CLOSED CRAWLSPACES DO DOUBLE DUTY

A field demonstration project in North Carolina shows that this robust moisture control method also offers significant energy savings.

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Closed crawlspaces represent both a new business opportunity and a risk management tool for many different stakeholders in the construction industry.

Wall-vented crawlspaces are widely used in building construction throughout North America. Approximately 250,000 new homes are built on crawlspaces every year, and an estimated 26 million such homes are already in existence. They are cheap to build; functional in terms of providing a level foundation for flooring on sloping sites; and popular as spaces in which to locate plumbing, ductwork, and heating and air conditioning systems. Unfortunately, wall-vented crawlspaces can also host a variety of serious moisture problems. Closed (also called sealed or unvented) crawlspaces represent both a new business opportunity and a risk management tool for many different stakeholders in the construction industry, from pest management companies to building performance contractors and foundation specialists. As complaints and legal action related to mold growth in homes have increased, homeowners, tenants, and the construction industry have become much more aware of the need to control moisture in homes. This awareness is prompting a growing number of owners and builders to invest the additional time and money required to install closed crawlspaces in both new and existing homes.

In response to these growing concerns, Advanced Energy has undertaken a multiyear effort to document how various crawlspace ventilation and insulation strategies affect moisture levels and energy use in houses in the southeastern United States. Another primary goal of this research has been to demonstrate practical, easily transferable, and clearly understandable crawlspace construction techniques that would solve a multitude of moisture problems and would be at least energy neutral; at best, we were hoping to reduce energy consumption for space conditioning. When the project began in the fall of 2001, we did not know whether the interventions would show energy savings. Some of us had our fingers crossed against the possibility that the moisture solutions might actually cause an increase in energy consumption. We were pleasantly surprised when measurements showed the techniques to be very beneficial for both moisture control and energy efficiency.

Experimental Setup

The 12 homes studied in this project are located in the same development in Princeville, North Carolina. Six houses are built, side-by-side, on each side of one street. All are the same size—1,040 ft^2—

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We outfitted all 12 houses with electricity submeters to record exact energy consumption by each home's package unit heat pump system.

with the same floor plan and window schedule. The development was built on controlled-fill soil to elevate it above the 100-year floodplain, which added to the uniformity of the site soil conditions, and each home site was graded to provide proper drainage.

The study homes are broken into three groups of four homes each: one control group and two experimental groups. We reduced duct leakage and house leakage to comparable levels across all the groups. Average duct leakage varies from 51 CFM$_{25}$ to 68 CFM$_{25}$ for these groups, which represents rates of 5%–7% CFM$_{25}$ per square foot of floor area. Dividing the leakage by the conditioned floor area lets us use a consistent target across many different sizes of home. Average house leakage varies from 0.22 to 0.27 CFM$_{50}$ per square foot of envelope area. Insulation deficiencies were corrected in all houses, and heat pump refrigerant charge and system air flow were measured and corrected as needed in all houses.

All the houses have a fresh-air ventilation intake integrated with the HVAC ductwork. A 6-inch insulated flex duct from outside routs air through a 1-inch pleated media filter and then connects directly to the return plenum. Whenever the HVAC system is operating, 40 CFM of filtered fresh air is mixed into the return airstream, conditioned, and then distributed to the house. No fan-timing or fan-cycling controls are used in the mechanical system.

The four control houses have conventionally vented crawlspaces, with 11 8 inch x 16 inch foundation vents. Each house has a 6-mil polyethylene ground cover that is mechanically secured to the soil with turf staples. The seams are lapped approximately 6 inches but are not sealed. The ground cover extends completely to the foundation wall and intermediate piers, covering 100% of the soil. Although the building code allows a reduction in the amount of wall venting when a ground vapor retarder is present, all 11 foundation vents were retained. (Note that current North Carolina code does not require the ground vapor retarder, since these vents provide the net free area to meet the 1:150 ventilation area to crawlspace area requirement.) The floors of the control houses are insulated with well-installed R-19 Kraft-faced fiberglass batts.

The crawlspace vents of the experiment homes were sealed with rigid polystyrene foam and mastic or spray foam. Each of these closed crawlspaces has a sealed, 6-mil polyethylene liner covering the floor and extending up the foundation wall, stopping 3 inches from the top of the masonry to provide a termite inspection gap. The seams of the liner are sealed with fiberglass mesh tape and mastic, and the edges are sealed with mastic and mesh tape to the foundation wall or intermediate piers. The liner is mechanically secured to the soil with turf staples and to the foundation wall with a furring strip.

