Crawlspace Design in Marine and Cold Climates

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ABSTRACT

With support from the USDOE's Building America program, researchers evaluated eight homes built to ENERGY STAR Homes Northwest™ standards; four each in marine and cold climates. The location of the ductwork varied (inside versus outside conditioned space) as did the floor insulation strategy (floor cavity insulation versus perimeter insulated crawlspace.)

Using field testing data as inputs, three energy simulation software models were used to evaluate energy use. The research design compares simulation models based on foundation type, duct location and duct insulation levels. Energy use for an ENERGY STAR Homes Northwest home was also compared to a base case Washington Code home. Utility savings, builder pricing and simple consumer affordability issues are presented.

The research may help ASHRAE, builders, code officials, homebuyers, and building-science and energy-policy stakeholders who are working with new energy efficient single-family residential construction.

INTRODUCTION

The purpose of the USDOE Building America crawlspace research project is to evaluate thermal, moisture and indoor air quality (IAQ) performance in eight newly constructed Pacific Northwest homes. These homes represent some of the most energy efficient production housing built in Washington State in 2006, exceeding requirements for both the Washington State Energy Code (WSEC), and the ENERGY STAR Homes Northwest™ program. The homes have also been benchmarked to USDOE Building America 30-40% whole-house savings (USDOE 2007) and evaluated for the $2000 federal energy tax credit for new homes (IRS 2006).

The project's basic research questions are:

- What is the modeled space heating, cooling and total energy use?
- What are the builder incremental costs and market pricing impacts?
- What is the impact on monthly mortgage payments versus utility bills?
- What are the ramifications for ENERGY STAR, IECC, WSEC, and federal energy tax credits?

Local utilities provide builders with various incentives for ENERGY STAR Northwest homes and Energy Efficiency Measure technologies. The utility incentives are based on savings determined by the Regional Technical Forum, a task force of regional utilities and other stakeholders.

Two ENERGY STAR builders were selected based on their willingness to participate in the research, demonstration and deployment phases of the project. In 2006-2007, each builder constructed four test homes in ENERGY STAR communities. The marine climate homes (sited in Vancouver, WA) are three-bedroom, two-story 2200 square foot (ft^2) homes with roughly 15% window-to-floor area. The cold-climate homes (sited in Moses Lake, WA) are 1550 ft^2 ranch style models, with less than 10% glazing.

Major features of these homes include:

- Duct and envelope leakage testing

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- ENERGY STAR Homes Northwest verification and quality assurance (QA) inspections
- ENERGY STAR Homes Northwest HVAC
- ENERGY STAR dishwasher (typically current practice)
- Compact fluorescent lighting (CFL) screw-in lamps or fixtures.

For consistent cross climate comparisons, the 2200 ft^2 marine prototype was used for the modeling analysis in both climates using typical envelope and duct leakage, and HVAC information inputs, based on home field testing and other studies.

This paper attempts to evaluate a number of parameters in the modeled energy use of these homes. These parameters include:

- Foundation type (conditioned vs. vented crawl)
- Climate (marine vs. cold climates)
- Heating system type (gas vs. hp)
- HVAC system location (inside conditioned space vs. outside)
- R-4 vs. R-7 duct insulation
- Impact of the use of different software programs

The paper also presents cost data associated with many of the energy efficiency improvements modeled under this effort.

RESEARCH DESIGN

Table 1 provides a breakdown of all modeling cases, including descriptions of HVAC location, equipment efficiency and crawlspace types. Cases 1-4 represent ENERGY STAR or better efficiency. Cases 5 and 6 represent current code practice.

Typical Meteorological Year (TMY) weather data from Portland, OR were used for the marine climate cases, while the cold-climate cases referenced TMY data for Spokane, WA, determined to be the most similar to the actual cold-climate site (Moses Lake, WA).

Each of the 6 cases was simulated in both climates using both natural gas furnaces with AC and heat pumps.

HVAC System Location

Cases 1, 2, 5,6 have the supply ductwork located in the crawlspace, return ducts in attic and the air handler in garage. This is typical in Washington and Oregon.

Many HVAC and building science experts recommend that the best way to increase HVAC system efficiency is by moving the air handler and ductwork from these unconditioned spaces into the home (ASHRAE, *Handbook* 2004). This approach is represented as cases 3 and 4.

