Premium Ventilation Package Testing

DECISION FRAMEWORK MATRIX REPORT – TASK 5

Final Submittal

October 24, 2008

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Delivered via electronic copy to BPA and partners.

Contract No. 00038702
RTU AirCarePlus & Premium Ventilation Program

PORTLAND ENERGY CONSERVATION, INC

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Scope for Task 5 Item: Decision Framework Matrix

Provide Decision Framework Matrix for one climate location identifying significant variables. The decision framework matrix shall be a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field with up to four (4) parametric variables analyzed. While it shall be based on actual DOE2 simulations, it is not intended to have the rigor required for actual use, but instead to is be an example to help frame discussion with the RTF economizer sub-committee for development of an appropriate method in the future.

Disclaimer

Executive Summary

This report reviews relevant parameters that impact savings for the premium ventilation measure package, available saving methodologies, parametric sensitivity analysis, and looks at two particular deemed savings methods: the matrix approach and an expected value approach.

Investigation found a matrix approach using parameter input to select savings to be a reasonable approach; however, input requirements are similar to a parametric based spreadsheet that would provide more customized results for each site. The alternative expected value deemed savings approach avoids the need for input outside the servicing contractor's expertise and provides a good weighted deemed savings for work in one climate zone. With this simplicity and reduced administration cost the weighted deemed approach may be more desirable than a parametric input approach when the program design does not include a site visit by an energy expert.

Decision Framework Matrix

In the Pacific Northwest, there are three paths to acknowledging savings for commercial energy saving measures incorporated into utility integrated resource plans that can be credited by BPA:

- Custom savings. These require pre-review and a high level of custom analysis not efficient for smaller projects.
- Lighting savings. This method uses a regionally approved calculation spreadsheet and allows individual site calculation without the need for method pre-approval and extensive custom simulation.
- Deemed measures & unit rebates. These measures have deemed savings per unit and while the regional technical forum (RTF) has established an extensive list of residential measures, the list of commercial sector HVAC measures has been relatively short. This is due in part to the more highly variable nature of parameters impacting HVAC savings in the commercial sector. Per fixture lighting rebates are one example of a deemed measure.

The goal of this work was to provide a Decision Framework Matrix for one climate location identifying significant variables. The decision framework matrix is a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field. We also explore an alternative method to find a single deemed savings per major climate zone, called *expected value deemed savings*. This method provides a good estimate of regional savings based on relevant parameter variation, but has the simplicity of a single deemed savings.

For the analysis, a premium ventilation measure package for packaged rooftop HVAC units is evaluated, as described in detail in Appendix A. The measure package includes a western premium economizer upgrade, optimum start thermostat, variable speed fan motor, and demand controlled ventilation (DCV).

Relevant Parameters

Relevant parameters are those which impact the same end uses that the measure will impact. Note that while the measure package under consideration does not impact lighting directly, lighting energy use in the baseline has a large impact on heating and cooling load, so it is considered a relevant parameter. Multiple parameters that were expected to have an impact on measure savings are listed below. These are grouped as meta-parameters, analyzed parameters and other parameters.

Drawbacks of Building Type as a Primary Parameter

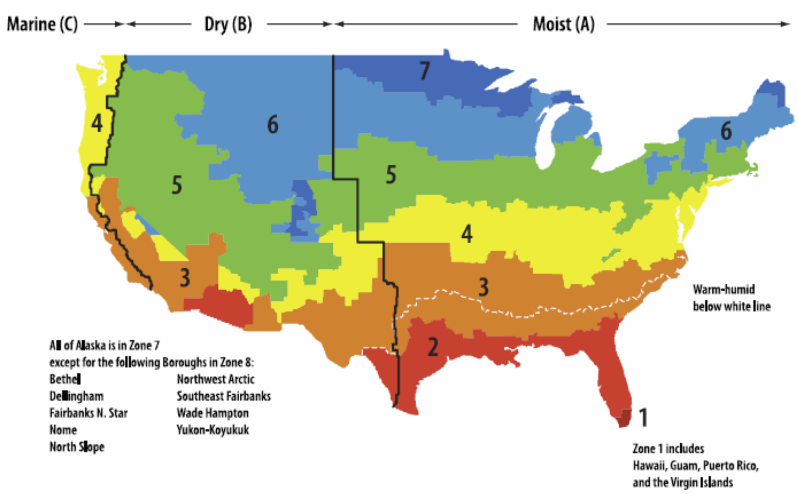
Note that building type is not among the parameters analyzed. While this is a common approach, both in the DEER[1] database in California and in many other measure characterization systems, there are flaws. Often the building types are limited in number. As a result, convenience stores might be included with small retail. This results in buildings with very different energy impacts getting lumped together. Some small retail shops have short hours, low occupancy and very low internal loads. Others, like a jewelry store, have high lighting loads, while some have very high internal loading and refrigeration use, such as a convenience store. Each of these can be characterized by parameters better than by type. Relevant parameters may include internal loads and operating hours. If the relevant parameters are found for a particular measure, or measure package, then the range of energy savings response will be better articulated than with building types, unless many sub-building types are included. If the sub-building type approach is taken, it may result in much more analysis than just focusing on the relevant parameters. The other problem with building type and vintage approach is that buildings with similar occupancies, vintage, and type may have widely different energy use, depending on whether these buildings have undergone an energy upgrade, such as a lighting retrofit, that significantly reduces internal gains.

Meta-Parameters

Meta-parameters typically require a separate analysis and separate treatment in savings allocation, although this is not always the case.

- Major climate: in the Pacific Northwest, measures are typically analyzed separately for the western area and eastern area, corresponding to ASHRAE climate zones 4 and 5 respectively. Areas in climate zone 6 are typically lumped with climate zone 5, as the climate zone 6 areas are low in population. This level of distinction typically results in adequate differentiation in results. ASHRAE climate zones are typical of major climate zones. Portland vs. Boise proxies are used in this analysis as proxies for the western and eastern regional climates. A single run with all typical settings was included for Boise, Idaho.

Figure 1: ASHRAE Climate Zones



[1] The **Database for Energy Efficient Resources** (DEER) is a California Energy Commission and California Public Utilities Commission sponsored database designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life.

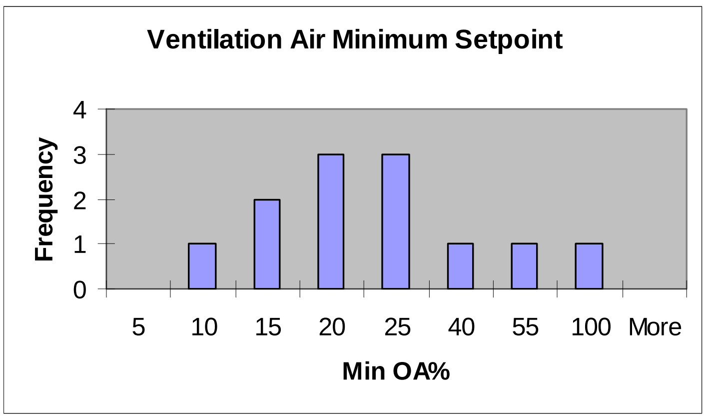
- Heating type: when the heating type changes fuel sources, a separate analysis is required to capture unit savings by fuel type.

Analyzed Parameters

The baseline parameters analyzed for this example, with the settings included, are listed. The typical or neutral setting for each parameter is bolded.

- Internal loads, primarily as indicated by lighting density: lights 1.0 Watts per square foot; **lights 1.8 Watts per square foot**; call center density: lights 1.8 Watts per square foot + double plug load (1.5 Watts per square foot) + density (100 sf/person)
- Envelope: quality glass, double pane low-e argon filled (2668); **standard glass – double pane tinted (2203 #2)**; Poor glass curtain wall, single pane (1001)
- Economizer found changeover: failed (or none); **55°F(D);** 65°F(C); full 75°F(B)
- Minimum outside air (OSA) setting found (includes damper leakage):
  25% = 37.6 cfm/person; **20.6% = 31.0** cfm/person**;** 15% =22.6 cfm/person
  Note that most measure analysis of this type would assume a code baseline of around 10-15% ventilation air setting. This measure takes credit for setting the ventilation minimum using DCV, so it is much lower than the typically found setting. The typically found setting is higher than code requires, based on a field study in the Eugene, as seen in Figure 2.

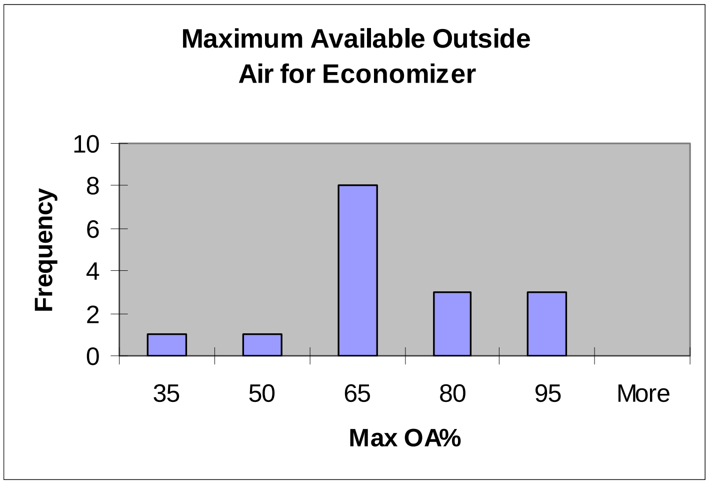
Figure 2: Distribution of Minimum Ventilation Settings



Source: Ecotope EWEB study – 2001

- Economizer maximum OSA flow: 50%, **65%,** 80%. Note that while the study results shown in Figure 3 indicate 65% is typical, the EWEB study focused on units smaller than 5 tons. Conversations with Mike Kennedy indicate that when larger units are included, such as in the Puget Sound Energy program, 80% is more typical.

