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CLEAN AND ECONOMICAL AIR IN HOUSES

BY DAVID T. HARRJE

BY BETTER UNDERSTANDING AND EXPLOITING THE RELATIONSHIP between envelope tightness and mechanical ventilation, architects and builders can improve the quality of air in houses (and office buildings) and optimize energy performance at the same time.

The first myth to overcome is that tightening the envelope of new or existing houses automatically degrades air quality. On the contrary, tightening the envelope—that is, limiting conduction and air losses through better insulation, air/vapor barriers, and seals at windows or doors—not only seals out pollutants, but permits pressure distribution and airflow within the structure to be optimized.

Following are the four primary strategies that can improve air quality and energy performance. Two provide a tighter envelope; the other two explain how more-efficient mechanical equipment can be employed. Each of these strategies can be utilized for new construction and often, in whole or in part, for retrofits to existing houses.

■ *Superinsulation.* Superinsulated houses incorporate walls, ceilings, and floors with high values of thermal resistance. Many of these houses show savings in heating energy of 70 percent or more. R-values of walls normally exceed R-25 and may be as much as R-40. Ceilings are insulated from between R-35 to R-65. Exterior surfaces, however, must be designed and constructed to avoid thermal bridging. Vapor and wind retarders are important parts of the envelope, and successful designs demonstrate special attention to the vapor/air barrier so that penetrations from piping and electrical wiring are eliminated. The result is a tighter building envelope, which means less air infiltration.

■ *High-performance furnace/boiler.* High-performance fossil-fuel furnaces or boilers save energy. New condensing units attain annual performance levels (AFUE—Annual Fuel Utilization Efficiency) of greater than 90 percent. Many older heating systems have seasonal efficiencies of less than 70 percent AFUE. From the standpoint of the building envelope, an added benefit of the newer high-performance heating units is that their high-efficiency combustion devices use a dedicated outside air supply and local exhaust. This closed-air system, with its low-temperature exhaust, dispenses with conventional chimneys and associated air-infiltration loss.

Heating units, thanks to superinsulation, can be smaller. And often, a high-efficiency heat pump, which requires no chimney at all, can be substituted.

■ *Window systems.* Low-energy-loss windows are the third leg in an air-quality strategy. Casement or awning types, which squeeze their seals, and double-hung or slider-window designs, with improved seals, work best. The seal around the total window system (the frame) is often as important as the window itself. Once tight frames are assured, several new options exist for improving the insulation performance of the glass itself, including heat-reflecting (low-emissivity) coatings on the glass, or coatings applied to polyester films suspended midway between the two panes of glass (resulting in improved insulating values because of the double air space).

■ *Controlled mechanical ventilation.* Few houses built recently permit enough outside air to infiltrate inside to meet the minimum rate of 10 cubic feet per minute (CFM) per room that ASHRAE specifies in its Standard 62-1981, let alone the 15 CFM recommended in the standard's revision (62-1981P). But increased tightness of the building envelope can actually help mechanical equipment work better in meeting these rates. Heat recovery using air-to-air heat exchangers requires tight buildings for efficient operation. Leaks in the envelope divert airflow from the central heat exchanger and defeat the energy-recovery process. When the envelope is properly tightened and the system is properly balanced, a heat-exchanger system can keep actual ventilation values very close to design goals—without fluctuation caused by wind- or stack-driven infiltration. With one of the more efficient heat exchangers, which can recover up to 70 percent of the exhaust heat or air conditioning, increased costs for mechanical ventilation moderate appreciably.

POLLUTION SOURCES

Efficient mechanical ventilation is clearly necessary to obtain acceptable indoor air quality. A better approach, however, is to keep pollutants out of the living space to begin with. Pollutants that are generated in specific areas should be removed using local exhaust. Diluting pollutants with ventilation air cannot mitigate high-strength sources such as radon (which is present in many soils) without imposing severe energy penalties. Every effort must be made to limit materials within the living space that degrade air quality such as certain chip boards, paneling, and furniture that off-gasses formaldehyde. Knowing how houses function under natural ventilation conditions is important in controlling sources. As illustrated in the drawing on page 35, and emphasized in ASHRAE's *Handbook of Fundamentals*, air tends to enter houses near ground level and exit near the roof. Pollutants introduced around the house perimeter, such as pesticides, termiticides, herbicides, and fertilizers, can very likely infiltrate indoors. Paint thinners and other volatile organics, including hobby-related materials, can vaporize into the air because of imperfect seals on their containers. For this reason, such chemicals should be stored away from the living space.

