Measured Energy Penalties From Crawl Space Ventilation

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ABSTRACT

While there is no convincing technical basis for current code requirements for crawl space ventilation, most codes still require operable vents and the practice is well established among builders and architects. While the evidence against venting is compelling to many if not most in the research community, builders and code officials apparently want to see hard evidence. In this research project I measured weekly energy consumption for space heating for a 1150 square foot home in a climate with 5900 heating degree days. The house was built to meet the 1992 Model Energy Code and the perimeter of the crawl space was insulated with R-10 foamboard. The supply ducts of the gas-fired, forced air system are located in the crawl space and were carefully sealed and pressure tested. Utilizing a "flip flop" research design, with the crawl space vents open one year and closed the next, I measured the "energy penalty" resulting from leaving crawl space vents open during the winter. This measured penalty or, conversely, the savings from closing and insulating the vents was 21% (12 MMBtu/yr) in year two of the research. Savings were 32% (19 MMBtu/yr) in the most recent winter, in which the crawl space access cover was insulated and made airtight in addition to closing and insulating the vents.

Introduction

The building science community appears to be nearing consensus regarding the current code requirements for vented crawl spaces. Not only does there appear to be no convincing technical basis for these crawl space ventilation requirements, but it is apparent that in many climates ventilation of crawl spaces during the summer months can actually serve to add moisture to the crawl space, not remove it. Nevertheless, most residential building codes still require operable vents and the practice of venting crawl spaces is well established among builders and architects.

While there remains some confusion on the issue, most of the building science community would agree that the code should be changed, or at minium clarified, because it makes no sense from a moisture control standpoint. Another strong impetus for change may lie in the energy penalty associated with crawl space venting as it is used in this part of the country. While it seems obvious that allowing cold winter air into the area beneath the floor of a home should result in increased energy consumption, especially if the crawl space contains uninsulated ducts, just how big is this "energy penalty?" The objective of this research was to measure the additional energy used for space heating in one home as a result of open or poorly sealed and insulated crawl space vents. Stated another way, what are the savings that can be realized from closing and insulating these vents?

A Ridiculous Research Question?

One of the most useful comments received from the peer review process said, in essence, nice research, but why would anyone investigate such a silly thing in the first place? "Even though the 92 and 93 MEC allow it, why would anyone insulate the crawl space walls and then leave big holes in the walls to vent the crawl space?" Moreover, the reviewer continued, measuring humidity levels in a crawl space which frequently contains standing water seriously skews any results. Unfortunately, the home examined in this research is all too typical of homes being built in eastern Indiana, and probably elsewhere as well. This fact, perhaps more than any research reported herein, may be the most important finding in this paper. There exists a large and serious gulf between what is understood by the building science community and what is being built by the residential construction industry.

Conflicting Code Requirements

There are two types of codes that apply to residential crawl space construction across much of the United States — codes dealing with moisture and codes dealing with energy conservation. One says, "thou shalt vent crawl spaces," the other says, "thou shalt insulate crawl spaces." In Indiana the residential building code is based on the CABO (1989) *One and Two-Family Dwelling Code* which requires a minimum net area of ventilation openings not less than 1/150 of the crawl space area or, if the ground surface is treated with an approved vapor barrier material, 1/1500 of the crawl space area. Indiana's energy conservation code, modeled on the CABO (1992) Model Energy Code (MEC), requires either R-19 floor insulation (between the crawl space and the subfloor) or perimeter insulation resulting in a U-value of 0.10 Btu/hr-°F-ft^2 for the wall of the crawl space. Since most crawl spaces contain ducts and water lines susceptible to freezing, most builders in our area elect to use perimeter insulation.

