The Role of Ventilation
15th AIVC Conference, Buxton, Great Britain
27-30 September 1994

Climate-based Analysis of Residential Ventilation Systems

N E Matson*, H E Feustel*, J L Warner*, J Talbott**

* Energy Performance of Buildings Group, Indoor Environment Program, Lawrence Berkeley Laboratory, Berkeley, California USA

** U.S. Dept of Energy, Washington, DC, USA

CLIMATE-BASED ANALYSIS OF RESIDENTIAL VENTILATION OPTIONS: NEW YORK ANALYSIS*

Nance E. Matson, Helmut E. Feustel and Jeffrey L. Warner
Energy Performance of Buildings Group
Indoor Environment Program
Lawrence Berkeley Laboratory
Berkeley, California, USA

John Talbott
U.S. Department of Energy
Washington, DC, USA

A study has been undertaken to (1) evaluate airtightness in recent construction dwellings in New York State, (2) evaluate the effectiveness of various strategies in providing adequate ventilation, and (3) study the use of various ventilation options by residential builders and heating, ventilation and air-conditioning (HVAC) contractors. Ventilation provided by infiltration and installed mechanical ventilation systems was analyzed in 97 New York post-1980 single-family dwellings, including 50 houses built to recent building standards (control houses) and 47 houses constructed to standards set by NYSE-Star, an energy-efficient residential building program. These houses were analyzed using RESVENT, which incorporates the LBL infiltration model and the ASHRAE Standard 136 air change rate calculation methodology. Based on the building characteristics of these houses and those of other data sets of U.S. residential buildings, quantitative descriptions of prototypical houses were developed to be used in evaluating the effectiveness of ventilation strategies. COMIS, a multizone air flow model, was used to evaluate hourly air change rates of a base case and three mechanical ventilation strategies in Buffalo, New York. Results of a survey of residential builders and HVAC contractors are presented. The survey explored the use of various residential ventilation strategies in New York State, the frequency of information requests from homeowners and developers regarding ventilation systems, comfort and health issues, and the influence of various factors on decisions about installing ventilation strategies.

Keywords: Ventilation, Infiltration, Ventilation Strategies, Modeling

LBL Report #36003, UC350

*The research reported here was co-sponsored in part by the New York State Energy Research and Development Authority and the California Institute for Energy Efficiency. Additional related support was provided by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technologies, Building Systems and Materials Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. Publication of research results does not imply NYSERDA or CIEE endorsement of or agreement with these findings, nor that of any CIEE sponsor.

Introduction

This study has been undertaken to (1) evaluate airtightness in recent construction single-family dwellings, (2) evaluate the effectiveness of various strategies in providing adequate ventilation, and (3) study the use of ventilation strategies by builders and heating, ventilation and air-conditioning (HVAC) contractors. This study is part of a larger ongoing effort, by many researchers, to quantify and understand the relationship and delicate balance between building tightness, energy efficiency, ventilation strategies, and adequate ventilation. To add to this understanding, a research project is ongoing, focusing on single-family detached dwellings in the states of California and New York. In order to provide a full picture of the process and results of this project, we have focused solely on the New York portion of our work in this paper.

Evaluation of Building Tightness and Ventilation Rates

Two leakage data sets were examined in order to evaluate airtightness and corresponding ventilation rates. One data set consists of 50 post-1980 construction houses (control houses) in New York State[1], while the other data set consists of 47 houses from the NYSE-Star energy-efficient residential building program[2]. The NYSE-Star program is a builder incentive program sponsored by a consortium of New York State utilities and energy agencies. The program requires that the houses be built to allow a maximum air change rate of 7 h^{-1} at 50 Pa pressurization. Mechanical ventilation systems are recommended but not required by the program.

Building and Leakage Characteristics

General building and leakage characteristics for the two data sets are given in Table 1. The NYSE-Star program houses are generally slightly larger than those of the control houses (240 m^2 vs. 212 m^2 of floor area). Most of the houses in each data sets are two-story houses with basements. Approximately 1/3 of the houses in each data set have heated basements.

