*Energy and Buildings*, *19* (1993) 215–220



# Air-to-air heat exchanger performance

M. K. Drost
*Pacific Northwest Laboratory, Richland, WA 99352 (USA)*

**Abstract**

The performances of air-to-air heat exchanger (AAHX) systems in 38 residences are evaluated using data collected as part of Bonneville Power Administration's Residential Standards Demonstration program. The primary goal of this analysis is to characterize the AAHX system use patterns and to determine the thermal performance of the installations. The results of the study showed that on average AAHX systems were operated approximately seven hours per day over the 1985/1986 heating season with a mean thermal efficiency of 52%. The lower-than-expected AAHX system utilization suggests that design ventilation rates are not being supplied and the combination of low utilization and thermal efficiency results in low annual energy recovery attributable to the AAHX system. Until the issue of low utilization is addressed, conservation planners must view the benefits of including AAHX systems with caution.

## Introduction

As weatherization programs and new construction standards reduce infiltration into homes, proper ventilation for maintaining indoor air quality becomes a concern. In very tight homes, mechanical ventilation is often used to introduce fresh air to the living space to maintain air exchange rates at levels believed to occur in standard construction. An air-to-air heat exchanger (AAHX) is typically used in combination with mechanical ventilation to recover some of the thermal energy that would otherwise be lost with the exhausting air. Air-to-air heat exchangers are designed to conserve energy in mechanically ventilated homes by transferring the heat from warm stale exhaust air to the incoming cool fresh air. The transfer of heat minimizes the energy required to warm the incoming air that is used to maintain indoor air quality at an acceptable level. A number of companies have been manufacturing these devices for several years.

This paper describes an evaluation of performance data taken from 38 AAHX installations that were part of Bonneville Power Administration's Residential Standards Demonstration Program (RSDP). When the RSDP was active from 1983 through 1986, approximately 500 new homes were built to thermal performance standards as dictated by the Model Conservation Standards (MCS). To meet these standards and maintain air quality, many of the homes included AAHXs. Seventy-one RSDP homes were monitored as part of the End-Use Load and Consumer Assessment Program (ELCAP) [1]. Of these, 38 included AAHXs that were monitored to allow for analysis of both use patterns and thermal performance. While a significant number of AAHX installations have been studied [2, 3], these homes provided the first large sample of installed AAHXs to be continuously monitored for performance and utilization patterns. The primary goal of this analysis was to characterize AAHX use patterns and to determine the thermal performance of the installations.

The structures included in the ELCAP sample were primarily instrumented to monitor end-use electric energy consumption. When an AAHX was present, instrumentation was included to allow an estimate of AAHX use patterns and thermal performance, but this was not the primary goal of the ELCAP project. The installed instrumentation was not as comprehensive as would be desired for a detailed evaluation of thermal performance. At the time of installation, AAHX technology was relatively new and many installers, builders, homeowners, and inspectors were working with little or no experience with the technology. It is possible that the evaluations of AAHX installations from a mature AAHX industry would give different results.

It is important to recognize that AAHXs are not energy-conserving devices, rather they allow construction practices that minimize natural infiltration and the associated heat loss. The AAHX actually

0378-7788/93/$6.00

consumes energy to operate fans, and the space-heating load increases during operation because the AAHX does not recover 100% of the thermal energy of the outgoing air. Energy savings associated with the use of AAHXs are a direct result of reducing infiltration through the building envelope to extremely low levels, and providing controlled amounts of pre-heated fresh air to maintain air quality. The energy savings due to the heat recovery in the AAHX are in comparison to heat losses from natural or mechanical ventilation that provide an equal quantity of fresh air without heat recovery.

General descriptions of AAHX systems are presented by the National Center for Appropriate Technology (NCAT) [4] and Shurcliff [5]. A number of researchers have investigated the performance and economics of installed AAHX systems. Fisk and Turiel [6] indicated that AAHX systems were only economically attractive in a cold climate using high-performance equipment. Turiel *et al.* [7] concluded that the use of AAHX systems in weatherized, electrically heated residences located in the Pacific Northwest is not economically attractive when compared to relying on natural infiltration. Offermann *et al.* [8] reached similar conclusions for a study of eight residences located in New York. Based on data from field studies, Fisk *et al.* [9] concluded that the annual savings of field-tested AAHX systems amounted to only 5–7% of the initial capital investment. Corbett and Miller [10] concluded that the value of energy recovery associated with three actual installations amounted to $116. Associated installed capital costs were not reported. Lubliner *et al.* [3] reported results of performance and utilization monitoring of AAHX systems installed as part of the Residential Construction Demonstration Project. Finally, Schell and Rogoza [11] investigated the attitudes of owners toward AAHX systems, but no previous investigations of AAHX utilization and use patterns were identified.

