#2604

#2604

AIVC
2130

Preliminary Air-to-Air Heat Exchangers Testing Results for the Residential Standards Demonstration Program

Paul Reiland

Mark McKinstry

Philip Thor

August 1985

Office of Conservation

Bonneville Power Administration

U.S. Department of Energy

7242V

TABLE OF CONTENTS

I. EXECUTIVE SUMMARY

Measurements are reported of airflow delivered by air-to-air heat exchangers (AAHX) installed in 227 single family homes in the Pacific Northwest. The homes are part of the BPA Residential Standards Demonstration Program, and represent approximately one-half of the entire sample of homes equiped with AAHX which will be tested. They were constructed to meet the Model Conservation Standards proposed by the Northwest Power Planning Council, and generally have lower natural infiltration rates than typical new homes. The airflow measurements reported here were made with the AAHX units operating on high speed. Installed cost for the AAHX's is also reported. Data for the remainder of the homes not yet measured will be reported in 1986.

Ten AAHX types accounted for 90% of the installations, with no one unit predominanting. Median installed cost was $1350, as reported by the builders. This is close to the program assumption of $1200.

The AAHX's delivered on average about one half of the airflow for which they were designed. This result is thought to be due primarily to distribution system pressure drops due to lengthly runs of flexible duct. Statistically significant differences ($P < 0.05$) were observed between climate zones 1 and 2, and for three individual AAHX types as compared with the entire sample, but the differences were minor.

The balance between intake and exhaust flow was good on a median basis, with most homes slightly pressurized (less exhaust flow than intake flow). However, a number of dwellings were quite out of balance, especially in climate zones 2 and 3, where heat exchanger core icing may have occured during the the measurements. Distribution system design, such as unequal supply and return duct lengths, is very likely causing this result.

These AAHX findings are not too surprising, considering the unfamiliarity of the builders and especially heating contractors with AAHX's, and the relatively young age of the AAHX industry. Because of the relatively low airflow rates involved, the design of the distribution system is more critical than for typical HVAC applications. The solution certainly involves better training of installers and better coordination between manufacturers, builders, and building officials.

II. INTRODUCTION

This report summarizes flow rate and cost information for 227 air-to-air heat exchangers (AAHX) installed in single family residential dwellings in the Pacific Northwest. The results include one-time measurements of as-installed, high-speed intake and exhaust volumetric airflow. These measurements were made with a rotating vane anemometer (RVA) and special flow hood developed for this application by Lambert Engineering of Bend, Oregon. The installed costs for the AAHX are also reported. The dwellings are part of the Bonneville Power Administration's (BPA) Residential Standards Demonstration Program (RSDP) (1), and represent approximately one-half of the total measurements which will be made and reported under the program. Measurements for all single family multi-family dwellings will be completed during 1986 and reported in a final report to be published later.

The RSDP is a field demonstration project of the Model Conservation Standards (MCS) proposed by the Northwest Power Planning Council (2). Under the RSDP, 500 all electric dwellings were constructed in compliance with the MCS (MCS dwellings), including both single and multi-family dwellings. These were matched on an aggregate basis to 500 control dwellings built over the last several years in compliance with current local building codes (control dwellings). A subset of the MCS dwellings (matched pair dwellings) were paired directly with control dwellings constructed concurrently with the MCS dwellings, and identical except for changes required by the new building code. The number of matched pair dwellings is currently insufficient for analysis. The dwellings in which these measurements were made are summarized in Table I.

In compliance with BPA's environmental policies, all MCS dwellings in the RSDP were equipped with an AAHX. These systems were designed to result in an overall infiltration rate (natural plus forced) of 0.6 air changes per hour (ach), the presumed rate for current practice dwellings. The control dwellings did not have an AAHX.

Construction cost, thermal performance, and indoor air quality effects of the MCS are being studied under the RSDP, principally through aggregate comparison of these parameters between the MCS and control dwellings. Construction cost is being studied using detailed cost accounting by the builder of the MCS dwelling and a hypothetical equivalent dwelling build to current practice. Thermal performance is being assessed using weekly summaries of submetered space and water heating energy, and concurrent actual heating degree days. These data are being recorded by occupants. Indoor air quality is also being studied using a fan pressurization infiltration test, three-month and one-year passive radon tests, a one-week passive formaldehyde test, and one-time test of AAHX flow. The AAHX results are reported here, and the other results are contained in reports similar to this one.

II. BACKGROUND

An AAHX is a heat-recovery ventilation system which exchanges warm, stale indoor air for colder, (typically) dryer outdoor air during heating conditions. The process of heat recovery is reversed during the cooling season in mechanically cooled buildings. Most residential units use a standard heat exchanger core constructed from thin sheets of plastic, treated paper or metal. However, some units use a rotating heat wheel. The AAHX reduces levels of indoor pollutants including moisture by replacing indoor air with outdoor air. Some mixing of intake and exhaust streams and some recycling of exhaust air from the exhaust grill to the intake grill may occur in duct systems are not properly designed (3). Some condensation of indoor humidity typically occurs during cold conditions, and this condensate must be drained away. AAHX's using water permeable cores (eg, paper) will tend to recycle humidity (and water soluble contaminants such as formaldehyde) from the outgoing stream. Figure 1 is a simplified schematic diagram which shows the essential components of an air-to-air heat exchanger, and Reference 3 provides an excellent overview of the subject.

Ventilation standards for residential dwellings have in general not yet been established. A minimum air exchange rate of 0.5 air changes be hour (ach) has been established in Sweden for new residential construction, and in California, a minimum air exchange rate at design conditions of 0.7 ach has been established for areas of the state where superinsulation is practiced (3). A minimum air exchange rate of 0.5 ach may be considered to be a generally accepted ventilation guideline, with extra ventilation for areas of pollutant and moisture sources such as kitchens, bathrooms, and laundry rooms.

In the case of the RSDP, BPA's environmental policies required that MCS dwellings have the same average infiltration rate as the control dwellings. Consequently, it was decided to comply with this requirement by requiring all MCS dwellings to incorporate an AAHX. In order to be consistent with the analysis used to develop the MCS, the average control dwelling (current practice) infiltration rate was assumed to be 0.6 ach. Most MCS dwellings in the program were designed and qualified under one of three prescriptive infiltration specifications (or packages). These were assigned estimated average infiltration rates, also chosen to be consistent with the MCS. In particular, infiltration packages A, B, and C were assumed to have average natural (not forced) infiltration rates of 0.4, 0.25, and 0.1 ach, respectively.

AAHX's were specified under the RSDP to provide enough forced ventilation such that the overall ventilation of the MCS dwellings (natural plus forced) was 0.6 ach (see Appendix 2). For example, if a home was designed with infiltration package C (0.1 ach), the AAHX was sized to provide 0.5 ach (ie 0.1 + 0.5 = 0.6 ach). This forced ventilation could be achieved with an appropriately sized unit running continuously, or an oversized unit cycled or varied with fan operation as required. A humidistat was also required which forced high speed operation when conditions of greater than 60% relative humidity occured withing the home. Builders were instructed to consider as-installed distribution system pressure drops, so that the installed system would deliver a proper balanced airflow. This was typically done using a fixed oversizing factor (often 20%) rather than careful fan curve calculations, and in practice additional oversizing was often allowed to accommodate units of limited speed control without expensive controls. At least one exhaust point and two supply points were required.

In practice, most units were installed by the general contractor, with some amount of assistance from manufacturers, heating contractors, and engineers. The contractors did attend a thorough MCS training session, including AAHX training, and received considerable AAHX information. Limited inspection has indicated, however, that duct systems were in most cases not properly laid out and designed for reasonable pressure drop and balance (5). All builders were paid a fixed incentive for installing the AAHX (approximately $800) as part of a larger incentive calculated to reimburse the entire cost of the changes required by the MCS.

IV: MEASUREMENT PROCEDURE

The performance of AAHX's in the RSDP was assessed using a one-time measurement of intake and exhaust airflow during high fan speed operation. These measurements were made using a rotating vane anemometer (RVA) mounted in a hand-held collector hood. This equipment was specifically designed and fabricated for this operation by Lambert Engineering of Bend, Oregon, who also performed the field measurements. Special equipment was required due to the unavailibility of reasonably priced flow monitoring equipment capable of operating at the required flow speeds (10 to 200 CFM) with acceptable accuracy (± 15 % of reading).

Measurements were made by temporarily sealing the system over the intake and exhaust grills of the AAHX using a gasket on the collector hood under hand pressure. An attempt was made to use the single intake and single exhaust grills located on the building exterior. If these were inaccessible, then the measurements were made at interior grills if. Thus in most cases, reported flows include losses in the distribution system. No account of these differences has been taken in this analysis. In all cases, the dwellings were tested in the "winter" configuration; all exterior windows and doors closed, and all other fans (furnace, dryer, exhaust, etc) turned off. Measurements were made at the highest occupant-selectable fan speed, and every effort was made to avoid testing in windy conditions. Additional AAHX testing is anticipated during 1986 for some of the RSDP dwellings, including measurement of distribution losses and pressure drops.

