IMPROVING CRAWLSPACES IN NEW YORK MULTIFAMILY BUILDINGS

Build your crawlspaces to keep energy losses to a minimum, while also keeping your pipes from freezing.

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This unimproved crawlspace featured many typical drawbacks, including moisture problems, a dirt floor, and rusty pipes.

Crawlspaces were developed as an affordable foundation alternative to basements. However, cold-weather crawlspaces, such as those in New York State, present a variety of challenges:

- limiting heat losses, both conductive, through the floor and walls of a crawlspace, and convective, via air flow through a crawlspace;
- controlling evaporation from soil or concrete floors in a crawlspace, to reduce moisture, which can cause a variety of problems in buildings;
- preventing cold floors in winter, and warm floors in summer, directly above a crawlspace;
- preventing radon from traveling from the ground into a building through a crawlspace;
- preventing freeze risks for piping located in a crawlspace; and
- preventing the mixing of crawlspace air and house air, through leakage in ducts located in a crawlspace.

During energy audits for the New York State Energy Research and Development Authority (NYSERDA)'s Assisted Multifamily Program, energy auditors have been reluctant to recommend insulating the subfloor between crawlspaces and heated spaces, because insulation will prevent heat from the conditioned spaces from traveling to the crawlspace. Heating the crawlspace in this way is how builders have typically prevented water pipes in the crawlspace from freezing.

An alternative is to insulate the crawlspace walls. But this alternative is not effective unless the builder also seals the crawlspace vents, and auditors have been reluctant to recommend sealing all vents for fear that when crawlspace moisture levels are excessive, the moisture cannot be dispelled if the vents are sealed. Another concern is the effectiveness and durability of any sheet moisture barrier that is installed over a soil floor, where maintenance traffic over the barrier may be likely in the future.

NYSERDA established the following general goal for this project: Identify the most effective way to reduce crawlspace energy losses while also reducing crawlspace moisture levels, and preventing associated risks, such as pipe freezing, in New York State climates. NYSERDA asked the company I work for, Taitem Engineering, to help in its analysis.

The objectives of the study were

- to perform humidity analysis of a typical crawlspace in order to examine the sensitivity of crawlspace relative humidity (RH) to floor moisture control and to crawlspace venting (natural ventilation, mechanical ventilation, or both);
- to perform temperature analysis of a typical crawlspace in order to examine the sensitivity of crawlspace temperatures to different levels of crawlspace venting (with and without insulation); and

• to analyze the cost effectiveness of energy improvements.

The study sought answers to the following questions:

• Does air sealing a crawlspace raise RH sufficiently to cause a mold risk?

• If so, does putting a vapor barrier on the floor and/or walls solve this problem?

• If so, can the vapor barrier be installed and function in such a reliable and robust way that it will not be damaged by people who walk on it?

• If a vapor barrier is poorly installed or accidentally damaged, how sensitive is moisture control in the crawlspace to minor failures in the vapor barrier?

• Does insulating and/or air sealing a crawlspace create a risk of pipes freezing?

Code Requirements

The New York State Building Code, which since 2002 has been based on the International Building Code, requires venting of crawlspaces, with 1 ft^2 of vent per 150 ft^2 of floor space. Exceptions are allowed if a vapor barrier ground cover is placed on the floor of the crawlspace, in which case either much smaller vents are still required (1 ft^2 of vent per 1,500 ft^2 of floor space), or the crawlspace must be heated. Other exceptions to passive vents are allowed; for example, the crawlspace may be vented to the interior space (typically an attached basement), or the crawlspace may have fan-powered ventilation at a rate of 2 CFM per 100 ft^2. The New York City Building Code is slightly different, requiring a vapor barrier (no option for vents only), and different amounts of ventilation than are required by the state code.

The New York State Energy Conservation Code requires a maximum value of exterior wall heat transmittance (U_0) of 0.06 for all climatic regions. This translates into a minimum R-value of 16.7. For electrically heated buildings, R-30 is required.

Humidity Analysis

For purposes of humidity analysis, a software program called *Indoor Humidity Tools* was used. *Indoor Humidity Tools* was developed by Taitem Engineering, and has been in commercial distribution since 1998. *Indoor Humidity Tools* performs a single-zone, homogeneous moisture mass balance on a building. "Homogeneous" means that the concentration of water in the air (humidity) is assumed to be uniform through the space—a reasonable assumption for crawlspaces that have reasonably uniform boundary conditions in the horizontal plane (exposure to floor below and building above), and that are low in height.

