Moisture Performance of Closed Crawlspaces and their Impact on Home Cooling and Heating Energy in the Southeastern U.S.

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ABSTRACT

This study compared the performance of closed crawlspaces, which had sealed foundation wall vents, a sealed polyethylene film liner, and 1.0 ft^3/min (0.5 L/s) of HVAC supply air for each 30 ft^2 (2.8 m^2) of crawlspace ground surface, to traditional vented crawlspaces with wall vents and polyethylene film covering 100% of the ground surface. The study was conducted at 12 owner-occupied, all-electric, single-family detached houses with the same floor plan located on one cul-de-sac in the southeastern United States. Using the matched pairs approach, the houses were divided into three study groups of four houses each. Comparative moisture measurements for these crawlspaces and submetered heat pump kWh use were recorded. Findings supported that for the humid conditions of the southeastern United States, properly closed crawlspaces were a robust measure that produced substantially drier crawlspaces and significantly reduced occupied space conditioning energy use on an annual basis.

INTRODUCTION

Wall-vented crawlspaces are widely used in building construction throughout North America. 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. Crawlspaces can be a source of a host of moisture problems. The crawlspace project is a multi-year effort focused on improving the moisture and energy performance of crawlspace systems. Of particular interest are crawlspaces built in the humid southeastern United States and other locations with similar climates.

We are not the first to investigate the moisture performance of wall-vented crawlspaces. Rose (1994) wrote a review of crawlspace investigation and regulation through history. Rose and TenWolde (1994) wrote a summary paper to review many of the issues associated with wall-vented crawlspace construction. The above material, along with that of several others, is included in Recommended Practices for Controlling Moisture in Crawl Spaces.[1] Additionally, during the first year of this study, in 2001, Rose contributed an update of the historical review of crawlspace regulation as part of a technology assessment report (Davis et al. 2002). These articles reference a wide range of the authors and activities over the years that built the understanding of wall-vented crawlspace moisture problems and solutions.

A goal of this research was to demonstrate practical, easily transferable, and clearly understandable dry crawlspace construction techniques that would, in addition to solving a multitude of moisture problems, be at least energy neutral and at best would reduce energy consumption for occupied space conditioning.

Current building codes generally enforce the use of foundation wall vents to provide for air exchange between the crawlspace and outside. The intention of these requirements has been to provide a drying mechanism for these spaces. However, applying a psychrometric chart to southeastern summer outdoor air and crawlspace air demonstrated that the moisture load of

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[1] Recommended Practices for Controlling Moisture in Crawl Spaces, ASHRAE Technical Data Bulletin, volume 10, number 3; available for download only at <www.ashrae.org> (in Bookstore, Out-of-Print Books).

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outdoor air often exceeded that of crawlspace air. The result has been that crawlspaces became wetter rather than drier from the exchange of air.

During the humid season, for crawlspace houses located in the southeastern United States, it has been common experience within the building industry to find mold growing on crawlspace framing, moisture beads in floor batt insulation, and condensation forming on truss plates as well as on air-conditioning equipment and ducts. Builders, HVAC contractors, and insulation contractors have received complaints because of these moisture conditions. Additionally, hardwood floor installation companies have been asked to correct floors that cup or buckle following move-in and use of air conditioning.

To address these and other widely divergent building moisture issues, the crawlspace project was set up to investigate the hypothesis that properly closed crawlspaces are a robust measure that could reduce the incidence of this family of problems that are related to crawlspace moisture. A second hypothesis is that these closed crawlspace construction methods would not increase and could potentially decrease the energy necessary to provide for space conditioning.

THE RESEARCH

Experiment Design

This paper reports on a study that was conducted at 12 identical, owner-occupied, all-electric single-family detached houses located on one cul-de-sac, six on each side of the street, in the southeastern United States. The 1040 ft^2 (97 m^2) houses were newly constructed on traditional wall-vented crawlspaces. Shortly before move-in during the spring of 2001, homeowners of all 12 houses agreed to participate in the study. Using the matched pairs approach, the houses were divided into three groups of four houses each. Additionally, the study design included two different phases.

The houses were all built on controlled fill soil, which added to the uniformity of the site. All houses had a series of building and duct air leakage performance measurements to confirm similarity of construction tightness. Given that the houses were substantially airtight, an outside air intake duct with integrated filter was installed for each heat pump system. This system provided 40 ft^3/min (19 L/s) of outside air into the house when the heat pump conditioning the house was operating.

Phase One, June 2001 Through May 2003

The three crawlspace groups were: control, experiment one, and experiment two. The control group had wall foundation vents and 100% of the ground surface was covered with 6-mil polyethylene film. The seams were overlapped 6 in. (15 cm) but were not sealed. The polyethylene film was held in place with turf staples. Although the building code allowed a reduction in the amount of wall venting when a vapor-retarding ground cover (VRGC) was present, all eleven, 8 × 16 in. (20 × 41 cm) foundation vents were retained. The floor was insulated with well-installed, R-19 fiberglass batt insulation placed between the joists with vapor retarder up. No liquid water was allowed to enter the crawlspace.

The first experiment group had the wall foundation vents blocked and sealed from the inside with foam plugs and mastic. The ground and walls were covered with a continuous, sealed liner system of 6-mil polyethylene film that was also sealed to the interior piers and to the foundation wall near the top. The top 3 in. (7.6 cm) of the foundation was not covered with the liner but was painted with white mastic. This provided a gap for termite inspection. Foundation penetrations and cracks were sealed to reduce air infiltration. The floor insulation was removed and no foundation wall insulation was added, thus producing closed but uninsulated crawlspaces.

