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Flair Homes Project
REPORT NO. 3
Design, Installation and Commissioning of the Ventilation Systems

Report of the Flair Homes
Enerdemo Canada/CHBA Mark XIV Project

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DESIGN, INSTALLATION AND COMMISSIONING
OF THE
VENTILATION SYSTEMS
IN THE
FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

PART OF THE

FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

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SUMMARY

Tracer gas tests and balancing studies were performed on the ventilation systems in ten houses to determine their performance under actual operating conditions. The work was performed as part of the Flair Homes Energy Demo/CHBA Flair Mark XIV Project in Winnipeg. The houses were unoccupied, unfurnished bungalows with identical floor plans and main floor areas of approximately 85 m^2. The ventilation systems studied consisted of:

1. Combined Heat Recovery Ventilator (HRV)/forced air heating systems
2. Dedicated HRV ventilation systems
3. Exhaust-only heat pump HRV ventilation systems (using a prototype HRV)
4. Integrated heat pump HRV, space and DHW heating systems

The tracer gas tests were used to determine the Total Ventilation Rates (TVR) and the Zone Ventilation Rates (ZVR). The TVR was defined as the total air exchange rate between the house and the outdoors due to the combined effects of the ventilation system and natural infiltration. The ZVR was defined as the total air exchange rate of outdoor air for a given zone within the house.

The Combined HRV/forced air heating and the Dedicated HRV ventilation systems, designed, installed and commissioned in accordance with recommended practice, were able to meet the design Total Ventilation Rates. The Integrated heat pump HRV, space and DHW heating systems also achieved the design rates although a large variation was noted between the two houses which used the system. One of the two houses which contained the (prototype) Exhaust-only heat pump HRV ventilation system had its Total Ventilation Rate measured. It did not achieve the design rates. Case and internal leakage in the HRV were believed to be the reason.

The Combined HRV/forced air heating and Integrated heat pump HRV, space and DHW heating systems were able to achieve the design Zone Ventilation Rates (ZVR) due to the high recirculation rates produced by the heating system blowers. The "contractor-delivered" Dedicated HRV and (prototype) Exhaust-only heat pump HRV ventilation systems did not meet the

design ZVR's. Once the Dedicated HRV systems were zone-balanced, they were able to achieve the design rates. Case and internal leakage are believed to be the reason the (prototype) Exhaust-only heat pump HRV system did not achieve the design ZVR rates.

The influence of interior door position upon ventilation rates was also studied. The Combined HRV/forced air heating systems, with return air registers in each zone, were found to be unaffected by door position. The Dedicated HRV ventilation systems, which used supply registers in each zone and relied upon under-door leakage for zone exhaust, were found to be only moderately affected. The (prototype) Exhaust-only HRV systems were also influenced by door position. No evaluations were performed on the Integrated heat pump HRV, space and DHW heating systems.

Duct and/or case leakage was found to be a significant problem in three of the systems studied. In the Dedicated HRV ventilation systems, duct leakage was identified as the reason for the system not being zone-balanced in the "contractor-delivered" state. Once the basement supply air grilles were closed off and only duct leakage was used to supply the basement, a satisfactory zone balance was achieved. The (prototype) Exhaust-only heat pump HRV ventilation systems demonstrated significant duct and case leakage which made proper balancing difficult. The Integrated heat pump HRV, space and DHW heating units were found to be extremely leaky. This created a problem since the systems moved large quantities of outdoor air into the house to serve as the "source" for the HRV's internal heat pump. As a result, case leakage from the units and their ductwork significantly degraded the measured airtightness of the houses.

Recommendations were made on: measures to control duct leakage and provide better zone distribution in several of the systems, the need to verify ventilation compliance in Integrated systems, testing of some HRV's at the manufacturing stage to assist in reducing leakage and the need to develop revised design procedures.

RÉSUMÉ

Des essais au gaz traçant et des analyses d'équilibrage ont été faites sur les installations de ventilation de dix maisons afin de déterminer leur performance dans des conditions réelles de service. Ces travaux ont été effectués à Winnipeg dans le cadre du projet Flair Mark XIV de Flair Homes Energy Demo et de l'ACCH. Les maisons étaient des bungalows inoccupés et sans ameublement ayant des plans d'étage identiques et une aire de rez-de-chaussée d'environ 85 m^2. Les installations de ventilation analysées étaient les suivantes :

1. Systèmes combinés-ventilateur récupérateur de chaleur (VRC) et chauffage à air pulsé.
2. Systèmes de ventilation dédiés avec VRC.
3. Installations de ventilation avec VRC et pompe à chaleur extraction seulement (utilisant un prototype de VRC).
4. Systèmes intégrés de chauffage d'eau sanitaire, chauffage des locaux, VRC et pompe à chaleur.

Les essais au gaz traçant ont été utilisés pour déterminer les débits de ventilation totaux (DVT) et les débits de ventilation de zone (DVZ). Le DVT était défini comme le débit total de renouvellement d'air entre la maison et l'extérieur par l'effet combiné de la ventilation mécanique et de l'infiltration naturelle. Le DVZ était défini comme le débit global de renouvellement d'air pour une zone donnée de la maison.

Les systèmes combinés VRC-chauffage à air pulsé et les systèmes dédiés de ventilation avec VRC, qui avaient été conçus, installés et mis en service conformément aux règles de l'art, pouvaient fournir les débits de ventilation totaux. Les systèmes intégrés de chauffage d'eau sanitaire, chauffage des locaux, VRC et pompe à chaleur permettaient également de fournir les débits de calcul bien qu'un écart important ait été relevé entre les deux maisons équipées de ces systèmes. On a mesuré le débit de ventilation total de l'une des maisons contenant le système de ventilation avec VRC et pompe à chaleur à extraction seulement (prototype). L'installation ne pouvait fournir les débits de calcul. La cause en a été imputée aux fuites par le carter et aux fuites internes dans le VRC.

Les systèmes combinés VRC-chauffage à air pulsé et les systèmes intégrés de chauffage d'eau sanitaire, chauffage des locaux, VRC et pompe à chaleur

pouvaient fournir les débits de ventilation de zone (DVZ) de calcul en raison des débits élevés de recirculation produits par les ventilateurs du système de chauffage. Les systèmes de ventilation dédiés avec VRC et pompe à chaleur à extraction seulement (prototype), tels que livrés par l'entrepreneur ne fournissaient pas les DVZ de calcul. Une fois que les systèmes dédiés à VRC ont été équilibrés par zones, ils ont pu produire les débits de calcul. On croit que les fuites par le carter et les fuites internes dans le VRC expliquent pourquoi le système avec VRC et pompe à chaleur à extraction seulement (prototype) ne pouvait fournir ces DVZ.

L'effet de l'emplacement de la porte intérieure sur les débits de ventilation a aussi été analysé. Les systèmes combinés VRC-chauffage à air pulsé, qui comportaient des grilles de reprise d'air dans chaque zone, n'étaient pas affectés par l'emplacement de la porte intérieure. Les systèmes dédiés de ventilation avec VRC, qui comportaient des grilles d'alimentation dans chaque zone et qui dépendaient des fuites sous la porte pour l'évacuation de l'air, semblaient être les seuls systèmes modérément affectés. L'emplacement de la porte avait aussi un effet sur les systèmes avec VRC-pompe à chaleur extraction seulement (prototype). Aucune évaluation n'a été effectuée sur les systèmes intégrés de chauffage d'eau sanitaire, chauffage des locaux, VRC et pompe à chaleur.

Les fuites par les conduits et/ou le carter ont posé des problèmes importants dans trois des systèmes analysés. Dans les systèmes de ventilation dédiés à VRC, le déséquilibre entre les zones des systèmes "tels que livrés par l'entrepreneur" a été imputé aux fuites par les conduits. Une fois que les grilles d'alimentation en air du sous-sol ont été obturées et que seules les fuites des conduits ont alimenté le sous-sol, un équilibre satisfaisant entre les zones a été réalisé. Les systèmes avec VRC-pompe à chaleur extraction seulement (prototype) subissaient d'importantes fuites par les conduits et le carter, ce qui rendait l'équilibrage difficile. Les systèmes intégrés de chauffage d'eau sanitaire, chauffage des locaux, VRC et pompe à chaleur se sont avérés très peu étanches. Ce défaut créait un problème étant donné que ces systèmes injectaient dans la maison des quantités importantes d'air extérieur qui servaient de "source" pour la pompe à chaleur intégrée au VRC. Par conséquent, les fuites par le carter des appareils et par leurs conduits diminuaient considérablement l'étanchéité à l'air mesurée des maisons.

Des recommandations ont été faites concernant les sujets suivants : les mesures à prendre pour limiter les fuites par les conduits et pour assurer une meilleure distribution aux zones dans plusieurs systèmes; la nécessité de vérifier si les débits de ventilation de calcul sont atteints par les systèmes intégrés; les essais à faire sur certains VRC lors de la fabrication afin de réduire les fuites et la nécessité de réviser les méthodes de conception.

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INTRODUCTION

1.1 MECHANICAL VENTILATION SYSTEMS

Tight building envelopes and a desire for improved control of indoor air quality have produced a growing requirement for mechanical ventilation systems in Canadian housing. While debate continues over which types of systems are most appropriate and what the cost impact will be on the price of a new home, there is no doubt that mechanical ventilation systems will be an integral component of future construction.

In recent years, this trend has been reflected in the development of ventilation standards. The 1980 National Building Code of Canada required that ventilation air (i.e. outdoor air) be supplied to each dwelling unit by either natural or mechanical means for houses heated with fuel-fired equipment (Ref. 1). A builder could meet this requirement by using operating windows or exhaust fans in rooms without windows. Implicit in this code requirement was the assumption that a significant portion of the ventilation air would be supplied by natural means through envelope leakage. The 1985 National Building Code became more explicit and requires all dwelling units to have a mechanical ventilation system capable of providing 0.5 air changes per hour, although the system is not required to operate continuously (Ref. 2). Further, there is no requirement for distribution of the ventilation air to the various rooms of the house.

ASHRAE 62-81, "Ventilation for Acceptable Indoor Air Quality", took a different approach to prescribing ventilation rates and uses the number of rooms rather than house volume as the determining factor, specifically requiring 5 litres/second (l/s) or 10 cubic feet per minute (CFM) per room (Ref. 3). The R-2000 Home Program ventilation requirements are based on ASHRAE 62-81 but have advanced the issue by stipulating distribution of the ventilation air to all rooms and defining limits on the degree of positive or negative pressurization which the ventilation system can impose across the building envelope (Ref. 4).

At the time of writing, the next step is being taken by the Canadian Standards Association with its "Residential Ventilation Requirements", CSA

F326. Currently in draft form, it would upon adoption, stipulate mechanical ventilation system requirements for all new houses (Ref. 5). This would include provisions for continuous mechanical distribution of ventilation air to all rooms, would restrict envelope pressure differentials, and would detail procedures to verify system performance.

Against this background of evolving technology and standards rests a growing need for a better understanding of the actual behaviour and characteristics of residential mechanical ventilation systems. The study described in this report was performed to add to that knowledge base.

1.2 THE FLAIR HOMES ENERGY DEMO/CHBA FLAIR MARK XIV PROJECT

The Flair Homes Energy Demo/CHBA Flair Mark XIV Project is a demonstration with three objectives:

1. To demonstrate and evaluate the performance of various low energy building envelope systems.
2. To demonstrate and evaluate the performance of various residential mechanical systems with particular emphasis on ventilation systems.
3. To transfer the knowledge gained in the project to the Canadian home building industry.

In addition, the project is structured to support the R-2000 Home Program funded by Energy, Mines and Resources Canada and administered by the Canadian Home Builders Association. The project acquired the Mark XIV designation when a substantial portion of the research priorities identified by the Technical Research Committee of the CHBA in 1983/84 was incorporated into the project.

Support for the project has been provided by Energy, Mines and Resources Canada under the Energy Demo Program and by Manitoba Energy & Mines under the Manitoba/Canada Conservation and Renewable Energy Demonstration Agreement (CREDA). Project management is the responsibility of Flair Homes (Manitoba) Ltd. Monitoring of the project houses is the responsibility of UNIES Ltd. and will continue until the spring of 1989.

To meet the project objectives, 20 houses employing various envelope and mechanical systems were constructed in 1985 and 1986 in the Genstar Development Co. Lakeside Meadows subdivision of Winnipeg. The houses were built by Flair Homes (Manitoba) Ltd. using two of their standard floor plans. The houses are divided into 10 pairs, with each pair having a different combination of envelope and mechanical systems. Conservation levels range from those of conventional houses to those which meet or exceed the R-2000 Standard.

1.3 OBJECTIVES

The broad objective of this study was to add to the knowledge base on residential mechanical ventilation system performance. Specifically, this report documents the experiences with the design, installation and commissioning of the mechanical ventilation systems in the Flair project.

1.4 REPORT STRUCTURE

Section 2 briefly describes the 20 project houses and their mechanical systems. Section 3 details the system design, installation and commissioning procedures and discusses the tracer gas and zone balancing work carried out on the ten houses studied. Sections 4 to 7 discuss the results of the monitoring for each system type. Conclusions on system performance and recommendations for action are presented in Section 8.

SECTION 2
HOUSE DESCRIPTIONS

2.1 SUMMARY DESCRIPTION

A summary of the 20 project houses is shown in Table 1 and more detailed descriptions are provided in Ref. 6. For this study, Houses #11 to #20 were available for detailed testing prior to possession by their owners. These were new, unoccupied single-family residences constructed and located adjacent to each other. Although built using a variety of envelope systems, their interiors were essentially identical: three bedroom bungalows with main floor areas of approximately 85 m^2 and internal volumes of 436 m^3. All had full depth cast-in-place concrete basements with concrete floor slabs. The air leakage of each house was measured using the fan depressurization test (Ref. 7) and the results shown in Table 2.

It should be noted that each pair of houses (e.g. #11/#12, #13/#14, etc.) was essentially identical in design, size and construction. Only small variations in the exterior architectural treatment and south-facing window layouts were allowed. The exteriors of all houses were designed to be stucco-covered on three sides. However, during the bulk of the testing described in this report, the stucco had not yet been applied.

2.2 VENTILATION SYSTEMS

The types of ventilation systems investigated in this study were:

- o Combined Heat Recovery Ventilator (HRV)/forced air heating system (#13, #14).
- o Dedicated HRV ventilation system (#19, #20).
- o Dedicated HRV ventilation system with a heat pump HRV (#17, #18).
- o Prototype exhaust-only heat pump HRV (#11, #12).
- o Integrated heat pump HRV, space and DHW heater (#15, #16).

Houses #11 to #20 used predominantly high sidewall supply registers in place of conventional floor registers to provide better ventilation distribution and to reduce homeowner discomfort caused by cool drafts.

TABLE 1
SUMMARY OF PROJECT HOUSES

HOUSE NO.	WALL CONSTRUCTION	BUILDING ENVELOPE AIR/VAPOUR BARRIER	BASEMENT INSULATION	ATTIC INSULATION	MECHANICAL SYSTEMS SPACE HEATING	DHW HEATING	VENTILATION SYSTEM	VENT. DIST-RIBUTION SYSTEM
1,2	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
3,4	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
5,6	38x140 (2x6), 38 mm (1½") Glasclad Insulated Sheathing c/w Tyvek Air Retarder (Reversed)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	HRV	Indirect Connection to Forced Air Heating System
7,8	38x140 (2x6)	ADA, Paint Vapour Barrier	Interior Batts/Framing	Cellulose Fibre	Forced Air Electric Furnace	Electric Tank	Central Exhaust	Fresh Air Intake to Return Air Plenum of Furnace
9,10	38x140 (2x6)	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Forced Air Naturally Aspirated, Gas Furnace	Gas Tank	Bathroom Exhaust Fan	None
11,12	38x140 (2x6), 51 mm (2") Glasclad Insulated Sheating c/w Tyvek Air Retarder (Taped)	ADA Limited Gaskets, Paint Vapour Barrier	76mm (3") Exterior Baseclad and 25mm (1") Glasclad Underslab	Blown Fiberglass	Electric Baseboards and Heat Pump	Heat Pump, Int. with Vent. System	Exhaust-only Heat Pump Int. with Space and DHW Systems	Envelope Leakage and Exhaust Vent. Heat Recovery
13,14	38x140 (2x6), 51 mm (2") Glasclad Insulated Sheating c/w Tyvek Air Retarder (Taped)	ADA Limited Gaskets, Paint Vapour Barrier	Interior Batts/Framing	Blown Fiberglass	Forced Air Electric Furnace	Electric Tank	HRV	Envelope Leakage and Unbalanced Heat Recovery Ventilator
15,16	Double Wall	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Air-to-Air Heat Pump Int. with Vent. and DHW Systems	2 Tank System Int. with Space Heating and Vent. Systems	A/A Heat Pump Int. with Forced Air Heating System	Combined Forced Air Heating and Ventilation System
17,18	Double Wall	6 mil Poly	Interior Batts/Framing	Cellulose Fibre	Electric Baseboards	Electric Tank	A/A Heat Pump HRV and Duct Heater	Dedicated Supply-only Ventilation System
19,20	38x89 (2x4), 51 mm (2") SM Insulated Sheathing	ADA, Paint Vapour Barrier	51mm (2") Exterior SM and Interior Batts/ Framing	Cellulose Fibre	Electric Baseboards	Electric Tank	HRV	Dedicated Supply-only Ventilation System

LEGEND

Int.	- Integrated	Vent.	- Ventilation	HRV	- Heat Recovery Ventilator
c/w	- Complete With	DHW	- Domestic Hot Water		
ADA	- Airtight Drywall Approach	A/A	- Air to Air		

TABLE 2

AIRTIGHTNESS TEST RESULTS
HOUSES #11 to #20

HOUSE	ac/hr_{50} [1]	NLA [2] (cm^2/m^2)
11 12	1.69 1.59	0.75 0.84
13 14	1.27 1.32	0.57 0.75
15 16	1.47 1.26	0.77 0.68
17 18	0.55 0.49	0.28 0.26
19 20	1.05 1.13	0.44 0.56

NOTES

1. Air Changes Per Hour at a pressure differential of 50 Pascals.
2. Normalized Leakage Area at 10 Pascals.
3. All tests performed in accordance with CAN/CGSB-149.10-M.
4. Stucco not applied at time of tests.