## Objectives of research

The two objectives of the research documented in this paper were:

(1) *AAHX use patterns*

Use patterns of installed AAHX systems are not well understood. The first objective of this study was to investigate AAHX use patterns and identify factors influencing AAHX use.

(2) *Thermal performance*

The second objective of this study was to investigate and characterize the thermal performance of the AAHX installations included in the sample.

## Instrumentation

Instrumentation related to AAHX performance monitoring included temperature, humidity, and power consumption measurements. Figure 1 shows the location of instrumentation in a typical AAHX system. Indoor air temperature ($T_i$) was measured at several locations in the residence and the mean value was used for the temperature of indoor air as it enters the AAHX. Outside air temperature ($T_o$) was measured by a sensor located on the northern exterior of the residence. Exhaust air temperature ($T_t$) was measured by a temperature sensor located in the exhaust air duct. Airflow data were not continuously taken but were based on a one-time measurement of intake and exhaust airflow during high-speed operation.

## Methodology

Air-to-air heat exchangers, sized to provide a design ventilation rate, are often turned off by the homeowner. Utilization or 'on time' was determined for each home by taking the ratio of actual AAHX energy consumption to the maximum AAHX energy consumption (assuming continuous operation).

Use patterns are reported in two formats. Annual use patterns were investigated by developing time-series plots of daily average utilization. Daily use patterns were obtained by calculating utilization for a typical day for a residence, yielding the mean

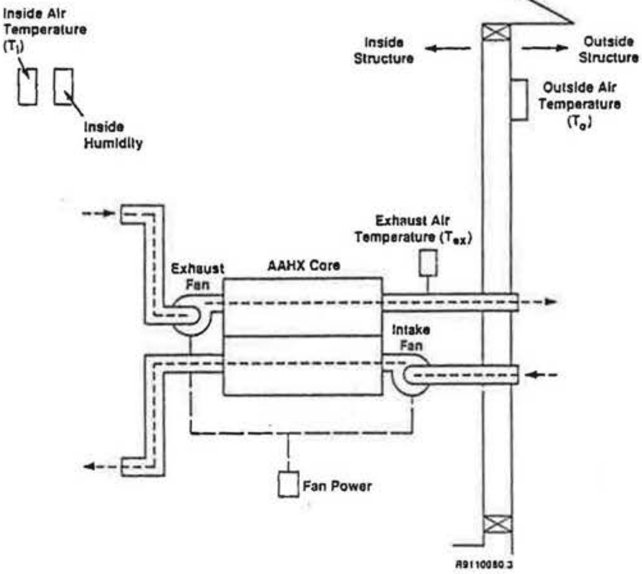


Fig. 1 Instrumentation in a typical AAHX system.

utilization and the standard deviation for each hour.

A number of thermal performance figures-of-merit have been proposed for evaluating the performance of AAHX systems [9–11]. Alexander [12] suggests that the appropriate figure-of-merit is what he called the first-law efficiency. This figure-of-merit includes the effect of heat transfer between air streams but does not include air stream temperature rises caused by viscous dissipation of fan work. Alexander's first-law efficiency is defined by eqn. (1), where $T_i$ is the residence internal temperature, $T_o$ is the outside air temperature, and $T_f$ is the temperature of the fresh air entering the residence. Other symbols are defined in the Nomenclature.

$$\eta = \frac{(T_f - T_o)\dot{V}_f \rho C_p - W}{(T_i - T_o)\dot{V}_e \rho C_p} \tag{1}$$

It can be shown that $\eta$ is equivalent to the more traditional heat-exchanger effectiveness. The temperature of the fresh air as it enters the structure can be calculated by conducting an energy balance on the AAHX. The resulting expression is given by eqn. (2).

$$T_f = \frac{\dot{V}_e \rho C_p (T_i - T_e) + W}{V_f \rho C_p} + T_o \tag{2}$$

When eqn. (2) is substituted into eqn. (1), the resulting relationship for $\eta$ is given by eqn. (3). Alexander's first-law efficiency in this form is identical to heat-exchanger effectiveness for balanced flow [13].

$$\eta = \frac{(T_i - T_e)}{(T_i - T_o)} \tag{3}$$

The space-heating energy saved by the AAHX ($Q_{SAV}$) was calculated by determining the space-heating energy that would be required to heat the incoming air to a temperature of $T_f$. This is the energy that would have to be supplied by some other means if the AAHX were not operating. $Q_{SAV}$ is calculated for the time period Δt by using eqn. (4).

$$Q_{SAVi} = \dot{V}_f \rho C_p (T_f - T_o)\Delta t \tag{4}$$

Displaced annual space-heating energy consumption is the sum of $Q_{SAVi}$ over the 1985/1986 heating season*.