TABLE 1: House and Leakage Characteristics - New York

Characteristics	NYSE-Star Houses	Control Houses
Average Air Change Rate @ 50 Pa	4.42 h^{-1}	6.81 h^{-1}
Average Normalized Leakage	0.30 (-)	0.42 (-)
Average Floor Area	240 m^2	212 m^2
Stories (predominant)	Two	Two
Foundation Type (predominant)	Basement	Basement
Houses with Heated Basements	33 %	32 %
Average Ceiling Height	3.0 m (9.7 ft)	2.5 m (8.1 ft)

The NYSE-Star houses, with an average ACH_{50} of 4.42 (std. dev. = 1.70), are tight compared to other U.S. residences that have been measured[3,4]. The control houses tend to be somewhat looser, but still relatively tight, with an average ACH_{50} of 6.81 (std. dev. = 2.50). The average normalized leakage, the equivalent leakage area per unit area of building envelope area is 0.30 (std. dev. = 0.16) for the NYSE-Star houses and 0.42 (std. dev. = 0.16) for the control houses. The ranges for the two data sets overlap and are similar.

The RESVENT Model

In order to analyze infiltration and ventilation and their energy and indoor air quality impacts, an hourly simulation model, RESVENT, was developed. RESVENT is an enhancement of VENTNRG[3], an hourly simulation model incorporating the LBL infiltration model[5] and calculation of infiltration-related space-conditioning loads. RESVENT incorporates the ability to schedule and model various ventilation strategies and the flexibility to perform multiple simulations using different combinations of houses and weather data.

Three input files are used with RESVENT, generically named "house," "fan," and "site." The "house" input file includes building and leakage characteristics. The "fan" input file includes the fan types (supply or exhaust), flow rates, and on/off times for the ventilation systems modeled. The "site" input file contains references to the weather data files to be used and general site information. Weather data files developed for use in RESVENT simulations were derived from existing DOE-2[6] weather files.

RESVENT outputs include (1) identification of the peak- and low-infiltration days (based on a 24-hour average) of the infiltration-only air change rates calculated using the LBL infiltration model, (2) air change rates calculated based on ASHRAE Standard 136[7] as well as by using the LBL infiltration model, and (3) infiltration and ventilation-related space-conditioning loads, and (4) ventilation-related electrical requirements.

RESVENT Modeling Assumptions

RESVENT was used to analyze both the NYSE-Star and control data sets. Input files were developed based on information provided by the data sources. In all cases, the houses were modeled with bathroom and kitchen exhaust fans (85 m^3/h and 170 m^3/h respectively), running for one hour at 6:00 a.m. and 5:00 p.m., respectively. Each house was modeled using the most appropriate available weather data, with respect to location and climate.

RESVENT Modeling Results

RESVENT results of interest section include the identification of minimum and maximum daily average infiltration air change rates and the combined effective air change rate calculated using the ASHRAE Standard 136 calculation methodology. For both data sets on the low-infiltration day, the average hourly air change rates, derived using the LBL infiltration model, are below the 0.35 h^{-1} minimum set by ASHRAE Standard 62[8]. The average hourly air change rates on the low-infiltration day range from 0.02 h^{-1} to 0.14 h^{-1} (mean = 0.07, std. dev. = 0.03) for the NYSE-Star houses and from 0.05 h^{-1} to 0.34 h^{-1} (mean = 0.15 , std. dev = 0.06) for the control houses.

For the peak-infiltration day, the average hourly air change rates are higher, but not always high enough to meet Standard 62. The average hourly air change rates on the peak-infiltration day range from 0.08 h^{-1} to 1.08 h^{-1} (mean = 0.45, std. dev. = 0.21) for the NYSE-Star houses and from 0.33 h^{-1} to 2.10 h^{-1} (mean = 0.93, std. dev. = 0.40) for the control houses.