Mechanical drying in the closed crawlspaces is provided by a 4-inch duct that delivers 35 CFM of conditioned air to the crawlspace from the supply plenum whenever the air handler is running. As designed, the extra air simply exfiltrates through the crawlspace perimeter wall. No fan-timing or fan-cycling controls are used in the mechanical system, and no stand-alone dehumidifiers are used for moisture control. A balancing damper permits adjustment of the flow, and a backflow butterfly gravity damper with a nonmetallic hinge prevents movement of air from the crawlspace into the supply plenum when the system is off.

Four of the closed crawlspaces are insulated with R-19 kraft-faced fiberglass batts in the floor, and the other four are insulated with 2 inches of R-13 foil-faced polyisocyanurate foam on the perimeter wall and on the band joist. This closed-cell foam was installed with a 3-inch gap between the top of the foam and the bottom of the sill plate, to allow for monitoring of termite activity, and there is a second gap at the bottom of the foam insulation to prevent ground contact and wicking of moisture into the foam insulation. This foam meets the ASTM E84 and Factory Mutual FM 4880 requirements of the International Residential Code for use without a thermal barrier. The ground vapor retarder is attached to the inside surface of the foam insulation with fiberglass mesh tape and mastic. We specifically did not install the wall insulation in the typically recommended form, which specifies wall insulation to 24 inches below outside grade or horizontally on top of the soil in from the foundation wall for 24 inches. Instead, the bottom edge of the crawlspace wall insulation extends only 3 to 6 inches below outside soil grade level.

Instrumentation and Data Collection

We have been recording outside air temperature and moisture content using three battery-operated data loggers distributed across the development in locations shielded from rain and direct sun. We used the same type of logger to record conditions inside each house and inside each crawlspace. Measurements were recorded at 15-minute intervals. The house data logger was placed at the center of the house in the HVAC return closet, and two loggers (one extra for redundancy) were located together in the center of the crawlspace on the support beam for the floor joists. We measured wood moisture content on a 60-day interval at ten locations in each crawlspace, including sill plate, band joist, floor joist, center beam, and subfloor readings.

After seeing the potential for energy savings during a billing analysis in early 2003, we outfitted all 12 houses with electricity submeters to record exact energy consumption by each home's package unit heat pump system. The whole-house meter and the submeters are read monthly.

The crawlspace experiment has been monitored for more than three years as of this writing. Ongoing measurements clearly indicate that the closed crawlspaces consistently outperform the wall-vented crawlspaces in terms of both moisture control and energy use. What follows is a cross section of our findings from a one-year period ranging from June of 2003 through May of 2004. Monitoring of these crawlspaces will continue until March 2005.

Moisture Performance

Typical problems we see regularly in wall-vented crawlspaces include condensation on air conditioning ducts, water lines, and insulation; standing water on top of the ground vapor retarder; stained walls from water penetration and efflorescence; and water-saturated soil inside the crawlspace. The presence of liquid water, which supports the germination of mold spores, along with high relative humidity (RH) for extended periods of time, makes a vented crawlspace in the Southeast an ideal location for mold growth and wood decay to take hold.

The closed crawlspaces in our project perform notably better than the vented crawlspaces with regard to RH and wood moisture content (see Figures 1 and 2).

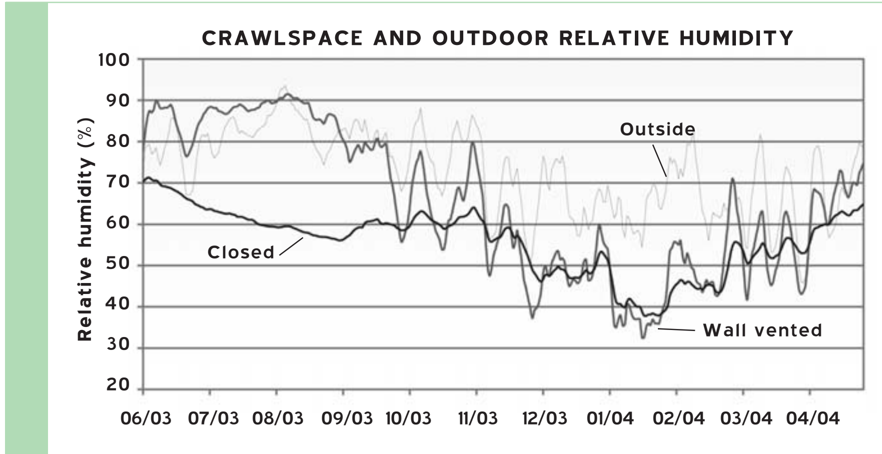

Figure 1. The closed crawlspaces performed better than the vented ones with regard to RH.

