Crawlspace Design in Marine and Cold Climates

KEYWORDS: HEAT PUMP, FURNACE, RESIDENTIAL BUILDNGS, DUCTS, SOFTWARE

CRAWLSPACE DESIGN IN MARINE AND COLD CLIMATES

ABSTRACT

With support from the U.S. Department of Energy Building America program (1), researchers evaluated eight homes built to ENERGY STAR Homes Northwest™ standards (2). Four marine-climate homes use gas furnaces; four cold-climate homes use heat pumps. The homes have heating, ventilation and air-conditioning (HVAC) systems located in crawlspaces, attics and garages, or within the home, and have "conditioned" or vented crawlspaces. The International Energy Conservation Code (IECC) permits conditioned crawlspaces; the Washington State Energy Code (WSEC) does not. Both codes allow ductwork in unconditioned attics, crawlspaces or garages (3-4).

Using field testing data as inputs, three energy simulation software models were used to evaluate energy use (5-7). The research design compares simulation models based on foundation type, duct location (inside or outside conditioned space) and duct insulation levels. ENERGY STAR Homes Northwest energy use is also compared to a base case WSEC home. Utility savings, builder pricing and simple consumer affordability issues are presented.

The research may help the American Society of Heating, Refrigerating and Air-conditioning Engineers (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 eight homes represent some of the most energy efficient production housing built in Washington State in 2006. These homes:

1. Exceed Washington State Energy Code (WSEC)
2. Are certified to ENERGY STAR Homes Northwest™ utility program requirments
3. Are benchmarked to USDOE Building America 30-40% whole-house savings (1).
4. Are evaluated for the $2000 federal energy tax credit for new homes (8).

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 (EEM) technologies. The utility incentives are based on savings determined by the Regional Techical Forum (9), 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 builders built four test homes in ENERGY STAR communities. The marine climate homes are three-bedroom, two-story 2200 square foot (ft^2) homes with a roughly 15% glass-to-window-to-floor area. The cold-climate homes are 1550 ft^2 ranch style models, with less than 10% glazing.

The eight homes were built to meet or exceed both WSEC and ENERGY STAR Homes Northwest requirements. Major features include:

- Duct and envelope leakage testing
- ENERGY STAR Homes Northwest verification and quality assurance (QA) inspections
- ENERGY STAR HVAC and 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.

Actual homes employed a number of supply and exhaust strategies to provide whole-house ventilation and crawlspace conditioning. . condition the crawlspace in the marine homes.

HVAC AND CRAWLSPACE DESCRIPTION

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 and 5, 6 represent current code practice in marine climates, where case 6 is the typical Code vented crawlspace., and 5 is a conditioned crawlspace.

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

Each of the 6 cases was simulated in both climates using both natural gas furnaces with AC or 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. One approach used to improve HVAC system thermal distribution efficiency is to move ductwork and HVAC system from crawlspace, attic and garage into the home, and are represented as cases 3 and 4 (11).

The marine climate test two story 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 (12).

The cold-climate single story 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 Fuel Utilization Efficency (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 Perfomance Factor (HSPF) and 14.5 SEER. These heat pumps are assumed to be installed and tested in accordance with a utility commissioning program, and are part of a USDOE heat pump research program. 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 R7 based on previous research (ACEEE-Palmiter). A separate analysis was conducted assuming R-4 ducts for all cases as well, to assess energy savings associated with duct R-value increases.

Vented and Sealed Crawlspace

During the research effort, half of the homes were built with floors insulated to R30 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, conditoned 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.

In the modeling, neither the energy use the crawlspace exhaust fan, nor the thermal implications of the fan and floor grill were included, in part due to software limitations and to simplify the comparitive analysis. A continuously operating 50 CFM, 50 watt crawlspace exhaust fan would add an additonal $29 per year.

Perimeter insulated crawlspaces are not allowed by code in Washington and Oregon , but are in use across the country; USDOE Building America projects regularly employ this approach, typically with EPS foam.

FIELD TESTING RESULTS

Field testing results are presented in Table 2.

Envelope Leakage

Researcher determined the envelope leakage using a Blower Door™. Blower door field testing of the non-crawspace envelope area results ranged from 3.3-4.7 air changes per house at 50 pascals (ACH50) for all homes as shown in table 2.