The combined effective air change rates, based on ASHRAE Standard 136, for individual houses range from of 0.07 to 0.82 (mean = 0.28, std. dev. = 0.16) for the NYSE-Star houses and from 0.15 to 0.77 (mean = 0.39, std. dev. = 0.15) for the control houses. Figure 2 shows the combined effective air change rate as a function of the measured air change rate at 50 Pa for the two data sets. While the NYSE-Star houses have lower values of combined effective air change rates and measured air change rates at 50 Pa, there is no significant difference between the two data sets in terms of the correlation between the measured and combined effective air change rates. Due to high normalized leakage values, two of the NYSE-Star houses have much higher combined effective air change rates than the others.

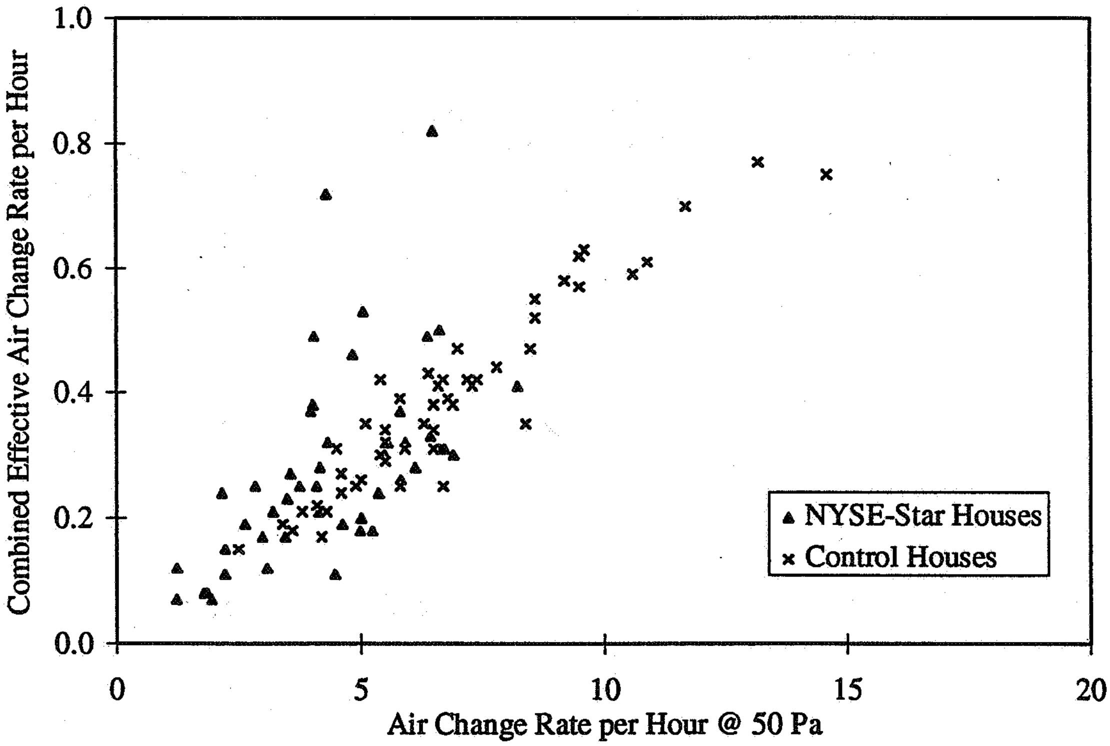

Figure 2: Calculated Air Change Rate (ASHRAE Standard 136) vs. Measured Air Change Rate (ACH_{50})

To determine compliance with the ASHRAE ventilation and tightness standards (Standards 62[8] and 119[9], respectively), the combined effective air change rates and the normalized leakage values were compared to the requirements of the relative standards. To meet Standard 62, a house must have a minimum air change rate of 0.35 h^{-1}. Standard 119, the tightness standard, specifies maximum normalized leakage values, taking into account climate and location. The percentage of the houses meeting the standards are shown in Table 2. Only 23% of the NYSE-Star houses meet the ventilation standard, while 79% meet the tightness standard. This suggests that adequate ventilation is sacrificed in tightening the houses and lowering the infiltration-related space-conditioning loads.. On the other hand, the control data set has a higher percentage of houses (56%) meeting the ventilation standard, while 52% of the houses meet the tightness standard. Only a small percentage, 2% of the NYSE-Star data set and 8% of the control data set, are able to meet both standards, suggesting that it is difficult to strike a balance between airtightness and adequate ventilation.

