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Effective Floor Cavity and Knee Wall Construction Techniques in Two-Story Homes in Hot Climates

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ABSTRACT

It is understood that the floor cavity between the first and second floors of residential construction should be isolated from unconditioned space by an effective air and thermal barrier. Although the construction materials utilized likely have reasonable air and thermal resistance, the application may not be applied correctly or some applications may not hold up well over time. A research project of existing homes (Withers and Kono 2015) measured impacts from this problem and identified durable construction techniques and cost-effective repairs. Floor cavity pathways to unsealed attics combined with natural or mechanical driving forces result in air transport between the attic and the floor cavity. Unconditioned air leakage into residential floor cavities has been found to cause elevated space-conditioning costs, increase peak electric utility demand, and cause moisture-related problems.

This paper provides new research on measured cooling and heating impacts from floor cavity and knee wall repair. Overall, 56 multistory homes were inspected and had performance tests completed, with 12 monitored for energy savings from floor cavity and some knee wall repairs. This paper describes practical inspection, testing, and dependable construction methods. Construction methods discussed consider challenges such as contractor experience, limited working access, and complex structural geometry. The measured energy savings from floor cavity repairs combined with cost-effective repair methods in 12 homes was found to be able to pay for repairs in about 3 to 4 years. Evidence from one home has shown that significant building moisture damage was eliminated as a result of floor cavity repair.

INTRODUCTION

Floor cavities are assumed to be an interstitial space within the primary air and thermal barrier of the home; however, even relatively minor defects around this space can have negative consequences. Portions of floor cavities are often exposed to attic spaces. Attic air can be transported into floor cavities through natural or mechanical forces. Natural forces such as wind can drive air through attic venting and create pressure differentials able to drive unconditioned air into floor cavities (Figure 1). The term *wind washing* is sometimes used to describe this. Wind washing is a general term referring to diminished thermal control caused by air movement over or through an intended thermal barrier. Given the extreme thermal conditions of vented attics, convective air transport can still transport air into floor cavity openings, even without wind forces. Mechanical forces induced by duct leakage can also create pressure differentials that will move unconditioned air into and out of floor cavities. During hot humid weather, condensation may occur on cold supply duct surfaces within the floor cavity, resulting in ceiling moisture damage. In cold climates, cold air from wind washing can chill surfaces within the interior floor space and result in frozen water pipes in severe cases. Besides potential building damage, diminished comfort and increased space-conditioning energy use may also result from poorly insulated and sealed floor cavities. Enlightened contractors already understand the importance of creating a barrier between floor cavities and attics, but failures continue to occur, and older construction has a legacy of fail-