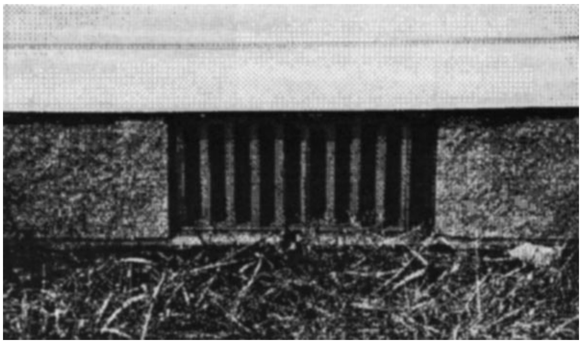

Figure 1. *A typical screened and operable vent used in crawl spaces.*

Strange but true construction practices

Builders, architects and code officials are good at following the rules, no matter how silly the outcome. Standard practice in this area is to meet the energy code requirement by insulating the crawl space perimeter with R-10 foamboard attached to the inside of the concrete block foundation walls and then, in order to meet the ventilation requirements, cutting out this insulation in the location of the vents. Because this seemed too strange to believe for more than one reviewer of this paper, allow me to repeat that. Builders carefully insulate the block wall then cut holes in the insulation, allowing outdoor air to completely bypass the insulation, thus undermining the construction's thermal integrity. To make matters worse, the crawl space vents often line up with the heating supply ducts so the supply register boots are just inches inside the vent. The hot air in the supply duct is thus cooled by exposure to temperatures near those of ambient winter temperatures.

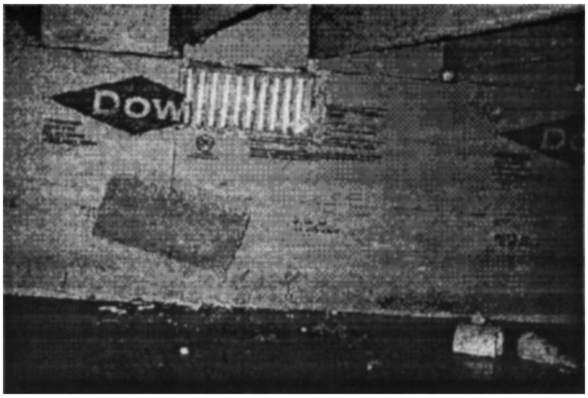

Figure 2. *View of operable vent from inside the crawl space. While standard practice is to discard the foamboard that is cut out behind the vent, in this house it has been hung by a string below the vent for later reinsertion.*

The "Science"`Behind Crawl space Venting Requirements

History

Rose (1994) has presented some fascinating research into the history of this particular code requirement. He traced the current requirements all the way back to the 1942 Federal Housing Administration's (FHA) *Property Standards and Minimum Construction Requirements for Dwellings* and found these standards predated any research on crawl space performance. Furthermore, Rose found that none of the research published in Britton's seminal paper on the subject in 1948 appears to support the recommendation for venting. The research did support the efficacy of ground covers (vapor diffusion retarders) as a moisture control strategy and, in Rose's opinion, ground covers alone probably would have been the recommendation had there been a product available at the time whose long-term durability could be guaranteed. Polyethylene, the material of choice today, did not come into use until the 1950s. Rose conjectures that "...even by 1948, the venting requirement appeared to have a shroud of authority that exceeded its empirical support." Over the years since 1942 the crawl space venting requirements appear to have grown in authority even while research continued to show that vapor diffusion retarders over the crawl space floors were a much more effective strategy.

Ventilation cannot do the job

Rose's (1994) historical research concluded that, "There is no technical basis in the literature for current or past crawl space ventilation requirements." A cursory examination of the amount of water researchers estimate can be removed by evaporation (as summarized by Rose and TenWolde (1994)) shows crawl space ventilation can never be expected to dry out crawl spaces with standing water. Assuming Trehowen's (1994) average evaporation rate of 400 g/m^2-day (0.82 lb/ft^2-day) which Rose and TenWolde (1994) say is already considered high, a quick calculation shows it would take 380 days of these drying conditions to evaporate six inches of water from a crawl space, a not unusual condition for a crawl space installed without perimeter drains in this part of Indiana. Clearly, even with ideal conditions, evaporation rates are simply not large enough to deal with standing water. Crawl space venting is a band-aid that, even under the best of circumstances, is not up to the job.

The solution, as described by Lstiburek and Carmody [1993] is source control -- preventing moisture from entering the space to begin with. This includes good site design with soil graded to slope away from the foundation; proper roof overhangs and correctly installed guttering and downspouts; perimeter drains installed to collect subsurface water and carry it either to daylight or a sump; and a carefully installed vapor diffusion retarder over the soil or pea gravel floor of the crawlspace. The solution is simple, but getting the details right is essential.