Figure 3: Distribution of Maximum Ventilation Capability



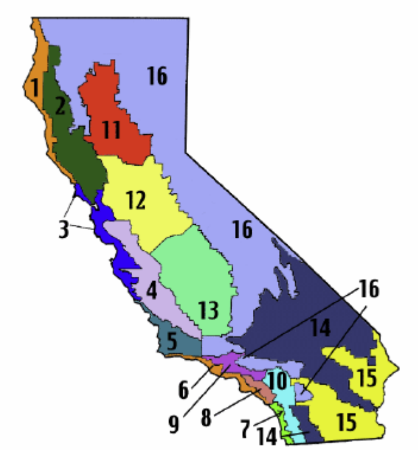
Source: Ecotope EWEB study – 2001

Other Relevant Parameters

The following parameters are thought to be relevant to the investigation. They were not included here due to budget considerations, but should be included in a final review of this measure package.

- Hours of operation: brief 9 hours per day, 5 days per week; **office 11 hours per day, 6 days per week**; 2-shift call center 18 hours per day, 7 days per week; 24/7.
- Perimeter ratio: 3000 square feet, single storey; **25**,000 square feet, two storey; 50,000 square feet three storey.
- Base case measure overlap. Where some measures in a package may already be included in the base case condition, the impact on total savings can be modeled based on estimates for the occurrence of those measures.
- Measure reliability. One difficult to measure item is the actual savings performance of measures involving tune-up of controls or variable reliability of control operation. Once a robust sample of units has been monitored for actual performance, probabilities and performance levels can be entered as an influence in a decision model analysis as discussed later in the paper.
- Minor climate zones: for some measures, there may be meaningful impacts from different local climate zones. California is one example where 16 climate zones seen in Figure 4 have been implemented over the range of 4-5 major climate zones. With minor climate zones, the range of impact on savings is likely to be less than the impact of other parameters, and such impacts can be treated in the decision analysis in a similar manner.

Figure 4: California Climate Zones



- The impact of market transformation effects and delivery improvements over time can be included as a parameter, improving the realized savings in balance to the reliability issue parameter previously discussed. It is important to understand the impact of market transformation effects so a valid long-term program strategy can be developed.

Savings Methodology Approaches

There are multiple approaches to analyzing or predicting program savings for energy measures. These are listed below from the most site-specific analysis to program-wide single deemed savings. Each method can have varying degrees of sophistication and hence presumed accuracy. For example a custom eQUEST (DOE2)[2] analysis can be run with or without calibration, and with custom envelope development or a simplified architectural configuration; parametric approaches can have a few or many parameters input; and deemed approaches can have a simplified or complex model behind the development of the deemed savings. Typical methodology approaches include:

- Custom analysis – this requires a model for each individual application and results in relative high accuracy. Too expensive for most contractor-delivered programs, it slows down the process when a contractor is trying to make a sale, as an energy analyst must visit the site first and complete the analysis. The level of custom analysis can range from a simplified or approximate method to an analysis that is fully calibrated to site energy bills. DOE-2 is commonly used, although a full range of modeling programs can be found at: http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

- Field-based monitoring approach – there have been some attempts to collect field data for HVAC systems pre- and post-retrofit and use that data to generate savings. So far, this method has been elusive, and the sample sizes or time of data collection have been too small to generate data that can be used to generate savings with a high degree of confidence.

- Field-driven model approach – this method obtains field data for primary parameters and feeds that data into a simplified model to generate savings. This method uses inputs that are familiar to the field technician and makes assumptions about the remaining inputs based on building type. Among examples of this approach is the Savings Estimator,[3] developed at Purdue University.

- Energy-bill-based parametric tool – this type of parametric tool looks at billing data for a site and resolves a parametric model to the data, sometimes correlated with average monthly temperature. One example is EZ Sim (www.ezsim.com). Similar approaches are used by web-based auditing tools produced by Nexus and Apogee. While an attractive method for whole building analysis, when savings for one rooftop unit among many at a site is desired, savings or energy impacts can be difficult to see in the site energy data.

- Parametric tool – a parametric tool requires much less effort per site than a custom analysis; however, the parameters required are often outside the expertise of an installing

[2] eQUEST is a widely used front end for DOE-2, an accepted building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills.

[3] A public version of the Savings Estimator called the Ventilation Strategy Assessment Tool (VSAT) with California climate zones is available at:
http://www.archenergy.com/cec-eeb/P3-LoadControls/P3-1_Reports.htm

HVAC contractor. Making accurate judgments about the lighting density, footprint-to-wall ratio, or glazing type will probably require an energy analyst to visit the site. Reporting for the parametric tool would be implemented similar to the current lighting spreadsheet or Energy Smart grocery program in the Pacific Northwest. Certain parameters, even within the skill of the HVAC contractor, require measurement such as baseline ventilation airflow. These measurements can be difficult to achieve accurately in a timeframe appropriate for the value of the savings. The parametric tool can be isolated to a particular unit, or attempt a whole building approach with the addition of building meter energy data.

- Simplified analysis – this is typically a spreadsheet tool that has relatively simple inputs. The lighting analysis spreadsheet used regionally is an example. Here lighting inputs are very specific, while any HVAC interaction is limited to adjustment factors based on gross system type.
- Matrix method – similar to a parametric tool, except that it would result in a "high, medium, or low" savings output, depending on certain key parameters. The original expectation was that this method would be recommended here; however, this approach is most useable only one or two field parameters are significant in the savings variation equation. In the case of the premium ventilation measure package, there are at least three input parameters that need to be attended to.
- Deemed savings by building type, vintage by measure and climate (California DEER database approach) – this method results in a very straightforward (if long) pick list of deemed values, based on multiple custom analyses of "typical" conditions. Somewhat flexible, except that a particular building may not reflect the typical building type at all. For example, an older vintage building that has been retrofitted with efficient lighting will have a completely different interaction with HVAC systems than the original with high internal loads, and there can be significant difference between sub types within a building type.
- Unit rebate – often used with lighting programs, assigns a fixed savings to unit measures such as a lighting fixture replacement. Easy to implement on a program basis, but not as well matched to control & HVAC measures, as the savings can vary widely based on unit size.
- Expected value deemed savings – this approach results in one expected value of savings for the measure or package, with the caveat that multiple results have to be generated when there are large changes in savings resulting from different meta-parameters, such as major climates or heating type changes. Does not require any site-specific input and maintains regional savings accuracy as long as installations occur with parameter variation similar to the original probability inputs to the model.

For purposes of illustrating methods that have not typically been used, this analysis explores a Matrix Method and Weighted Expected Value Approach. It should be noted that while representative parametric analysis with eQUEST was completed, the intention was to generate values for an example approach and not a final analysis of the premium ventilation package. To develop a field useable expected value, more investigation into different typical parameter values and the probability of occurrence for each value would be undertaken.

Parametric Run Results

Building on prior analysis performed by EWEB for the premium ventilation package, parametric analysis was performed with eQUEST version 3.62c for selected parameters, listed in Table 1.

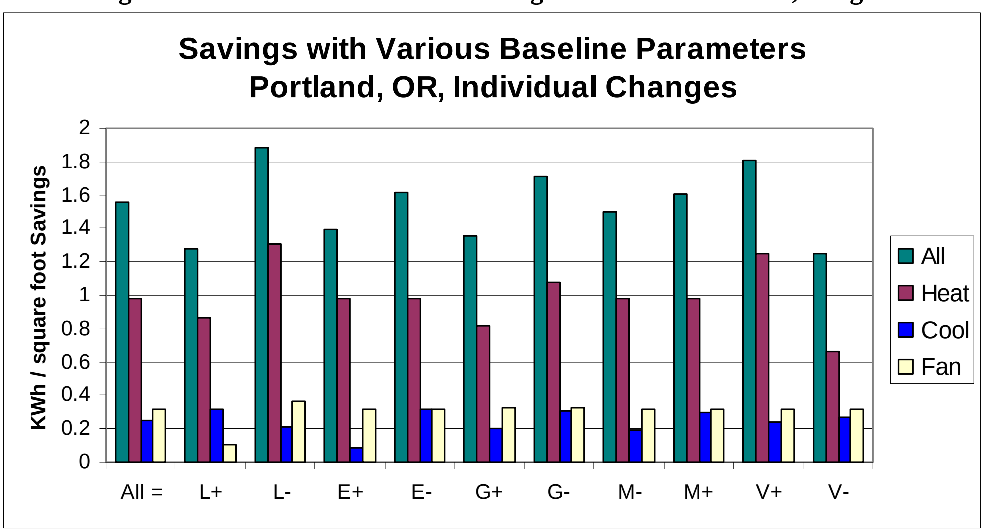
The same ECM parameters used in the EWEB premium ventilation package measure were maintained. Note that the premium ventilation package excludes the evaporative condenser pre-cooling in the earlier analysis, as this measure was found to be too expensive relative to savings except in hot/dry climates, as a plumbing trade must be involved for proper installation.