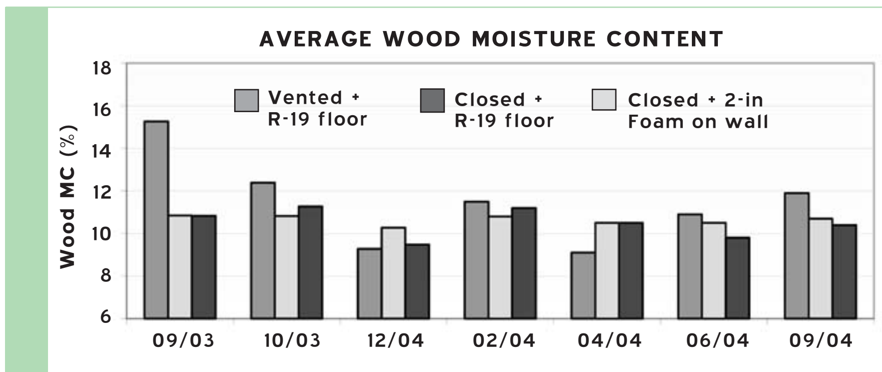

Figure 2. Closed crawlspaces were also better off than vented ones with regard to wood moisture.

TABLE 1. SUMMER (JUNE–AUGUST) RELATIVE HUMIDITY SUMMARY

	2002		2003	
RH Threshold	**Vented**	**Closed**	**Vented**	**Closed**
Above 90%	0%	0%	23%	0%
Above 80%	39%	0%	86%	0%
Above 70%	79%	0%	98%	5%
Above 60%	94%	0%	100%	64%
Above 50%	100%	100%	100%	100%

The fact that the framing lumber in the closed crawlspaces stays below the 12% wood moisture threshold is notable, not only because it reduces the likelihood of surface mold growth but also because dry lumber is less attractive to termites and very inhospitable to Southeastern species of wood-boring beetle pests.

As fate would have it, 2003 was the wettest year in recorded history in most of North Carolina, while 2002 was a record-setting drought year. In the summer of 2003, the RH in the vented crawlspaces stayed above 70% almost all the time, while the closed crawlspaces reached similar humidity levels only 5% of the time (see Table 1).

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The wall-vented control houses in this study have much better crawlspaces than the typical crawlspace we encounter in the field. The control houses have well-installed insulation and 100% ground vapor retarder coverage of the soil, and no problems with intrusion of liquid water from outside.

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A more typical vented crawlspace in North Carolina exhibits water leakage, poor drainage, a low-quality vapor retarder, if any, and various complications such as attached under-porch areas.

Clearly, the closed crawlspaces provided far better performance under the harshest conditions than the vented crawlspaces did under even the mildest conditions. These results highlight the fact that even a carefully installed and maintained ground vapor retarder covering 100% of the soil is not sufficient to control crawlspace moisture levels in a vented crawlspace. Well-constructed, extensively wall-vented crawlspaces without water intrusion and with a 100% vapor retarder ground cover may prevent wood rot in crawlspaces, but moisture control would be even worse in typical vented crawlspaces, given the usual poor quality of ground vapor retarder installation and maintenance in general construction.

During any warm season here in Princeville, the outside air contains more moisture than the air in the vented crawlspaces and instead of providing drying potential, contributes moisture. Consider this: The average dew point of the outside air at Princeville during the summer of 2003 was 73°F. This corresponds to relatively moderate conditions of 88°F and 60% RH. When that air goes into the crawlspace and encounters any object that is cooler than 73°F, the RH peaks at 100% and the water vapor in the air will condense on that object just as it would on a cool drink set out on the porch railing. Supply ducts (55°F–65°F), water pipes and tanks (55°F–65°F), and even the floor of the crawlspace (65°F–70°F) and the wood framing above (70°F–78°F) can experience this condensation, especially if the homeowner likes to condition the house to temperatures below 72°F. Even if conditions aren't bad enough for condensation, the RH of the air entering the crawlspace will still easily reach levels of 90% or higher for prolonged periods of time.

