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AIR-TO-AIR HEAT EXCHANGERS AND THE INDOOR ENVIRONMENT

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Introduction

In the Pacific Northwest in the United States, the Northwest Power Planning Council (the Council) has proposed energy efficiency standards for new electrically heated houses in the region, and the Council and the Bonneville Power Administration (BPA) have been conducting a demonstration program (the Residential Standards Demonstration Program (RSDP)) to examine the costs and energy savings associated with building houses to levels of higher energy efficiency (1,2). Because these new houses are expected to significantly reduce air leakage (primarily through the use of tight-fitting windows and doors and the installation of continuous polyethylene air/vapor barriers in the ceilings, walls, and floors of the structures), there is concern about the impact of these measures on indoor air quality. In expectation of potential indoor air problems, all houses built to these new standards in the RSDP were equipped with air-to-air heat exchangers (AAHX) so that an overall infiltration rate (natural plus forced) of 0.6 air changes per hour (ach) could be maintained without sacrificing all of the energy savings of the energy-conserving measures. In this paper, we present our findings on the cost of AAHX, occupants' use of and satisfaction with AAHX, and occupants' experience with the indoor environment in their homes.

The Cost of Air-to-Air Heat Exchangers

Air-to-air heat exchangers can save a substantial amount of end-use energy by preheating or precooling incoming outdoor air to a temperature closer to indoor temperatures and, at the same time, AAHX can improve indoor air quality by flushing out airborne pollutants (3). In the RSDP, all the AAHX installed were central ventilation systems (rather than window units) that often required extensive supply and exhaust ductwork. Builders had to meet certain design specifications, although some flexibility was permitted. For example, a specified ventilation rate could be achieved with an appropriately sized unit running continuously, or by an oversized unit cycled or varied with fan operation as required. On the other hand, a humidistat was required which forced high speed operation of the AAHX when conditions of greater than 60% relative humidity occurred within the home.

Most units were installed by a general contractor with some assistance from manufacturers, heating contractors, and engineers. Because the builders in the RSDP and their HVAC contractors were generally unfamiliar with AAHX, the contractors attended AAHX training sessions and received considerable AAHX information. All builders were paid a fixed incentive for installing the AAHX (approximately $800 (1984 dollars)) as part of a larger incentive calculated to reimburse the entire cost of the changes required by the proposed standards (4). As part of their participation in the RSDP, builders agreed to monitor and calculate the cost of building an energy-efficient house by determining the costs of air-to-air heat exchangers, insulation, glazing, etc, as well as provide additional information, such as floor area and type of heating system (1). In addition to calculating the costs of the energy-efficient houses, builders were also asked to estimate costs for similar types of houses built to "current practice" (current practice typically refers to existing state or local building standards), so that "incremental costs" (the difference betwen the cost of the energy-efficient house and the cost of a house built to current practice) could be calculated. However, since very few current practice homes have AAHX, the incremental cost reported below is approximately the AAHX's actual cost.

The median incremental cost for installing air-to-air heat exchangers under the RSDP was $1268. This cost was in 1984 dollars, included labor and materials (e.g., the AAHX and duct costs), but excluded builder overhead, fees, and profit, and was based on a sample size of 366 houses. The mean incremental cost was $1308 with a standard deviation of $557, and the incremental costs ranged from $0 (i.e., no additional costs were incurred in installing the AAHX because in some cases it was already in the builder's current practice) to $4180.

Because more ductwork and larger capacity AAHX units are expected with larger houses, we expected greater AAHX system costs with greater house size. In addition, we expect the relationship between house area and AAHX cost to be non-linear because there is a fixed cost associated with the AAHX and increasing costs for ducts as the house gets larger. As shown in Fig. 1, the correlation between AAHX cost and floor area is statistically significant (at the 0.05 level) and positive, but not very strong (pearson correlation (r) = 0.33).