Table 1: Baseline Parameter Variations Applied & Symbols

Parameter	Sym	Parameter variation in baseline BEFORE measure is installed
Internal Load	L+	1.8 LPD, 1.5 plug, 100 sf/person
LPD	=	1.8 w/sf LPD; eQuest defaults
Density	L-	1.0 w/sf LPD; eQuest defaults
Ventilation	V+	37.6 cfm/person
Minimum	=	31 cfm/person (typical)
	V-	22.6 cfm/person
Glazing	G+	Low-e Argon, double pane
Type	=	Double pane, solar Bronze
	G-	Single Pane
Economizer	E++	B, double stage
Changeover	E+	C, single stage
	=	D or Snap Disk
	E-	Failed Economizer
Economizer	M+	80% Max OSA
Max OSA	=	65% Max OSA
	M-	50% Max OSA

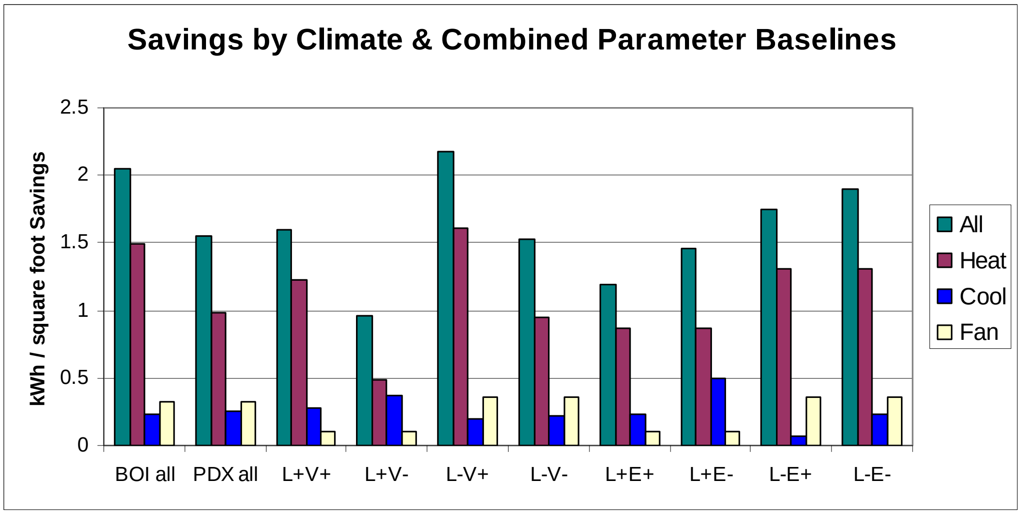
The overall savings on a building area basis when individual parameter values were changed is shown in Figure 5.

Figure 5: Individual Parametric Savings Results for Portland, Oregon



When parameters are varied together, they can either cancel each other out or amplify their impact. Figure 6 shows the total savings for Boise and Portland, along with variation for combinations of lighting (internal loads) and ventilation (L,V) and combinations of lighting and economizer baseline changeover (L,E). Note that there are often cases where heating or cooling move opposite each other or the fan savings, but the overall savings is similar.

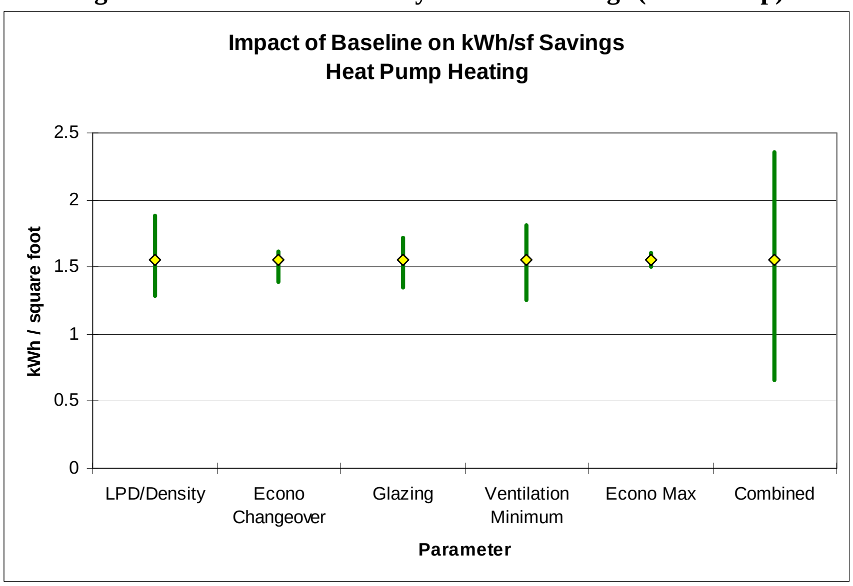
Figure 6: Combined & Climate Parametric Savings Results



Parametric Analysis

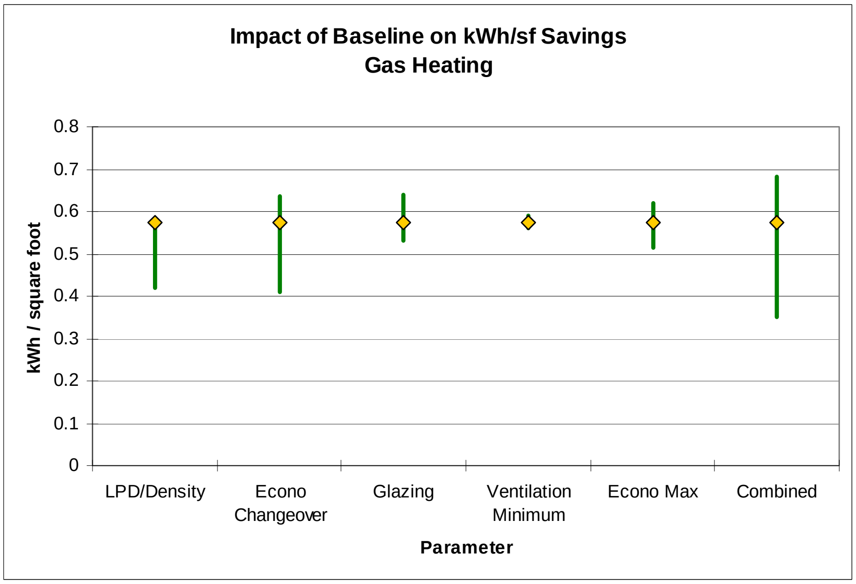
Results from changing analyzed parameter values in both directions from the neutral case are shown in Figure 7. The variation when all parameter values are changed together is also shown. Note that for total energy savings impact the lighting (internal load) and ventilation minimum parameters create the most change.

Figure 7: Parameter Sensitivity for Total Savings (Heat Pump)



When a similar analysis is performed for a gas-furnace heated system, the electric results show different sensitivities. In Figure 8, since electric savings no longer include heating, the economizer changeover condition becomes the most important parameter, with lighting (internal load) the second most important. Hence, attempts to reduce the analysis cost by limiting the number of parameters analyzed may result in misleading results unless sensitive parameters are determined for all meta-parameters.

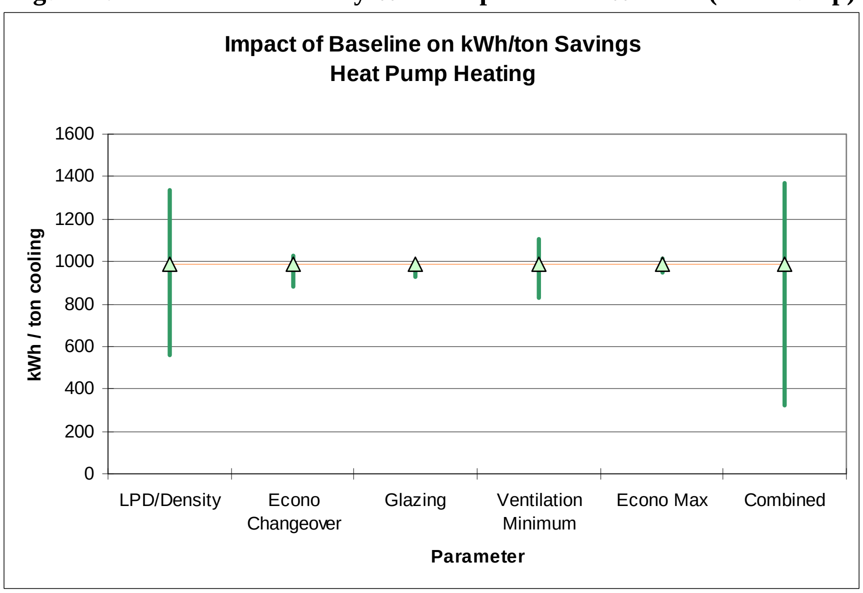
Figure 8: Parameter Sensitivity, Electric Savings for Gas Heating



Impact of Reported Units

Savings have been compared on a building area basis so far. For HVAC program design, it is often popular to base incentives or rebates on unit tonnage. This reduces the impact of certain parameters. In comparing Figure 9 with Figure 7, we see that the savings are less sensitive to the impact of glazing type, and probably to other envelope parameters. This is because a unit for a building with a less efficient building envelope will be sized to handle the greater cooling load.

Figure 9: Parameter Sensitivity When Reported as kWh/Ton (Heat Pump)



Note that using either savings per building area or per unit size will require accurate collection of that data at each site. Some programs have been developed that assume an average or set mix of unit sizes and postulate a fixed savings for the measure. This can be attractive for measures or packages like the premium ventilation package where the cost does not vary by unit size but is similar for a wide range of unit sizes. While a unit-based (RTU-based in this case) deemed savings works well for a region over time, it may not reflect the results for a specific utility in a specific program year. This can result from utilities serving urban areas having a higher average unit size than more rural utilities or a particular delivery contractor focusing more on larger or smaller units. Based on this reality, reporting savings for these measures on a per-ton basis makes the most sense. The rebate can be designed to be uniform per unit, since essentially the same work gets done, or the rebate can be on a per-ton basis, with a cap to avoid windfalls on larger units. Whatever approach is taken, it will be best to implement regional consistency to avoid confusing contractors who serve multiple utility areas. It will also be best on the marketing side of the program to prepare customer savings estimates that are based on a typical unit rather than savings per ton.