TABLE 2: Compliance with ASHRAE Ventilation and Tightness Standards - New York

ASHRAE Standard	NYSE-Star Houses	Control Houses
Standard 62 Only	21 %	48 %
Both Standards (62 & 119)	2 %	8 %
Standard 119 Only	77 %	44 %
Neither Standard	0 %	0 %

Evaluation of Residential Ventilation Strategies

As shown in the analysis above, supplemental ventilation may be necessary to provide adequate ventilation. In order to explore the effectiveness of various ventilation options, a prototypical house was developed for use in modeling efforts. COMIS, a multizone air flow model[10], was used to evaluate the air change rates of a base case and three ventilation strategies in the prototypical house on peak- and low-infiltration days in Buffalo, New York. The appropriate peak- and low-infiltration days for the air flow simulations were determined using RESVENT.

Prototypical House

The prototypical house was developed to represent current construction practices for residential buildings in New York. The building was a 144 m^2, one-story house with a full unconditioned basement and attached garage.

For air flow simulation purposes, the prototypical building was divided into zones: a common living space, a laundry room, three bedrooms, two bathrooms, a garage, an attic, and a basement. The modeled background leakage between the conditioned building and the exterior or unconditioned spaces (around window and door perimeters and through joints in framed surfaces) was based on an air change rate of 7 h^{-1}, determined at an induced pressure difference of 50 Pa. Proportionate leakage rates were assigned to the surfaces between zones and to the exterior. Equally sized cracks were specified at 1/4, 1/2, and 3/4 of the heights of all walls to the exterior and between conditioned and unconditioned zones to model the stack effect.

Air flow between the basement and the exterior was assumed to occur around the perimeters of the basement windows. Attic vents were also modeled as effective leakage areas. Interior doors were modeled as large openings.

Eight supply ducts ran from the supply plenum in the basement to floor registers in the conditioned rooms. A single return duct also ran through the basement to a central floor return grille. It was assumed that 8.5% of the supply air leaked from the ducts and supply plenum, while 12% leakage occurred at the return plenum.

The flow exponent, n, for leaks through the building envelope was taken to be 0.67. Open interior doors and ducts were assumed to have orifice flow with a flow exponent of 0.5. For the leakage from the ducts, a value of 0.65 was assumed for n.

The prototypical house was located in a suburban area. Wind pressure coefficients for a building surrounded by obstructions of equal height were used[11]. The weather data used in the COMIS simulations were the same as those used with RESVENT.

Ventilation Strategies

Four ventilation scenarios were modeled using COMIS, as explained below. Hourly space-conditioning loads were determined by summing the ventilation-induced loads and the loads simulated using DOE-2.1D. Oversizing factors of 175% for heating and 125% for cooling were applied, and the part-load-ratios were determined based on the peak load results from DOE-2.

1) *Base case*: a 2040 m^3/h rated central heating and air-conditioning system with intermittent bathroom, kitchen, and laundry exhaust fans with design flow rates of 85 m^3/h, 170 m^3/h, and 425 m^3/h, respectively, running one hour per day, at 6:00 a.m., 5:00 p.m., and 8:00 p.m., respectively.

2) *Central exhaust system with an outside air duct*: the base case with a 140 m^3/h rated single-port central exhaust fan, running 24 hours per day. An air duct with a motorized damper supplied outside air to the return plenum of the furnace. The outside air damper was closed from 75% to 25% when the furnace fan was in operation to counter higher pressure differences and higher flow rates.