The second experiment group was modified to be the same as the experiment one group but had the addition of approximately R-3 rockwool insulation blown onto the foundation wall liner membrane and band joist. The 3 in. (7.6 cm) gap for termite inspection was retained.

Duct air leakage was measured for all 12 houses. Duct repair was primarily limited to items that would ensure that the ducts would not become disconnected during the study. There were two exceptions. One system needed two duct runs replaced because of a plumbing leak at move-in. The other system was repaired to correct a substantial return duct air leak. That repair brought its duct air leakage in line with the rate of duct air leakage of the other houses. This measured duct air leakage was retained throughout Phase I of the study.

Phase Two, June 2003 Through March 2004

Air sealing work was applied to all 12 houses during April and May 2003. This involved sealing all the floor penetrations and substantially sealing the existing duct air leakage. R-19 fiberglass batts, vapor retarder up, were added between the floor joists to the experiment one group, which previously had no insulation, and in experiment two houses, the rockwool wall insulation was replaced with 2 in. (5 cm) of R-13 foam insulation. Please note that the termite view strip was retained and that the wall insulation was not installed in the typically recommended form that specifies wall insulation should be continuous from the subfloor to 24 in. (61 cm) below outside grade or horizontally on the soil in from the foundation wall for 24 in. (61 cm). All 12 houses received the same battery of pre- and post-air leakage measurements that they received at the beginning of the study. In addition, both experiment one and experiment two crawlspaces were fitted with an HVAC supply air duct that was adjusted to deliver 35 cfm, or 1 ft^3/min (0.5 L/s), of supply air per 30 ft^2 (2.8 m^2) of crawlspace ground surface. This supply air was delivered whenever the thermostat called for the heat pump to condition the living space of the house. To prohibit passive airflow between the crawlspace and the heat pump duct system, the crawlspace supply was fitted with a passive backflow damper that remained closed when the heat pump was off and only opened when the heat pump was running. Each heat pump was fitted with a standard utility electric meter so that kWh use could be recorded each month. All houses retained the outside air duct that provided 40 ft^3/min (19 L/s) of filtered, outside air to the house when the heat pump was on.

Measurement

To record outside air temperature and moisture content, three battery-operated data loggers were placed in protected locations at the experimental site. The same type of data logger was used for recording conditions inside each house and inside each crawlspace. Data were recorded every 15 minutes. One data logger was placed in the center of the house at the return grille, and two loggers (for redundancy) were located together in the center of the crawlspace on the support beam for the floor joists. These loggers were designed to operate from –22°F to 122°F (–30°C to 50°C) and from 0 to 100% relative humidity [RH]. The RH sensor was designed to withstand intermittent condensing environments up to 86°F (30°C) and noncondensing environments above 86°F (30°C). In the high resolution mode, temperature accuracy equaled ±0.33°F at 70°F (±0.2°C at 21°C). RH accuracy equaled ±3% from 32°F to 122°F (0°C to 50°C) and ±4% in condensing environments. As mentioned above, each heat pump was submetered with a standard utility kWh meter to track occupied space conditioning energy. The total house kWh was recorded from the utility customer account meter. Readings were taken from both meters at each house once per month. The submeters were calibrated to ±0.2% accuracy under both light- and full-load conditions, and readings were rounded to units of whole kWh. Wood moisture content readings were taken manually at several dedicated locations in the crawlspace during specific site visits. The pin wood moisture meter readings were adjusted for both temperature and species. The wood moisture content meter had an accuracy of ±0.5% for the 6% to 12% range, ±1.0% for the 12% to 20% range, and ±2% for the 20% to 30% range. The noncontact temperature meter was designed to provide an accuracy of ±1% of reading or ±2°F (±1°C), whichever was greater, for ambient operating temperature from 73°F to 77°F (23°C to 25°C). For ambient temperatures between 0°F and 73°F (–18°C to 23°C) the accuracy was rated at ±3°F (±2°C).

While the study generated many other data sets, this article's focus on crawlspace moisture and occupied space conditioning energy use are depicted in Figures 1 through 9. In several of the figures, the data for experiment one and experiment two houses were so similar that they were combined under the title "closed" for closed crawlspaces. The 15-minute raw data were averaged to provide one plot point for each 24-hour period. For Figures 1 through 6, the graphed lines were generated using a seven-day rolling average to depict the general trends in the data.

Findings

Figures 1 and 2 graph relative humidity in the crawlspaces for both Phase I and II. They show that for the critical summer months the relative humidity in the closed crawlspaces remained substantially lower than in the wall-vented crawlspaces. This is especially significant for the Figure 2, Phase II graph because the summer of 2003 was one of the wettest on record for the test location and the closed crawlspaces still remained dry. For the summer seasons, air in the closed crawlspaces was generally below 60% relative humidity and air in the wall-vented crawlspaces was often above 80% relative humidity. For Figure 1, the June 2001 period reflects two start-up activities for the study. First, the relative humidity for the closed crawlspaces was as high as that for the vented crawlspaces. This is the point in time that the experiment one and experiment two crawlspaces were closed. Second, a couple of weeks later the closed crawlspaces dropped to 40% relative humidity. This represents the brief period of time during which we experimented with using small dehumidifiers as a supplemental drying mechanism. The dehumidifiers were then disconnected and the closed crawlspaces stabilized between 55% and 60% relative humidity with the measured duct air leakage as the supplemental drying mechanism. The transition of the crawlspaces from Phase I to Phase II took place during April and May 2003 and required that the closed crawlspaces be open for an extended period of time. The transition is reflected in the rise in relative humidity shown in Figure 1. In Figure 2, for June 2003, it can be seen that the transition work was completed and the crawlspaces were again closed and began to dry. With the opening and adjustment of the HVAC supply air duct, the necessary supplemental drying mechanism was achieved (1 ft^3/min [0.5 L/s] of supply air per 30 ft^2 [2.8 m^2] of crawlspace ground surface). For the air temperatures measured during these summer periods, high relative humidity was associated with increased wood moisture content and with mold growth in the vented crawlspaces.

