How Tight Are America's Houses?

Researchers at Lawrence Berkeley National Laboratory (LBNL) recently collected blower door data from across the country to analyze the airtightness of the U.S. housing stock. Along with other data sources and computer models, researchers used this database to make national approximations of the infiltration- and ventilation-related energy consumption of existing housing. In a second study, LBNL analyzed the same numbers to determine the potential energy savings from tightening and ventilating houses, and decide which ventilation strategies would be most economical in different parts of the country.

The studies describe the overall tightness (or looseness) of U.S. houses and show how tightness varies with the age of the house, type of construction, location, size, and weatherization. Researchers also looked at the total energy picture for the country's building stock, the effect of airtightness on indoor air quality, and ventilation strategies that are cost-effective if houses are tightened to conform to ASHRAE Standard 119.

Before these studies, LBNL maintained a database of blower door test results that included about 240 homes, mostly in California and the Pacific Northwest. Now the database includes 12,946 individual measurements on more than 12,500 single-family detached houses all over the United States.

Leakage results from the database didn't correlate with any climate- or location-related trends. The studies found that leakage trends are more affected by construction quality, local practices, and age distribution than by weather. Table 1 shows minimum, maximum, and mean leakage measurements for the houses in the study and gives minimum, maximum, and mean figures for the age of the houses and the floor areas. Air leakage is expressed in two ways—air changes per hour at 50 Pascals of pressure (ACH_{50}) and normalized leakage (NL). These are the two ways of measuring most commonly used in practice and in standards.

Comparison of Variables

The first study compares five building criteria that may influence leakage—number of stories, year of construction, type of floor or basement, age of the house, thermal distribution system, and retrofitting. LBNL researchers found a correlation between each of these criteria and the normalized leakage values.

Number of stories. Approximately 56% of the measurements are for multistory houses. Multistory houses were 11% leakier (NL = 1.8) than single-story houses (NL = 1.6).

Type of floor or basement. Two types of house were examined with respect to this issue—houses that had floor leakage to the outdoors (built with crawlspaces or unconditioned basements) and houses that had no floor leakage to outdoors (built slab-on-grade or with fully conditioned basements). The vast majority (80%) of the houses had floor leakage (NL = 1.75). The 20% that did not have floor leakage were 5% tighter overall. This is a minor difference, but statistically significant.

Age of house. Of the houses with information about the year the house was built, those built after 1980 didn't show increasing leakiness with age and were tighter (NL = 0.47) than average. The houses built before 1980 showed increased leakage with age and were on average much leakier (NL = 1.05) than new houses.

Thermal distribution system. Eleven percent of the total sample contained information about the presence (or absence) of a duct system. The surprising result was that the homes with duct systems (43% of this subset) were tighter overall (NL = 0.7) than homes without duct systems (NL = 0.9). Where duct systems were measured separately (about 1% of the total sample), they accounted for just under 30% of the total leakage—a finding consistent with those of other studies.

Retrofitting. Four hundred sixty-five houses were measured as part of retrofit or weatherization projects; measurements were taken both before and after the retrofits were done. These measurements showed that the average retrofit reduced leakage by about 25%.

Ventilation Strategies

Using the newly expanded LBNL leakage database, the second study analyzes the energy and cost factors associated with providing the current levels of ventilation and estimates the energy savings or penalties associated with tightening or loosening the building

Table 1. Summary of Leakage Measurements

	Number of houses	Minimum	Maximum	Mean	Standard deviation
Year built	1,492	1850	1993	1965	24.2
Floor area [m²]	12,946	37	720	156.4	66.7
Normalized leakage	12,946	0.023	4.758	1.72	0.84
ACH_{50}	12,902	0.47	83.6	29.7	14.5
Exponent (n)	2,224	0.336	1.276	0.649	0.084

Table 2. Ventilation Equipment Costs

Equipment and installation first cost inputs	Exhaust-only system	Heat recovery ventilator
First cost	$785	$2,298
Annualized cost	$187	$247
Annual interest rate	7%	7%
Years in service	5	15
Annual heat recovery efficiency	0%	70%
Fan wattage (watts/CFM)	0.6	1.0

envelope while still providing adequate ventilation.