Another connection between the living space and pollution sources often taken for granted is the wall for an attached garage. Seals on the door from the house to the garage frequently are inferior to seals used on other exterior doors. Often, the level of wall insulation and weather treatment is lower than on other exterior surfaces. Ducts may be routed through garage spaces—as if the garage were an internal space. Each of these design/construction shortcomings can waste energy and degrade indoor air quality. A leaky envelope permits air laden with auto fumes, gasoline vapors, and volatiles from

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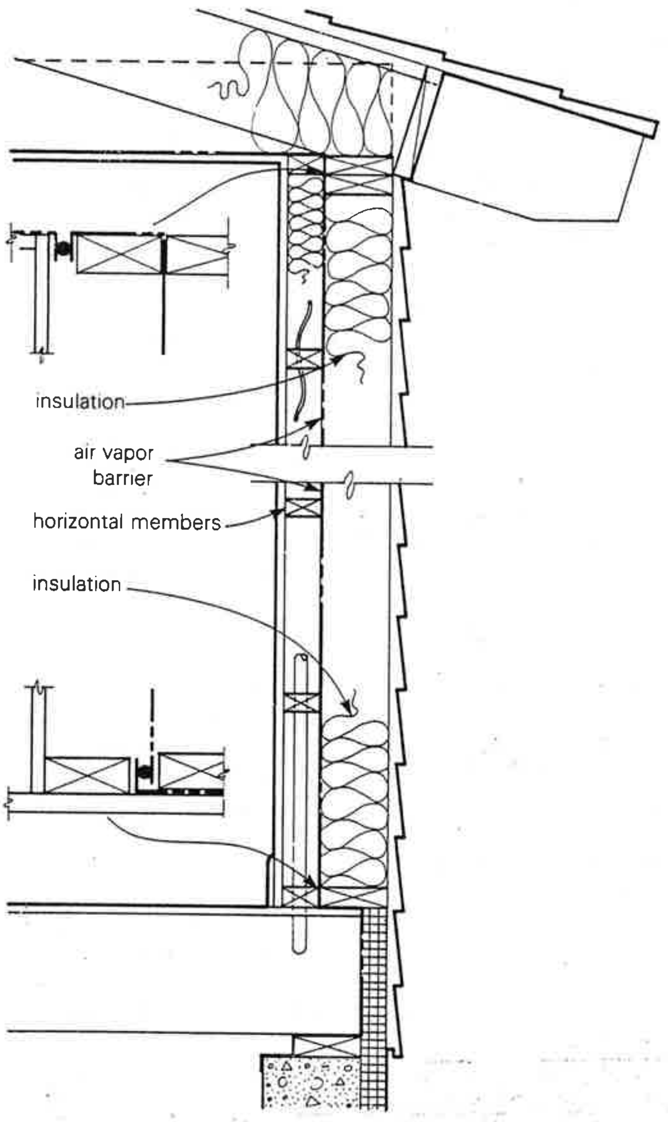
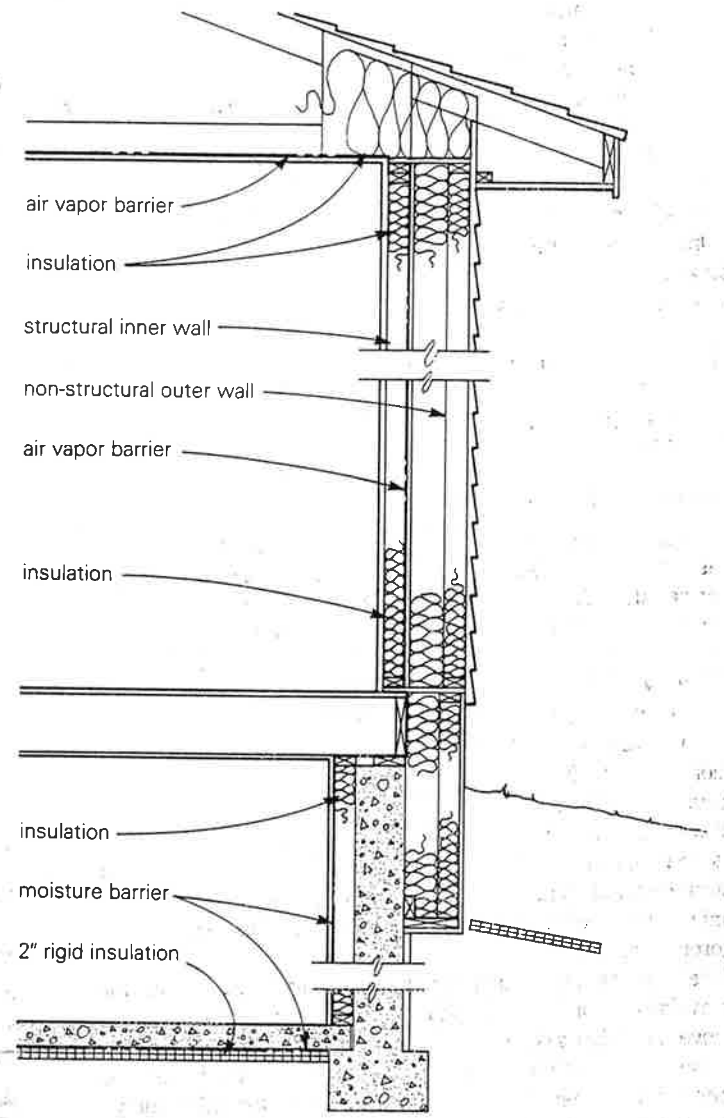
Basement cracks are where most radon enters homes