Figures 3 and 5 graph the crawlspace dew-point temperatures for both Phase I and Phase II. The data for the closed crawlspaces show the drier characteristic when the summer season is examined. Figure 3 graphs summer data for 2001 and 2002, which again shows the difference in moisture between closed and wall-vented crawlspaces. Both 2001 and 2002 had slightly lower dew-point temperatures than did the 2003 data. Outside air dew-point temperatures for Phases I and II are shown in Figures 4 and 6 as references and show the moisture load potential that would impact the crawlspace conditions if outside air had entered a crawlspace. Figure 5 shows that the dew-point temperature of the air in the closed crawlspaces for much of the summer of 2003 stayed below 60°F (16°C), while that in the wall-vented crawlspaces stayed above 70°F (21°C).

For Phase II, wood moisture content averages for a dedicated sample of floor joists in the three study groups is represented in Figure 7. Wood moisture content for the wall-vented crawlspaces had a large range from the end-of-summer high of above 15% to a low of around 9.0%. Joists in the two experiment groups retained more stable wood moisture content from a high of around 11% to a low of around 9.5% to 10%.

Figure 8 is provided to more clearly show the potential for outside air to increase the moisture content of a wall-vented crawlspace during the summer 2003 Phase II period. The

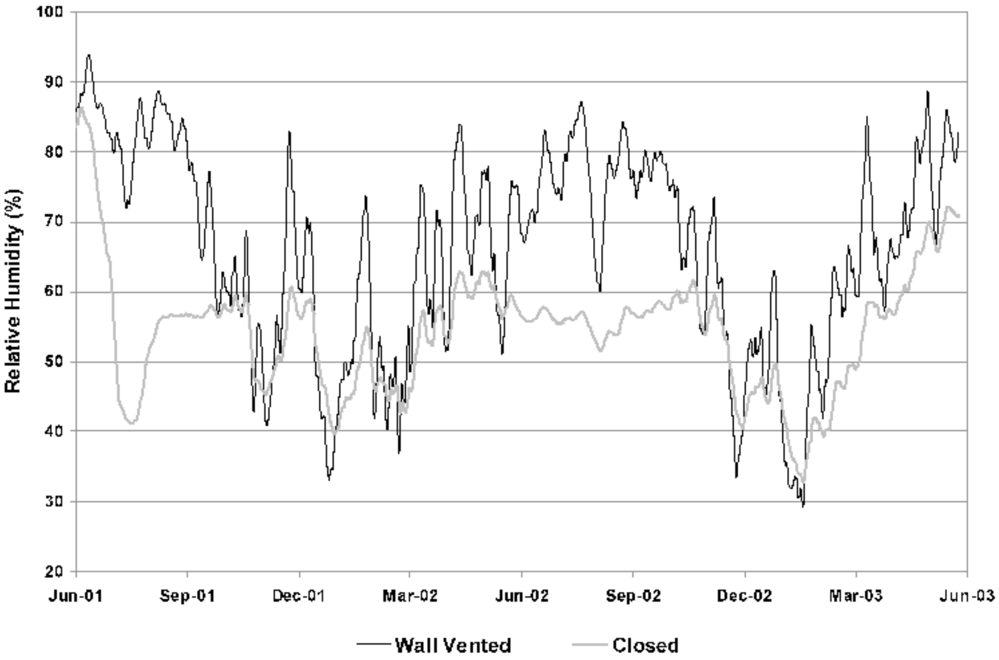

Figure 1 Relative humidity in the crawlspaces, Phase I.

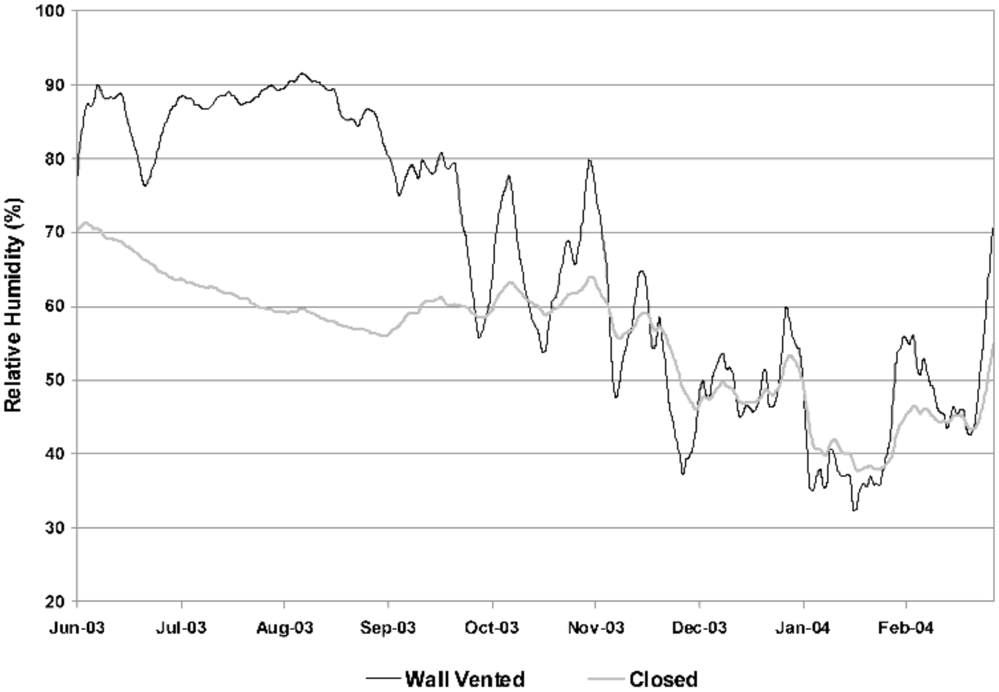

Figure 2 Relative humidity in the crawlspaces, Phase II.