In both the marine and cold climate homes, the builder's first homes (noted by an *) tested with leakage rates above 4.0 ACH50. Envelope leakage rates for subsequent homes were reduced to below 4.0 ACH50 as a result of improved air leakage control.

For the analysis, a value of 0.35 ACH was used for the ENERGY STAR homes. A value of 0.4 ACH was used for the WSEC homes, based on previous energy code random-sample research (14). In the software, adjustments were made to the blower door fan flow to provide consistant ACH 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 85-128 CFM of whole-house mechanical ventilation (dependent on house size and number of bedrooms) with timers set to operate eight hours a day, while Standard 62.2 requires roughly 50 CFM minimum at constant operation (4). Whole-house exhaust fans and crawlspace exhaust fans (for conditioned crawlspace cases) flow rates were roughly 50 CFM, measured with an Energy Conservatory Flow Box™.

For the analysis, no ventilation systems were assumed; this decision was made to avoid inconsistencies between the software modeling tools that in some instances led to a significant energy usage penalty when ventilation systems were modeled.

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 modelling analysis is also presented in Table 2, along with HVAC system size.

ENERGY USE MODEL SAVINGS COMPARISONS

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 attempted to consistently model the cases. 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.

Table 3 provides 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 R4 and effective R7 (nominal R8) duct insulation levels. As noted above, these values do not include an estimated $29 per year for operating crawlspace fan or any thermal penalties associated with the use of whole house mechnical ventilation.

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 perimiter 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 R7 (effective) vs. R4 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 derived from an informal builder survey, with WSEC assumed as the base case. Builder costs were then converted to homebuyer costs, using a markup of 1.35%, typical of the residential new homes market.

The incremental costs for the marine climate builder is $2816 (a 2200 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 $3830 (a 1550 ft.^{2}, or $2.47/ft.^{2}.)

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 $300 to $1000 throughout the Northwest region. These costs also do not include pricing impacts from the $2000 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 $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 R19 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. Mositure condensation in the fiberglass foudation wall has already been observed.
3. The incremental homeowner cost of all of the energy efficiency measures ranges from $2800-$3800, 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 utilty 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 assesment 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.
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 – sealed crawlspace situation agree better with vented crawlspace than with the conditioned crawlspace. Fairly profound differences between the models.
10. Savings values are uncertain given the uncertianty of many of the model inputs values , limited ability of models to assess impacts of duct leakage and ground contact. This unceratinty is compouded as the samll difference of two large numbers.

RECOMMENDATIONS

None of the modelling 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 and model development may be needed to investigate the interactions of cralwspace and whole house ventilations. The use of the crawlspace exhuast fan to provide some crawlspace conditioing and whole houseexhuast ventilation should be furthr explored.

As mentioned above, the energy usage analysis comparing vented crawlspaces with perimeter insulated crawlspaces ignores potential moisture and indoor air quality impacts. Current research into these impacts is important to building codes and utility programs such as Energy Star. Moisture and IAQ investigations are currently underway on these eight home.

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. Limitations on the models' ability to properly model for tax credit.

Practioners need to understand the limitation of energy modelling when asssessing small incremental energy savings. "Confusious say man with three models never no energy savings"

ACKNOWLEDGEMENTS

This research, deployment and demonstration collaborative effort is funded by the USDOE Building America CONSOL (BIRA) and Northwest Energy Efficiency Alliance residential programs.

Special thanks to Bruce Carter at Clark County Pubic Utility District (PUD), Jim Frank at Grant County PUD, and other regional and national stakeholders.

Special thanks are also due to all Building America teams; Building Science Corporation and IBACOS, and Advanced Energy Corporation for their advisory roles on this project.