The brands of HRV's used in the project were selected because they were considered typical of the industry's product for each type of unit.

SECTION 3
PROCEDURES AND EXPERIMENTAL METHODS

3.1 DESIGN

The mechanical systems in Houses #11 to #20 were designed by UNIES Ltd. in compliance with recommended design practices. The forced air heating systems (Houses #13, #14, #15 and #16) were designed according to the "Residential System Design Manual", published by the Heating, Refrigerating and Air Conditioning Institute of Canada (HRAI), (Ref. 8). The ventilation systems were designed using a version of Ref. 8, which has subsequently been modified into the "Design Manual for Residential Ventilation Systems" also published by the HRAI (Ref. 9).

3.2 INSTALLATION AND COMMISSIONING

Houses #11 to #20 were completed in the spring of 1986. All system installations were performed by a large mechanical contracting firm with several years of experience on a variety of residential mechanical system installations including HRV's in R-2000 houses. Additional on-site support and inspections were provided by the system designers.

For testing, Houses #11 to #18 and #20 were left in a "contractor-delivered" state in which only the total ventilation supply and exhaust flow rates were measured and adjusted to their design values. A single house, #19, was also zone-balanced to adjust the internal air distribution.

3.3 TRACER GAS TESTING

Tracer gas tests were performed to determine the actual air change rate experienced by the house due to the combined effects of mechanical ventilation and natural infiltration.

3.3.1 N_2O Testing

Prior to occupancy by their owners, the ventilation systems in Houses #11 to #20 were evaluated using the N_2O grab bag tracer gas decay technique. In addition, continuous air change rate measurements were performed on Houses #12 and #13 using the constant concentration SF_6 tracer gas technique. This work was performed by personnel from the Institute for Research in Construction (IRC) in Saskatoon (Ref. 10). With the exception of the stucco, the houses were complete at the time of testing. However, no interior furnishings had been installed.

The total mechanical ventilation supply and exhaust rates were measured using calibrated C.E.S. eight point pitot tube Flow Measuring Stations (FMS) installed in the ductwork. The grid pressure was measured using an inclined fluid manometer with an accuracy of ± 0.5 Pa. Air flow rates through room supply and exhaust grilles were measured by traversing the grilles using a TSI Model 1650 heated probe anemometer.

Blueprints and field measurements were used to calculate the interior volumes of the houses. The houses were subdivided into four zones:

1. 2nd bedroom
2. master bedroom
3. kitchen/living room/dining room/hall/3rd bedroom/bathroom
4. basement

The N_2O tracer gas experiments involved manually injecting a volume of N_2O gas into the house (with all interior doors open) to produce an initial concentration of approximately 100 ppm. Over time, this concentration diminished as outdoor air was introduced into the zone by the ventilation system or natural infiltration.

Approximately 15 minutes after the N_2O gas was injected, a grab sample of air was taken from each zone using a hand pump to collect a one litre air sample in a mylar gas sample bag. The pump inlet was moved throughout the zone during the sampling to achieve an "average" sample for the zone. Three additional consecutive grab samples were taken in each zone at approximately twelve minute intervals. The interior doors were then closed, isolating the zones from each other, and after 15 minutes, another series of four grab samples was taken. By measuring the decay rate of N_2O, the ventilation rate was determined. Because of the degree of operator input, there was no strict control of the initial concentration of N_2O in each zone.

A Beckman Model 865 infrared gas analyzer was used to measure the N_2O concentration of the grab samples.

3.3.2 SF_6 Testing

Continuous four-zone air exchange rate measurements were taken over approximately four day intervals in Houses #12 and #13 using an IRC developed constant concentration SF_6 tracer gas system. This technique determines the total air change rate by measuring the amount of SF_6 required to maintain a constant level of tracer in the house. The SF_6 concentration in each zone was sampled every three to five minutes and equivalent air change rates calculated for each two hour interval.

3.3.3 Analysis

Two basic criteria commonly used to define ventilation in buildings are:

1) Total Ventilation Rate (TVR)

The TVR is defined as the total outdoor air exchange rate (air changes per hour, ac/hr) for the building enclosure. It is calculated as:

$$TVR = \frac{Q_T}{V_T} \tag{1}$$

where:

Q_T = total outdoor air flow rate to the building (m³/hr)

V_T = total building volume (m³)

2) Zone Ventilation Rate (ZVR)

The ZVR is defined as the outdoor air exchange rate (ac/hr) for a specific area (zone) within the building enclosure. It is calculated as:

$$ZVR = \frac{Q_Z}{V_Z} \tag{2}$$

where:

Q_Z = net outdoor air flow rate to the zone (m³/hr)

V_Z = zone volume (m³)

The basic difference between the ZVR and the TVR is that the ZVR considers ventilation air distribution within the house.

The ventilation rate in each zone (ZVR) was calculated from the N_2O tracer gas test data using the equation:

$$C_i(t) = C_{io}e^{-(ZVR)\ t} \qquad (3)$$

where:

$C_i(t)$ = indoor N_2O concentration measured at time t
C_{io} = initial indoor N_2O concentration

With knowledge of the initial N_2O concentration in the zone (C_{io}) and the concentrations (C_i) over measured periods of time, the Zone Ventilation Rate can be determined.

The design ZVR, measured TVR rates and "Apparent" ZVR values for the N_2O and SF_6 tracer gas testing are shown in Tables 3(a), 3(b); 4(a), 4(b) and 5(a), 5(b). The design rates were calculated in accordance with the R-2000 Installation Guidelines to Ventilation Systems (Ref. 4). Since the calculated zone rates are derived from the net exchange of N_2O in the zone, they cannot explicitly distinguish between outside (fresh) air and air from another zone at a different N_2O concentration. Therefore, the term Apparent is used to describe the ZVR values in Tables 4 and 5. Apparent and Actual values for a given zone can be significantly different when the zone receives (tracer-laden) air from another zone. For example, with the Dedicated ventilation systems, Zone 3 (the kitchen/living room/dining room/hall/3rd bedroom/bathroom) would receive inflow from Zones 1 and 2 thus increasing or decreasing the N_2O concentration and suggesting a lower- or higher-than-actual ventilation rate. When no inflow exists from another zone (such as for Zones 1 and 2), the Apparent ZVR can be regarded as a reasonable estimate of the Actual ZVR. Plots of the tracer gas decay curves are attached in Appendix A.

TABLE 3 (a)

TOTAL VENTILATION RATES
(AIR CHANGES/HOUR)

HOUSE	VENTILATION SYSTEM	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	DESIGN TVR FOR OPERATIONAL MODE	FMS-MEASURED TVR	N_2O-DETERMINED TVR[1]	
					INTERIOR DOORS OPEN	INTERIOR DOORS CLOSED
11	Exhaust-only Heat Pump HRV	Speed 4	0.62	0.56	0.38	0.50
12		Speed 1	see note 2	0.18	0.15	0.22
13	Combined HRV/Forced Air Heating System	Low	0.47	0.54	0.67	0.64
14		Low	0.47	0.43	0.53	0.49
15	Integrated Heat Pump HRV, Space & DHW Heating System	High (doors open)/ Low (doors closed)	0.62/0.47	Not Done	0.59	0.24
16		High (doors open)/ Low (doors closed)	0.62/0.47	Not Done	0.39	0.26
17	Heat Pump HRV with Dedicated Ventilation System	Low	0.47	0.50	0.61	0.58
18		Low	0.47	0.47	0.59	0.60
19	HRV with Dedicated Ventilation System	High	0.62	0.62	0.72	0.77
20		High	0.62	0.62	0.78	0.79

Notes

1. N_2O-determined TVR values include natural air infiltration.
2. The Exhaust-only heat pump HRV used a 4-speed control on the ventilation system. Speed (1) did not correspond to the design TVR at "low" speed.

TABLE 3 (b)

TOTAL VENTILATION RATES
(LITRES/SECOND)

HOUSE	VENTILATION SYSTEM	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	DESIGN TVR FOR OPERATIONAL MODE	FMS-MEASURED TVR	N_2O-DETERMINED TVR[1] INTERIOR DOORS OPEN	N_2O-DETERMINED TVR[1] INTERIOR DOORS CLOSED
11	Exhaust-only Heat Pump HRV	Speed 4	75	68	46	61
12		Speed 1	see note 2	22	18	27
13	Combined HRV/Forced Air Heating System	Low	57	65	81	78
14		Low	57	52	64	59
15	Integrated Heat Pump HRV, Space & DHW Heating System	High (doors open)/ Low (doors closed)	75/57	Not Done	71	29
16		High (doors open)/ Low (doors closed)	75/57	Not Done	47	31
17	Heat Pump HRV with Dedicated Ventilation System	Low	57	61	74	70
18		Low	57	57	71	73
19	HRV with Dedicated Ventilation System	High	75	75	87	93
20		High	75	75	94	96

Notes

1. N_2O-determined TVR values include natural air infiltration.
2. The Exhaust-only heat pump HRV used a 4-speed control on the ventilation system. Speed (1) did not correspond to the design TVR at "low" speed.

TABLE 4 (a)

N_2O-DETERMINED APPARENT ZONE VENTILATION RATES
(AIR CHANGES/HOUR)

HOUSE	VENTILATION SYSTEM	INTERIOR DOOR POSITION	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	DESIGN ZVR	ZONE 1	ZONE 2	ZONE 3	ZONE 4
				LOW	1.02	0.78	0.78	0.16
				HIGH	1.37	1.05	1.05	0.22
11	Exhaust-only Heat Pump HRV	Open	Speed 4		0.84	0.68	0.73	0
		Closed	Speed 4		0.93	0.50	0.44	0.49
12		Open	Speed 1		0.34	0.40	0.27	0
		Closed	Speed 1		0.31	0.25	0.25	0.18
13	Combined HRV/Forced Air Heating System	Open	Low		0.55	0.55	0.96	0.63
		Closed	Low		0.65	0.68	0.62	0.64
14		Open	Low		0.50	0.49	0.51	0.55
		Closed	Low		0.52	0.51	0.47	0.50
15	Integrated Heat Pump HRV, Space & DHW Heating System	Open	High		0.64 (0.64)	0.60 (0.61)	0.60 (0.70)	0.58 (0.27)
		Closed	Low		0.25	0.27	0.25	0.23
16		Open	High		0.54	0.51	0.44	0.32
		Closed	Low		0.27	0.24	0.27	0.26
17	Heat Pump HRV with Dedicated Ventilation System	Open	Low		0.62	0.60	0.58	0.64
		Closed	Low		1.08	0.53	0.43	0.66
18		Open	Low		0.58	0.58	0.47	0.69
		Closed	Low		0.95	0.44	0.51	0.66
19	HRV with Dedicated Ventilation System	Open	High		1.26	1.25	1.11	0.26
		Closed	High		1.45	0.92	0.87	0.58
20		Open	High		0.51	0.55	0.97	0.84
		Closed	High		1.50	0.31	0.73	0.85

Notes

1. Apparent ZVR values include natural air infiltration.
2. Bracketted figures for House #15 were re-test values, with drain holes in bottom of HRV cabinet blocked.

TABLE 4 (b)

N_2O-DETERMINED APPARENT ZONE VENTILATION RATES
(LITRES/SECOND)

HOUSE	VENTILATION SYSTEM	INTERIOR DOOR POSITION	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	DESIGN ZVR	ZONE 1	ZONE 2	ZONE 3	ZONE 4
				LOW	8.8	10.6	26.4	10.4
				HIGH	11.8	14.3	35.5	14.3
11	Exhaust-Only Heat Pump HRV	Open	Speed 4		7.2	9.2	24.7	0
		Closed	Speed 4		8.0	6.8	14.9	31.9
12		Open	Speed 1		2.9	5.4	9.1	0
		Closed	Speed 1		2.7	3.4	8.5	11.7
13	Combined HRV/Forced Air Heating System	Open	Low		4.7	7.5	32.4	41.0
		Closed	Low		5.6	9.2	21.0	41.6
14		Open	Low		4.3	6.7	17.2	35.8
		Closed	Low		4.5	6.9	15.9	32.5
15	Integrated Heat Pump HRV, Space & DHW Heating System	Open	High		5.5 (5.5)	8.2 (8.3)	20.3 (23.7)	37.7 (17.6)
		Closed	Low		2.2	3.7	8.5	15.0
16		Open	High		4.6	6.9	14.9	20.8
		Closed	Low		2.3	3.3	9.1	16.9
17	Heat Pump HRV with Dedicated Ventilation System	Open	Low		5.3	8.2	19.6	41.6
		Closed	Low		9.3	7.2	14.5	42.9
18		Open	Low		5.0	7.9	15.9	44.9
		Closed	Low		8.2	6.0	17.2	42.9
19	HRV with Dedicated Ventilation System	Open	High		10.8	17.0	37.5	16.9
		Closed	High		12.5	12.5	29.4	37.7
20		Open	High		4.4	7.5	32.8	54.6
		Closed	High		12.9	4.2	24.7	55.3

Notes

1. Apparent ZVR values include natural air infiltration.
2. Bracketted figures for House #15 were re-test values, with drain holes in bottom of HRV cabinet blocked.

TABLE 5 (a)

APPARENT ZONE VENTILATION RATES WITH CONTINUOUS SF_6 TRACER GAS MONITORING

(AIR CHANGES/HOUR)

HOUSE	VENTILATION SYSTEM	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	ZONE VENTILATION RATES ZONE 1 (MEAN/SD)	ZONE 2 (MEAN/SD)	ZONE 3 (MEAN/SD)	ZONE 4 (MEAN/SD)	TVR
12	Exhaust-only Heat Pump HRV	Speed 4	0.61/0.38	0.45/0.29	0.44/0.19	0.66/0.23	0.57
13	Combined HRV/Forced Air Heating System	Automatic[2]	0.87/0.19	0.42/0.17	0.58/0.27	0.87/0.15	0.74

Notes

1. SD = Standard Deviation.
2. HRV under automatic dehumidistat control.

TABLE 5 (b)

APPARENT ZONE VENTILATION RATES WITH CONTINUOUS SF_6 TRACER GAS MONITORING

(LITRES/SECOND)

HOUSE	VENTILATION SYSTEM	MODE OF OPERATION OF VENTILATION SYSTEM DURING TESTS	ZONE VENTILATION RATES ZONE 1 (MEAN/SD)	ZONE 2 (MEAN/SD)	ZONE 3 (MEAN/SD)	ZONE 4 (MEAN/SD)	TVR
12	Exhaust-only Heat Pump HRV	Speed 4	5.2/3.3	6.1/3.9	14.9/6.4	42.9/15.0	69.0
13	Combined HRV/Forced Air Heating System	Automatic[2]	7.5/1.6	5.7/2.3	19.6/9.1	56.6/9.8	89.6

Notes

1. SD = Standard Deviation.
2. HRV under automatic dehumidistat control.

The TVR values were calculated by combining the four measured zone ventilation rates as:

$$TVR = \Sigma \ ZVR_n \cdot VF_n \qquad (4)$$

where:

ZVR = ventilation rate for the zone

VF_n = fraction of the total building volume contained in the zone

The TVR is an explicit measurement of the total indoor-to-outdoor air exchange since it is based on the total mass balance of the tracer gas in the entire building. Both tracer gas techniques assume perfect mixing of the tracer within the zone. In houses with high air recirculation rates, such as those with combinations of HRV/forced air heating systems, this is a reasonable assumption. For systems without mechanical recirculation capability, such as dedicated HRV systems, mixing will be less pronounced and the tracer gas results should be viewed accordingly.

3.4 BALANCING

Detailed balancing exercises were carried out in seven of the houses (#11 to #14 and #18 to #20). Houses #15 to #17 were not available for testing. With the exception of House #19, these were performed after the tracer gas testing had been completed. Protocols varied somewhat depending on the type of system, but typically consisted of measuring the branch and main duct flow rates in the system and then making the necessary adjustments to achieve the design flow rates. In the case of forced air heating systems, only the total supply and exhaust rates were measured and adjusted.

Branch duct air flows were measured at the appropriate supply or exhaust grille by traversing the face of the grille with a heated probe anemometer. Average grille face velocities were then multipled by the grille free area to estimate the total air flow rate. Main duct flow rates were measured using the permanently installed Flow Measuring Stations (FMS).

The results are summarized in the house Balancing Reports in Tables 6 to 12 which give the design and measured flow rates at different locations in the systems under various operating conditions. They should be read in conjunction with the system schematics which appear in following sections. The information is arranged in chronological order and reads from top to bottom. The top row of each report gives the design flow rates in litres per second. The measured flow rates are then reported at various locations in the system with the house in a "contractor-delivered" state. Subsequent measured flow rates are shown after specific "actions" have been performed on the system. The nomenclature used is as follows:

ST	- Total supply flow rate of ventilation (i.e. outdoor) air measured at the HRV
S1, S2, etc.	- Measured supply flow rate of ventilation air at grilles S1, S2, etc.
ΣS	- The sum of S1, S2, etc.
ET	- Total exhaust air flow rate measured at the HRV
E1, E2, etc.	- Measured exhaust air flow rate measured at grilles E1, E2, etc.
ΣE	- The sum of E1, E2, etc.
RT	- Total recirculation air flow rate measured at the HRV (Exhaust-only heat pump HRV only)
[ ]	- Indicates that the measurement was performed with the system operating at low speed

These symbols are also used in the system schematics.

Notice that differences between "ST" and "ΣS" and between "ET" and "ΣE" represent duct leakage in the supply and exhaust systems respectively.

Most of the measurements were conducted with the systems operating at high speed whereas most of the N_2O tests (with the exception of those in Houses #11, #19 and #20) were carried out with the systems in low speed.