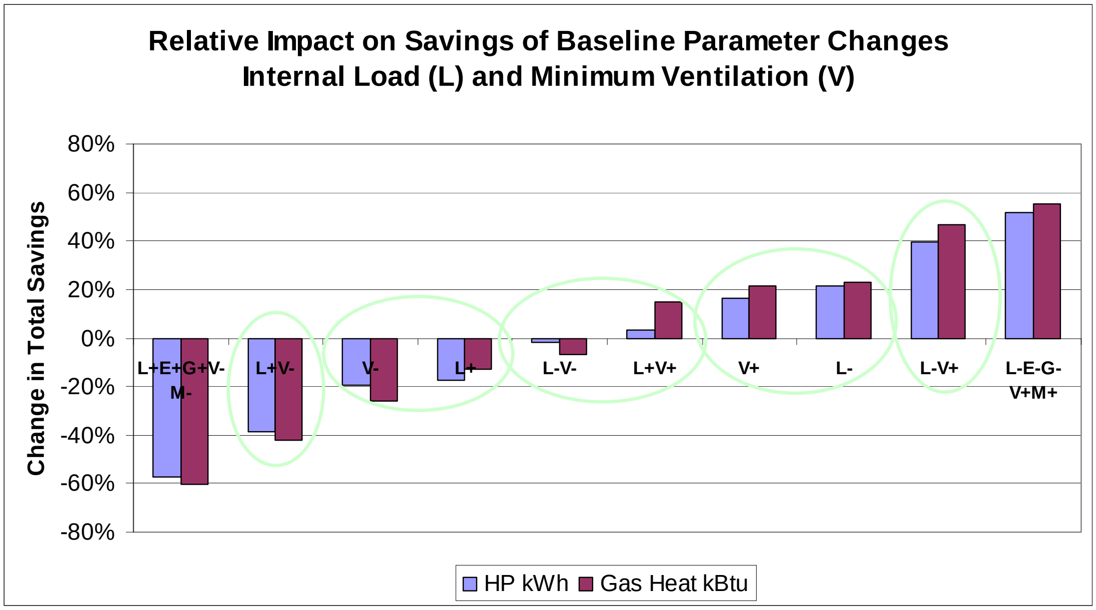
Two Savings Methods Explored

This work develops two savings methods: a *Decision Framework Matrix* and *Expected Value Deemed Savings.* Both methods react to significant parameters. The decision framework matrix is a simplified example of a possible path to developing a parametric path for deemed savings evaluation based on different conditions encountered in the field. The *Expected Value Deemed Savings* provides a good estimate of regional savings based on relevant parameter variation but has the simplicity of a single deemed savings and no need for site specific parameter input.

Decision Framework Matrix Savings Method

The purpose of a matrix savings method is to look at the most relevant parameters, place them in a matrix, and then group results that are similar to reduce the number of "line items" that must be maintained as separate measures in the RTF database. In Figure 10, the total saving results from all combinations of parameter values for lighting (L) and ventilation minimum (V) are shown. In addition, the results when all five parameters are changed together in a way that pushes the results in a common direction are shown. While changing parameter values for lighting and ventilation minimum capture most of the savings variation, there is some additional change when all parameters move together. Fortunately, the cases where all parameters move savings in the same direction are likely to be low probability situations.

Figure 10: Ventilation and Internal Load Impact on Savings



The results in Figure 10 are circled where the saving results are similar. These parameters are matrixed in Table 2, where for each combination of lighting and ventilation, one of five "savings conditions" is assigned

Table 2: Savings Condition Based on Combined Parameters

			Internal Density		
Base Condition Savings Matrix			L- 1.0 w/sf	L= 1.8 w/sf	L+ call center
Ventilation Minimum	V-	≈15%	=	-	- -
	V=	≈20%	+	=	-
	V+	≈25%	++	+	=

Then these savings conditions can each be assigned a deemed savings as shown in Table 3.

Table 3: Deemed Savings Matrix Based on Savings Conditions

Condition From Table Above	Deemed Savings		
	Gas Heat		HP Heat
	Gas therms/ton	Electric kWh/ton	Electric kWh/ton
- -	36	214	433
-	27	182	557
=	44	363	985
+	63	406	1336
++	75	384	1479

The matrix demonstrated shows a possible approach for two parameters with three states each. In this case, nine possible savings results are reduced to five. If the matrix were expanded to more variables, then it is expected that the reduction in required outcomes would be a greater percentage. Note that the sensitive parameters were selected based on total savings results for heat pump heating. In the case of gas heating, electric savings requires economizer changeover condition to be considered as well.

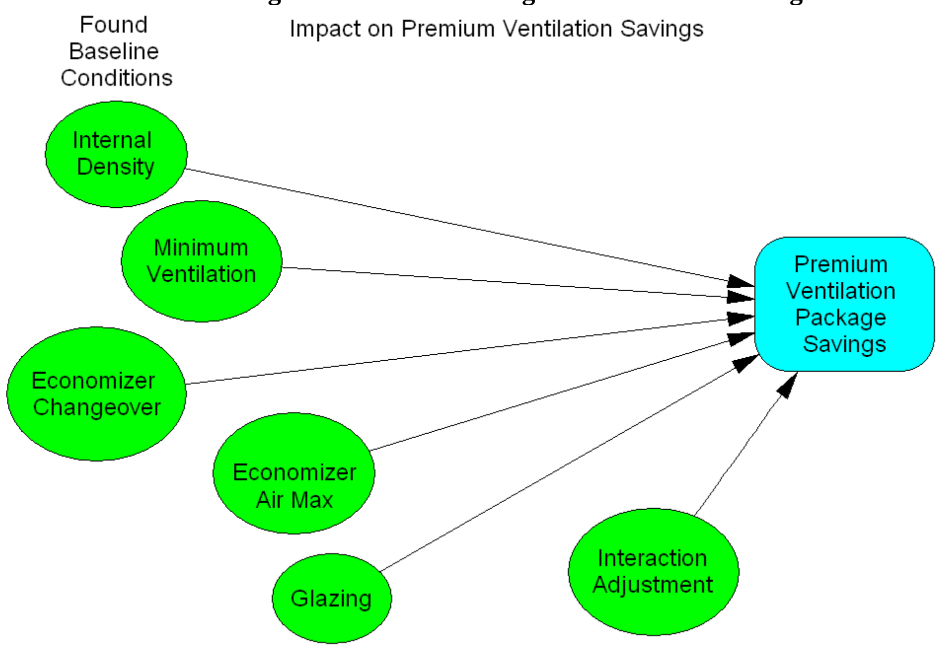
Expected Value Deemed Savings Method

For most energy savings measures or measure packages, determining the savings is not as straightforward as a typical run for each building type and climate as done for the DEER database in California. Multiple parameters impact the savings, and each parameter may interact with others. A discrete savings impact for a particular building type will be an estimate at best and may not reflect the actual weighted impact of multiple parameters. Using expected value analysis, it is possible to make an expert projection of what the likely states for parameters might be with a reasonable estimation of their probability. This approach is complicated by the influence of multiple parameters that interact with each other. While a multiple variable regression approach could be applied with this method, a simplified approach that requires fewer simulation runs may be just as effective in projecting the overall program or regional impact of savings from a measure or measure package.

The approach taken here is to use Decision Programming Language (DPL)[4] in conjunction with eQUEST (DOE 2) results. DPL has been used to analyze a wide variety of decision problems including branding and marketing decisions, market entry strategies, capital investment decisions, capital allocation decisions, environmental restoration decisions and multi-attribute decision applications. These decisions have been analyzed in numerous industries including oil & gas, power, pharmaceuticals, financial services, media, sport, and technology as well as for various areas of government such as defense, regulation and community services. Though DPL is extremely powerful and flexible, it is also easy to use for less complex decisions. The decision applications have ranged from quite complex with many uncertainties and a high degree of asymmetry, to real options applications with learning models, to the relatively straightforward decisions. Here the "decision" is whether or not to implement the measure package, and the thrust of the analysis is to determine an expected value of savings. The advantage of a probability based expected value analysis is that it is very forgiving regarding accuracy of a particular parameter value or probability. This is unlike a custom analysis, where a single incorrect input can result in a very inaccurate savings projection for a particular site.

An influence diagram for this package of measures is shown in Figure 11. The value of each of the analyzed parameters is expected to influence the expected weighted value of savings for the measure package on a program basis. The interaction adjustment provides a simple method to deal with parameter interaction and is discussed later.