3) *Central exhaust system with room intake louvers*: the base case with a 140 m^3/h rated single-port central exhaust fan, running 24 hours per day. Intake louvers were located in the exterior walls of each bedroom and the common living space to provide make-up air for the exhaust fan.

4) *Balanced ventilation system with heat recovery*: the base case with a 130 m^3/h rated cross-flow heat recovery ventilator, running 24 hours per day with a 70% heat recovery efficiency. Supply air was provided to the return plenum of the furnace, while exhaust was drawn from a separate grille in the common living space.

COMIS Modeling Results

Figure 3 shows the peak-infiltration day hourly air change rate profiles for the four scenarios modeled. In all four cases, the hourly average air change rates are roughly constant, with the exception of the hours when intermittent fans are operating. Due to HVAC system impacts, total air change rates fluctuate within the hour in cases when an outside air duct or air-to-air heat exchanger is connected to the central HVAC system.

On the peak-infiltration day, the base case shows air changes on the order of 0.25 h^{-1}. As the ASHRAE Standard 62 specifies a minimum air change rate of 0.35 h^{-1}, the need for supplemental ventilation is indicated.

The central exhaust system with an outside air duct, on the peak-infiltration day, provides ventilation rates of approximately 0.40 h^{-1} when the HVAC system fan is on and 0.47 h^{-1} when the system fan is off. The performance differences are a consequence of the air duct damper setting, which allows more air to enter during the furnace fan off time. The central exhaust system with intake louvers shows a steady ventilation rate on the order of 0.50 h^{-1}. Only the operation of additional exhaust fans increases this rate.

On the peak infiltration day, the balanced ventilation system with heat recovery provides a slightly higher ventilation rate than the central system options, on the order of 0.52 h^{-1}. Due to the balanced character of the system, the influence of additional exhaust fans is less pronounced than in the central exhaust fan cases.

On the low-infiltration day (Figure 4), the base case system provides ventilation of approximately 0.10 h^{-1}. The central exhaust fan with an outside air duct increases the ventilation rate to 0.30 h^{-1}. Since the furnace fan is off most of the time, the damper is in its open position (75% open) most of the time as well. The central exhaust fan with intake louvers increases the ventilation rate to 0.40 h^{-1}. The balanced system with heat recovery provides 0.35 h^{-1}, slightly less than the central exhaust fan with intake louvers.

Based on this analysis, on both the peak- and low-infiltration days, the base-case house does not have adequate ventilation as required by ASHRAE Standard 62. The central exhaust/outside air duct option, while providing adequate ventilation on the peak-infiltration day, does not provide sufficient ventilation on the low-infiltration day. This standard is met using two options, the central exhaust fan with intake louvers and the air-to-air heat exchanger.