The design, calibration, and fabrication of the RVA/collector hood is described in reference 4. The unit is shown in Figure 2. The collecting hood had an opening of 8.0 x 11.25 inches, and tapered over about 15 inches to the four inch diameter RVA. It was constructed of 10 mil polyethelene over a wood frame. A ball bearing RVA manufactured by Davis Instrument Co. (Part number DI 10102-A/2) was used. The entire system was calibrated by Lambert Engineering against laboratory flow measurement and a minimum accuracy of ± 15% of reading determined over a range of 10 CFM to 150 CFM.

V: MONITORING RESULTS

The results of the AAHX measurements are summarized in Tables II through VII for the sample as a whole and by climate zones (as defined for the MCS (2)) and by AAHX type. Mean and standard deviations were computed. Medians were also computed as a measure of central tendency. These measurements represent approximately one-half of the total number of units which will be tested and reported.

AAHX types were compared for differences in performance. Differences in mean concentrations were assessed for statistical significance using Z scores. Differences were considered to be statistically significant for $Z < 1.96$ ($P > 0.05$), where:

$$Z = (X_1 - X_2)/(\sigma_1^2/N_1 + \sigma_2^2/N_2)^{0.5}$$

and:

X_i = mean for sample i
σ_i = standard deviation for mean of sample i
N_i = number of observations in sample i.

The distribution of AAHX types for these dwellings is summarized in Table II and in Figure 3. It can be seen that ten AAHX types were relatively evenly used, with four other units used once or twice. Installed costs for there units as reported by the builders is summarized in Table III and Figure 4. The costs are relatively normally distributed with a median of $1350.

The results of the AAHX flow rate measurements are summarized in Tables IV and V and Figures 5 to 8. It can be seen that the ratio was normally distributed, and on a median basis, the units were delivering about half of the flow for which they were designed. (Design flows were estimated based upon heated volume, taken as floor area times eight feet, and natural infiltration rate based upon infiltration package used). On a statistically significant basis ($P < 0.05$), it can also be seen from Tables V and VI that units B and F were somewhat better than average and unit O was somewhat poorer than average in delivering design flow. The design and delivered flows in Zones 2 and 3 were higher because of a greater prevalence of infiltration package C. A statistically valid difference in means was found only between zones 1 and 2.

Ratios of high-speed intake to exhaust flows are summarized in Table V and Figures 7 and 8. It can be seen that the distribution was relatively normal, and that on average the dwellings were sightly pressurized. Some units were, however, quite out of balance. On a statistically significant basis ($P < 0.05$), it can be seen from Table VII that units A and F were slightly better balanced than average and unit R slightly more pressurized than average. Statistically valid differences were also observed between climate zones 1 and 2 and between climate zones 1 and 3.

VI: DISCUSSION

AAHX systems in the RSDP have been preliminarily studied using limited on-site inspections (generally of "problem homes"), an occupant survey (reported elsewhere), and the high-speed flow tests (reported above). These systems represent the largest collection of such units in the Pacific Northwest. Because the builders in the program and their HVAC contractors were generally completely unfamiliar with AAHX before the program, and because the AAHX industry was still in a developmental stage, it is not surprising that not all units performed as expected. Overall performance and homeowner satisfaction with the systems was, however, good.

Problems observed through on-site visits include both poorly laid-out duct systems (unequal supply and return duct lengths, use of high-resistance ducting (ie., flexible duct), poor supply grill locations, and excessive duct bends), and poorly installed AAHX's (limited accessibility, inadequate condensate drains, and poor separation between intake and exhaust points on the building exterior) (5). Control system problems and actual as-operated flow will be investigated using results from three-month tracer gas infiltration measurements which are currently being processed or scheduled to occur during the 1985/6 heating season. Occupant complaints regarding AAHX's have mainly been of cold air drafts.

The observed problems of low high-speed flow and poor flow balance are likely due principally to poorly designed distribution systems. Most builders have apparently used flexible duct instead of metal ducts, and not paid enough attention to pressure drop considerations. This is understandable considering most builders installed the systems themselves due to lack of experience and/or enthusiasm in their HVAC contractor. Although duct layout was covered in training, the subject is not one most builders are familiar with handling, especially for these low airflow systems. Clearly more training and coordination is needed not only for builders but also HVAC contractors and building officials.

Some of the problems may also be due to the AAHX's. Most, but not all, manufacturers provided fan curves for their units, and the builders were assisted by the state Energy Offices in using these for sizing the AAHX. Because these units may frequently be required to drive distribution systems of considerable pressure drop, it is important that the fan curves and supporting information concerning duct design be provided so that nominal (ie maximum) unit flow rates are not assumed by the installer to be actual flow rates achieved in a typical house.

Correction of low flow problems will in most cases be somewhat difficult. Options include installation of a larger AAHX, replacement of all or part of the duct system with a lower pressure drop system, or installation of in-line duct booster fan. The duty cycle of the system could, of course, be increased for those systems not currently operated continuously.

Poor system balance is also probably linked to the distribution system, and in particular, to systems with very different equivalent duct lengths for the supply and return sides. In some cases (ie., Montana), the flow measurements were likely made with some amount of core icing on the exhaust side, leading to greatly reduced exhaust flow. Although the builders were instructed to perform a simple balance test (by observing a thread suspended in a single open window and noting any residual airflow), apparently not all did. Options for correction of poor balance problems include installation (or readjustment) of dampers in the duct system, although this could add to the low flow problems, replacement of all or part of the distribution system, and installation of booster fans. Poor system balance, and in particular pressurization due to intake flow exceeding exhaust flow, will lead to moisture problems as humid indoor air is driven into the building envelope through openings in the moisture retarder.

VII. SUMMARY CONCLUSIONS

1. Ten AAHX models accounted for 90% of installations in the RSDP. No one model was predominant.

2. The median installed cost for 227 units was $1350, or reasonably close to the program assumption of $1200.

3. The AAHX delivered approximately half the high-speed airflow for which they were designed, on a median basis. Average delivered flow over the heating season is very likely also half of design. Statistically significant differences ($P < 0.05$) were observed for three units, two delivering more flow relative to design flow than the average unit in the sample, and one less. Statistically significant differences were also observed between climate zones 1 and 2, with zone 2 having less airflow. Poor distribution systems (high pressure drop) are the most likely cause. Potential fixes, including duct replacement, installation of larger AAHX's, and use of in-line booster fans, would be expensive in most cases.

4. The AAHX systems were slightly unbalanced on a median basis, with intake flow exceeding exhaust flow. Many units, however, were quite out of balance. Some of the worst cases (exhaust flow very low) may have been due to heat exchanger core icing. Statistically significant ($P < 0.05$) differences in mean balance were observed for two units as compared the the sample as a whole, and between climate zones 1 and 2 and between climate zones 1 and 3. Poor distribution systems, and in particular, unequal supply and return duct equivalent lengths, were likely the principle cause. Fixes include reducting and installation of dampers, although the later would exacerbate low flows.

5. Homeowner satisfaction with the AAHX's appears to be high based upon an occupant survey (reported elsewhere). Cold air drafts appear to be the principle complaint, and are likely due to poor supply duct placement.

6. High-speed flow measurements for the remainder of the RSDP sample will be reported in 1986.

VIII: FURTHER ANALYSIS

Further analysis of these systems could be done on the following topics:

1. AAHX average delivered flow as operated.

2. Distribution duct pressure drops.

3. Distribution duct leakage.

4. Comparison of airflows by infiltration package.

5. Comparison of airflows with measured natural infiltration rates.

IX: REFERENCES

1. "Issue Backgrounder for the Residential Standards Demonstration Program",
Bonneville Power Administration; September 1985.
Available from: Public Information Office, AAHX
Bonneville Power Administration
PO BOX 3621
Portland, Oregon 97208
(503) 230-xxxx

2. "Northwest Conservation and Electric Power Plan; Appendix J: Standards Conservation in New Buildings"; Northwest Power Planning Council, 1983.
Available from:
Northwest Power Planning Council
700 SW Taylor Street
Portland, Oregon 97207
(503)222-5161

3. "Heat Recovery Ventilation for Housing, Air-to-Air Heat Exchangers"; National Center for Appropriate Technology, P.O. Box 3838, Butte, Montana 59702.5

4. Lambert, Les and Cramer, Chuck; "Testing of Air-to-Air Heat Exchangers FLow Rates for the Residential Standards Demonstration Program"; Proc. of Conservation in Buildings Conference; Butte, Montana; May, 1985; pg. I-61.

5. Private communication; Jim Maloney, Oregon Department of Energy, and Mike McSorley, Idaho Department of Water Resources.