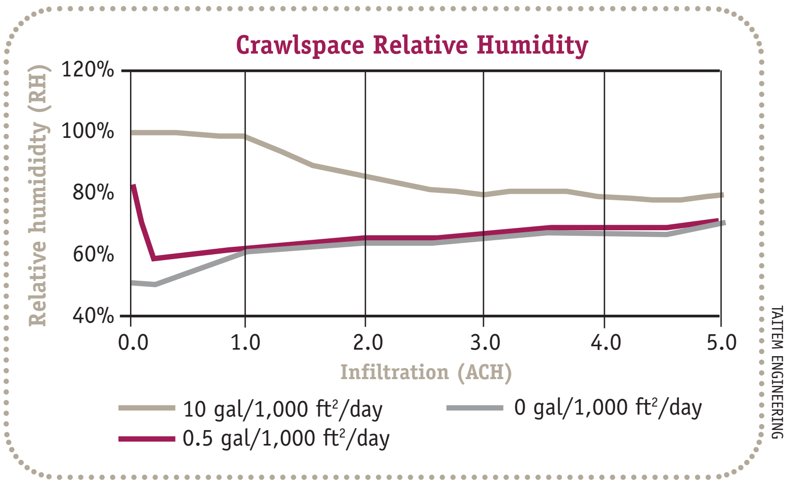

Figure 1. If the crawlspace is not vented (zero/low ACH) and does not have a ground vapor barrier (giving it a high evaporation rate, for example 10 gallons per 1,000 ft^2 per day), the RH in the crawlspace is 100%. This is not good.

To run *Indoor Humidity Tools*, the user can enter combinations of indoor temperature/humidity conditions, outdoor temperature/humidity conditions, the ventilation rate, and the indoor moisture generation rate, and solve for any one of these variables if the others are known.

Inputs and Assumptions

For the purposes of this study, summer (cooling) ASHRAE design weather conditions for New York City were used.

The indoor moisture generation rate is, for the purposes of this study, the rate at which moisture is evaporated from the soil in the crawlspace. A literature survey indicated that evaporation rates are in the range of 0.9–27 gallons per 1,000 ft^2 per day. For the parametric analysis, evaporation rates were varied from 0–10 gallons per 1,000 ft^2 per day. Ventilation rates were varied from 0–5 air changes per hour (ACH). By way of reference, Kurnitski measured 0.4 ACH in a naturally ventilated crawlspace, and 2–5 ACH in a mechanically ventilated crawlspace. Trethowen measured natural ventilation rates in the 2–8 ACH range in a study of five New Zealand homes in a temperate windy climate. In short, ventilation rates vary widely and are unpredictable.

While the model does not allow examination of the effect of air exchange with the building upstairs, we regarded this as a minor effect, due to the low air exchange rate, relative to air exchange between a crawlspace and the outdoors.

Furthermore, this is a first-order steady-state model that does not account for varying conditions or adsorption and desorption of water vapor by surfaces. These phenomena do affect what happens in real crawlspaces. But the simple steady-state model does give some insight into risks and risk avoidance for humidity in crawlspaces.

Results and Analysis

The results are consistent with those of an earlier study (Samuelson), and give us additional insight into crawlspace moisture issues (see Figure 1).

If the crawlspace is not vented (zero/low ACH) and does not have a ground vapor barrier (giving it a high evaporation rate, for example 10 gallons per 1,000 ft^2 per day), the RH in the crawlspace is 100%. This is not good.

If the crawlspace is vented mechanically or naturally (high ACH) and does not have a ground vapor barrier (giving it a high evaporation rate), the RH moves from 100% down into the 80%–90% range. This is the common practice of the last 50 years in building construction. The RH has been nudged away from being dangerous (although it is still high), while energy use has been increased due to the crawlspace ventilation. It should be noted that if conditions prevent good ventilation—for example, in a building sheltered from wind, or with blocked vents—the humidity can quickly rise to 100% as the ventilation rate drops below 1 ACH.

If a crawlspace is not vented (low ACH) and does have a good ground vapor barrier (giving it a zero evaporation rate), RH decreases significantly, moving down into the much safer 50%–60% range. This validates much research that has shown that a ground vapor barrier is extremely effective in reducing evaporation rates.

Now what happens if the ground vapor barrier fails? What happens, in other words, if it is not installed properly (edges or seams are not sealed well), or if it is broken when people walk on it? Assuming that 10% of the no vapor barrier evaporation rate, or 0.5 gallons per 1,000 ft^2 per day, gets through the ground vapor barrier, and still assuming very low air leakage rates, let's say 0.2 ACH or lower, the RH in the crawlspace rises above 60% and can go significantly higher as the air leakage drops to zero.

