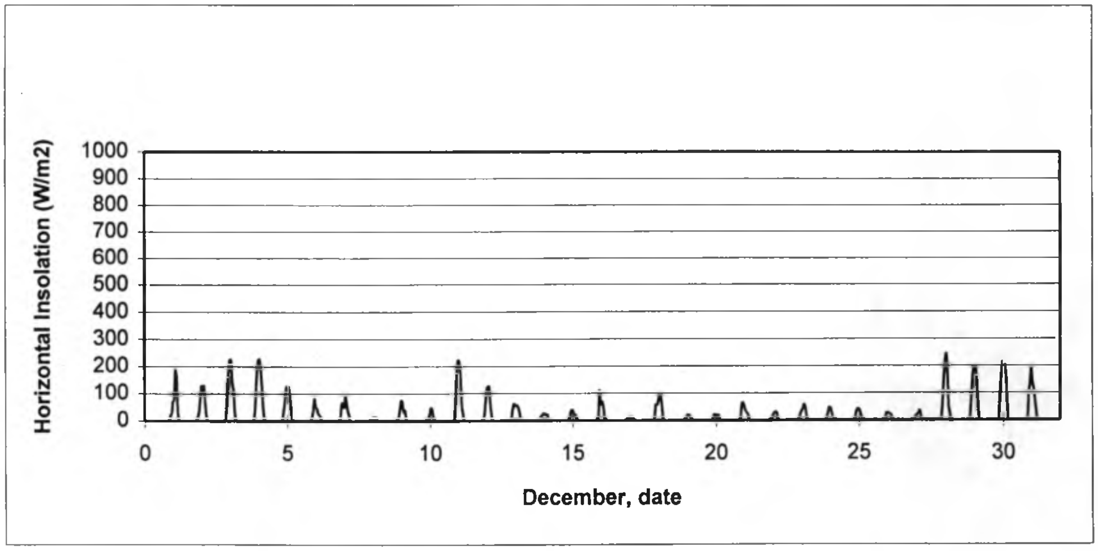


Figure C11.2
Horizontal Insolation

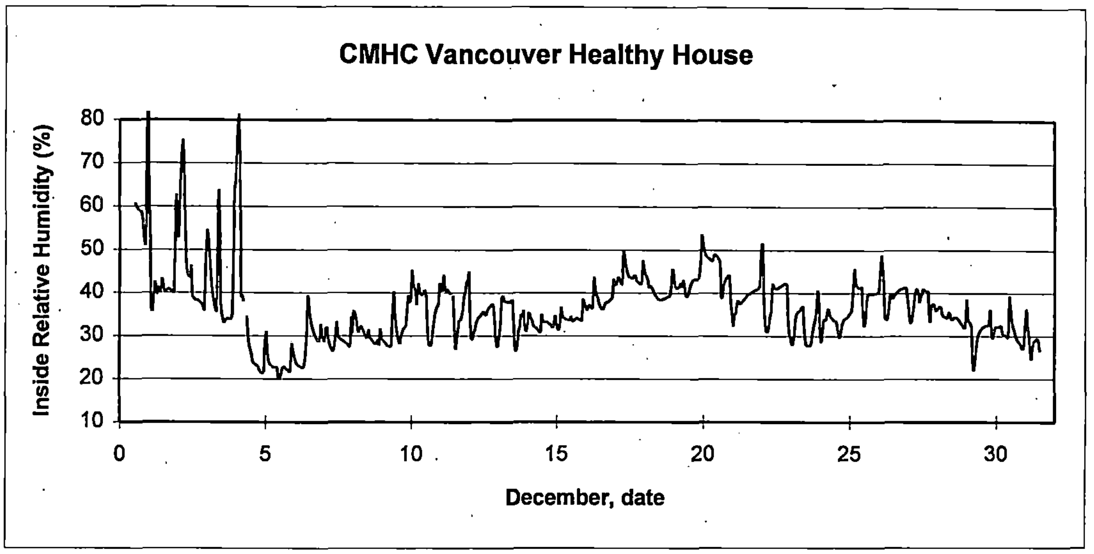


Figure C11.3
Inside Relative Humidity

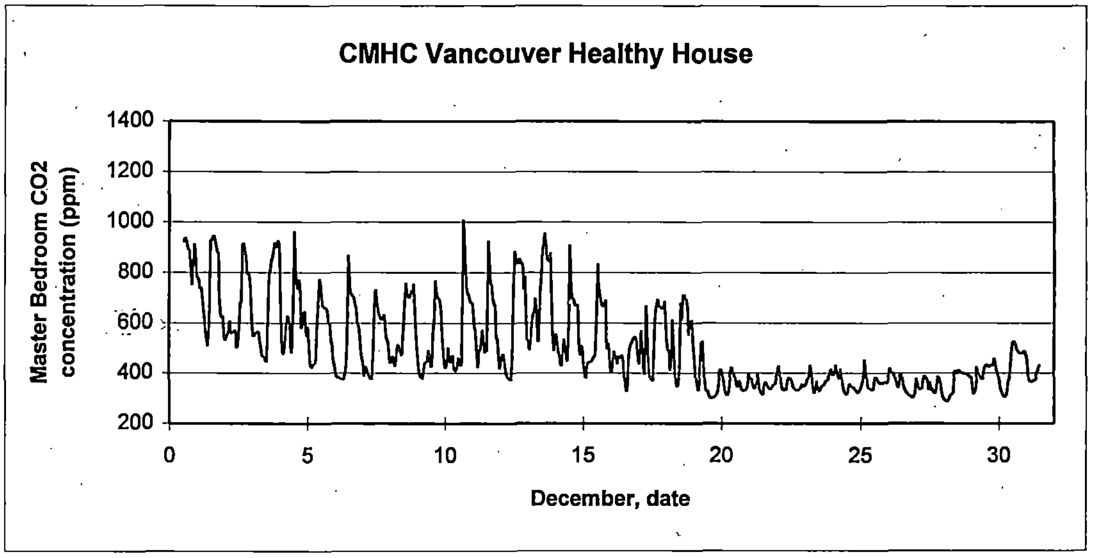


Figure C11.4
Carbon Dioxide Concentration

January, 1995

Two adults and three cats occupying house.
Garage 22 C on February 10th. Electric heater on (outside circuit)

Temp. (C)	Living rm.	M. Bdrm	CO2 concentration (ppm)	% of time
	% of time in each bin			
<18C	0%	38%	<350	10%
18-20	8%	51%	350-450	63%
20-22	52%	11%	450-550	23%
22-24	33%	0%	550-650	3%
24-26	7%	0%	650-750	1%
26-28	0%	0%	750-850	0%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	736	741		742

	Outside (C)	Inside Conditions: Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	14.3	25.4	21.9	64%	693
Average	**5.3**	**21.8**	**18.3**	35%	420
Minimum	-3.4	18.0	14.2	17%	306