7TABLE I: SUMMARY OF SITES

State	Zone 1	Zone 2	Zone 3	Total
Idaho	4	16	9	29
Montana	–	–	58	58
Oregon	11	2	–	13
Washington	97	30	–	127
Total	112	48	67	227

TABLE II: DISTRIBUTION OF AAHX TYPES

Type	Manufacturer/Model	Number Used
A	Air Changer	14
B	Airxchange (Nutone)	30
E	VanEE	30
F	Des Champes (79m–4)	13
G	Des Champes (79m–6)	2
H	Des Champes (200 Series)	26
I	Des Champes (300 Series)	21
M	Mountain Energy and Res.	2
N	NuTech (Lifebreath 250)	2
O	Star (100A)	25
P	Star (200A)	28
R	Enermatrix	14
X,Z	Other	20

Table III: Summary of AAHX Installed Costs ($)

Type	N	Mean	Std. Dev.	Median
A	14	1390	260	1760
B	30	1070	260	1000
E	30	1530	270	1590
F	13	1460	750	1140
H	26	1380	360	1330
I	21	1810	570	1830
O	25	1430	440	1390
P	28	1490	600	1350
R	14	1260	180	1250
X	20	1470	380	1480
G	2	2079	-	-
M	2	1545	-	-
N	2	1898	-	-
T	2	2633	-	-
Z	1	1681	-	-
All	227	1440	810	1350

TABLE IV: SUMMARY OF FLOW RATES

		Median Flow (CFM)		
Case	N	Intake	Exhaust	Design
All	227	72	72	127
Zone 1	112	68	71	113
Zone 2	48	73	66	133
Zone 3	67	81	77	142

TABLE V: SUMMARY OF BALANCING AND DESIGN FLOW RATIOS

		Intake Flow/Exhaust Flow			Actual Flow/Design Flow		
Case	N	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median
All	227	1.17	0.83	1.05	0.60	0.27	0.55
Zone 1	112	1.00	0.37	1.00	0.64	0.25	0.62
Zone 2	48	1.25	0.74	1.15	0.50	0.33	0.49
Zone 3	67	1.40	1.27	1.06	0.60	0.21	0.57
Type A	14	0.99	0.18	0.99	0.64	0.17	0.63
Type B	30	1.16	0.82	1.05	0.72	0.31	0.77
Type E	30	1.47	1.55	1.12	0.63	0.23	0.59
Type F	13	0.83	0.19	1.02	0.78	0.32	0.82
Type H	26	1.05	0.22	1.07	0.56	0.34	0.53
Type I	21	1.11	0.48	0.97	0.56	0.24	0.54
Type O	25	1.04	0.23	0.94	0.46	0.22	0.48
Type P	28	1.06	0.29	1.04	0.53	0.20	0.50
Type R	14	1.65	1.42	1.08	0.56	0.23	0.50
Type X	20	1.13	0.72	1.06	0.57	0.27	0.51
Type G	2	1.29	–	–	0.76	–	–
Type M	2	1.09	–	–	0.66	–	–
Type N	2	1.01	–	–	0.78	–	–
Type T	2	1.44	–	–	0.49	–	–
Type Z	1	1.46	–	–	0.87	–	–

TABLE VI: Statistical Significance of Mean Actual Flow to Design Flow Ratio for Specific AAHX Types as compared to the Entire Sample (P<0.05)

Type	Median Ratio	Z score	Statistical Significance
A	0.63	0.82	No
B	0.77	1.96	Yes
E	0.57	0.66	No
F	0.82	1.99	Yes
H	0.53	0.58	No
I	0.54	0.72	No
O	0.48	2.95	Yes
P	0.50	1.67	No
R	0.50	0.62	No
Z	0.51	0.48	No

TABLE VI: Statistical Significance of Mean Intake Flow to Exhaust Flow Ratio for Specific AAHX Types as compared to the Entire Sample (P<0.05)

Type	Median Ratio	Z score	Statistical Significance
A	0.99	2.46	Yes
B	1.05	0.06	No
E	1.12	1.04	No
F	1.02	4.46	Yes
H	1.07	1.71	No
I	0.97	0.51	No
O	0.94	1.81	No
P	1.04	1.42	No
R	1.08	3.84	Yes
Z	1.06	0.24	No

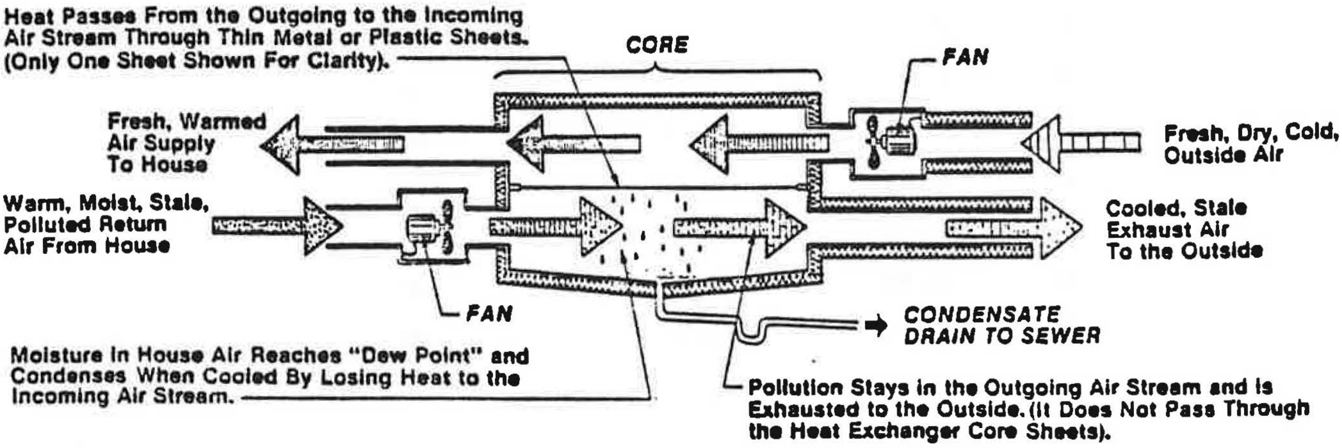

Figure 1: Schematic AAHX cross section (3).

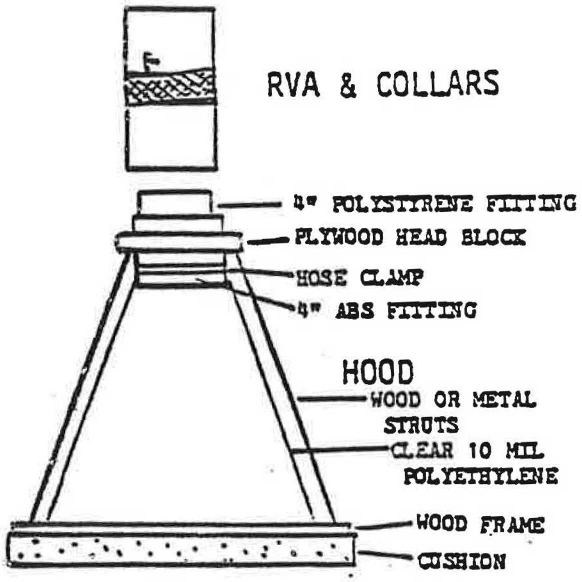

Figure 2: Rotating Vane Anemometer and Collector Hood Assembly (4).

