April 2002 • NREL/CP-550-31665

Conference Paper

Barriers to Improved Ventilation in Production Housing

Preprint

C. Dennis Barley

To be presented at the International Academy of Indoor Air Sciences, Indoor Air 2002 Conference
Monterey, California
June 30—July 5, 2002

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

BARRIERS TO IMPROVED VENTILATION IN PRODUCTION HOUSING

C. Dennis Barley[1]

National Renewable Energy Laboratory, Golden, CO, USA

ABSTRACT

In addressing the goals of energy-efficiency and indoor air quality (IAQ) in homes, industry teams in the U.S. Department of Energy's Building America program are installing mechanical ventilation systems in tight homes. A variety of designs – some simple and inexpensive, some more sophisticated – have been demonstrated. The advanced designs provide more consistent ventilation over time, more uniform ventilation among rooms, and source control measures that reduce the air-change requirement. However, most homebuyers are not fully aware of IAQ issues and whole-house ventilation requirements, and are thus not willing to pay the incremental cost of improved systems. Because the applicable standards do not require these improvements, lower-performance systems are often installed despite the best intentions of the engineering teams. This paper describes the ventilation approaches used by the teams, shows test results that illustrate performance issues, and discusses obstacles that hinder more widespread application of improved systems.

INDEX TERMS

Mechanical ventilation, residential, standards, production housing

I. INTRODUCTION

Building America (2000) is an industry driven program sponsored by the U.S. Department of Energy, in which crosscutting residential building industry teams use systems engineering approaches to accelerate the development and adoption of advanced building energy technologies in production housing. The basic goal of the program is to foster the widespread construction of homes that are energy efficient, healthy, comfortable, and affordable. To date, over 11,000 Building America homes exceed the requirement of 30% energy savings compared to the Home Energy Rating Systems (HERS) Reference Home (NASEO, 1999). The National Renewable Energy Laboratory (NREL) serves as the field manager of the Building America program; this role includes research, technical support, and monitoring the activities of the various industry teams.

In addressing the goals of energy efficiency and indoor air quality (IAQ), the general approach of the teams is to install mechanical ventilation systems in tight houses. The author has provided an overview of residential ventilation issues and the approaches of the various Building America teams (Barley, 2001). Although some very effective ventilation systems have been demonstrated in prototype homes, there is currently no consensus regarding recommended approaches, and our test results show that performance varies widely among homes. Four important aspects of performance variations are as follows:

[1] Author email: Dennis_Barley@nrel.gov

A. The annual average air-change rate;
B. The consistency of the air-change rate throughout the year;
C. The uniformity of the air-change rate from room to room within the home; and
D. The level of source control due to the choice of building materials, which affects the relationship between air-change rate and IAQ.

Most homebuyers are not fully aware of IAQ issues and whole-house ventilation requirements, and are thus not willing to pay the incremental cost of optional ventilation features, based on our experience with the Building America program. The applicable standards are American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE) 62 (ASHRAE, 1999); ASHRAE 62.2P (ASHRAE, 2000), a new standard specifically for residences, currently in a public review stage; and U.S. Department of Housing and Urban Development (HUD) 24 CFR Part 3280 (HUD, 1994) for manufactured housing. These standards, which have the intent of requiring a minimum net air-change rate of 0.35 ACH, do address point A, address point B although perhaps not adequately, and do not address points C and D listed above. Furthermore, the allowances in the ASHRAE 62.2P and HUD standards for the contribution of natural infiltration to the net air-change rate may not be realistic in tightly built homes, especially in mild weather. The result of all this is that many of the ventilation systems being installed in production housing are low-budget approaches that do not provide the intended 0.35 ACH on a consistent and uniform basis. This is demonstrated by sample performance data presented in Section III.

II. APPROACHES OF THE BUILDING AMERICA TEAMS

There are currently 5 consortia, or industry teams, involved in the Building America program:

- Building Science Consortium (BSC)
- Consortium for Advanced Residential Buildings (CARB)
- Hickory Consortium
- Integrated Building and Construction Solutions Consortium (IBACOS)
- Industrialized Housing Partnership (IHP)

Building projects implemented by these teams are located in a variety of climates, including severe cold, cold, mixed humid, hot humid, and hot/mixed dry. System designs vary across climate regions and among the teams. The choice of an approach often involves a compromise between the engineering goals of the team and cost constraints that are imposed by the builders and the housing market. The simplest and least expensive approach is:

- Single-port exhaust system, often an upgraded bathroom exhaust fan, controlled manually or by a programmable timer.

