WHAT'S IN THE AIR FOR TIGHTLY BUILT HOUSES?

The developing consensus is that 0.5 air changes per hour can keep indoor pollutants below critical levels.

By Winslow Fuller

The air infiltration rates in today's generation of energy-efficient houses range from 0.2 to 0.5 air changes per hour (AC/hr), compared with 0.8 to 1.0 AC/hr in conventional residential buildings. Are these tightly constructed, heavily insulated homes so well sealed that the quality of the indoor air poses a health hazard?

In any discussion of the health effects of air pollution, it must be realized that there are two potential sources of pollution: the outside and the inside. Air quality in many major cities is not always safe. To assume that people require high air infiltration rates to flush out indoor air pollutants ignores this fact. Houses give shelter from some outdoor sources of pollutants, so real benefits can stem from building houses with low air infiltration rates.

Surprisingly little has been reported on the subject of indoor air pollution. Nonetheless, good data are found in three studies, which form the basis for much research that remains to be done. (See references at the conclusion of this article.)

Hollowell and researchers at Lawrence Berkeley Laboratory conducted analyses both in laboratory conditions and at test houses that have low air infiltration rates (see references). Figure 1 shows the indoor air pollutant levels in a test kitchen under four gas cooking procedures from no stove vent to a hood vent with fan at high speed. To reduce the levels of carbon monoxide (CO), nitrogen dioxide (NO_2), and formaldehyde (HCHO) to the most stringent health standard, a gas kitchen range must have a hood vent with a fan capable of approximately 140 cfm.

Lawrence Berkeley Laboratory also noted the effects of gas cooking in a low infiltration house it maintains in Walnut Creek, Calif. (Figure 2). In this test the home's air infiltration rate varied from .33 to .43 AC/hr. The gas consumption pattern of the stove was typical for the nation as determined by the American Gas Association. NO_2 concentrations were higher than recommended on a one hour peak basis in the kitchen and the living room. CO was below acceptable levels on

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Figure 1. Contaminant concentrations in a test kitchen.

Ventilation Conditions	Mechanical Ventilation Rate (m^3/hr)	Air Exchange Rate (AC/hr)	Contaminant Concentrations[a] CO (mg/m^3)	NO_2 ($\mu g/m^3$)	HCHO[b] ($\mu g/m^3$)
No stove vent or hood		0.25	48	2500	460
Hood vent (with no fan) above stove		1.0	25	1500	280
Hood vent with fan at low speed	84 (50 cfm)	2.5	14	800	150
Hood vent with fan at high speed	240 (140 cfm)	7.0	4	200	40
	Typical Outdoor Concentrations During Test		1.5	50	5
	Air Quality Health Standards	Concentration	40[c]	470[d]	120[e]
		Averaging Time	1 hour	1 hour	maximum

a 1 hour average concentration in center of kitchen in which gas oven is operated at 180°C (350°F).
b Calculated from measured emission rate for gas stoves
c EPA promulgated standard (1)
d EPA recommended standard (1)
e European standard (1)

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Figure 2. NO_2 and CO concentrations in an energy-efficient research house.

	NO_2 (μg/m³)	CO (mg/m³)
Peak 1-hour average		
Kitchen	850	27.8
Living Room	750	24.1
Bedroom	440	17.8
Outside	130	0.5
24-hour average		
Kitchen	140	5.9
Living Room	140	5.9
Bedroom	85	4.7
Outside	66	0.5
Air exchange rates (air changes per hour-AC/hr)		
Morning	0.43	
Mid-day	0.33	
Evening	0.34	

the same basis. However, indoor air pollutants disperse throughout a house on a one hour peak and 24 hour average basis. Although the concentrations were elevated for the 24 hour average, they were still below the recommended levels.

HCHO is found in many products used by the building trades, including particle board, plywood, and adhesives. HCHO is also produced in the combustion process of gas cooking and heating, and in tobacco smoke. In concentrations above 100 micrograms per cubic meter (μg/m³), HCHO irritates eyes and the upper respiratory tract. The HCHO measurements made by Lawrence Berkeley Laboratory at an energy-efficient house in Mission Viejo, Calif. are highlighted in Figure 3. The indoor HCHO concentration did not meet health standards (the Netherlands has established a maximum level of 120 μg/m³) day or night during occupancy, or during the period of vacancy with furniture in the house. During the test the outside air HCHO level was always less than 10 μg/m³. During occupancy in the day, the air infiltration rate was about 0.4 AC/hr. While the HCHO concentration was reduced at night when windows were opened for ventilation, the HCHO concentration was still above 120 μg/m³.