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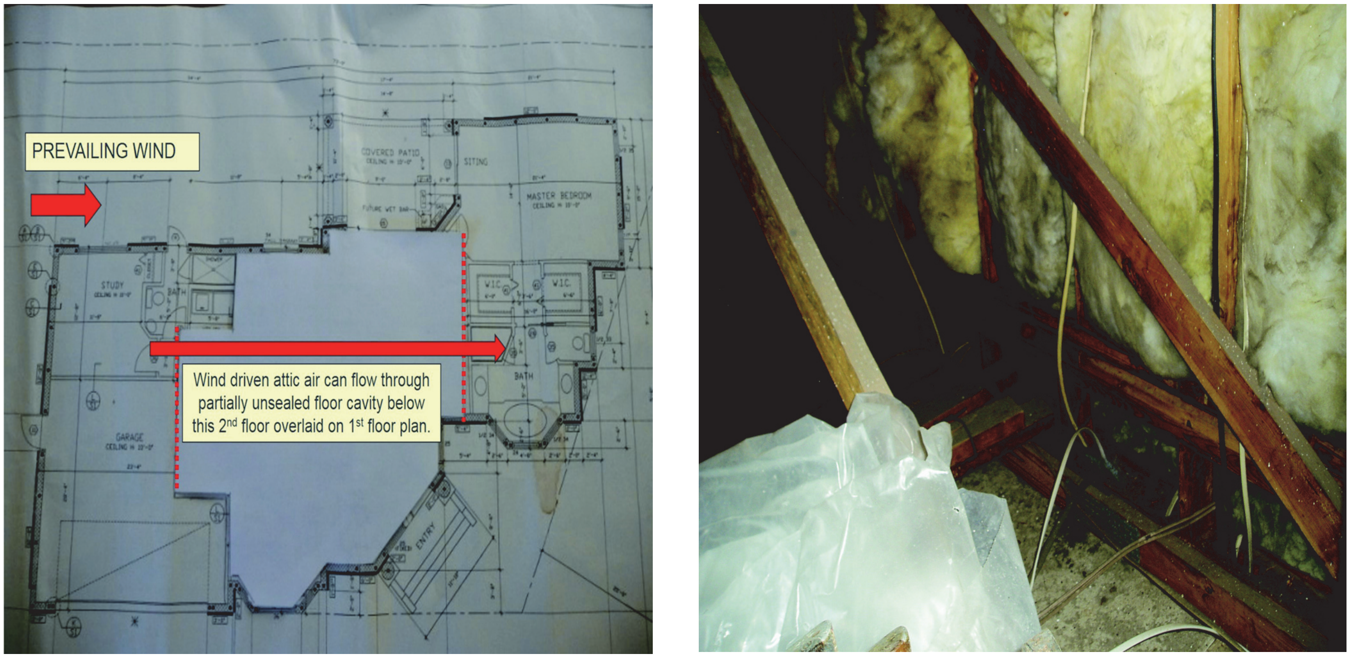


(a) (b)

Figure 1 *(a) Conceptual illustration of wind washing through floor cavity shown on a floor plan. (b) View from within attic of poorly insulated knee wall and floor cavity with areas of missing and compressed batts. Batts were dirty from years of air movement across them. Attic soffit vent is nearby in dark left region of photo.*

ures. An adequate air and thermal barrier may have been installed but another trade penetrated or removed portions without repairing it. In the worst cases there are no air or thermal barriers installed at all.

BACKGROUND

The past emphasis on wind washing has concentrated on U-factor impacts and specific types of construction or scenarios (Bankvall 1978; Harrje et al. 1985; Lecompte 1990; Silberstein et al. 1991; Uvslokk 1996; Janssens and Hens 2007). Knee wall, floor cavity, and wind washing problems have been recognized in other published literature, such as that by Sidall (2009), Lstiburek (2005), and EERE (2012), which provided some information on best practices in specific applications. While wind washing has been known about for years, there had been no obtainable published results associated with measured energy impacts or cost-benefit analysis of retrofit opportunities. This paper is based upon results from more recent wind washing research in Florida carried out in two phases. The first phase resulted in published results covering details on the study method and results but was limited to measured cooling energy impacts in six homes (Withers and Cummings 2010; Cummings and Withers 2012). A second phase was added to increase sample size and measure heating and cooling impacts in six more homes (Withers and Kono 2015). The primary goal of the Florida study was to evaluate inspection methods and determine the cost-effectiveness of retrofit solutions for wind washing in two-story homes in hot humid climates. The retrofit solutions covered here may also be applied to new construction primarily in hot- or warm-dominant climate regions.