ASHRAE Standard 119-1988, which sets maximum leakage levels of building envelopes based on energy considerations, was used to evaluate the tightness of the housing stock. ASHRAE Standard 62-1989 sets minimum ventilation rates for providing acceptable air quality in all kinds of buildings. For residential buildings, the standard specifies 0.35 ACH. The researchers used an approach similar to ASHRAE Standard 136–1993 to estimate the combined contributions of envelope leakage and other ventilation systems toward meeting Standard 62.

The study looks at natural, exhaust-only, and heat recovery ventilation. It assumes that both the exhaust system and the balanced heat recovery ventilator are sized to provide 0.35 ACH at all times. (Most users would probably not operate these systems at all times, but this assumption helps to avoid overstating the savings associated with the alternative scenarios.) The projections assume three things:

- The houses are intended to be occupied and conditioned full time, without setback.
- People will use their windows only when it is comfortable outdoors.
- Intermittent bathroom and kitchen exhaust fans run one hour each day.

Table 2 shows the equipment assumptions and costs for the two mechanical ventilation strategies. The annualized equipment costs were determined based on equipment and installation first costs obtained from a 1995 survey of California and New York ventilation equipment distributors. First costs were annualized using a 7% annual interest rate over 15 years. Residential electricity and natural gas price information for the 1993 calendar year was obtained from the Energy Information Agency.

What Does It All Mean?

The researchers profiled three scenarios for comparing cost-effectiveness of airtight houses: the base case scenario, the ASHRAE scenario and the Scandinavian scenario. The base case scenario uses the same leakage measurements as found in the current existing housing stock. The ASHRAE scenario assumes that any houses that do not meet ASHRAE 119 are tightened until they meet the standard. The Scandinavian scenario is modeled after the northern European trend toward tighter building envelopes and few operable air inlets, and assumes a minimum NL of 0.14. This trend began with the Swedish standard, which requires no more than 3 ACH_{50}. Researchers analyzed the stock to determine which houses no longer met ASHRAE Standard 62 and determined the most cost-effective ventilation strategy for those houses. Tables 3 and 4 show which strategy for each of the three scenarios will most economically provide ventilation sufficient to meet Standard 62.

—Nance Matson

Table 3. ASHRAE Standards and Ventilation Strategies

Tightness case	% Meeting ventilation standard	% Meeting tightness standard	Natural ventilation (%)	Exhaust systems (%)	Heat recovery systems (%)
Base	95%	15%	96%	2%	2%
ASHRAE	49%	100%	49%	22%	29%
Scandinavian	5%	100%	5%	44%	51%

Table 4. Annualized Costs

Tightness case	National annualized cost ($/yr)	Average annualized cost ($/yr/house)	Range of annualized cost ($/yr/house)
Base	$6.0 billion	$820	$50–$7,000
ASHRAE	$3.6 billion	$490	$20–$2,200
Scandinavian	$4.0 billion	$550	$45–$1,776

Regulating Ventless Heaters

Ventless gas heaters have seen sales take off over the past few years, buoyed by their low cost, attractive design, and high efficiency. Meanwhile, building scientists working on indoor air quality and building durability have warned that these heaters can produce enough combustion products to make occupants sick, while also degrading building structures. Recently, the controversy has moved to regulatory bodies in New York and California, and to a subcommittee within International Approval Services (IAS), home of the vaunted ANSI (American National Standards Institute) Standards.

The gas industry defends unvented heaters, pointing out that they are allowed by 42 state building codes in the United States, and that they are widely used in Europe. Mike Calderrera of the Gas Appliance Manufacturers Association says the heaters have safety measures intended to guard against dangerous combustion products. "Every heater since 1980 has been required to have an oxygen depletion sensor (ODS)," Calderrera says. "This has certainly improved safety. Today's products are built to satisfy all the requirements of the ANSI safety standard." Ken Maitland, director of engineering at the California-based gas appliance maker Fireplace Manufacturers Incorporated (FMI), says, "I believe as an engineer that they're safe, if designed correctly and the ODS is installed."

The safety features are widely proclaimed by the Vent-Free Alliance (VFA), a coalition of members of the Gas Appliance Manufacturers Association. *Nice & Warm,* a booklet published by the VFA, says that the Consumer Product Safety Commission (CPSC) data "show no documented deaths due to emissions associated with the use of an ODS-equipped vent-free gas heating appliance" since 1980.

Sandy Weisner of Medford, Oregon, is not soothed by these assurances. She installed an FMI ventless heater in 1996, and soon after developed symptoms of