#5563

Energy efficient residential building foundations

Controlling foundation-related problems can enhance the quality and health of indoor building spaces

By Jeffrey E. Christian
Member ASHRAE

A well-designed foundation not only is structurally sound and insulated to save energy, but also provides appropriate moisture, radon and termite control. Reflecting increased concern for energy conservation, several national building energy codes and standards were revised in 1989-91 to recommend foundation insulation in climates with over 2,500 heating degree days.

The importance of proper foundation insulation can be better appreciated by knowing that an uninsulated, conditioned basement may represent up to 50% of the annual heat loss in a tightly sealed house that is well insulated above grade.

Building systems interactions

While saving energy is one reason for good foundation design practices, there are other benefits. Insulating a foundation almost always results in warmer floors during winter in above-grade spaces, thus improving comfort. Insulating basement foundations creates more comfortable conditions in below-grade space as well, making it more usable for a variety of purposes at a relatively low cost. Higher basement surface temperatures can also reduce condensation, thereby minimizing mold and mildew.

Besides energy conservation and increased thermal comfort, the goals of good foundation design also include structural soundness, preventing water and moisture problems and, where appropriate, controlling radon and termites. However, achieving these goals may be more difficult with an energy-efficient design because some potential problems can be caused by incorrect insulation practices.

Under certain circumstances, when water control is not adequate, insulation may compromise the foundation's structural integrity. For instance, insulating the interior of a basement wall that leaks could cause more freezing and thawing of moisture in the wall and reduce the wall's durability. Without properly installed vapor retarders and adequate air sealing, moisture can degrade foundation insulation and create other problems.

Insulating and sealing a foundation to save energy results in a tighter building with less infiltration. However, if radon is present, it can accumulate and reach higher levels in the building than if more air exchange with the outside was occurring.

All of these potentially bad side-effects can be avoided if recommended practices are followed. In particular, residential foundations can be constructed that reduce energy consumption without creating health, moisture, radon, structural or other foundation-related problems.[3]

For an engineer to design a proper residential HVAC system, more knowledge is needed about foundations. Accordingly, this article provides a brief description of foundation construction systems, design principles and insulation systems. Additional information is also provided on radon control.

Foundation construction systems

The three basic types of foundations are full basement, crawlspace and slab-on-grade, with several construction systems for each type. The most common systems, cast-in-place concrete and concrete block foundation walls, can be used for all foundation types. Other systems include pressure-preservative-treated wood foundations, precast concrete foundation walls, masonry or concrete piers, cast-in-place concrete sandwich panels, and various masonry systems.[1,2]

Factors affecting foundation type and construction system include site conditions, overall building design, climate, local market preferences and construction costs.

Site conditions affecting choice of a foundation type include topography, watertable depth, presence of radon, soil type and depth of bedrock. Any foundation type can be used on a flat site, but a sloping site often necessitates a walkout basement or crawlspace. On steep slopes, a walkout basement combines a basement foundation wall on the upper side, a slab-on-grade foundation on the lower side, and partially bermed foundation walls on other sides. A watertable depth within 8 ft (2.4 m) of the surface will usually make a basement foundation undesirable.

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The preferred foundation type varies with climatic and local market demand. A major factor in selecting a type of foundation is the local frost depth. The greater the frost depth (i.e., the colder the climate), the greater the need for deeper foundations. However, the historic perception that foundations must extend below the natural frost depth is not entirely accurate. Very shallow foundations can be used in cold climates if they are insulated properly.

Design principles

Basement, crawlspace and slab-on-grade design principles consider structural integrity, location of insulation, drainage and waterproofing, and radon, termite and wood decay control.

Increasing insulation produces energy savings, but the installation cost must be compared to these savings. A lifecycle cost analysis presented in worksheet form[3] is recommended. This takes into account several economic variables including installation costs, mortgage rates, HVAC efficiencies, current local energy costs and energy escalation rates.

A flowchart describing the worksheet is shown in *Figure 1*. This worksheet can be used to select the optimal insulation level for new and retrofit applications. Using economic variables consistent with the underlying methodology of the envelope criteria for the prescriptive insulation recommendations in the proposed *ASHRAE Standard 90.2P*, "Energy Efficient Design of New Low-Rise Residential Buildings," a set of insulation recommendations is available in tabular form for several different foundations.[3] These tables provide economically optimal configurations for a range of climates and fuel prices.