INSPECTION METHODS

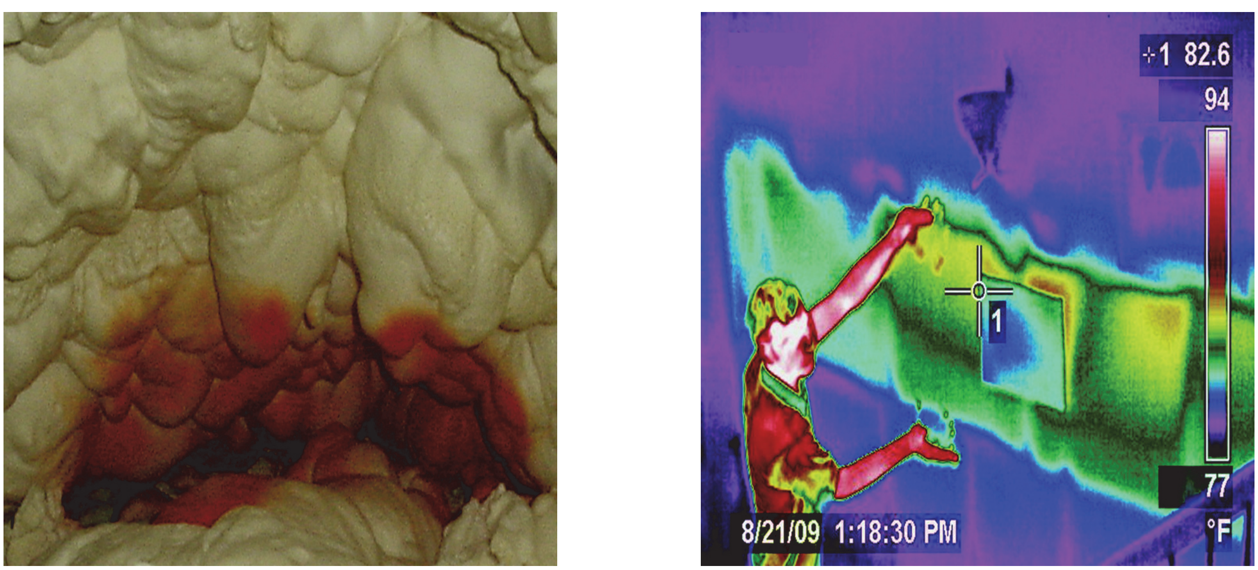
House performance-related tests were completed in 56 Florida single-family multistory homes of various ages. The purpose of the house tests was to gather data relevant to wind washing and to find reasonable candidates for monitoring and retrofit. The field assessments characterized wind washing failures of the house air and thermal boundary. Assessments included a house tightness test, primary air boundary evaluation, air differential pressure mapping, air leakage assessment, duct leakage assessment, infrared scans of house surfaces, and visual inspections.

A comprehensive visual inspection completed within the attic focused around floor cavities or dropped ceiling areas was found to be the most important and effective method of identifying homes needing floor cavity repair. Figure 1b shows a commonly found issue of poorly fit knee wall insulation and areas of floor cavity open to attic spaces commonly over garage areas. Inspections should focus efforts on locating an effective air and thermal barrier over the floor cavity. Some homes have very small attic areas that were either inaccessible or had limited accessibility for inspection. Equipment such as a bore scope may be needed in such cases, or material disassembly may be warranted in some instances, such as moisture damage issues. Figure 2 shows an example where soffit venting was removed for inspection in areas where floor cavities terminated nearby in a home with severe moisture damage found to be related to floor cavity wind washing. Spray foam applications can also have failures if not applied carefully. Figure 3a shows an area of leakage within an attic that was found and painted so the contractor could come back to seal it.

Infrared (IR) thermography and pressure differential measurements were useful diagnostics under specific circumstances. IR thermography worked best with large temperature

(a) (b)

Figure 2 *(a) Sections of vented soffit were removed to inspect floor cavities not accessible from attic space. (b) View within cavity sections found pathways about 0.05 m (2 in.) high under floor joist supports that connect to small attic space beyond.*



(a) (b)

Figure 3 *(a) Air leak in spray foam painted for contractor to come back and seal it. (b) Inspection using IR camera shows elevated wall temperature at floor cavity area.*

differentials occurring between attic and indoors for at least a few hours. Figure 3b shows warm summer indoor wall temperatures due to wind washing into the floor cavity. This is the same home of the floor plan shown in Figure 1a. At times this author found it more useful to use the IR camera from within the attic looking at knee wall and floor cavity areas instead of from indoors.