The two story marine climate test homes have a drywalled duct chase and upstairs floor joists provide an area to run all supply and return ductwork. An insulated wall was built around the air handler to move it inside without significantly altering its location on the floor.

The single story cold-climate homes were designed with return ducts and HVAC systems within the homes, and builders only had to move supply ducts.

For the purposes of the modeling analysis, the marine home duct location assumptions were used.

HVAC Efficiency

ENERGY STAR gas heating cases assume a furnace with a rated output capacity of 60 kBTUH and a 94% Annualized

Table 1. Case Descriptions

Program Efficiency	AFUE - SEER HSPF - SEER	Nominal R-Value Roof/Wall/Window	Lights—% CFL WH Ventilation	Crawlspace Configuration	HVAC Location (Sup/Ret/AH)
1 ENERGY STAR	0.94 - 14.5 9.0 – 14.5	R = 49 R = 21 U =.32	50% None	Conditioned R-15 perimeter	crawl/attic/garage “inside crawl” R-4 and R-7
2 ENERGY STAR	0.94 - 14.5 9.0 – 14.5	R = 49 R = 21 U =.32	50% None	Vented 1:300 R-30 floor	crawl/attic/garage “outside” R-4 and R-7
3 ENERGY STAR +	0.94 - 14.5 9.0 – 14.5	R = 49 R = 21 U =.32	50% None	Conditioned R-15 perimeter	between floors “inside” R-4 and R-7
4 ENERGY STAR +	0.94 - 14.5 9.0 – 14.5	R = 49 R = 21 U =.32	50% None	Vented 1:300 R-30 floor	between floors “inside” R-4 and R-7
5 WSEC	0.8 - 13 8.0 – 13	R = 38 R = 21 U =.35	50% None	Conditioned R-15 perimeter	between floors “inside crawl” R-4 and R-7
6 WSEC	0.8 - 13 8.0 – 13	R = 38 R = 21 U =.35	50% None	Vented 1:300 R-30 floor	crawl/attic/garage “outside” R-4 and R-7

Fuel Utilization Efficiency (AFUE), along with air conditioning with a 14.5 Seasonal Energy Efficiency Ratio (SEER). Code gas cases assume a furnace with a rated output capacity of 60k BTUH and a 80% AFUE; cooling is assumed to be 13 SEER.

ENERGY STAR heat pump cases assumed an air source unit with 9.0 Heating Seasonal Performance Factor (HSPF) and 14.5 SEER. These heat pumps are assumed to be installed and tested in accordance with a regional commissioning program (RTF 2006), and are part of a USDOE State Technologies Advancement Collaborative research program (STAC 2007). The code homes are assumed to use 8.0 HSPF, 13 SEER heat pumps, and assumed to be installed to the same utility commissioning program standards.

All ducts are assumed to have a nominal R-value of R-8 and an effective R-value of R-7 based on previous research (Palmiter and Kruse 2006). A separate analysis was conducted assuming R-4 ducts for all cases as well, to assess energy savings associated with increased duct insulation.

Vented and Sealed Crawlspace

During the research effort, half of the homes were built with floors insulated to R-30 over vented crawlspaces; these homes are represented in the analysis as cases 2, 4 and 6.

The other homes were built with perimeter insulated crawlspaces, though they differed in their particulars by builder. The cold climate homes employed an R-19 fiberglass batt perimeter insulation system, whereas the marine climate homes employed an R-15 foam (EPS) perimeter insulation located on the interior foundation wall. For the purposes of the analysis, the R-15 foam perimeter insulation was assumed for both climates. These homes are represented in the analysis as cases 1, 3 and 5.

In the cold climate homes, the perimeter insulated crawlspaces are conditioned with supply ducts. In the marine climate homes, however, conditioned air is provided to the crawlspace via a passive grill between the crawlspace and first floor; the air exits the crawlspace via an exhaust fan.

Perimeter insulated crawlspaces are not allowed by code in Washington (SBCC 2005), but are permitted in much of the rest of the country (ICC 2006). USDOE Building America projects regularly employ this approach, typically with EPS foam (USDOE 2007).

FIELD TESTING RESULTS

Field testing results are presented in Table 2.

Envelope Leakage

Researchers determined the envelope leakage using a Blower Door™; results are shown in Table 2. Results ranged from 3.3-4.7 air changes per house at 50 Pascals (ACH_{50}).