In our area of eastern Indiana with heavy clay soils and little topography, most moisture-related problems -- such as moisture condensing on windows, peeling paint, mold and mildew -- can usually be traced to wet crawl spaces. Often, the simple addition of a good vapor diffusion retarder on the floor of the crawl space takes care of the problem. In other cases, where site design and perimeter drainage were improperly attended to during construction, the solution can be much more difficult and expensive to effect.

Ventilation can make matters worse

The conventional wisdom is that, while crawl space venting may not help, it doesn't hurt. If people want to open their vents in summer and close them in winter, that's fine. This thinking turns out to be wrong. A careful examination of the psychometric chart shows why venting cannot help remove moisture from crawl spaces in this (and many other) areas of the country during most parts of the year when the temperatures are mild enough for energy losses not to be a concern. As warm and humid summer air enters the cool crawl space its relative humidity quickly reaches saturation levels. Not only will crawl space venting not remove moisture, it will probably result in additional moisture being deposited in the crawl space.

Effect of vents on crawl space U-value

Another strategy used by those who don't want to vent the crawlspace but do want to pass the code official's inspection is to "install the vents but don't open them." After all, they reason, the code simply says there shall be "operable vents." The flaw in this approach is that the provision of operable vents means leaving the area of the walls containing the vents uninsulated. While the areal extent of the vents may be relatively small, their effect on overall thermal performance can be large. Table 1 shows the effective U-value calculations for a crawl space for a 28 foot by 45 foot (1150 ft^2) three bedroom home with both the vents and the typically uninsulated metal crawl space access hatch included in the calculation. These small areas of metal, with negligible R-values, account for only 5% of the crawl space wall area, but, according to Table 1, can account for almost a third of the heat loss through crawl space walls[1]. While the mechanics of heat loss from the house, through the floor, into the crawl space and then to the outside are more complex than this, Table 1 suggests the performance of the crawl space insulation can be seriously degraded by leaving these vents and access hatches uninsulated.

Table 1. UA Calculations for Crawl Space Walls With and Without Insulation Over Vents and Hatch

		R-10 foam insulation on inside of block only			R-10 foam insulation over vents and hatch as well as block		
Component	Area (ft^2)	R-value	UA	Percent	R-value	UA	Percent
Concrete block	306	11.9	25.7	68%	11.9	25.7	96%
Vents	5	0.85	5.8	15%	10.9	0.46	2%
Access hatch	5.5	0.85	6.5	17%	10.9	0.51	2%
Total	316		0.12			0.08	
Meet code?			No			Yes	

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[1] The actual effect on energy consumption would be even larger as the area of the crawl space containing the vents is exposed to cold winter winds while the block wall beneath the vents is below grade and "sees" warmer soil temperatures..

The analysis in Table 1 ignores the effect of air infiltration across these vent and hatch areas. These vents are not airtight in their closed position and the metal access hatches typically installed in our area are uninsulated and seal poorly. How much is the insulating ability of the foamboard further degraded by air leakage through the vents and hatch area? Probably quite significantly. Research in the last ten years, primarily in low-income weatherization programs, has shown that when the pressure boundary and thermal boundary aren't aligned, the insulation simply doesn't work very well. If the wall with the thermal insulation isn't airtight, and cold air can migrate into the crawlspace behind it, the insulation ceases to perform as intended. That foamboard might just as well be sitting out on the lawn.

Change is slow

There is some evidence that code-setting bodies may finally be moving on this issue. Last year the American Society of Heating, Refrigeration and Air-Conditioning Engineers removed the requirement for crawl space venting from its Handbook of Fundamentals (ASHRAE 1997). Also, as one of the reviewers of this paper pointed out, "the CABO 1995 MEC corrected the long-standing mistake in the code" which allowed this practice of both insulating and venting crawl space perimeters. Even after the codes are changed it will be an uphill battle to educate and change all those who are accustomed to the current requirements. The residential building industry is, for many reason, slow to adopt changes[2]. Builders, architects and code officials tend to be a risk adverse group not easily swayed from "current practices."

Research Design

The objectives of the research were first, to quantify the "energy penalty" associated with crawl space venting in the winter, the only time in which venting can possibly dry out crawl spaces in our climate, and second, to measure relative humidity levels in crawl spaces to ascertain whether venting helped or hindered crawl space moisture problems. While I had hoped to be able to make use of 12 nearly identical homes for which I had been measuring both electrical and gas consumption on a weekly basis, this did not prove possible for a variety of reasons. In the end, the research design became a single house case study.