From our dew point measurements, we observed that the closed crawlspaces stay moister than the vented crawlspaces in winter. Limiting the moisture swing seen by the house over the course of the year reduces the likelihood of common cosmetic problems like shrinking and swelling of hardwood floors and trim carpentry and cracking or nail pops in drywall.

Energy Performance

Going beyond our expectations, the closed-crawlspace houses exhibit clear energy savings over the control houses (see Figure 3). This is true even for the four closed-crawlspace houses with wall insulation where we provided a termite inspection gap and did not install the insulation either down 24 inches below grade or 24 inches horizontally onto the crawlspace floor, as is typically recommended in energy codes and design guidelines.

For the 12 months analyzed, the floor-insulated closed-crawlspace houses have used an average of 15% less energy for space conditioning than the control houses. This represents a savings of approximately 870 kWh, or roughly $87, per year for each household. The wall-insulated closed-crawlspace houses have used, on average, 18% less energy than the control houses over the same 12-month period. This represents a savings of approximately 1,030 kWh, or roughly $100, per year for each household.

By the luck of the draw, the control houses ended up with higher occupancy numbers and more children than the experiment houses. While we could and did control for the variables of climate, site drainage, architecture, insulation, shell leakage, duct leakage, and mechanical equipment performance, there remain variations in base- load consumption and occupant thermostat settings among the groups that may be significant due to the small sample size.

We did not submeter the appliance, lighting, water heating, or exhaust fan loads, but noted that the total baseload use in the control houses was significantly higher—10%-20% in any given month—than that in the experiment houses over the entire year. The extra occupant and baseload in the controls would theoretically increase the need for cooling in the summer and decrease the need for heating in the winter. The difference in baseload use between the controls and the floor-insulated experiment houses is about the same in both summer and winter, which suggests that the surpluses offset each other in terms of heat pump energy used and saved in the control houses to compensate for the difference. However, there is more of a difference in baseload consumption between the controls and the wall-insulated experiment houses in the summer than there is in the winter, which makes the summertime wall-experiment house performance look better.

A review of the interior house data indicates that the control houses were operated 1°F –2°F cooler than the experiment houses in the summer and 1°F–2°F warmer than the experiment houses in the winter. To normalize the heat pump energy consumption with regard to these differences in thermostat setpoint, we graphed average temperature difference between outside and inside for each house in each month and plotted that against the kWh consumption for space conditioning for that house in the same month. The trendlines for each group of houses indicate the same seasonal patterns of performance that we observed in the raw submeter data.

We have not administered a formal survey of occupant comfort, but we recently had an experience that indicated that the crawlspace's moisture performance may also affect the occupant's thermostat settings. In June of this year, we modified the vented control crawlspaces to test a new version of a closed crawlspace. We installed a crawlspace supply duct to provide supplemental drying, as was done in the other closed crawlspaces. When we returned to the site four days later, one resident (who rarely adjusts her thermostat) excitedly told us that the day after we improved her crawlspace, she had to turn up her thermostat because she felt too cold in the house!