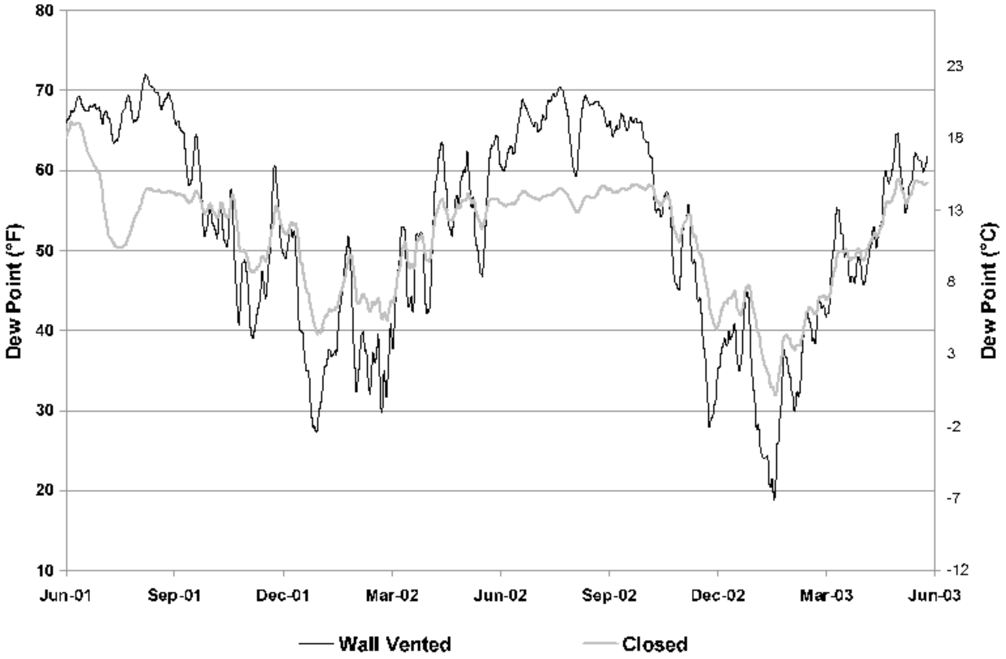

Figure 3 Crawlspace dew-point temperatures for Phase I.

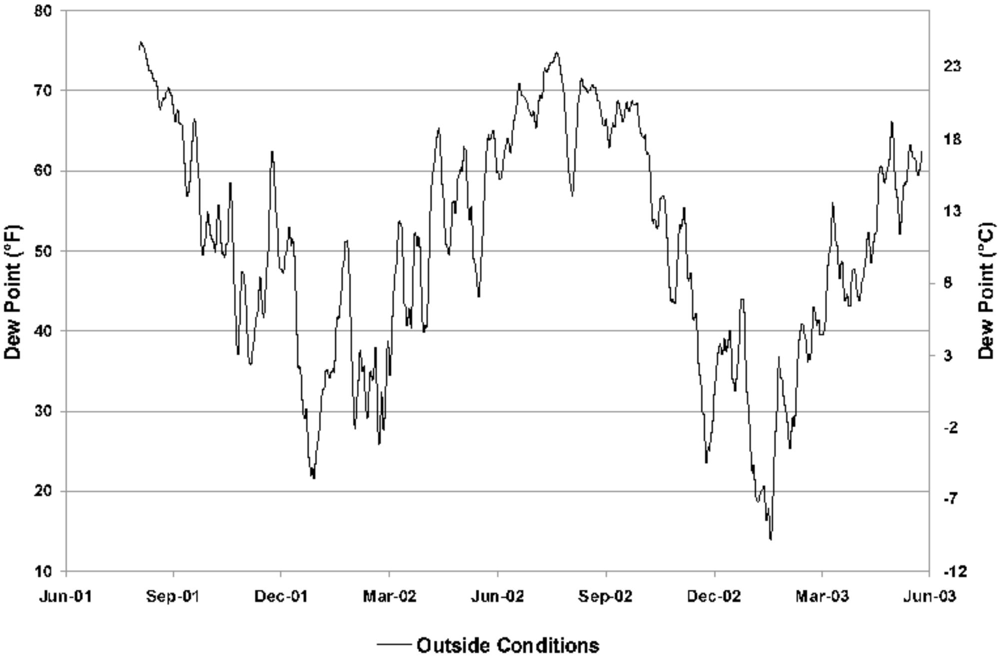

Figure 4 Outside air dew-point temperatures for Phase I.