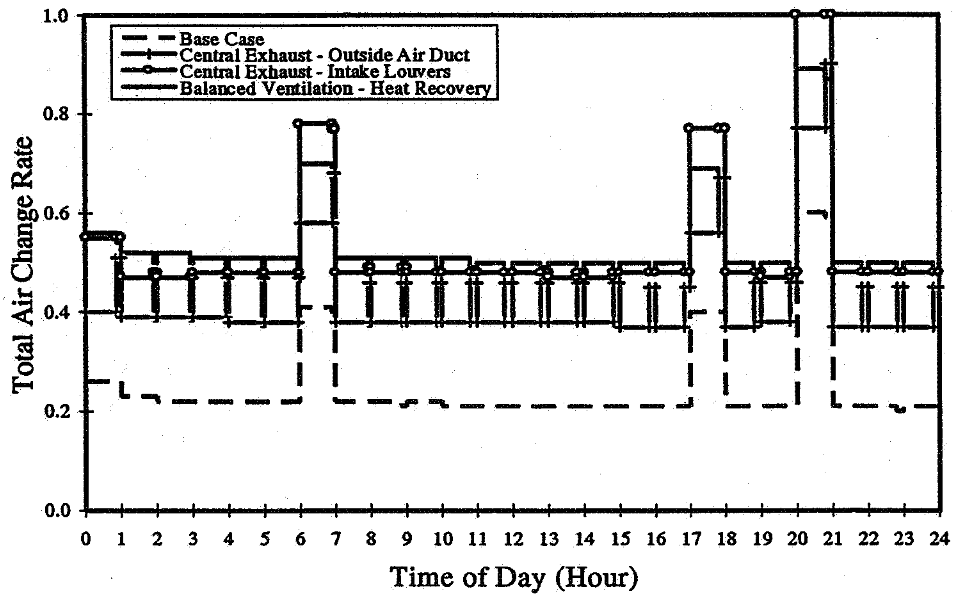

Figure 3: Hourly Air Change Rates on the Peak-Infiltration Day, January 26th (heating season), for the Prototypical House in Buffalo, New York

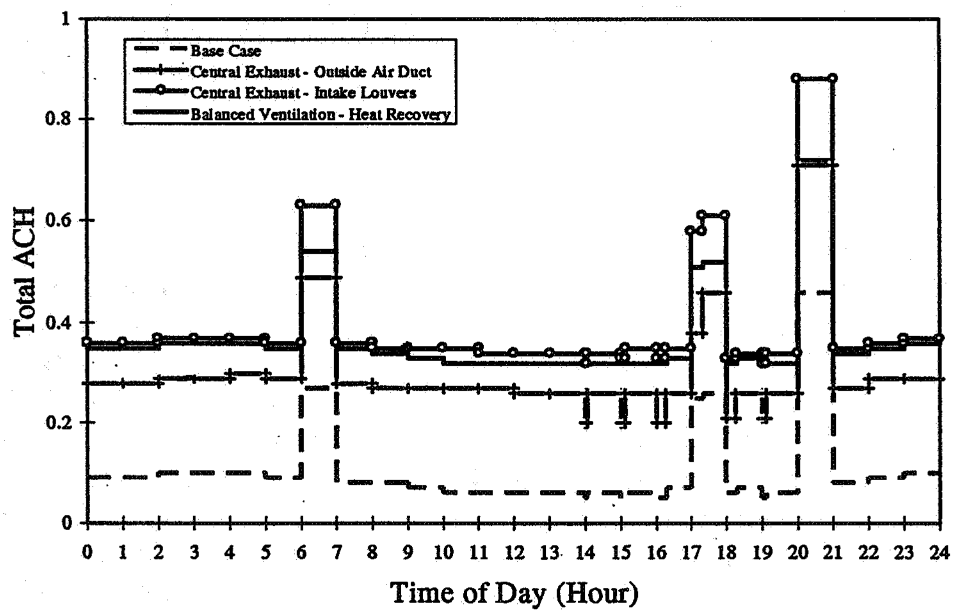

Figure 4: Hourly Air Change Rates on the Low-Infiltration Day, June 13th (cooling season), for the Prototypical House in Buffalo, New York

Residential Ventilation Surveys

As was discussed in the previous sections of this paper, when houses have been constructed to airtightness standards, supplemental ventilation is often required. We have also evaluated the effectiveness of various ventilation options and have discovered that, between infiltration and ventilation systems, adequate ventilation can be provided. However, the familiarity of builders and contractors with ventilation options and the commercial availability of residential ventilation equipment has not been known. To answer these questions, two surveys on residential ventilation systems and equipment availability are currently being conducted. One survey focuses on residential builders and HVAC contractors, while the other survey focuses on equipment distributors and retailers. Synertech Systems Corporation and Syracuse University in Syracuse, New York, are administering these surveys. While these surveys are being conducted in both New York and California, only the New York results are presented here.

Builder / Contractor Survey

The builder and contractor survey respondents consisted of a pool of residential builders and HVAC contractors who may or may not have had experience with residential ventilation systems beyond bathroom and kitchen exhaust fans. The survey sample includes 60 builders and 40 HVAC contractors per state, with the stipulation that a minimum of 50% of the respondents have had at least some experience with advanced residential ventilation systems. The survey sample was also split evenly between respondents who have participated in utility or public agency incentive or rebate programs and those who have not participated in such programs. The builder and contractor survey covers the number and types of residential ventilation strategies installed, system-specific issues, and perceived market barriers.