In both the marine and cold climate homes, the builder's first homes (noted by an *) tested with leakage rates above 4.0 ACH_{50}. Envelope leakage rates for subsequent homes were

Table 2. Envelope Leakage, HVAC Leakage Results From Field and Used in Modeling

Case	Tested Blower Door ACH50	Tested Duct Leak CFM50 Out	Tested HVAC Flow Rate (**)	Model Used CFM50 (EG and REM)	Model Used ACH (fixed) (SEEM)	Model Duct Leak CFM25 Out (EG and REM)	Model Duct Leak CFM25 Out/CFM AH flow (SEEM)	Tons AC + HP	Model HVAC Flow (CFM)
1 marine*	4.7	130	880	2135	0.35	77	0.11	2	700
2 marine	3.4	95	788	2135	0.35	77	0.11	2	700
3 marine	3.3	32	910	2135	0.35	0	0.0	2	700
4 marine	3.7	45	925	2135	0.35	0	0.0	2	700
5 marine	n/a	n/a	n/a	2460	0.4	192.5	0.22	2.5	875
6 Marine	n/a	n/a	n/a	2460	0.4	192.5	0.22	2.5	875
1 Cold	3.7	25	725	1880	0.35	96.3	0.11	2.5	875
2 Cold	3.7	65	731	1880	0.35	96.3	0.11	2.5	875
3 Cold*	4.3	25	798	1880	0.35	0	0	2.5	875
4 Cold*	4.6	25	DH	1880	0.35	0	0	2.5	875
5 Cold	n/a	n/a	n/a	2150	0.4	264	0.22	3	1200
6 Cold	n/a	n/a	n/a	2150	0.4	264	0.22	3	1200

* First homes prior to ENERGY STAR QC.
** Flow for cases 1–4 (ENERGY STAR) is on high speed setting for ECM motor.

reduced to below 4.0 ACH_{50} as a result of improved air leakage control.

For the analysis, a value of 0.35 natural air changes (ACH_n) was used for the ENERGY STAR homes. A value of 0.4 ACH_n was used for the WSEC homes, based on previous energy code random-sample research (Palmiter and Brown 1989). In the software, adjustments were made to the blower door fan flow to provide consistent ACH_n results across climate zones.

Ventilation Systems

Both ASHRAE 62.2 and Washington's Ventilation and Indoor Air Quality (VIAQ) consider all new homes to have low leakage rates and to be "exceptionally tight".

For the homes in the research, the VIAQ requires between 85 and 128 CFM of whole-house mechanical ventilation (dependent on house size and number of bedrooms) with timers set to operate eight hours a day (SBCC 2004)., while Standard 62.2 requires roughly 50 CFM minimum at constant operation (ASHRAE, *Standard* 2004). Whole-house exhaust fan and crawlspace exhaust fan (for conditioned crawlspace cases) flow rates were roughly 50 CFM, measured with an Energy Conservatory Flow Box™.

HVAC Thermal Distribution System Leakage

Researchers determined duct leakage using a Duct Blaster ™. Duct leakage values measured and those used in the modeling analysis are shown in Table 2. It is worth noting that in the marine climate homes, significant improvements were made to the duct leakage rates as a result of feedback from QA testing for home 1.

Table 2 also provides the measured HVAC system high-speed flow rates, using the Energy Conservatory's True Flow™ device.

The air handler flow rates used in the modeling analysis are also presented in Table 2, along with HVAC system size.

ENERGY USE MODELING

Three energy simulation modeling software tools were used for the energy usage analysis. Energy Gauge USA™ version 2.6 (EG) and REMRate™ version 12.2 (REM) are commercially available software programs generally used by home energy raters for qualifying homes for ENERGY STAR and federal energy tax credits. SEEM is a proprietary, not-for-sale model used for Pacific Northwest utility program assessment. EG and SEEM are based on hourly simulations, whereas REM results are based on a modified load curve.

Across these three software tools, with differing allowed inputs and assumptions, researchers made every attempt to consistently model the cases. Authors focused on providing comparable inputs for envelope and duct leakage; appropriate modeling assumptions are noted in Table 2. Additional effort was made to ensure that envelope u-values were as consistent as possible across the different models.

