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SOME RESIDENTIAL ANSWERS

Despite fears to the contrary, residential buildings can be made energy efficient without sacrificing the quality of the indoor air

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HOW MANY TIMES has it been said that tightening the building envelope of new or existing homes automatically means degradation of the indoor air quality? In many instances this is not what takes place, especially if tightening keeps out sources of pollution by sealing air leakage sites in the building envelope or by altering the pressure distribution within the building.

Listed in *Table 1* are major design and construction actions that can be taken in our houses to limit conduction losses, increase heating performance, reduce energy losses through windows, and provide adequate ventilation air. These actions are highly recommended for new construction, and often can be applied, at least in part, as retrofits to existing houses.

Superinsulation: Superinsulated houses, as the name implies, incorporate walls, ceilings and floors with high values of thermal resistance as a central design feature. Many of these houses have shown savings in heating energy of 70 percent or more[2]. The superinsulation R-values of walls are normally more than 25 (R-25 to R-40) and ceilings are built to R-35 to R-65.[2] Each exterior surface is well designed to avoid thermal bridging. Associated with this high R-value envelope are vapor and wind retarders, and extra attention to penetrations such as piping and electrical wiring. The net effect is a tighter building envelope, and a lower air infiltration rate.

High Performance Furnace/Boiler: Use of high performance fossil fuel furnaces or boilers is another way to save energy. Annual performance levels (AFUE) of greater than 90 percent are no[t] uncommon with the new condensin[g] units, contrasted to seasonal efficiencie[s] of less than 70 percent AFUE for man[y] of the older heating systems[3]. The add[i]tional benefit, from a building envelop[e] standpoint, is that many of these high per[formance] combustion devices use [a] dedicated outside air supply with a loca[l]

TABLE 1

Major design actions to save energy and their influences on air quality and building tightness

Design Action	Energy	IAQ	Building Tightness
Super Insulation	X		X
High Performance Furnace or Boiler	X	X	X
High Performance Windows	X		X
Controlled Ventilation	?	X	Needed