It should be noted that if the crawlspace is perfectly sealed (0 ACH), even the smallest failure in the ground vapor barrier will result in 100% RH in the space. Any space that has even the smallest moisture source will go to 100% relative humidity if it has no way to get rid of the moisture.

However, if a small amount of air exchange, anywhere between 0.2 and 1ACH, can be provided to the crawlspace with a vapor barrier, the RH in the crawlspace can be kept in the 60% range, which is acceptable, and is much better than what results from current construction practice.

The analysis leads us to the following conclusions:

A ground vapor barrier reduces RH in crawlspaces more significantly than do vents. And something must be done to prevent high humidity in crawlspaces in case of vapor barrier failure. In addition to periodically measuring humidity in the crawlspace, we recommend that builders do one of these three things:

- Install a dehumidifier in the crawlspace. This dehumidifier will rarely, if ever, run, as long as its setpoint is not set too low. Instead, its purpose is to control humidity only in the case of vapor barrier failure. In order to comply with building code, a heater should also be installed in the crawlspace. The heater setpoint should be set low, for example at 55°F. A small heater can be used—even an electric heater—as the heater is not expected to come on, even in midwinter.
- Provide vents in the floor between the crawlspace and the building above. This will allow any small amount of moisture that enters the crawlspace to be transported away from the crawlspace, through the vents and through the building. These vents will also provide compliance with building code. Since this crawlspace design is intended to keep the crawlspace clean, dry, and essentially free of organisms and pests, it is important to note that pans should be placed under these vents to catch debris and prevent it from entering the crawlspace. Also, the crawlspace should be inspected regularly to make sure that these dry, debris-free conditions are maintained.
- Include the crawlspace within a forced-air system that is heating a building. This includes installing both supply and return ductwork in the crawlspace.

Temperature Analysis

Crawlspace temperatures were modeled to evaluate the risk of pipe freezing in crawlspaces.

To examine temperature in a crawlspace, a software program called *TREAT* was used. *TREAT* was developed by Taitem Engineering and Performance Systems Development, both of Ithaca, New York, and has been in commercial distribution since 2002. *TREAT* uses an hourly model called SUNREL for its calculations, including the calculation of quasi-equilibrium temperature in unheated rooms such as crawlspaces. SUNREL does include earth temperature effects.

To run *TREAT*, the user chooses a climate/location, and describes the building (wall area and type, floor area and type, heating system, and so on). *TREAT* provides as an output the average monthly temperature for each month of the year, for unheated spaces.

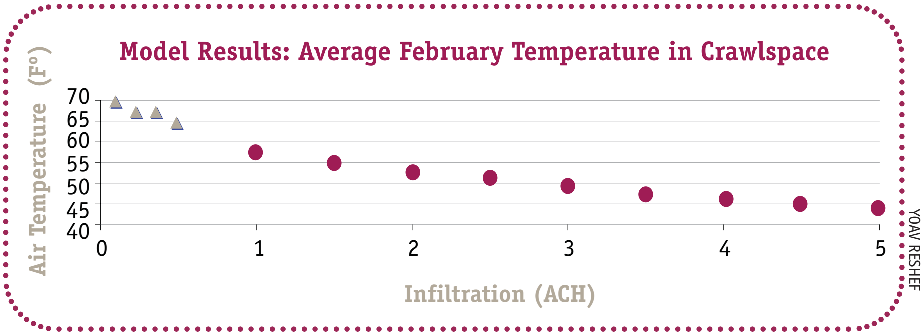

Figure 2. The four beige triangular data points on the left represent the crawlspace with insulated walls. The round burgundy data points on the right represent the crawlspace with uninsulated walls.

Inputs and Assumptions

The climatic region modeled is Syracuse, New York, a cold climate with approximately 6,000 heating degree-days.

The dimensions of the crawlspace modeled match those found in an actual apartment building in nearby Utica, New York. It is 15,288 ft^2 in area and 5 $^1/_2$ ft high; 4 $^1/_2$ ft of the exterior wall is below grade. The indoor temperature in the heated space above the crawlspace is modeled at 70°F.

The R-value of the floor between the crawlspace and the heated space above is assumed to be R-2.9. Insulating this surface is not recommended, as it will decrease the crawlspace temperature and increase the risk of freezing water pipes in the crawlspace in cold climates.