Finally, thanks to Steve Tapio and his staff at New Tradition Homes, as well as Ken Condit of Condit Homes

REFERENCES

1. US Department of Energy Building America Program http://www/buildingamerica.gov
2. Northwest Energy Efficiency Alliance ENERGY STAR Home Northwest™ Program http://www.nwalliance.org
3. International Energy Conservation Code (IECC)
4. Washington State Energy Code and Ventilation and Indoor Air Quality Code. http://www.energy.wsu.edu
5. EGUSA http://www.fsec.ucf.edu
6. REMRATE http://archenergy.com
7. SEEM – Converations with Ecotope, Jan 2007
8. Federal Energy Residential Tax Credit
9. Northwest Power and Conservation Council. Regional Techncial Forum. http://www.nwcouncil.org
10. ASHRAE. 2004. *ANSI/ASHRAE Standard 62.2, Ventilation for acceptable indoor air quality*. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
11. ASHRAE. 2004. *2004 ASHRAE Handbook—HVAC Systems and Equipment*, Chapter 9.
12. The Energy Conservatory, operations manuals for Blower Door™, Duct Blaster™ and True Flow™ http://www.energyconservatory.com
13. NEEA current practice residential code study

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 R15 perimeter	crawl/attic/garage "inside crawl" R4 & R7
2 ENERGY STAR	0.94 - 14.5 9.0 – 14.5	R= 49 R= 21 U=.32	50% None	Vented 1:300 R30 floor	crawl/attic/garage "outside" R4 & R7
3 ENERGY STAR +	0.94 - 14.5 9.0 – 14.5	R= 49 R= 21 U=.32	50% None	Conditioned R15 perimeter	between floors "inside" R4 & R7
4 ENERGY STAR +	0.94 - 14.5 9.0 – 14.5	R= 49 R= 21 U=.32	50% None	Vented 1:300 R30 floor	between floors "inside" R4 & R7
5 WSEC	0.8 - 13 8.0 – 13	R= 38 R= 21 U=.35	50% None	Conditioned R15 perimeter	between floors "inside crawl" R4 & R7
6 WSEC	0.8 - 13 8.0 – 13	R= 38 R= 21 U=.35	50% None	Vented 1:300 R30 floor	crawl/attic/garage "outside" R4 & R7

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 Out (EG & REM)	Model Used ACH (fixed) (SEEM)	Model Duct Leak CFM25 Out (EG&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

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**

Bold Indicates vented crawlspace

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**

Bold Indicates vented crawlspace

Table 4a: Savings of R30 Vented over R15 Conditioned Crawlspace – R-4 duct insulation ($/year)

R15 Cond. vs. R30 Vented Crawl: R4				
		SEEM	**EG**	**REM**
Marine - Gas	Case 1-2	($37)	$48	($20)
	Case 3-4	$27	$50	$45
	Case 5-6	($52)	$61	($17)
Marine - HP	Case 1-2	($50)	$12	($10)
	Case 3-4	$8	$23	$22
	Case 5-6	($51)	$18	($20)
Cold - Gas	Case 1-2	($60)	$70	($9)
	Case 3-4	$48	$75	$69
	Case 5-6	($97)	$84	($2)
Cold - HP	Case 1-2	($119)	$6	($18)
	Case 3-4	$21	$38	$47
	Case 5-6	($119)	$19	($24)

Table 4b: Savings of R30 Vented over R15 Conditioned Crawlspace – R-7 duct insulation ($/year)

R15 Cond. vs. R30 Vented Crawl: R7				
		SEEM	**EG**	**REM**
Marine - Gas	Case 1-2	($14)	$53	($5)
	Case 3-4	$27	$50	$45
	Case 5-6	($31)	$64	($6)
Marine - HP	Case 1-2	($27)	$19	$0
	Case 3-4	$8	$23	$22
	Case 5-6	($33)	$26	($11)
Cold - Gas	Case 1-2	($23)	$77	$9
	Case 3-4	$48	$75	$69
	Case 5-6	($58)	$90	$12
Cold - HP	Case 1-2	($63)	$29	$1
	Case 3-4	$21	$38	$47
	Case 5-6	($76)	$41	($6)

Table 5a: Savings of Moving Ducts Inside Home – R4 Ducts ($/year)

Ducts Inside: R4				
		SEEM	**EG**	**REM**
Marine - Gas	Case 1-3	$46	$76	$44
	Case 2-4	**$110**	**$78**	**$109**
Marine - HP	Case 1-3	$44	$148	$20
	Case 2-4	**$102**	**$159**	**$52**
Cold - Gas	Case 1-3	$81	$153	$64
	Case 2-4	**$189**	**$158**	**$142**
Cold - HP	Case 1-3	$115	$320	$50
	Case 2-4	**$255**	**$352**	**$115**