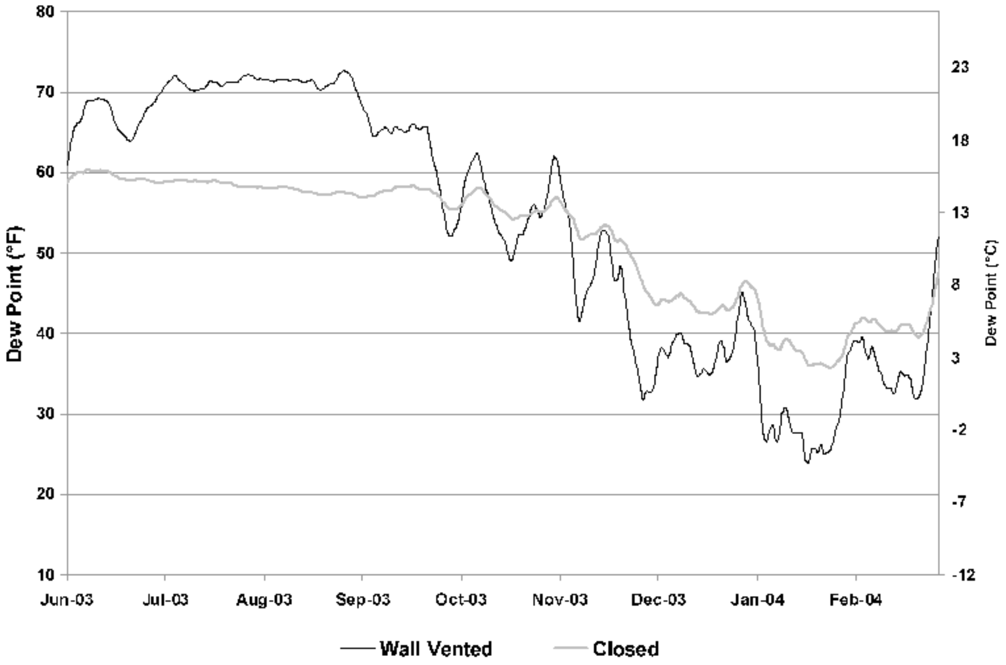

Figure 5 *Crawlspace dew-point temperatures for Phase II.*

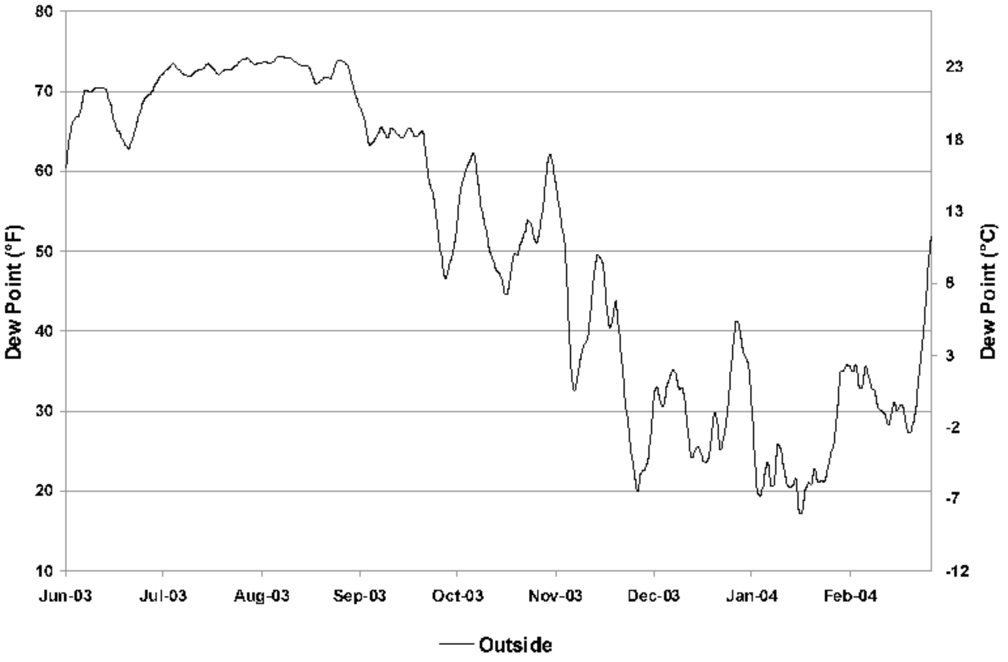

Figure 6 *Outside air dew-point temperatures for Phase II.*

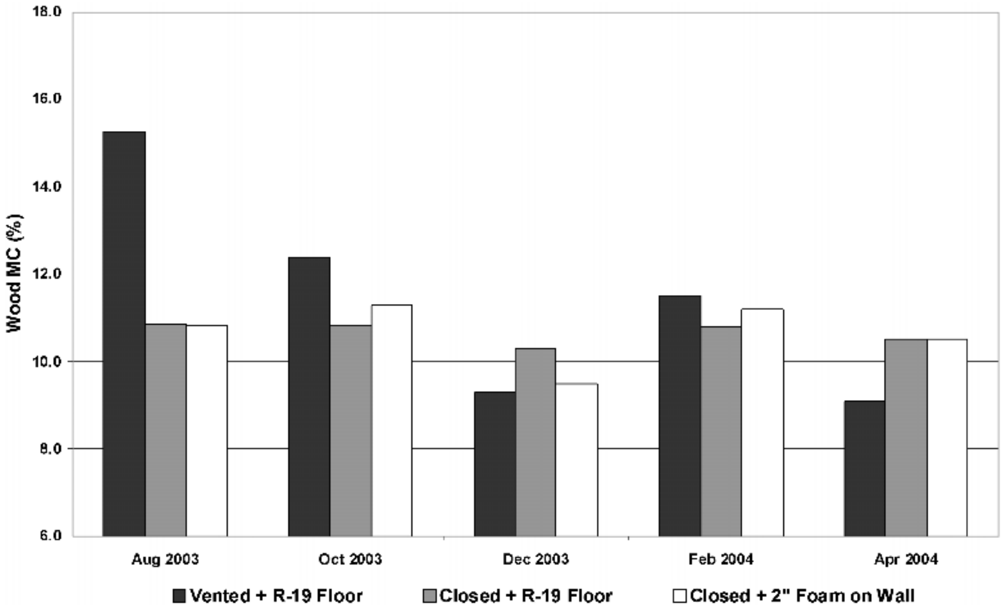

Figure 7 *Wood moisture content averages for a dedicated sample of floor joists in the three study groups, Phase II.*