One house, four years of weekly data

Weekly energy consumption data were gathered over four heating seasons using the following "flip-flop" research design: In year one the crawl space vents were open; in year two they were closed and the foam pieces which had been cut out for the vents were reinserted and foamed into place. In year three the vents were again opened, and in year four not only were the vents closed, insulated and foamed, but the crawl space access hatch was insulated and made air-tight as well.

The Case Study House

The house is a 1150 square foot three-bedroom single story constructed in 1994 by a local not-for-profit community development agency. The home was designed by an architect and was the second of

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[2] See Burby and Marsden (1980) for an excellent discussion of information diffusion in the building industry and the many obstacles to change.

approximately 20 homes of similar design ultimately constructed by the agency over a three-year period. The home has been occupied by its first owner, a single parent with three children, since its completion. The home owner reports that the thermostat is never touched and is kept at 72°F all winter. In a "typical year" the area experiences approximately 5900 heating degree days (base 65).

Figure 3. The house used in the case study.

Built to just meet the 1992 MEC

The home was constructed to meet Indiana's Energy Conservation Code which is based on CABO's 1992 Model Energy Code. The house has 2 by 4 framing with R-13 fiberglass batts and half-inch exterior isocyanurate sheathing for most of the walls, half-inch OSB for shear bracing at the corners. The attic is insulated with R-37 blown cellulose and the house has regular double pane windows. The perimeter of the crawl space is insulated with R-10 foamboard insulation attached to the interior of the concrete block walls. The UA calculations for the home are shown in Table 2.

Some attention was given to air-sealing during construction, and a blower door test on the completed house found it relatively tight, compared with typical construction practices in this area, with measured air leakage of 975 cfm_{50} (6.1 ACH_{50}). To provide adequate indoor air quality, the specifications for the house called for the installation of an 80 cfm bath fan set to run continuously, however, this specification was over-ruled by the architect and the fan was never installed.

Crawlspace moisture problems

The crawlspace has a 6 mil polyethylene installed as a vapor diffusion retarder over 4 inches of pea gravel. Unfortunately, no perimeter drain was installed and the site grading was improperly done so storm water drains from the adjacent street, is ponded by a sidewalk and ends up in the crawl space. After heavy rains it is not uncommon to find two to six inches of water in the crawl space. A sump pump was installed in 1995 in an attempt to solve this problem and has been replaced at least once since.

HVAC and hot water

Heat for the home is provided by a gas forced air system utilizing a two-stage, 80% AFUE furnace. The supply ducts run in the crawl space with a single return in the hall. The ducts were carefully sealed with mastic and pressure tested at 25 Pascals. When interior doors are closed the furnace air handler results in positive pressures (3 to 6 Pascals) in the bedrooms and bath and a negative pressure (-3 Pascals) in the main part of the home. Under worst case conditions (air handler, clothes dryer and bath fan all running) the main part of the house goes to -7 Pascals. As Cummings et al. (1990) first demonstrated, this can have a dramatic impact on infiltration. It is likely that this would affect air leakage into the crawl space.

Short "over the wall" ducts were proposed to provide pressure relief of the bedrooms but this was over-ruled by the architect. Since the depressurization of the mechanical room made backdrafting of the water heater a distinct possibility, it was imperative that no atmospherically-coupled gas water heater be installed. An off-peak electric water heater leased from the local electric company was installed to solve the problem.

Table 2. Heat Loss (UA) Calculations for the Case Study House

Component	Description	Area (ft^2)	R-value (hr-ft^2-°F/Btu)	UA (Btu/hr-°F)	Percent of heat loss
Ceiling	Blown cellulose	1150	37	31.1	12%
Wall #1	R-13 batts with isocyanurate sheathing	673	15.7	42.8	16%
Wall #2	R-13 batts with OSB sheathing	378	12.42	30.4	11%
Windows	Wood frame, double pane	111	1.96	56.6	21%
Doors	Insulated metal	38	5	7.6	3%
Crawl space perimeter	R-10 foamboard over block		10	50.2	19%
Infiltration	0.3 ACH assumed			49.7	19%
Energy intensity	5.6 Btu/ft^2-DD			268 Btu/hr-°F	

Weekly energy consumption data

Both gas and electric consumption data have been collected on a weekly basis from the time the home was first occupied in October 1994 to the present. The fact that there are no gas appliances except the furnace makes for nice clean space heating data. The furnace has also been monitored since November 1995 with run-time meters attached to the two stages of the furnace. This has served to provide a check on the data from the gas meter.