TABLE 6
BALANCING REPORT, HOUSE #11
MEASURED FLOW RATES (l/s)

HOUSE #11; EXHAUST-ONLY HEAT PUMP HRV

DESIGN			76			
LOCATION	RT	ST	E1&E2	ET	ACTION	COMMENTARY
						o HOUSE IN "CONTRACTOR-DELIVERED" STATE o E3 CLOSED
					o UNIT IN "WINTER" MODE, EXHAUST FAN ON HIGH (SPEED 4)	
	44	0	62	69		o 7 l/s OF LEAKAGE INTO EXHAUST DUCTWORK FROM HOUSE o ENVELOPE LEAKAGE (69-0) = 69 l/s
					o EXHAUST FAN SET TO SPEED 3	
				50	o EXHAUST FAN SET TO SPEED 2	
				40	o EXHAUST FAN SET TO SPEED 1	
				31		
					o UNIT SET TO "SUMMER" MODE, EXHAUST FAN ON HIGH (SPEED 4)	
	77	0	55	56		o 1 l/s OF LEAKAGE INTO EXHAUST DUCTWORK o ENVELOPE LEAKAGE (56-0) = 56 l/s

SUMMARY
o Exhaust duct leakage in "winter" mode at Speed 4: 10% of ET (7/69)
o Exhaust duct leakage in "summer" mode at Speed 4: 2% of ET (1/56)
o Induced envelope leakage in "winter" mode at Speed 4: 69 l/s
o Induced envelope leakage in "summer" mode at Speed 4: 56 l/s

TABLE 7
BALANCING REPORT, HOUSE #12
MEASURED FLOW RATES (l/s)

HOUSE #12; EXHAUST-ONLY HEAT PUMP HRV

DESIGN				76		
LOCATION	RT	ST	E1&E2	ET	ACTION	COMMENTARY
						o HOUSE IN "CONTRACTOR-DELIVERED" STATE
					o UNIT IN "WINTER" MODE, EXHAUST FAN ON HIGH (SPEED 4)	
	57	12	67	57		o MINIMUM 20 l/s OF LEAKAGE OUT OF EXHAUST DUCTWORK INTO HOUSE o ENVELOPE LEAKAGE (57-12) = 45 l/s
				39	o EXHAUST FAN SET TO SPEED 3	
				30	o EXHAUST FAN SET TO SPEED 2	
				21	o EXHAUST FAN SET TO SPEED 1	
	66	0	47	65	o UNIT SET TO "SUMMER" MODE, EXHAUST FAN ON HIGH (SPEED 4)	o 18 l/s OF LEAKAGE INTO EXHAUST DUCTWORK o ENVELOPE LEAKAGE (65-0) = 65 l/s

SUMMARY

- o Exhaust duct leakage in "winter" mode at Speed 4: 35% of ET (20/57)
- o Exhaust duct leakage in "summer" mode at Speed 4: 28% of ET (18/65)
- o Induced envelope leakage in "winter" mode at Speed 4: 45 l/s
- o Induced envelope leakage in "summer" mode at Speed 4: 65 l/s

TABLE 8
BALANCING REPORT, HOUSE #13
MEASURED FLOW RATES (l/s)

HOUSE #13; COMBINED HRV/FORCED AIR HEATING SYSTEM

LOCATION	ST	ET	ACTION	COMMENTARY
DESIGN	76	76		
				o HOUSE IN "CONTRACTOR-DELIVERED" STATE
	89	71 75	o EXHAUST DUCTWORK TAPED BETWEEN HRV & FMS	o 4 l/s OF LEAKAGE ELIMINATED DUE TO TAPING
	75		o ST DAMPER ADJUSTED TO BALANCE SUPPLY & EXHAUST FLOWS o HRV SET TO LOW SPEED, SPEED CONTROL ADJUSTED TO GIVE MINIMUM FLOW OF (APPROX.) 57 l/s	
	[56]	[58]		o LOW SPEED FLOWS OUT OF BALANCE BY -2 l/s

SUMMARY
o Exhaust duct leakage between HRV and Flow Measuring Station: 5% of ET (4/75)

TABLE 9
BALANCING REPORT, HOUSE #14
MEASURED FLOW RATES (l/s)

HOUSE #14; COMBINED HRV/FORCED AIR HEATING SYSTEM

DESIGN	76	76		
LOCATION	ST	ET	ACTION	COMMENTARY
				o HOUSE IN "CONTRACTOR-DELIVERED STATE
		71	o EXHAUST DUCTWORK TAPED BETWEEN HRV & FMS o ST DAMPER ADJUSTED TO BALANCE SUPPLY & EXHAUST FLOWS	
	74	76		o 5 l/s OF LEAKAGE ELIMINATED DUE TO TAPING o HIGH SPEED FLOWS OUT OF BALANCE BY -2 l/s
	[57]	[65]	o HRV SET TO LOW SPEED, SPEED CONTROL ADJUSTED TO GIVE MINIMUM FLOW OF 57 l/s	o LOW SPEED FLOWS OUT OF BALANCE BY +9 l/s

SUMMARY
o Exhaust duct leakage between HRV and Flow Measuring Station: 7% of ET (5/76)

TABLE 10
BALANCING REPORT, HOUSE #18
MEASURED FLOW RATES (l/s)

HOUSE #18; HEAT PUMP HRV WITH DEDICATED VENTILATION SYSTEM

LOCATION	S1	S2	S3	S4	S5	S6	ΣS	ST	E1	E2	E3	ΣE	ET	ACTION TAKEN	COMMENTARY
DESIGN	24	14	12	12	7	7	76	76	38	19	19	76	76		
															o HOUSE IN "CONTRACTOR-DELIVERED STATE
													59 74	o 2 m OF EXHAUST DUCTWORK TAPED BETWEEN HRV & FMS	o 15 l/s OF LEAKAGE ELIMINATED DUE TO TAPING
														o INLINE DUCT FILTERS REPLACED BY INLINE SOCK FILTERS	
	9	6	5	3	13	15	51	64	25	21	22	68	72		o DUCT LEAKAGE:SUPPLY-13 l/s EXHAUST-4 l/s
								64	33	28	6	67	70	o E3 DAMPER (LAUNDRY ROOM EXHAUST) CLOSED	o HIGH SPEED FLOWS OUT OF BALANCE BY +6 l/s
								[54]					[49]	o HRV SET TO LOW SPEED	o LOW SPEED FLOWS OUT OF BALANCE BY +5 l/s

SUMMARY
- o Exhaust duct leakage between HRV and Flow Measuring Station: 20% of ET (15/74)
- o Exhaust duct leakage (after taping 2 m of ductwork): 6% of ET (4/72)
- o Supply duct leakage: 20% of ST (13/64)

TABLE 11
BALANCING REPORT, HOUSE #19
MEASURED FLOW RATES (l/s)

HOUSE #19; HRV WITH DEDICATED VENTILATION SYSTEM

DESIGN	24	14	12	12	7	7	76	76	38	19	19	76	76		
LOCATION	S1	S2	S3	S4	S5	S6	ΣS	ST	E1	E2	E3	ΣE	ET	ACTION	COMMENTARY
															o HOUSE IN "CONTRACTOR-DELIVERED STATE
								82					89	o ALL DUCTWORK TAPED BETWEEN HRV & BOTH FMS STATIONS	
	18	4	12	9	17	17	77	85					89		o DUCT LEAKAGE:SUPPLY -8 l/s
	23	8	9	15	4	8	66	85						o S5 & S6 DAMPERS (BSMT.) CLOSED AND S3 DAMPER (BDRM) PARTIALLY CLOSED	o DUCT LEAKAGE:SUPPLY-19 l/s

SUMMARY
o Supply duct leakage: 9% of ST (8/85)
o Supply duct leakage (basement dampers closed and one bedroom damper partially closed): 22% of ST (19/85)

TABLE 12
BALANCING REPORT, HOUSE #20
MEASURED FLOW RATES (l/s)

HOUSE #20; HRV WITH DEDICATED VENTILATION SYSTEM

DESIGN	24	14	12	12	7	7	76	76	38	19	19	76	76		
LOCATION	S1	S2	S3	S4	S5	S6	ΣS	ST	E1	E2	E3	ΣE	ET	ACTION	COMMENTARY
															o HOUSE IN "CONTRACTOR-DELIVERED STATE o SUPPLY AIR GRILLES NOT INSTALLED
	15	3	10	7	15	17	67	76					85 76	o MAIN SUPPLY & EXHAUST DAMPERS PARTIALLY CLOSED	
								[57]					[57]	o SUPPLY AIR GRILLES INSTALLED, REBALANCE APPROX. 2.5 MONTHS LATER o MAIN SUPPLY & EXHAUST DAMPERS FULLY OPENED o S5 & S6 GRILLE DAMPERS (BSMT.) CLOSED o HRV SET TO LOW SPEED, SPEED CONTROL ADJUSTED TO GIVE MINIMUM FLOW OF 57 l/s	o LOW SPEED FLOWS BALANCED
														o E3 (BSMT.) AUTOMATIC DAMPER FULLY CLOSED	
	16	7	8	7	5	5	47	81	29	20	0	49	85		o DUCT LEAKAGE:SUPPLY-34 l/s EXHAUST-36 l/s

SUMMARY
o Supply duct leakage (with basement dampers closed): 42% of ST (34/81)
o Exhaust duct leakage (with basement dampers closed): 42% of ET (36/85)

SECTION 4

COMBINED HRV/FORCED AIR HEATING SYSTEMS

4.1 SYSTEM DESCRIPTION

The most common type of ventilation system in R-2000 houses is the Combined HRV/forced air heating system in which an HRV supplies outdoor air to the return air plenum of the furnace which in turn mixes and distributes the air throughout the house. Continuous operation of the furnace blower is required. The mechanical systems in Houses #13 and #14 use this type of approach. Figure 1 shows the system layout and gives a brief description of its operation. Two important features of the systems in these two houses are: a) return air registers were used in each room to assist air circulation when interior doors were closed and b) all supply registers were mounted high on interior partition walls to minimize occupant discomfort.

The HRV was a CES Inc. van EE 2000 air-to-air heat exchanger.

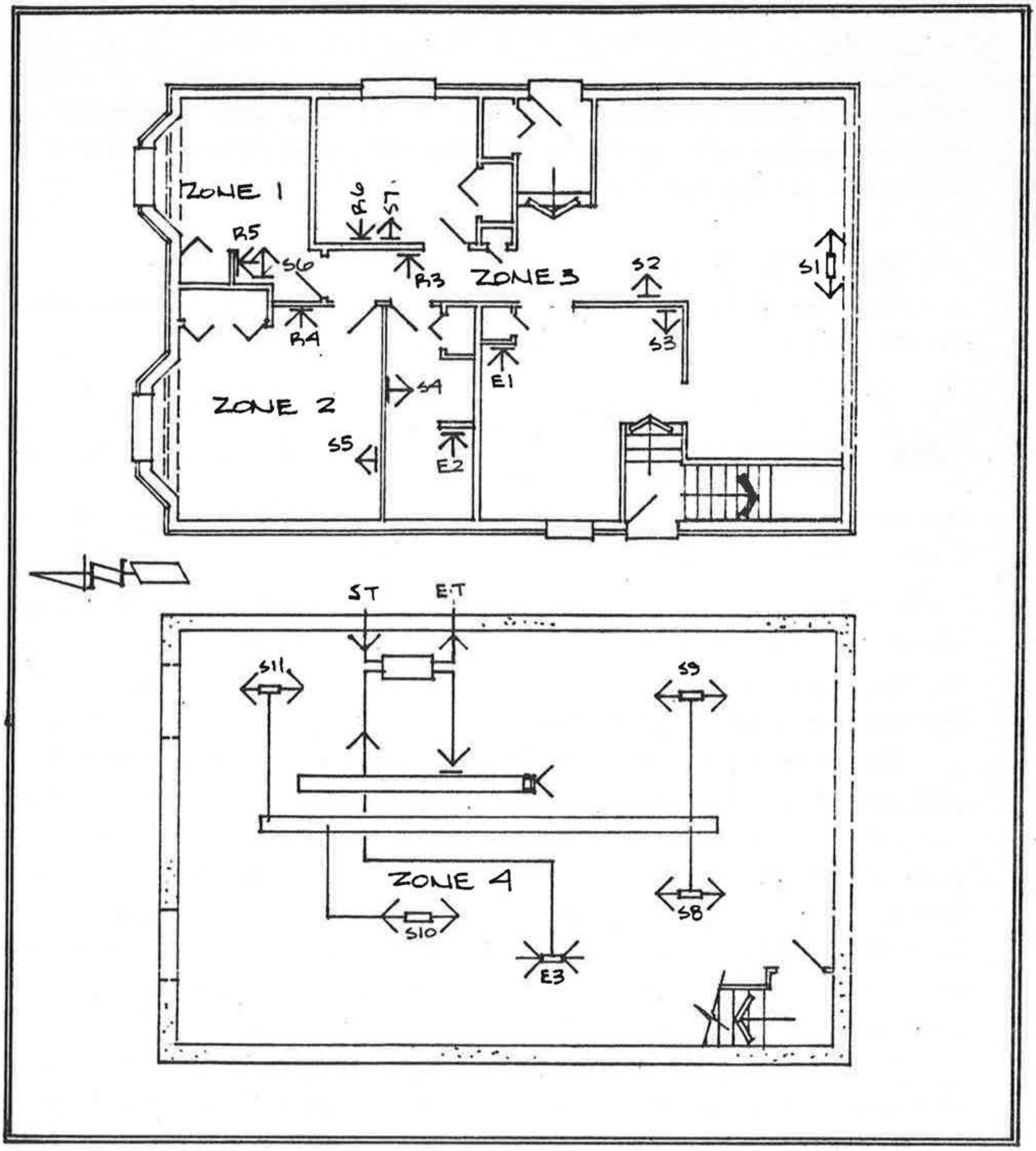
4.2 DESIGN COMMENTS

To design the heating and ventilation systems for one house in compliance with Refs. 8 and 9 required approximately 12 hours for an experienced designer. This included the HRV ductwork, supply and return systems and the high-sidewall supply ductwork.

Zone balancing, using a heated probe anemometer, required approximately 3 hours of time in the house and consisted of balancing to a predetermined standard and completion of a simple written report. This could be reduced to approximately 1 to 2 hours with a high quality, low resistance flow hood which can be used to rapidly measure grille air flow rates.

From a design perspective, no major problems were encountered with the systems. A point to note with high-sidewall supply registers is that 38x89 (2x4), or wider, partition walls may be required to provide adequate cross-sectional area for the ductwork. This is a restriction for builders wishing to use 38x64 (2x3) partition walls.

Initial operational experience indicated no major problems with the



COMBINED HRV/FORCED AIR HEATING SYSTEM (HOUSES #13 and #14)

The HRV draws exhaust air from the bathroom, kitchen and laundry area and provides supply air to the return air plenum of the forced air electric heating system (through an indirect connection). The system is operated in a balanced mode with low and high speeds to provide continuous and peak ventilation respectively. Distribution of the ventilation air is provided through continuous operation of the furnace blower. Supply and return air registers are provided to each zone of the house. With the exception of a single floor-mounted register in the living room (under the windows), only high-sidewall supply air registers are used. Ventilation system control is provided by a dehumidistat and manually activated override switches.

FIGURE 1

systems. It should be noted that the HRV's were later generation units which represented improvements over earlier generation models in terms of reliability and maintainability.

4.3 TOTAL VENTILATION RATES

The relevant test data, extracted from Tables 3 and 5, are shown below for the two houses:

HOUSE	HRV SPEED	DESIGN TVR (ac/hr)	FMS-MEASURED TVR (ac/hr)	TRACER GAS-DETERMINED TVR DOORS OPEN (ac/hr)	
				N_2O	SF_6
#13	Low	0.47	0.54	0.67	0.74
#14	Low	0.47	0.43	0.53	(see text)

The "doors open" data are shown for the tracer gas results since this is the condition under which the FMS-measured TVR values were determined.

The Design and FMS-measured TVR values were in reasonable agreement with each other. The N_2O results indicated consistently higher ventilation rates while the SF_6 results (for House #13) indicated a rate considerably above the design values. Part of the explanation for the higher values is that the tracer gas rates include air change due to natural infiltration while the Design and FMS-measured data do not. Also, during the SF_6 tests, the HRV may have operated for a portion of the test period at high speed since it was under automatic control of the dehumidistat.

The results clearly show that the Combined HRV/forced air heating systems were able to achieve Total Ventilation Rates which met the design requirements. Further, the results were approximately the same for the two houses considering their initial balance condition.

4.4 ZONE VENTILATION RATES

Due to the significant inter-zone transfer characteristic of recirculation systems, the Apparent ZVR values can not be regarded as approximations to the Actual rates. However, the N_2O decay curves in Appendix A, show that the concentrations of N_2O in the four zones rapidly moved to, or continued to sustain, roughly equal levels after initial injection. Significant inter-zone mixing distributed the N_2O throughout the house and then maintained equal concentrations in the four zones. With the individual returns located in each zone, good mixing should be expected. From a ventilation perspective, therefore, the house behaved as if it were one large zone.

The consequences of these results are significant since one of the criticisms of Combined ventilation/forced air heating systems has been that the ductwork has to be designed to meet the heating load distribution which may not be the same as the ventilation distribution. If the recirculation system effectively turns the house into a single zone, this criticism would not be valid provided the Total Ventilation Rate is properly established and the ventilation system efficiency (i.e. the ability to introduce fresh air and remove contaminants) is adequate.

4.5 INTERIOR DOOR POSITION

The N_2O Tracer Gas results for Houses #13 and #14 indicated only slight reductions in the Total Ventilation Rates with the interior doors closed.

The N_2O decay plots show that the tracer gas concentrations were similar in all four zones with the interior doors closed. This again suggests that the recirculation system maintained the house as if it were a single zone and would mean that the Zone Ventilation Rates were not affected by door position.

4.6 DUCT LEAKAGE

As shown in Tables 8 and 9, exhaust duct leakage between the HRV and the flow measuring stations were 5% and 7% respectively, of the total exhaust flow rate for Houses #13 and #14 with the HRV operating at high speed. Although these amounts are relatively small, they occurred over short lengths of ducting (approximately 1 m to 2 m). Total exhaust duct leakage from the basement can likely be assumed to be significant compared to the total flow. Although more detailed testing would be desirable, these results indicate that duct leakage in an unsealed duct system can be expected to provide a significant portion of the total basement ventilation requirements.