An indication of whether the floor cavity is more indoors than outdoors regarding the primary air barrier was evaluated using differential pressure (dp) measurements while the house was depressurized to 0.2 in. w.c. (50 Pa) with reference to outside. This diagnostic can be performed quickly if a house tightness test is already planned. The project evaluation results indicated that this diagnostic was clearly not adequate on its own to be a replacement of visual inspection to determine if a floor cavity has a significant potential for wind washing (Withers and Kono 2015). Measuring the house pressure with reference to the floor cavity could be considered a simple and quick diagnostic test that can be done to determine if more detailed visual investigation of the floor cavity is warranted, particularly if the measurement is between –0.136 in. w.c. (–34 Pa) to 0 in. w.c. (0 Pa) (house depressurized). The dp diagnostic could be useful to prompt a more careful visual inspection and to consider possible leakage to areas not easily accessible that may require some disassembly.

WHY TIGHT INSULATED FLOOR CAVITIES MATTER

Inadequately insulated and sealed floor cavities can result in occupant health and comfort problems, building damage, and elevated heating and cooling costs. Sealed floor cavities also help minimize duct leakage impacts occurring within these spaces. Return duct leakage decreased 37% and supply leakage decreased by 38% from sealing floor cavities and making no direct repairs to ducts in 10 homes. This is not surprising since ducts were located within the floor cavity of all these homes. Sealing the floor cavity is a more cost-effective way to limit duct leakage impacts within the floor cavities of existing constructions. House airtightness, ACH_{50}, became 11% tighter and homes with vented recessed can lights in the floor cavity had house tightness reductions double (23% tighter). ACH_{50} is an industry measure of building airtightness measured at a pressure of 0.2 in. w.c. (50 Pa) and normalized by the house conditioned volume. Implementing good practice in new construction would not necessarily add cost if current building codes are followed and enforced. Failure to implement good practice or damage created by trades may have an average cost of repair around \$350. The range in homeowner repair cost can vary widely depending upon particular circumstances and materials used—from as little as \$170 up to \$800 or more in very large homes.

Moisture Issues

In heating-dominant climates, water damage within the floor cavity is most likely to occur due to water pipe freeze damage resulting in water leakage or condensation on cold building surfaces. Weatherization programs have worked at improving this in older homes over the years, but a breach or degradation over time can increase the potential of this problem during prolonged severe winter conditions. Cooling-dominated climates are more likely to experience moisture issues in the summer due to condensation on cool duct or building surfaces and material damage associated with moisture absorption under specific circumstances. One of the homes had severe moisture damage exhibited by mold and mildew stains on first-floor ceilings occurring under cold supply air ducts, severely warped wood flooring on the second floor, and cracked wood and paint on sections of stair risers. Photos and additional details on this can be found in the paper by Withers and Cummings (2010). Prior to repair, a section of faced batt that had been wrapped around a cold air supply duct where it entered the floor cavity was found to be drenched in condensation. Wood moisture content was measured before and after floor cavity repairs in this home during hot and humid weather. Moisture content in wood stair sections closest to the floor cavity were at 13.1% and gradually decreased to 9.5% on lower sections farther away from the floor cavity. Interior air conditions were cool and dry and wood furniture had a moisture content around 7% to 8% by comparison, which is expected for an air-conditioned space. The average stair moisture content decreased to 9.0% after repair and cracks in paint and wood stair risers decreased within a few weeks of repair. Evidence of duct condensation also stopped after repair. Other homes in the Florida study did not exhibit such severe moisture problems. The severe moisture issues in this home were attributed to severe floor cavity leakage on opposing sides of the home (complimentary pathways) oriented in line with daily occurring wind combined with the occupant preference for low interior summer temperatures (73°F [22.8°C] overnight and 76°F [24.4°C] daytime).

