

**EXPERIENCE WITH  
AIR-TO-AIR HEAT EXCHANGERS IN THE  
RESIDENTIAL STANDARDS DEMONSTRATION PROGRAM  
IN WASHINGTON STATE**

Michael Lubliner, William Kingrey, and Richard Byers  
Washington State Energy Office

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The Residential Standards Demonstration Program introduced a major new housing construction technology to participating builders and homeowners -- the air-to-air heat exchanger (AAHX). This paper summarizes the experience of the authors in the design, installation, cost, operation and performance of AAHX systems. Specific problems encountered by both builders and occupants are described and analyzed. Recommendations for manufacturers, installers, builders and code officials are presented.

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## INTRODUCTION

In its first regional electric power plan the Northwest Power Planning Council (NWPPC) established Model Conservation Standards (MCS) to which new electrically heated residential structures were to be constructed in the Pacific Northwest (NWPPC, 1983). To introduce these new and more energy efficient construction practices to the building industry and to the home buying marketplace, the NWPPC directed the Bonneville Power Administration to undertake a regionwide Residential Standards Demonstration Program (RSDP). This program was to accomplish the goals of technology transfer, marketplace demonstration and research through builder training and incentive payments, the construction and marketing of several hundred homes, and the monitoring of both construction costs and energy usage in these homes. The energy agencies in each of the four states comprising the region (Idaho, Montana, Oregon, and Washington) were responsible for administering the RSDP in their state. The program was accomplished in Washington under the name Thermabilt. Regionwide, 423 single-family RSDP homes were constructed. Of this total, 228 were built in Washington. A detailed description of the Washington Thermabilt program is included in these Proceedings as a companion paper (Watson et al, 1986).

The MCS were developed by the NWPPC using the best estimates available for the construction costs and energy savings to be reasonably expected for each individual conservation measure. A major emphasis was placed upon the reduction of heat-loss attributable to air leakage, both infiltration and exfiltration. The standards called for homes to be constructed tightly enough to allow no more than an average .10 air-change

per hour (ACH) through natural ventilation. To ensure adequate air quality in such tightly constructed homes, heat recovery ventilation was required. The MCS specified that an air-to-air heat exchanger (AAHX) and appropriate ducting be installed to supply a minimum of .50 average ACH. Homes could thus be expected to ventilate at an average .60 ACH, .10 ACH natural and .50 ACH mechanical. This paper reports what the collection of data on RSDP homes in Washington state revealed concerning actual costs for AAHX installation, rudimentary field performance measurements, builder attitudes toward installing AAHX systems, and homeowner attitudes and responses toward this non-traditional and unfamiliar ventilation appliance.

Descriptive statistics are reported in graphic format to emphasize the large range of values in each sample and subsample. The variability in these samples is too large to permit precise measures of central tendency and was not sufficiently controlled to support the use of inferential statistics. Nonetheless, the graphic representations do demonstrate general trends and tendencies. The box-plots used through-out this paper exhibit the range from maximum to minimum value for each subsample. The box represents the range from the first quartile value (that value below which 25 percent of the sample values fall) to the third quartile value (that value above which 25 percent of the sample values fall). The sample median (the 50th percentile value) is marked by the line in the box. Box width is proportional to subsample size relative to total sample. Sample and sub-sample sizes are noted in each graphic.

Both cost and performance data are reported by manufacturer and brand name. This report is intended to document the findings of the RSDP program in Washington state and should in no way be construed as an endorsement of, or critical commentary on, any product, manufacturer or brand name.

### AAHX SYSTEM COST

AAHX costs are system costs, including the cost for the AAHX unit, the associated duct and grillwork, and installation labor. Builder mark-up is not included. The distribution of costs observed in Washington's RSDP is presented in Figure 1 (Douglas et.al, 1986). The overall median was \$1259. This is 6 percent below the regional RSDP median cost of \$1350 reported by Reiland, McKinstry, and Thor (1985). Values ranged from \$480 to \$3980.

Anticipating that AAHX system costs would show a positive correlation with house size (due to more ductwork and larger capacity AAHX units), the NWPPC power plan (NWPPC, 1983 and Eckman, 1986) included cost estimates for three house size categories. Table 1 presents the estimated costs by size category as well as the median costs derived from the Washington RSDP sample for similar size categories (Douglas et.al, 1986).