Example recommendations are shown in *Table 1* and *Table 2*. The optimal configurations for several different construction types are shown by the darkened circles for several climates and three different fuel prices. The column referring to the medium fuel costs (labeled M) will lead to similar insulation levels as recommended by the prescriptive part of *Standard 90.2P*.

Basements. For conditioned basements, three general approaches to insulating the concrete/masonry wall include: on the exterior covering the upper half of the wall; on the exterior covering the entire wall; and on the interior covering the entire wall.

The same approaches used in conditioned basements can be used for unconditioned basements. Also, insulation can be placed between the floor joists in the ceiling above the unconditioned basement, thermally separating the basement from the above-grade space. This results in lower basement temperatures in winter and usually necessitates insulating exposed ducts and pipes in the basement.

Crawlspaces. Most building codes require vents near each corner of a crawlspace to provide cross-ventilation, generally with openings of 1 ft^2 per 1,500 ft^2 (1 mm^2 per 1.5 m^2) when a groundcover is in place. A groundcover always should be installed to prevent soil moisture entry into the building. The vents may also have operable louvers.

The temperature of a vented crawlspace is between house temperature and exterior temperature. Unvented crawlspaces insulated at the perimeter are similar to unconditioned basements, with temperatures between 50° to 70°F (10° to 21°C) most of the year, depending on climate and insulation placement.

In a vented crawlspace, insulation is placed between the floor joists in the crawlspace ceiling. In an unvented crawlspace, the two most common wall insulation locations are the entire exterior wall or the entire interior wall.

Besides these conventional approaches, insulation can be placed on the interior wall and horizontally on the perimeter of the crawlspace floor. With pressure-preservative-treated wood

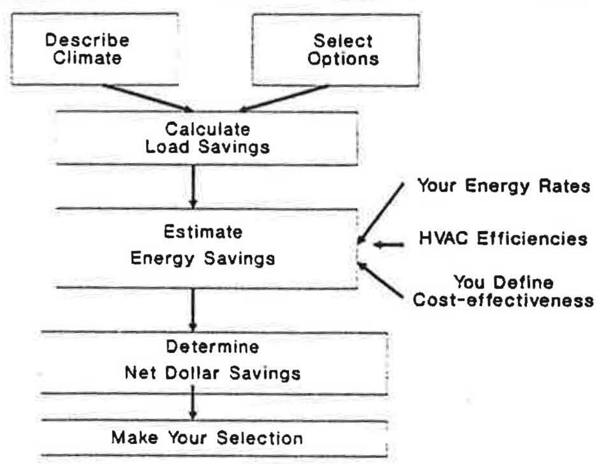


Figure 1. Selection of optimal foundation insulation.

Table 1. Insulation Recommendations for Fully Conditioned Deep Basement

A: Concrete or Masonry Foundation Walls with Exterior Insulation

CONFIGURATION	DESCRIPTION	RECOMMENDED CONFIGURATIONS AT THREE FUEL PRICE LEVELS: 0-2000 HDD (LOS ANG) L	M	H	4-6000 HDD (KAN CITY) L	M	H	8-10000 HDD (MPLS) L	M	H
EXTERIOR: HALF WALL	NO INSULATION	●	●	○	○	○	○	○	○	○
	4 FT: R-5 RIGID	○	○	●	○	○	○	○	○	○
	4 FT: R-10 RIGID	○	○	○	○	○	○	○	○	○
EXTERIOR: FULL WALL	8 FT: R-5 RIGID	○	○	○	○	○	○	○	○	○
	8 FT: R-10 RIGID	○	○	○	●	●	○	●	○	○
	8 FT: R-15 RIGID	○	○	○	○	○	●	○	●	●
	8 FT: R-20 RIGID	○	○	○	○	○	○	○	○	○

B: Concrete or Masonry Foundation Walls with Interior Insulation
(Costs do not include interior finish materials)

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	4-6000 HDD L	M	H	8-10000 HDD L	M	H
INTERIOR: FULL WALL	NO INSULATION	○	○	○	○	○	○	○	○	○
	8 FT: R-6 RIGID	●	○	○	○	○	○	○	○	○
	8 FT: R-8 RIGID	○	○	○	○	○	○	○	○	○
	8FT: R-11 BATT	○	●	●	●	○	○	○	○	○
	8 FT: R-19 BATT	○	○	○	○	●	●	●	●	●