Energy

Overall cooling energy savings resulting from floor cavity repair varied from 1% up to 33%, and heating savings varied from 0% to 39%. It was not surprising that some homes did not demonstrate high energy savings, since the study homes had varying degrees of thermal bypass issues. The case with no heating savings is most attributed to mild winter monitoring conditions and the preference for low heating set point, which did not provide much heating data for analysis. The previously discussed house with severe moisture issues had 8% cooling savings, but it was a large upscale home that used a lot of cooling energy, so the annual cooling energy savings of 2770 kWh/yr and peak cooling reduction of 1.8 kW were quite large. Table 1 shows the predicted annual and peak energy savings based on 12 homes; heating results are based on 5 homes. Regression least-squares best-fit analysis was performed from monitored heating and cooling data along with local monitored indoor and outdoor conditions for each home to create equations that could be used with typical meteorological year (TMY) data of four Florida cities to predict the annual cooling and heating savings for typical weather conditions. The average predicted annual cooling and heating energy savings was 1034 kWh per home from wind washing repairs. This was potentially $119 saved each year by each homeowner based on an average rate of $0.115/kWh. The savings can be expected to last as long as the home, because the repair lifetime has no limit under reasonable circumstances. These results are limited here to represent hot and humid climate regions; monitoring in colder climate regions should be done to more accurately reflect regional construction practice and measurement under much more extreme winter conditions.

Table 1. Predicted Average Annual and Peak Energy Cooling and Heating Impacts from Floor Cavity Repairs

	Annual Cooling kWh	Summer Peak Hour Cooling kW	Annual Heating kWh	Winter Peak Hour Heating kW
Pre-repair	9392	3.66	502	1.86
Post-repair	8483	3.27	378	1.53
Savings	909	0.39	125	0.33
Savings %	9.7%	10.7%	24.9%	18.7%

SEALING FLOOR CAVITY AREAS EXPOSED TO ATTIC SPACES

New Construction

Good air and thermal barriers begin with a good design. First, designs should not place structural members within about 18 in. (0.45 m) of the floor cavity or knee wall to allow room to correctly install continuous sections of air and thermal barrier materials. This distance is less critical if spray foam is used to insulate and seal the floor cavity and knee walls. Figure 4a shows structural members directly against the floor cavity, which makes it difficult to install a continuous air and thermal barrier with faced batts. Figure 4b shows the roof truss further away from the plywood placed over the knee wall and floor cavity. The continuity of air barrier should be maintained from the roof deck at top of knee wall, covering the knee wall, and continuing down over the floor cavity opening and onto drywall of first floor below. If rigid panels or fabric-based air barrier are used, all panel seams should be sealed with materials appropriate for attic conditions. Insulation should be applied with approved mechanical fastening materials and methods. This is especially important for thick batts. If applied meticulously, kraft-faced batts have the potential to perform well and to be the lowest-cost option. However, the long-term durability is less certain than rigid or spray-applied materials. New homes with batt insulation are more likely to use R-30 batts. Batts are prone to sag in vertical installations, do not hold up well to physical impacts, and are not typically repaired after intentional displacement or penetration. Since ducts,

(a)

(b)

Figure 4 *(a) Existing construction showing multiple truss sections tightly against each other and the knee wall and floor cavity structure that does not allow sheet stock to simply be applied continuously as cover. (b) New construction shown uses plywood sheet over knee wall and floor cavity sections with room to seal seams and add insulation to improve wall R-value.*

wires, and pipes are typically run inside floor cavities, each trade should be held responsible for maintaining the integrity of the air and thermal barrier around their work. Protect cold supply ducts from condensation in vented attics whenever envelope insulation is placed in contact with the exterior duct surface (see Figure 5), particularly in cooling-dominated climates. Condensation potential can be decreased by wrapping ducts at contact points with a thin insulative wrap having an exterior vapor barrier before insulation is placed in contact with it. This cannot guarantee that condensation will never occur, but it has been demonstrated to work in homes with cooling set points maintained above 74°F (23.3°C). In regard to limiting general water vapor issues, materials with low vapor permeability, less than 1, should not be placed on the dominantly coldest side of a wall/cavity barrier assembly.