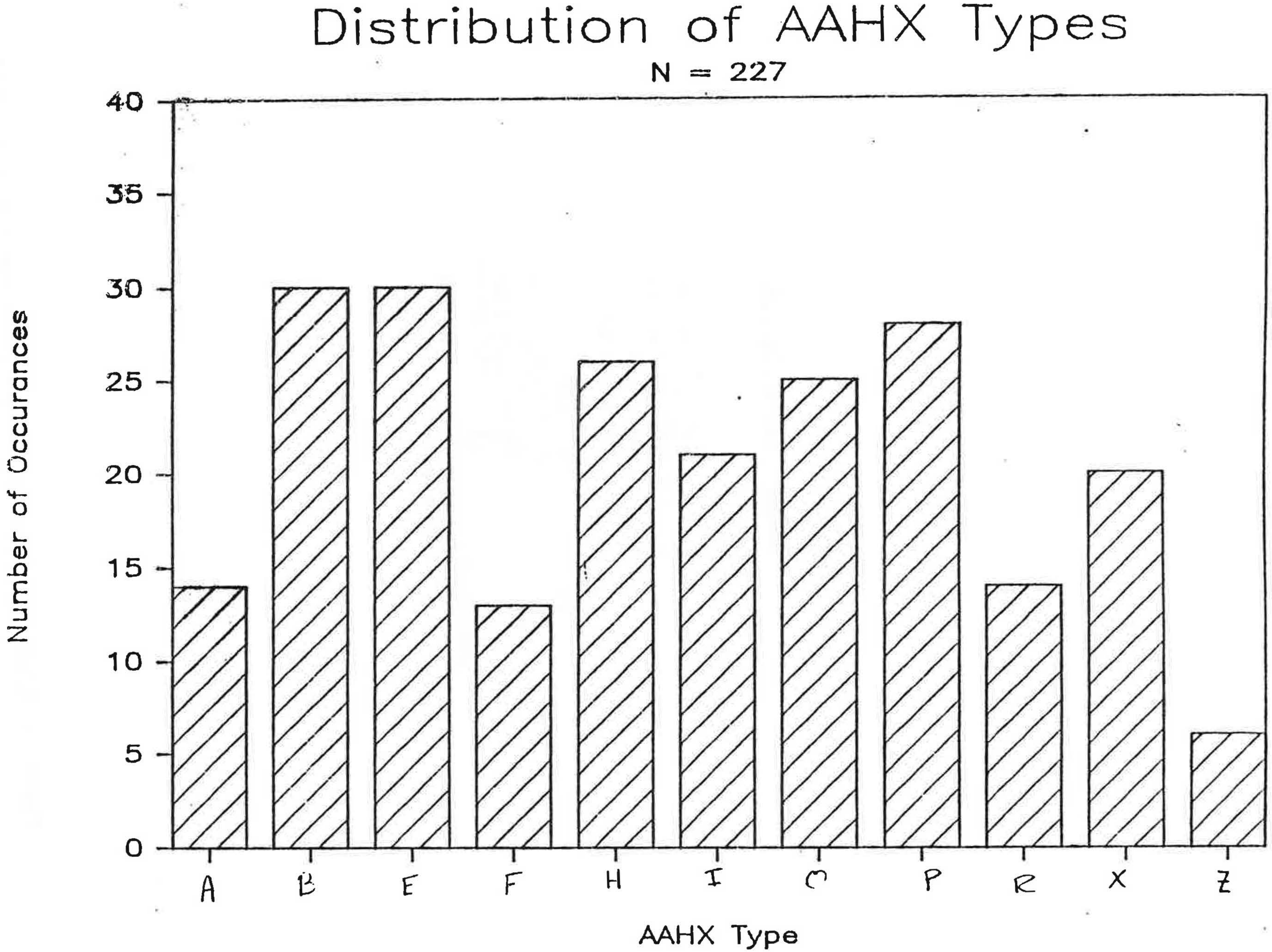

Figure 3: Distribution of AAHX Types.

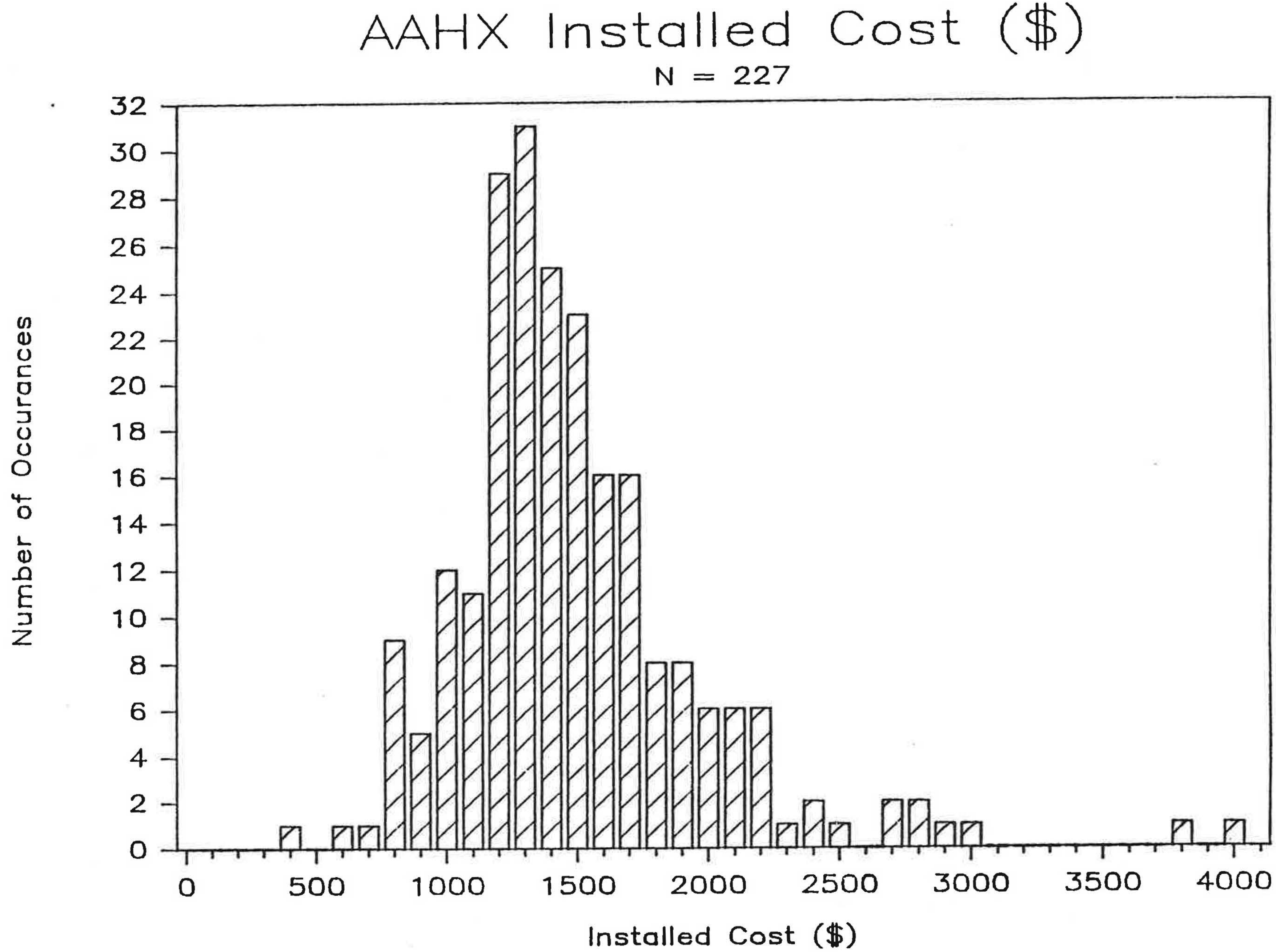

Figure 4: Distribution of AAHX Installed Costs.

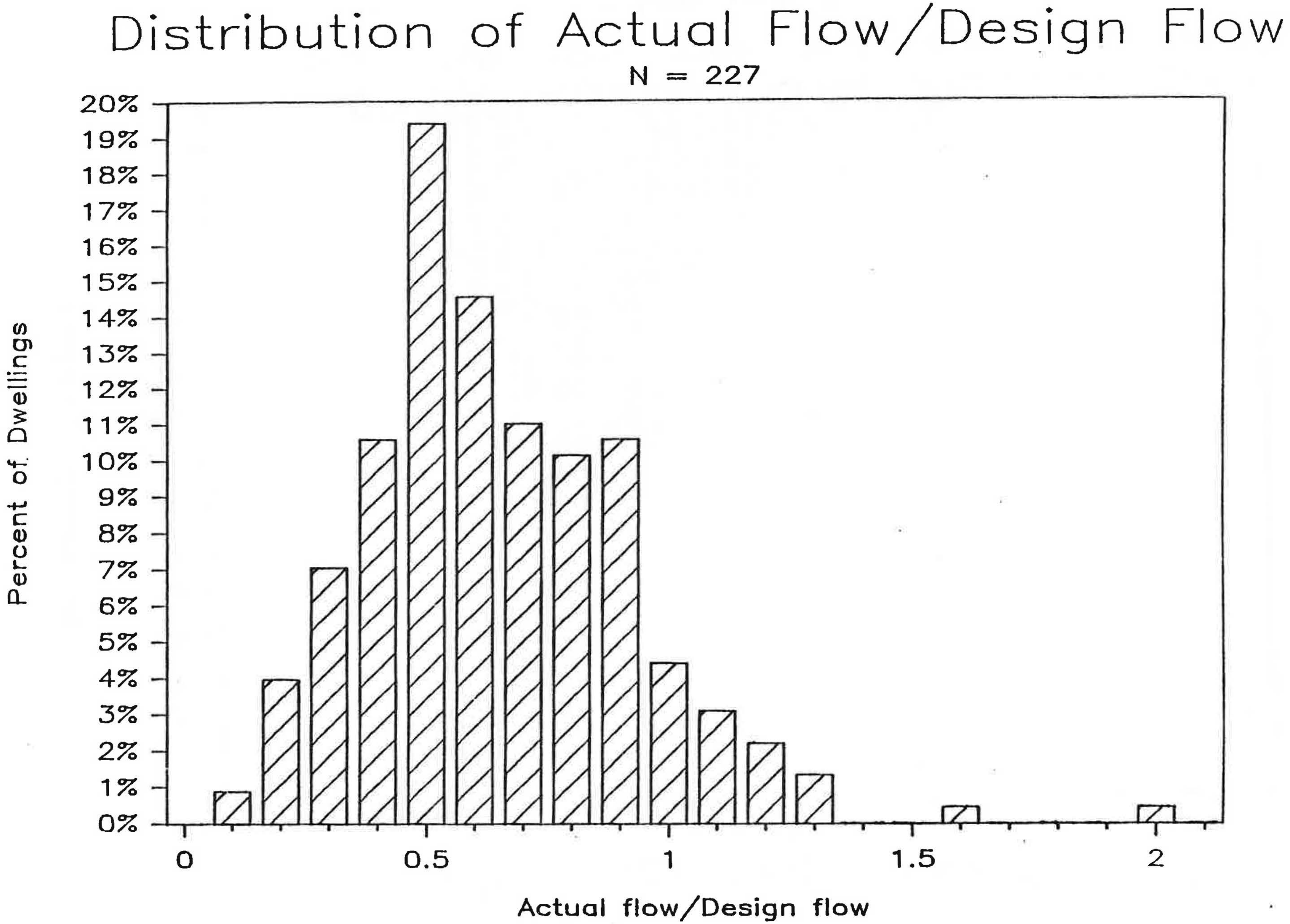

Figure 5: Distribution of Actual Flow to Design Flow.

