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INDOOR AIR QUALITY/AIR INFILTRATION IN SELECTED LOW-ENERGY HOUSES

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Abstract

Indoor air quality and air infiltration were measured in 16 low-energy Californian houses. Eleven houses had gas stoves; all had average infiltration rates of 0.5 h^{-1} or less, recent construction dates, low natural ventilation, and no mechanical ventilation. HCHO levels in 12 houses and radon-222 and NO_2 levels in all houses were measured using passive monitors. Blower door measurements and local weather data were used to calculate average infiltration rates during the monitoring period. Correlations of pollutant concentrations with infiltration rates and building characteristics indicate that new houses with average heating season infiltration rates less than 0.5 h^{-1} do not necessarily experience poor indoor air quality. However, HCHO and radon-222 levels in a ew houses exceeded the lowest currently proposed standards or guidelines, and much higher levels probably exist elsewhere. Therefore, some strategy for identifying "problem" houses is needed. We recommend an approach for future research in this area.

Introduction

Inadequate understanding of indoor air quality factors currently discourages efforts to conserve building energy use by reducing infiltration. Outside air infiltration in a building can impose a major space-conditioning load on heating and cooling systems. If infiltration is decreased, however, the level of internally generated indoor pollutants tends to increase. Several researchers have documented cases in which indoor pollutant levels exceeded outdoor air quality standards, and have shown that increasing infiltration reduces indoor pollutant levels (8). Yet the relationship between indoor air quality and infiltration rate is affected by many additional factors, e.g. outdoor source strengths, building materials age, gas apppliance use, presence of smokers, indoor use of common chemicals, and removal of pollutants by absorption, chemical reactions, or decay. Because the effects of these factors are currently incompletely understood, the uncertainties associated with determining a "safe" infiltration rate are large.

These large uncertainties compel regulatory agencies to set conservative building standards (3). This is especially true for new houses, where the potential for cost-effective infiltration reduction is greatest. Furthermore, owners of existing houses may unnecessarily forego cost-effective conservation measures to maintain high infiltration rates as a safety measure. To maximize energy conservation while maintaining indoor air quality, we must reduce these uncertainties by acquiring a better understanding of pollutant sources and removal mechanisms.

To assist current research in this area, the California Energy Commission (CEC) contracted with the Universitywide Energy Research Group and Lawrence Berkeley Laboratory (LBL) to conduct a pilot field study to analyze the interaction between indoor air quality, air infiltration, and pollutant source strengths in new, low-energy houses. The following sections describe the design, experimental results, and conclusions of this field study.

Study Design

Existing data on indoor air quality are so limited that the scope of the problem, even for conventional houses, is unknown. We therefore designed this field study with the goal of setting some preliminary bounds on residential indoor air quality problems and indicating the best directions for future research. To achieve this goal, "worst case" houses were selected for monitoring which had the following building and occupancy characteristics: infiltration rates below the 0.9 air changes per hour (h^{-1}) estimated for the 1983 California new residential building standards (2); gas stoves; new construction; and low natural and mechanical ventilation. However, since indoor air quality also depends on other factors such as occupant operation of stoves and windows), this selection process did not guarantee identification of an absolute "worst case" house. Rather, it enabled us to investigate indoor air quality in a group of houses with important characteristics associated with potential indoor air quality problems.

The monitoring occurred in January and February, 1982 in 16 low-energy houses, 4 near Riverside and 12 in the Sacramento/Davis area. Indoor air concentrations of nitrogen dioxide (NO_2), radon-222 (radon), and formaldehyde (HCHO) were monitored using passive monitors, i.e., small, inexpensive devices which require no power or operation by building occupants or researchers. The NO_2 and HCHO monitors work by absorbing the pollutants from indoor air at a known rate (10, 4); the radon monitors register radon levels by exposing sensitive film to room air (1). In all houses, we measured NO_2 and radon levels. In addition, as part of field tests of a formaldehyde passive monitor being developed by LBL, we measured levels of formaldehyde in the Sacramento/Davis area houses.

Average infiltration rates for the heating season and for the actual monitoring period were calculated for each house from blower door measurements of effective leakage areas and local weather data, as outlined by Sherman and Grimsrud (11). This method reproduces directly-measured infiltration rates using tracer gas methods within 15-20% (6, 7, 11). In all houses, infiltration rates averaged 0.5 h^{-1} or less, as shown in Table 1.

Table 1. Infiltration Rates and Characteristics Related to Air Quality of 16 Low-Energy Houses in California

ID	Infiltration (h^{-1})[a]	Location	Year Built	Gas Stove[d]	Notes[e]
1	.33	Riverside	1978	no	infiltration barrier, slab
2	.27	Riverside	1977[b]	no	infiltration barrier, slab
3	.28	Riverside	1978	no	infiltration barrier, slab
4	.35[c]	Colton	1980	no	passive, concrete walls, leaky vents, slab
5	.50	Rio Linda	1980	no	passive, no major ducts, slab batts, same design as #6
6	.22	Rio Linda	1981	yes	passive, slab, spray-on cellulose insulation, same design as #5
7	.36	Rio Linda	1980	yes	passive, no major ducts, slab, batts, solarium, same design as #18
9	.34	Rio Linda	1980	yes	passive, same design as #10, slab, batts
10	.26	Rio Linda	1980	yes	passive, same design as #9, slab, batts
12	.46	Davis	1977	yes	passive, woodstove, slab
13	.41	Davis	1980	yes	woodstove
14	.46	Davis	1980	yes	woodstove, continuous closed cell insulation
15	.19	Rio Linda	1981	yes	solar-tempered/conservation, slab, spray-on cellulose insulation
16	.32	Rio Linda	1981	yes	passive, slab, spray-on cellulose insulation
17	.41	Rio Linda	1980	yes	conservation, slab, batts
18	.29	Rio Linda	1980	yes	slab, batts, same design as #7

[a]Air changes per hour, heating season average based on local weather data, blower door measurement of effective leakage area, and number of vents taped during measurement (allowing 10 cm^2 per vent).