Types of Ventilation Strategies Installed

Table 3 summarizes the number of respondents (builders and contractors) surveyed who have installed each specific ventilation strategy during the past year. Also summarized for each strategy, based on the number of respondents who have reported installing that strategy, are the total number of systems installed in the past year as well as the range, average and median number of each strategy installed per respondent. Most of the respondents (80%) have experience with the basic systems (bathroom and kitchen exhaust fans), which was to be expected. Over half of the respondents (53%) have installed outside air ducts into a central system. Whole-house fans (18%), central exhaust fans (14%), and intake louvers (13%) were installed by fewer respondents. Only a few of the respondents have installed economizers (7%), located windows for optimum ventilation (6%), and installed ventilation shafts (2%). The total number of systems installed is impressive, but a comparison of the average and median number of systems shows that only a handful of respondents have installed the bulk of the systems reported. Most of the builders and contractors have installed only a few of the advanced ventilation strategies.

TABLE 3: Number of Ventilation Strategies Installed - 100 New York Builders and HVAC Contractors Surveyed					
Ventilation Strategy	Number of Respondents	Total Systems per Year	Range per Respondent	Average per Respondent	Median per Respondent
Bathroom and Kitchen Exhaust Fans	80	3,457	1-496	43	20
Whole-House Fans (High Volume)	18	266	1-100	15	5.5
Central Exhaust Fans (Single- or Multi-Port)	14	285	1-100	20	5
Ventilation Shafts	2	15	5-10	8	7.5
Wall Inlet Louvers	13	241	1-200	18	2
Locate Windows for Optimum Ventilation	6	131	2-100	22	7
Outside Air Ducts into a Central HVAC System	53	1,650	1-688	31	10
Air-to-Air Heat Exchangers	23	370	1-100	16	3
Residential Economizers	7	150	1-100	21	2

Requests for Advanced Ventilation Systems

Respondents were asked how often homeowners and developers asked about advanced ventilation systems (e.g., central exhaust, air-to-air heat exchangers, or economizers). A few of the respondents stated that homeowners (8%) and developers (15%) always or often asked about advanced systems. The majority of the respondents indicated that homeowners (78%) and developers (58%) seldom or never asked about advanced ventilation systems. While only a few homeowners or developers tended to ask about advanced ventilation systems, these percentages indicate that there is some level of understanding about ventilation and indoor air quality issues.

Homeowner Questions about Comfort and Health

Respondents were asked how often homeowners asked about general comfort and health issues. Only a small percentage of respondents indicated that homeowners always or often asked about these issues, ranging from a high of 15% for comfort and 10% for health to a low of 3-4% for more air flow and fresh air. 20-25% of the respondents stated that homeowners sometimes asked about these issues, with the bulk of the respondents (53-67%) stating that homeowners seldom or never ask about these issues.

Importance of Factors in Installing Systems

The factors that directly affected the ability of the builder or contractor to complete their work easily and profitably rated highest and were deemed more important than those that would probably be of more importance to the homeowner, such as ease of operation and operating costs. Of the six factors given, system price was most important to the respondents, followed by product availability, ease of installation, ease of maintenance, ease of operation, and, occasionally important, system operating costs.

Overall Impressions

The builders and contractors who had experience with specific ventilation strategies felt at ease with the systems, stating that the systems were relatively easy to install and that they had very few callbacks to make repairs. Obtaining ventilation system equipment did not seem to be a problem to these builders and contractors, who ranked obtaining equipment as somewhat to very easy. Similarly, system installation was often ranked as somewhat to very easy.