SECTION 5
DEDICATED HRV VENTILATION SYSTEMS

5.1 SYSTEM DESCRIPTION

Dedicated HRV ventilation systems are usually employed when baseboard heating systems are used in R-2000 type housing. In the absence of forced air heating ductwork, the Dedicated HRV ventilation system is designed to supply outdoor air to each zone of the house. Houses #17 to #20 use this system. Figure 2 shows the system layout and gives a brief description of its operation. Note that high-sidewall supply registers were used in the houses.

The HRV was a CES Inc. van EE 2000 air-to-air heat exchanger.

5.2 DESIGN COMMENTS

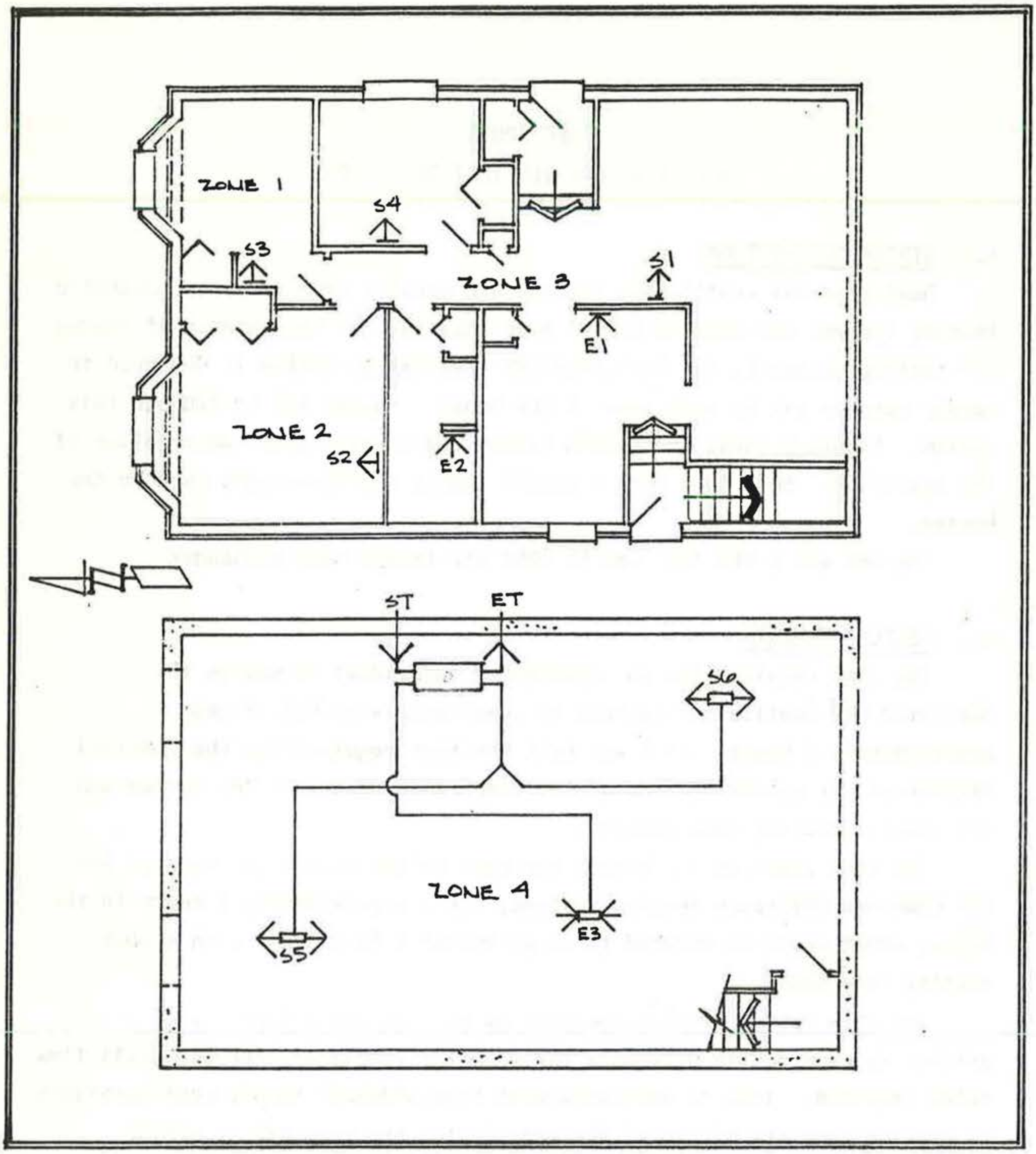
The time required for an experienced individual to design the Dedicated HRV ventilation systems in compliance with Ref. 7 was approximately 6 hours. This was half the time required for the Combined HRV/forced air system because of the simplified nature of the system and its reduced ducting requirements.

The time required to perform the zone balancing was the same as for the Combined HRV/space heating systems, i.e., approximately 3 hours in the house, which could be reduced to an estimated 1 to 2 hours with a good quality flow hood.

The only design problem encountered was the unavailability of proper grilles to provide the necessary throw to the supply air for the small flow rates required. This is desirable with high-sidewall supply configurations to provide adequate mixing of the ventilation and room air to avoid discomfort and to prevent short-circuiting of the ventilation air out of the room through open doorways.

5.3 TOTAL VENTILATION RATES

The relevant test data extracted from Table 3 for the four houses are shown below. Note that Houses #17 and #18 were operated at low speed while #19 and #20 ran at high speed during the tracer gas tests.



DEDICATED HRV VENTILATION SYSTEM (HOUSES #17 to #20)

The system consists of an HRV and a complete ductwork system to provide distribution of the ventilation air to each zone of the house. Exhaust air is taken from the bathroom, kitchen and laundry area by the HRV. The system is operated in a balanced mode with low and high speeds to provide continuous and peak ventilation respectively. The supply air ductwork is sized to meet the ventilation load and is therefore dimensionally smaller than a forced air heating system. High-sidewall registers are used for the ventilation air. System control is provided by a dehumidistat and manually activated override switches. The HRV is either a conventional air-to-air unit (Houses #19 and #20) or an air-to-air heat pump unit (Houses #17 and #18). From a ventilation perspective (i.e. ignoring energy), both function in basically the same fashion. A conventional electric baseboard heating system is used.

FIGURE 2

HOUSE	HRV SPEED	DESIGN TVR (ac/hr)	FMS-MEASURED TVR (ac/hr)	N_2O-MEASURED TVR, DOORS OPEN (ac/hr)
#17	Low	0.47	0.50	0.61
#18	Low	0.47	0.47	0.59
#19	High	0.62	0.62	0.72
#20	High	0.62	0.62	0.78

In all cases the design and FMS-measured TVR values were in excellent agreement with each other. The N_2O results indicated higher air change rates although the latter figures include natural air infiltration.

The results show that the Dedicated HRV ventilation systems were able to achieve Total Ventilation Rates which met the design requirements. Further, the results were consistent among houses operated at the same HRV speed setting.

5.4 ZONE VENTILATION RATES

As discussed earlier, the Apparent ZVR rates for Zones 1 and 2 of the Dedicated HRV ventilation systems can be regarded as reasonable approximations to the Actual ZVR's. With reference to Table 4, it is apparent that the Dedicated systems in houses #17, #18 and #20, which were not zone-balanced, did not provide the design ventilation rates to Zones 1 and 2. The system in House #19, which was zone-balanced prior to testing, was able to achieve adequate distribution to these zones.

The Balancing Reports for Houses #18 to #20 show that the bedroom supplies (S2, S3 and S4) did not deliver the minimum flows of 5 l/s (10 CFM) at low speed or 7 l/s (14 CFM) at high speed when the basement supplies (S5 and S6) were open. This is critical since S2, S3 and S4 were the sole sources of ventilation air for each of the three bedrooms. When S5 and S6 were closed (in Houses #19 and #20), the supply flows increased to the R-2000 recommended levels. This also reduced the initial overventilation of the basement. Thus, intentionally reducing supply-air rates to the basement and relying on duct leakage for basement ventilation increased main floor ventilation rates to the recommended levels. It should be noted that the observed distribution problem would not be solved by more sophisticated design methods.

5.5 INTERIOR DOOR POSITION

Total Ventilation Rates in Houses #17 to #20 were unaffected by the position of the interior doors. This is an interesting result since only Zones 3 and 4 contained exhaust air grilles. Exhaust from Zones 1 and 2 occurred solely by inter-zone transfer, most notably under the interior doors.

Dedicated HRV ventilation systems typically rely upon under-door leakage, although there are practical limits to the amount of undercut possibly due to increased noise transfer. Clearance between the carpet and the partition doors for Houses #17 to #20 was typically 6 to 25 mm (1/4 to 1 in.).

ZVR values for Zone 1 increased substantially when the interior doors were closed. This may have been an apparent effect resulting from better mixing of the ventilation and room air prior to air moving out of the zone under the door rather than a change in the actual air supply from the grille. The N_2O tracer gas technique assumes perfect mixing within the zone. Supply grille location may have resulted in short circuiting of ventilation air through the doorways in the open door tests. Closing the door would have produced better air mixing.

ZVR values for Zone 2 dropped in all four houses with the doors closed. The physical layout of the room and the grille location suggest that short-circuiting was probably not occurring to the same extent as in Zone 1. Measured ZVR results for Zone 2 are considered more representative of actual performance than the Zone 1 results.

5.6 DUCT LEAKAGE

The Balancing Reports for Houses #18, #19 and #20 reveal that excess air was being supplied to the basement (S5 and S6) while insufficent flows were reaching the main floor. With the basement supplies closed, the system in House #19 was able to achieve a good distribution. From observation of the systems in operation, it appears the basement was able to receive adequate ventilation solely by duct leakage. Reviewing the balancing data, substantial leakage was identified in both the supply and exhaust ductwork. Since most of the ductwork is located in the basement, leakage would provide extra ventilation air to the basement (since the supply ductwork is positively pressurized) and extra exhaust (since the exhaust ductwork is negatively pressurized). For example, in House #20, 34 l/s (71 CFM) of supply side leakage and 36 l/s (77 CFM) of exhaust side leakage were identified. These represented 42% of the total flows in each duct. It is also interesting that in House #18, taping of 2.4 m (8 ft.) of ductwork between the HRV and flow station resulted in 15 l/s (32 CFM) of leakage being eliminated (20% of the total flow).

Considering their manner of operation, it is reasonable to expect Dedicated HRV ventilation systems to be more vulnerable to duct leakage than forced air heating systems. Dedicated systems are designed to run at higher static pressures, typically 100 to 150 Pa (0.40 to 0.60" H_2O) as opposed to 30 to 50 Pa (0.12 to 0.20" H_2O) for forced air systems. However, the length of cracks from sheet metal seams, elbow and transition joints, etc. per unit length of ductwork is not significantly less for a Dedicated system, even though it may be carrying only 20% to 40% of the air flow of a forced air system. The exposed crack length per unit volume of flow is therefore higher for the Dedicated system. Also, despite (or perhaps because of) the Dedicated system's ductwork being physically smaller, it is often more difficult to install without leaving exposed cracks, particularly at transitions and other fittings. Special measures may be needed to control duct leakage in Dedicated HRV ventilation systems.

Unfortunately, zone balancing, while capable of producing the desired results, was found to be a slow and tedious project which required considerable care as well as the necessary equipment.

If high-throw grilles had been used, the duct leakage problem would have been further aggravated because the higher pressure drops created across the grilles would have increased the system static pressures. It may have also made compliance with the zone distribution schedule more difficult. However, high-throw grilles have the advantage of providing better mixing of ventilation air with room air and can thereby improve the ventilation efficiency of the system.

SECTION 6
EXHAUST-ONLY HEAT PUMP HRV VENTILATION SYSTEMS

6.1 SYSTEM DESCRIPTION

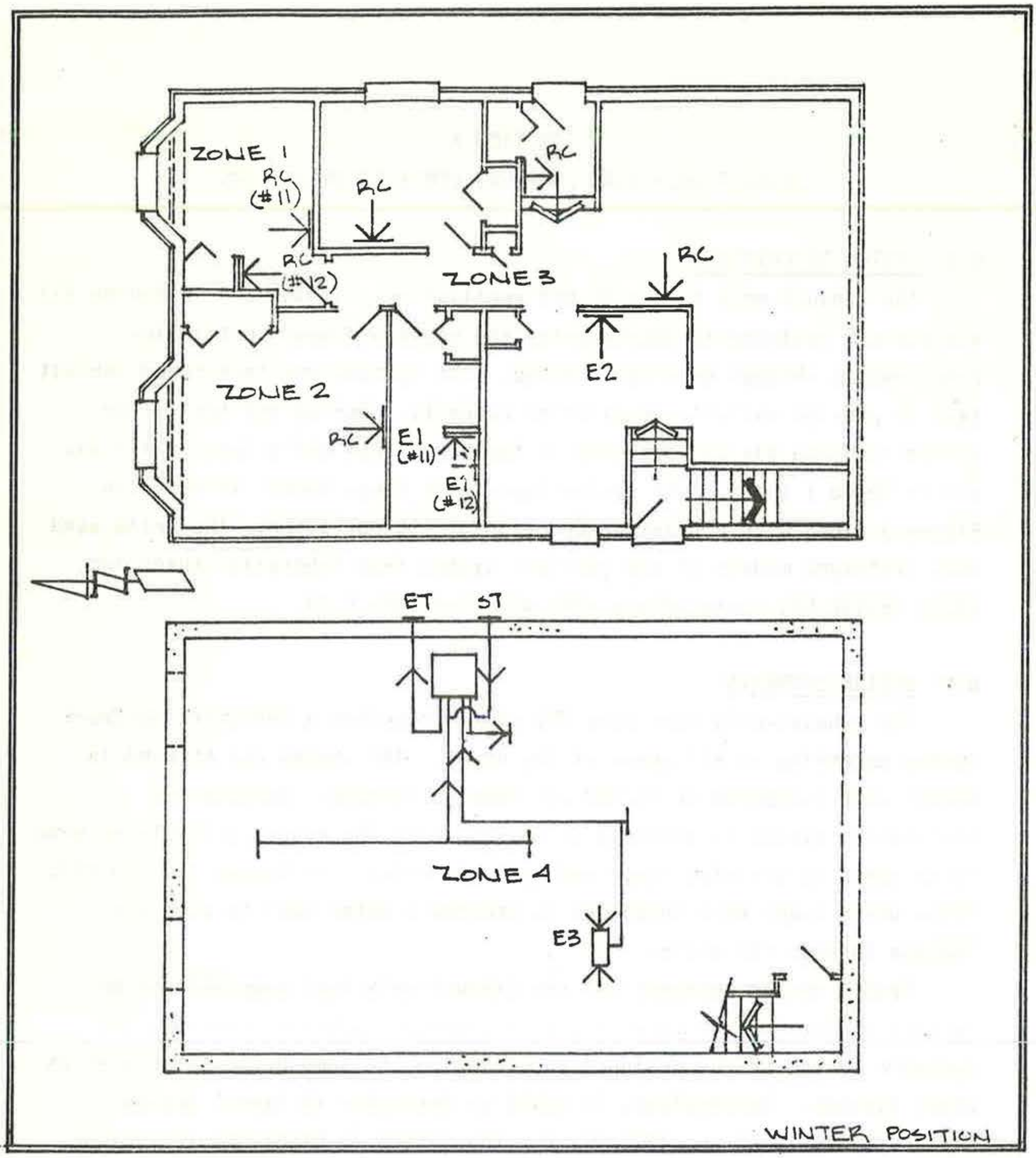
The Exhaust-only heat pump HRV ventilation systems used in Houses #11 and #12 are designed to depressurize the house and meet ventilation requirements through envelope leakage. The systems use four-speed exhaust fans to provide variable ventilation capacity. During the tests, the system in House #11 was operated at Speed 4 (high) while that in #12 was run at Speed 1 (low). The system layout for these houses is shown in Figure 3 along with a brief description of its operation. The units used were prototype models of the Habitair system from Fiberglas Canada Inc. whose design has subsequently been modified (see 6.7).

6.2 DESIGN COMMENTS

The Exhaust-only heat pump HRV system required a dedicated ductwork system extending to all zones of the house. The system can be used in houses with baseboard or forced air heating systems. Because the ventilation system is intended to depressurize the house, precautions need to be taken to minimize radon and soil gas entry. In Houses #11 and #12, floor drain traps were installed to provide a water seal to stop air leakage through the drain.

From a design perspective, the Exhaust-only heat pump HRV system appears different from conventional mechanical systems. However, the ductwork system can be designed according to the same basic principles as other systems. Nonetheless, it would be desirable to have a design procedure developed specifically for the system to highlight its unique features.

The initial installations used a two-stage thermostat located in the living room which did not permit the living room or bedroom baseboards to be energized unless the HRV was unable to meet the heating load. This created a discomfort problem since the bedrooms, located on the north side of the house, became cool when solar gain in the front of the house (where the thermostat was located) prevented the bedroom baseboards from being



EXHAUST-ONLY HEAT PUMP HRV SYSTEM (HOUSES #11 AND #12)

This is an integrated system which provides exhaust-only ventilation, supplementary space heating, DHW heating and a degree of air conditioning. In the "winter mode", an exhaust fan in the HRV depressurizes the house by drawing air from the bathroom, kitchen and laundry area. Supply air is introduced into each zone in the form of air leakage through the building envelope. A recirculation system draws air from the bedrooms and distributes it to the living room. Heat recovery is provided with an air-to-water heat pump which extracts energy from the exhaust air stream and uses it to preheat the DHW. Once the DHW load has been met, any supplemental energy recovered by the system is then made available for space heating of the recirculation air. The HRV exhaust fan has four manually adjusted speeds to provide control on the ventilation rate. An electric baseboard heating system, sized to meet the full design load, is used. In the "summer mode", the system operation is reconfigured so that supplemental air conditioning is provided. The HRV is a pre-production unit.

FIGURE 3

activated. The problem was eliminated when the bedroom baseboards were disconnected from the living room thermostat and left under the sole control of their own thermostats.

The homeowners also experienced some uncertainty with respect to operation of the control system. In particular, the function of the three dials and three flip/flop switches on the HRV's Heat Recovery Module were not readily understood. Based on these experiences, it is recommended that integrated mechanical systems be designed to require limited homeowner interaction and have minimal exposed controls.