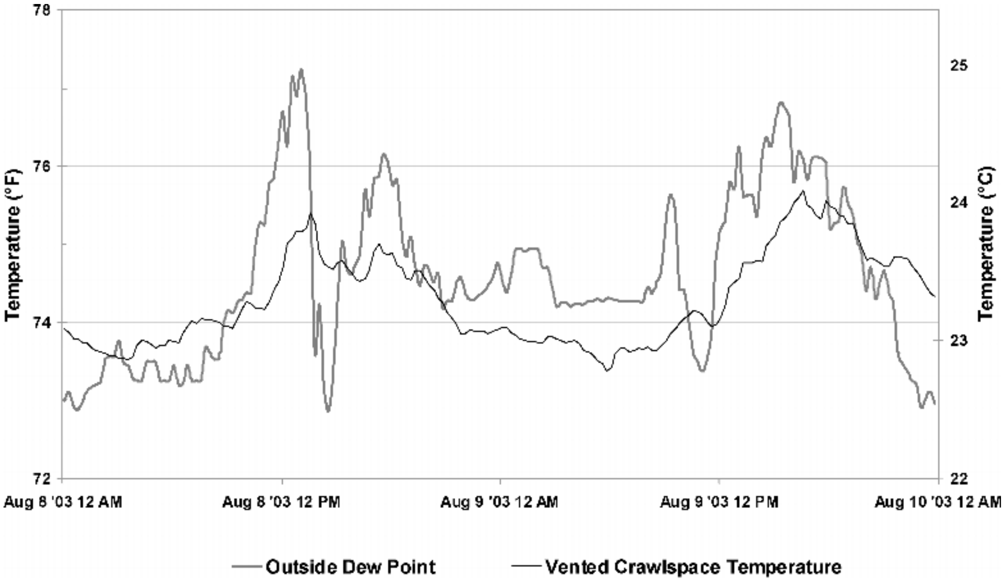

Figure 8 *The potential for outside air to increase the moisture content of a wall-vented crawlspace during summer 2003, Phase II.*

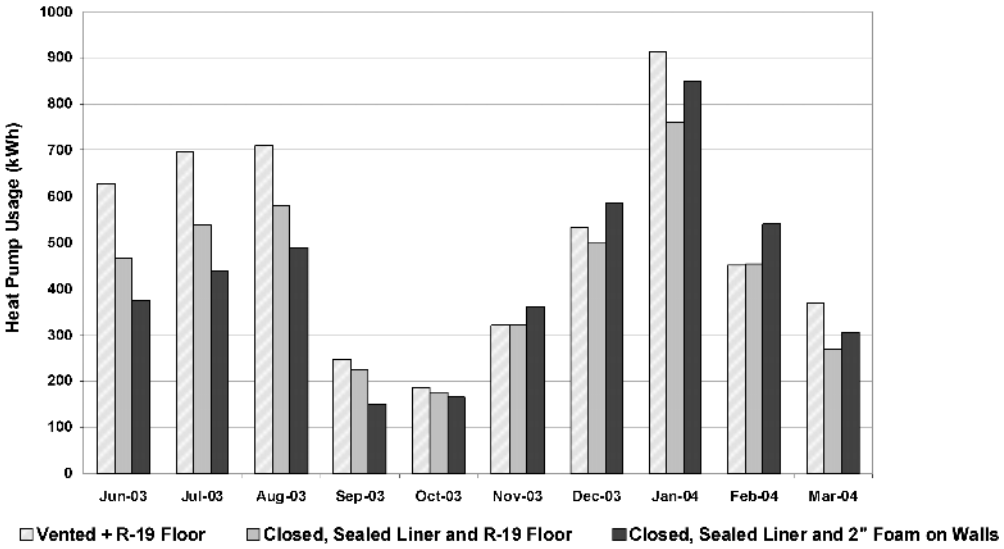

Figure 9 *The average energy used for occupied space conditioning for a house in each of the three study groups for each month since the beginning of Phase II in June 2003.*

outside air dew-point temperature is the average value for the three outside data loggers. The crawlspace temperature is the average value for the four wall-vented crawlspaces. This graph is the 15-minute data points plotted over a 48-hour period. If outside air entered the wall-vented crawlspaces, as is the design intention, it would encounter surfaces at or below its dew point for a majority of this time, resulting in condensation. These conditions occur repeatedly throughout the summer season. Such condensation on wood framing is absorbed and is likely to be slow to reevaporate and provides a microclimate to support mold growth.