Figure 11: Influence Diagram for Electric Savings

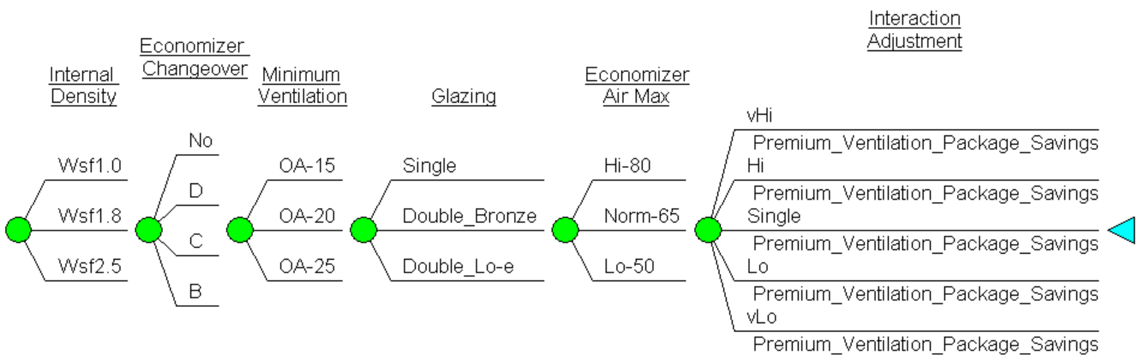


[4] An early version (3.1) of DPL was used for this analysis. There are reasonably priced shareware spreadsheet add-in calculators to determine expected value from a decision tree using similar methodology.

Probability and Factor Assignments

The influence diagram is resolved into a decision tree, as shown in Figure 12. For each of the chance nodes (green circles), state assignments are made for each state. Each state is assigned a probability and a value that cascades through to the final result. The assigned factors and probabilities are shown in Table 4. For this example, a simplified approach is taken where the results of the individual parameter variation eQUEST runs were used to determine a factor that, when multiplied by the neutral case energy savings, results in the high or low case energy savings. Note that for the neutral case runs the factor is 1.0.

Figure 12: Decision Tree for Combined Saving Analysis



The probabilities in Table 4 are rough estimates used for this exploratory view of the method. In actual use, the probabilities would be based on building characteristic surveys or field investigations and could be enhanced by having a group of experts meet to agree on a set of probabilities for a particular measure or package.

Table 4: Parameter Impact on Savings Condition and Parameter Variation Probabilities

Parameter	Sym	Parameter variation in baseline BEFORE measure is installed	Probability	Factors for % of neutral savings		
				Gas Heat		HP Heat
				Gas	Electric	Electric
Internal Load	L+	1.8 LPD, 1.5 plug, 100 sf/person	20%	0.909	0.732	0.825
LPD	=	1.8 w/sf LPD; eQuest defaults	45%	1.000	1.000	1.000
Density	L-	1.0 w/sf LPD; eQuest defaults	35%	1.295	1.0003	1.212
Ventilation	V+	37.6 cfm/person	25%	0.659	1.027	1.162
Minimum	=	31 cfm/person (typical)	50%	1.000	1.000	1.000
	V-	22.6 cfm/person	25%	1.282	0.979	0.806
Glazing	G+	Low-e Argon	10%	0.861	0.929	0.869
Type	=	Double Bronze	40%	1.000	1.000	1.000
	G-	Single Pane	50%	1.079	1.118	1.103
Economizer	E++	B, double stage	5%		0.500	0.750
Changeover	E+	C, single stage	30%		0.715	0.895
	=	D or Snap Disk	45%		1.000	1.000
	E-	Failed Economizer	20%		1.109	1.040
Economizer	M+	80% Max OSA	20%		0.897	0.964
Max OSA	=	65% Max OSA	70%		1.000	1.000
	M-	50% Max OSA	10%		1.082	1.029

Simplified Parameter Combination Impact Approach

For this analysis, a simplified approach was used to account for combinations of parameters. A run was completed for the neutral case for all parameters, and then runs were completed changing each individual parameter to its other conditions. Finally, two runs were done to find the overall impact of changing all parameters at once to the condition that either increases or reduces savings. Then the result of multiplying all individual parameter factors in Table 4 was compared to the actual result of the "all parameters" separately for the increased savings and reduced savings cases. An example of developing these combination adjustment factors for the premium ventilation package with heat pump heating is shown in Table 5.

Table 5: Simplified Combination Adjustment Factors – Heat Pump

Compare to Neutral	LPD/ Density	Econo Changeover	Glazing	Ventilation Minimum	Econo Max	*Factor of All*	Combined Run	Combination Adjustment
Plus	1.212	1.040	1.103	1.162	1.029	*1.663*	1.517	**0.912**
Minus	0.825	0.895	0.869	0.806	0.964	*0.499*	0.424	**0.850**

A high and low adjustment factor was determined that would make the product of all parameter factors equal the actual high or low case, and this is shown bold in Table 6 as the Lim+ and Lim-. A neutral case where only one parameter changes receives an interactive factor of 1.0, and an intermediate factor is the average of 1.0 and the limit factor. Each of the 5 cases is assigned a probability.

Table 6: Parameter Combination Impacts and Probabilities

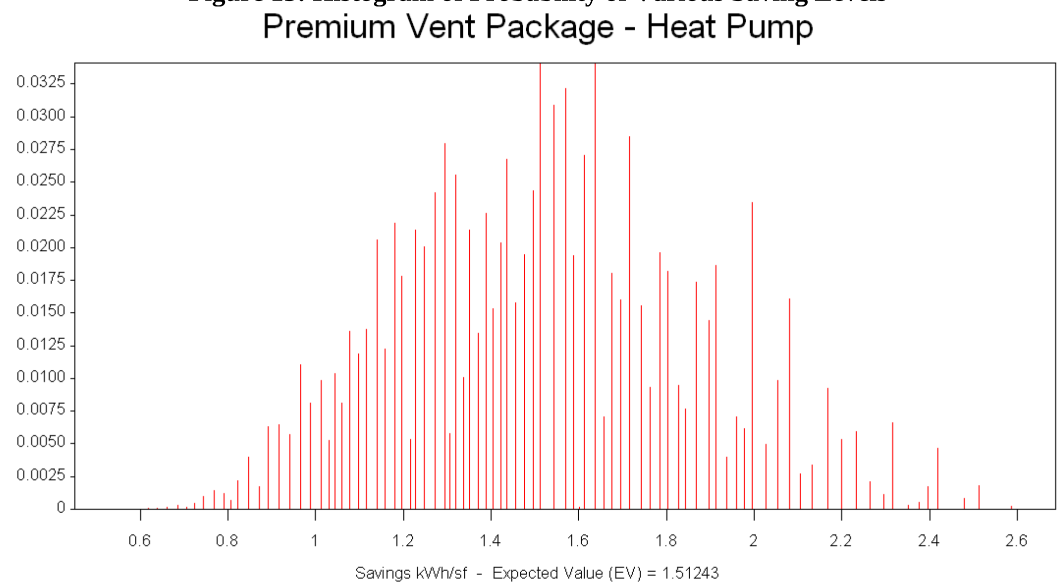
Simplified approach to adjust for combination impact from multiple parameter changes						
		Parameter Combination	Probability	Gas Heat		HP Heat
				Gas	Electric	Electric
Interaction	**Lim+**	All parameters increase	10%	**0.865**	**0.924**	**0.912**
factors	avg()		25%	0.932	0.962	0.956
from full	1	Single Parameter change	30%	1.000	1.000	1.000
combination	avg()		25%	1.215	0.825	0.925
	Lim-	All parameters decrease	10%	**1.430**	**0.649**	**0.850**

This simplified adjustment method has the advantage of requiring the fewest number of runs. For a given climate and heating system type, one run is needed for each parameter state, plus two runs for the high and low savings impact cases. An alternative approach is to develop multiple runs with all possible combinations of parameters and use these results in a weighted fashion to develop a multiple regression model that can be called from the decision analysis model. While this may produce more accurate results, the increase in accuracy may be minimal related to the extra work.

Program or Regional Expected Value of Savings

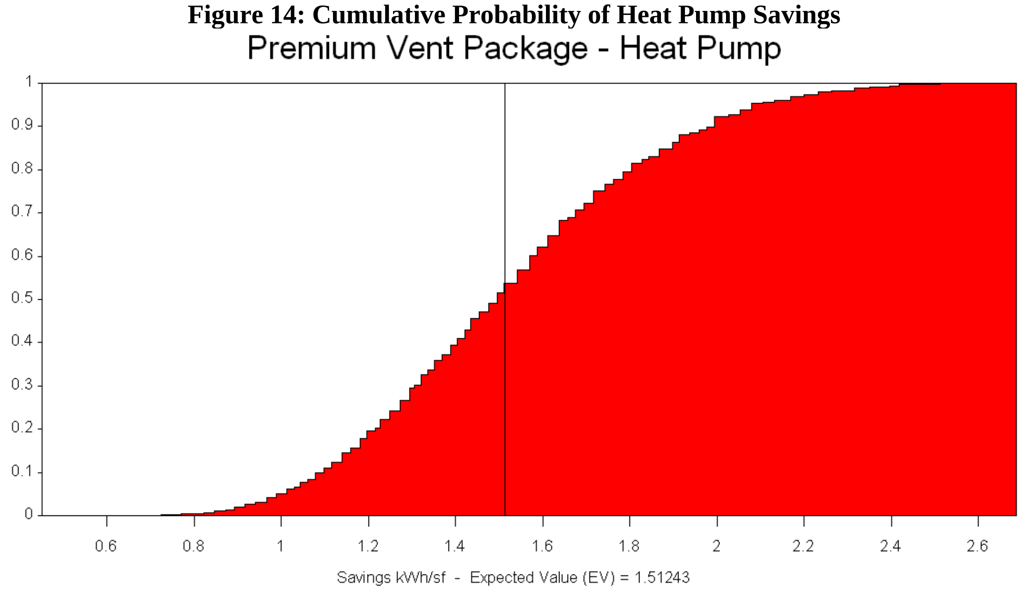
When all the possible combinations of parameter states are explored, a resulting savings for each combination is determined. The probability of occurrence of various savings results can be seen in the histogram in Figure 13.