Strapped wall.

Horizontal members nailed onto the inside of a conventionally framed stud wall create a deeper, strapped wall in which up to 3½ inches of extra insulation can be placed. Locating the air/vapor barrier between the strapping and the studs simplifies installation of piping and electrical wiring, lessens the necessity of penetrating the barrier, and reduces the potential for damage from careless workers. Seams in the barrier fall adjacent to the horizontal straps. Terminations occur at the top and bottom plates of the wall. The barrier is also sealed to horizontal barriers in the ceiling and floor for continuity.



Saskatchewan-type double wall.

This double wall, employed in houses built under Canada's R-2000 Super Energy-Efficient Home Program, utilizes an inner load-bearing wall and an outer non-load-bearing wall separated by a 5½-inch-space that is filled with 6-inch nominal fiberglass batt insulation. Insulation placed within the framing brings the total R-value of the wall section to R-41. Note the placement of the air/vapor barrier, a 6-mil polyethylene sheet, on the outside surface of the inner wall. Canadian researchers say that no moisture problems will occur as long as the insulation on the cold side of the barrier has twice the R-value of the insulation located on the vapor barrier's warmer side.

other stored substances in the garage to move indoors easily. Leaks in the ducts passing through the garage can pressurize the garage and force pollutants into the living space (through the envelope openings just mentioned) or, if the leak is on the return side of the forced-air system, draw pollutants into the duct and circulate them indoors. The recommended design approach is to avoid running ducts through the garage and to treat seals and other envelope components of the garage wall with at least the same care given components of an exterior wall. Occupants can help too, by allowing auto exhaust to vent before closing garage doors and storing toxic substances in an outdoor shed.

One way pollutants can be removed from various zones of the house is to take advantage of the natural tendency for cold air to rise in a house when it is heated—the "stack effect." But although such passive systems may prove successful during part of the year, they are difficult to design well. Variations in climate render interior stack exhaust ineffective much of the time; mechanical ventilation would still be necessary, particularly in high-pollutant areas such as kitchens and bathrooms.