Conclusions

We have shown that there is often a need to provide some type of supplemental ventilation when building houses tight. Only in a few cases is it possible to tighten buildings while still allowing sufficient air change rates without providing supplemental ventilation. However, supplemental ventilation, either through enhanced natural ventilation or mechanical ventilation, may be necessary to provide adequate indoor air quality.

We looked at three ventilation options for a prototypical house in Buffalo, New York, including a central exhaust fan with an outside air duct into the central HVAC system, a central exhaust fan with wall intake louvers, and an air-to-air heat exchanger. While all three options increased the building air change rates on the peak-infiltration day sufficiently to exceed the minimum required air change rate of 0.35 h^{-1}, the central exhaust fan with an outside air duct was not able to meet this requirement on the low-infiltration day.

Our survey shows that, while builders and contractors have had experience with various ventilation strategies, on average they have installed very few of these systems. Only a handful of builders and contractors stated that homeowners or developers ask about advanced strategies, and very few homeowners ask questions regarding comfort and health. As with other construction-related decisions, we found that system price, availability, and ease of installation and maintenance are more important to the builders and contractors than ease of operation and operating costs.

In conclusion, we found that there is a definite need to consider ventilation when building a tight house. Our analysis of ventilation strategies show that central exhaust with intake louvers and air-to-air heat exchangers are effective in providing sufficient ventilation. And, while builders and contractors do have experience with various ventilation strategies, homeowners and developers do not ask very often about installing such systems.

Future Work

The work on this project is continuing, including evaluation of building tightness and ventilation rates for post-1980 California dwellings and climate-based COMIS simulation of ventilation strategies in the one-story as well as a two-story prototype. The California and New York surveys are nearing completion and are expected to provide vital information on the use of residential ventilation systems in the building sector. A ventilation guidebook for New York contractors and builders is also being developed. A proposed phase II of the New York work includes a demonstration project, consisting of installing and monitoring various ventilation strategies in New York houses, to verify and fine-tune the effectiveness of residential ventilation strategies.

References

1. STRUNK, P.R., "Air Leakage and the Effects of Mechanical Ventilation: Measurements in Fifty Newer Homes in New York State," Synertech Systems Corporation for NYSERDA, Syracuse, NY, February 1994.

2. CARVER, B., Data Collection of NYSE-Star Building and Leakage Characteristics for LBL Project (Personal Communication), New York State Energy Research and Development Authority, Albany, NY, January 1994.

3. SHERMAN, M.H. and N.E. MATSON, "Ventilation-Energy Liabilities in U.S. Dwellings," 14th Annual AIVC Conference Proceedings, Copenhagen, Denmark, 1993.

4. DICKERHOFF, D.J., personal communication, August 1994.

5. SHERMAN, M.H. and M.P. MODERA, "Infiltration Using the LBL Infiltration Model," Special Technical Publication No. 904, Measured Air Leakage Performance of Buildings, pp. 325-347. ASTM, Philadelphia, PA, 1984. Lawrence Berkeley Laboratory Report, LBL-17487.

6. BIRDSALL, B., W.F. BUHL, K.L. ELLINGTON, A.E. ERDEM, and F.C. WINKELMANN, "Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D," LBL-19735, Rev. 1, Lawrence Berkeley Laboratory, Berkeley, CA, 1990.
7. -, "Standard 136: A Method of Determining Air Change Rates in Detached Dwellings," American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, GA, 1993.

8. -,"Standard 62: Ventilation for Acceptable Indoor Air Quality," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1989.

9. -, "Standard 119: Air Leakage Performance for Detached Single-Family Residential Buildings," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1988.

10. FEUSTEL, H.E. and A. RAYNER-HOOSON "Fundamentals of the Multizone Air Flow Model - COMIS," Air Infiltration and Ventilation Centre, TN 29, 1990, LBL-28560, Lawrence Berkeley Laboratory, Berkeley, CA, 1990.

11. LIDDAMENT, M.W., "Air Infiltration Calculation Techniques - An Applications Guide," Air Infiltration and Ventilation Centre, Bracknell, Berkshire, Great Britain, 1986.