[b]Estimate

[c]Pressurization measurement only; the vents in the ceiling of this solar house did not stay closed under depressurization of the house. The vents appeared to be significant contributors to total leakage area; the owner sealed them before the indoor air quality monitoring period, but a blower door for a second measurement was unavailable at that time.

[d]Almost all were pilotless--#12 and 14 had one pilot light each.

[e]#1-3 were built by one builder; #5-10 and #15-18 (9 total) were all built by one (different) builder. In this column, "batt" means fiberglass batt insulation.

Building/occupant characteristics were also audited using a survey developed by Geomet (5). Eleven of the sixteen houses had gas stoves with vents requiring operation by occupants; thirteen had gas water heaters or gas back-ups to solar water heaters; and thirteen had gas central or wall furnaces in use. All houses had concrete slab foundations (a potential radon source), and many also had substantial amounts of concrete in thermal mass walls. All houses were built within the last five years; twelve were built within the last two years, and three were built less than a year before measurements.

Results and Discussion

A significant difficulty which arose repeatedly in evaluating the measured pollutant levels was inadequate health effects data on which to base air quality standards. For many pollutants, the dose-response relationship at chronic, low level exposures is not clear. Current air quality standards do not always consider such health effects, expecially those from indoor exposures. While we base comparisons in the following sections in part on current standards or guidelines, we recognize that they may be revised up or down (perhaps more than once) to reflect new health effects research.

The time-weighted weekly average concentrations of indoor NO_2 measured in this study ranged from 2.6 to 28 parts per billion (ppb), well under the current long-term National Primary Ambient Air Quality Standards of 50 ppb for outdoor air. NO_2 concentrations decreased with decreasing infiltration rates due to reaction and absorption inside the house, and the relatively greater strength of outdoor NO_2 sources (e.g., auto exhaust) compared to the strength of indoor sources (pilotless gas stoves and vented gas appliances) in the selected houses. Indoor NO_2 levels showed a weak, positive correlation with the intensity of gas stove use, but a strong correlation (r^2=0.86) with infiltration rates and gas stove used combined. This correlation suggests that NO_2 source strength may equal the importantance of infiltration and ventilation rates in "problem" houses. However, the recent trend toward replacement of conventional gas stoves by microwave ovens and gas stoves with automatic ignition systems may tend to reduce NO_2 source strengths in the future.

Measured radon levels ranged from 0.32 to 2.24 picoCuries per liter (pCi/l). Swedish standards correspond to an approximate range of 2.7 to 6.3 pCi/l for new buildings and 7.7 to 18 pCi/l for old buildings; the U.S.A.'s special proposed standards for houses on contaminated land correspond approximately to a radon level of at least 2.1 to 5 pCi/l. One house was slightly above the low end of these ranges; another was slightly below. All were below both Swedish standards. Measured radon concentrations did not correlate strongly with infiltration rate or other building/occupant characteristcs, indicating that house-to-house variations in radon concentrations depend strongly on other variables such as source strength and capture rates. However, other studies have shown that for a given source strength, infiltration rates can strongly influence indoor radon concentrations (9).

Measured HCHO concentrations ranged from 78 to 163 ppb, overlapping the lower range of proposed standards (100 to 500 ppb). However, 1) these measurements were made during field validation of passive monitors and were about 15% higher than conventional bubbler monitor measurements made concurrently in five houses, and 2) all houses in which measured HCHO levels exceeded 100 ppb were less than two years old. Thus, we expect HCHO levels in these houses to drop as they age. Indoor HCHO levels did not show a strong correlation with infiltration rate, stove use, house age, or furniture age. We expect that other buildings with greater quantities of particleboard and plywood will prove to have higher HCHO levels.

Conclusions

The results of this study indicate that new low-energy houses in California do not necessarily experience poor indoor air quality. Most of the houses measured with average infiltration rates less than 0.5 h^{-1} did not experience levels of NO_2, radon, or HCHO above the lowest current standards or recommendations. Only a few houses exceeded or approached the current standards or recommendations for radon and HCHO. These higher levels may only occur rarely or for short periods. The limited size and non-random selection of our sample precludes extrapolation of our results to all new, low-energy houses.

However, since a few buildings do exist which have much higher air pollutant levels than those we observed, some strategy for identifying such "problem" houses is needed. The results of this study suggest that a useful strategy would be to combine field monitoring with statistical analysis of pollutant and building data. This strategy would reveal potential interactions between such key indoor air quality factors as infiltration rates, source strengths, and occupancy effects. For instance, this study's statistical analysis of field monitoring data suggested that NO_2 source strength may be just as important as infiltration and ventilation in problem houses. More definitive identification of potential problem houses would be of great value in formulating healthful energy conservation programs and building standards.

Regulatory agencies could adopt more stringent building standards, by including mitigation strategies for potential problem houses, , however, more accurate monitoring of indoor pollutants and building/occupant characteristics is necessary to identify potential problem houses from a few selected household characteristics. In addition, the development of appropriate mitigation strategies requires additional research to establish health-based standards or criteria which are appropriate for the indoor environment. The use of passive monitors in health effects studies could prove very useful in developing such standards, and hence healthful energy-conserving building standards.

Acknowledgements

The authors gratefully acknowledge the contributions by many people at the University of California, the CEC, and the California Building Industries Association; and particularly to the builders, designers, and homeowners who contributed their time, interest, and houses for this study.

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