Table 1. AAHX System Costs by House Size Category

Size Category (SF)	NWPPC Estimate	WA RSDP Median	WA RSDP Sample
0 - 1500	\$ 640	\$1150	38
1501 - 2500	\$ 935	\$1205	131
2501 - +	\$1551	\$1453	47

Comparison suggests that system costs are not nearly so strongly related to house size as was originally supposed. Figure 2 tends to support this conclusion by plotting AAHX system cost on total house floor area. Costs do appear to increase with house size, but the relationship is very weak and largely determined by a few exceptionally big houses (the trend line is only included as a guide for the eye). Apparently, the increased costs to duct larger houses and to provide more AAHX unit capacity are small relative to basic system cost.

The median sized house built in Washington's RSDP was 1818 square feet. Nearly sixty percent of the sample fell into the middle size category in Table 1. Referring back to this table it would appear that the NWPPC estimate for the most commonly occurring house sizes was somewhat low. It is interesting to observe that, as a consequence of the weak relationship between system costs and house size, it is cheaper on a cost per square foot of house basis to install heat recovery ventilation in larger houses than it is in smaller houses (Figure 3). House volume is proportional to floor area and energy savings from heat recovery ventilation proportional to volume. Consequently, when compared with many other conservation measures, AAHX systems are likely to increase in cost effectiveness with house size.

Figure 4 presents the distribution of AAHX systems installed by type. Nearly two-thirds (63%) of the systems used one of three AAHX units; the Airxchange manufactured by NuTone (23%), or the Star Heat Exchanger models 100A or 200A (40%). The range of system costs by AAHX type is presented in Figure 5. Costs varied greatly, both between types and within types. Lowest cost systems tended to be associated with the Airxchange AAHX unit. Median cost for these systems was less than \$1000.

Figure 6 exhibits the range in system costs by house type, or architecture. Once again, the range in costs within types is remarkable, suggesting great variability in builder experience in installing such appliances and in the market conditions controlling the cost and availability of the necessary equipment. House type is strongly related to house size, with smaller houses being single story ramblers and the larger houses tending to be multistory, or split level in design. Again, there appears to be no strong trend for larger house types to have significantly higher AAHX system costs.

## SYSTEM PERFORMANCE

The NWPPC estimated that a properly designed and installed AAHX ventilation system should be capable of providing .50 ACH and this was included as a design specification requirement of the RSDP. Maximum speed AAHX system flow rate tests were conducted on all RSDP homes. Air-flow rates were measured at intake and exhaust hoods on the exterior of the home, or at all intake and exhaust grills within the home. Testing was accomplished by Lambert Engineering of Bend, Oregon using a custom designed rotating vane anemometer flowhood. During the course of the testing program it was determined that use of this procedure was likely to introduce bias to the measurements due to the additional pressure introduced to the ductwork by the flowhood. Measurements of operating flow rates are thus likely to have underestimated actual system capabilities. Efforts are currently underway to quantify the magnitude of this measurement bias through retesting. The consequences for this report are that measurements of mechanical ventilation rates are likely to be somewhat underestimated. (Lambert, 1986)

Figure 7 presents the mechanical ventilation rates stated in ACH calculated from measured air-flow rates for each AAHX system type. (Note XT is the heat exchanger type (XT).) ACH was calculated from measured air-flow rates using equation 1.

$$\text{ACH} = ((\text{ICFM} + \text{ECFM}) / 2) * (60 \text{ MIN/HR}) / \text{VOLUME} \quad (1)$$

Where:

- ICFM = Intake air flow rate in cubic feet per minute.
- ECFM = Exhaust air flow rate in cubic feet per minute.
- VOLUME = Total volume of heated space (exterior dimensions).

Based on this set of measurements it appears that only very few systems were capable of achieving the .50 ACH target. The median values for all system types fall well below .50 ACH and the overall median was .27 ACH. This finding agrees well with the regionwide RSDP results reported by Reiland, McKinstry, and Thor (1985). While these results appear discouraging, the effect of the measurement bias remains unknown and conclusions must await the results of the retesting.