Results — significant savings from closing and insulating the vents

The weekly gas consumption data was combined with local temperature data to yield weekly energy intensities (Btu/ft^2-DD_{65}). These were calculated only for weeks in which there was an average of 12 heating degree days (base 65) per day or greater because, as discussed at length in Hill et al. (1992), in weeks with less than 10 to 15 HDD_{65} the relationship between energy use and HDD breaks down. Indoor temperatures, while not monitored, are assumed to have remained essentially the same (72°F) over the four-and-a-half year period.

Figure 4 shows weekly energy intensities for the home over the four heating seasons from October 1994 to mid-March 1998. The heavy line is a five-week moving average which shows the trends better by smoothing out the week-to-week variations. The dip in the first heating season (94-95) is the result of a two-day power outage in one week, followed by furnace problems in the next two. The trend in each year except the last is for progressively increasing energy intensities as the winter progresses. This seems to show the gradual cooling of the crawl space, more quickly in years 94-95 and 96-97 when the vents were open, and less quickly in 95-96 when the vents were closed but the access hatch was not air-tight. As the house "sees" a cooler and cooler crawl space over the winter, its energy intensity gradually increases[3].

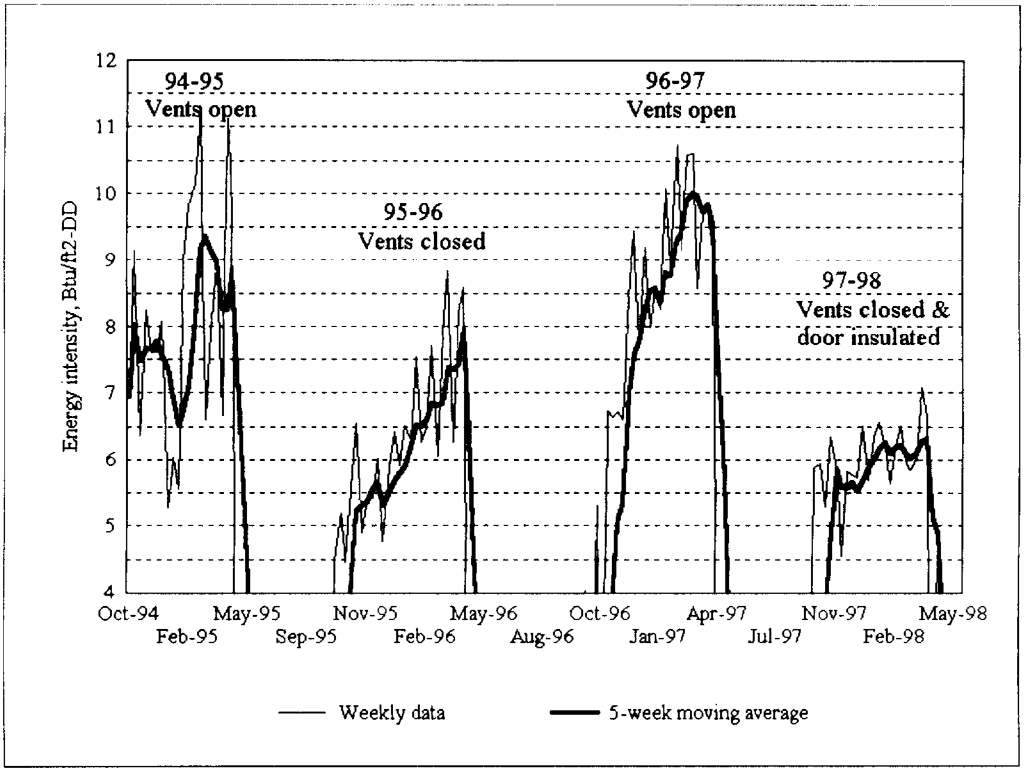

Figure 4. Weekly energy intensities of case study house over four heating seasons, showing the effect of open crawl space vents on energy consumption. Vents were open in the winters of 94-95 and 96-97, closed in 95-96. In 97-98 the crawl space access door was also insulated and air-sealed.