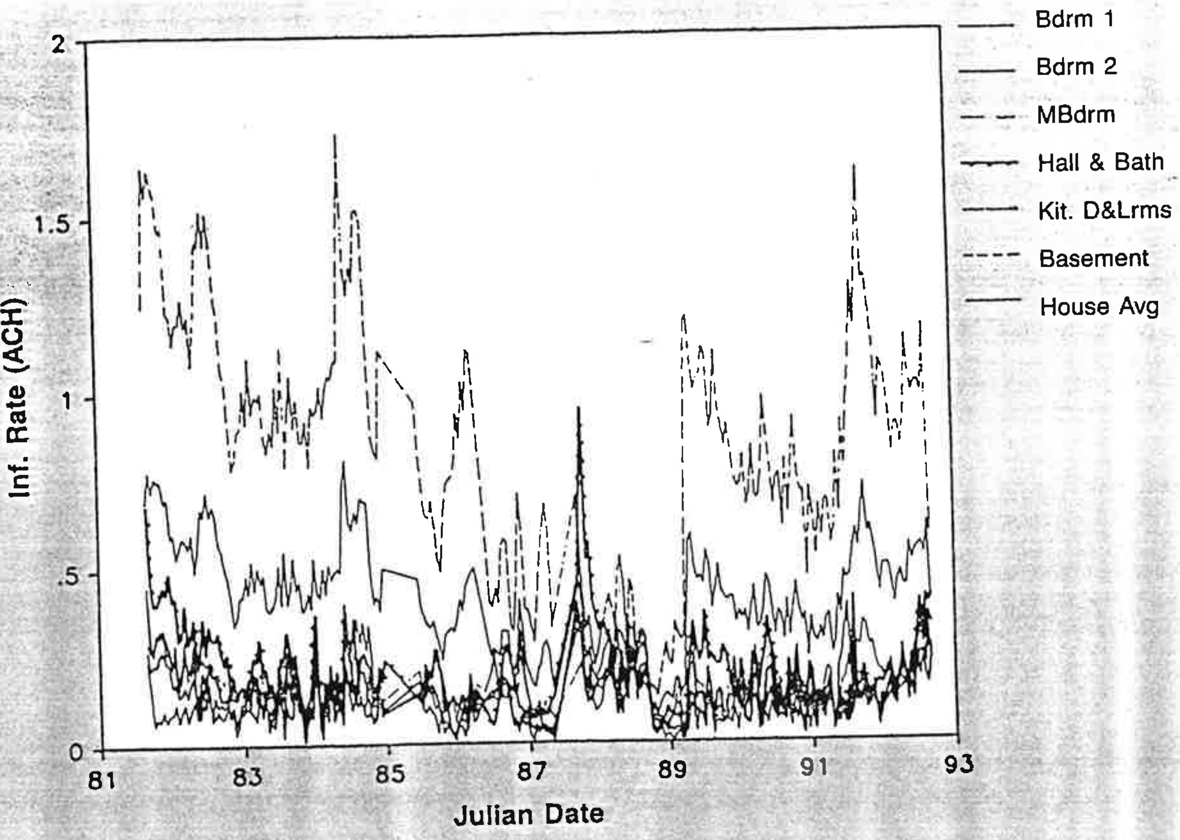

Figure 1—Detailed time history of the air exchanger rate in six zones of a bilevel house using a constant concentration tracer gas system

exhaust. With this "closed air system" and a low temperature exhaust, use of a conventional chimney is unnecessary. The air infiltration loss associated with the chimney is thereby eliminated. The indoor air quality (IAQ) box is also checked in *Table 1*, since no back drafting, with exhaust spillage of pollutants into the house, can take place with these designs.

The lower energy requirements, which result from the use of superinsulation, means that heating units can require a much smaller output. Electrical heating, e.g., using a high efficiency heat pump, is another choice for supplying the reduced heating needs and naturally requires no chimney, and hence also results in a tighter building envelope.

Window Systems: Low energy loss windows (and doors) are another logical choice for energy efficient house designs (or as a retrofit to existing housing, where the present windows require more than storm windows to achieve energy goals). Associated with better windows are better seals, providing another check in the building tightness column of *Table 1*. The sealing improvement can result from window choices such as casement of awning types, which squeeze the seals[4], or from improved sliding seals on double-hung and slider window designs. Concern for sealing around the window is often as important as the window choice itself[5], and must be part of the "total house design".

Controlled Ventilation: The last item in *Table 1* is controlled ventilation. The question mark in the energy column is because the desired values chosen for controlled ventilation are often higher than the values we live with in today's homes. *Figure 1* illustrates the ventilation variability that air infiltration dependent ventilation provides to a house[6]. These measurements employed the latest constant concentration, tracer gas equipment to evaluate individual rooms in this bilevel home.

The individual room rates are shown to fall below 0.1 of an air change per hour (ACH), i.e., of the order of 2 cfm, 20 percent of the 10 cfm per room rate specified in ASHRAE Standard 62-1981, *Ventilation for Acceptable Indoor Air Quality*[7]. Therefore, if we increase the ventilation rate to the 0.35 - 0.50 ACH, currently considered to be appropriate air exchange rates, the energy levels will actually increase substantially during some portions of the year[7].

If improved ventilation rates are desired, then the increased building envelope tightness associated with each of the energy saving improvements listed in *Table 1* is of great help in achieving that goal. Heat recovery using air-to-air heat exchangers requires tight buildings for efficient operation, otherwise envelope leaks divert air flow from the central heat exchanger and defeats the energy level recovery process[2,8]. The recovery of 70 percent of the exhaust heat (or air conditioning) in the more efficient air-to-air exchanger designs (as well as moisture recovery in certain designs) can make up for the associated increased ventilation rates.

The benefits of controlled ventilation are very evident when the high energy use periods occur during the year. A well designed air-to-air heat exchanger, in a house with a tight building envelope, will keep the ventilation rate from exceeding desired ventilation values during those times when wind- and stack-driven air infiltration would normally cause excessive ventilation rates[9].

One alternative method to achieve the desired ventilation rates makes use of controlled exhaust ventilation with the addition of heat recovery via a small heat pump in the exhaust. The recovered energy is applied to domestic water heating. This approach is becoming very popular in Scandinavia[10], and since ventilation is a year-round need, as is the heating of domestic hot water, the needs balance and high efficiency is achieved.

Indoor air quality

Ventilation and building tightness clearly are important in obtaining acceptable indoor air quality, but overriding these conditions is the question of sources of pollutants in the home. Source control is the first line of defense. Keeping the sources out of the living space, or using local exhausts to immediately remove the pollutants if they are generated within the space[7], are the preferred approaches. Dilution of the pollutants with ventilation air cannot take care of high source strengths, such as in radon-plagued houses, except at a high energy penalty. Every effort must be made to limit the use of materials within the living space that degrade the indoor air quality. One example is materials that outgas formaldehyde such as certain chip boards, paneling and furniture.