6.3 TOTAL VENTILATION RATES

The relevant TVR data results from Table 3 are shown below:

HOUSE	HRV SPEED	DESIGN TVR (ac/hr)	FMS MEASURED TVR (ac/hr)	N_2O-MEASURED TVR, DOORS OPEN (ac/hr)
#11	4	0.62	0.56	0.38
#12	1	N/A	0.18	0.15

The results are somewhat ambiguous. The Design and FMS values are in reasonable agreement for House #11, however, the N_2O and FMS values are significantly different. For House #12, the N_2O and FMS values display somewhat better agreement. Localized duct leakage could have resulted in significant differences between FMS values and N_2O results by producing poor mixing of the tracer. The inability to reconcile the test results and interpret consistent patterns makes it difficult to draw firm conclusions and assess whether the results were an anomaly created by the installed equipment or an inherent characteristic of this type of system. However, based on the observed results for House #11, it appears that the Exhaust-only HRV system was unable to achieve the design Total Ventilation Rates. This likely resulted from the significant case leakage which was observed as well as internal cross leakage.

6.4 ZONE VENTILATION RATES

The ZVR values in Table 4 for Zones 1 and 2 of House #11 indicate these zones were ventilated at rates slightly below the design figures. This is not surprising since the TVR values were below design figures. Significant leakage from the ductwork and the Air Distribution Module (ADM) and Heat Recovery Module (HRM) was identified. This would have resulted in overventilation of the basement and reduced flows to the main floor zones. However, examination of the N_2O data shows that the basement ZVR was zero.

House #12 was operated at Speed 1 during the N_2O tests so no comparison to design values is available. However, it is interesting that the ratio of Zone 1 flows to Zone 2 flows in House #11 was approximately the same as the ratio of the design values for these zones, $\frac{0.84}{0.68} = 1.2$ vs $\frac{1.37}{1.05} = 1.3$. In House #12 they were somewhat different $\frac{0.34}{0.40} = 0.9$ vs 1.3. Whether this was a result of an installation difference or a system characteristic is unknown.

This type of system also relies upon a "proper" distribution of envelope leakage sites to provide correct air infiltration into each zone. This may or may not have been achieved in the test houses.

6.5 INTERIOR DOOR POSITION

Both the Total and Zone Ventilation Rates for Houses #11 and #12 were affected by the position of the interior doors. TVR values in the houses increased significantly with the doors closed, a result which was not anticipated for this type of system. The N_2O tracer gas decay plots in Appendix A and the Apparent ZVR values indicate that the Zone 4 (basement) ventilation rates may have increased significantly with the doors closed while the Apparent ZVR values for the other zones changed considerably less. This could have occurred because of increased duct and HRV leakage in the basement, caused by increased static pressures with the doors closed. In particular, significant leakage from the ADM had been identified during inspections of the unit. Also, the basement floor drain traps (intended to control infiltration when the house was depressurized) had not been installed during the tests. With the entire system operating at higher static pressures, leakage rates of ducted air into and out of the basement could have changed. If this assumption is correct, then it must be recognized that a modified system with reduced case leakage may behave substantially different than the units studied. These issues are of particular importance because of the possible impact of interior door position on radon migration with an exhaust-only HRV system.

6.6 DUCT AND SYSTEM LEAKAGE

Duct and system leakage have already been discussed. However, the balancing reports show that exhaust duct leakage was significant, although the results again appear somewhat confusing. In House #11, leakage occurred into the exhaust ductwork while in House #12 it appears to have occurred out of the exhaust ductwork. In the "summer" mode, duct leakage was minimal in House #11 but quite significant in House #12.

6.7 PRODUCT NOTE

Following completion of these tests, the HRV manufacturer replaced the units in Houses #11 and #12 with updated models which are designed to have lower case leakage, improved air moving capabilities, simplified control operations and generally improved performance. The pre-production models described in this report are no longer available.

SECTION 7

INTEGRATED HEAT PUMP HRV, SPACE AND DHW HEATING SYSTEMS

7.1 SYSTEM DESCRIPTION

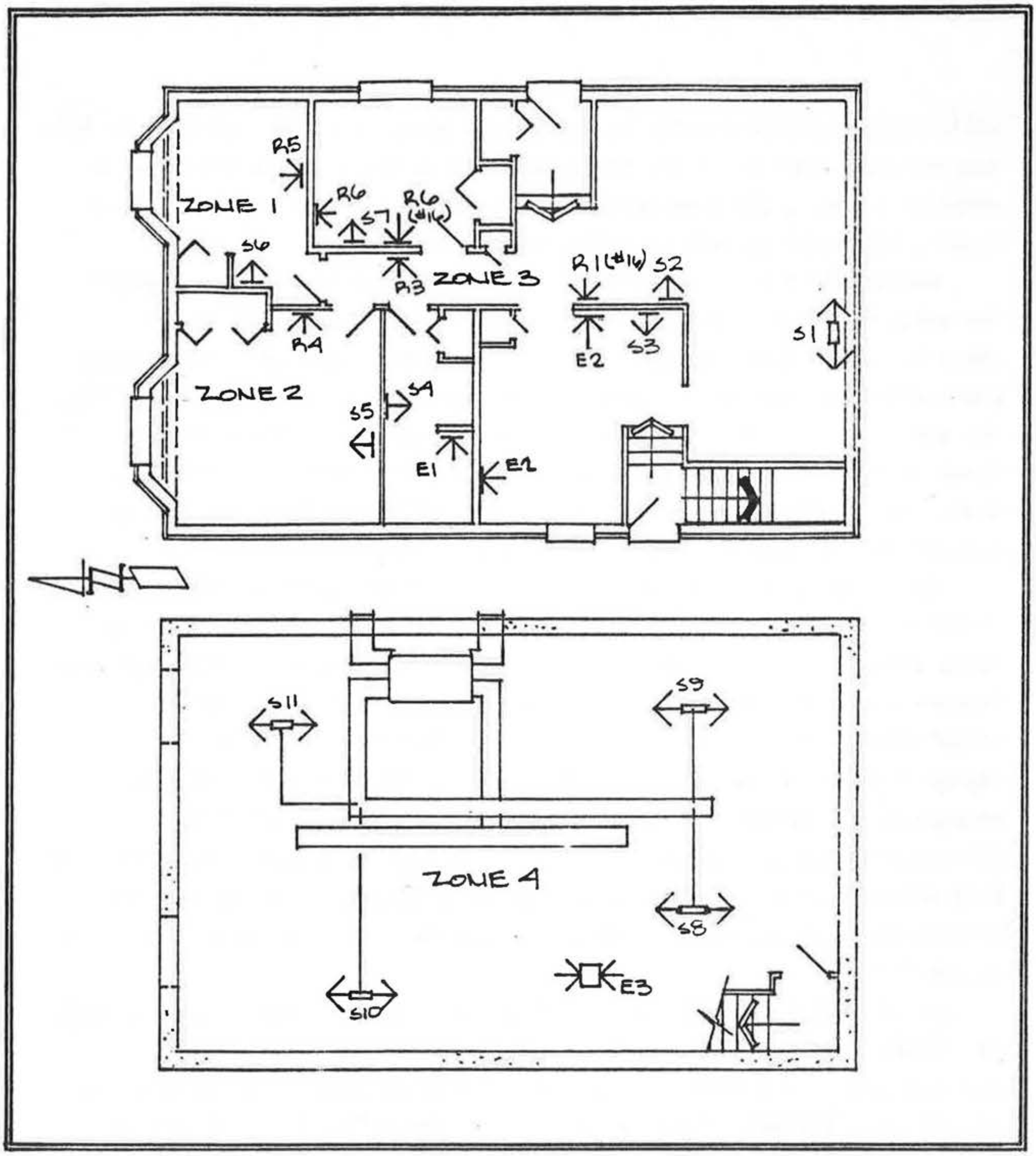
From a distribution perspective, the Integrated heat pump HRV, space and DHW heating systems used in Houses #15 and #16 are similar to Combined HRV/forced air heating systems. The major difference is that the integrated system combines several components into a single unit. The systems in Houses #15 and #16 employed two-speed circulation blowers. Supplemental exhaust capacity was provided by manually activated exhaust fans drawing air from the bathroom, kitchen and laundry area (not activated during the tests). The layout for the two houses is shown in Figure 4 along with a brief description of its operation.

The HRV used was a Peach PPHC12/45 produced by Cambridge Manufacturing Ltd.

7.2 DESIGN COMMENTS

Since this system was unique relative to standard mechanical systems, considerable learning time was required on the part of the designers. Careful planning of the installations was found to be more critical than with conventional mechanical systems. The units were physically large and might not fit through some doorways and framed stairwells. Also they were quite heavy and required several men to manoeuvre into place. Second, the two ductwork penetrations through the envelope were large, approximately 20 cm x 81 cm (8 in. x 32 in.) and had to be provided for during the framing or basement pouring stage of construction. In Houses #15 and #16, the units were suspended from the floor joists which had to be doubled up to support the load. In the future, slab-mounted installation would be recommended because vibration transmitted into the floor system caused objectionable noise. Vibration isolators had to be retrofitted to successfully control this problem.

To operate in the Winnipeg climate, a Honeywell T6031 controller was added to the compressor power supply circuit to shut down the compressor at outdoor air temperatures below -12°C. Normally, this model of the HRV



INTEGRATED HEAT PUMP HRV, SPACE AND DHW HEATING SYSTEM (HOUSES #15 AND #16)

This is an integrated system in which all the functions of the house's mechanical system are combined into one unit. The system consists of an outdoor air loop, an indoor recirculation air loop and a DHW circulation loop. The recirculation loop also functions as the ductwork for the integral electric forced air heating system. Ventilation air is introduced into the recirculation loop from the outdoor air loop through an internal damper "door" and then distributed to each zone of the house by the continuously operating recirculation blower. A second internal damper "door" exhausts some of the indoor recirculation air into the outdoor air loop. Damper "door" adjustment is done manually at the time of commissioning. The outdoor air loop ducts outdoor air into the unit for the internal heat pump. Under normal heating conditions, the outdoor air blower only operates when there is a demand for space or DHW heating. The recirculation system uses high-sidewall supplies and individual return air registers in each zone. To meet peak ventilation load, separate exhaust fans are provided for the bathroom/laundry and kitchen.

FIGURE 4

would switch to ground water as its energy source for the heat pump at this temperature. However, since the space heating loads of the houses were relatively small, the groundwater source option was not included. As a result, there was no heat recovery on ventilation air below -12°C.

Uncontrolled air leakage from the HRV case was found to be a problem. The units had four condensate drain holes through the bottom of the chassis, two in each air stream. Since these were located in positively pressurized sections of the unit, large quantities of air were dumped into the basement. The holes were subsequently covered with funnels whose ends terminated in drain hoses which in turn led to the drain pan under the unit. The funnel/hose combination created sufficient pressure drop to control the air leakage within acceptable limits.

Case leakage was also found to be significant, particularly around the filter housings and fabric vibration isolators on the ductwork. Since large volumes of outdoor air were ducted into the house (for the heat pump "source") and then routed outdoors, the impact of this leakage is significant. The airtightness test data in Table 2 shows that the air change rates at 50 Pascals for Houses #15 and #16 were 1.47 and 1.26 respectively. Houses #17 and #18, which used identical envelope construction but with conventional HRV's, had measured air leakage rates of 0.55 and 0.49 ac/hr_{50} respectively. Although several hours were spent attempting to reduce case leakage, the results were only moderately successful.

Concerns were also raised regarding the conductive heat losses through the outdoor air ductwork. Although all ductwork was insulated to approximately RSI 1 (R-5), the air inside the ductwork would normally be at, or near, ambient outdoor temperature. Therefore, higher levels of ductwork insulation would be recommended for future installations.

Providing proper separation between the inlet and outlet to avoid cross contamination was found to be a problem beyond that normally encountered with HRV's because of the size of the grilles on the outside of the house. In Houses #15 and #16, it was necessary to build duct chases, approximately 20 cm x 71 cm x 2.4 m (8" x 28" x 8') up the outside wall for the inlet line.

The unit's method of providing ventilation air is also different from that used on most HRV's. Two small metal slots or doors between the recirculating house air stream and outdoor heat pump source air stream permit recirculation air to be exhausted and fresh air to be introduced. Their physical placement permits cross contamination to occur. Also, the slots have to be pre-set at the time of installation and cannot be easily adjusted afterwards. Quantifying the delivered ventilation rate on an actual installation is therefore virtually impossible. This is considered a major limitation since the installer cannot verify that the design ventilation rates are being attained.

With the control strategy used, the outdoor air blower will not be operating unless the thermostat is calling for heating or cooling. With this blower off, the effective ventilation rate would likely drop significantly, thereby creating a potential air quality problem.

With respect to the energy logic of the unit, the system would probably be best suited to a mild climate (where the outdoor air source heat pump could work to better advantage and the benefits of the unit's air conditioning capabilities could be more effectively utilized) and in a large structure (in which the capital investment for an integrated system could be applied against a larger heating load).

7.3 TOTAL VENTILATION RATES

The relevant test data from Figure 3 for the systems in Houses #15 and #16 are shown below:

HOUSE	HRV SPEED	DESIGN TVR (ac/hr)	FMS-MEASURED TVR (ac/hr)	N_2O-MEASURED TVR, DOORS OPEN (ac/hr)
#15	Continuous	0.47	Not Determined	0.59
#16	Continuous	0.47	Not Determined	0.39

Because of the physical configuration of the HRV, it was impossible to determine the actual ventilation rate using Flow Measuring Stations. The N_2O results indicate that the system was able to achieve the desired TVR although the large variation between the two houses is noted. This is not believed to have been caused by any differences in the ductwork but possibly by differences in the HRV itself. A possible cause could have been differences in adjustment of the metal slots used to set the amount of outdoor air being introduced into the recirculation system.

7.4 ZONE VENTILATION RATES

The tracer gas decay curves in Appendix A show that Zones 1, 2 and 3 (the main floor) maintained virtually identical N_2O concentrations indicating very good mixing. As a result, the Zone Ventilation Rates should have been adequate, even though they could not be explicitly measured. Zone 4 (the basement) maintained consistently lower concentrations during the Open Door tests. This result is not entirely understood because significant leakage was identified from the ventilator which should have enhanced inter-zone mixing.

7.5 INTERIOR DOOR POSITION

No assessment of the impact of interior door position upon TVR or ZVR values was made for this system. During the "Open Door" tests on Houses #15 and #16, the system was run at high speed, thus activating the outdoor air loop blower. The "Closed Door" tests were run at low speed (to bracket the systems performance), which caused the outdoor air loop blower to turn off.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 COMBINED HRV/FORCED AIR HEATING SYSTEMS

CONCLUSIONS

1. The Combined HRV/forced air heating systems designed, installed and commissioned in accordance with recommended practice, were able to achieve the design Total Ventilation Rates.
2. The systems produced good distribution of ventilation air to the individual zones due to the high recirculation rates produced by the furnace blower.
3. Disparity between the design heating and ventilation load distributions was overcome by the excellent mixing provided by the recirculation system. This indicates that designing the duct system to meet the heating load would result in an acceptable supply of ventilation air to each zone.
4. Total Ventilation Rates for the systems, which used individual zone return air registers, were not significantly affected by the position of the interior doors. Zone Ventilation Rates appear also to have been unaffected by door position.
5. Exhaust duct leakage provided a significant portion of the basement design ventilation rate.

8.2 DEDICATED HRV VENTILATION SYSTEMS

CONCLUSIONS

1. The Dedicated HRV ventilation systems, designed, installed and commissioned in accordance with recommended practice, were able to achieve the design Total Ventilation Rates.
2. The Dedicated HRV ventilation systems did not achieve the design distribution of ventilation air without zone balancing. Duct leakage was observed to be significant and was suspected as the main reason for this problem. When the basement supply air dampers were closed, ventilation rates rose to the recommended levels on the main floor.
3. The use of high-throw grilles with the Dedicated HRV ventilation system would have likely increased duct leakage and made compliance with the design distribution of ventilation air more difficult. However, high-throw grilles have the advantage of providing better mixing of ventilation air with room air and can thereby improve the ventilation efficiency of the system.
4. Zone Ventilation Rates were observed to be only moderately reduced when the interior doors were closed even though no avenues for air movement were available out of several zones

other than under-door leakage.

5. Grille location and direction of throw were observed to have a strong impact upon mixing of ventilation air with room air. By improperly locating supply air grilles, significant reductions in actual Zone Ventilation Rates could occur due to short-circuiting of ventilation air through open interior doorways.

RECOMMENDATIONS

1. To minimize poor air distribution caused by duct leakage in Dedicated HRV ventilation systems, the following measures are recommended:

   a) Reduce supply air rates to the basement by closing the supply dampers if the basement is not occupied to the same extent as the rest of the house.

   b) Keep main floor supply dampers wide open and verify air delivery. Even the relatively small flow rates of a Dedicated system can be detected by a hand placed over the grille.

   c) Design for low system static pressure by using adequately sized ductwork and grilles (although this latter measure creates a problem achieving adequate throw).

   d) Ideally, some effort should be made to seal the ductwork located in the basement. This should at least consist of sealing ductwork between the outdoors and the main balancing dampers (where the static pressures and hence leakage are greatest) and sealing any obvious sources of leakage. Sealing of the ductwork between the outdoors and the Flow Measuring Station is required if the total supply and exhaust rates are to be accurately measured.

2. In view of the time required to design a Dedicated HRV ventilation system for even a simple house layout and the inability of the design process to achieve a satisfactory zone distribution without balancing, it may be desirable to develop alternative design procedures. One possibility would be to develop a method which used simple rules-of-thumb to design a system that is intentionally oversized and then to damper that system to achieve a satisfactory distribution. Any added material costs might be offset by reduced design time.

8.3 EXHAUST-ONLY HEAT PUMP HRV VENTILATION SYSTEMS (USING PROTOTYPE HRV)

CONCLUSIONS

1. Although the test results were somewhat inconsistent, the prototype Exhaust-only heat pump HRV system appears to have been unable to achieve the design Total Ventilation Rates, likely because of case and internal leakage.