While temperatures were continuously monitored, airflow rates were based on one-time measurements taken during high-speed operation. Uncertainties in airflow will not affect the calculation of AAHX heat exchanger effectiveness ($\eta$) but will directly introduce uncertainty into the calculation of space-heating energy savings.

When condensation is experienced in the exhaust of an AAHX, additional heat transfer occurs that improves the performance of the device. Latent heat effects were estimated by determining when the saturation pressure in the exhaust air stream exceeded the vapor pressure and then calculating the energy transferred to the incoming air by conducting an energy balance on the AAHX.

Time periods during a defrost cycle were identified by high energy consumption. These time periods were not included in the analysis. Consequently, estimates for AAHX electrical energy consumption do not include energy used in defrost cycles.

## Results

### *AAHX use patterns*

The best overall characterization of AAHX operation is mean annual utilization over an entire heating season. Table 1 presents the mean utilization by climate zone. Climate Zone 1 includes western Oregon and Washington. Climate Zone 2 consists of eastern Oregon, eastern Washington, and southern Idaho. The third climate zone includes northern Idaho and western Montana. Figure 2 shows this data for each of the 38 homes where the mean annual utilization is plotted in order from lowest to highest. Mean utilization for the complete sample was 6.9 hours of AAHX operation per day. This indicates that the average AAHX installation is operated 30% of the day. The standard deviation is quite large suggesting a wide variation in mean utilization between structures. These results are consistent with other research [3].

It was suggested that utilization would decrease in cold climates because cold outside air would be introduced into the structure, resulting in occupant discomfort, but a review of Table 1 shows no indication of a reduction in utilization in the colder climate zones. The results of this sample actually show an increase in utilization in Climate Zones 2 and 3. Given the small sample size in Climate Zone 3 and the large standard deviation in all climate zones, it is not possible to reach a firm conclusion, but the data presented here does not show a reduction in utilization in the colder climate zones.

Daily average utilization for each structure was arranged as a time series. Figure 3 presents this data for one residence. These results were reviewed to identify any pattern in annual utilization. In

*The heating season is assumed to start on September 1 and end on April 15.

TABLE 1. Mean utilization of air-to-air heat exchangers (hours of operation per day)

| | Climate Zone 1<br>4000–6000 HDD* | Climate Zone 2<br>6000–8000 HDD | Climate Zone 3<br>>8000 HDD |
|---|---|---|---|
| Mean (hours) | 5.4 | 8.4 | 9.1 |
| Median (hours) | 3.1 | 5.4 | 7.8 |
| Standard deviation | 6.5 | 7.9 | 3.9 |
| Number in sample | 20 | 12 | 6 |

*Range of heating degree-days for the climate zone.

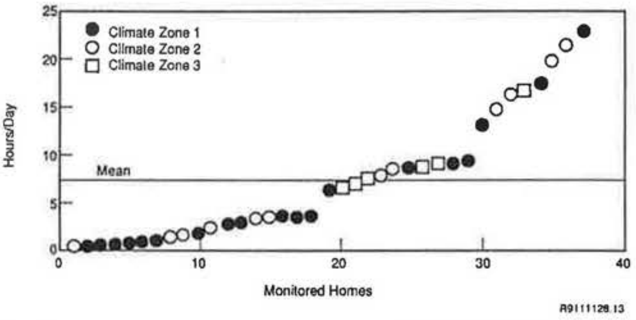


Fig. 2. Mean annual utilization (hours of operation/day) for 38 air-to-air heat exchangers arranged from lowest to highest utilization.

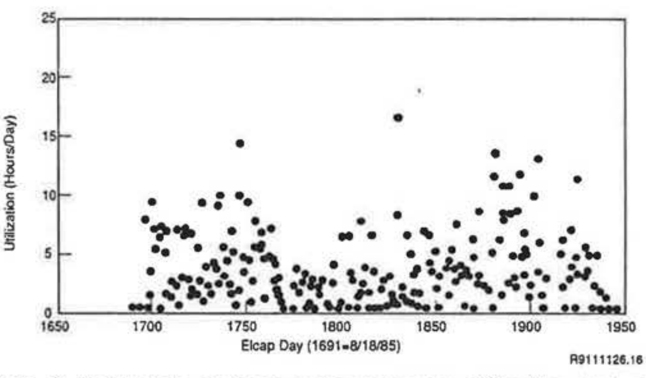


Fig. 3. Daily air-to-air heat exchanger mean utilization during the 1985–1986 heating season for a typical site.

general, the review did not show a seasonal pattern for utilization, suggesting that ambient conditions did not significantly affect utilization.