The homes were modeled without ventilation systems, in order to simplify the comparative analysis, and to avoid inconsistencies between the software modeling tools that in some instances led to a significant energy usage penalty when ventilation systems were modeled.

For similar reasons, the sealed crawlspace homes were modeled without the crawlspace fan. As a result, neither the energy use of the crawlspace exhaust fan, nor the thermal implications of the fan and floor grill were included in the analysis.

While EGUSA and REM allow duct leakage to be input as CFM leakage to outside, SEEM requires duct leakage to be input as a function of airhandler flow rate per ASHRAE standard 152. Both inputs are shown in Table 2.

In all cases the duct supply/return leakage was assumed to be split 50% with roughly 440ft^2 and 110ft^2 of supply and return duct surface area respectively.

Thermostat settings are assumed to be 78°F for cooling and 68°F for heating. Internal gain assumptions are based on individual program assessments of various input values. Fuel costs were assumed to be typical of PNW rates - \$0.0658 per kilowatt-hour (kWh) and \$1.2189 per therm.

Tables 3a and 3b provide estimates of current annual utility heat and cooling costs of all three software models. Costs are provided for marine and cold climate homes for both gas heat with AC and heat pumps, with both R-4 and effective R-7 (nominal R-8) duct insulation levels. As noted above, these values do not include the cost of operation for a crawlspace fan (estimated at \$29 per year for a continuously operating 50 watt fan.)

Table 4 compares the vented crawlspace versus the perimeter insulated crawlspace. SEEM indicates consistent savings for the perimeter insulated crawlspace when the ducts are outside the heated space, but savings for the vented crawlspace when the ducts are located in the heated space. EG indicates consistent savings for the vented crawlspace, whereas REM indicates consistent savings for the perimeter insulated crawlspace. Both EG and REM are consistent with the SEEM results that indicate added benefit to the R30 underfloor vented crawlspace when the ducts are inside.

Table 5 provides the savings of moving the ducts inside the home. As expected, all three models reflect savings for bringing the ducts inside, with the greatest benefit accrued in the vented crawlspace cases. This benefit is least significant with EG.

Table 6 provides the savings of the combination of ENERGY STAR and moving ducts inside over code homes with ducts outside the conditioned space. As in the previous case, EG shows the least benefit from this combination.

Table 7 provides savings associated with average R-7 (effective) vs. R-4 duct insulation.

Builder Cost Breakdown and Incremental Costs

Tables 8a and 8b provide a summary of builder-estimated incremental costs for the efficiency measures. The costs were

Table 3a. Heating and Cooling Energy Costs—R4 Duct Insulation Cases ($/year)

Climate Case	R4 Ducts Case	SEEM $ heating	SEEM $ cooling	SEEM $ htg+clg	EGUSA $ heating	EGUSA $ cooling	EGUSA $ htg+clg	REM $ heating	REM $ cooling	REM $ htg+clg
marine	House 1	$470	$26	$496	$507	$12	$519	$500	$56	$556
marine	**House 2**	**$497**	**$36**	**$533**	**$457**	**$14**	**$471**	**$511**	**$65**	**$576**
marine	House 3	$428	$22	$450	$432	$11	$443	$461	$51	$512
marine	**House 4**	**$393**	**$30**	**$423**	**$381**	**$12**	**$393**	**$412**	**$55**	**$467**
marine	House 5	$645	$32	$677	$720	$18	$738	$635	$65	$700
marine	**House 6**	**$686**	**$43**	**$729**	**$655**	**$22**	**$677**	**$640**	**$77**	**$717**
marine	House 1—hp	$246	$26	$272	$366	$15	$381	$281	$56	$337
marine	**House 2—hp**	**$286**	**$36**	**$322**	**$351**	**$18**	**$369**	**$293**	**$54**	**$347**
marine	House 3—hp	$206	$22	$228	$221	$12	$233	$266	$51	$317
marine	**House 4—hp**	**$190**	**$30**	**$220**	**$196**	**$14**	**$210**	**$240**	**$55**	**$295**
marine	House 5—hp	$338	$32	$370	$491	$21	$512	$350	$56	$406
marine	**House 6—hp**	**$378**	**$43**	**$421**	**$469**	**$25**	**$494**	**$366**	**$60**	**$426**
cold	House 1	$805	$39	$844	$847	$24	$871	$783	$58	$841
cold	**House 2**	**$853**	**$51**	**$904**	**$774**	**$27**	**$801**	**$781**	**$69**	**$850**
cold	House 3	$730	$33	$763	$698	$20	$718	$724	$53	$777
cold	**House 4**	**$673**	**$42**	**$715**	**$620**	**$23**	**$643**	**$650**	**$58**	**$708**
cold	House 5	$1,114	$49	$1,163	$1,192	$29	$1,221	$992	$67	$1,059
cold	**House 6**	**$1,196**	**$64**	**$1,260**	**$1,099**	**$38**	**$1,137**	**$981**	**$80**	**$1,061**
cold	House 1—hp	$523	$39	$562	$714	$25	$739	$607	$52	$659
cold	**House 2—hp**	**$630**	**$51**	**$681**	**$704**	**$29**	**$733**	**$620**	**$57**	**$677**
cold	House 3—hp	$414	$33	$447	$399	$20	$419	$556	$53	$609
cold	**House 4—hp**	**$384**	**$42**	**$426**	**$358**	**$23**	**$381**	**$504**	**$58**	**$562**
cold	House 5—hp	$713	$49	$762	$966	$33	$999	$737	$53	$790
cold	**House 6—hp**	**$817**	**$64**	**$881**	**$942**	**$38**	**$980**	**$756**	**$58**	**$814**