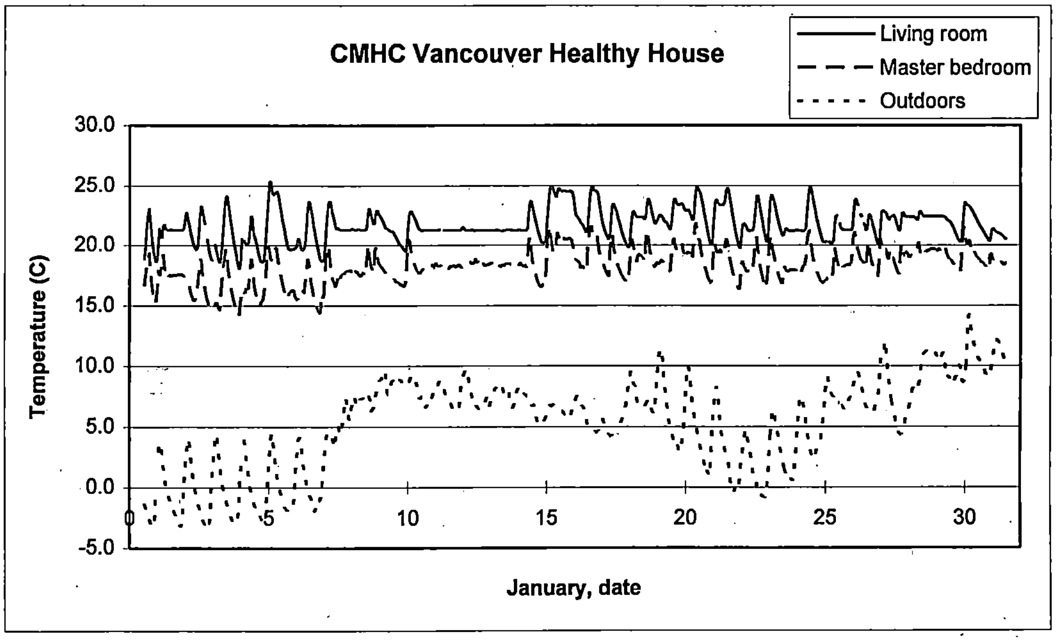


Figure C12.1
Inside & Outside Temperatures

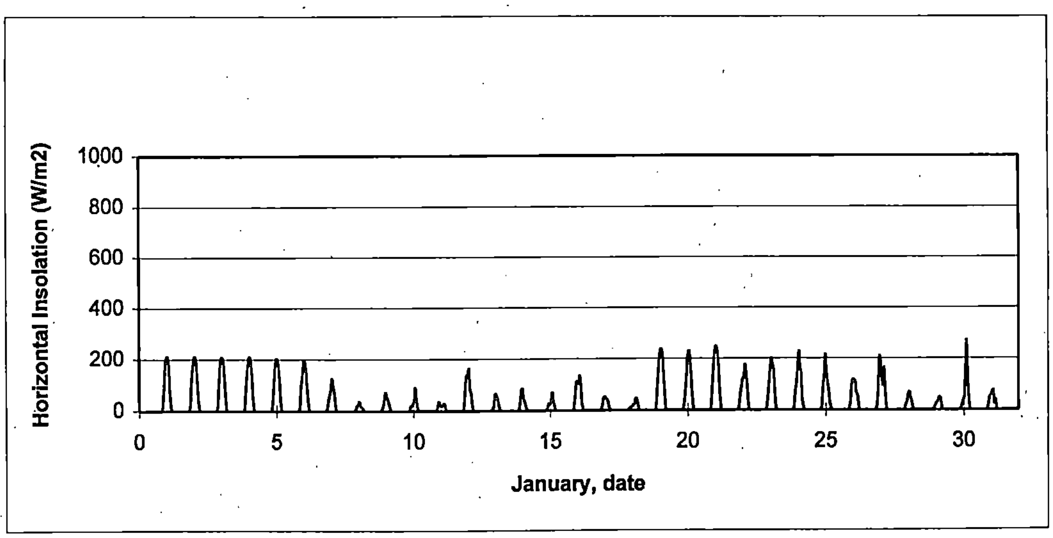


Figure C12.2
Horizontal Insolation

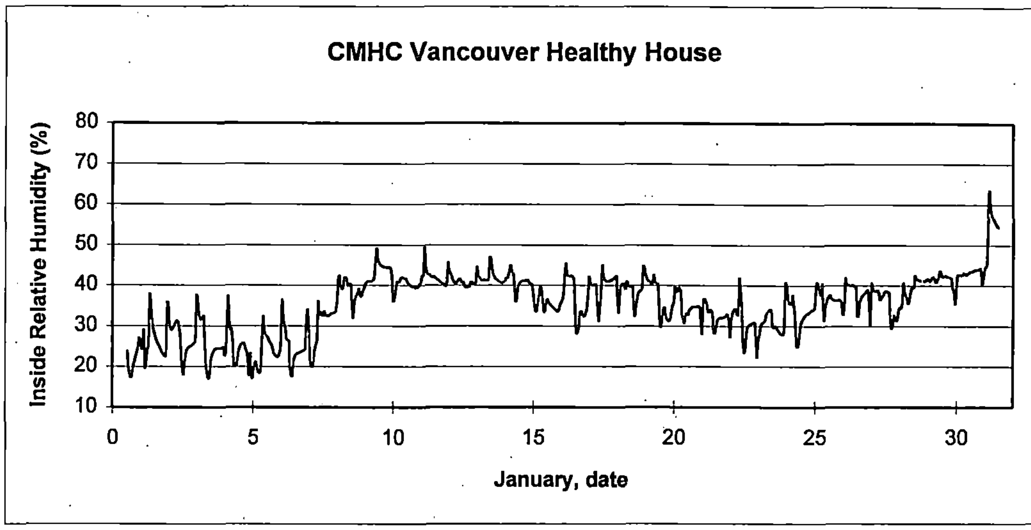


Figure C12.3
Inside Relative Humidity

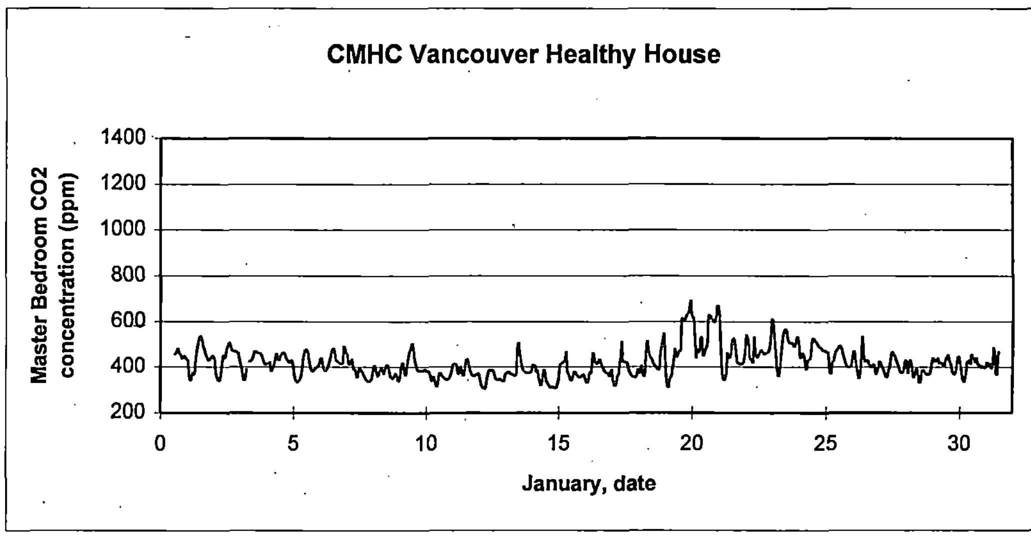


Figure C12.4
Carbon Dioxide Concentration

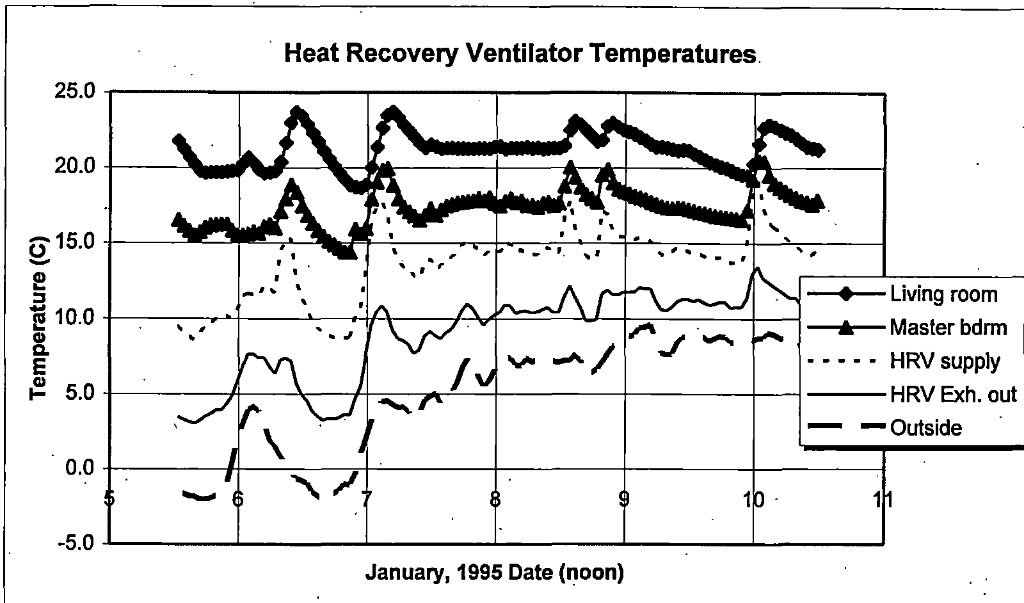


Figure C12.5
HRV Performance

For the period from January 6th to 10th, 1995

Average Conditions:		**Results:**	
Inside temperature:		Supply air temp. below inside:	5.7 C
Living room	21.2 C		
Master bedroom	17.4 C	Temperature recovery	60%
Inside average	19.3 C	(Tsupout - Tout)/(Tin - Tout)	
Heat recovery ventilator		HRV sensible efficiency	**53%**
Exhaust core out	9.0 C	assume: balanced 70 L/s	
Supply core out	13.6 C	no cross leakage	
		no supply duct pre-heat	
Outside temperature	5.1 C	fan power of 115 W	

February, 1995

Two to four adults occupying house.
Garage 23.7C with 9C outdoors on March 11th: electric heater on

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	15%	<350	23%
18-20	7%	61%	350-450	37%
20-22	32%	22%	450-550	32%
22-24	45%	2%	550-650	8%
24-26	16%	0%	650-750	1%
26-28	1%	0%	750-850	0%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	672	672		669

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	13.2	26.6	23.4	57%	737
Average	**6.4**	**22.3**	**19.3**	37%	427
Minimum	-3.5	18.6	16.3	15%	282