These findings agree with the study headed by Moschandress of indoor air pollution in energy conserving houses (see references). The researchers evaluated indoor air pollution in 15 residential structures in five cities across the country. The air exchange rates in these houses ranged from 0.2 to 1.05. Sophisticated equipment was used to measure indoor and outdoor air pollution levels in a 14-day period. Summarizing their findings:

- Concentrations of nitrogen dioxide, total suspended particulates, and respirable suspended particulates are sometimes higher than they were outdoors;
- Concentrations of sulphur dioxide, ozone, sulfates, nitrates, and lead are often lower indoors than outdoors; and
- On the average the observed indoor air pollution concentrations were not high, but there were persistent moderate, sometimes elevated, levels in some of the monitored buildings.

This study supports the contention that various indoor air pollutants in residences with gas appliances are aggravated by measures taken to reduce air infiltration rates. Nevertheless, indoor air quality was not drastically affected for air infiltration rates between 0.4-0.6 AC/hr. Findings on specific pollutants found in the 15 residential environments are summarized below.

Carbon Monoxide. During the monitoring period, the observed levels of CO, both indoors and outdoors, were not high enough to cause a health hazard. The overwhelming majority of observed ambient levels were between 1.0 and 2.5 parts per million (ppm). In houses with no CO sources, i.e., houses with electric heating and stoves and non-smoking occupants, the long-term indoor concentration levels of CO are essentially equivalent to the corresponding outdoor levels. Houses with indoor CO sources had higher levels than the ambient.

Nitric Oxide. Generally, residences can be grouped into three categories. The first has electric cooking and heating appliances, and the indoor concentration of NO is almost always lower than the corresponding outside concentration. The house shelters occupants from NO. The second type has an electric stove and a gas space heating furnace, and NO levels are higher most of the time indoors than they are outdoors. The third type has both gas heating equipment and a gas stove, and indoor NO levels are consistently higher than outdoor levels. The indoor peaks of NO correspond with the cooking periods in most houses.

Nitrogen Dioxide. The residential structures often shelter occupants from outdoor NO_2. All-electric houses have hourly indoor concentrations, that are almost always lower than the corresponding ambient levels. Total gas residences do not offer such protection. Approximately 70 percent of the hourly values obtained for the all-gas appliance house were higher than the corresponding outdoor concentrations of NO_2.

Sulfur Dioxide. Concentrations in the monitored residences were very low. None of the indoor concentrations exceeded the national air quality standards for SO_2.

Carbon Dioxide. Levels were consistently higher indoors than the outside levels. CO_2 levels indoors are clearly a function of the number of occupants and their activity levels. Th ASHRAE 8-hour indoor level of 500 ppm is exceeded frequently in most residences.

Ozone. Indoor concentrations are lower than levels observed outdoors. Generally speaking, there are few indoor ozone sources, and the national air quality standard of .08 ppm was not frequently violated indoors.

Particulates. The ambient respirable suspended particulates level varied from 1-91 μg/m³. Corresponding indoor concentrations ranged from 1-160 μg/m³. One group of residences had consistently higher indoor levels than levels monitored outdoors. This group had children of either pre-school age or in the first or second grades, and/or occupants who smoked more than 10 cigarettes a day. However, few of the RSP concentrations measured inside exceeded the 24-hour maximum national air quality standards for respirable suspended particulates.

Figure 3. Indoor/outdoor formaldehyde and aliphatic aldehyde concentrations measured at an energy-efficient residence, August 1979.

Condition	Number of Measurements	Sampling Time	Formaldehyde (μg/m³)[a]	Aliphatic Aldehydes (μg/m³)[b]
Unoccupied, without furniture	3	12	80± 9%	90±16%
Unoccupied, with furniture	3	24	223± 7%	294± 4%
Occupied, day[c]	9	12	261±10%	277±15%
Occupied, night[d]	9	12	140±31%	178±29%

a Determined using pararosaniline method (120 μg/m³ = 100 ppb). All outside concentrations <10 μg/m³.
b Determined using MBTH method, expressed as equivalents of formaldehyde. All outside concentrations <20 μg/m³.
c Air exchange rate ≈ 0.4 AC/hr.
d Windows open part of time; air exchange rate significantly greater than 0.4 AC/hr and variable.

Water Soluable Nitrates. The indoor nitrate concentrations were lower than the corresponding outdoor levels 90 percent of the time.

Water Soluable Sulfate. Residential homes with gas cooking and heating appliances have an indoor-to-outdoor sulfate concentration ratio of .81. Sulfur is commonly added to residential gas to aid in leak detection. Although no indoor air quality standards for sulfate have been established, a daily threshold value of 8 and 10 $\mu g/m^3$ has been suggested by Colucci (see references). Ambient daily sulfate concentrations varied from 1.5-48.3 $\mu g/m^3$, while the corresponding indoor concentrations ranged from 1.0-41.0 $\mu g/m^3$.

Aldehydes. Outdoor levels were always lower than indoor levels by as much as a factor of 6 or by an order of magnitude. Indoor sources of aldehydes are chipboard, pressboard, and furniture. The highest levels by far were observed in mobile homes, and the source was the pressboard used in construction. The levels in mobile homes often exceeded 300 $\mu g/m^3$, but the majority of houses studied had levels below 200 $\mu g/m^3$ and some below 120 $\mu g/m^3$.