A knowledge of how the house functions under natural ventilation conditions is important to source control efforts. As illustrated in *Figure 2*, and emphasized in the *ASHRAE Handbook of Fundamentals* Chapter 22, air tends to enter our homes near ground level, and leaves the house near the roof during the heating season when the stack effect is dominant. Considering outdoor pollutant sources, this means the area immediately surrounding the house is critical. Use of pesticides, termite controls, herbicides and fertilizers around the house perimeter can prove to be the first step in introducing these contaminants into the indoor environment. Storage of such chemicals should be remote from the living space.

In addition, paint thinners and other volatile organics, including hobby-related materials, vaporize into the air because of non-perfect seals on their containers[1]. For this reason, care should be also exercised as to where these materials are stored. The precautions do have minor energy implications in that remote storage can free interior areas for other activities.

Figure 3 points out another connection between the living space and pollution sources. The attached garage is often treated differently, from an energy loss standpoint, than other exterior areas. Seals on the door from the house to the garage often aren't of the same quality as those of other exterior doors. The wall insulation level and weather treatment may also be inferior to other exterior surfaces. Ducting may pass through the garage space, treating the garage as internal space.

Each of these design/construction shortcomings can adversely impact

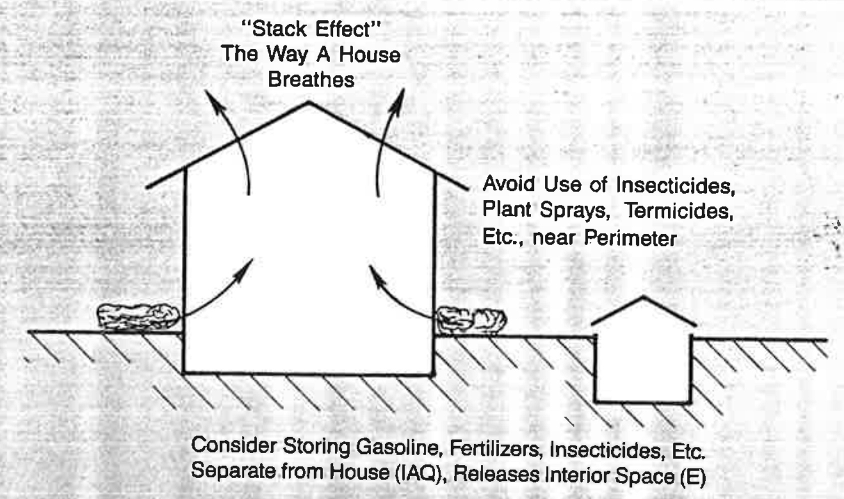

Figure 2—Influence of stack effect flow on entraining pollutants

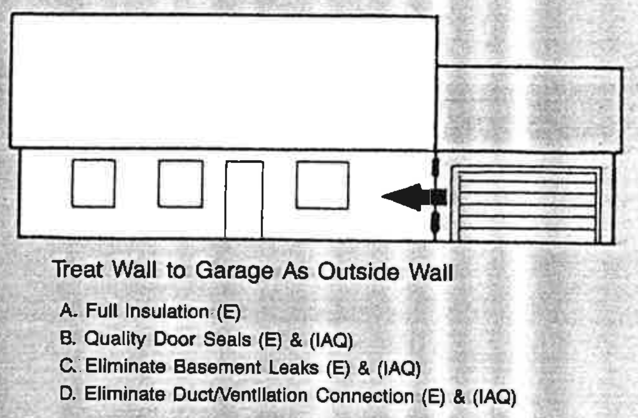

Figure 3—Pollution involvement with the garage

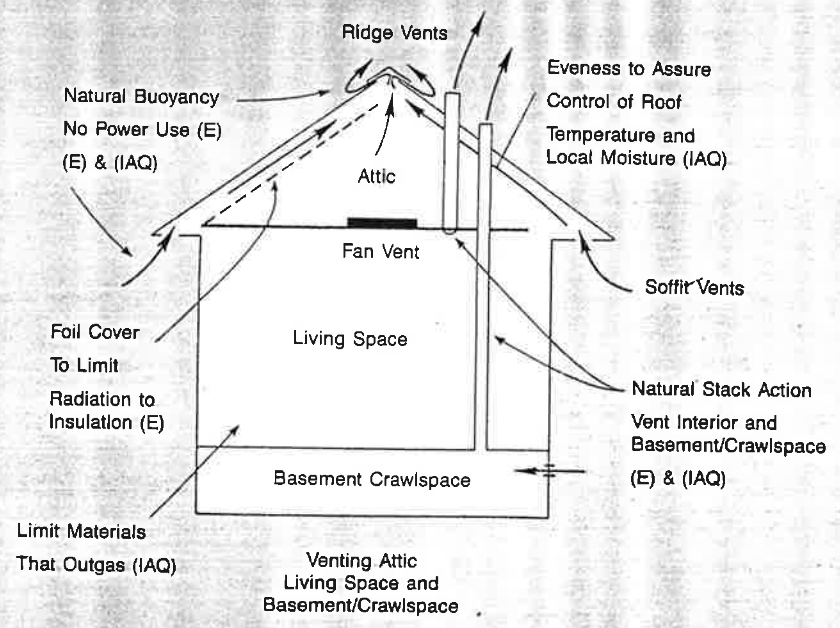

Figure 4—Removal of pollutants can be aided by natural stack flow

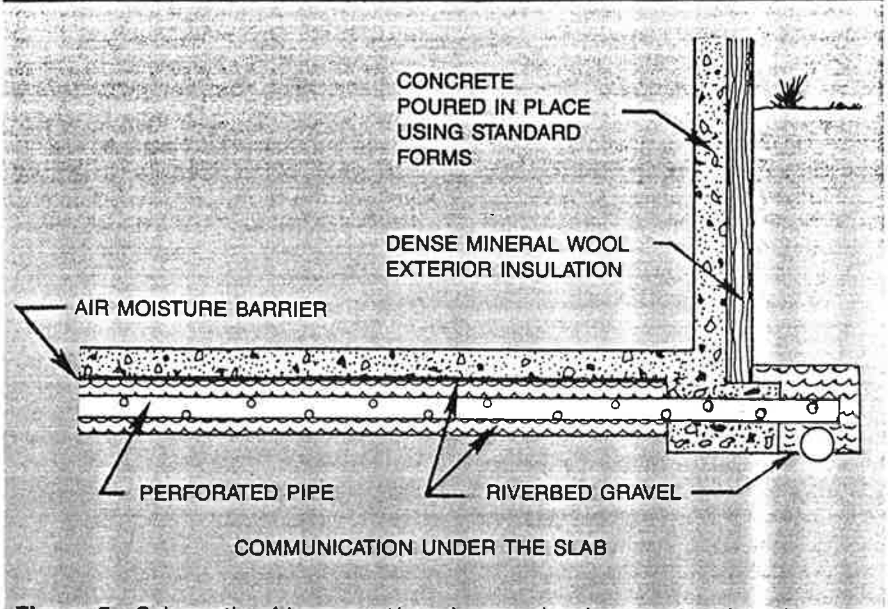

Figure 5—Schematic of basement/crawlspace showing construction elements

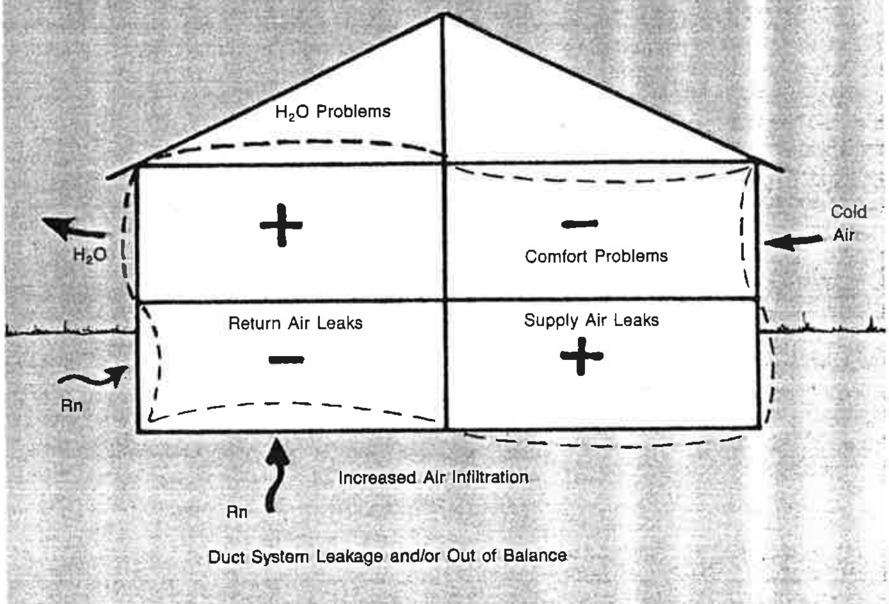

Figure 6—The balance of air ducting and ventilation influences pollutant levels in the house