The RSDP specifications required that the AAHX system intake and exhaust air-flow rates be equivalent. The specification was included to ensure that ventilation systems be designed to operate in balance. Systems operating out of balance can result in houses being "pressurized" when the intake air-flow rate exceeds the exhaust rate, or "depressurized" when the exhaust rate exceeds the intake rate. Pressurizing a building can increase the rate at which water vapor moves into exterior walls, floors and ceilings. Depressurizing a building can increase the rate of cold air infiltration into the building (above the rate expected from natural ventilation alone), or the rate at which environmental pollutants such as radon gas migrate into the structure. It may also tend to increase the frequency of backdrafting through woodstoves, or other combustion appliances, introducing combustion-related air pollutants. Both the conditions are to be avoided.

A scatter plot of intake versus exhaust measured air-flow rates (CFM) is presented in Figure 8. The line was drawn through the scatter with a slope of 1.00 to represent perfect system balance. Points falling above the line represent homes pressurized by their ventilation systems. Those falling below the line represent depressurized homes. Figure 9 presents the distribution of the sample balance ratio ICFM/ECFM in bins .14 wide. While the majority of the homes exhibit balance ratios quite near unity, there are a significant number of homes that are clearly out of balance. Further investigation of these data are underway to identify system, installation characteristics, or measurement considerations that might result in such undesirable balance ratios.

## BUILDERS' OBSERVATIONS

Builders were asked several questions regarding the air-to-air heat exchangers (AAHX) installed in their MCS homes. (Johnson, 1986a) When asked if they had difficulty obtaining materials, 58 percent of Washington builders had no response. Of the 42 percent who presumably had problems obtaining materials, 13 percent of Washington builders had problems obtaining AAHX. Of the remaining products that were reported difficult to obtain, caulking, sealant, and vapor barrier materials made up 37 percent of the total.

When asked about the difficulty of installing MCS-related components, such as the AAHX or the air/vapor barrier, builders reported that these measures were more difficult than conventional construction by 61 percent and 66 percent, respectively. Large builders had the most trouble with the new technology -- 40 percent indicated the installation of air/vapor barriers (AVB) and AAHX was very difficult, and another 40 percent indicated the installation of these measures was somewhat difficult.

Was it worth all the extra trouble? Sixty-nine percent of the builders responding reported that it is very likely that they would build to the levels required by the MCS in the future. The table below, taken from Johnson (1986a), tabulates the responses of small, medium, and large builders when asked if they would build to the levels required by the RSDP in the future.

Table 2. Builder Exist Survey Report

	Small	Medium	Large
Very Likely	76%	50%	36%
Somewhat Likely	16%	21%	18%
Not Likely	5%	24%	45%
No Response	3%	6%	0%

Builders in Washington have, for the most part, been willing to spend extra time and money to ensure customer satisfaction by making necessary changes to their AAHX systems.

## OCCUPANT RESPONSES / INSTALLATION PROBLEMS

Information gathered through home owner surveys and field observations by Lambert Engineering yields insight into home owner operation of their AAHX systems. Figure 10 illustrates heat exchanger usage as reported in the occupant survey (Keating and Bavry, 1986). Nearly 70 percent of the homeowners reported they seldom or never used their AAHX. Additional site visits made to a small subsample of RSDP homes in which the status of control settings were recorded seems to confirm that many of the systems are routinely not in operation. (Johnson, 1986b)

The relatively large number of systems which were apparently little used, or permanently turned-off, illustrate what we are calling the "mothball" reaction. The effect can be stated as follows: Any subsystem which is not clearly essential to the operation of the whole system will be mothballed when it presents problems that are not easily understood or resolved, (i.e., noise, cold draft, or control problems). Often, instead of totally abandoning a system, the homeowner will reduce the operating time to a few hours a day. In either case, the consequences are not immediate -- particularly during the summer when windows are open for natural ventilation. We may hear about a moisture problem months later that turns out to be another mothballed AAHX. These problems can often be resolved by providing the homeowner with information about the AAHX, or by suggesting possible solutions for minor problems.

Most problems and complaints concerning AAHX systems were reported directly to the RSDP toll-free hotline. Lambert Engineering reported additional system problems

gathered from weekly homeowners' thermal data reports. In addition, many problems were discovered by Lambert field technicians during the course of their system testing.