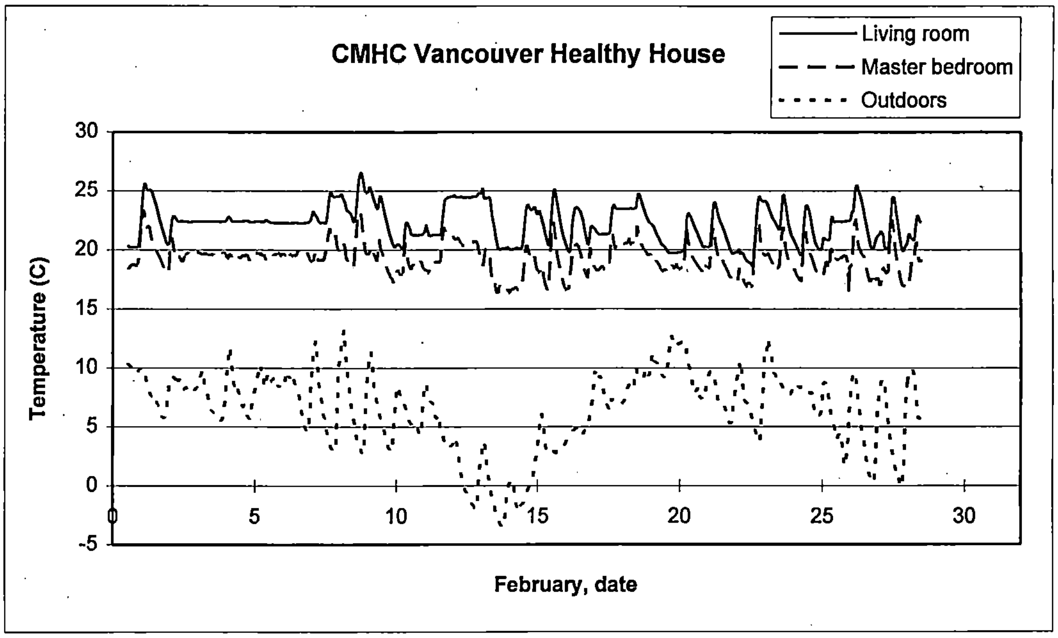


Figure C13.1
Inside & Outside Temperatures

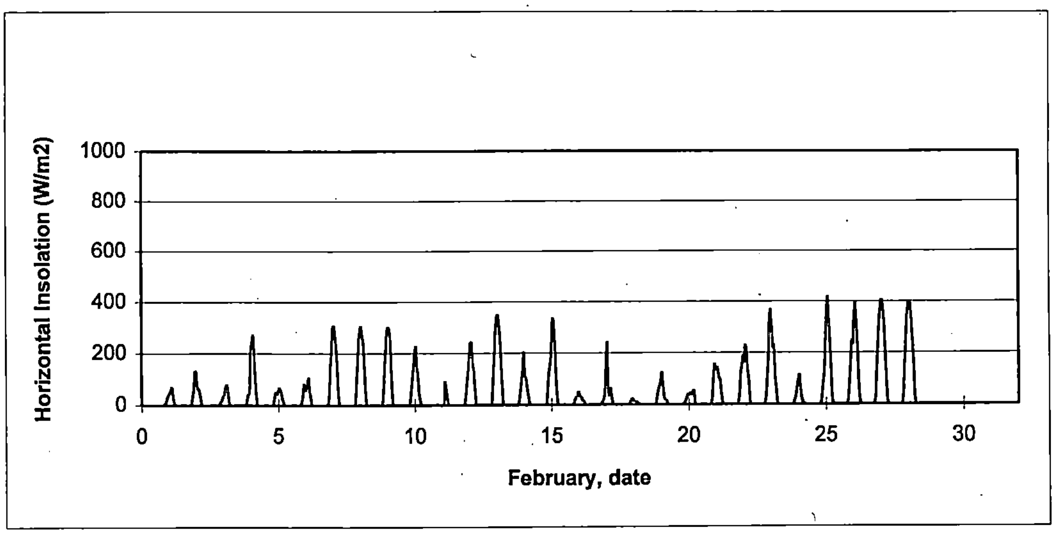


Figure C13.2
Horizontal Insolation

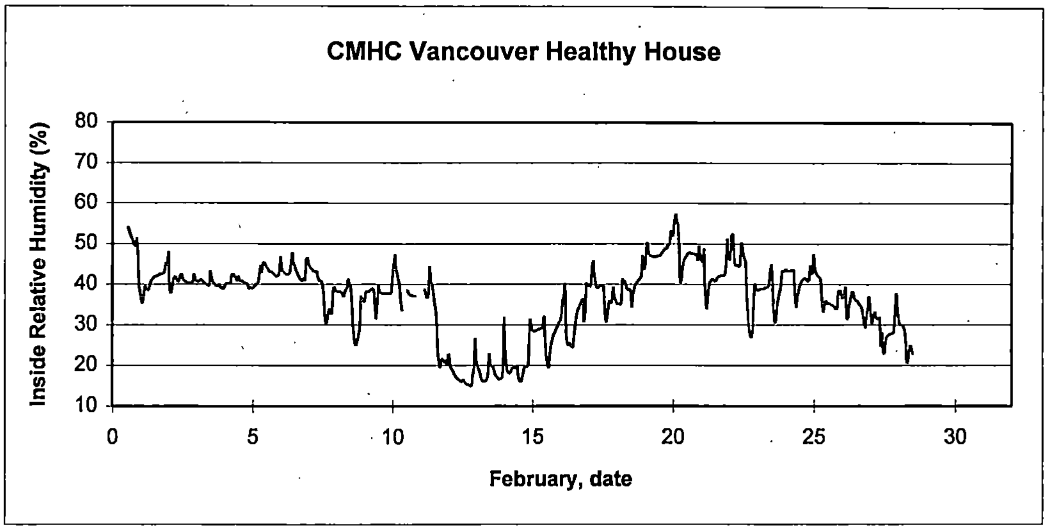


Figure C13.3
Inside Relative Humidity

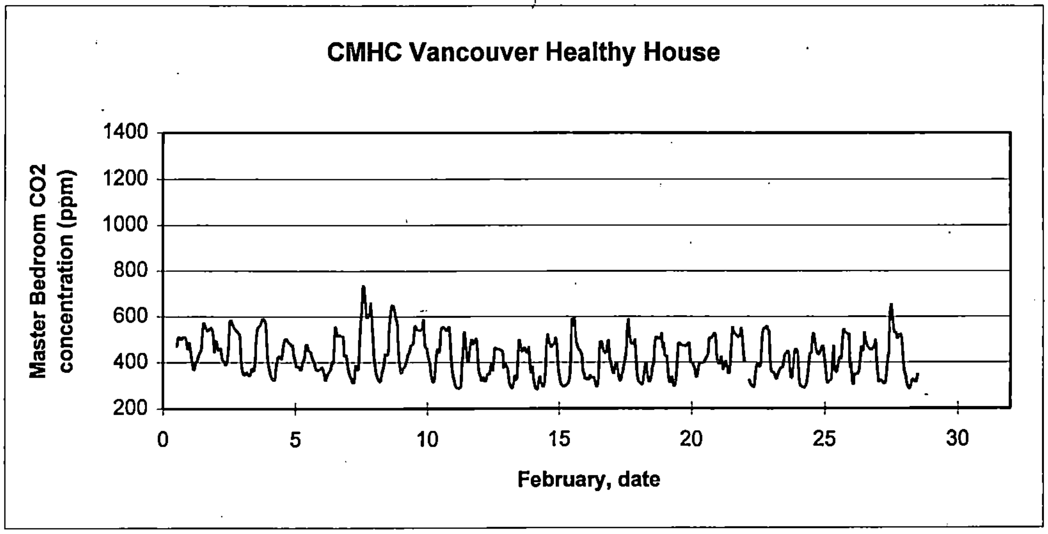


Figure C13.4
Carbon Dioxide Concentration

March, 1995

Two to three adults occupying house.
HRV fan on, using 104W (0.91 pf)
Furnace fan on continuous; using 211W (0.97 pf)

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	10%	<350	33%
18-20	6%	62%	350-450	44%
20-22	59%	26%	450-550	11%
22-24	31%	2%	550-650	5%
24-26	5%	0%	650-750	4%
26-28	0%	0%	750-850	1%
28-30	0%	0%	850-950	1%
>30	0%	0%	>950	0%
Total hours:	739	739		739

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	21.3	24.9	23.0	50%	1,029
Average	**8.0**	**21.8**	**19.4**	34%	412
Minimum	-0.7	18.6	16.3	19%	281