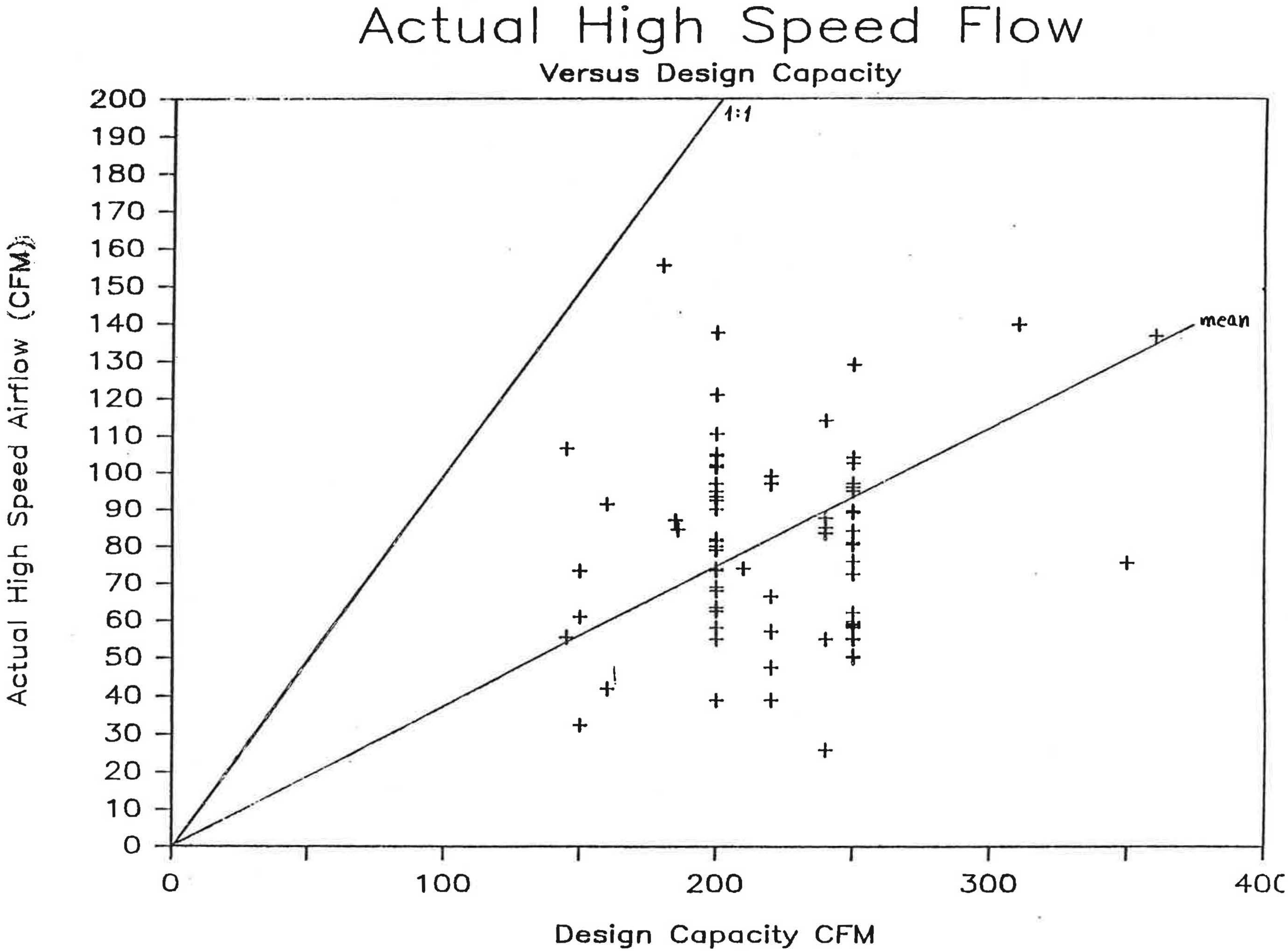

Figure 6: Scatter Plot of Actual Flow to Design Flow.

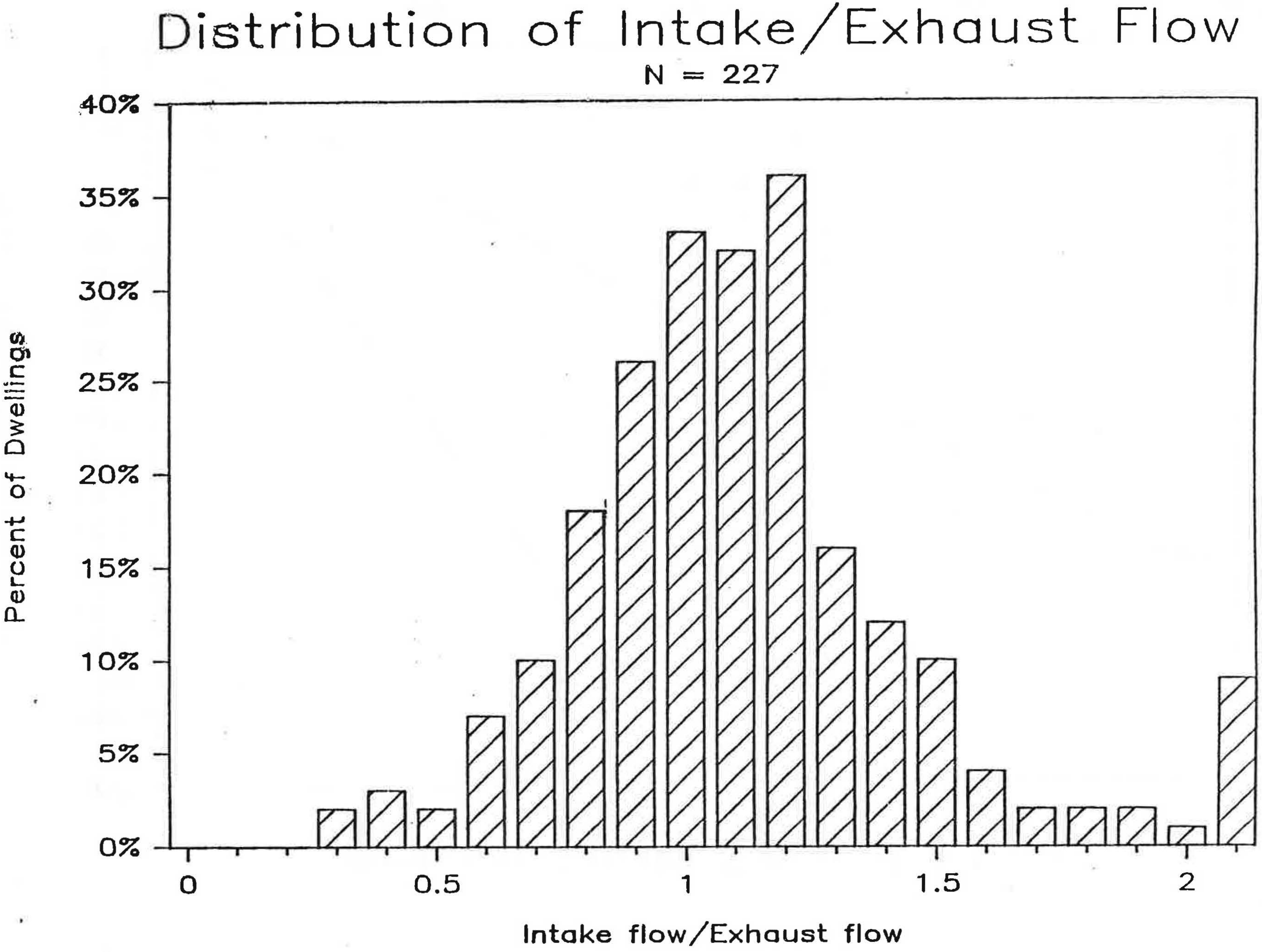

Figure 7: Distribution of Intake Flow to Exhaust Flow.