The following are examples of the variety of problems reported:

1. Water dripping into bathroom from exhaust grill (exhaust duct not insulated in unheated space).
2. Water dripping on air intake duct exterior in basement (supply duct not insulated).
3. Drafts of AAHX cold-air blowing at floor level (main supply duct located on floor in middle of room near occupants).
4. Drafts of cold air in main entryway (fresh air ducts branches were not balanced).
5. Occupant cannot turn system off (misunderstanding of how controls work).
6. Cold air drafts and higher than expected space heat bills (rotary heat wheel not working).
8. Icing problems of the AAHX core (defrost control and design problems).
9. Noise of AAHX unit or ventilation system.

The reported problems fall into two major categories: Those relating to comfort and those relating to system operation and maintenance.

#### Comfort-related Issues

Cold drafts were frequently reported as problems in the RSDP homes and were commonly due to improper selection or location of supply air diffusers. To understand the reasons for these cold drafts, it is useful to review air diffusion theory as it applies to air conditioning systems. The supply air temperature from a properly operating AAHX when it is 20°F outside and 70°F inside is about 50°F -- close to the supply air temperature of an air conditioner. Air at this temperature is denser than room air at 70°F, so that if a jet of cool air is projected outwards from a side wall, it will flow downwards. If the jet flows into an area occupied by people before it has had a chance to slow down to under 50 feet per minute (FPM) and mix with the warmer room air, it will be perceived by occupants as a cold draft.

Most of the installations we saw in the RSDP used heating-type diffusers with a short throw, fan-shaped pattern. They are usually for a 4" x 8", 4" x 10", 4" x 12", etc., floor opening and are made to slip inside a piece of ductwork. These diffusers are very commonly used in residential heating systems and work well for heating, but when used with cool air, they do a poor job of mixing and usually result in localized drafts. The result is an even layer of cool air at ankle level. When fresh air supply ducts introduced cold air at floor height, this comfort problem was aggravated.

Experiences with air diffusion problems in RSDP led to the following requirements in the new BPA AAHX specifications:

"For AAHX systems without preheated supply air, all supply diffusers installed in frequently occupied rooms shall be designed for air conditioning use and shall be installed in accordance with manufacturer's recommendations. Supply diffusers installed in rarely occupied and less thermally sensitive areas may use air distribution systems that minimize air velocity to reduce drafts."

### Noise Problems

Excessive noise was another common reason homeowners gave for not operating or seldom operating their AAHX. Noise in an AAHX system is mostly fan-generated, with small contributions from air-generated noise (from grills and ducts) and vibration from the casing of the AAHX unit.

The fans used in small AAHX are required to develop a maximum total static pressure of about 0.8 inches water gauge (Wg.) at around 200 cubic feet per minute (CFM). Most small fans are designed for much lower static pressures -- 0.4" Wg. or less. In order to increase the pressure available from their fans, manufacturers were forced to either speed-up the fans and/or increase the radius of the centrifugal fan wheel. In either case, the tip speed of the fan and the noise it generates increased. Since nearly all manufacturers of AAHX mount the supply and exhaust blowers on the warm side of the heat exchanger, ductwork on the supply and return of the unit connect directly to fan outlets and inlets. This arrangement guarantees that designers will have a source of fan noise to deal with in their ductwork designs.

One home we visited provided an excellent illustration of noise produced by the AAHX installation. The system was controlled by a time clock and a dehumidistat. The time clock had been set to run the AAHX unit for only two hours a day. The owner said she knew she should be using the AAHX more, but it was so noisy she hated to run it. When we checked the AAHX, we found a very compactly designed attic installation. The supply ductwork consisted of an 8" Y-joint that split into two 7" rounds which were then split by another Y-joint into two 6" rounds each. These were connected directly to ceiling outlets located to serve four different spaces, with only about four feet between each outlet. The return air ducting from the house was also quite compactly designed using about four feet of flexible ducting to connect a single exhaust grill to the unit. This resulted in a relatively low cost ductwork system with minimal duct pressure losses, but maximum noise transmission. For noise generated at the fan, this ductwork arrangement looks like a trumpet -- increasing in size to the outlets which are located in the bedrooms -- the most acoustically sensitive area in the home. The flexible duct on the return air side of the system did a little better at dampening sound, but its short length, and nearly line of sight arrangement between the fan inlet and the return air grill minimized the dampening effect of the duct material. In general, our observations indicate that systems using longer lengths of flexible ductwork had fewer noise problems.