C: Concrete or Masonry Foundation Walls with Interior Insulation
(Costs include sheetrock on interior wall)

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	4-6000 HDD L	M	H	8-10000 HDD L	M	H
INTERIOR: FULL WALL	NO INSULATION	●	●	○	○	○	○	○	○	○
	8 FT: R-6 RIGID	○	○	○	○	○	○	○	○	○
	8 FT: R-8 RIGID	○	○	○	○	○	○	○	○	○
	8FT: R-11 BATT	○	○	●	●	●	○	●	○	○
	8 FT: R-19 BATT	○	○	○	○	○	●	○	●	●

D: Pressure-Treated Wood Foundation Walls

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	4-6000 HDD L	M	H	8-10000 HDD L	M	H
WOOD: FULL WALL	NO INSULATION	●	●	○	○	○	○	○	○	○
	8 FT: R-11 BATT	○	○	●	○	○	○	○	○	○
	8FT: R-19 BATT	○	○	○	●	●	●	●	●	●
	8 FT: R-30 BATT	○	○	○	○	○	○	○	○	○

1. L, M, and H refer to low, medium, and high fuel cost levels.
2. The darkened circle represents the recommended level of insulation in each column for each of the four basic insulation configurations.

construction, batt insulation is placed in the cavities between the wood studs.

Venting can complement other moisture and radon control measures such as groundcover and proper drainage. However, although increased air flow in the crawlspace may offer some dilution potential for ground source moisture and radon, it will not necessarily solve a serious problem.

The principal disadvantages of a vented crawlspace over an unvented one are that: pipes and ducts must be insulated against heat loss and freezing; a larger area usually must be insulated; and, in some climates, warm humid air in the cool crawlspace can cause condensation, resulting in excessive moisture levels in wood and, in some cases, wood decay.

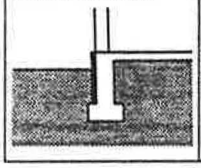
Vented crawlspaces are often provided with operable vents that can be closed to reduce winter heat losses and to keep out moist summer air. However, closing these vents can also potentially lead to increased radon levels.

There are several advantages to designing crawlspaces as semi-conditioned zones. Duct and pipe insulation can be reduced, and the foundation can be insulated at the perimeter instead of at the ceiling. This usually requires less insulation, simplifies installation, and minimizes condensation.

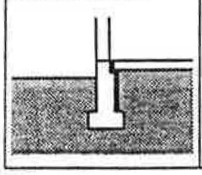
Continuous venting may be desirable in areas of high radon hazard. However, venting should not be considered a reliable radon mitigation strategy. Pressurizing the crawlspace can effectively minimize soil gas infiltration, but its walls and ceiling must be tightly constructed to be effective.

Table 2. Insulation Recommendations for Slab-on-Grade Foundations

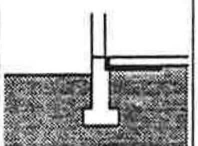
A: Concrete or Masonry Foundation Walls with Exterior Insulation Placed Vertically

CONFIGURATION	DESCRIPTION	RECOMMENDED CONFIGURATIONS AT THREE FUEL PRICE LEVELS: 0-2000 HDD (LOS ANG) L	M	H	2-4000 HDD (FT WORTH) L	M	H	4-6000 HDD (KAN CITY) L	M	H
EXTERIOR VERTICAL 	NO INSULATION	●	●	●	●	○	○	○	○	○
	2 FT DEEP: R-5	○	○	○	○	●	●	●	●	○
	2 FT DEEP: R-10	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-5	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-10	○	○	○	○	○	○	○	○	●
	4 FT DEEP: R-15	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-20	○	○	○	○	○	○	○	○	○

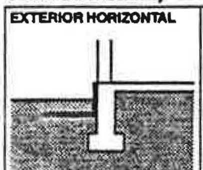
B: Concrete or Masonry Foundation Walls with Interior Insulation Placed Vertically

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	2-4000 HDD L	M	H	4-6000 HDD L	M	H
INTERIOR VERTICAL 	NO INSULATION	●	●	●	○	○	○	○	○	○
	2 FT DEEP: R-5	○	○	○	●	●	●	●	●	○
	2 FT DEEP: R-10	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-5	○	○	○	○	○	○	○	○	●
	4 FT DEEP: R-10	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-15	○	○	○	○	○	○	○	○	○
	4 FT DEEP: R-20	○	○	○	○	○	○	○	○	○