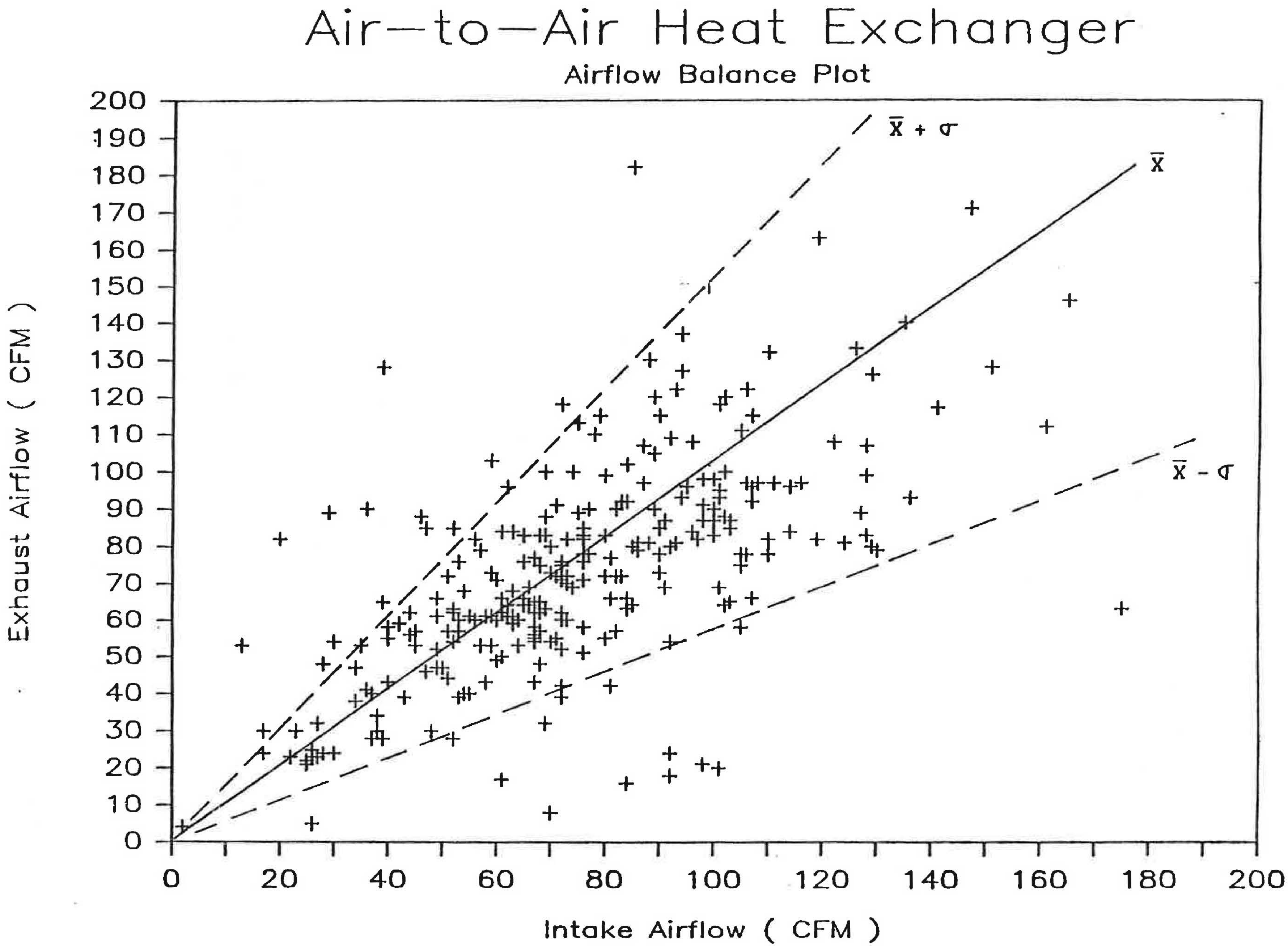

Figure 8: Scatter Plot of Intake Flow to Design Flow.

APPENDIX

This appendix contains site-by-site primary data used in the analysis contained in this report. The following column abbreviations have been used:

St:.......State: 1 = Idado
2 = Montana
3 = Oregon
4 = Washington

Zn:.......Climate zone

Mp:.......Matching: 1 = matched pair
2 = unmatched

MCS:......Dwelling type: 1 = MCS dwelling
2 = control dwelling

S/M:......Dwelling type: 1 = single family
3 = multi-family

Area:.....Official program heated floor area in ft^2

Volume:...Approximate heated volume in ft^3

Pkg:......MCS infiltration package used

Type:.....AAHX type, see Table 2 for explanation of letters

Cost:.....Installed cost of AAHX in $

Cap:......Nameplate capacity of AAHX in CFM (999 if unavailable

Intake:...Measured overall intake airflow in CFM

Exhaust:..Measured overall exhaust airflow in CFM

St	Zn	MP	MCS	S/M	Area	Volume	Infl	Type	Cost	Cap	Intake	Exhst
1	1	1	1	1	1598	12784	3	I	2120	160	30	54
1	1	2	1	1	1426	11408	3	I	1800	160	100	83
1	1	2	1	1	1996	15968	3	X	1200	999	84	92
1	1	2	1	1	1890	15120	3	X	2060	999	20	82
1	2	1	1	1	2252	18016	3	X	1500	999	2	4
1	2	2	1	1	3370	26960	3	X	1825	999	128	107
1	2	2	1	1	4225	33800	3	T	2633	360	161	112
1	2	2	1	1	1896	15168	3	X	1247	999	101	95
1	2	2	1	1	3200	25600	3	X	1686	999	130	79
1	2	2	1	1	2700	21600	3	X	2390	999	80	83
1	2	2	1	1	3352	26816	3	E	1260	200	91	69
1	2	2	1	1	2059	16472	3	X	1500	999	13	53
1	2	2	1	1	2616	20928	3	E	1677	185	74	100
1	2	2	1	1	1423	11384	2	X	1507	999	98	91
1	2	2	1	1	1288	10304	3	E	1592	999	84	102
1	2	2	1	1	3200	25600	3	X	1462	999	85	80
1	2	2	1	1	1396	11168	3	X	1431	999	101	118
1	2	2	1	1	1352	10816	3	O	1266	150	37	28
1	2	2	1	1	1224	9792	3	H	1840	180	165	146
1	2	2	1	1	2049	16392	3	X	1532	999	107	92
1	3	2	1	1	1277	10216	3	I	2654	415	69	88
1	3	2	1	1	2400	19200	3	E	1718	999	102	120
1	3	2	1	1	1294	10352	3	H	1966	210	65	83
1	3	2	1	1	2136	17088	3	I	2137	310	151	128
1	3	2	1	1	2208	17664	3	X	1326	999	90	115
1	3	2	1	1	1920	15360	3	H	1424	240	53	57
1	3	2	1	1	2496	19968	3	H	1405	240	86	81
1	3	2	1	1	2526	20208	3	I	1195	999	76	82
1	3	2	1	1	2628	21024	3	I	2397	415	175	63
2	3	2	1	1	1478	11824	3	E	1247	200	65	83
2	3	2	1	1	2800	22400	3	E	1613	200	114	96
2	3	2	1	1	3352	26816	3	E	1407	250	64	53
2	3	2	1	1	2040	16320	3	R	1118	250	89	90
2	3	2	1	1	1926	15408	3	R	1464	250	68	48
2	3	2	1	1	2286	18288	3	R	1135	250	76	85
2	3	2	1	1	1872	14976	3	E	1801	200	105	75
2	3	1	1	1	1392	11136	3	E	1269	200	102	88
2	3	2	1	1	2332	18656	3	H	1296	200	81	66
2	3	2	1	1	2240	17920	3	H	1135	240	77	90
2	3	2	1	1	1709	13672	3	N	1635	250	110	82
2	3	2	1	1	1356	10848	3	R	1202	250	76	76
2	3	1	1	1	1144	9152	3	M	1568	150	67	55
2	3	2	1	1	3170	25360	3	R	1621	999	51	57
2	3	2	1	1	2221	17768	3	R	1271	250	100	90
2	3	2	1	1	2860	22880	3	R	1251	250	61	84
2	3	2	1	1	1167	9336	3	E	1237	186	69	100
2	3	2	1	1	1889	15112	3	R	1353	250	29	89
2	3	2	1	1	3133	25064	3	E	1368	200	94	127
2	3	2	1	1	2800	22400	3	I	1390	145	116	97
2	3	2	1	1	2688	21504	3	H	1374	240	90	85
2	3	2	1	1	3313	26504	3	E	1579	200	76	51
2	3	2	1	1	2944	23552	3	I	2234	250	103	65
2	3	2	1	1	2312	18496	3	E	1161	200	129	80
2	3	2	1	1	1879	15032	3	R	945	250	72	52
2	3	2	1	1	1974	15792	3	E	1645	200	105	58
2	3	2	1	1	2016	16128	3	E	1720	999	73	82