Figure 13: Histogram of Probability of Various Saving Levels



The histogram can be recast as a cumulative probability as shown in Figure 14. The cumulative probability of possible individual savings results is shown, and the ability to view results in a certain "risk range" is improved. For example, the range of savings that occurs between 0.2 and 0.8 probability can be easily reviewed. The expected value (EV) is the product of each combination result and its probability (the product of all node probabilities down the tree for that case) is shown as a vertical line in Figure 14. Expected value analysis shows the range of results that can occur in individual cases as well as the expected value for the program or region as a whole.

Figure 14: Cumulative Probability of Heat Pump Savings



While it is true that the range of individual savings results goes from close to half the EV to almost double the EV, the EV does represent a good estimate of savings for the region as a whole, given all the analyzed parametric changes. Overall results for the west side (Portland, Oregon) are shown in Table 7 for two heating system types. The expected value can be compared with the "typical case" with all parameter states at a neutral or typical value. For this particular measure the heat pump heating overall savings is about the same for the neutral measure and the decision tree analysis. For a gas heated system, the gas savings is higher and the electric savings is lower than the neutral parameter case.

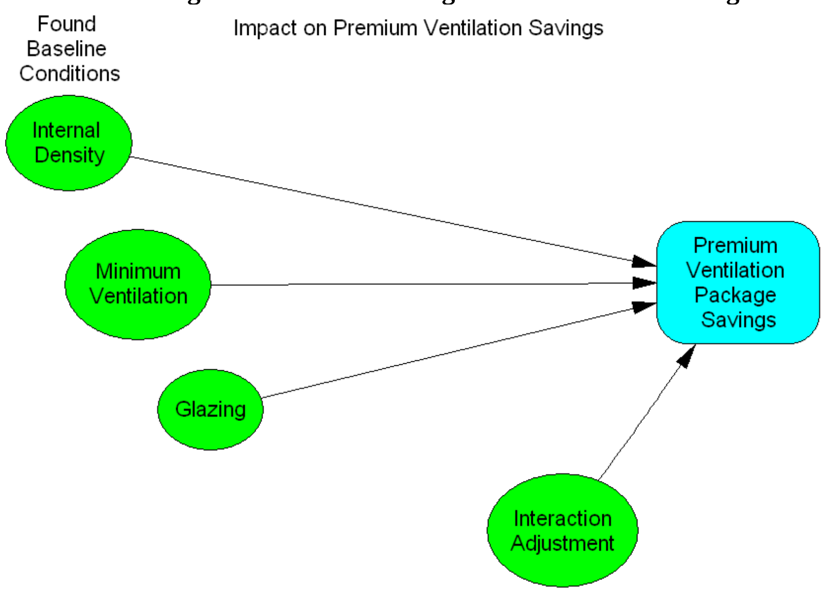
Table 7: Neutral Parameter Case vs. Expected Value of Savings

Premium Ventilation Package	Gas Heat		HP Heat
Portland, Oregon	Gas	Electric	Electric
Energy Saving units	kBtu/sf	kWh/sf	kWh/sf
Neutral (=) parameter energy savings case	6.893	0.573	1.555
Expected Value with probable adjustments	**8.191**	**0.465**	**1.512**

Gas Savings – Fewer Variables

While for a rigorous analysis separate gas runs would be completed, in this case, heat pump and supplemental resistance heating were converted to gas use with a flat efficiency. Because the cooling and fan savings are electric, the influence diagram shown in Figure 15 is less complex for the gas case than it is for the electric case.

Figure 15: Influence Diagram for Gas Heat Savings



The cumulative probability curves for the electric and gas savings with a gas-heated system are shown in Figures 16 and 17 respectively. The curves show the wide range of possibilities for individual site savings. While there is a small probability that there will be a very high or low savings for individual cases, the range of savings shown between 0.20 and 0.80 cumulative probability is a good reflection of the individual savings a customer might expect.

Figure 16: Cumulative Probability of Electric Savings with Gas Heat

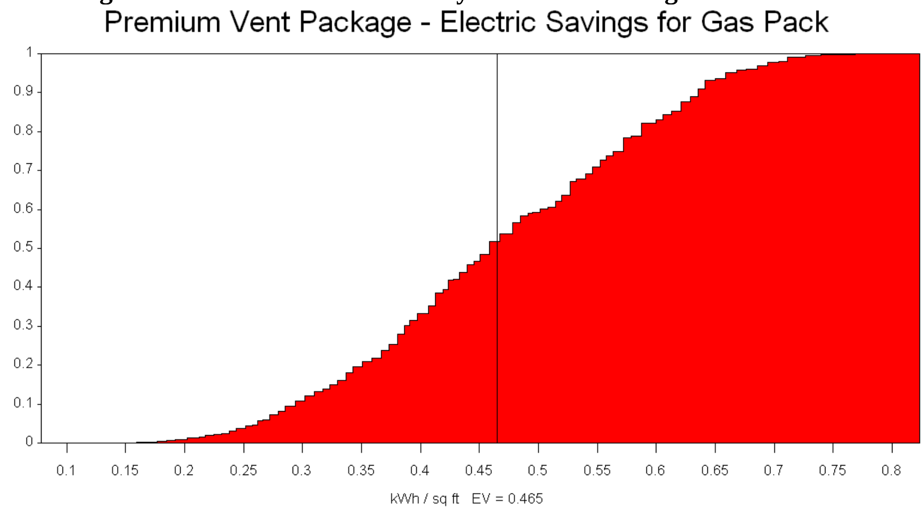
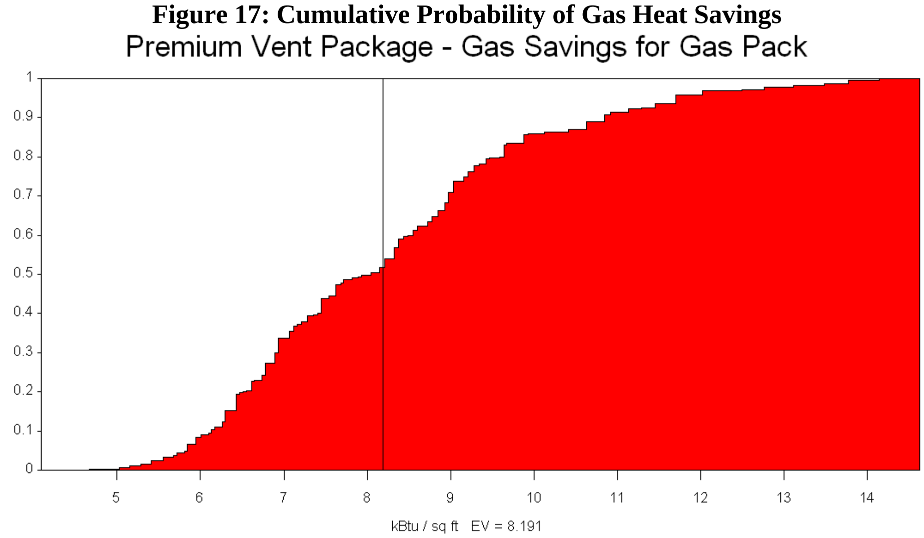


Figure 17: Cumulative Probability of Gas Heat Savings



Method Comparison

With a low number of parameters, there is not a significant difference in the number of runs required to develop a *Decision Framework Matrix* or parametric tool versus an *Expected Value Deemed Savings.* Assuming that a baseline and ECM run are required in two climate zones for two heating types with three states per parameter, the number of cases and analysis runs are shown in Table 8. There is a big difference in the number of analysis runs required once four or more parameters are considered. It is true that automated methods have been developed to generate multiple runs and that initial sensitivity analysis can reduce the parameters investigated, but some expert attention is required to vet the results from the runs and verify that parameter variations are producing expected results. The “number of runs” question extends to parametric-based models designed for particular measure groups.

Especially in the early stages, a more reasonable analysis investment may favor the *Expected Value Deemed Savings* approach. The decision analysis model can be updated with information collected under pilot programs to improve the accuracy of state variables, especially reliability and market transformation effects.

Table 8: Analysis Run Requirements by Method

Parameters of Interest	Regression-based Parametric model or Matrix		Expected Value Deemed Approach	
	Cases	Runs	Cases	Runs
2	9	72	6	48
3	27	216	8	64
4	81	648	10	80
5	243	1944	12	96
6	729	5832	14	112
7	2187	17496	16	128

A Regional Path Forward

There have been delays in identifying acceptable regional deemed savings for HVAC measures in the commercial sector, with the exception of a lighting approach and a few measures added to the list over the last few years. Consequently, approaches for HVAC savings in the commercial sector have relied on custom analysis. It is important to develop a reasonable method that provides a good projection of regional savings combined with an easier program implementation path.

The Analysis Quandary

On the surface, it seems that the most attractive approach is to provide the most accurate savings on a site-by-site basis. This accuracy comes at the cost of increased administrative costs to provide the analysis and may reduce implementation rates from the program point of view. Negative marketing impacts result from delays in the authorization process that can dissuade customers who do not meet a perfect payback threshold or confuse customers who do not fully understand the subtleties of energy conservation measure implementation and savings estimates. Approaches can range from fully custom to fully deemed. The various approaches to analysis discussed previously are:

- Custom analysis
- Field-based monitoring approach
- Field-driven model approach
- Energy-bill-based parametric tool
- Parametric tool
- Simplified analysis
- Matrix Method (parametric selection of a range of deemed savings)
- Deemed savings by building type, vintage by measure and unit rebate
- Weighted expected value deemed savings

While there may be varying balances of result accuracy vs. program effectiveness to be considered for each of these approaches, the custom approach vs. a single deemed approach are broadly compared to provide a context for recommendations.