Note: **Bold** Indicates vented crawlspace.

derived from an informal builder survey, with WSEC assumed as the base case. Builder costs were then converted to home-buyer costs, using a markup of 1.35%, typical of the residential new homes market.

The incremental costs for the marine climate builder is $2,816 (a 2,200 ft^2 home, or $1.28/ft^2) for both the ENERGY STAR upgrade and bringing the HVAC system inside the home. For the cold climate builder, the incremental costs for the same upgrades is $3,830 (a 1,550 ft^2, or $2.47/ft^2.)

These cost estimates do not include the incremental cost of an ENERGY STAR dishwasher. Most dishwashers on the market at the time of these homes' construction met the 0.58 energy factor requirement for ENERGY STAR; incremental costs were therefore not applicable. It is worth noting that while new ENERGY STAR dishwasher requirements are for an energy factor of 0.65, analysis conducted by the Northwest's Regional Technical Forum suggests little incremental cost between the 0.58 and 0.65 units (RTF 2007).

These costs are based on the builders early attempts to implement these energy efficiency measures, and do not take into account potential utility incentives, which range from $250 to $2,000 throughout the Northwest region. These costs also do not include pricing impacts from the $2,000 federal tax credit for new homes.

FINDINGS

1. In the marine climate homes, the vented and conditioned crawlspaces were comparable on a cost basis, before the addition of a crawlspace fan and floor grill in the conditioned crawlspace homes; these added costs are estimated at $250. Cost of the rat slab increased these costs another

Table 3b. Heating and Cooling Energy Costs – R7 Duct Insulation Cases ($/year)