energy loss. Each can degrade indoor air quality. Any relaxation in the treatment of envelope tightness means that air can move more readily through the envelope, carrying with it auto fumes, gasoline vapors, plus volatiles from other stored substances in the garage.

In addition, leakage in the duct work passing through the garage area can either pressurize the garage, forcing 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, the pollutants will be drawn directly into the living space[12]. The design approach is to avoid all ducting in this often polluted area, and to treat the seals and other envelope components with at least the same respect as any exterior wall. Allowing auto exhaust to vent prior to garage door closure, and avoiding toxic substance storage in this zone of the house are highly recommended.

Removal of pollutants from various zones of the house can be aided by natural stack flow. Examples are shown in *Figure 4* where the air passing through the vertical stack is heated by the living space causing it to exhaust to the outside. Placing openings at the ceiling level will mean exhaust of warm house air during the heating season. Passive controls of attic air involves soffit vents and ridge vents with the possible addition of foil covers to channel flow and/or limit radiation heat transfer. While such passive systems may prove successful part of the year, our varied climate also would predict that interior stack exhausts will be ineffective under other weather conditions and therefore critical areas such as kitchens and bathrooms should have mechanical ventilation available when needed.

The radon concern

Unfortunately, one needs to be concerned with more than man-produced pollution. Radon gas is one component of soil gas and is an environmental factor that must be dealt with. Radon gas decays into radioactive progeny that build up in concentrations within the home and have a definite negative health impact[1]. Although the radon concentration level below which no remedial action is deemed necessary is still being debated (ASHRAE 62-1981 recommended 0.01 working levels or two pico Curies per liter[7], but more recent recommendations from the National Council on Radiation Protection and Measurements, NCRP, places these values at 0.04WL or 8 pCi/L)[13], it is clear from the preliminary national surveys that millions of homes exceed these limits[1].

The best way to control the radioactive radon progeny (which emit alpha radiation that is linked to lung cancer) is to limit or eliminate the radon gas from entering the structure. Previous tests have pointed out that source strength of the radon dominates the individual house situation, and that in high radon locations ventilation rates of individual homes are only a secondary factor[13,14].

To provide the house with the best design features, one would wish to: limit any radon or other soil pollutants[15] penetration, try to avoid solutions that require long-term energy expenditure (e.g., fans that must run constantly to remove the radon gas), and not compromise the energy use in the house. One source of radon entry is in the water supply in some areas of the country. Equipment to remove such radon is commercially available.

The most prevalent source of radon gas, however, is via entry of soil gas through cracks and other openings in the basement, crawlspace or slab. The conventional wisdom for prevention is to seal all cracks in these areas. Unfortunately, this is easier said than done. Experience has shown that missing even minor cracks in the sealing process compromises the entire radon reduction effort.

Furthermore, houses are dynamic in the sense that minor movement takes place throughout the year. Unless the sealant adheres perfectly to the concrete floor or walls, is able to flex with the seasons and even has the attribute of being self-healing, new cracks will quickly reappear. Sealants that can meet these needs are being developed for this retrofit challenge, but first every effort to avoid the problem should be made in our new housing stock. One point that should not be overlooked is that sealing air leakage sites in the building envelope alters the pressure distribution within the house. This can result in less tendency to draw in radon soild gas by reducing the stack effect.

Stopping radon entry

Figure 5 points out a suggested design approach to avoid radon entry into the house, and at the same time control energy losses in basements and crawlspaces. First, floor and wall constructions are recommended to be poured concrete. Hollow block wall construction offers an easy path for radon to move into the building structure, and presents a difficult challenge to possible retrofit solutions should radon problems be encountered.