2. The prototype Exhaust-only heat pump HRV system did not achieve the design distribution of ventilation air. Duct and case leakage from the Air Distribution Module, internal cross leakage in the Heat Recovery Module and a reliance on a proper distribution of envelope leakage sites for infiltration were suspected as the reasons for the difference between design and observed Zone Ventilation Rates.

3. Both Total and Zone Ventilation Rates were affected by the position of the interior doors. This could have resulted from increased duct and ventilator leakage in the basement with the doors closed.

RECOMMENDATIONS

1. Mechanical systems, particularly those with integrated functions, should be designed on the assumption of limited homeowner interaction and should have minimal exposed controls.

2. Design methods, developed explicitly for this type of system, would be a definite asset to the designer and should be developed.

3. Subsequent models of Exhaust-only heat pump HRV ventilation systems need to be studied in more detail to document their behaviour, particularly with respect to interior door position. This should include an investigation of the impact of case and duct leakage on ventilation rates. Also, see the Recommendations in Section 8.4 below.

8.4 INTEGRATED HEAT PUMP HRV, SPACE AND DHW HEATING SYSTEMS

CONCLUSIONS

1. The Integrated heat pump HRV, space and DHW heating systems were found to have specialized design and installation requirements beyond those of more conventional mechanical systems.

2. Ventilation rates could not be determined by the system installer due to the method used in the HRV to introduce outdoor air with the recirculating house air. Thus it would be impossible for an installer to verify compliance with a ventilation standard.

3. The control strategy used by the HRV would likely result in significantly reduced ventilation rates during periods when the outdoor air blower is shut off. This could result in air quality problems.

4. The measured airtightness of the houses containing the systems was found to be considerably poorer than equivalent houses with conventional HRV systems. This was caused by leakage of outdoor air into the house through the outdoor air loops of the units.

5. The Integrated heat pump HRV, space and DHW heating systems, designed, installed and commissioned in accordance with recommended practice, were able to produce satisfactory Total Ventilation Rates, although a large variation was found in the TVR's between the two houses.

6. The systems were able to produce good zone distribution of the ventilation air on the main floor due to the high air recirculation rate. The results suggest that the distribution to the basement may not have been uniform or well mixed.

RECOMMENDATIONS

1. Integrated systems should be designed to permit easy determination of ventilation rates to verify compliance with ventilation standards.

2. Control strategies for Integrated systems should be designed to insure proper ventilation rates under all operating modes.

3. Integrated ventilation systems which move significant quantities of exhaust, supply and/or recirculation air in close relative proximity to one another need to be carefully checked for internal and case leakage. The tracer gas technique currently used to determine crossover leakage in HRV's is noted, although for development purposes, a simpler system using inlet and outlet flow stations to identify leakage could be extremely useful.

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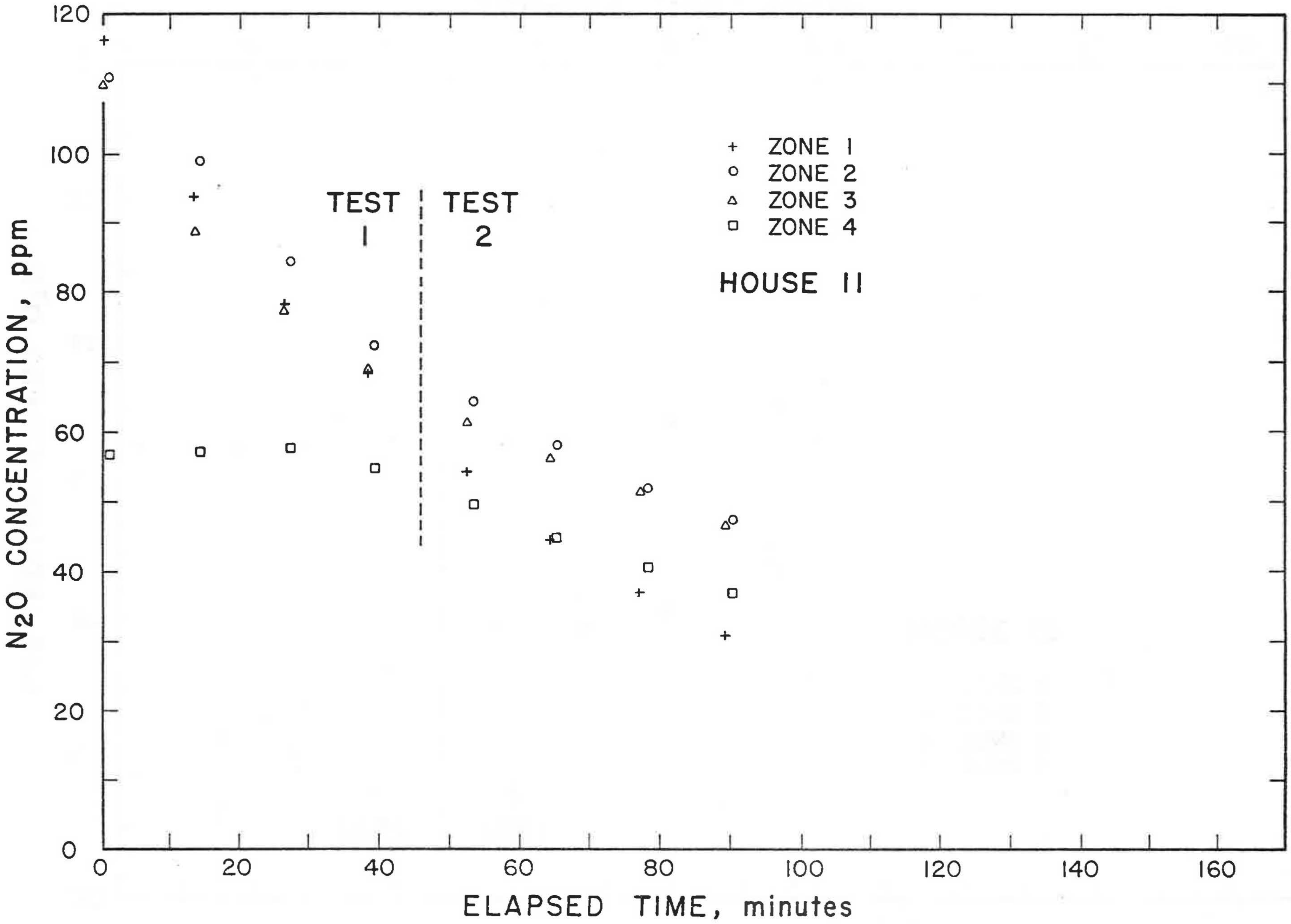
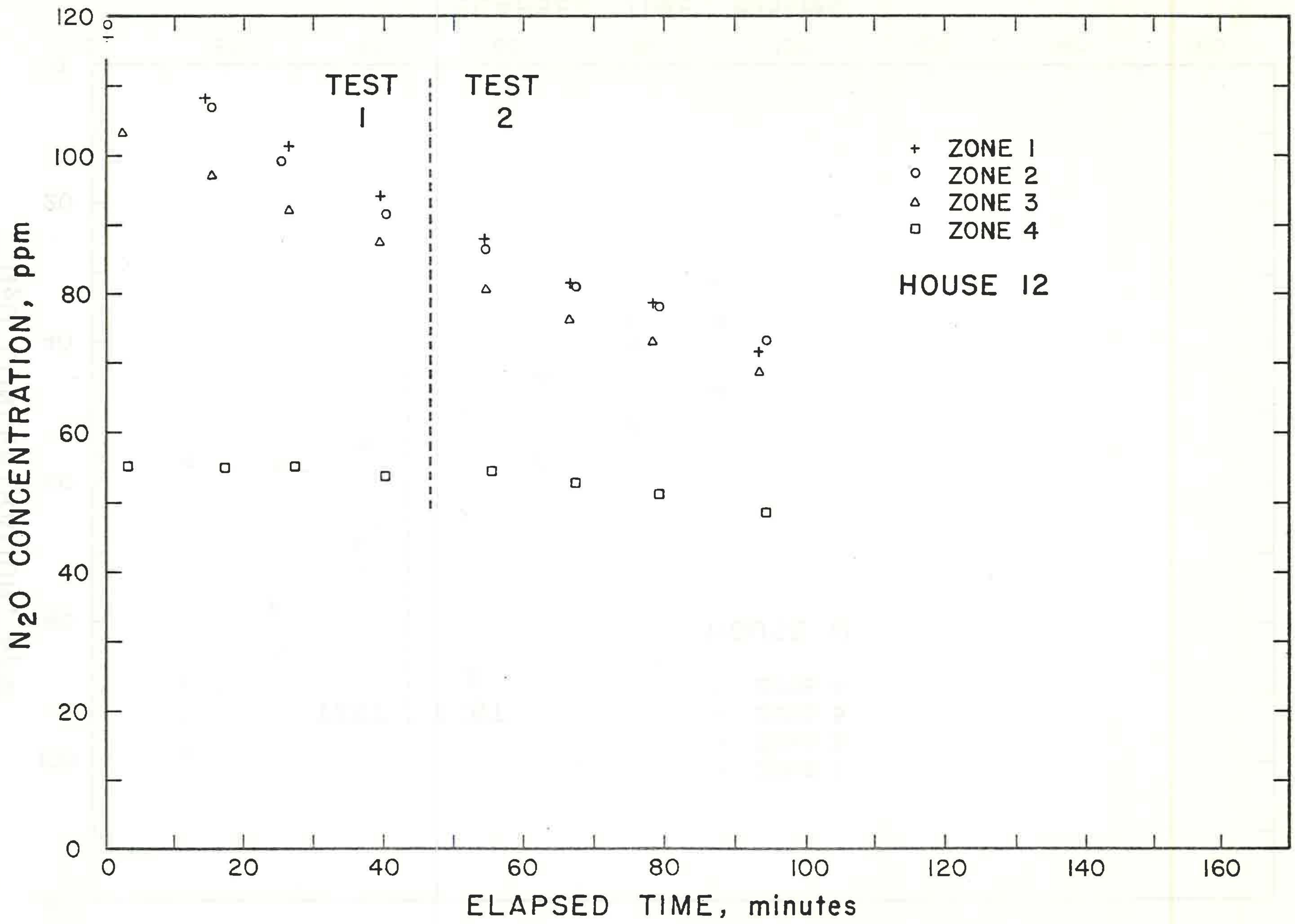
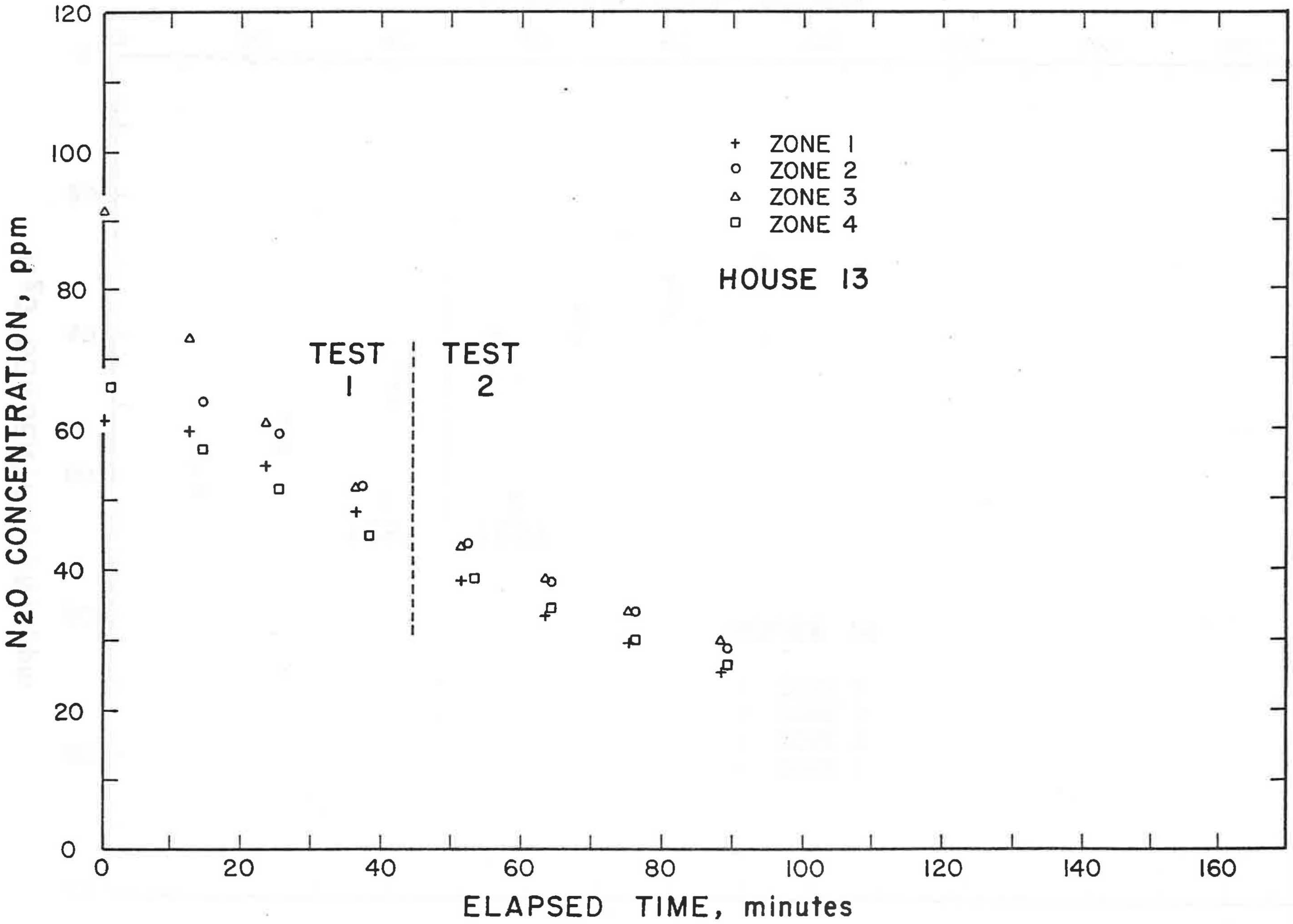
APPENDIX A

N_2O TRACER GAS DECAY CURVES
(from Ref. 9)

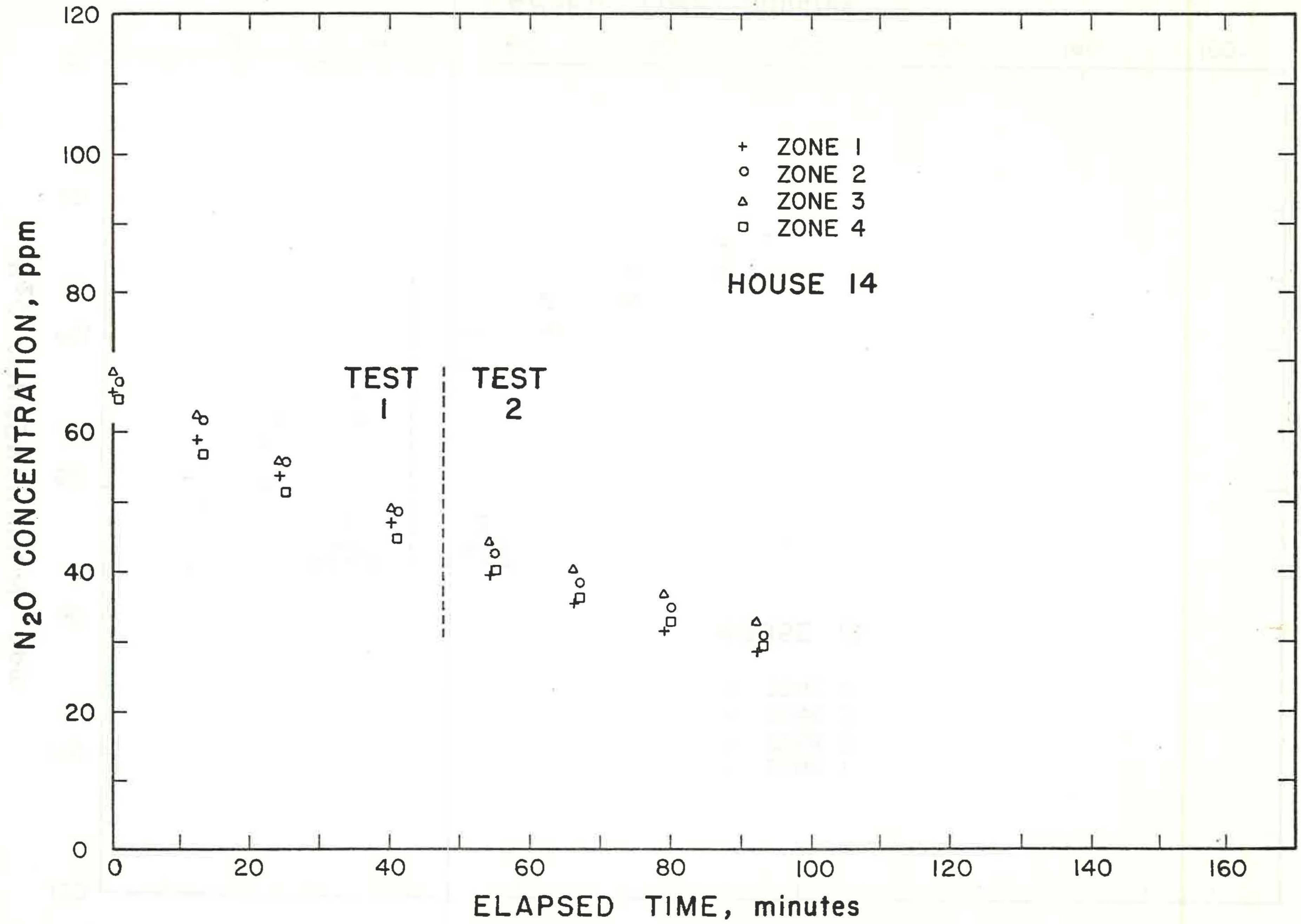


120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
N2O CONCENTRATION, ppm
ELAPSED TIME, minutes
TEST 1
TEST 2
+ ZONE 1
○ ZONE 2
△ ZONE 3
□ ZONE 4
HOUSE 11