Typical hourly data were reviewed for each structure but the results did not show a dominant daily use pattern.

*Thermal performance*

Mean thermal efficiency is presented by climate zone in Table 2. Figure 4 shows this data for the 25 sites with sufficient data for analysis. The mean thermal efficiency for the complete sample was 52%. As Fig. 3 illustrates, there is a large variation in the results. The data did not provide an explanation for the low mean thermal efficiency in Climate Zone 3, but the small sample size may have contributed to the results. The mean measured thermal efficiency is below the 60%–70% thermal efficiency reported in the literature for AAHX units, but may be in approximate agreement for complete system efficiencies [4, 5]. Lubliner *et al.* [3] reported similar system efficiencies for residences included in the Residential Construction Demonstration Project.

Of the 22 sites analyzed for latent heat effects, only five sites experienced significant time periods with condensation in the exhaust air stream. When condensation did occur, it had a significant impact on thermal performance increasing the savings in space heating by approximately 15%. However, condensation occurred so rarely that latent heat effects did not have a major impact on performance.

Low utilization of the AAHX system resulted in corresponding low annual estimates for displaced space-heating energy consumption compared to mechanical ventilation without heat recovery operated in a similar fashion. Figure 5 shows the calculated displaced space heat for each home. The overall mean is 743 kWh/yr, while the annual energy consumption of the AAHX was 220 kWh/yr, for a net savings of 523 kWh/yr per residence.

## Conclusions

This study documents an evaluation of AAHX use patterns in a large number of residences. Therefore, the results are of particular interest. The major findings include:

- *Mean utilization*

The most significant finding from this study is the lower-than-expected mean utilization of AAHX devices. The AAHX is intended to operate nearly continuously, but the results of the study show that on average the devices are operated approximately seven hours per day. Maintenance of design ventilation rates in structures with reduced infiltration depends on the operation of the AAHX system. The low utilization rates reported by this study clearly

TABLE 2. Mean thermal efficiency of air-to-air heat exchangers

| | Climate Zone 1 4000–6000 HDD* | Climate Zone 2 6000–8000 HDD | Climate Zone 3 >8000 HDD |
|---|---|---|---|
| Mean (%) | 0.50 | 0.60 | 0.37 |
| Median (%) | 0.50 | 0.63 | 0.23 |
| Standard deviation | 0.22 | 0.17 | 0.29 |
| Number in sample | 12 | 10 | 3 |

*Range of heating degree-days for the climate zone.

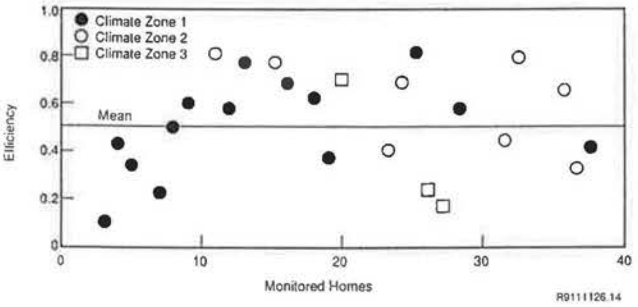


Fig. 4. Mean thermal efficiency (or heat exchanger effectiveness) for 25 air-to-air heat exchangers.

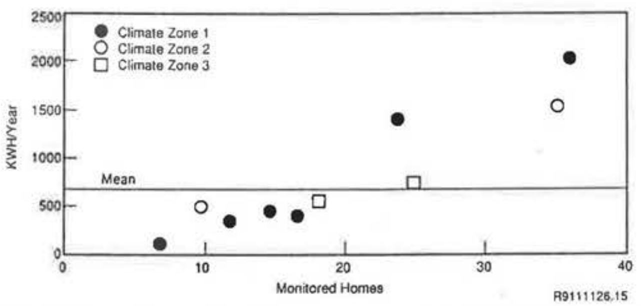


Fig. 5. Annual space-heating energy savings (kWh/yr) credited to air-to-air heat exchangers for 10 residences.

indicate that, on average, design ventilation rates are not present for two-thirds of a typical day.

- *Displace space-heating energy*

The mean net space-heating energy savings for each residence were approximately 500 kWh/yr. If power were available at 10 cents/kWh, this would represent a net annual savings of $50 per year. It is unlikely that this annual cost savings is enough to recover the capital cost of the device when compared to providing similar ventilation without heat recovery. The low energy savings are primarily due to low utilization. If the device is not operating, it cannot be credited with reducing space-heating energy consumption.