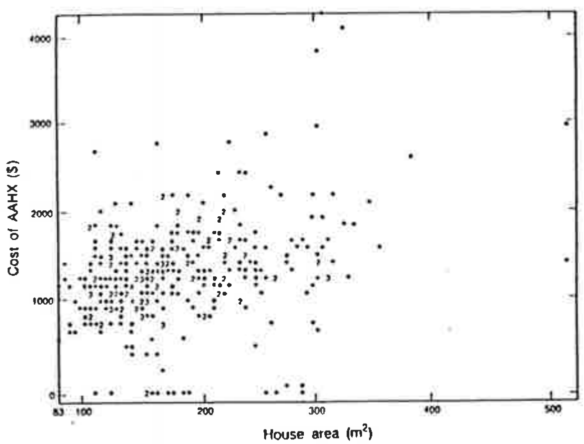

Fig. 1. Comparison of cost of AAHX with house area.

However, when AAHX costs are divided by floor area, we find that it is cheaper to install AAHX in larger houses than it is in smaller houses (Fig. 2). The correlation is statistically significant, negative, and stronger (pearson correlation (r) = -0.45). The standardized median cost for the AAHX was $7.42/m²; the standardized mean incremental cost was also $7.42/m² with a standard deviation of $3.23/m², and these costs ranged from $0/m² to $22.38/m². The large range in costs indicates that the market for AAHX is not mature and that competition has not forced a leveling of prices.

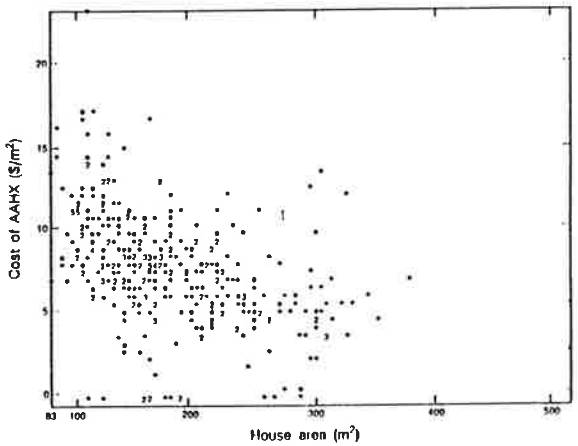

Fig. 2. Comparison of per unit cost of AAHX with house area.

Occupant Experience with Air-to-Air Heat Exchangers

BPA hired us to send a mail questionnaire to all occupants participating in the RSDP to obtain information on a number of project-related issues, including the use and operation of air-to-air heat exchangers and the occurrence of indoor environment "problems" (e.g., mold/ mildew, condensation, humidity, and odors) (5).

Owning an AAHX did not necessarily mean that the equipment was operating all the time. In fact, 5% of the AAHX owners who responded to the AAHX use question reported that they never used the heat exchanger. In addition, we found AAHX use to be very bimodal: 42% used it for 1-4 hours per day, and 30% used it for more than 18 hours per day. The implications of this result are straightforward: we would expect more problems with the quality of the indoor air with those households experiencing reduced ventilation (i.e., not using their AAHX).

The operation of an AAHX is highly dependent on proper care and maintenance by occupants. For example, if dust and particulates plug filters and sections of the core of the AAHX, airflow rates will be reduced and the effectiveness of the

AAHX will deteriorate (3). Accordingly, periodic cleaning or replacement of filters is required. In our sample of 294 households, most people had access to the heat exchanger, and 46% of the respondents felt confident that they understood the basic operations of the AAHX and could use the instruction manual that was left with them to solve any specific problem. Another 25% knew how to change the filter but nothing else, and 27% elected to wait until some problem arises before attending to it. A majority of households (58.2%) changed the filter, but about 40% of the sample reported that they had not yet changed the filter since its installation (approximately one year). The most common reasons given for not changing the filter were the following: the filter did not need to be changed (37.7% of the reasons), they did not know there was a filter (15.6%), they did not know how to change the filter (10.4%), they could not reach the filter (9.1%), and they were unable to find the right size filter (7.8%).

Water vapor from the warm outgoing airstream often condenses as the hot air is cooled in the core of the heat exchanger (3). Most AAHX are provided with an outlet for drainage of condensate. If the outside air temperature is sufficiently below -5°C, condensed water may freeze inside the heat exchanger core and obstruct all or some portion of the airflow. Despite the presence of freeze protection systems, about 10% of the RSDP sample reported the freezing of their AAHX core, and this problem occurred in the entire region, but especially in the coldest areas (greater than 8000 heating degree days, base 18° C).