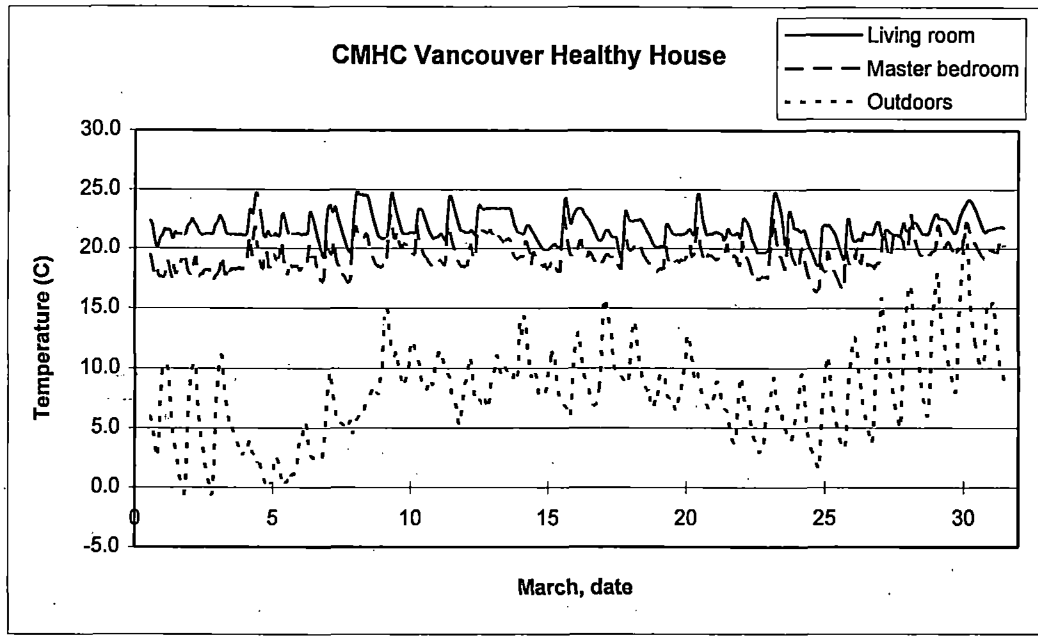


Figure C14.1
Inside & Outside Temperatures

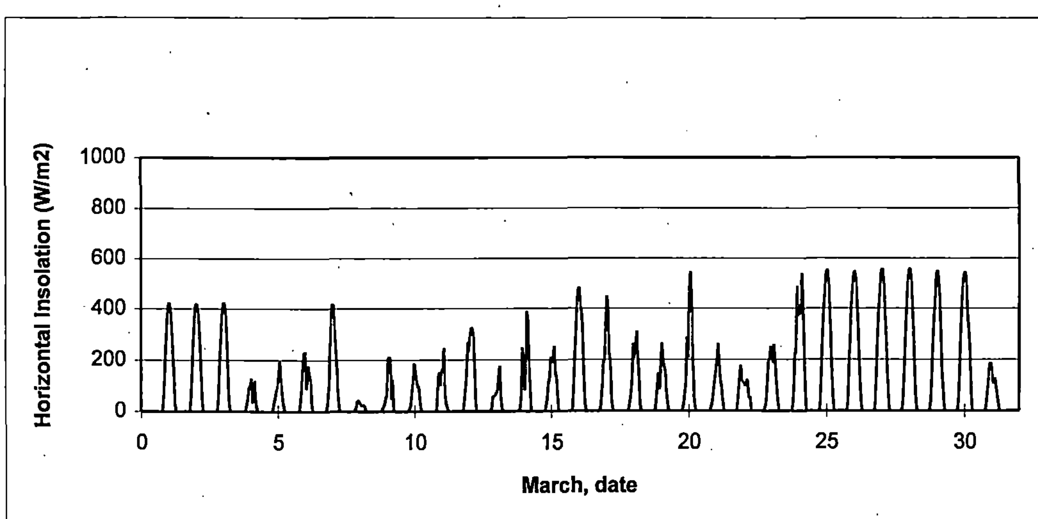


Figure C14.2
Horizontal Insolation

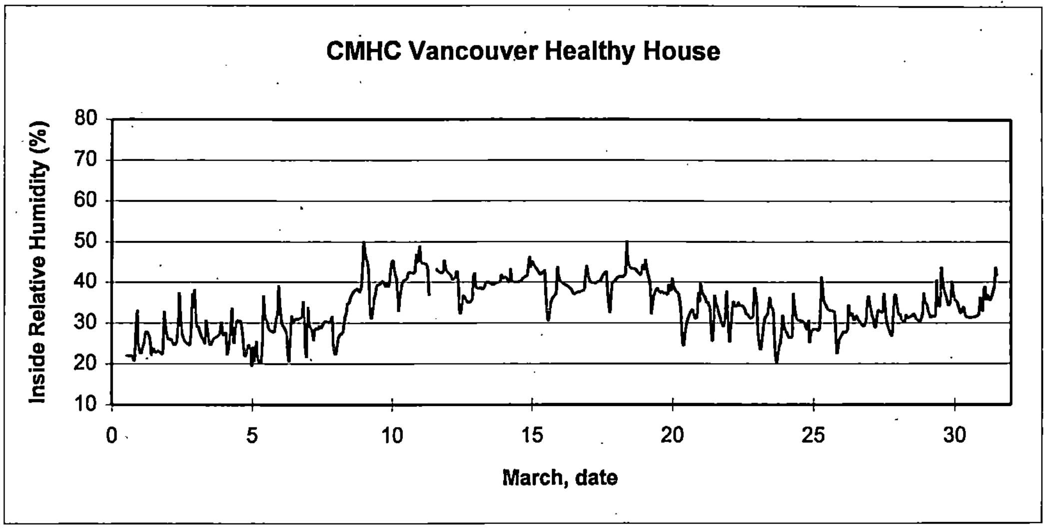


Figure C14.3
Inside Relative Humidity

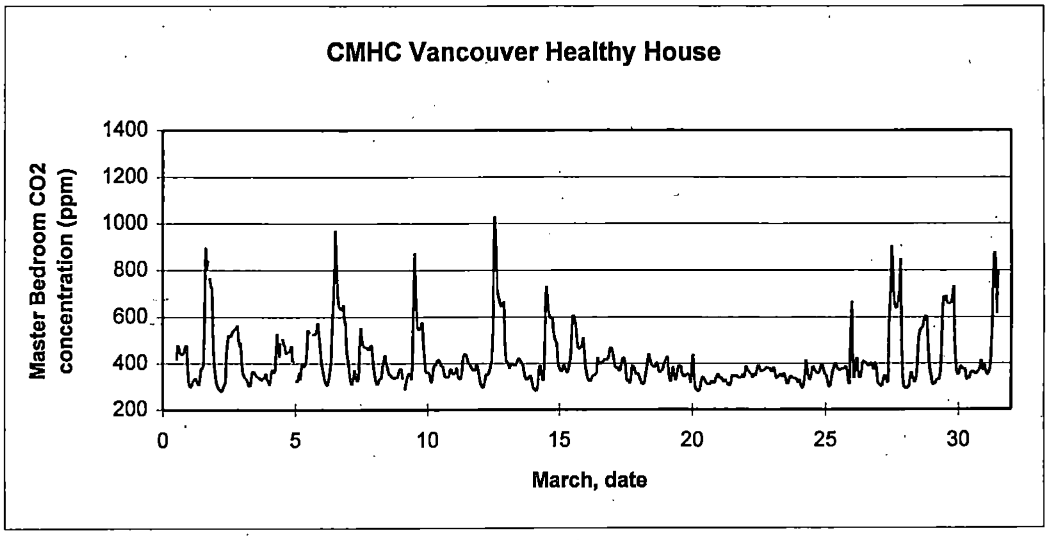


Figure C14.4
Carbon Dioxide Concentration

April, 1995

Two to three adults occupying house.
HRV fan on.

Temp. (C)	Living rm. % of time in each bin	M. Bdrm	CO2 concentration (ppm)	% of time
<18C	0%	10%	<350	32%
18-20	10%	50%	350-450	40%
20-22	63%	34%	450-550	15%
22-24	27%	6%	550-650	10%
24-26	0%	0%	650-750	2%
26-28	0%	0%	750-850	1%
28-30	0%	0%	850-950	0%
>30	0%	0%	>950	0%
Total hours:	718	718		718

	Outside (C)	Inside Conditions Living rm. (C)	M. Bdrm (C)	RH (%)	CO2 (ppm)
Maximum	22.6	24.2	24.0	48%	855
Average	**10.8**	**21.4**	**19.7**	37%	411
Minimum	3.3	18.9	16.7	24%	258