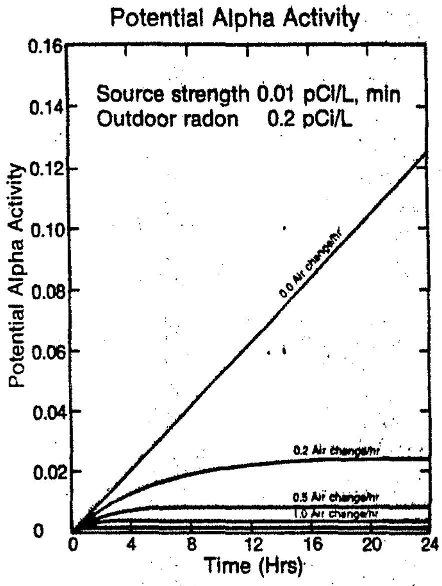
Lead. Levels between 0.1 and 2.8 $\mu g/m^3$ were detected. California has a 30-day level average of 1.5 $\mu g/m^3$. This level was found in only a few cases for the test houses during the monitoring period.

Asbestos. No fibers of the six asbestos types were found during the test period.

Radon and Daughter Products. Radon 222 is a gas found in the atmosphere. It is the decay product of radium. Radium is found naturally in soil, masonry materials, and groundwater. Radon can be absorbed by solids and dissolved in water. Radon and its daughter products are short-lived. However, they are alpha particle emitters. If they are inhaled, lung tissue can be damaged. Because the daughter products are solids, they are suspected to attach themselves to dust particles due to their atomic charge. Kusuda et. al. (see references) have generated a model that compares indoor radon concentrations to air infiltration rates for residences given typical levels of outdoor air radon concentrations and total indoor radon/daughter products source strengths (Figure 4). Residences with air infiltration rates between 0.5 and 1.0 AC/hr have approximately the same level of alpha particle activity under these conditions. Houses with lower air infiltration rates (0.2 AC/hr) can have concentrations several times higher than conventionally built residences. Unfortunately, long-term low level exposure standards have not been established.

If the assumption can be made that the outside air quality is safe, then a clear solution is to ventilate the house at a rate that maintains low indoor pollutant concentrations. A consensus seems to be developing in the building industry that an air infiltration rate of 0.5 AC/hr can keep air pollutants below critical levels in residences.

Figure 4. Comparison model of indoor radon concentrations and air infiltration rates for residences given typical levels of outdoor air radon concentrations and total indoor radon/daughter products source strengths.



Solution: Air-to-Air Heat Exchangers

Energy conservation measures in well-insulated buildings can be maintained if a simple air-to-air heat exchanger is added to the ventilation system. Approximately 70 percent of the sensible heat content can be recovered through these units. Several manufacturers have products on the market. The following is a sampling of what is available.

Mitsubishi Electric Industrial Products makes the Lossnay air-to-air heat exchanger, which is marketed through **Melco Sales, Inc., 3030 East Victoria St., Compton, Calif. 90221 (213) 537-7132.** This unit exchanges both sensible and latent heat through a paper heat exchanger. It should be noted that various gases can be transmitted through this heat exchanger from the exhaust to the incoming air. Carbon monoxide, carbon dioxide, hydrogen sulfide, ammonia, and smoke can be transmitted.

FLAKT of Sweden markets the REXOVENT heat recovery ventilation system for residences. This system includes a kitchen range hood, bathroom vents, and central heat exchanger to take up exhaust air from typical source locations of indoor air pollution. Heat is exchanged to the incoming air supply, then distributed to the living room and bedroom areas of the house. **FLAKT Products, Inc.,** is located at **3339 Southwest 13th Ave., P.O. Box 21500, Fort Lauderdale, Fla. 33335 (305) 524-6521.**

Des Champs Labs, Inc., P.O. Box 348, East Hanover, N.J. 07936 (201) 884-1460, makes a residential air-to-air heat exchanger called the Z-Duct. This is a sensible heat exchanger that can be mounted in the attic or basement.

Q-Dot Corp., 151 Regal Row, Dallas, Texas 75247 (214) 630-1224 manufactures a residential heat pipe exchanger system.

Additionally, for houses with forced hot air systems or heat pumps, an electronic air cleaner can be added to the ventilation system to remove any dust or particulate matter from the ambient air. The size of particles in residences range from .001 to 100 μm. Electronic air cleaners are capable of removing particles as small as .01 μm. They are substantially better at removing debris than are panel filters found on most residential forced air heating systems. A combination of air-to-air heat exchanger with an electronic air cleaner could eliminate the current confusion and worry over the long-term health effects of elevated levels of indoor air pollutants. This equipment seems to represent a middle ground between adequate energy conservation and good air quality levels in residences.

References

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