Possible problems with *exhaust* systems in general, caused by depressurization of the home, include: (1) they may entrain pollutants from combustion appliances, an attached garage, a crawl space, etc. if adequate precautions are not taken; and (2) they may cause moisture damage to the structure in hot humid climates. In addition, (3) single-port systems may not provide adequate ventilation to all rooms, and (4) manual control systems may not provide adequate ventilation much of the time if the occupants do not run it consistently. Examples of more sophisticated designs, with significant performance advantages over the single-port exhaust system, include the following:

- Multi-port exhaust system. One exhaust fan is ducted to ports in several rooms. This improves the room-to-room uniformity of the ventilation effect. There is an added expense for the additional ductwork.
- Single-port exhaust fan coordinated with a forced-air heating system blower to mix the outside air throughout the house. This improves the room-to-room uniformity of the ventilation effect. There is an added expense for the operation of the furnace blower when heating or cooling is not needed.

Supply ventilation systems use a fan to blow air into the home, with make-up air forced out through cracks in the building shell. These systems resist entraining pollutants from combustion appliances or adjacent spaces. They may cause moisture damage in cold climates if adequate precautions are not used. Three variations of this approach are:

- Single-port supply system. Control is manual or by a programmable timer. There is an added expense for the whole-house ventilation fan, in addition to any spot exhaust fans in the house.
- Multi-port supply system. One supply fan is ducted to ports in several rooms. This improves the room-to-room uniformity of the ventilation effect. There is an added expense for the additional ductwork.
- Forced-air-integrated supply system, by means of an outside air duct connected to main return air duct. Control is by a duty-cycle timer or the normal thermostatic operation of the air handler fan. A motor damper may or may not regulate the air intake. There is an added expense for the operation of the air handler fan when heating or cooling is not needed, if such a control strategy is used to achieve adequate ventilation in mild weather.

Balanced ventilation systems use both supply and exhaust fans to neutralize the pressure effects. These are generally more expensive due to multiple fans and perhaps additional ductwork. Three variations of this approach are:

- A single-point exhaust fan added to a forced-air-integrated supply system.
- A balanced heat recovery ventilation system. More energy efficient, more expensive.
- A single-port exhaust fan added to a multi-port supply system.

Although most of these designs have been demonstrated in Building America pilot homes, the simplest and least-expensive approaches remain the most common. Some consequences of this are shown in the next section.

III. PERFORMANCE TESTING

Part of NREL's technical support role in the Building America program is the testing of new homes to provide feedback to the teams and to ascertain how well the program goals are being met. In this section, two selected ventilation test results are shown to illustrate performance issues. In each case, the home was unoccupied during testing.

The first example is a 1-story, 3-bedroom home in Indianapolis, Indiana. The floor area is 274 m^2 (2950 ft^2), including the conditioned basement. A blower door test indicated 3.1 ACH50, making this a rather tight house. Based on ASHRAE Standard 136 (ASHRAE, 1993), the estimated annual average infiltration rate for this house is 0.16 ACH. The single-port supply ventilation system was designed to deliver 28.3 L/s (60 ft^3/minute, or cfm), corresponding to 0.13 ACH, on a continuous basis.

Sulfur hexafluoride (SF_6) tracer gas testing was conducted during the first week of June 2001. During the test, indoor temperatures were held between 19 °C and 22 °C (66 °F and 72 °F) while the outdoor temperature varied between 12 °C and 27 °C (53 °F and 80 °F), and various modes of operation were tested. The results of this test are shown in Figure 1. During a time when both the ventilation system and the air handler were off (interval A), the natural infiltration rate was less than 0.05 ACH. This illustrates the large difference that can occur between an annual average air-change rate and that which occurs during a season of mild weather. During a period when the ventilation system and the air handler were individually turned on and off (interval B), the air-change rate rose to about 0.10 to 0.15 ACH. Thus, even though this ventilation system meets the requirements of ASHRAE 62.2P, the net ventilation rate is less than half of the benchmark 0.35 ACH for most of the 5-day period.