Climate Case	R7 Ducts Case	SEEM $ heating	SEEM $ cooling	SEEM $ htg+clg	EGUSA $ heating	EGUSA $ cooling	EGUSA $ htg+clg	REM $ heating	REM $ cooling	REM $ htg+clg
marine	House 1	$460	$25	$485	$492	$12	$504	$500	$56	$556
marine	**House 2**	**$464**	**$35**	**$499**	**$438**	**$13**	**$451**	**$497**	**$64**	**$561**
marine	House 3	$428	$22	$450	$432	$11	$443	$461	$51	$512
marine	**House 4**	**$393**	**$30**	**$423**	**$381**	**$12**	**$393**	**$412**	**$55**	**$467**
marine	**House 5**	**$633**	**$31**	**$664**	**$696**	**$18**	**$714**	**$634**	**$65**	**$699**
marine	**House 6**	**$653**	**$42**	**$695**	**$629**	**$21**	**$650**	**$629**	**$76**	**$705**
marine	House 1—hp	$236	$25	$261	$326	$14	$340	$280	$56	$336
marine	**House 2—hp**	**$253**	**$35**	**$288**	**$304**	**$17**	**$321**	**$282**	**$54**	**$336**
marine	House 3—hp	$206	$22	$228	$221	$12	$233	$266	$51	$317
marine	**House 4—hp**	**$190**	**$30**	**$220**	**$196**	**$14**	**$210**	**$240**	**$55**	**$295**
marine	House 5—hp	$328	$31	$359	$450	$21	$471	$349	$56	$405
marine	**House 6—hp**	**$350**	**$42**	**$392**	**$421**	**$24**	**$445**	**$356**	**$60**	**$416**
cold	House 1	$788	$38	$826	$816	$24	$840	$781	$58	$839
cold	**House 2**	**$800**	**$49**	**$849**	**$737**	**$26**	**$763**	**$762**	**$68**	**$830**
cold	House 3	$730	$33	$763	$698	$20	$718	$724	$53	$777
cold	**House 4**	**$673**	**$42**	**$715**	**$620**	**$23**	**$643**	**$650**	**$58**	**$708**
cold	House 5	$1,095	$48	$1,143	$1,147	$27	$1,174	$990	$67	$1,057
cold	**House 6**	**$1,139**	**$62**	**$1,201**	**$1,047**	**$37**	**$1,084**	**$965**	**$80**	**$1,045**
cold	House 1—hp	$500	$38	$538	$634	$24	$658	$605	$52	$657
cold	**House 2—hp**	**$552**	**$49**	**$601**	**$602**	**$27**	**$629**	**$598**	**$58**	**$656**
cold	House 3—hp	$414	$33	$447	$399	$20	$419	$556	$53	$609
cold	**House 4—hp**	**$384**	**$42**	**$426**	**$358**	**$23**	**$381**	**$504**	**$58**	**$562**
cold	House 5—hp	$691	$48	$739	$879	$33	$912	$735	$53	$788
cold	**House 6—hp**	**$753**	**$62**	**$815**	**$834**	**$37**	**$871**	**$736**	**$58**	**$794**

Note: **Bold** Indicates vented crawlspace.

$675. Costs of radon mitigation for sealed crawlspaces increased the costs by $405, where required by code.

2. In the cold climate homes, the vented crawlspace cost $719 more than the conditioned crawlspace. While this fiberglass crawlspace wall system is less expensive it may be more prone to moisture damage from crawlspace foundation wall condensation than the foam system employed in the marine climate homes.
3. The incremental homeowner cost of all of the energy efficiency measures ranges from $2,800-$3,800, setting aside any price adjustments associated with potential utility incentives or tax credits. This translates into an increased mortgage payment of $17-$23/month (assuming a 30 year loan at 6% interest.)
4. At current energy costs, the homebuyers' monthly energy savings from the ENERGY STAR+ package with the ducts moved inside compared to WSEC ranges from $10-$38 per month. This provides the consumer with positive cash flow at current assumed utility rates, for most cases without incentives and for all cases with incentives.
5. All three software models predicted significant savings for the use of heat pumps compared to gas furnaces, based on assumed utility rates of $0.0658 per kilowatt-hour (kWh) for electricity and $1.2189 per therm for gas. This assumes that the heat pump has been properly commissioned per the regional utility heat pump program. SEEM predicted an average $282 in savings, compared to $195 for EG and $200 for REM.
6. Though a full assessment of tax credit qualifications is beyond the scope of this research, it is worth noting that EG and REM, the two analysis tools that also provide tax credit compliance, delivered different results. Using the same inputs, REM complied both cases 3 and 4 (ducts inside) in both climates; EG did not comply any of the homes. It is

Table 4. Savings of R-30 Vented over R-15 Conditioned Crawlspace ($/year)

		R-4 Duct Insulation			R-7 Duct Insulation		
		SEEM	**EG**	**REM**	**SEEM**	**EG**	**REM**
Marine—Gas	Case 1-2	($37)	$48	($20)	($14)	$53	($5)
	Case 3-4	$27	$50	$45	$27	$50	$45
	Case 5-6	($52)	$61	($17)	($31)	$64	($6)
Marine—HP	Case 1-2	($50)	$12	($10)	($27)	$19	$0
	Case 3-4	$8	$23	$22	$8	$23	$22
	Case 5-6	($51)	$18	($20)	($33)	$26	($11)
Cold—Gas	Case 1-2	($60)	$70	($9)	($23)	$77	$9
	Case 3-4	$48	$75	$69	$48	$75	$69
	Case 5-6	($97)	$84	($2)	($58)	$90	$12
Cold—HP	Case 1-2	($119)	$6	($18)	($63)	$29	$1
	Case 3-4	$21	$38	$47	$21	$38	$47
	Case 5-6	($119)	$19	($24)	($76)	$41	($6)