### Operation and Maintenance

Instruction manuals for AAHX operation varied significantly in quality and in many instances, were not made readily available to the home buyer. As a result, some homeowners were not well trained in the function of their AAHX, nor in its proper operation and maintenance. The major problems arising from this lack of knowledge were "mothballing" of the system as noted above, or system failures suspected to be the result of poorly cleaned, or clogged filters. In addition, some builders made maintenance of the AAHX difficult by installing their units in an attic or crawl space. If AAHX are to be regularly maintained, they need to be accessible without the use of tools or ladders. This requirement is also now part of the new BPA AAHX specifications.

The original RSDP AAHX control specifications required a humidistat wired to run the unit on high speed when the relative humidity (RH) in the space reached the

humidistat setpoint. In addition, the systems were to have been designed to operate on either a timer, or continuously at a low speed setting. However, these specifications were not always met and some systems were controlled with the dehumidistat alone. Such control arrangements left homeowners frustrated, with no way to turn off their system. In some instances, the unit could only be turned off at the circuit breaker panel; in others, home owners would turn the humidistat setpoint to the highest setting possible in order to turn the system off. To ensure proper homeowner operation of these systems, installers should provide easily understood controls and specific instructions concerning operation of these controls.

## RECOMMENDATIONS

The following recommendations have been developed from WSEO's experiences with AAHX systems in RSDP:

### Manufacturers

1. Provide detailed AAHX installation and operation manuals to designers, installers, and homeowners.
2. Provide training sessions and/or a certification program for designer, installers, and builders.
3. Provide a complete line of AAHX accessories required for an installation.
4. Assure that all designers and installers using your products are adequately trained.
5. Conduct periodic surveys of designers, installers, and homeowners in order to identify problems, and improve AAHX system performance, installation and operation manuals.

### Installers/Designers

1. Select a manufacturer(s) that provides training, technical assistance, and detailed installation and operation manuals.
2. Install the unit in an area where it is easily accessible for routine maintenance.
3. Install quality systems with attention to workmanship and efficient design.
4. Test the flow rates, controls and operation of the AAHX and balance as required.
5. Follow all guidelines and specifications provided by the manufacturer and other regulatory authority.
6. Provide sound attention such as 8 feet of internally insulated duct with two 90° turns or equivalent sound attenuation between a fan and the first air outlet or inlet.

### Builders

1. Select an experienced/trained AAHX designer and installer.
2. Utilize the AAHX specifications of the regulatory authority and/or manufacturer's guidelines as the basis for the installation contract with the AAHX designers and installers.

3. Work with the designer/installer early in the project to make space available to locate the AAHX and duct runs within the heated shell of the house.
4. Inspect the installation and check the system to ensure it is operating correctly before final payment is made to the installer.
5. Understand the controls and correct operation of the AAHX well enough to explain and demonstrate its use to the homeowner. Ensure written instructions are provided by the installer/designer for the homeowner.
6. Assure that homeowners are provided with and understand instruction manuals.

#### Regulatory Authority (Code Officials)

1. Determine the quality of the AAHX workmanship (ductwork, controls, insulation, etc.).
2. Have builders explain and test the system control, and operation.
3. Check that air is moving in and out of ductwork as indicated on plans.
4. Request certification that the system is properly installed, balanced, and is capable of providing the minimum required air flow rates throughout the home.

#### **SUMMARY**

The RSDP introduced a major innovation to residential construction and home operation to the Pacific Northwest by requiring the installation of heat recovery ventilation systems. Median cost for the hardware and installation of these systems in the most commonly occurring house sizes in Washington's RSDP was \$1205, somewhat higher than the NWPPC's original estimate of \$935 for similar sized houses. The relationship between AAHX system cost and house size or type was found to be weak. This suggests that the large fixed cost associated with the AAHX unit, taken together with the greater potential for savings from heat recovery ventilation in larger volume buildings, may make AAHX systems a relatively more attractive conservation measure investment in larger homes than in small homes.