Custom Site Analysis – Pros and Cons

Individual site analysis, as provided with a custom analysis, a parametric input spreadsheet model, a parametric based matrix model or other suitable methods will provide the following impacts:

Advantages:

- A site-specific custom savings result is determined to inform the decision maker.
- Site based savings are reported for regional results, avoiding any skew that might occur if the implemented measures did not match deemed assumptions.
- Involvement of expert auditors may result in identification of other savings or referral to other energy programs.

Disadvantages:

- An energy expert is usually required to develop appropriate inputs:
  - Higher administrative costs.
  - If parameters or custom inputs are generated by service contractors who implement energy efficiency programs directly, they are unlikely to get proper input variables correct when they are outside their specialty, for example HVAC contractors will have difficulty estimating internal loads or glazing type.
  - At this time, well trained energy auditors are difficult to find in the industry.
  - Important parameters may require testing or monitoring.
- Differing site savings are likely to result in different rebates or incentives, although this may vary depending on the type of measure to be installed:
  - For lighting measures, varying incentives may be appropriate, as the quantity of material installed at different sites will vary widely.
  - For measures like the premium ventilation package, the work per unit is fairly constant; hence, a single rebate per unit or per ton may be preferable in program design to varying the rebate with custom calculated savings, as varying rebates can cause contractor confusion.
- For the sites where savings is lower than an expected value average, the lower savings may result in the simple payback falling below an inappropriately low business case threshold and the measure not being approved for installation.
- Typically, the custom analysis must be prepared for and delivered to the customer, resulting in a multi-step sales process that results in loss of momentum and a lower measure realization rate.

Deemed Savings – Pros and Cons

Advantages:

- A reasonable range of expected savings can be presented for the decision maker.
- An installing contractor can implement the program expediently:
  - Lower administrative costs.
  - Quick single-step sales process that maintains momentum and a higher chance of closing the deal.
- A single or per-ton deemed savings supports standard rebates, reducing contractor and decision maker confusion and maintaining program consistency.
- Rolling up a region-wide deemed savings result would allow the cost effectiveness of the measure to be evaluated globally. This avoids the measure or package being eligible in some situations, but not in others—a situation that leads to customer and contractor confusion and negative market feedback in program implementation.

Disadvantages:

- There could be a skew in reported savings if the measures actually implemented in a particular territory or time period did not match the weighted probabilities used in the deemed analysis.
- A deeper relationship with expert auditors is not developed, limiting consideration of measures to the specific program and limiting the possibility of selling more sophisticated measures in a later trip.
- For the sites where savings is higher than an expected value average, the lower deemed savings may result in the measure not being approved for installation.

Recommendations

Based on the work so far, there are method recommendations specific to program type and also recommendations for further research.

Methodology to Fit Specific Programs

The best savings methodology for commercial buildings depends on the program approach.

- Complex measures with large savings should receive some level of custom analysis.
- Contractor-delivered lighting programs, where there is a large variation in work performed at each site, are best served by a simple spreadsheet approach with simple adjustments for heating system type.
- Contractor-delivered HVAC programs, where the work performed per unit is fairly consistent, can benefit from a standardized savings per ton by major climate zone where a decision-analysis-based expected value of savings is developed based on estimates of field parameters.
- Programs that rely on a marketing approach involving visits by a field energy analyst, benefit from using a parametric model that customizes savings to the site.
- A matrix method to select from multiple deemed savings does not provide significant advantages over a parametric model approach, although it may be less costly to develop.

Further Research

If the RTF is interested in developing the *Expected Value Deemed Savings* method, further research should be undertaken to fully vet the method.

- This measure package should be further explored to determine deemed expected values in a process that includes research into extant characterization data and a “committee of experts” process to develop probabilities for the parameter variations that have a more solid consensus footing.
- Evaluate the differences in expected value and range of results for unit basis (kWh/unit) versus floor area basis (kWh/sf) versus size basis (kWh/ton) results.
- A regression model for high impact parameters should be developed for inclusion in the decision analysis model to determine the acceptability of the less costly simplified interactive method used in this work.
- Other software tools for a multiple node expected value analysis should be explored to make recommendations on effective methods to the energy community.
- A more in-depth review of how program impacts change as programs and technology mature. For many parameter state probabilities we need to rely on data from short-run efforts. Once we understand how past programs impacts have changed as they mature and economy of scale takes hold, we can apply anticipation factors to the projections over longer time frames.
- Develop a step-by-step *Expected Value Deemed Savings* method for use in the region.

Appendix A: Summary of Prior EWEB Simulation Work

This simulation work was completed in preparation for a paper[5] presented at ACEEE in 2008 by Eugene Water & Electric Board (EWEB), a municipal utility in Eugene, Oregon. The simulations and specification form the basis for the analysis of the premium ventilation package of measures.

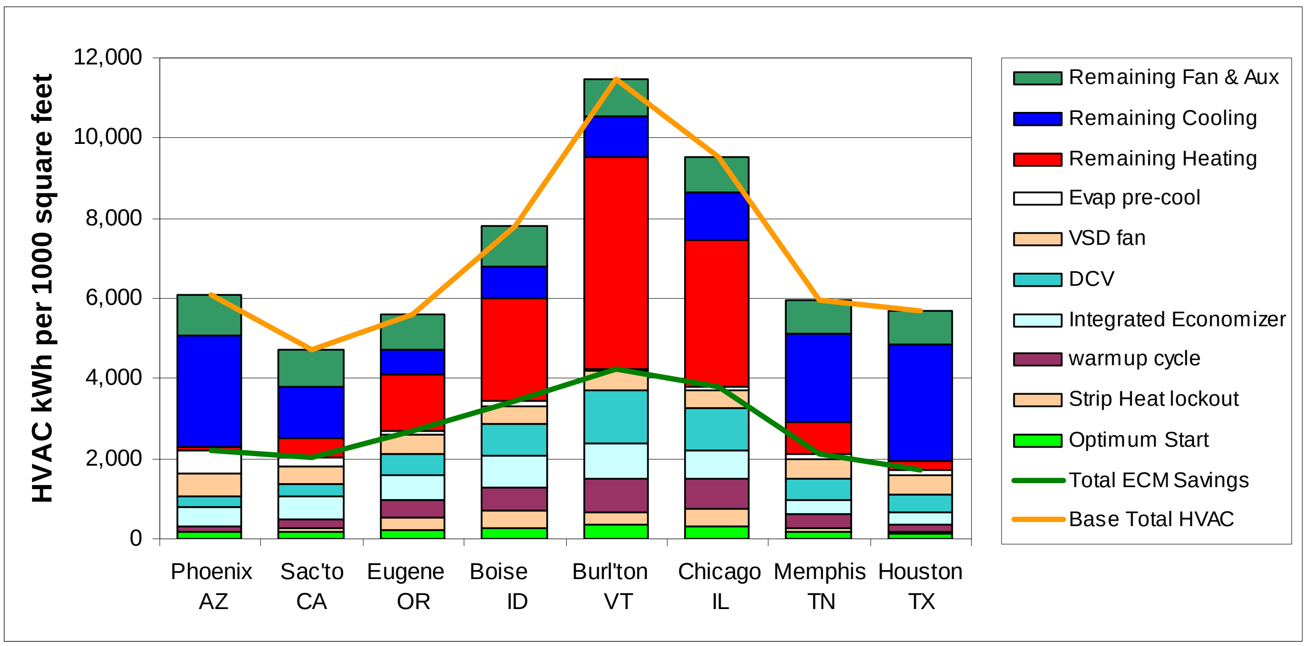
[5] Hart, R., D. Morehouse, W. Price, J. Taylor, M. Cherniack & H. Reichmuth. "Up on the Roof: From the Past to the Future." *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Summary of prior EWEB simulation work

The prior simulation work was completed at EWEB in early 2008 by Reid Hart, Will Price and Dan Morehouse. The savings results of the analysis are shown in the figure below. These results include evaporative pre-cooling, but those savings are minimal in the Northwest. The premium ventilation package of measures results in 5 to 25 times the savings of an upgrade from SEER 13 to 15. The technologies in the premium ventilation package include:

- Optimum start
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- VSD fan control

Rooftop Unit Savings in Representative Climates



Reworking the numbers as previously analyzed for just the Premium Ventilation Package (excluding the evaporative pre-cooling of the condenser) for climates of interest shows the following expected results:

Heat Pump kWh saved /2000 sf	**Sacram. CA**	**Eugene OR**	**Boise ID**	**ECM Cost**
Optimum Start	343.3	424.3	557.2	$378
Strip Heat lockout	203.8	665.3	856.5	$282
Warmup cycle	426.5	810.1	1,184.9	$528
Integrated Economizer	1,118.9	1,243.3	1,523.0	$995
DCV	669.0	1,131.4	1,602.5	$611
VSD fan	896.9	898.7	879.4	$636
Premium Ventilation kWh	**3,700**	**5,200**	**6,600**	**$2,144**

$/kwh	0.083	0.048	0.033	
Annual Savings	$307	$249	$220	
Simple Payback	7.0	8.6	9.8	
Incentives @ 0.15/kWh	555	780	990	
Net Customer Cost	$1,589	$1,364	$1,154	
Net payback	5.2	5.5	5.3	

Analysis for Gas Pak	**Sacram. CA**	**Eugene OR**	**Boise ID**
Electric Savings, kWh	1967	1511	1607
Gas Savings, Therms	94	203	278
$/kwh	0.083	0.048	0.033
$/therm	1.344	$1.25248	0.901
Annual Savings	$290	$327	$304
Simple Payback	7.4	6.6	7.1
Incentives @ 0.15/kWh	$295	$227	$241
Net Customer Cost	$1,849	$1,918	$1,903
Net payback	6.4	5.9	6.3

Unrecognized Technologies Old & New

There are multiple strategies available for small rooftop technologies that go beyond straight efficiency (SEER/EER). Many of these have been commercially available for decades but have not had a testing procedure available to allow them to be reliably compared. Table 1 summarizes the technologies that are candidates for an efficiency test procedure, indicates why they save energy, and indicates their status in the smaller packaged unit marketplace. Features that provide maintenance benefits or are difficult to test in a standard procedure are not listed.