The performance of the AAHX is also constrained by discomfort due to noise and/or excessive air movement. In a quiet house (typical of highly insulated houses), noisy fans sound noisier and, therefore, exhaust fans may be used less often to avoid the hum (6). The effective removal of exhaust fans causes imbalances in the mass flow rates of the airstreams in the house, and imbalanced air flow causes air leakage through the building envelope, thereby increasing the heat load of the furnace, so that the energy saved by using the AAHX will not be as high (3). In addition, the imbalances may cause other problems: positive pressure in the house may push moisture into walls (creating humidity and condensation problems), and negative pressure in the house may draw radioactive gases, such as radon, from the soil into the house. Similarly, the improper design of distribution systems (e.g., unequal supply and return duct lengths, use of high-resistance ducting, poor supply grill locations, and excessive duct bends) may cause airflow problems leading to discomfort to the occupants (4). For instance, supply grills should be located in areas where occupants are not directly affected by the flow of the supply air. This is particularly important since the initial supply of outdoor air is cooler than existing indoor temperatures. If occupants are uncomfortable with the flow of supply air, they may be likely to limit their use of the AAHX, or never use it.

In the RSDP sample, approximately 10% of the sample felt that AAHX were noisy, 70% slightly noisy, and 20% did not think that they were noisy at all. Similarly, about 14% of the sample felt that there were unpleasant drafts created by the AAHX while another 29% experienced drafts that they claimed were only a minor discomfort. A small percentage (6.4%) felt the drafts to be rather pleasant, and 51% experienced no drafts at all.

Air-to-air heat exchangers are a relatively new technology, and, therefore, there is very little information available on the reliability and life expectancy of this type of equipment. In our study, we found a small percentage (6%) of the AAHX had broken down. Of these households, about 27% were difficult to repair, 18% had not been repaired at the time of the survey, and 55% were found to be easy to repair.

As a final note, we constructed a variable which measured whether people who owned AAHX had problems with unpleasant drafts, repairs, or core freezing, and we found that 50% of AAHX owners had experienced at least one of these problems.

The Indoor Environment

Most air-quality problems in houses can be traced to high pollutant sources, rather than low infiltration rates. However, by constructing well insulated houses and reducing the infiltration of outside air, problems with the quality of the indoor air *may* be more severe and more frequent (3,7,8). For instance, humidity can rise to uncomfortable levels because of moisture generated indoors from occupants, cooking, and bathing. Levels of indoor-generated airborne contaminants may also be high: combustion emissions (nitrogen dioxide, particulates from cooking, heating, tobacco smoking, woodburning stoves, and fireplaces), odors (from cooking and cleaning), and chemicals outgassed by building materials and furnishings (formaldehyde and vinyl chloride). Finally, radon gas from the soil surround building basements and foundations may also reach high levels in tightly sealed homes.

The energy-efficient homes built in this program were designed to meet certain prescriptive standards (following a determined path, or a path with tradeoffs) or performance standards (estimating an energy budget, or meeting an overall thermal integrity). A number of options were available for meeting the design standards: ceiling insulation ranging from R-30 to R-38, wall insulation ranging from R-19 to R-31, underfloor insulation ranging from R-19 to R-30, perimeter insulation for slab-on-grade or basements ranging from R-10 to R15, double or triple-glazed windows with thermal breaks, insulated exterior doors, control of air-infiltration through careful caulking, weatherstripping, and installation of vapor barriers, and passive solar designs. Five major heating system types were represented in our sample: 36% of the homes were heated by electric baseboard systems, 28% by central forced air, 22% by wall forced air, 8% by heat pumps, and 6% by radiant heat.

Indoor air quality measurements (e.g., formaldehyde and radon) are being measured in separate investigations of the RSDP homes (9,10). As noted above, we sent a mail questionnaire to all households participating in the RSDP, and received valid responses from 317 households living in energy-efficient houses (the MCS group), and 387 housholds living in houses built to current practice (the Control group). The Control group was composed of houses that were electrically heated and were built after 1977 to current, energy codes, or they were built earlier than 1978 and weatherized to approximately current construction standards.

In the survey questionnaire, we asked all occupants about the presence of mildew/mold, condensation, humidity, and odors in their home, and we compared the two groups using statistical tests at a 0.05 significance level.