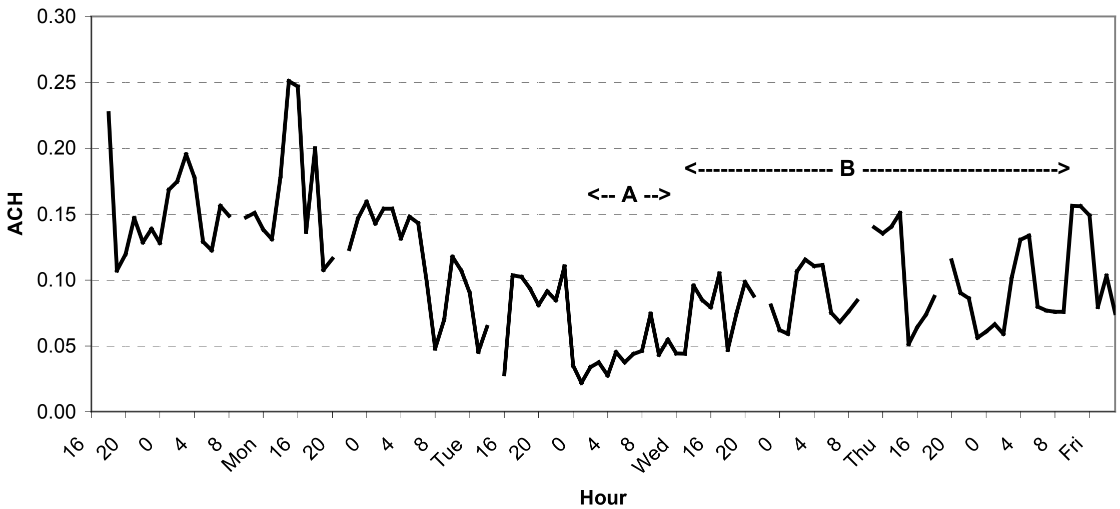

Figure 1. Tracer gas test results for sample home #1, with a single-port supply ventilation system, in mild weather. "A" shows infiltration only; "B" shows intermittent operation of the ventilation system and the air handler.

The second test case is a 2-story, 4-bedroom home, also in Indianapolis, Indiana. The floor area is 297 m^2 (3200 ft^2), including the conditioned basement. A blower door test indicated 6.0 ACH50, so this house has more leakage area than former, with an estimated annual average infiltration rate of 0.35 ACH. The mechanical ventilation design is single-port supply, with an air exchanger that mixes outside air with return air to avoid cold drafts. It was designed to deliver 33 L/s (70 cfm), corresponding to 0.15 ACH of mechanical ventilation, on a continuous basis.

A multizone SF_6 tracer gas test was conducted during the first week of June 2001. In this test, the tracer gas was initially mixed throughout the house using the air handler fan. Then the mixing was stopped, and the decay of tracer gas was monitored at six locations in the house. Indoor temperatures were held between 20 °C and 23 °C (68 °F and 73 °F) while the outdoor temperature varied between 12 °C and 19 °C (53 °F and 66 °F). The decay curves are shown in Figure 2, superimposed over the primary reference case of a single, well-mixed zone receiving 0.35 ACH and secondary reference cases receiving 20% more or less than this amount. The results show that the bedrooms received significantly less ventilation effect than other rooms in the house. The standards do not distinguish between this situation and one in which a more sophisticated ventilation system achieves more uniform ventilation throughout the house. Therefore, there is nothing to officially indicate that this is unacceptable. However, because occupants typically spend more time in bedrooms than elsewhere in the home, this situation has a large impact on the IAQ to which occupants are exposed.

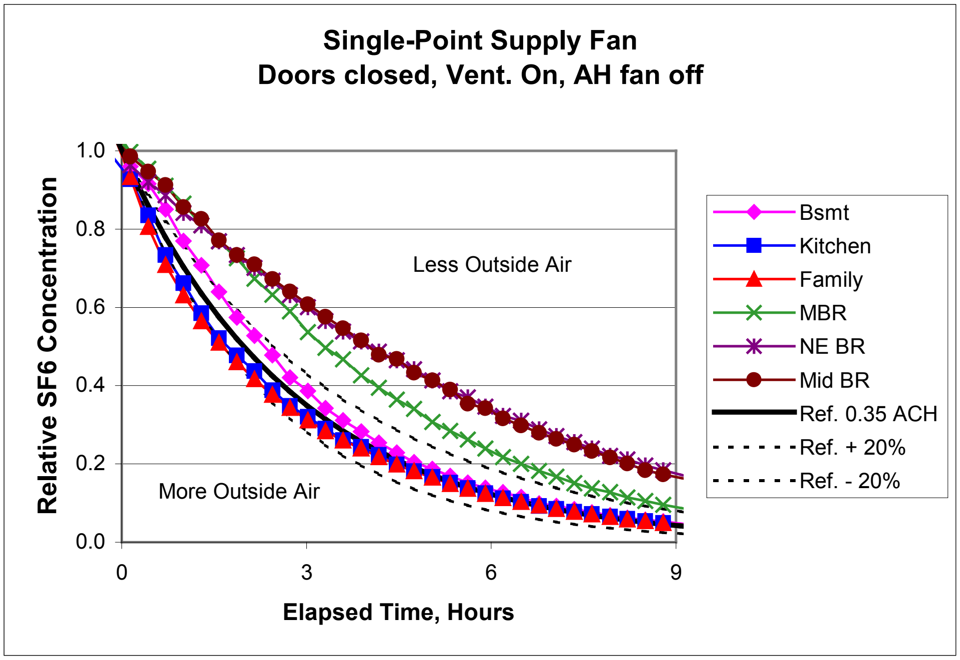

Figure 2. Multi-zone tracer gas test results for sample home #2, in mild weather.