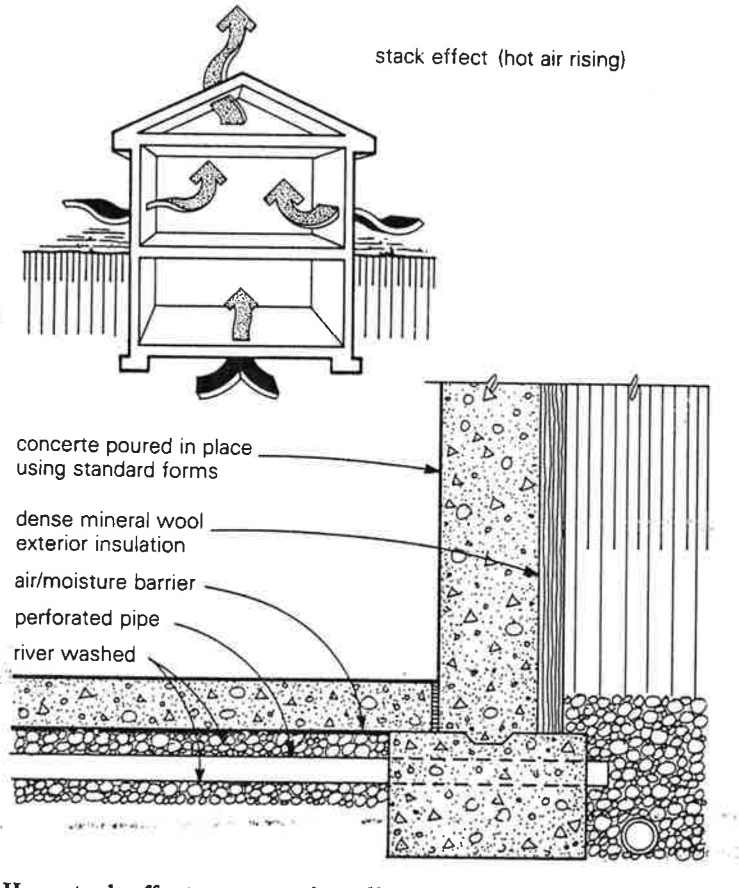
Radon and its progeny

Radon gas decays into radioactive progeny that build up in concentrations within the home and have a definite negative health impact (the alpha radiation they emit has been linked to lung cancer). Although the radon concentration level below which no remedial action is deemed necessary is still being debated, preliminary national surveys show that millions of homes have concentrations that exceed even liberal limits. (ASHRAE Standard 62-1981 recommended 0.01 working levels or 2 picocuries per liter, but more recent recommendations from the National Council on Radiation Protection and Measurements places these values at 0.04 working levels or 8 picocuries per liter.) The best way to control the radioactive progeny is to limit or stop radon gas from entering a structure. Previous tests have indicated that in some areas high concentrations of radon can dominate a house's atmosphere and reduce the effectiveness of even vigorous mechanical ventilation.

The best solution eliminates building materials that contain radon and avoids fans or other equipment that must run constantly to remove the radon gas.

In some areas of the country, radon enters houses through the water supply. In general, though, the main path for radon entry is through cracks and other openings in basement/crawl-space walls or the slab. If even minor cracks form, radon-reduction efforts can prove futile. Furthermore, houses are dynamic in the sense that minor movement takes place throughout the year. Walls of masonry block or even poured concrete (if not properly reinforced) can develop cracks that are difficult to seal. Unless the sealant is able to flex with the seasons, and even has the attribute of being self-healing (whereby the sealant "heals" itself by flowing into cracks or splits that develop), new cracks or splits may quickly reappear. Sealants that can assure tight, monolithic basement/crawl-space envelopes are being developed for this retrofit challenge, but first, every effort should be made to avoid the problem to begin with.

Floors and foundation walls constructed of reinforced concrete (made of materials themselves free of radon) instead of hollow-block are a good way to minimize radon entry while controlling energy losses. Hollow-block construction offers an easy path for radon (and cold air) to move into a house and presents difficult challenges for mitigation. Radon-impermeable construction employing poured concrete begins with wire mesh, which helps reduce or eliminate cracks, especially when the mesh is correctly placed in corners and junctures between wall and slab. A low-permeability membrane beneath the slab further discourages soil gas containing radon from infiltrating the slab. A layer of round river-washed gravel beneath the membrane permits the soil gas under the foundation to move more freely to the perimeter, where it can escape, while also protecting the membrane from puncture. Obviously, the membrane must be tough enough to resist tears that may occur during the placement of



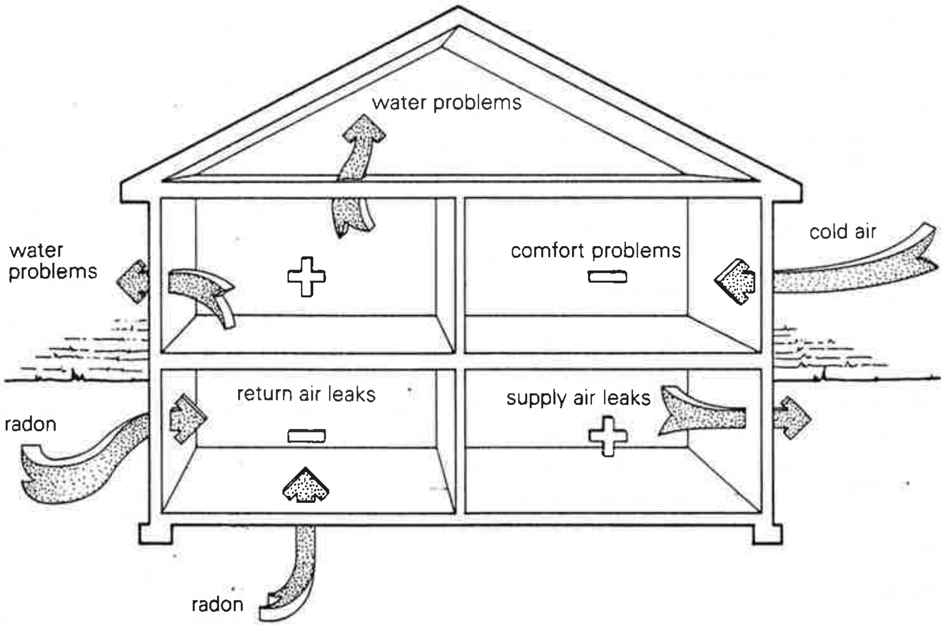
How stack effect can entrain pollutants.