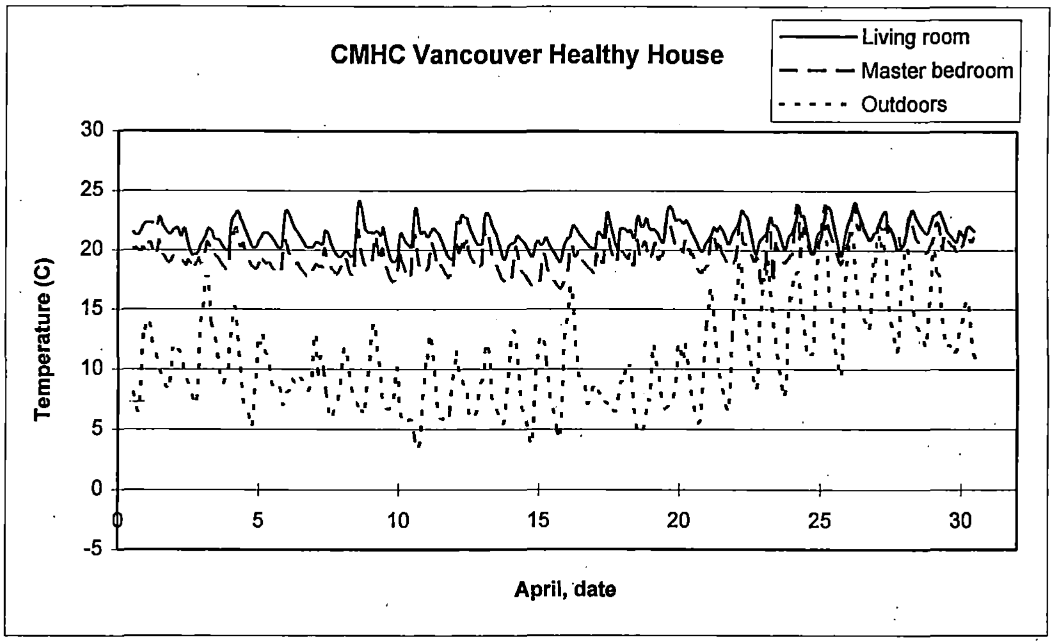


Figure C15.1
Inside & Outside Temperatures

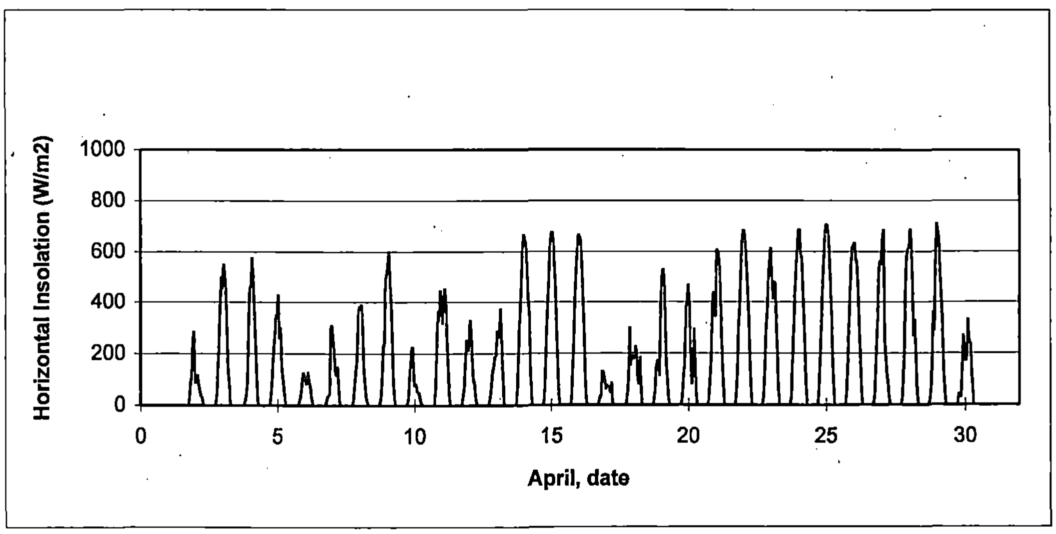


Figure C15.2
Horizontal Insolation

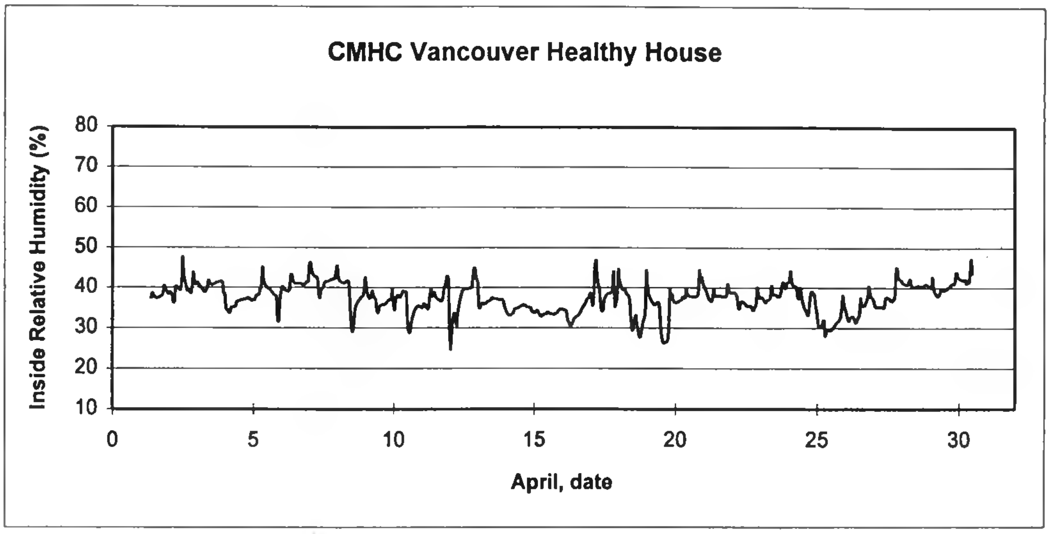


Figure C15.3
Inside Relative Humidity

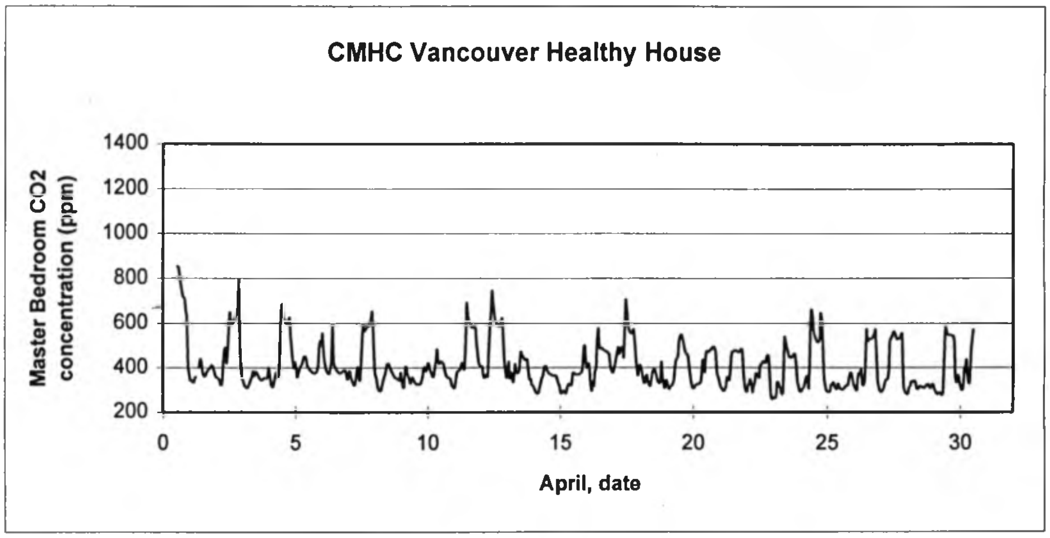


Figure C15.4
Carbon Dioxide Concentration