C: Concrete or Masonry Foundation Walls with Interior Insulation Placed Horizontally Under Slab Perimeter

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	2-4000 HDD L	M	H	4-6000 HDD L	M	H
INTERIOR HORIZONTAL 	NO INSULATION	●	●	●	●	○	○	○	○	○
	2 FT WIDE: R-5	○	○	○	○	●	●	●	●	○
	2 FT WIDE: R-10	○	○	○	○	○	○	○	○	○
	4 FT WIDE: R-5	○	○	○	○	○	○	○	○	●
	4 FT WIDE: R-10	○	○	○	○	○	○	○	○	○

D: Concrete or Masonry Foundation Walls with Exterior Insulation Extending Outward Horizontally

CONFIGURATION	DESCRIPTION	0-2000 HDD L	M	H	2-4000 HDD L	M	H	4-6000 HDD L	M	H
EXTERIOR HORIZONTAL 	NO INSULATION	●	●	●	○	○	○	○	○	○
	2 FT WIDE: R-5	○	○	○	●	●	●	●	●	●
	2 FT WIDE: R-10	○	○	○	○	○	○	○	○	○
	4 FT WIDE: R-5	○	○	○	○	○	○	○	○	○
	4 FT WIDE: R-10	○	○	○	○	○	○	○	○	○

1. L, M, and H refer to low, medium, and high fuel cost levels.
2. The darkened circle represents the recommended level of insulation in each column for each of the four basic insulation configurations.

Moisture problems in crawlspaces are common enough that many code agencies have been unwilling to endorse eliminating vents or closing the vents year-round. Soil type and the groundwater level are key factors influencing moisture conditions.

Slab-on-grade. Insulate slab-on-grade foundations with concrete/masonry walls by placing insulation either vertically on the entire exterior of the wall, on the entire interior of the wall, or under the slab perimeter. When insulation is placed either vertically or horizontally on the interior, it is important to place insulation in the joint between the slab edge and foundation wall. Sketches of these different slab insulation locations are shown in *Table 2*.

It is not necessary to place more than R-5 insulation in this joint. Exterior vertical insulation ranging from R-5 to R-10 is typically justified in most climate zones.[5]

Insulation is occasionally placed horizontally on the building exterior, extending typically 2 to 4 ft (60 to 120 cm) into the surrounding soil. In some regions, it is common practice to have a footing shallower than 2 ft (60 cm) or have no foundation wall at all, just a thickened slab edge.

In these cases, a full 2 ft (60 cm) of vertical insulation is not an option. However, additional horizontal insulation on the exterior is possible. Exterior and interior vertical insulation are roughly thermally equivalent, but exterior insulation costs more to install due to the need for protective covering.

Insulation systems

Basements and crawlspaces. There is not a significant difference in energy use between the same amount of full-wall insulation applied to the exterior versus the interior of a concrete or masonry wall. However, rigid insulation on the exterior has some advantages in that it:

- Provides continuous insulation with no thermal bridges;
- Protects and maintains the waterproofing and structural wall at moderate temperatures;
- Minimizes moisture condensation problems; and
- Does not reduce interior basement floor area.

Exterior insulation at the rim joist leaves joists and sill plates open to inspection from the interior. Interior wall insulation increases the wall's exposure to thermal stress and freezing and may increase the likelihood of condensation on the wood structure.

Energy savings may also be reduced with some systems due to thermal bridges. For example, partial interior wall insulation is not recommended because the insulation can possibly be circumvented through the wall construction. Insulation can be placed on the inside of the rim joist, but with greater risk of condensation problems and less access to wood joists and sills for termite inspection.

Insulation placement in the basement or vented crawlspace ceiling is acceptable. Most commonly, batt insulation is placed between the floor joists. This placement leaves sill plates open to inspection. This approach is relatively low in cost and provides significant energy savings. However, ceiling insulation should be used with caution in colder climates where pipes may freeze and structural damage may result from lowering the frost depth.

Rigid board insulation is easier to apply to an interior masonry wall than batt insulation because it requires no framing for support, is continuous, can be installed prior to backfilling

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against the foundation wall or installing the floor, and may require no additional vapor retarder. Insulation around the perimeter of the crawlspace floor can provide additional thermal protection, but it may also create paths for termite entry.