Installed system performance, measured in terms of ventilation rate delivery capability, was found to fall below the targeted level of .50 ACH. These findings must be tempered by the qualification that deficiencies in the testing procedure are known to have introduced measurement error. Mechanical ventilation rates calculated from these measurements are believed to underestimate actual ventilation capabilities under operating conditions. Further work is underway to establish the magnitude of this bias and improve the accuracy of measured mechanical ventilation rates and system balance ratios.

Of those Washington builders who responded to a survey concerning their RSDP experience only 1 in 8 reported a problem obtaining the necessary hardware for installing the AAHX system. On the other hand, nearly 2 out of 3 reported that installation of the AAHX system made construction of a RSDP home more difficult than a conventional home. Larger volume builders reported more difficulty with the new technology than did medium or small volume builders.

The addition of a heat recovery ventilation system to a home introduces a new and unfamiliar aspect of home operation to home-owners. Home-owner survey responses, as

well as anecdotal observations and reports, suggest that a large proportion of the RSDP home-buyers do not clearly understand the function of their ventilation systems, or the importance of operating them routinely. Nearly 7 out of 10 homeowners responded that they seldom, or never, operated their AAHX systems. This finding becomes particularly important in light of the reduced natural ventilation rate in these tightly constructed homes. Improving the quality and availability of instruction manuals, as well as system design, installation and controls will serve to improve the acceptance of these systems by homeowners.

Further research is underway, not only to improve system performance measurement procedures, but to compare house specific AAHX system data with measured house energy usage and indoor air quality as well.

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 Lambert Engineering: Les Lambert and Chris Dent.