Bold Indicates vented crawlspace

Table 5a: Savings of Moving Ducts Inside Home – R7 Ducts ($/year)

Ducts Inside: R7				
		SEEM	**EG**	**REM**
Marine - Gas	Case 1-3	$35	$61	$44
	Case 2-4	**$76**	**$58**	**$94**
Marine - HP	Case 1-3	$33	$107	$19
	Case 2-4	**$68**	**$111**	**$41**
Cold - Gas	Case 1-3	$63	$122	$62
	Case 2-4	**$134**	**$120**	**$122**
Cold - HP	Case 1-3	$91	$239	$48
	Case 2-4	**$175**	**$248**	**$94**

Bold Indicates vented crawlspace

Table 6a: Savings of ENERGY STAR+ and Moving Ducts Inside – R-4 ducts ($/year)

Ducts Inside & Energy Star+: R4				
		SEEM	**EG**	**REM**
Marine - Gas	Case 5-3	$227	$295	$188
	Case 6-4	**$306**	**$284**	**$250**
Marine - HP	Case 5-3	$142	$279	$89
	Case 6-4	**$201**	**$284**	**$131**
Cold - Gas	Case 5-3	$400	$503	$282
	Case 6-4	**$545**	**$494**	**$353**
Cold - HP	Case 5-3	$315	$580	$181
	Case 6-4	**$455**	**$599**	**$252**

Bold Indicates vented crawlspace

Table 6b: Savings of ENERGY STAR+ and Moving Ducts Inside – R-7 ducts ($/year)

Ducts Inside & Energy Star+: R7				
		SEEM	**EG**	**REM**
Marine - Gas	Case 5-3	$214	$271	$187
	Case 6-4	**$272**	**$257**	**$238**
Marine - HP	Case 5-3	$131	$238	$88
	Case 6-4	**$172**	**$235**	**$121**
Cold - Gas	Case 5-3	$380	$456	$280
	Case 6-4	**$486**	**$441**	**$337**
Cold - HP	Case 5-3	$292	$493	$179
	Case 6-4	**$389**	**$490**	**$232**

Bold Indicates vented crawlspace

Table 7: Savings of R7 (effective) Duct Insulation over R4 ($/year)

R4 vs. R7				
		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**

Bold Indicates vented crawlspace

Table 8a: Incremental Costs – Marine (2200 ft2)

<u>Crawlspace:</u>
Vented Crawlspace R30 floor insulation = $1279
Conditioned Crawlspace (R15 Foam) = $1364
Additional "rat-slab" w/drain = $675
Additional crawlspace exhaust fan & grill = $250
(Or) Two supply ducts to crawlspace = $30
Radon Pipe from crawlspace = $ 405
Exterior drain pipe/rock = $300

<u>HVAC Upgrade:</u> = **$1525**
AFUE 80% to 94% w/ECM (60K) = $850
Moving HVAC Inside = $675

<u>ENERGY STAR NW Upgrade:</u> = **$1290**
Duct sealing w/mastic & testing = $200
Ducts testing & 3rd party verification = $400
Envelope air sealing beyond code practice = $100
DHW upgrade from EF=.58 to EF=.61 = $150
R49 ceiling insulation from R38 = $320
50% CFL lighting = $120

Table 8b: Incremental Costs – Cold (1550ft2)

<u>Crawlspace:</u>
Vented Crawlspace R30 floor insulation = $1432
Conditioned Crawlspace (R19 batt) = $713

<u>ENERGY STAR/Tax Credit HVAC Upgrade</u>: = **$2420**
HSPF/SEER w/ECM (2ton) = $1620
Moving HVAC Inside = $810

<u>ENERGY STAR NW Upgrade:</u> = **$1410**
Duct sealing w/mastic & testing = $270
Ducts testing & 3rd party verification = $203 (free by utility)
Envelope air sealing beyond code practice = $608
DHW upgrade from EF=.88 to EF=.94 = $113
50% screw-in CFL bulbs vs. Incandescent = $216