IV. CONCLUSIONS

In the Building America program, a sequence of design, test, evaluation, and redesign is used to improve the quality of production housing. Ventilation test results indicate that some of the designs being demonstrated by the teams show significant improvements with respect to the consistency of the air-change rate throughout the year and the uniformity of the air-change rate among rooms. However, there is currently no consensus as to how to evaluate the test results in terms of what is and what is not acceptable. Obstacles include:

- The improved designs have higher first costs and/or operation costs.
- Most homebuyers are not fully aware of IAQ issues and whole-house ventilation requirements, and are thus not willing to pay the incremental cost of improved systems.
- Builders are often reluctant to incur any added cost for improved IAQ, because their customers have not demonstrated a willingness to pay for it.
- The applicable standards do not require these improvements.

The result is that lower-performance systems are often installed despite the best intentions of the engineering teams.

One controversial issue that makes it difficult to reach a consensus on ventilation requirements is manual control by building occupants. This applies both to natural ventilation, with occupants opening windows in mild weather, and to mechanical ventilation, with occupants switching on a fan. Advantages include simplicity, low cost, and the ability of occupants to have ventilation whenever they want it. A disadvantage is the likelihood of underventilation if occupants do not understand the need for whole-house ventilation or forget to use it. Another concern is pollutants that might pose health threats, even though their presence is not perceptible to the occupants. Would an occupant open a window because the concentration of radon gas is too high? In addition, there may be circumstances where opening windows is not practical. Outdoor conditions such as noise, dust, rain, or security risks may be deterrents to opening windows. If the outdoor temperature is, say 10 ^{o}C (50 °F), the stack effect may provide insufficient ventilation through cracks, but opening windows may create chilly drafts. If the outdoor temperature is, say 30 ^{o}C (85° F), the stack effect may provide insufficient ventilation through cracks, but high humidity may require air conditioning, which precludes opening windows. When occupant behavior is factored in, manually controlled systems may not meet the intent of the standards.

Work is currently underway in the United States to develop a new residential ventilation standard, ASHRAE 62.2P. This is a consensus document intended to establish minimum requirements. Many of the design criteria initially proposed for this standard have been criticized as lacking a scientific basis, and the requirements have been diminished. These may be difficult issues to address, but it seems unlikely that good practice can be established without resolving them. Any research that helps to establish a basis for more explicit definition of ventilation requirements would be helpful in advancing the cause of improved IAQ in residences.

VII. REFERENCES

ASHRAE. 1993. *ANSI/ASHRAE Standard 136-1993*, A Method of Determining Air Change Rates in Detached Dwellings. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASHRAE. 1999. *ASHRAE Standard 62-1999*, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc.

ASHRAE. 2001. *BSR/ASHRAE Standard 62.2P*, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings, Second Public Review Draft. Atlanta, GA: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc.

Barley, D. 2001. *An Overview of Residential Ventilation Activities in the Building America Program (Phase I).* Golden, CO: National Renewable Energy Laboratory. NREL/TP-550-30107.

Building America Home Page. 2000. www.eren.doe.gov/buildings/building_america/. Last accessed 1/31/02.

HUD. 1994. *Manufactured Home Construction and Safety Standards*, Part 3280. U.S. Department of Housing and Urban Development.

NASEO. 1999. *National Home Energy Rating Technical Guidelines.* Alexandria, VA: National Assn. of State Energy Officials.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
April 2002

3. REPORT TYPE AND DATES COVERED
Conference Paper

4. TITLE AND SUBTITLE
Barriers to Improved Ventilation in Production Housing: Preprint

5. FUNDING NUMBERS
BET2.8004

6. AUTHOR(S)
C. Dennis Barley

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/CP-550-31665

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In addressing the goals of energy-efficiency and indoor air quality (IAQ) in homes, industry teams in the U.S. Department of Energy's Building America program are installing mechanical ventilation systems in tight homes.

14. SUBJECT TERMS
IAQ; indoor air quality; energy efficiency; mechanical ventilation systems; residential; production housing; standards

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102