Table 5. Savings of Moving Ducts Inside Home ($/year)

		R-4 Duct Insulation			R-7 Duct Insulation		
		SEEM	**EG**	**REM**	**SEEM**	**EG**	**REM**
Marine—Gas	Case 1-3	$46	$76	$44	$35	$61	$44
	Case 2-4	**$110**	**$78**	**$109**	**$76**	**$58**	**$94**
Marine—HP	Case 1-3	$44	$148	$20	$33	$107	$19
	Case 2-4	**$102**	**$159**	**$52**	**$68**	**$111**	**$41**
Cold—Gas	Case 1-3	$81	$153	$64	$63	$122	$62
	Case 2-4	**$189**	**$158**	**$142**	**$134**	**$120**	**$122**
Cold—HP	Case 1-3	$115	$320	$50	$91	$239	$48
	Case 2-4	**$255**	**$352**	**$115**	**$175**	**$248**	**$94**

Note: **Bold** Indicates vented crawlspace.

Table 6. Savings of ENERGY STAR+ and Moving Ducts Inside—R-4 Ducts ($/year)

		R-4 Duct Insulation			R-7 Duct Insulation		
		SEEM	**EG**	**REM**	**SEEM**	**EG**	**REM**
Marine—Gas	Case 5-3	$227	$295	$188	$214	$271	$187
	Case 6-4	**$306**	**$284**	**$250**	$272	$257	$238
Marine—HP	Case 5-3	$142	$279	$89	$131	$238	$88
	Case 6-4	**$201**	**$284**	**$131**	$172	$235	$121
Cold—Gas	Case 5-3	$400	$503	$282	$380	$456	$280
	Case 6-4	**$545**	**$494**	**$353**	$486	$441	$337
Cold—HP	Case 5-3	$315	$580	$181	$292	$493	$179
	Case 6-4	**$455**	**$599**	**$252**	$389	$490	$232

Note: **Bold** Indicates vented crawlspace.

Table 7. Savings of R-7 (Effective) Duct Insulation over R-4 ($/year)

	R-7 vs. R-4			
		SEEM	EG	REM
Marine—Gas	Case 1	$11	$15	$0
	Case 2	**$34**	**$20**	**$15**
	Case 3	$0	$0	$0
	Case 4	**$0**	**$0**	**$0**
	Case 5	$13	$24	$1
	Case 6	**$34**	**$27**	**$12**
Marine—HP	Case 1	$11	$41	$1
	Case 2	**$34**	**$48**	**$11**
	Case 3	$0	$0	$0
	Case 4	**$0**	**$0**	**$0**
	Case 5	$11	$41	$1
	Case 6	**$29**	**$49**	**$10**
Cold—Gas	Case 1	$18	$31	$2
	Case 2	**$55**	**$38**	**$20**
	Case 3	$0	$0	$0
	Case 4	**$0**	**$0**	**$0**
	Case 5	$20	$47	$2
	Case 6	**$59**	**$53**	**$16**
Cold—HP	Case 1	$24	$81	$2
	Case 2	**$80**	**$104**	**$21**
	Case 3	$0	$0	$0
	Case 4	**$0**	**$0**	**$0**
	Case 5	$23	$87	$2
	Case 6	**$66**	**$109**	**$20**

Note: **Bold** Indicates vented crawlspace.

also worth noting that neither software could comply homes which used heat pumps as the heating source.

7. In heating-dominated climates such as those being analyzed here, homes meeting the ENERGY STAR Northwest requirements for lighting (50% CFLs) gain little benefit from a reduction in cooling load ($2 average savings compared to homes with only 10% CFLs), and penalized for the reduction in internal gains ($10 average increase in heating costs.) Since the tax credit modeling does not take into account the energy savings from the use of efficient lighting (an average $31 savings) the use of CFLs creates a disadvantage for tax credit qualification.
8. All of the models predict some level of savings for bringing the ducts inside the heated space.
9. Duct insulation—all three models showed savings for increased duct insulation in the vented crawlspace. SEEM and Energy Gauge showed some savings for improved duct insulation in the conditioned crawlspace (but less than the vented crawlspace). REM showed little to no savings in the conditioned space.
10. Savings values are uncertain given the uncertainty of many of the model inputs values and limited ability to see small differences in energy use (typically ±8%–10%).