We found a statistically significant difference between the two groups in reporting the presence of mildew or mold in the home: only 8.3% of the MCS group, compared to 16.4% of the Control group, reported mildew problems. This finding is not too surprising since the control houses were occupied longer than the MCS houses, which allows for a longer build-up of molds and mildew. For those reporting problems, we inquired about the location of the mildew problem (bathroom, kitchen, dining area, living room, or other areas) and found statistically significant differences in some of these areas. For the Control sample, most mildew problems occurred in the bedroom and the kitchen; for the MCS sample, most mildew problems occurred in the bedroom. Surprisingly, no one in either sample reported mildew to be a problem in the bathroom, although condensation (see below) was a major problem in this room.

Approximately 60% of both samples experienced some kind of condensation. As above, for those reporting problems, we inquired about the location of the condensation (bathroom, kitchen, bedroom, dining area, living room, around humidifier, around heat exchanger, or other areas). Everyone who listed condensation to be a problem cited the bathroom as a major source. The Control group experienced significantly more condensation in the kitchen than the MCS group, while 7% of the MCS group experienced condensation around the air-to-air heat exchanger. In connecting condensation to events in the home (e.g., showering, cooking, sleeping, and washing clothes), all reported condensation when showering, but no one reported condensation while cooking. Although there was no statistically significant difference in the reporting of bedroom condensation, there was a significant difference in those reporting condensation when they were sleeping (i.e., at night) (22% of the MCS group vs 12% of the Control group). There were no statistically significant differences between the two groups for the other activities. The MCS group did report humidity problems when the air-to-air heat exchanger was off.

Slightly more MCS households (26.2%) than Control households (20.6%) found their home to be stuffy or humid, although the difference was not statistically significant. In connecting stuffiness to events in the home (e.g., cooking, sleeping, and washing clothes), no significant differences were evident. One-quarter of those reporting problems cited cooking as the main source of stuffiness (particularly the Control group (31.6%)) while 10% of the total sample cited the other two activities. Odors were difficult to get rid of for about 16% of each group, and there were no statistically significant differences. In sum, the MCS group appeared to be consistently better off in the kitchen than their counterparts: less mildew, condensation, and stuffiness.

We compared high AAHX users (operate their heat exchangers 5 or more hours per day) with low AAHX users (less than 5 hours per day, or never use their heat exchangers) and found no differences in perceived problems with the indoor environment between the two groups. This finding was surprising because we expected more indoor environment problems in those households with reduced ventilation. Consequently, usage of air-to-air heat exchangers may not significantly affect indoor quality in energy-efficient homes. However, many important aspects of indoor air quality are not perceptual: for example, radon concentrations are not noticeable until they have affected one's physical health. Thus, an analysis of indoor air quality measurements by other investigators may give us a more definitive answer on the effectiveness of AAHXs in preventing problems in the indoor environment (9,10).

Conclusions

Air-to-air heat exchangers, a major new housing construction technology, were installed in 366 energy-efficient homes as part of a demonstration program in the Pacific Northwest. The median incremental cost of AAHX was $1268 ($7.42/m^2), and it was less expensive (per square meter) to install this equipment in larger houses than in smaller houses. AAHX use was very bimodal: 42% used it for 1-4 hours per day and 30% used it for more than 18 hours per day (5% never used the AAHX). While most occupants did not notice problems with their AAHX, some households did experience problems related to noise, unpleasant drafts, condensation around the AAHX, and core freezing. While only a small percentage of AAHX had broken down, future AAHX problems may become more significant as the program continues and as households choose not to clean filters and repair AAHX.

Occupants of energy-efficient homes were found to have less problems with their indoor environment (especially mildew/mold and condensation) than a group of control homes. The lack of vapor barriers and AAHX in the control homes may account for these differences (or differences in window-type and the amount of insulation), and future investigations will help answer this question.

Based on our survey and other investigations (4,11), information and training programs need to be targeted to five groups to improve the effectiveness of AAHX: manufacturers, installers/designers, builders, building code officials, and homeowners. These programs would ensure that the AAHX were designed and installed properly, and that operating and maintaining the AAHX was understandable to the user. Due to the large initial cost of AAHX, energy savings become very important in making this investment attractive to homeowners and builders, and these savings are highly dependent on the quality of system design and installation as well as on the acceptance of these systems by the homeowner. While the future of air-to-air heat exchangers in the Pacific Northwest is uncertain (due to its high cost and opposition by the building community), we intend to continue to examine the use of AAHX in this area and related problems with the indoor environment.