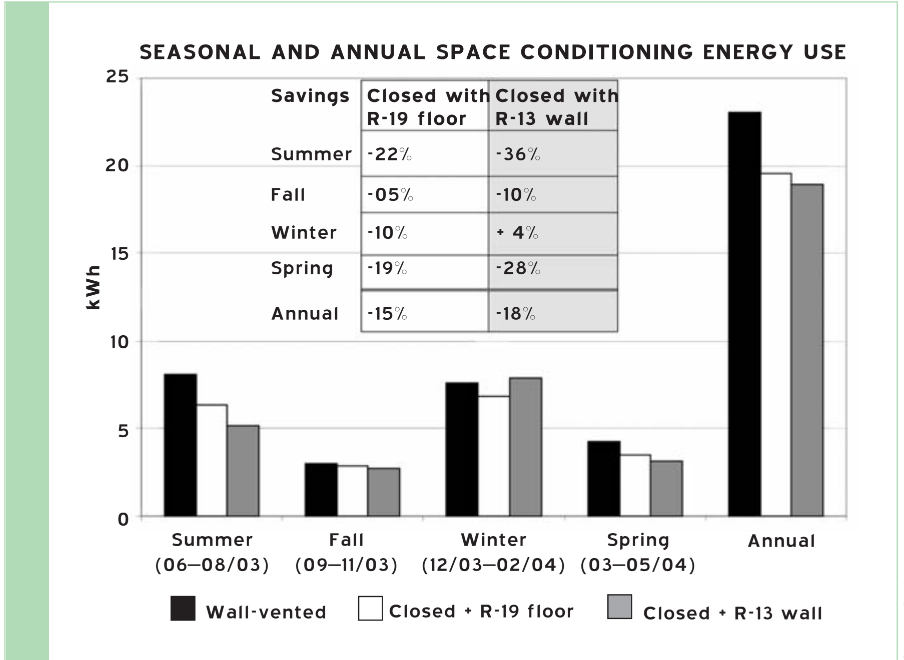

Figure 3. The submetered heating and cooling energy use for the period June 2003 through May 2004 indicates significant energy savings. (The bars represent the average per house usage for each group.)

Implications

This project is scheduled to conclude after the winter of 2004-05, when we will test one final configuration to assess the energy impact of 24 inches of foam insulation installed horizontally on the ground of the wall-insulated, closed-crawlspace houses. Final results and additional analysis will be posted on the project Web site, www.crawlspaces.org.

We're very excited about the degree of performance improvement shown by the closed crawlspaces, especially considering that our control houses represent the best possible performance of wall-vented crawlspaces. The vast majority of newly built vented crawlspaces are not installed or maintained to the standards used for this project. We believe that the findings of this study will transfer well to houses whose geometry and geography are similar to those of the study homes. However, additional consideration and study are required for houses in other locations or with different geometry. The energy results seem to indicate that wall-insulated closed crawlspaces will perform best in cooling-based climates; it seems likely that floor-insulated closed crawlspaces will perform best in heating-based climates. Of course, these homes have shallow foundations, and we have not tested crawlspace foundations with deeper footings, such as may be found farther north. A wall insulation strategy may prove to perform best in such houses. We won't know with any certainty how well the improvements in moisture and energy performance will transfer to houses in other climates until a number of such houses are actually constructed and monitored. We are now starting up a project to gather those data in multiple climate zones. This project will also demonstrate the ability of the production housing market to incorporate closed crawlspace technology into their construction processes.

Currently we find that the energy benefits of closed crawlspaces are not completely predicted by popular energy analysis software packages, so it may be some time before closed crawlspaces get their due respect when builders choose house specifications aimed at achieving a certified minimum energy rating. We hope that our research findings will spur refinements in the analysis tools, and that in the meantime the data will reinforce the argument that consumers can improve their homes by building or retrofitting a properly closed crawlspace. Data from a subset of two highly instrumented houses in the project are being used to validate a hygrothermal modeling tool under development at Oak Ridge National Laboratory.

Initial construction costs associated with building closed crawlspaces will almost always be more than for traditional wall-vented construction. As the new construction methods are evaluated by both builders and researchers, it will be important to factor in the value of reduced callbacks for moisture and mold complaints, the perception of enhanced value by the consumer, and the resulting improvement in sales price and volume, and reduced legal action. Reduced maintenance; a reduction in costly, long-term repairs; and significant energy savings will enhance the value of closed-crawlspace construction to the consumer. Other Advanced Energy research is focused on the potential indoor air quality (IAQ) and health impacts of closed-crawlspace construction, which could indicate a whole new class of benefits from this technology. The future could include insurance premium savings for houses built on certified closed crawlspaces.

One specific measure of IAQ that we have addressed in this project is radon risk. Long term radon monitoring was performed in all the crawlspaces and conditioned areas. Slightly higher average concentrations were found in the closed crawlspaces, with measurements averaging 0.5 picocuries per liter (pCi/l) in the vented crawlspaces and 1.1 pCi/l in the closed crawlspaces. The radon measurements in the conditioned space do not show any difference correlated with the type of foundation they are on; all houses average approximately 0.5 pCi/l with a maximum reading of 0.7 pCi/l in any house. The commonly accepted action level for radon remediation is 4 pCi/l. We believe that a closed crawlspace should be thought of as a short basement when it comes to radon mitigation, since similar measures are applicable for assessment and control of risk where needed.

Professionals seeking to install closed crawlspaces face a formidable learning curve to be successful. As with all aspects of the construction industry, choosing the correct materials, tools, and techniques is only half the battle; training and quality assurance are also critical to ensure that the right work is performed the right way at the right time. A good closed crawlspace must be designed properly with regard to control of internal and external water sources from the very start of construction. You must choose a drying mechanism—conditioned air supply or a dehumidifier, for example—for long term, active moisture control. Other important design issues include pest management, combustion safety, fire safety, proper insulation, and radon control, if applicable.