To model the crawlspace with vents open and no wall insulation (common current practice), the R-value of the crawlspace wall was modeled at R-0.86, and the air leakage was varied from 1 to 5 ACH.

To model a crawlspace with vents sealed and wall insulation installed, the R-value of the crawlspace wall was modeled at R-6.3, and the air leakage was varied from 0.05 to 0.2 ACH.

Results and Analysis

Results are for the month of February, the coldest month of the year (see Figure 2). Note that the result shows the average monthly air temperature. The results show, predictably, that increased air exchange results in lower crawlspace air temperatures. The coldest average February temperature in the crawlspace is 44°F. Since this is the average for the month, it is very plausible that this represents a scenario where short-term air temperatures in the crawlspace could dip down to or below freezing. Since a literature survey showed cases of air exchange above 5 ACH in crawlspaces, it follows that a ventilated crawlspace presents a freezing risk for water piping. Anecdotal evidence supports this conclusion, as pipes can freeze even in crawlspaces above 32°F, when outdoor air below 32°F enters the crawlspace and flows over pipes located near the point of air leakage.

Now let us examine the four data points in the 0.05–0.2 ACH range, representing a crawlspace with the vents sealed and with minimum wall insulation. Note that the crawlspace temperature is 66°F–68°F. Even with the minimum wall insulation in the model, the risk of freezing water pipes is clearly eliminated, if the crawlspace vents are sealed.

These four data points suggest that the amount of energy required to heat a sealed insulated crawlspace, in order to comply with the one code compliance path ("provide heat") that allows the elimination of all exterior and interior vents, is likely to be small.

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A sealed and insulated crawlspace with a vapor barrier on the floor has many advantages over the traditional vented crawlspace; it's dry, and energy losses are minimal.

Table 1. Energy Analysis

	Building with Vents in Crawlspaces	Building without Vents in Crawlspaces
Apartments	108	199
Estimated cost to insulate and air seal crawlspaces	$150,000	$200,000
Annual energy savings	$ 11,200	$ 7,200
Recommended	Yes	No

Energy Analysis

Energy analysis was also conducted using *TREAT*, examining two specific complexes in Utica, New York (see Table 1). The two complexes are similar: They were built within a few years of each other in the 1940s. Both have two above-grade stories and a crawlspace below, both have dirt floors in the crawlspaces, both lack insulation between the crawlspace and the heated building above, and both lack insulation between the crawlspace and the outdoors. However, one complex has crawlspace vents and the other does not.

We recommended air sealing and insulating the building with vented crawlspaces, because the energy savings justify the capital cost, passing the Assisted Multifamily Program's threshold for economic justification. However, we did not recommend improving the building with unvented crawlspaces, because this improvement does not pass the economic threshold test. Clearly, for this building, the fact that there are no vents means that there is less air leakage to reduce, and that the absence of an opportunity to reduce air leakage prevents the overall improvement—insulation plus air sealing—from being justified. These two examples point to the necessity for building-specific analysis in order to evaluate the merits of insulating and air sealing crawlspaces.

Recommendations

A sealed and insulated crawlspace with a vapor barrier on the floor has many advantages over the traditional vented crawlspace (see Table 2). While these results were developed in analysis for the New York State climate, they are probably applicable to other climates as well. We recommend that building designers, builders, and contractors conduct a climate-specific analysis, however, before they apply these conclusions to other geographic regions.

As a result of this analysis, we recommend the following as best practices to minimize energy losses, to control moisture—in fact, to reduce moisture problems relative to current practice, and to comply with building code requirements. It should be noted that variations on these best practices are possible, as long as the principles of air sealing and insulation are maintained.

Multifamily

Materials

We recommend that builders use the following materials:

1. Vapor barriers: 10-mil polyethylene; EDPM rubber in areas with heavy traffic.

2. Vapor barrier sealants: polyurethane; siliconized acrylic is not as durable as polyurethane, and pure silicone peels easily if disturbed. Note: some specialists simply recommend 12-inch overlap, without caulk.

3. Furring strips: 2 x 2.

4. Furring strip fasteners: powder-actuated nails of manufacturer's recommended size using appropriate charge, or grip cons—galvanized spiral nails set in a pilot hole with an ordinary hammer.

5. Insulation: any rigid foam board stock, or spray polyurethane or isocyanurate foam; one-part polyurethane foam to seal odd spaces and between foam panels. Note: foam insulation requires protection if there are utilities in the crawlspace, per New York State Code section §2603.4.1.6.