RECOMMENDATIONS

None of the models included whole house mechanical ventilation or crawlspace exhaust ventilation, in large part because the researchers determined that the modeling softwares each assess the energy impact of ventilation in different ways. Further research is needed to determine the extent of these variations, and how they may have an impact on results generated by these softwares, including qualification for tax credits.

As mentioned above, the energy usage analysis comparing vented crawlspaces with perimeter insulated crawlspaces does not take into account potential moisture and indoor air quality impacts associated with the use of perimeter insulated systems. Further research into these impacts is important for decisions regarding potential changes to code requirements or ENERGY STAR specifications.

The discrepancies between the three modeling tools suggests that further investigation into the inherent biases of the tools is justified. Aligning these tools is of importance to researchers and the rating industry; this is of particular and immediate concern with the tax credit.

Related to this is the difficulty in qualifying heat pump homes for the tax credit. The challenge here is twofold. First, the RESNET procedures that guide the tax credit qualification process assume that the reference home is properly commissioned, contrary to standard practice observed in the field. In addition, there is an inherent bias in the underlying calculation for the reference home for all electrically heated homes, including heat pumps (RESNET 2005). Project staff are working with RESNET, along with other regional and national partners, to correct these inequities.

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Table 8a. Incremental Costs—Marine (2200 ft^2)

Component	Vented Crawlspace		Sealed Crawlspace	
	Measure	Cost	Measure	Cost
Crawlspace	R-30 floor insulation	$1,279	R-15 perimeter insulation	$1,364
			Additional "rat slab" with drain	$675
			Additional crawlspace exhaust fan and grill or Two supply ducts to crawlspace	$250 $30
			Radon pipe from crawlspace	$405
			Exterior drain pipe/rock	$300
Total Crawlspace	**$1,279**		**$2,774–$2,994**	
HVAC	AFUE 80% to 94% with ECM (60K)	$850	AFUE 80% to 94% with ECM (60K)	$850
	Moving HVAC inside	$675	Moving HVAC inside	$675
Total HVAC	**$1,525**		**$1,525**	
ENERGY STAR Homes Northwest	Duct sealing with mastic and testing	$850	Duct sealing with mastic and testing	$850
	Duct testing and third-party verification	$400	Duct testing and third-party verification	$400
	Envelope air sealing to beyond-code practice	$100	Envelope air sealing to beyond-code practice	$100
	Hot water heater upgrade—EF .58 to .61	$150	Hot water heater upgrade—EF .58 to .61	$150
	Attic insulation upgrade—R-38 to R-49	$320	Attic insulation upgrade—R38 to R49	$320
	50% CFL lighting	$120	50% CFL lighting	$120
Total ENERGY STAR	**$1,290**		**$1,290**	
Incremental Cost—All Upgrades	**$4,094**		**$5,589–$5,809**	

Table 8b. Incremental Costs – Cold (1550 ft^2)

Component	Vented Crawlspace		Sealed Crawlspace	
	Measure	Cost	Measure	Cost
Crawlspace	R-30 floor insulation	$1,432	R-19 batt insulation	$713
HVAC	9.1 HSPF/14 SEER Heat pump with ECM—2 ton	$1,620	9.1 HSPF/14 SEER Heat pump with ECM—2 ton	$1,620
	Moving HVAC inside	$810	Moving HVAC inside	$810
Total HVAC	**$2,430**		**$2,430**	
ENERGY STAR Homes Northwest	Duct sealing with mastic and testing	$270	Duct sealing with mastic and testing	$270
	Duct testing and third-party verification	$203*	Duct testing and third-party verification	$203*
	Envelope air sealing to beyond-code practice	$608	Envelope air sealing to beyond-code practice	$608
	Electric hot water heater upgrade—EF .88 to .94	$113	Electric hot water heater upgrade—EF .88 to .94	$113
	50% CFL lighting	$216	50% CFL lighting	$216
Total ENERGY STAR	**$1,410**		**$1,410**	
Incremental Cost—All Upgrades	**$5,272**		**$4,553**	

*Duct testing and verification provided for free by utility.

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