Figure 9 represents the average energy used for occupied space conditioning for a house in each of the three study groups for each month since the beginning of Phase II in June 2003. We had been advised when we were beginning this study that we should not expect to measure any space conditioning energy savings during the summer season from our experiment modifications. However, when we analyzed utility billing records for the first year, we realized that there could be notable energy savings. With the installation of the submeters on the heat pumps for Phase II, we recorded the different space conditioning energy use patterns for the three different study groups for the different seasons. For the 10 months displayed, the closed, floor-insulated houses (experiment one) have each used an average of 15.3% less energy, 772 kWh ($77), for space conditioning than the vented houses (control). The closed, wall-insulated houses (experiment two) have each used an average of 15.7% less energy, 795 kWh ($80), than the controls.

The experiment one houses did not save as much as the experiment two houses during the summer, but they did outperform them during the winter. However, both experiment groups used less energy for space conditioning than the wall-vented crawlspace group. The energy use data have not been normalized for indoor thermostat setting. While we did not attempt to control homeowner thermostat setpoint selection, an examination of the indoor temperature data found that each of the three groups as a whole were within one to two degrees Fahrenheit of each other throughout all seasons.

DISCUSSION

Phase I of this study demonstrated that a measured amount of duct air leakage would provide crawlspace moisture vapor control. However, we are not advocating duct leakage as a standard moisture vapor control strategy. For a temporary, three-week period during Phase I, the study also demonstrated that small dehumidifiers would easily provide control for crawlspace relative humidity. The relative humidity was reduced to 40% during that period. Phase II demonstrated that a measured amount of HVAC supply air (1 ft^3/min [0.5 L/s] for each 30 ft^2 [2.8 m^2] of crawlspace ground surface) would also provide the necessary supplemental moisture vapor control.

Well-constructed, extensively wall-vented crawlspaces without water intrusion and with a 100% vapor retarder ground cover may prevent wood rot in crawlspaces. For these houses, the wood moisture content in the vented crawlspaces did rise but did not reach 19% during the summers studied. This crawlspace configuration did not, however, prevent moisture condensation and surface mold growth in these same crawlspaces. It is these additional conditions, plus the energy savings, that tilt the balance toward the construction of new or the retrofit of existing crawlspaces that are properly closed. Crawlspaces with reduced wall vent area as allowed by code were not examined in this study and it is not known whether that configuration would perform as well as the wall-vented crawlspaces in this control group.

The minimum goal of this study was to have the experiment modifications result in comparable space conditioning energy consumption relative to the controls. However, both experiment house groups actually reduced energy consumption by 15% relative to conventional crawlspace construction. The closed, wall-insulated (experiment two) houses performed best during the summer. The closed, floor-insulated (experiment one) houses performed best during the winter. The magnitude of the impact of this research for national energy policy is important. What these levels of energy savings could mean for crawlspace houses in the United States has not yet been calculated, but it would be significant. In addition to the potential annual energy savings, there are the added benefits of preventing several common moisture problems, which, in turn, reduce the rate of deterioration of structures and the costs of those associated repairs. Pleasantly (and fortunately!), the construction solution that provides these benefits is a practical, straightforward measure.

When the choice is made to place insulation on the foundation wall for a closed crawlspace, current code requires that the insulation be continuous from the subfloor down to 24 in. (61 cm) below outside grade or to turn the insulation in and lay it on the ground to achieve the equivalent of that 24 in. (61 cm) of insulation. This is referred to as the "L-shaped" installation of insulation. This method of installation is not viable for two reasons. First, there are the multiple stakeholders in crawlspace construction whose positions will need to be accommodated. For example, the pest management industry desires an inspection gap at the top of the masonry foundation wall. We provided a 3 in. (7.6 cm) gap or insulation void. Second, there is also the need for construction practicality when changing crawlspace construction techniques. With regard to the L-shaped installation, there are no practical materials at this point in time that would not interfere with access, inspections, real life construction sequences, and potential pest treatments. Our energy savings were achieved without continuous insulation and without the L-shaped application. The wall insulation was installed to a depth of only about 3 in. (7.6 cm) below outside soil grade. Had the inside soil level been deeper relative to outside soil level, the insulation would have been installed farther below outside soil grade.

A final caution is appropriate. The findings of this study would transfer well to houses with similar geometry and geography as the study homes. However, additional consideration and study are required for houses in other locations and with different geometry. Given the matched pair experiment design, there should be considerable transfer of results for both moisture control and energy savings. But we will not know how well the moisture and energy performance will transfer to production houses in other climates until a number are actually constructed. Explanation of these energy performance results includes the influence in closed crawlspaces of the soil temperature, the change in building air leakage patterns, and the reduction in building moisture load. Another portion of this study will try to predict results ahead of time. A hygrothermal model is being tested against the actual performance of two of these study houses. Once the model is calibrated, it will be used to project performance for a number of construction types in different climates.

The dry crawlspace construction techniques employed in this study should provide for long-term success. The supplemental drying mechanism was provided by the house space conditioning equipment. Homeowners would be motivated to repair the system should it malfunction and thus will maintain the crawlspace drying function. The airflow damper was manually set and should not require additional adjustment. The backflow damper on the HVAC supply air to the crawlspace was a simple gravity model with a nonmetallic hinge. The liner material is reasonably durable and repairable, and there are more durable materials available for areas with heavy use. The outside ventilation air brought in by the heat pump return duct more than made up for the airflow to the crawlspace. Air that would normally flow out of the house because of the outside air intake was used to dry the crawlspace. The homeowner was provided with a remote sensing temperature and relative humidity meter so that they would be able to be informed if the crawlspace relative humidity were to rise. It is always the case that homeowner behaviors can overwhelm any building or equipment system. For the system to maintain its performance, the homeowner must change air filters, provide basic home and equipment maintenance over time, and observe the meter reading and react as necessary. On the construction industry side, there are always builders and subcontractors who provide faulty housing. This is true today for houses built on slabs, basements, or wall-vented crawlspaces. There are several alternative approaches to maintain these systems. For example, some forward-thinking pest control operators are installing dehumidifiers in closed crawlspaces and including equipment service during their annual crawlspace inspection for termites. Other manufacturers have liquid water alarms to install in crawlspaces. Closed crawlspace construction is not a magic, silver bullet that will solve all construction wrongs. Its practical construction methods must also be properly applied.