St	Zn	MP	MCS	S/M	Area	Volume	Infl	Type	Cost	Cap	Intake	Exhst
2	3	2	1	1	2570	20560	3	E	1612	250	92	18
2	3	2	1	1	2960	23680	3	E	1232	200	81	77
2	3	2	1	1	2128	17024	3	E	1595	200	70	8
2	3	2	1	1	2886	23088	3	E	1600	200	107	96
2	3	2	1	1	1560	12480	3	R	1202	250	69	32
2	3	2	1	1	2034	16272	3	E	1965	250	111	97
2	3	2	1	1	1628	13024	3	F	1142	200	75	89
2	3	2	1	1	3240	25920	3	R	****	250	91	87
2	3	2	1	1	3690	29520	3	I	1827	220	51	44
2	3	2	1	1	2125	17000	3	M	1523	150	72	75
2	3	2	1	1	2260	18080	3	I	1892	220	68	65
2	3	2	1	1	1720	13760	3	R	1026	250	141	117
2	3	1	1	1	1184	9472	3	R	1310	250	98	21
2	3	2	1	1	1792	14336	3	A	1350	200	49	61
2	3	2	1	1	1824	14592	3	I	1214	240	106	122
2	3	2	1	1	1889	15112	3	E	1560	200	96	108
2	3	2	1	1	2223	17784	3	I	1758	220	52	62
2	3	2	1	1	2544	20352	3	E	1328	250	108	97
2	3	2	1	1	2400	19200	3	H	1178	200	57	79
2	3	2	1	1	1874	14992	1	I	965	145	61	50
2	3	2	1	1	2474	19792	3	I	2151	220	87	107
2	3	2	1	1	2456	19648	3	I	2460	145	72	39
2	3	2	1	1	2703	21624	3	R	1464	250	84	16
2	3	2	1	1	2132	17056	3	E	1765	200	110	132
2	3	1	1	1	960	7680	3	H	1232	240	28	24
2	3	2	1	1	2395	19160	3	E	980	200	98	87
2	3	2	1	1	1787	14296	3	H	1684	220	48	30
2	3	2	1	1	2034	16272	3	E	1965	250	71	91
2	3	2	1	1	2016	16128	3	N	2160	250	79	115
2	3	2	1	1	2359	18872	3	E	1694	200	135	140
2	3	2	1	1	1582	12656	3	H	1250	240	101	69
3	1	2	1	1	1495	11960	2	B	910	999	73	60
3	1	2	1	1	2303	18424	1	A	1213	999	67	56
3	1	2	1	1	1450	11600	3	B	1320	200	94	93
3	1	2	1	1	2948	23584	1	B	789	999	62	96
3	1	2	1	1	1844	14752	1	H	400	999	38	34
3	1	2	1	1	2089	16712	1	I	600	350	68	83
3	1	2	1	1	1247	9976	1	B	938	999	129	126
3	1	2	1	1	1304	10432	1	B	1016	999	36	90
3	1	2	1	1	1334	10672	2	X	730	200	56	82
3	1	2	1	1	2678	20540	3	H	927	200	67	58
3	1	2	1	1	1900	22800	1	X	1370	200	92	24
3	2	2	1	1	1967	15736	3	H	1300	220	114	84
3	2	2	1	1	1776	14208	3	H	1333	200	89	105
4	1	2	1	1	2647	21176	3	P	1827	999	39	128
4	1	1	1	1	1246	9968	3	O	1528	999	34	38
4	1	2	1	1	1278	10224	3	O	1652	999	55	61
4	1	2	1	1	2475	19800	3	H	2045	999	64	60
4	1	2	1	1	2535	20280	3	O	2750	999	68	75
4	1	2	1	1	2040	16320	3	H	1752	999	63	68
4	1	2	1	1	1852	14816	3	O	2750	999	61	66
4	1	2	1	1	1425	11400	3	A	1639	999	59	103
4	1	1	1	1	1658	13264	2	O	1288	999	70	73
4	1	2	1	1	1750	14000	3	A	1450	999	69	83
4	1	2	1	1	1011	8088	3	O	1133	999	73	70
4	1	2	1	1	1592	12736	3	H	1020	999	103	87

St	Zn	MP	MCS	S/M	Area	Volume	Infl	Type	Cost	Cap	Intake	Exhst
4	1	1	1	1	1323	10584	2	O	1486	999	50	47
4	1	2	1	1	1248	9984	3	G	1245	999	92	80
4	1	2	1	1	1692	13536	3	O	1468	999	64	60
4	1	2	1	1	1327	10616	3	F	1090	999	105	78
4	1	2	1	1	1730	13840	3	A	1339	999	66	64
4	1	1	1	1	1422	11376	1	X	745	999	110	78
4	1	2	1	1	1176	9408	3	A	1150	999	69	63
4	1	2	1	1	1327	10616	3	F	1134	999	43	39
4	1	2	1	1	1176	9408	3	A	1150	999	68	62
4	1	2	1	1	1124	8992	3	F	1214	999	62	61
4	1	2	1	1	1934	15472	3	A	1403	999	54	40
4	1	2	1	1	3300	26400	3	I	1961	999	70	80
4	1	2	1	1	1288	10304	3	B	780	999	47	85
4	1	2	1	1	1792	14336	3	I	1341	999	22	23
4	1	2	1	1	3366	26928	1	B	678	999	39	65
4	1	2	1	1	1388	11104	3	F	1121	999	105	111
4	1	1	1	1	1143	9144	3	B	1155	999	72	118
4	1	2	1	1	1418	11344	3	F	1058	999	93	122
4	1	1	1	1	1143	9144	3	B	1155	999	52	85
4	1	2	1	1	1449	11592	3	A	1865	999	58	61
4	1	2	1	1	1883	15064	3	P	784	999	78	110
4	1	2	1	1	1713	13704	3	I	1266	999	90	73
4	1	2	1	1	1738	13904	3	P	1480	999	44	62
4	1	2	1	1	1176	9408	3	A	1150	999	62	64
4	1	2	1	1	2002	16016	3	P	1058	999	54	68
4	1	2	1	1	1588	12704	3	B	1200	999	102	64
4	1	2	1	1	2320	18560	3	P	872	999	45	53
4	1	2	1	1	1936	15488	3	A	1407	999	60	60
4	1	2	1	1	2460	19680	3	P	1763	999	65	76
4	1	2	1	1	1625	13000	3	O	1522	999	46	88
4	1	2	1	1	1611	12888	2	P	1199	999	87	97
4	1	2	1	1	1649	13192	3	O	1215	999	28	48
4	1	2	1	1	2078	16624	3	P	1585	999	40	43
4	1	2	1	1	1176	9408	3	A	1150	999	65	64
4	1	1	1	1	1143	9144	3	B	1155	999	75	113
4	1	2	1	1	1284	10272	3	O	1217	999	23	30
4	1	2	1	1	2636	21088	3	P	1026	999	49	52
4	1	1	1	1	1851	14808	3	O	1395	999	60	71
4	1	2	1	1	1883	15064	3	P	784	999	95	96
4	1	2	1	1	2193	17544	3	H	1230	999	101	93
4	1	2	1	1	2714	21712	2	P	1447	999	98	98
4	1	2	1	1	2028	16224	3	X	1620	999	92	54
4	1	2	1	1	1916	15328	3	P	2195	999	72	71
4	1	2	1	1	3356	26848	3	G	2913	999	127	89
4	1	2	1	1	1462	11696	2	P	2070	0	74	69
4	1	2	1	1	2868	22944	3	I	2872	999	85	182
4	1	2	1	1	2306	18448	3	P	812	999	106	97
4	1	2	1	1	3100	24800	3	F	1684	999	67	62
4	1	2	1	1	1916	15328	3	P	2195	999	80	72
4	1	2	1	1	1221	9768	1	F	1115	999	66	69
4	1	2	1	1	1715	13720	3	P	866	999	93	81
4	1	2	1	1	1210	9680	1	F	1069	999	67	77
4	1	2	1	1	1651	13208	3	B	884	999	53	76
4	1	2	1	1	1326	10608	3	E	1035	999	90	78
4	1	2	1	1	1634	13072	3	P	1593	999	72	62
4	1	2	1	1	2388	19104	3	A	1250	999	77	78