Batt insulation is commonly placed inside the rim joist, covered on the inside face with a vapor retarder. In place of batts, using tight-fitting rigid foam pieces between the floor joists is effective. Less expensive batts are an alternative to rigid foam insulation on the interior of basement and unvented crawl space walls.

A common, low-cost approach to insulating crawlspace walls is simply draping batts with a vapor retarder facing over the inside of the wall. However, it is difficult to maintain continuity of the vapor retarder around joist ends and to seal the termination of the vapor retarder.

With a wood foundation, insulation is placed in the stud cavities similar to above-grade insulation in a wood frame wall. This approach has a relatively low cost and provides sufficient space for considerable insulation thickness.

Besides more conventional interior or exterior placement, several systems incorporate insulation into the construction of the concrete or masonry walls. These include: rigid foam plastic insulation cast within a concrete wall; systems of concrete blocks with insulating foam inserts; formed, interlocking rigid foam units that serve as permanent, insulating forms for cast-in-place concrete; and masonry blocks made with polystyrene beads instead of aggregate in the concrete mixture, resulting in significantly higher R-values.

The effectiveness of systems that insulate only a portion of the wall area should be evaluated closely because thermal bridges through the insulation can impact the total performance significantly.

Insulating the ceiling of an unconditioned basement or unvented crawlspace is generally more cost-effective than insulating the walls to an equivalent level. This is because batt insulation in the spaces between floor joists is cheaper than placing rigid insulation on the walls. Thus, higher levels of ceiling insulation can be economically justified when compared to wall insulation.

Table 1 shows recommended insulation levels for three climates and different fuel cost assumptions for conditioned basements.[3] (Similar tables are provided in the *Builders Foundation Handbook* for other foundation types such as unconditioned basements and crawlspaces.) The darkened circles under the column labeled M represent national average fuel prices in 1988 and are consistent with those levels recommended in the prescriptive portion of *Standard 90.2P.*

Slabs. The highest heat losses of slab-on-grade per unit area are through the small portion of foundation wall above grade. Heat losses to the soil are greatest at the edge, and diminish rapidly with distance from it. Both components of the slab heat loss (at the edge and through the soil) must be considered in designing the insulation system.

Insulation can be placed vertically outside the foundation wall or grade beam, extending down to reduce heat flow from the floor slab to the ground outside the building. Vertical exterior insulation is the only method of reducing heat loss at the edge of an integral grade beam-and-slab foundation. A major advantage of exterior insulation is that the interior joint between the slab and foundation wall need not be insulated, which simplifies construction.

A limitation is that the depth of the exterior insulation is controlled by the footing depth. Additional exterior insulation can be provided by extending insulation horizontally from the foundation wall, which can reduce footing depth requirements under certain circumstances. This can substantially reduce the initial foundation construction cost. Insulation also can be placed vertically on the interior of the foundation wall or horizontally under or above the slab.

Table 2 shows recommended insulation levels for three climates for slab-on-grade constructions.[3] The darkened circles under the column marked M for medium fuel costs are more or less consistent with the prescriptive insulation recommendations in *Standard 90.2P.*

To place insulation above the floor slab, a wood floor deck can be placed on sleepers, leaving cavities that can be filled with rigid board or batt insulation, or a wood floor deck can be placed directly on rigid insulation above the slab. This avoids some construction detail problems, but may lead to greater frost depth in the vicinity of the slab edge.

Radon control

Construction techniques for minimizing radon infiltration through the foundation are appropriate where there is a reasonable probability that radon may be present. To determine this, contact the state health department or environmental protection office.

General approaches to minimizing radon include sealing joints, cracks and penetrations in the foundation[3] and evacuating soil gas surrounding the foundation.

To mitigate radon hazard, reduce stack effect by building a tight foundation in combination with a generally tight above-grade structure. Make sure a radon collection system and, at the very least, provisions for a discharge system are an integral part of the initial construction.

Once the house is built, if radon levels are excessive, a passive discharge system can be connected. If further mitigation is needed, the system can be activated by installing an inline duct fan (see *Figure 2*).

Subslab depressurization is a technique for reducing radon concentrations to acceptable levels, even in homes with extremely high concentrations.[4] This causes the soil gas to be routed into a collection system to outdoors.