The data for the most recent year (97-98) is most interesting in that this phenomenon of gradually increasing energy intensity over the winter does not appear. This suggests that making the crawl space more airtight and better insulated by modifying the poorly fitting and uninsulated metal crawl space hatch cover may pay large dividends.

Table 3 summarizes the data for the four heating seasons. The mean energy intensity for each of the two years with the crawl space vents open is 7.72 Btu/ft2-DD, with approximately the same standard error in each of the two winters (0.54 and 0.57, respectively). The mean energy intensity for 95-96, in which the crawl space vents were closed but the poorly fitted access hatch remained uninsulated, is 6.30 ± 0.25 Btu/ft2-DD. In the most recent winter (97-98), with the vents closed and the access hatch insulated and air-tight, the energy intensity drops to 5.71 ± 0.27 Btu/ft2-DD. Note that the standard errors for the years in which the vents were closed is much smaller than it is for the years in which the vents were open. This lower variability in the data may be a result of the fact that the crawl space is working as intended, providing an insulated "buffer" against the elements. When the vents are open the entire floor of the house "sees" conditions that are more dependent on which way the wind is blowing.

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[3] This effect was also evident in the PRISM regression curves, with data from early in the winter plotting below the regression line and data from late in the winter plotting above the regression line.

Table 3. Weather Normalized Annual Energy Consumption and Savings (MMBtu)

Year	Crawl space vent position	Mean energy intensity (Btu/ft^2-DD)	PRISM NAC (MMBtu/yr)	PRISM NAS (MMBtu/yr)	Percent change
1994-95	Open	7.72±0.54	55.8±2.8		
1995-96	Closed	6.30±0.25	44.3±1.4	11.5 ± 3.1	21%±4.7%
1996-97	Open	7.72±0.57	57.3±1.8		
1997-98	Closed with insulated and airtight hatch	5.71±0.27	38.7±1.1	21.2 ±2.0	32±2.7%

Table 3 also shows the results of running PRISM (the Princeton Scorekeeping Method) (Fels 1986) on this weekly energy consumption data. The normalized annual consumption (NAC) was computed for each year and the normalized annual savings (NAS) computed for each pre/post (vents open/vents closed) pair of years. The percent savings given are based on the PRISM NACs.

Why these savings might be larger in "more typical" homes

Energy savings expressed as a percentage of annual consumption are likely larger in this house than they would be in other homes because this house is energy efficient to begin with. Absolute savings, however, might be expected to be larger in other homes. The house was built to the 1992 MEC and, while it is not as air-tight as it could be, a significant amount of attention was paid to air-sealing. Since neither building to code nor air-sealing is common practice in our area, it is likely both infiltration rates and UAs for "typical homes" in the area are larger. If a major mechanism for pulling cold air into crawl spaces is infiltration into the house above as a result of stack effect and/or house depressurization from the furnace air handler, then it is probable that there is greater infiltration into the crawl spaces in more typical homes. If so, the energy penalty of venting more typical homes might well be larger than that measured in this research.

The other difference that sets this house apart from a typical house is its airtight ducts. As noted above, the ducts were carefully sealed with mastic and pressure tested. In a home with leaky ducts a vented or less than airtight crawl space would probably result in an even greater energy penalty.

Economic analysis

Using the PRISM results and assuming the cost of gas at $5 per MMBtu, the annual savings for this home appear to range from about $50 per year with closed and insulated vents but a standard issue uninsulated access hatch, to about $100 per year with a totally insulated and airtight crawl space. The costs of achieving these savings could be negative, since the savings from not installing vents in the first place might be greater than the additional cost of providing an insulated and air-tight access cover. By any measure of cost effectiveness, not venting the crawl space appears to make sense from an energy standpoint.