To avoid future cracks in the concrete, wire mesh should be part of the concrete design. Wire mesh should also bridge the corners between walls and floor. Beneath the floor is a low perm membrane to further discourage soil gas containing radon from proceeding into the building. Beneath the membrane is a gravel layer using riverbed gravel, if possible. The round riverbed gravel allows for freer movement of the soil gas under the foundation, as well as offering a friendly environment to the air/vapor retarder (no sharp edges to penetrate the membrane as with other types of gravel).

Within the gravel bed are lengths of perforated pipe to further assure free soil gas movement under the entire poured concrete floor. The ends of these pipes are just beyond the perimeter of the foundation. On the exterior of the walls of the basement/crawlspace a layer of dense mineral wool is suggested. This material performs three functions. It provides the desired high level of insulation, while diverting any water (approaching the walls) down to the gravel bed. It also can perform the function of relieving any soil gas pressure so that soil gas can move freely to the outside atmosphere.

Costs are not excessive for this basement/crawlspace design approach. In some areas of the country, it is already routine to pour walls of concrete, rather than stack blocks, because costs are basically the same. The procedure also directs itself to avoiding water problems in the basement/crawlspace area, at the same time it attacks the radon entry problem.

The use of exterior insulation retains the thermal storage aspect of the concrete mass, and places the insulation such that basement/crawlspace plumbing is at interior temperatures (contrasted with living space floor insulation which causes basement/crawlspace temperatures to drop, resulting in possible pipe freezing problems). Further insulation beneath the foundation and floor may prove desirable in northern locations where soil temperatures cause significant heat loss through the floor (especially near the perimeter).

The design lends itself to a "fall back" position. If radon levels have not been controlled to concentrations less than the guidelines, then an exterior blower can be installed at the end of the perforated pipe(s) to remove the radon-rich soil gas from the gravel bed. This procedure maintains the subslab at slightly negative pressures. Any air leaks through the slab are from the living space or basement/crawlspace. Subslab depressurization has proved very successful in reducing the radon concentrations in existing homes where sump or drains within the house are used to access the gravel bed. The presence of the perforated piping also allows one to introduce a tracer gas to check for leaks in the slab in one final effort to avoid the blower solution that involves long-term energy expenditure.

System imbalance

Moving to the interior of the house, air duct system operation can directly influence both energy use and indoor air quality. System imbalance can lead to pressurization in some zones and depressurization in others, as shown in *Figure 6*. The case of the garage ducting was mentioned previously. But as the figure points out, pressurization in the living space can mean forcing moisture laden air into wall systems and attic, while at the same time depressurization in the basement/crawlspace area encourages higher 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 cold air drafts and comfort problems, but this can be cured by providing a tight building envelope. Balance in the system includes appropriately designed supplies and return paths[12] so that pressures can be balanced in the various rooms, and that all rooms in the house are suitably ventilated so that indoor air quality can be achieved.

The use of the air mixing and circulation characteristics of the duct system can also have a positive influence by making certain that the pollutants are not allowed to build up in one limited zone in the house, but rather makes use of the entire house volume. One example is the bedroom area where carbon dioxide will build up during the night if natural infiltration fails to provide the desired ventilation rate; e.g., see the bedroom air exchange rates in *Figure 1*. Operation of the central blower, even on a periodic basis, can be used to make the air in the total house volume available to the occupants. In this mixing process, temperature uniformity is also enhanced. This means improved comfort and relief of cold (or hot) room conditions which often results in windows being opened, with resultant energy loss.

Conclusions

Energy conservation measures can compliment the achievement of improved indoor air quality in our homes. The major energy savings measures to limit conduction losses, increase heating performance and reduce losses through windows all have an improved building tightness component. When controlled ventilation is desired, it is essential that the building possess a very tight envelope, and therefore air exchange rates on the order of 1.5 ACH at 0.2 inches of water are desired[16]. Thus the energy saving actions directly couple with the provisions for controlled ventilation in the home.

In order to deal with many of the indoor air quality problems a knowledge of how the building functions is essential. Making use of local exhaust in those areas where pollutants are generated and minimizing intrusion of the pollutant sources into the living space are the best ways to proceed. Source control must always be the first priority, with ventilation dilution the next method to use.

Improved occupant safety and comfort goals can be met with good engineering of our residences. From the initial design phase of a new home, care must be taken to consider reducing all pathways of pollutants into the living space. With radon soil gas this means emphasis on suitable basement/crawlspace designs that prevent radon entry and at the same time limit energy use. ■

See page 64 for the references