Initial information from contractors who are providing closed crawlspace systems to general contractors for new construction has found packages priced from \$1.50 to \$3.50/ft^2 for a range of installations. These sample installation costs do not take into account the cost reductions that the builder will realize from not installing certain other features that are replaced by the different closed crawlspace systems. 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 both by 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 resulting improvement in sales price and volume; and reduced legal exposure. Reduced maintenance, a reduction in costly, long-term repairs, and significant energy savings will enhance the value of closed crawlspace construction to the consumer. The future could include insurance premium savings for houses built on certified closed crawlspaces.

RECOMMENDATIONS

There is a need to make building codes accommodate and provide for closed crawlspace construction. During our work to set up the houses in this study, the scattered and conflicting nature of different elements within the building code 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 created that draft code language for a separate section. As long as closed crawlspace construction is presented as a fragmented set of exceptions in the code for traditional wall-vented crawl spaces, it will be subject to varying interpretations by code bodies unfamiliar with and uncertain about these closed crawlspace construction techniques.

Properly closed crawlspace strategies must address the following design issues: (1) pest management, (2) moisture management, (3) fire safety standards, (4) thermal standards, (5) combustion safety, and (6) radon management. Successful implementation strategies will require attention to the following construction management issues: (1) understanding crawlspaces as physics- and logic-free zones (people have beliefs about crawlspaces rather than knowledge) and the necessity of beginning discussions with that in mind; (2) selection of a closed crawlspace system; (3) pricing closed crawlspace work; (4) managing labor (confined space safety, hard work, job skills, pay); (5) managing job site logistics; and (6) applying and adjusting codes and working with code officials. Closed crawlspace construction is a very effective measure, but it is not a magic bullet. One can inadequately apply closed crawlspace details and sequences as easily as any other construction component. Installers have to responsibly plan and deliver the work to achieve the total package of benefits.

CONCLUSIONS

Closed crawlspace construction techniques are robust measures in the hostile southeastern humid climate for providing dry crawlspaces for new construction and for retrofitting existing houses. These crawlspaces have a sealed polyethylene film liner system to reduce moisture intrusion from the soil and the masonry walls and from outside air flow into the space. They require that both ground and surface water be prevented from entering the crawlspace. They also require some type of supplemental drying mechanism to control the limited amount of moisture vapor that will still migrate to the space and would accumulate over time. Phase I of this study has demonstrated that a measured amount of duct air leakage would provide that control. However, we are not advocating duct leakage as a standard moisture control strategy. For a temporary period during Phase I, the study also demonstrated that small dehumidifiers would easily provide even greater control for crawlspace relative humidity. Phase II has demonstrated that a measured amount of HVAC supply air (1 ft^3/min [0.5 L/s] for each 30 ft^2 [2.8 m^2] of crawlspace ground surface) also provided the necessary supplemental moisture vapor control. Other supplemental drying mechanisms have not yet been evaluated. Closed crawlspace construction produced an environment that slowed down and reduced the extremes of the moisture and temperature swings that were experienced in wall-vented crawlspaces.

Closed crawlspace experiment groups one and two maintained air relative humidity below 60% and dew-point temperature below 60°F (16°C). Wall-vented crawlspaces maintained extended periods of time with air relative humidity above 80% and dew-point temperature in the mid-seventies (21°C). In addition they experienced periodic episodes of dew-point condensation. These conditions resulted in microclimatic conditions that supported mold growth and moisture deterioration of materials and equipment located in these types of crawlspaces.

Insulation in closed crawlspaces in the southeastern United States has been demonstrated to be effective when fiberglass batts were applied in the floor cavity. It has also been effective when foam board was applied against the inside of the foundation wall. These two approaches have different performance characteristics for the different seasons. On an annual basis they both outperform conventional crawlspace construction methods with a 15% reduction in space conditioning energy used. This magnitude of space conditioning energy savings was unexpected and when combined with the moisture benefits of closed crawlspaces bolsters the argument for adoption of closed crawlspaces in the construction industry. Future study is necessary to determine how well these results will transfer to other houses with different geometry and located in different climates. However, several production builders and some product manufacturers are already benefiting by promoting dry crawlspace construction techniques, and this segment of the construction industry is poised for substantial growth. The widespread application of these construction methods where it is determined to be appropriate will benefit homeowners, construction businesses, energy policy, and the environment.

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REFERENCES

ASHRAE. Recommended Practices for Controlling Moisture in Crawl Spaces, ASHRAE Technical Data Bulletin, volume 10, number 3.

Davis, B., W.E. Warren, and W.B. Rose. 2002. Technology Assessment Report. A field study comparison of the energy and moisture performance characteristics of ventilated versus sealed crawl spaces in the south. Advanced Energy, Raleigh, NC.

Rose, W. B. 1994. A review of the regulatory and technical literature related to crawl space moisture control. *ASHRAE Transactions* 100(1). Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Rose, W.B., and A. TenWolde. 1994. Issues in crawl space design and construction— A symposium summary. Recommended Practices for Controlling Moisture in Crawl Spaces, ASHRAE Technical Data Bulletin, volume 10, number 3. <www.ashrae.org>.