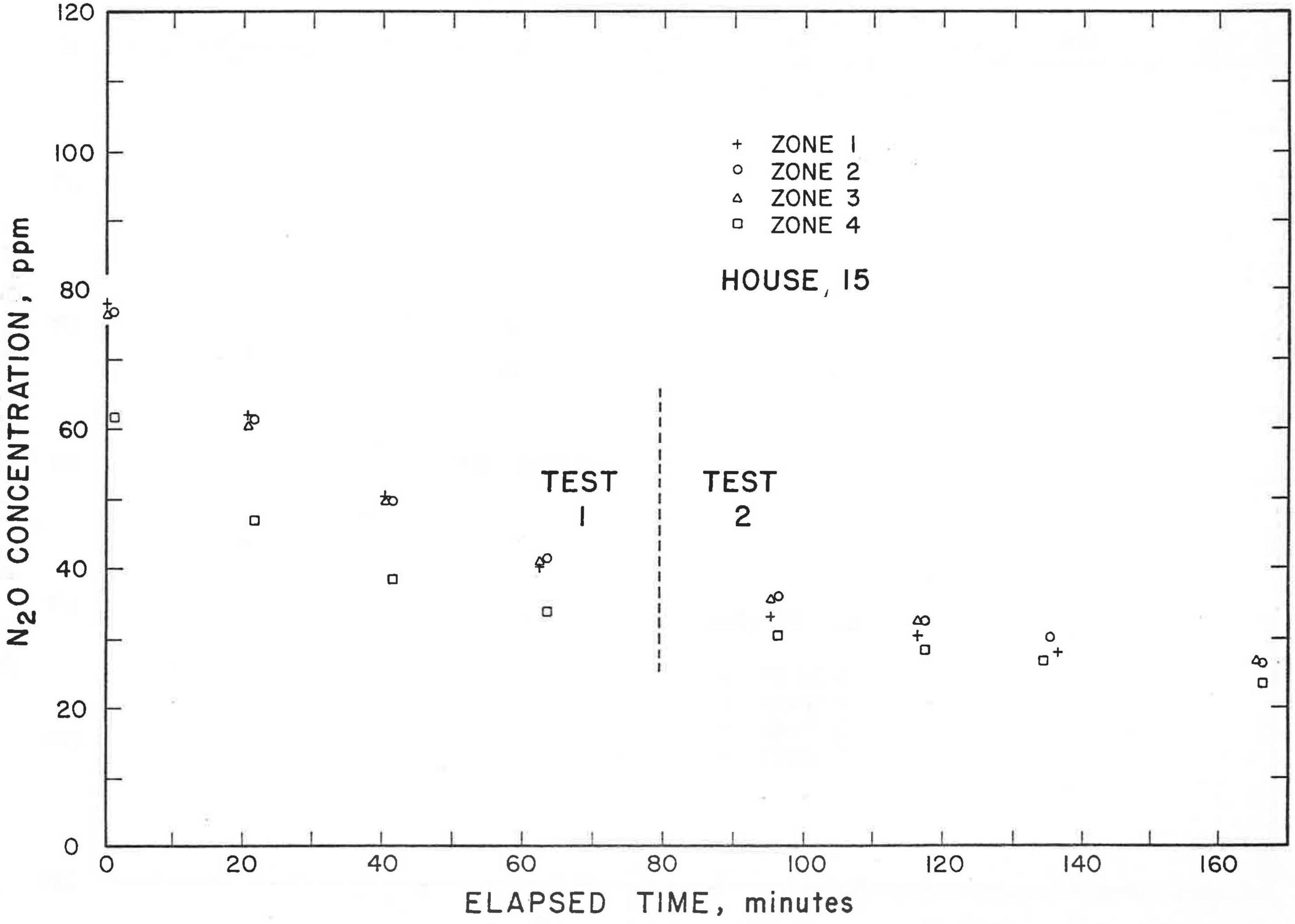

120
100
80
60
40
20
0
N_2O CONCENTRATION, ppm
0
20
40
60
80
100
120
140
160
ELAPSED TIME, minutes
TEST 1
TEST 2
ZONE 1
ZONE 2
ZONE 3
ZONE 4
HOUSE 12



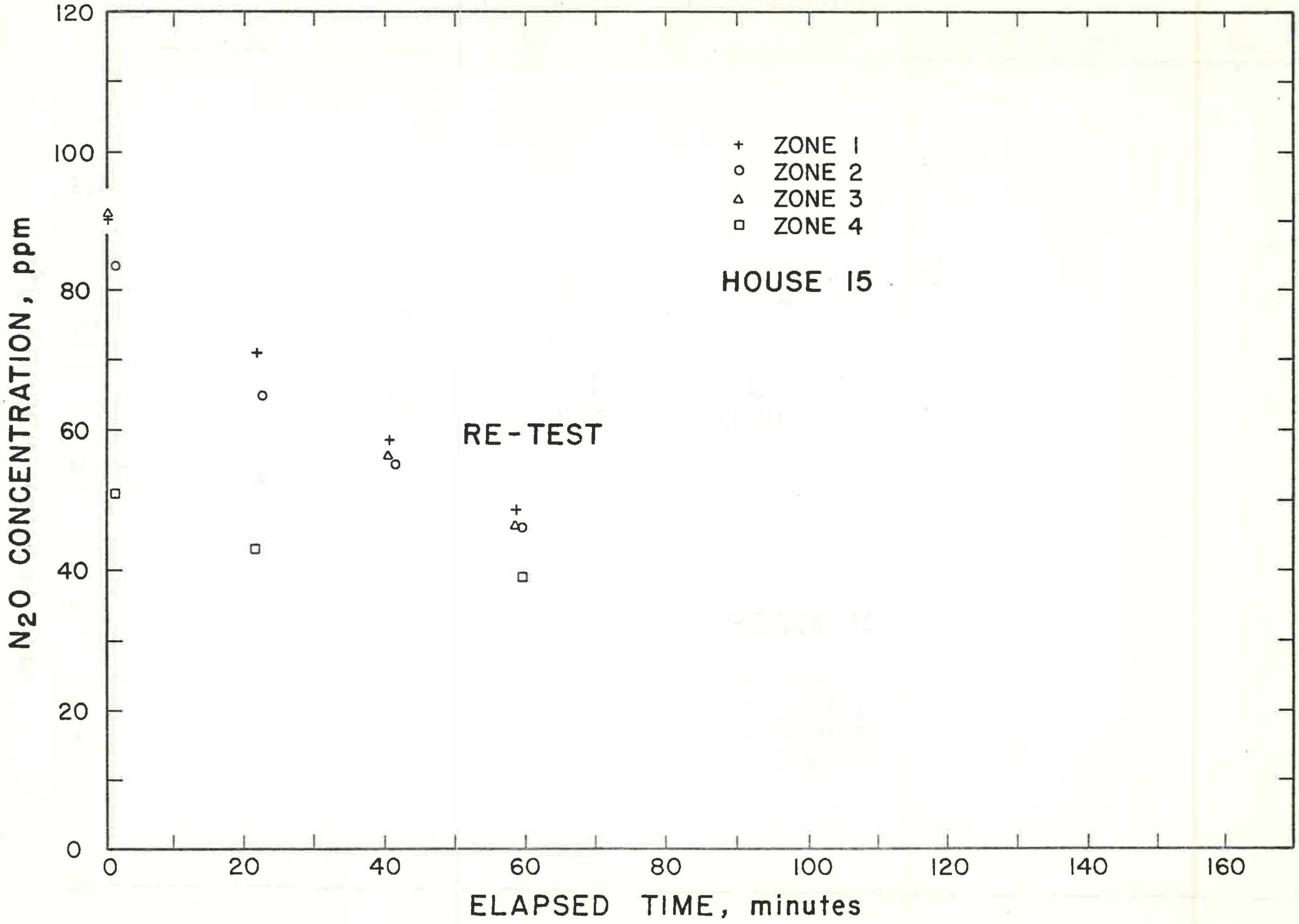
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes
+ ZONE 1
o ZONE 2
Δ ZONE 3
□ ZONE 4
HOUSE 13
TEST 1
TEST 2



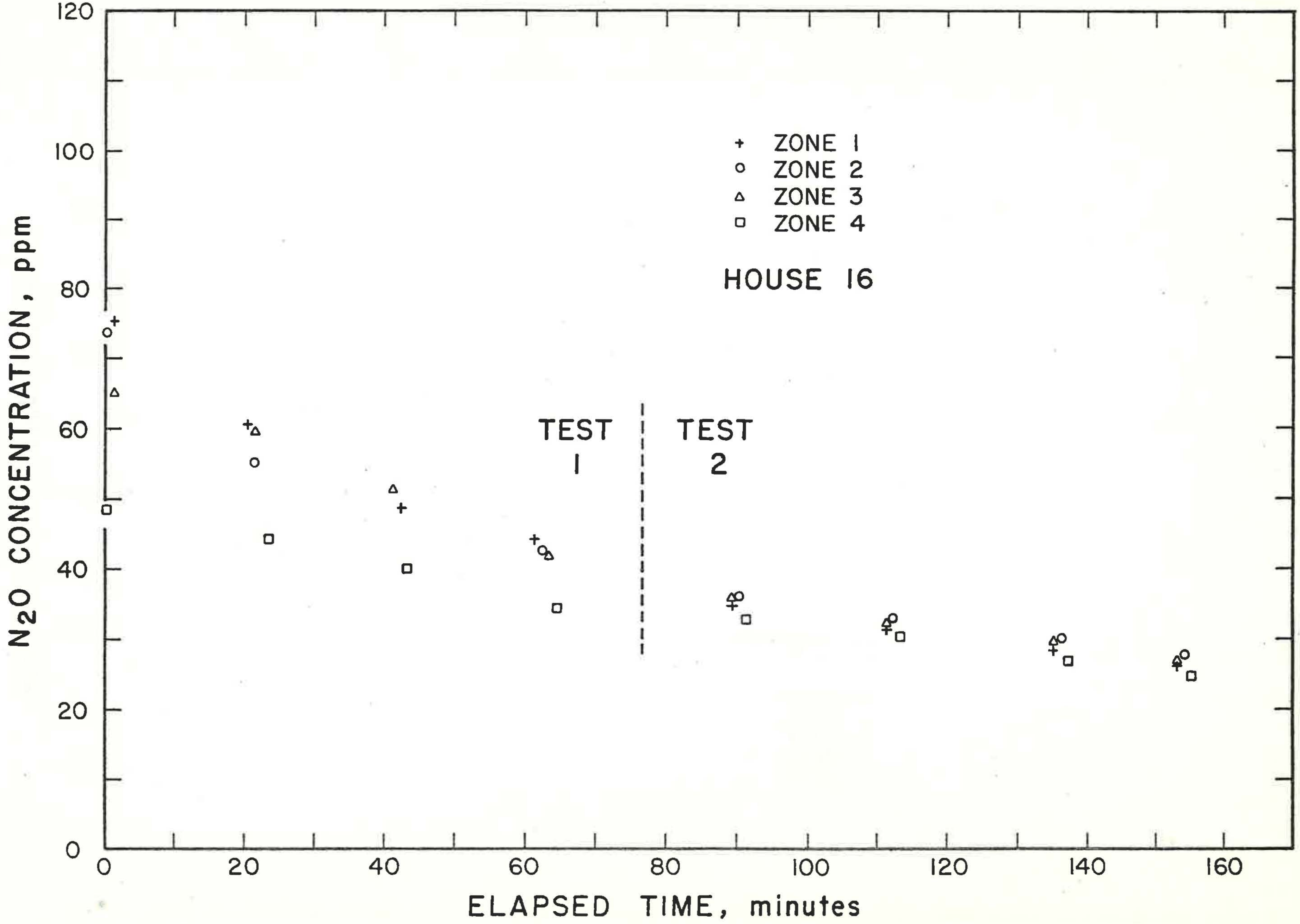
ZONE 1
ZONE 2
ZONE 3
ZONE 4
HOUSE 14
TEST 1
TEST 2
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes
0
20
40
60
80
100
120
140
160



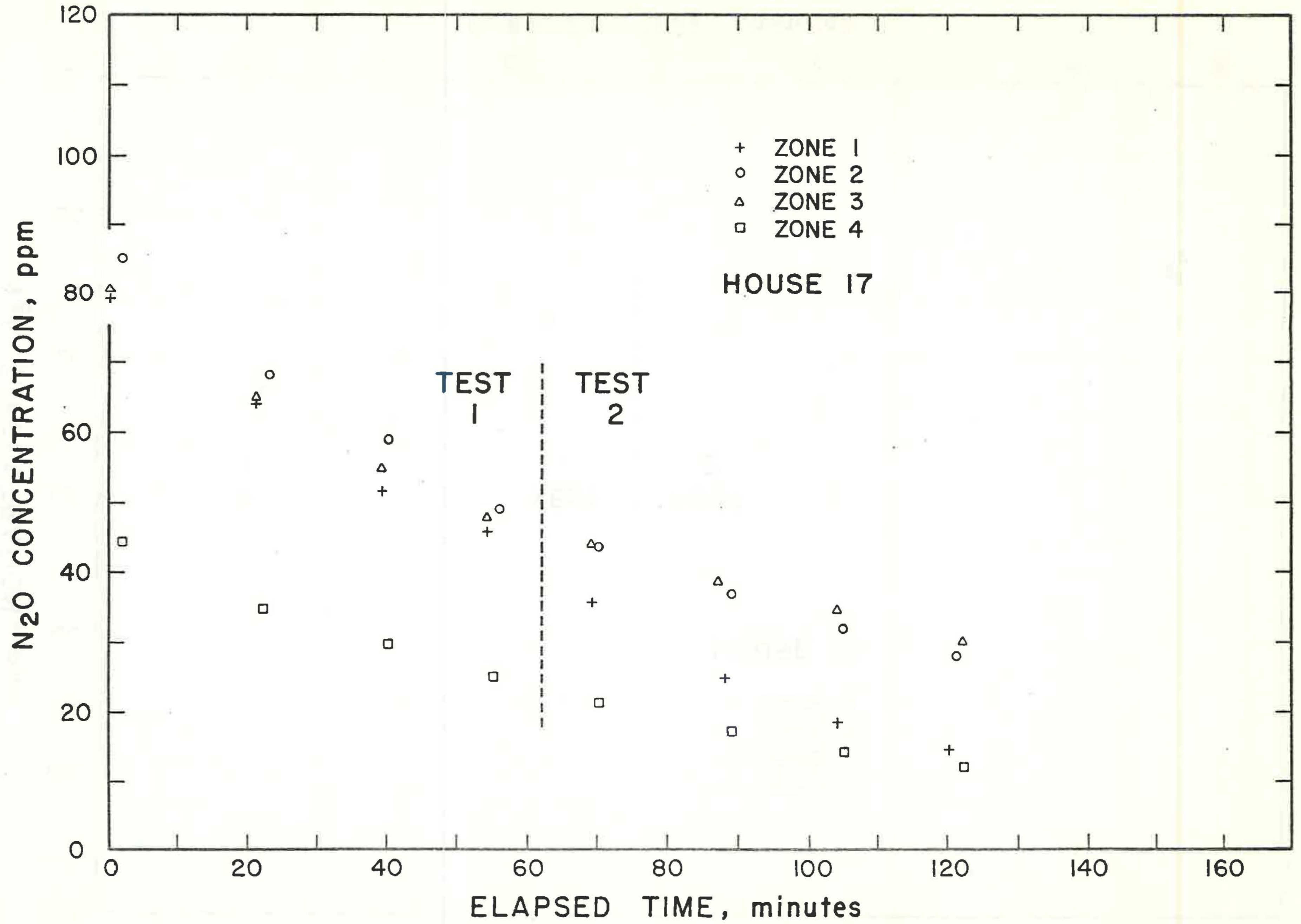
120
100
80
60
40
20
0
N2O CONCENTRATION, ppm
0
20
40
60
80
100
120
140
160
ELAPSED TIME, minutes
+ ZONE 1
o ZONE 2
Δ ZONE 3
□ ZONE 4
HOUSE, 15
TEST 1
TEST 2



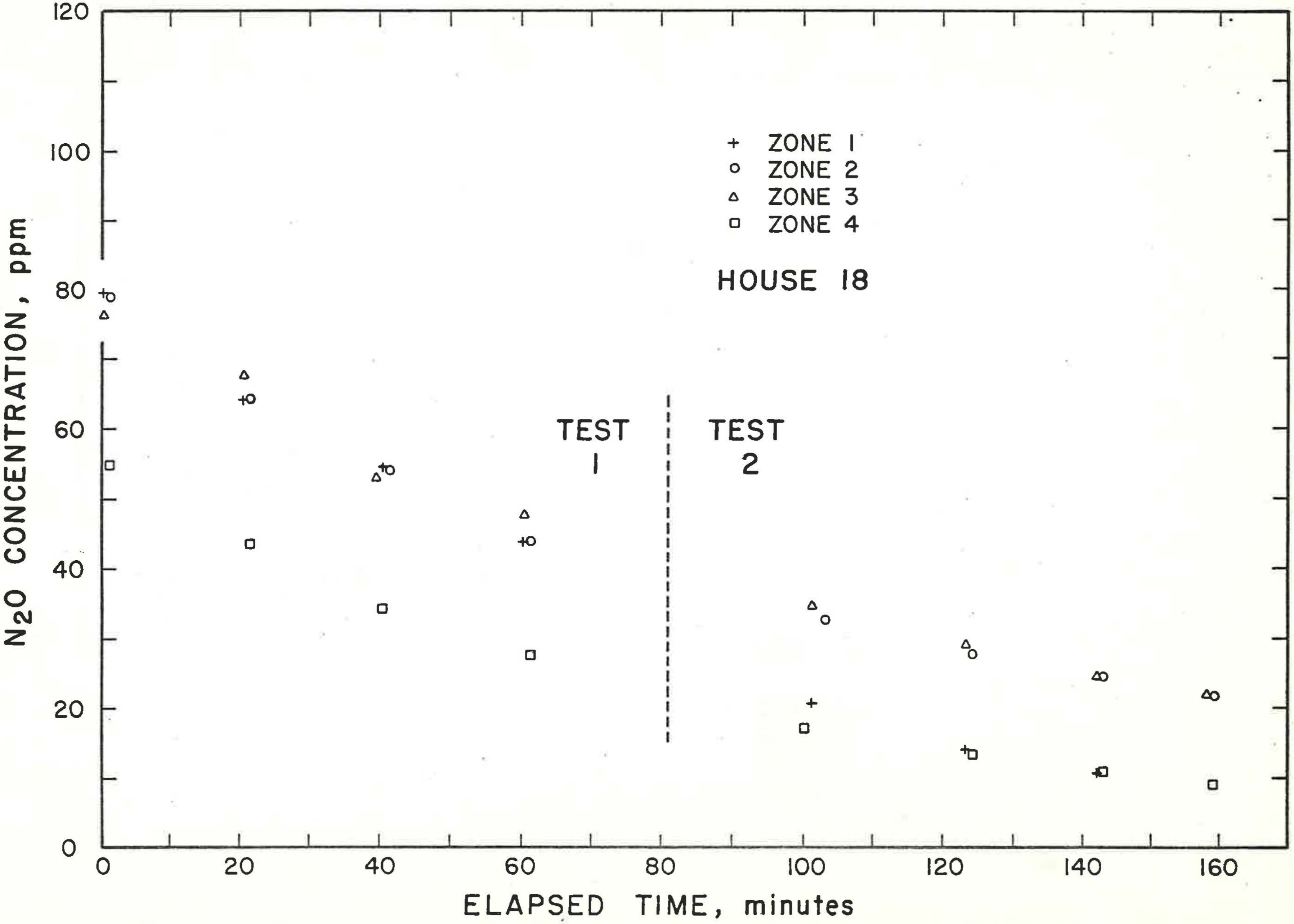
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes
+ ZONE 1
o ZONE 2
△ ZONE 3
□ ZONE 4
HOUSE 15
RE-TEST