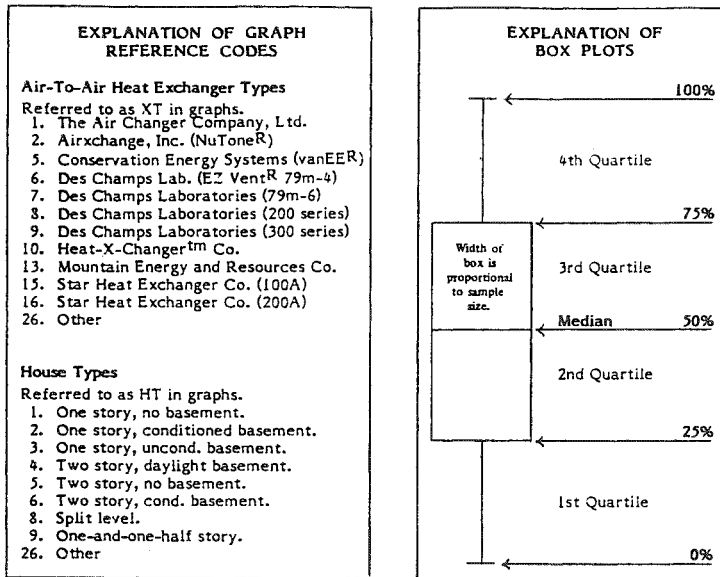


Figure 1. DISTRIBUTION OF AAHX SYSTEM COST

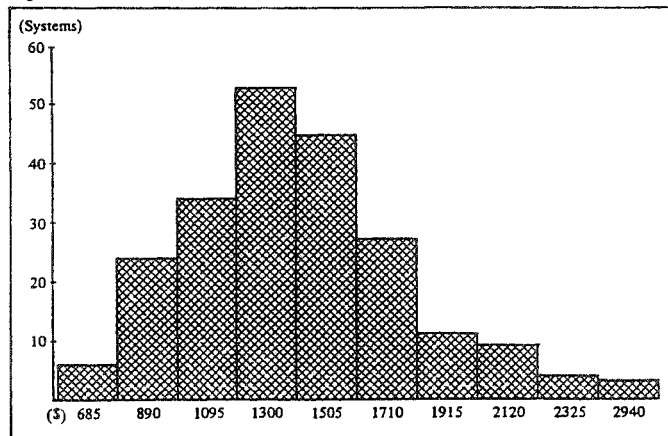


Figure 2. COST OF AAHX SYSTEM vs. TOTAL HOUSE FLOOR AREA

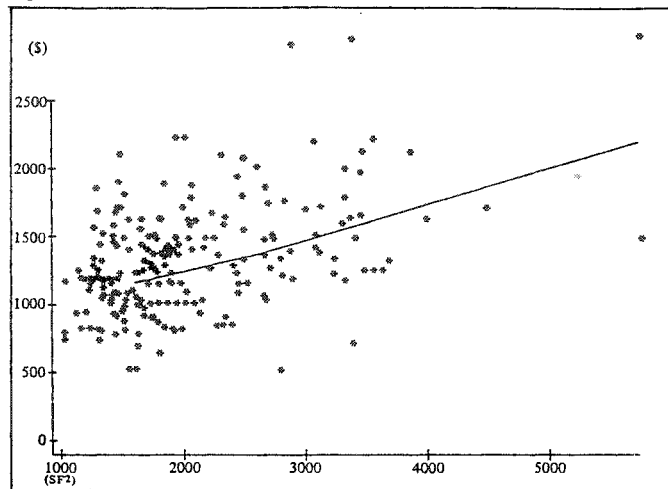


Figure 3. AAHX SYSTEM COST/SF vs. TOTAL HOUSE FLOOR AREA

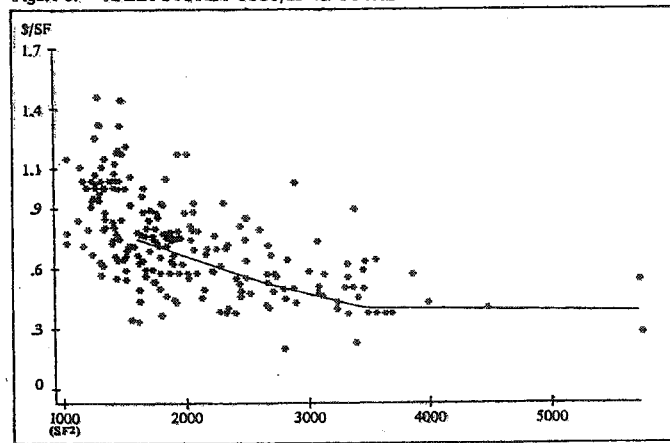


Figure 4. NUMBER OF AAHX SYSTEMS BY AAHX TYPE

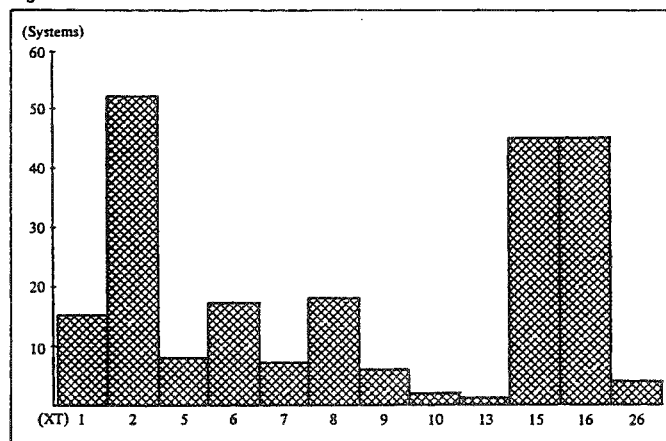


Figure 5. AAHX SYSTEM COST BY AAHX TYPE

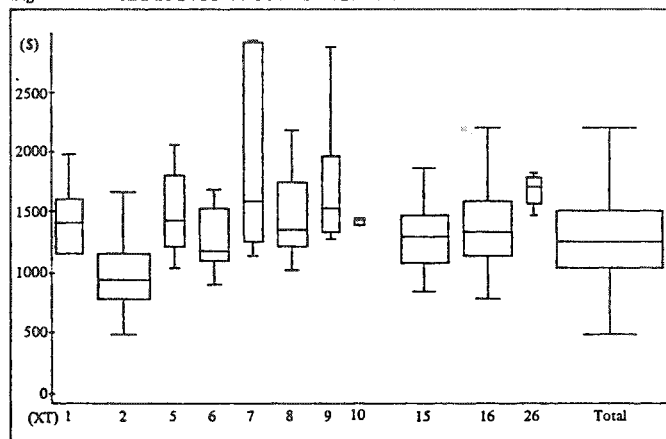