Summary and discussion

The energy intensity data, while limited to just one house, are of good quality and clearly show a significant energy penalty as a result of crawl space venting. Savings of 21% were realized by closing, insulating and air-sealing the home's six vents, an area totaling approximately five square feet. Insulating the crawl space access door and making the entire crawl space airtight resulted in additional savings, totaling 32% over the base case (vents open). This suggests that "unvented" crawl spaces need to be unvented in a purposeful way. That is, it is not be enough to simply close the vents. Careful attention should be paid to maintaining the integrity of the insulation over the entire perimeter and air-sealing the crawl space as carefully as the rest of the house. This research suggests that crawl spaces should be treated as "conditioned spaces," even if the only conditioning is from sealed ducts running through them..

While not shown in this paper because of space limitations, the research also suggests crawl space venting alone is not capable of removing the large amount of moisture that can result from poor site design and a lack of perimeter drains. Even in winter the relative humidity levels of the vented crawl space remained consistently high.

Further research

While I do not think more research is needed to abolish the practice of insulating crawl spaces then cutting holes in them, some additional research appears to be justified. It would be useful to look at a sample of more typical homes to see if the large energy savings apparently resulting from insulating and air-sealing the crawl space vents and access door is replicated.

Ramifications for weatherization and retrofit work

The energy savings demonstrated in this research, while based on only one house, are large enough to suggest more attention should be given to insulating and air sealing crawl spaces as an energy efficiency measure in weatherization and retrofit work. We have long suspected that insulating uninsulated crawl spaces, especially those that contain ducts, would make sense. However, this research suggests crawl spaces which are already insulated but contain operable vents might also be good candidates for treatment. Insulating the vents and access door and air sealing the whole crawl space might be an extremely cost effective treatment strategy. The problem with any attempt to address crawl spaces to date has been institutional rather than technical. Code officials have been reluctant to waive the requirement for operable vents and utility companies have been concerned about exposure to liabilities for moisture problems. Perhaps it will soon be possible to get beyond these concerns.

Do operable vents ever make sense?

The discussion below goes well beyond conclusions that can be drawn from this one case study. There are, however, many conclusions which can and should be drawn based solely on science and logic, which do not require further research, and need to be discussed in order to make progress on this issue.

Is there any condition in which operable vents might make sense? Let's examine the logic of operable vents. Presumably, the only reason to have *operable* crawl space vents is to be able to open and close them. Further, one would presumably open them to dry out the crawl space. When would one do that?

The vents could be opened during the winter months when the moisture content of the outside air would provide good drying potential. As the cold outside air, with high relative humidity but low absolute humidity, is brought into the relatively warmer crawl space, its relative humidity would drop and it would be able to pick up moisture and carry it away. However, as suggested by this research and common sense, this venting strategy comes with a fairly serious energy penalty.

One could instead open the vents during the "non-heating season" months in order to avoid the energy penalty. However, opening crawl space vents in our area of the country would too often serve to bring in more moisture than it removed. The warm and humid outside air would tend to reach dewpoint when it came into contact with the cooler crawl space.

How about in other climates where summer temperatures and humidity levels are lower? Yes, in those areas summertime ventilation might work to dry out a crawl space. However, the vents would still need to be closed in winter, and as suggested by this research, it appears they should not just be closed, but insulated and made airtight as well. This is a task not many homeowners would be willing to complete twice a year.

What about insulating the floor and venting the crawl space? A perfectly fine alternative, though probably more expensive because the ducts and water pipes in the crawl space will probably need to be insulated. Moreover, there is no need for the vents to be *operable* in this case as the vents can and should stay open all year.

Venting is not the issue

Perhaps the best reason for eliminating operable crawl space vents as a moisture control strategy is that it gives the "appearance of a solution" so that builders and architects aren't pursuing the solutions which *do* solve the problem. They understand wet crawl spaces are a serious problem, but instead of solving the problem, they install crawl space vents. If venting were to disappear as an option, architects and contractors would be forced to look at other alternatives which actually solve the moisture problem.

A final word

The issue of crawl space venting is just one example of a much larger problem -- the gulf that exists between what the building science community knows and what the residential construction industry is doing. There is evidence that homes could be made more energy efficient, as well as more durable, comfortable and safe, with little additional cost. What we need is not technological breakthroughs or new products. What we need is a better understanding, on the part of those involved in residential construction, of how buildings work and why they fail, and how to make sure they don't fail. We in the building science community have not done a good job of information transfer. We need to redouble our efforts to bridge this gulf between researcher and practitioner.

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