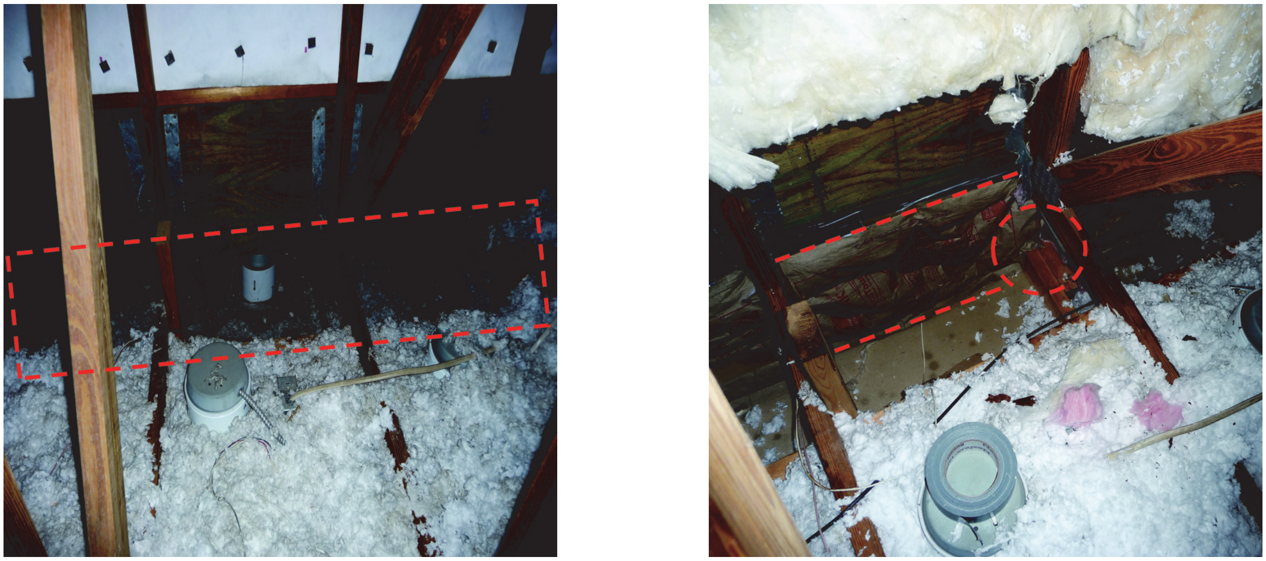
Existing Construction

Implementing repairs in existing construction can be more challenging. Two basic methods were implemented within the Florida study. One method used low-density spray foam and the other used well-placed kraft-faced insulation batts. Floor cavity and knee wall wind washing repairs typically use much less insulation material than is common in conventional insulation jobs. The average repair area was 169 ft^2 (15.7 m^2) with a range of 48–510 ft^2 (4.5–47.4 m^2). The relatively small repair area and high mobilization cost of spray foam rigs can make repair by spray foam twice as costly as using batts or insulated board stock. Low-density spray foam had a starting cost of at least $370 but is more likely to be around $650, compared to batts, which could average more around $300. Homes with garage attic space next to second-story floor space (the most common location) generally have easy access and often require less than 40 ft^2 (3.7 m^2) of material to seal and insulate the floor cavity from the attic. If the knee wall is also insulated, the total area typically increases to 70–100 ft^2 (6.5–9.3 m^2). Repair cost of an easy-to-access floor cavity and knee wall area of about 100 ft^2 (9.3 m^2) and 2.8 person-hours could cost as little as $173 and even less, at about $85, if only the floor cavity is sealed with faced batt and sealant. Of all homes having floor cavity pathways, about 25% of those inspected had very small leakage pathways (longitudinal seams) that could be sealed inexpensively using canned expansive foams for perhaps as little as $20–$40 in retail material costs.