Pollutants common around house foundations, including radon, insecticides, termiticides, and fertilizers, can be entrained in air and drawn into some foundations by the stack effect. Though more expensive than many other constructions, the monolithic foundation shown above offers energy efficiency and imperviousness to water and the variety of contaminants found around foundations, especially radon. The perforated pipe and the river-washed gravel vent soil gases to the atmosphere. If need be, blowers installed at the ends of the pipe can draw gases out at advanced flow rates.

Careful HVAC balancing can direct contaminants back outside

Balancing duct systems.

A tight building envelope not only reduces infiltration of air into and out of a house, saving energy, but permits simpler balancing of mechanical ventilation systems to optimize air movement through a house. In a poorly balanced system, shown here, positive pressure in living spaces can create moisture problems by forcing air into wall systems and attics. Basements or crawl spaces under negative pressure can draw contaminants in soils, such as radon, into the house. Reversing the pressures can reduce radon-gas influx. A negative pressure in the living space could produce cold drafts and comfort problems, but the tight building envelope, which is a main design goal, would merely act to improve ventilation effectiveness.



the reinforcing mesh, the pouring of concrete, or from general foot traffic during construction. Lengths of perforated pipe installed within the gravel bed further assure free movement of gas under the entire poured concrete floor. The ends of these pipes should extend just beyond the perimeter of the foundation.

A layer of dense mineral wool placed on the exterior walls of the basement/crawlspace enhances the mitigation strategy by performing three functions: It provides the desired high level of insulation, diverts water to the gravel bed, and relieves soil-gas pressure so that soil gas can move freely to the outside atmosphere. Further, the insulation's placement on the outside of the wall allows the thermal mass of the concrete to store heat and moderate interior temperatures, assuring among other things that plumbing in the basement or crawlspace does not freeze. Additional insulation beneath the foundation and floor may prove desirable in northern locations, where soil temperatures cause significant heat loss through the floor in winter (especially near the perimeter).

Added value

Costs are not excessive for this foundation design. In some areas of the country, because costs are basically the same, it is already routine to pour walls of concrete rather than build them with blocks. Moreover, at the same time the procedure mitigates the radon-entry problem, it can help eliminate water problems. Further, if radon levels cannot be held within guidelines by this strategy alone (such as in houses built on the Reading Prong, a land formation rich in radium that runs from Pennsylvania through New Jersey and New York), an exterior blower could be installed at one end of the perforated pipe to exhaust the radon-rich soil gas from the gravel bed. This procedure maintains the subslab at slightly negative pressure so that any air movement through cracks in the slab would be from inside to outside. Subslab depressurization has proved successful in reducing radon concentrations in existing houses where sumps or drains within the house are used to access the gravel bed. The presence of the perforated pipe also allows tracer gas to be injected beneath the foundation to check for leaks in the slab—in one final effort to avoid an interior blower, which wastes energy.

Operation of an air-duct system inside the house directly influences both energy use and air quality. More often than not, the influence is negative. System imbalance can lead to pressurization in some zones and depressurization in others. Pressurization in the living space may force moisture-laden air into wall systems and attics. A basement/crawlspace area under negative pressure can cause radon and other soil pollutants to flow into that zone. If the pressures are reversed, increased pressure in the basement can reduce radon-gas influx. In the living space, negative pressures encourage air drafts and comfort problems, but this effect can be cured by providing a tight building envelope. For an effective system, appropriately designed supply- and return-air paths must be provided so that pressures and ventilation rates can be balanced in all rooms.

By maximizing the air-mixing and circulation characteristics of the duct system, the entire volume of air in a house is utilized and helps assure that no one pollutant builds up in any area. An example is the bedroom, where carbon dioxide (exhaled by sleepers) may accumulate during the night if natural infiltration fails to provide the necessary ventilation.

Operation of the central blower, even on a periodic basis, can help make the air in the total house volume available to its occupants. In this mixing process, temperature uniformity is also enhanced. This means improved comfort and relief of cold (or hot) room conditions, which is one of the main reasons people open a window—and then wonder where their energy savings go. ■