This system could be installed in two phases. The first phase is the collection system located on the soil side of the foundation, which should be installed during construction. The collection system, which may consist of nothing more than 4 in. (100 mm) of gravel beneath the slab floor, can be installed at little or no additional cost in new construction. The second phase is the discharge system, which could be installed later if necessary.

A foundation with good subsurface drainage already has a collection system. The underslab gravel drainage layer can be used to collect soil gas. Stack pipes could also be installed horizontally through below-grade walls to the area beneath adjoining slabs. If necessary, the standpipe can be uncapped and connected to a vent pipe.

However, it is normally less costly to complete the vent stack routing through the roof during construction than to install or complete the vent stack after the building is finished. Connecting the vent pipe initially without the fan provides a passive depressurization system that may be adequate in some cases and could be designed for easy modification to an active system if necessary.

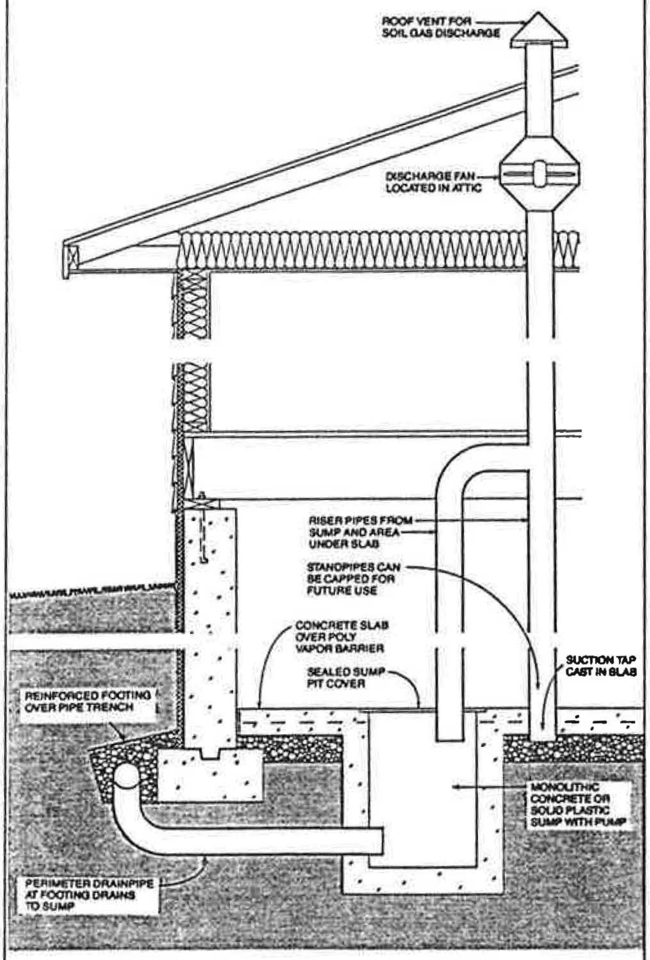

Figure 2. Soil gas collection and discharge techniques.

A subslab depressurization system requires the floor slab to be nearly airtight so that collection efforts are not short-circuited by drawing excessive room air down through the slab and into the system. Cracks, slab penetrations and control joints must be sealed. Sump hole covers should be designed and installed to be airtight. Floor drains that discharge to the gravel beneath the slab should be avoided, but when used, should be fitted with a mechanical trap that provides an airtight seal.

Do not depend on a continuously operating fan. Ideally, a passive depressurization system should be installed, radon levels tested and, if necessary, the system made active by adding a fan.

Active systems use inline duct fans to draw gas from the soil. The fan should be located in an accessible section of the stack so that any leaks from the positive pressure side of the fan are not into the living space. The stack should extend above the roof. The exhaust should be located away from doors and windows.

Conclusions

This article describes optimal insulation levels for several foundation types that are more or less consistent with the prescriptive portion of ASHRAE *Standard 90.2P.*

Based on average energy prices and other "typical economic assumptions," at least some insulation is recommended for most conventional foundations in most U.S. climates.

The most important conclusion drawn from examining all the building system issues requiring resolution by a single foundation design is that energy efficiency can be attained while simultaneously enhancing the general quality and health of the indoor building spaces, by controlling moisture, radon and other foundation-related problems. ■

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