St	Zn	MP	MCS	S/M	Area	Volume	Infl	Type	Cost	Cap	Intake	Exhst
4	1	1	1	1	1143	9144	3	B	1155	999	83	92
4	1	2	1	1	1900	15200	3	B	770	999	128	99
4	1	2	1	1	2468	19744	3	P	1295	999	60	49
4	1	2	1	1	1684	13472	3	O	1117	999	42	59
4	1	2	1	1	2032	16256	3	P	1552	999	67	54
4	1	2	1	1	1280	10240	3	O	1171	999	27	32
4	1	2	1	1	1740	13920	3	P	1230	999	55	40
4	1	2	1	1	2453	19624	3	H	1197	999	72	76
4	1	2	1	1	3275	26200	3	P	1558	999	119	82
4	1	2	1	1	3635	29080	2	F	3980	999	39	28
4	1	2	1	1	3344	26752	3	P	3800	999	80	55
4	1	2	1	1	1494	11952	3	F	1455	999	65	66
4	1	1	1	1	1143	9144	3	B	1155	999	59	61
4	1	2	1	1	2576	20608	3	A	1978	999	126	133
4	1	1	1	1	1505	12040	3	B	999	999	100	98
4	1	2	1	1	1764	14112	3	B	834	999	84	63
4	1	2	1	1	1521	12168	3	B	1047	999	67	65
4	1	2	1	1	1185	9480	3	O	910	999	63	84
4	1	2	1	1	1623	12984	3	B	996	999	103	85
4	1	2	1	1	3056	24448	3	H	1380	999	88	130
4	1	2	1	1	1630	13040	3	B	997	999	96	84
4	1	2	1	1	4456	35648	3	I	1673	999	76	78
4	1	2	1	1	1497	11976	3	B	775	999	82	72
4	1	2	1	1	2184	17472	3	X	1400	999	73	72
4	1	1	1	1	1222	9776	3	B	790	999	63	61
4	1	2	1	1	1406	11248	3	F	1543	999	122	108
4	1	2	1	1	2419	19352	3	B	1956	999	63	59
4	1	2	1	1	2193	17544	3	X	1714	999	59	53
4	1	2	1	1	1390	11120	3	B	997	999	76	71
4	2	2	1	1	3213	25704	3	P	1300	999	40	58
4	2	2	1	1	1910	15280	3	O	1452	999	26	23
4	2	2	1	1	1820	14560	3	O	1319	999	40	55
4	2	2	1	1	1888	15104	3	B	1368	999	30	24
4	2	2	1	1	1824	14592	3	O	1253	999	17	30
4	2	2	1	1	1860	14880	3	P	1354	999	124	81
4	2	2	1	1	2019	16152	3	B	1450	999	70	54
4	2	1	1	1	1860	14880	3	P	1331	999	83	72
4	2	2	1	1	1652	13216	3	B	940	999	81	42
4	2	2	1	1	2216	17728	3	H	1637	999	72	76
4	2	2	1	1	1876	15008	3	X	1120	999	57	53
4	2	2	1	1	2144	17152	3	O	1384	999	61	17
4	2	2	1	1	1893	15144	3	B	1368	999	26	5
4	2	1	1	1	1824	14592	3	B	1370	999	38	30
4	2	2	1	1	1848	14784	3	E	1403	999	52	63
4	2	2	1	1	1876	15008	3	O	1120	999	27	23
4	2	2	1	1	2289	18312	3	E	2065	999	97	82
4	2	2	1	1	3838	30704	3	P	2083	999	72	42
4	2	2	1	1	2044	16352	3	E	1845	999	82	57
4	2	2	1	1	3087	24696	3	P	1344	999	107	115
4	2	2	1	1	1406	11248	3	F	1424	999	71	55
4	2	2	1	1	1314	10512	3	O	1011	999	53	39
4	2	2	1	1	3458	27664	3	H	1213	999	17	24
4	2	2	1	1	3210	25680	3	B	1186	999	88	81
4	2	2	1	1	2640	21120	3	H	1442	999	100	87
4	2	2	1	1	2464	19712	3	H	2040	999	71	72
4	2	2	1	1	1860	14880	3	P	1332	999	72	60

St	Zn	MP	MCS	S/M	Area	Volume	Infl	Type	Cost	Cap	Intake	Exhst
4	2	2	1	1	2159	17272	3	O	1454	999	25	21
4	2	2	1	1	3458	27664	3	H	1213	999	25	22
4	2	2	1	1	1971	15768	3	X	1681	999	136	93

APPENDIX 2: RSDP AAHX Specifications

1 DESIGN

The AAHX shall be specifically designed for use in residential buildings, and shall be capable of ventilating the conditioned space by introducing outdoor air. Such air shall be conditioned (during the heating season) through an exchange of heat from the indoor air that is being exhausted to the outside of the building.

2 TYPE

The AAHX shall be of the central system type which delivers air to at least two locations in the conditioned space. Window and wall mounted units are specifically excluded. The AAHX may be used in place of bathroom exhaust fans if approved by the manufacturer.

3 SIZE

The heat exchanger shall be sized and controlled to ventilate the conditioned space such that the heating season average overall air exchange rate is 0.6 ACH.

3.1 Control System: Use of either an automatic control system to cycle or continuously vary AAHX ventilation rate, or use of a fixed forced infiltation rate may be used to meet this sizing specification.

3.2 Natural Infiltration Rate: The natural infiltration rate used for this sizing shall be 0.4 ACH if infiltration package A is used, 0.25 ACH if infiltration package B is used, and 0.1 ACH if infiltration package C is used.

3.3 Sizing Calculations: The sizing calculations shall be done according to manufacturer's specifications and using standard engineering practice.

3.4 Humidistat: A humidistat shall be provided which will automatically operate the AAHX on its highest fan speed when the humidity exceeds 60 percent. The humidistat shall be located near the (main) house thermostat and away from sources of moisture such as bathrooms and laundry rooms.

3.5 Efficiency Multipliers: Use shall be made of the following ventilation efficiency multipliers in sizing:

Generic AAHX Type	Ventilation Efficiency Factor
Fixed plate	1.0
Rotary heat wheel	1.2

Actual mechanical ventilation shall be calculated by dividing the volumetric air flow of the unit by the ventilation efficiency factor for use in determining overall building ventilation.

3.6 Moisture Transfer: The AAHX shall not be capable of transferring more than 25 percent of the moisture from the air stream being discharged from the conditioned space to the air stream entering from outside on a heating season average basis. Calculation of seasonal average moisture transport shall be made for Portland, Oregon, Spokane, Washington, and Missoula, Montana, for compliance in Zones 1, 2, and 3, respectfully, if the heat exchange surfaces are permeable to water.

3.7 Moisture Control: The AAHX shall be capable of controlling moisture condensation which occurs in the unit, if any, and appropriately disposing of the condensate that collects. Provision shall also be made for controlling the formation of frost and for melting any frost that forms. Condensation and frost protection shall be adequate under both design and normal operating conditions.

3.8 Outside Air Inlet: The outside air inlet to the AAHX shall be located to minimize contamination of the inlet stream with either the air exhausted by the AAHX or other sources of contaminants. Air shall be delivered to at least two different rooms through discharge diffusers which are located far enough away from the AAHX return to prevent significant recycling of air. The rooms shall be located such that the air is delivered to a reasonable degree to all principle areas of the conditioned space.

3.9 Air Return Location: At least one return shall be provided for exhausting air from conditioned space. This return may be located at the unit, and shall be located to result in balanced air flow. Consideration shall be given in siting the outside exhaust duct to possible ice buildups of nearby surfaces.

3.10 AAHX Ducts: All AAHX ducts located in unconditioned space, except the one(s) ducting outdoor air into the unit, shall be sealed and insulated to a nominal level not less than R-11 with insulation having an exterior vapor barrier.

3.11 Duct Arrangement: Ducts shall be arranged and installed in such a manner to minimize the length of duct used. Ducts shall be sloped to allow condensate that may form inside to drain to the unit.

3.12 Balancing: Ducts shall be sized appropriately and fans operated such that the AAHX operates with balanced intake and exhaust air flows.

3.13 AAHX Location: The AAHX shall be located in conditioned space to minimize thermal losses. The AAHX should be located to minimize problems of condensation and frost buildup. The AAHX shall be located and installed in such manner as to be easily accesible for routine maintenance.

3.14 Noise: The AAHX should be installed such that noise produced by the unit is not excessive within the main living areas of the building.

4 AAHX FILTER

The AAHX shall have a particulate filter for the exhaust airstream located upstream of the heat exchanger which is adequate to remove general airborne dust. The filter shall be able to be replaced or cleaned on a periodic basis. The AAHX shall also have such a filter or an insect screen for the inlet air stream located upstream of the heat exchanger. Units located in severe snow climates should use an insect screen instead of a filter for the inlet airstream.

5 AAHX DAMPER

The AAHX shall have a tight-fitting backdraft damper on the outside exhaust duct, and should have a tight-fitting backdraft damper on the outside inlet duct.

6 EXPOSURE TO WEATHER

Any portion of the AAHX exposed to the outside environment shall be resistant to degradation from weather.

7 UL LISTING

The AAHX shall be listed with Underwriters Laboratories (UL) or the Canadian Standards Authority (CSA). If the AAHX is listed, then it is assumed that the various components (e.g., motor(s), cord, plug, and switches) are also listed and approved for use in the product.

8 MANUAL SWITCH

A UL listed manual electrical switch shall be provided for manually turning the unit on and off. The switch shall be easily accessible to the building occupants, and may be located on the unit itself or seperately located.

9 AAHX RATING

The AAHX shall be rated for 120 VAC, 60 hertz. Power shall be supplied to the unit through UL listed three conductor wire (one conductor is ground) either permanently wired to the building electrical service or through the use of a UL listed electrical cord and three-prong plug.

10 INSTALLATION, OPERATION, AND MAINTENANCE MANUALS

The AAHX shall be accompanied with a complete set of manuals providing clear instructions and sizing information for installation and operation as well as clear instructions for the homeowner to perform routine maintenance. Technical information should include specifications for CFM, horsepower, wattage, size, weight, etc.

11 MAINTENANCE

Any routine, periodic maintenance shall be capable of being completed on the AAHX with the use of common hand tools.