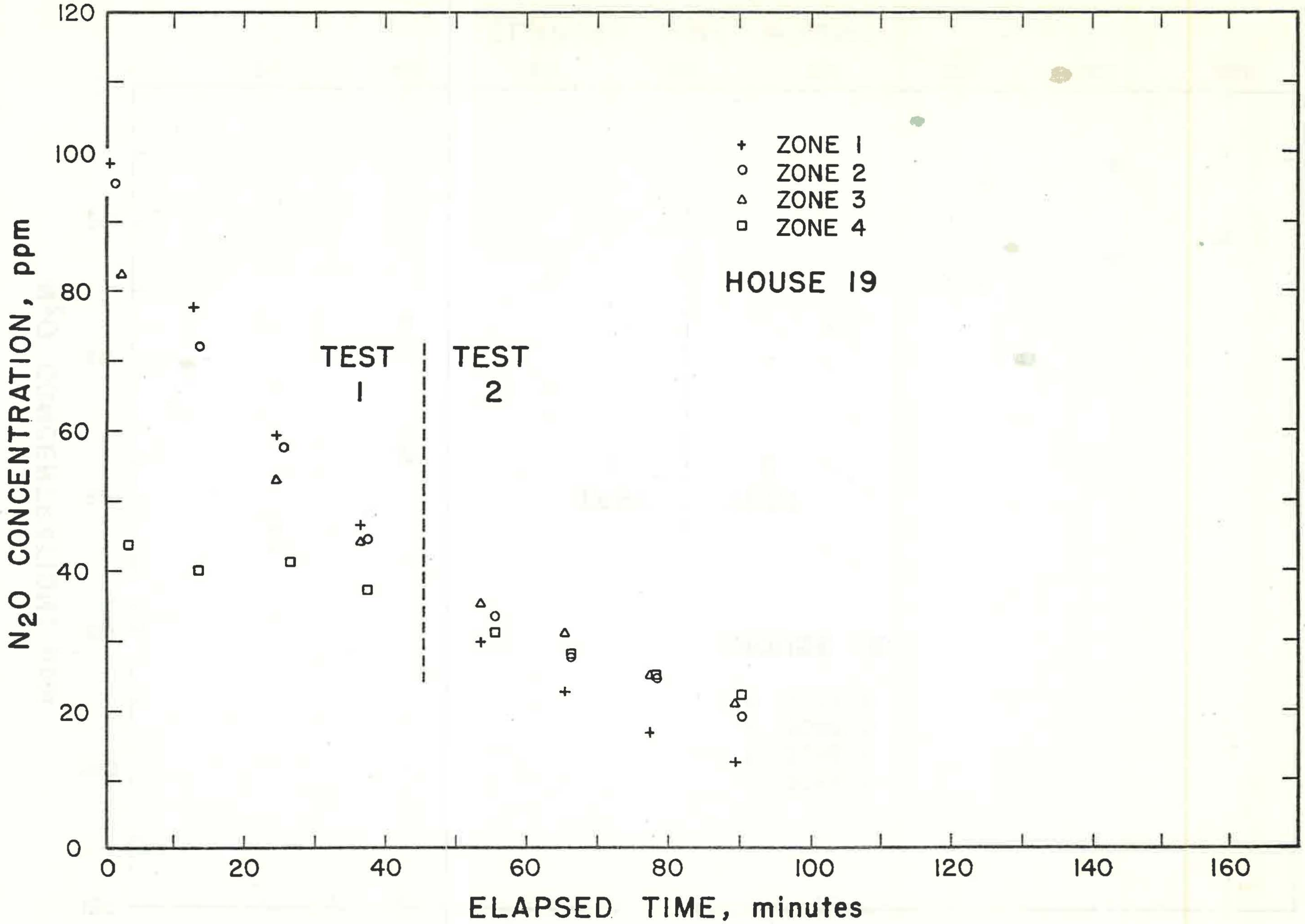
120
100
80
60
40
20
0
N2O CONCENTRATION, ppm
ZONE 1
ZONE 2
ZONE 3
ZONE 4
HOUSE 16
TEST 1
TEST 2
0
20
40
60
80
100
120
140
160
ELAPSED TIME, minutes



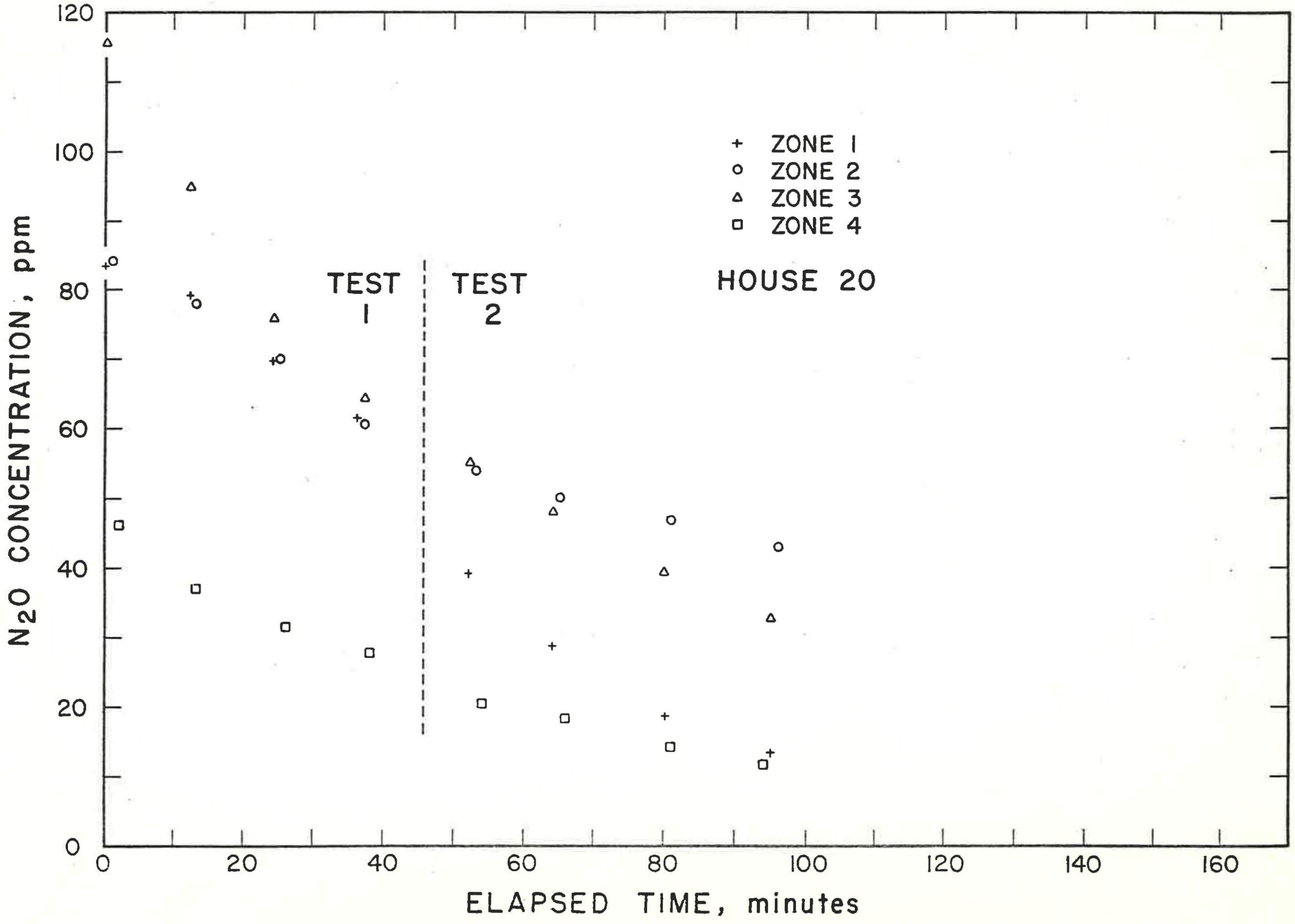
ZONE 1
ZONE 2
ZONE 3
ZONE 4
HOUSE 17
TEST 1
TEST 2
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes



120
100
80
60
40
20
0
N2O CONCENTRATION, ppm
0
20
40
60
80
100
120
140
160
ELAPSED TIME, minutes
+ ZONE 1
o ZONE 2
△ ZONE 3
□ ZONE 4
HOUSE 18
TEST 1
TEST 2

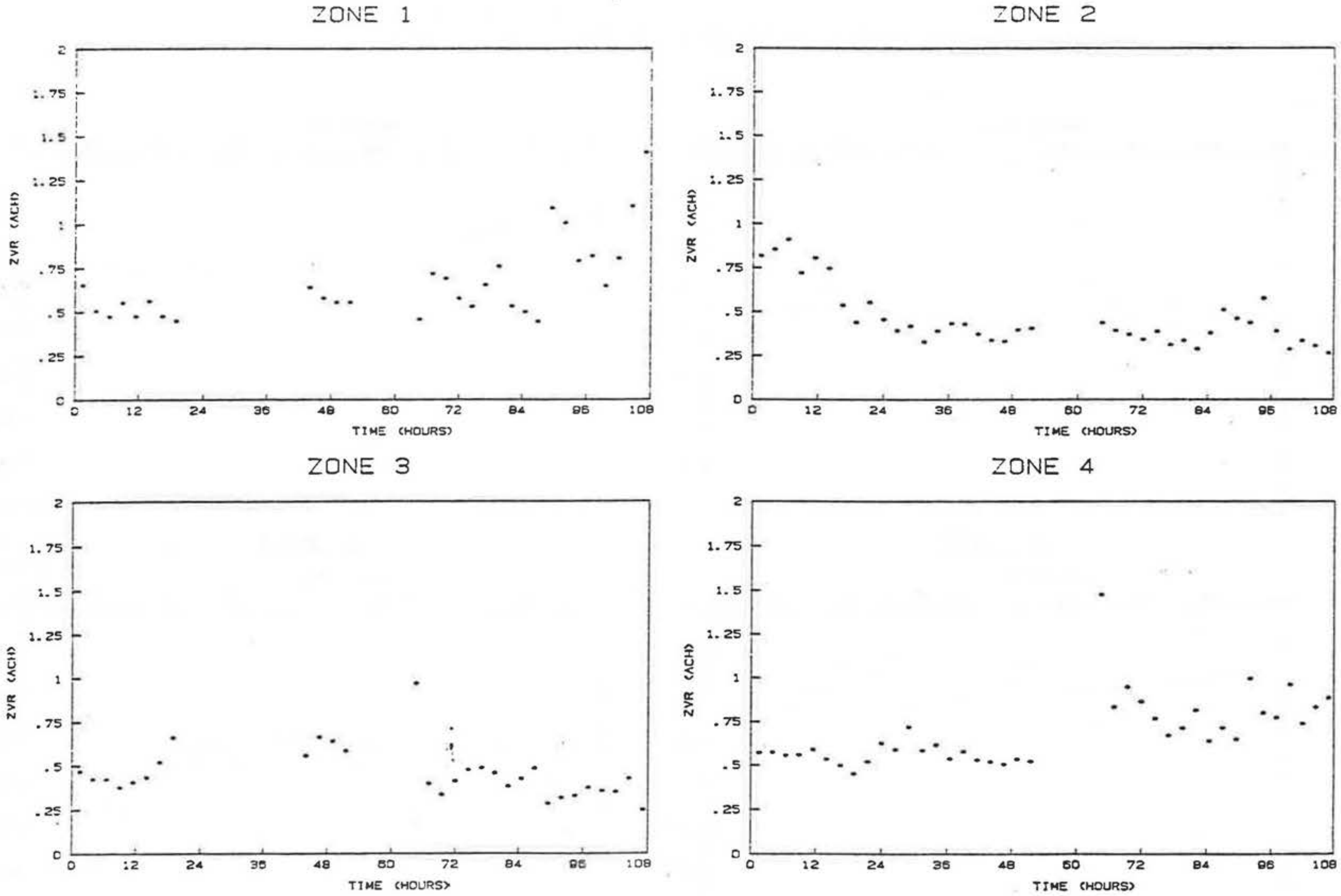


ZONE 1
ZONE 2
ZONE 3
ZONE 4
HOUSE 19
TEST 1
TEST 2
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes
0
20
40
60
80
100
120
140
160

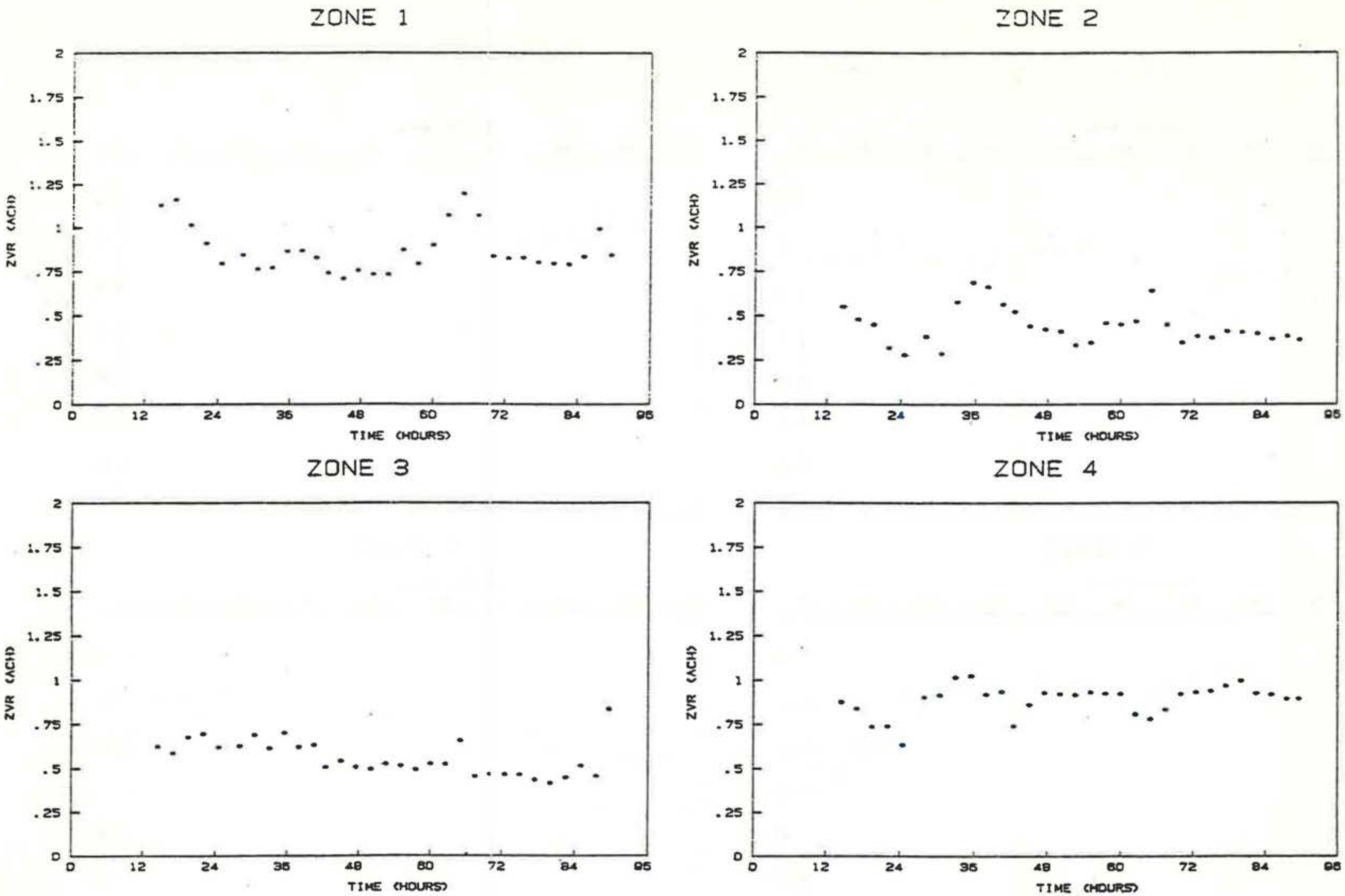


120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
N_2O CONCENTRATION, ppm
ELAPSED TIME, minutes
+ ZONE 1
○ ZONE 2
△ ZONE 3
□ ZONE 4
TEST 1
TEST 2
HOUSE 20

SF_6 TRACER GAS DECAY CURVES
(from Ref. 9)



Continuously Monitored Zone Ventilation Rates
For House 12



Continuously Monitored Zone Ventilation Rates
For House 13