Figure 6. AAHX SYSTEM COST BY HOUSE TYPE

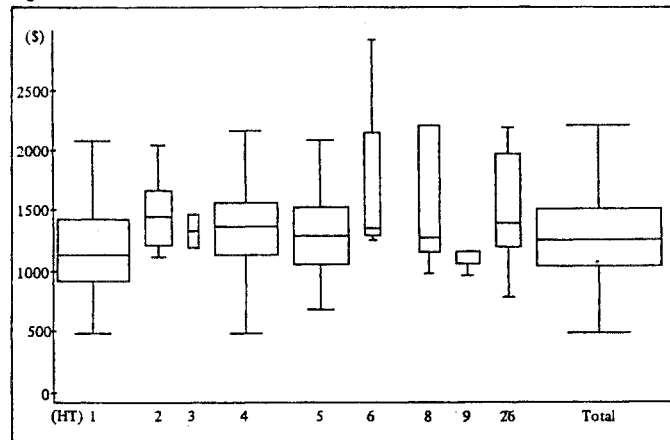
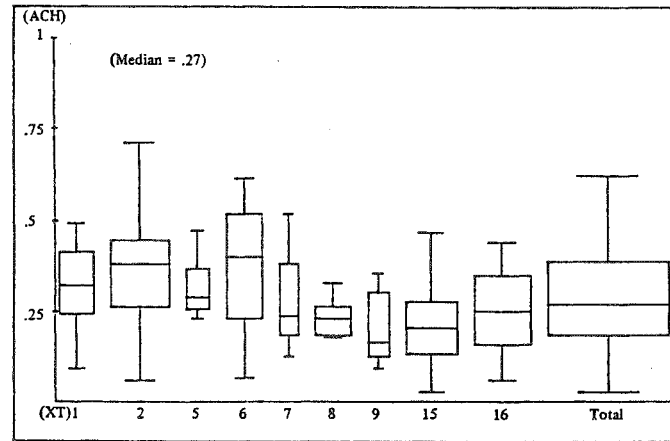


Figure 7. MECHANICAL VENTILATION RATE (ACH) BY AAHX TYPE



Note: ACH rates were underestimated due to measurement errors.

Figure 8. INTAKE CFM vs. EXHAUST CFM

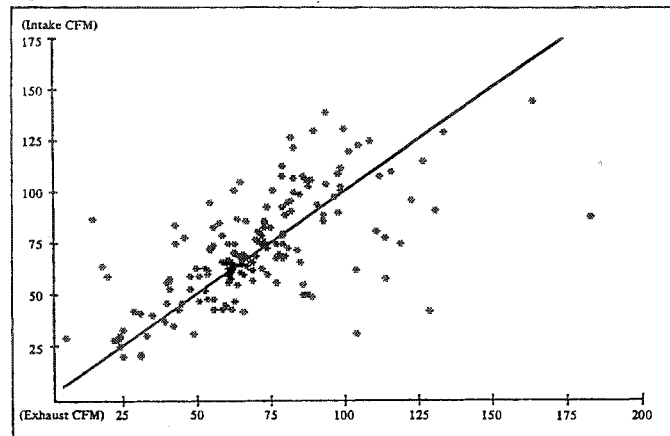
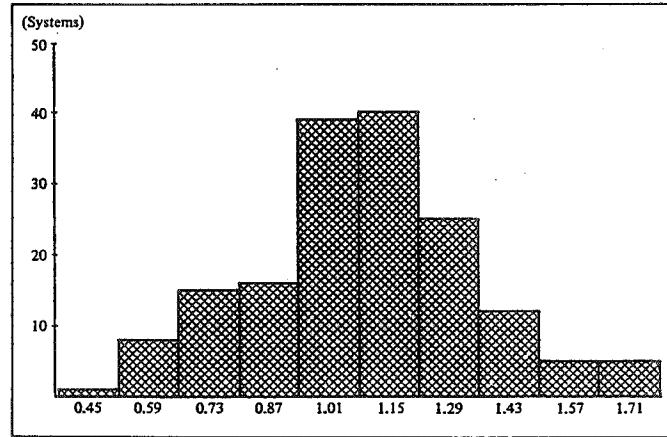


Figure 9. DISTRIBUTION OF AAHX SYSTEM BALANCE RATIO I/O



I/O Ratio Bins (width: .14)

Figure 10. OCCUPANT REPORTED USAGE OF AAHX