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This floor-insulated crawlspace has a termite inspection gap at the top of the vapor retarder. Note that penetrations are thoroughly sealed with mastic.

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This wall-insulated crawlspace uses 2-inch-thick foil-faced polyisocyanurate insulation. The foam plugs in the band could be replaced by sections of batt insulation. A termite inspection gap is visible at the top of the wall insulation.

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The butterfly damper of this crawlspace supply opens while the system is running. The assembly is sealed with mastic and supported by strapping to ensure that the butterfly damper continues to operate properly.

Implementation requires close coordination with building officials, since the building codes are lagging behind this technology, and many current codes provide only a tortuous compliance path for closed crawlspaces. During our work to set up the houses in this study, the scattered and conflicting nature of different building code elements governing closed crawlspaces became evident. For closed crawlspaces to be practical for both builders and code enforcement officials, we are recommending a separate section in the code that is specifically dedicated to these construction methods. We have helped the North Carolina Building Code Council and code services staff to draft new code language for closed crawlspaces with the assistance of the North Carolina Structural Pest Control Board, the National Pest Management Association, and several installers of closed crawlspaces across the state. The draft language has been approved by the Building Code Council and is now under final review by state agencies before it becomes available for use.

Pricing contracts, and managing the safety and training of employees, are both especially important when one is developing and offering any new service. In closed-crawlspace work, coordination with other trades becomes an even greater factor, since they will be literally walking all over that work to do their own. As one example of pricing, closed crawlspaces in one North Carolina market, assuming a 2,000 ft^2 house, range from $4,200 for a simple, new-construction project to $6,700 for a complex retrofit project. Including wall insulation adds $1,500–$3,000 to the sale for these examples, minus the cost of floor insulation if it is a new construction project. Complexities that increase the price over the simple baseline include the extra length of perimeter for houses with lots of angles, the number of support columns that break up the floor of the crawlspace, and a sloping grade that requires additional material and fitting on the crawlspace walls. Retrofit complications can also include existing water problems, contaminated or damaged materials, and debris that must be removed before the work starts.

Closed crawlspaces clearly represent both a new business opportunity and a risk management service for the shelter industry. Firms that rise to the challenge of implementing specifications and procedures for installing closed crawlspaces as a moisture control technique will be able to profit from the knowledge that they are also giving their customers the benefit of energy savings.

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FOR MORE INFORMATION:

We are by no means the first to investigate the moisture performance of wall-vented crawlspaces. Previous work includes a review of crawlspace investigation and regulation through history (Rose 1994) and a review of many of the issues associated with wall vented crawlspace construction (Rose & TenWolde 1994). These reviews, along with several others, are included in Recommended Practices for Controlling Moisture in Crawl Spaces, ASHRAE Technical Data Bulletin, volume 10, number 3.

Davis, Bruce and William E. Warren. “Field Study Pilot Report: A Field Study Comparison of the Energy and Moisture Performance Characteristics of Ventilated Versus Sealed Crawlspaces in the South,” Raleigh, N.C.: Advanced Energy, 2002.

Davis, Bruce, William E. Warren, and William B. Rose. “Technology Assessment Report: A Field Study Comparison of the Energy and Moisture Performance Characteristics of Ventilated Versus Sealed Crawlspaces in the South,” Raleigh, N.C.: Advanced Energy, 2002.

Davis, Bruce, and Cyrus K. Dastur. “Moisture Solution Becomes Efficiency Bonanza in the Southeastern United States,” in *Proceedings of the 2004 Summer Study on Energy Efficiency in Buildings,* Vol. 1. Washington, D.C. American Council for an Energy Efficient Economy, 2004.

Hill, William W. “Measured Energy Penalties from Crawl Space Ventilation,” in *Proceedings of the 1998 Summer Study on Energy Efficiency in Buildings,* Vol. 1. Washington, D.C. American Council for an Energy Efficient Economy, 1998.

Rose, W. B. “A Review of the Regulatory and Technical Literature Related to Crawlspace Moisture Control,” in *ASHRAE Transactions,* Vol. 100 Pt. 1. Atlanta, Ga. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1994.

Rose, W. B. and A. TenWolde. “Issues in Crawl Space Design and Construction — a Symposium Summary.” ASHRAE Technical Data Bulletin: *Recommended Practices for Controlling Moisture in Crawlspaces* 10 (3), 1994.