An example of a repair using faced batts is shown in Figure 6. The kraft face is intended to perform as the air barrier so it must be carefully sealed to the rigid materials around the perimeter of the floor cavity. Figure 6b shows the kraft facing the attic. To comply with fire-related building codes, the facing should not be left exposed to the attic. The facing was placed in this way to show how it must be able to seal around the perimeter and framing members. The correct way to install is to generously apply an appropriate construction adhesive, caulk, or foam on the entire perimeter of floor cavity and apply the kraft face against the adhesive towards the inside of the cavity with the unfaced insulation side visible from the attic. The batt should also be mechanically fastened to the perimeter using staples. If preferred, an air-barrier wrap or rigid board stock could also be used as the air barrier in place of faced batt as long as it is also covered by an appropriate code-approved ignition and thermal barrier.

(a) (b)

Figure 5 *(a) The cold air supply duct is first wrapped using a thin insulation sheet with a vapor barrier on the exterior face. (b) Then insulation can be placed around and in contact with the barrier wrap, where a low-density spray foam was used.*



(a) **(b)**

Figure 6 *(a) An open dropped ceiling connected to a large open floor cavity was sealed and insulated using faced batts. (b) The batt paper facing should not be left exposed to the attic. Consult local codes to address approved fire safety practices for each specific type of repair.*

While using relatively inexpensive materials (such as kraft-faced insulation batts) can result in lower installation costs, specific installation details must be carefully followed to ensure effective air and thermal barrier performance. Materials have to be carefully cut to fit within framing, be fastened mechanically, and have a functional air seal. Tight attic spaces or complex framing require much more labor and skill to apply the inexpensive materials and the final results are less likely to be successful compared to spray foam. If duct leakage is known to exist within the floor cavity, an airtight seal is even more important. Therefore, spray-applied low-density foam may be the best choice in certain circumstances. *2012 International Residential Code*, Section R316.5.3 (ICC 2012), requires a fire ignition barrier on foam insulation exposed in attic spaces. Some manufacturers may accomplish this by spraying the attic exposed foam with a code-approved fire ignition barrier coating, also referred to as an *intumescent material*. Mineral fiber or cellulose insulation 1.5 in. (0.038 m) thick or 1/4 in. (0.0064 m) thick hardboard or wood structural panel are some other examples of approved ignition barrier materials noted in this code. One should be aware of local code requirements and practices that may vary from this.

CONCLUSION

Floor cavities can be insulated and sealed with a variety of materials relatively inexpensively in well-designed new construction. In retrofits, the primary consideration is cost and limitation of the work space. Using materials readily available at home improvement stores will likely be less expensive than using spray-applied foams. However, that alone does not imply the lowest-cost materials are the best choice. Complex structural geometry and tight restrictive working environments may make it difficult and even impossible to make good airtight installations that maintain continuity of the air and thermal barriers. Low-cost material such as faced batt insulation is more prone to damage in areas occasionally accessed by trades or homeowners. Therefore, spray-applied foams may be the best or only choice in certain circumstances. Methods discussed in this paper managed moisture, decreased air leakage, and reduced energy in a hot-and-humid-dominant climate. However, local codes and best local practices should be followed along with application by knowledgeable contractors to help ensure a safe, healthy, and durable result in other climate regions.

Based on monitoring results in Florida, the total annual estimated energy savings from repair was 1034 kWh/year. At a cost of \$0.115/kWh, this equates to \$119/year saved in consumer energy costs. It is believed that the average cost of repair could be \$350, assuming about 75% of homes can be sealed by professional contractors using off-the-shelf air and thermal barrier products and the other 25% are sealed using professionally applied low-density spray foam. The average simple payback would be about three years. Average peak cooling and heating reduction were about 0.3 kW and 0.4 kW, respectively, providing additional benefit to electric utilities and consumers with peak use charges.

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