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References

(1) Vine, E., Residential Standards Demonstration Program: Builder Cost Analysis. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1986.

(2) Meier, A., Nordman, B., Conner, C., and Bush, J., A Thermal Analysis of Homes in Bonneville Power Administration's Residential Standards Demonstration Program. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1986.

(3) Fisk, W., Roseme, G., and Hollowell, C., Performance of Residential Air-to-Air Heat Exchangers: Test Methods and Results. LBL Report 11793. Lawrence Berkeley Laboratory, Berkeley, California, 1980.

(4) Reiland, P., McKinstry, M., and Thor, P., Preliminary Air-to-Air Heat Exchangers Testing Results for the Residential Standards Demonstration Program. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1985.

(5) Vine, E. and Barnes, B., Residential Standards Demonstration Program: Occupant Survey Analysis. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1986.

(6) Bliss, S., The Importance of Ventilation, Part II. Solar Age 11(3):39-40, 1986.

(7) Diamond, R. and Grimsrud, D., Manual On Indoor Air Quality. EPRI report EM-3469. Electric Power Research Institute, Palo Alto, California, 1984.

(8) Turiel, I., Indoor Air Quality and Human Health. Stanford University Press, Stanford, California, 1985.

(9) Reiland, P., McKinstry, M., and Thor, P., Preliminary Formaldehyde Testing Results for the Residential Standards Demonstration Program. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1985.

(10) Reiland, P., McKinstry, M., and Thor, P., Preliminary Radon Testing Results for the Residential Standards Demonstration Program. Office of Conservation, Bonneville Power Administration, Portland, Oregon, 1985.

(11) Lubliner, M., Kingrey, W., and Byers, R., Experience with Air-to-Air Heat Exchangers in the Residential Standards Demonstration Program in Washington State, Proceedings from the 1986 Summer Study on Energy Efficiency in Buildings, Santa Cruz, California, 1986.

EFFECT OF SOME ARCHITECTURAL AND ENVIRONMENTAL FACTORS ON AIR FILTRATION OF MULTISTOREY BUILDINGS

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1. Introduction

In Hungary, and all over Europe, most of the residential buildings have natural ventilation, that is largely influenced by the air-tightness of the building, the weather, architectural features of the building and aerodynamical character of the environment. Two separate research projects have been carried out to size up these effects. The primary target of the first project was to compile a wind pressure coefficient /CP values/ data bank especially for filtration and natural ventilation calculations. The wind being one driving force of natural ventilation has an important role in the ventilation flow rates. Wind forces are usually presented in form of pressure coefficients /CP/ where the mean pressure at any external point of the building envelope is normalised by the reference dynamic pressure, in our case that measured at the eave height the building. Pressure coefficient differences between the windward and leeward surfaces are characteristic to the acting wind forces. This fir project gave on opportunity to analyse the effect of environmental factors on pressure coefficients.

The second project was a case study where the above factors were analys by a simple single-cell ventilation and filtration simulation program. Here not only the environmental factors but architectural features of a tual buildings were also considered, and seasonal values of ventilation heat demand were calculated.

2. Analysis of wind pressure coefficients for filtration calculations

Simulating 3 types of atmospheric boundary layers (Fig.1.) in the wind tunnel of the ÉTI, 4 types of block buildings, each in 4, 6 and 10 story versions, were exposed to the wind in 3 exposure situation (Fig.2.). Overall analysis of the measured pressure coefficients lead to the results that are roughly sketched on Fig.3. For all building types, heigh upwind terrain types. Regarding the difference between pressure coefficients on the windward side (CP1) and on the leeward surfaces (CP2) the environmental and shelter effects are illustrated in Table 1. with mean values and range limit estimates.

The exposure situations of Fig.2., though arbitrary, still represent Hungarian traditional and new settlements, and no significant variation of the above values was found if the tested 2·H spacing between the sheltering and exposed buildings decreased to H.