- *Ambient temperature*

It has been hypothesized that cooler ambient temperature will reduce AAHX use because the AAHX system will be introducing cold air into the residence resulting in drafts. The study investigated this issue from two perspectives. First, utilization was disaggregated by climate zone. The results showed that utilization actually increased in cold climate zones. Secondly, mean daily utilization plotted sequentially did not show significant seasonal variation in utilization. The resulting conclusion is that AAHX utilization is not strongly determined by ambient temperature.

The general conclusion is that educators, designers, manufacturers, and installers of AAHX systems must identify and understand the causes of low AAHX utilization and find ways of increasing homeowner awareness and use of AAHXs if they are to become an effective measure for the energy-efficient homes of the future.

## Acknowledgements

This work was supported by the Bonneville Power Administration under a Related Services Agreement with the US Department of Energy (DOE) under Contract DE-AC06-76RLO 1830. Pacific Northwest Laboratory is operated for DOE by Battelle Memorial Institute.

## Nomenclature

| | |
|---|---|
| $C_p$ | constant pressure specific heat of air (kJ/(kg − *K)) |
| $Q_{SAV}$ | displaced space heating (kWh) |
| $t$ | time (h) |
| $T_e$ | exhaust air temperature |
| $T_f$ | temperature of fresh air entering residence (°C) |
| $T_i$ | residence internal temperature (°C) |
| $T_o$ | outside temperature (°C) |
| $V_f$ | fresh-air volume flow rate ($m^3$/s) |
| $V_e$ | exhaust-air volume flow rate ($m^3$/s) |
| $W$ | fan power (kW) |

$\eta$ thermal efficiency (1st law efficiency, heat-exchanger effectiveness)

$\rho$ air density (kg/m$^3$)

## References


1 G. B. Parker and L. O. Foley, *Development of the Sample for ELCAP Monitoring in RSDP Homes, DOE/BP-13795-5*, Bonneville Power Administration, Portland, OR, 1985.

2 M. Riley, Mechanical ventilation system requirements and measured results for homes constructed under the R-2000 Super Energy-Efficiency Home Program, *Proc. 6th Air Infiltration Conference, Ventilation Strategies and Measurements Techniques, September 16–19, 1985, Het Meerdal Park, South Netherlands*, 1985.

3 M. Lubliner, R. Byers and N. Young, The residential construction demonstration project air-to-air heat exchangers performance monitoring, *Single Family Building Technologies — Proc. 1988 ACEE Summer Studies on Energy Efficiency in Buildings, Santa Barbara, CA.*

4 *Heat Recovery Ventilation for Housing: Air-to-Air Heat Exchangers, DOE/CE/15095-9*, National Center for Appropriate Technology, Butte, MT, 1984.

5 W. A. Shurcliff, *Air-to-Air Heat Exchangers for Houses*, Brick House Publishing Co., Andover, MA, 1982.

6 W. J. Fisk and I. Turiel, Residential air-to-air heat exchangers: performance, energy savings, and economics, *Energy Build.*, *5* (1983) 197–211.

7 I. Turiel, W. J. Fisk and M. Seedall, *Energy Savings and Cost Effectiveness of Heat Exchanger Use as an Indoor Air Quality Mitigation Measure in the BPA Weatherization Program*, Lawrence Berkeley Laboratory, Berkeley, CA, 1982.

8 F. J. Offermann, W. J. Fisk, B. Peterson and K. L. Reozan, *Residential Air-to-Air Heat Exchangers: A study of the Ventilation Efficiencies of Wall- or Window-Mounted Units*, Lawrence Berkeley Laboratory, Berkeley, CA, 1982.

9 W. J. Fisk *et al.*, *Indoor Air Quality Control Techniques: A Critical Review LBL-16493*, Lawrence Berkeley Laboratory, Berkeley, CA, 1984.

10 R. J. Corbett and B. A. Miller, Preliminary performance assessment of three ventilation systems employing air-to-air heat exchangers, *Proc. Conservation in Buildings: Northwest Perspective, Butte, MT, 1985.*

11 M. Schell and D. Rogoza, Field experiences with air-to-air heat exchangers: the real story, *Proc. Conservation in Buildings: Northwest Perspective, Butte, MT, 1985.*

12 R. Alexander, Measured performance of a central air-to-air heat recovery ventilation system, *Proc. Conservation in Buildings: Northwest Perspective, Butte, MT, 1985.*

13 J. R. Welty, C. E. Wicks and R. E. Wilson, *Fundamentals of Momentum Heat and Mass Transfer*, John Wiley & Sons, New York, 1976.