6. Rigid insulation fasteners: as per manufacturer's instructions; typically powder-actuated fasteners or tapping screws. Volatile construction adhesives are not appropriate in sealed crawlspaces.

7. Sump pump system: good-quality submersible pump; plastic crock: fabricate crock cover using 1/2-inch acrylic sheet; pure silicone to seal cover and cord and piping penetrations, easily peeled for service access.

Preparation

Preparation should include the following steps:

1. Grade exterior to deflect surface water from crawlspace exterior walls. In some cases, perimeter drainage may be required.

2. Remove hard and sharp materials from the crawlspace floor; if there are sharp objects or an uneven ground surface that cannot be smoothed out, take measures to protect the vapor barrier from being pierced when people walk on it.

3. Excavate, wire, and plumb for sump pump installation if required.

Table 2. Summary of Crawlspace Study

	Traditional with Vented Crawlspace	Sealed and Insulated Crawlspace with Vapor Barrier on Floor
Conductive energy losses	High	Low
Convective energy losses	High	Low
Distribution (ductwork) energy losses	High	Low
Risk of pipes freezing due to low crawlspace temperature	High	Low
Risk of pipes freezing due to cold outside air passing across pipes	High	Low
Temperature of floor above crawlspace in winter	Cold	Warm
Temperature of floor above crawlspace in summer	Warm	Cool
Relative humidity in crawlspace, and associated health and wood rot risk	High	Moderate
Resistance to radon entering crawlspace from the ground	Poor	Excellent
Risk of pests	High	Low
Risk of condensation on pipes/ducts	High	Low
Insulation difficulty	Difficult (floor)	Easier (wall)
Insulation reliability	Poor	Good

Execution

Here is a step-by-step approach to treating crawlspaces:

1. Floor

a. Overlap vapor barrier seams by 12 inches and seal with polyurethane.

b. Run the vapor barrier 6 inches up the walls, fasten with furring strip, power-nailed into wall every 16 inches; seal between top of furring strip and wall with polyurethane.

c. Run the vapor barrier 6 inches up any support posts and seal with polyurethane. Band or clamp barrier to steel posts; fasten as for wall on concrete or wood posts.

d. Seal vapor barrier to sump crock with polyurethane.

2. Walls

a. Install insulation to achieve whole-wall R-16.7, or to meet local codes (R-30 for electrically heated buildings).

b. Seal wall insulation to vapor barrier furring strips with polyurethane.

c. Cover and insulate existing exterior vents.

d. Air seal the walls, including all penetrations, the sill plate, and the covered vents.

e. Seal gaps in insulation layer with one part polyurethane foam.

3. Provide an access hatch to the crawlspace, for inspection and maintenance purposes and to comply with New York State Building Code, either from the building above or from the outdoors (in which case it should be insulated and gasketed), minimum 18 inches x 24 inches. Consider installing a light in the crawlspace to facilitate inspections.

4. In general, prevent wood or paper products from touching concrete.

5. If necessary, in high radon areas, exhaust air from beneath the ground cover.

6. Take steps to prevent high humidity in the crawlspace in case of vapor barrier failure, and to comply with code requirements for sealed crawlspaces. Periodically or continuously measure humidity in the crawlspace with a digital humidity gauge. Also, do one of the following:

a. Install a dehumidifier in the crawlspace, as well as a heater. The dehumidifier setpoint should be high (60% RH) and the heater setpoint should be low (55°F).

b. Provide vents between the crawlspace and the heated space above. New York State Code requires 1 ft^2 open area per 1,500 ft^2 of crawlspace, and a minimum of two vents, to provide cross ventilation. The purpose of the vents is to remove any moisture that enters the crawlspace, for example through an imperfect ground vapor barrier; to minimally and indirectly heat the crawlspace to further reduce RH; and to provide compliance with the building code.

c. A third approach is to actively condition (heat and cool) the crawlspace.

If a crawlspace is partial (that is, if it is not under the whole house), the same basic approach applies: Bring it into the thermal envelope of the house. If any ductwork does run through the crawlspace and the crawlspace air mixes with the house air, this will not be a problem, since the crawlspace is intended to be part of the house.

Ian Shapiro started Taitem Engineering in 1989. He is a licensed engineer in New York, Pennsylvania, and Connecticut, and is a LEED-accredited professional.

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Excellent additional details and options for crawlspace construction are provided in Section 3.3 of *Builder's Foundation Handbook*. (Oak Ridge, Tennessee: USDOE, Oak Ridge National Laboratory, 1991).

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