Table 1. Technologies Considered

Technology	Savings Rationale	Status
Readily available items:		
Optimum start	Reduces energy use during building startup with moderated space temperatures	Established - in most thermostats
Resistance heat lockout for heat pumps based on outside air temperature	Reduces electric energy used for heat pump units by restricting use of resistance heating to colder ambient temperatures	Established as an option – often not installed
Ventilation lockout during morning warm-up with improved damper seals	Reduces energy use during building startup with less heating (sometimes less cooling) of ventilation air	Established option – rarely installed
Economizer control with integration and comparative changeover control	Reduces mechanical cooling by using outside air when appropriate to reduce mixed air temperatures	Established option – full application is rare
Demand controlled ventilation (DCV)	Reduces energy use during weather extremes with less heating or cooling of ventilation air, as quantity of ventilation is reduced to match actual occupancy requirements.	Established as an option – rarely installed
Limited availability items:		

VSD fan control	Reduces fan energy use and impacts from duct leakage by reducing airflow when the unit is not actively heating or cooling.	Rarely installed in commercial; two known manufacturers

Each measure is described briefly below with discussion of availability and market placement. Some items like optimum start thermostats, economizer controls, and warm-up cycle are independent of the unit itself, yet there has been an increasing call for factory supplied control packages that have been tested with the unit to verify compatibility (AEC 2005). The ability of the unit to respond properly to the controls is important in several cases, including interaction of outside air damper configuration and seals, exhaust air damper placement to minimize re-entrainment of exhaust air, and response of controls to outside temperatures.

The baseline building for savings analysis is a 20,000 square foot 2-story office building primarily using the Title 24 eQuest defaults, with an increase in unoccupied lighting and equipment loads to reflect reality and higher than required ventilation (31 cfm/person or 13%) to reflect field observation of ventilation minimums greater than 20% (Hart, Mangan & Price 2004; Davis et. al. 2002). Packaged single zone units with a SEER rating of 13.0 were simulated.

Optimum start. Most programmable thermostats have an optimum start option that slowly increases the setpoint temperature during building warm-up rather than moving immediately to the occupied setpoint.

Resistance heat lockout. A simple thermostat control that has been available from heat pump manufacturer's for decades. Typical installation simply interrupts the low voltage signal to the resistance heat relay when the outside air is warmer than a set temperature.

Ventilation lockout during morning warm-up with improved damper seals. HVAC units typically start 2 to 3 hours before occupancy with full ventilation provided. This uses a significant amount of unnecessary heating. The measure requires a thermostat with a separate relay signaling actual occupancy period start and an economizer controller allowing this input. Outside air dampers for small package units are also notoriously leaky, with air leakage of 5% to 25%. Properly installed low-leakage dampers can reduce the leaks and could be tested with the proposed testing procedure.

Outside air economizer. Outside air economizers have been marketed for decades, but no testing procedure has ever been fully developed. Modifying the test apparatus to allow interaction of the unit with the simulated outside environment will verify operation and impacts of these controls. The unit is simulated here with integration and differential changeover control. Dry-bulb sensors are used in the Western US, and enthalpy sensors in the East.

Demand controlled ventilation. Demand controlled ventilation (DCV) has traditionally been applied to larger units and areas with dense and variable populations. Because of a reduction in benefit when a properly operating economizer is employed, the measure rarely pays in general density areas with proper system testing, adjusting, and balancing (TAB). Package units do not normally receive proper TAB and ventilation minimums are significantly higher than required (Davis et. al. 2002). Beyond minimum ventilation correction, a DCV system also provides the same benefits of warm-up lockout without the need for a special thermostat. DCV will also adjust ventilation to meet actual load when building occupancy is less than design (almost always). Installation requires a higher quality economizer controller and a carbon-dioxide sensor. The cost of sensors for large-volume contractors continues to drop and is less than $150. If the typical excessive ventilation air is accounted for in the baseline, and the additional benefits of ventilation lockout considered, DCV is cost effective.

VSD fan control. Several manufacturers provide this option in their high-end units marketed to residential customers. There are at least two retrofit products available that contain both a motor speed drive and a control package for fan motors under 10 amps. These units will provide significant fan savings and quieter operation during the ventilation cycle when the unit is not heating or cooling. They can also improve dehumidification in appropriate climates. These units typically include controls designed to modulate fan speed to maintain discharge temperatures within a range or unit temperature difference in a range, reducing speed to a set minimum when there is no call for heating or cooling. Installation of this measure in a commercial building requires installation of DCV to maintain ventilation when the fan speed is reduced.

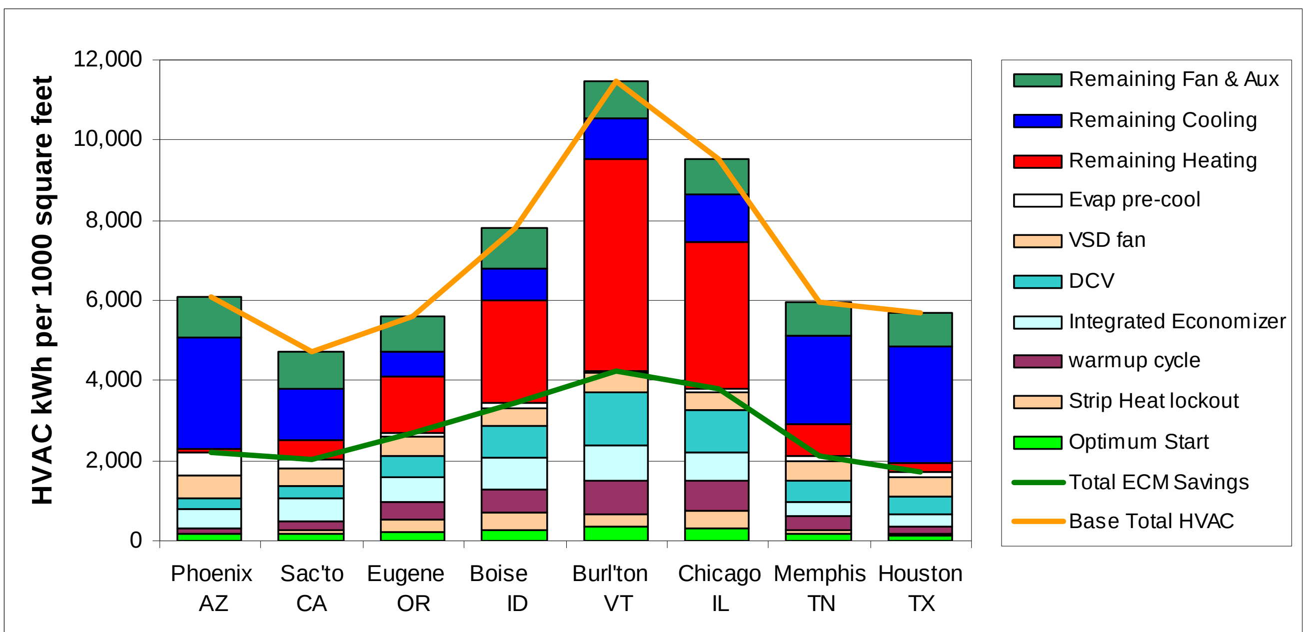
Premium Ventilation Rooftop Package Potential Savings

Measure items included:

- Optimum start
- Resistance heat lockout for heat pumps based on outside air temperature
- Ventilation lockout during morning warm-up with improved damper seals
- Economizer control with integration and comparative changeover control
- Demand controlled ventilation (DCV)
- VSD fan control
- Evaporative assist condenser pre-cooling (not included in Premium Ventilation Package).

Measure savings were analyzed using DOE 2.2 for eight cities in the United States, covering a range of climate zones. Heat pump systems on a typical small office building were analyzed so all results would be electric for easy comparison. The allocated interactive[5] measure saving results from the DOE2 analyses are shown in Figure 6, along with remaining HVAC energy use after all measures are completed.

Figure 6: Rooftop Unit Savings in Representative Climates



[5] For individual saving results in Figure 6 the interactive package savings are allocated using the share of savings for each measure's independent results (shown in Table 4). This method eliminates order of consideration issues inherent in a rolling baseline calculation.

Overall interactive results for the comprehensive package of measures are shown in Table 2 along with a conversion of heat pump heating to natural gas furnace heating. It is interesting to note that this package of measures results in 5 to 25 times the savings of an upgrade from SEER 13 to 15.

Table 2. Overall Package Measure Results & Climate Zone Information

Savings for composite run:	**Phoenix AZ**	**Sac'to CA**	**Eugene OR**	**Boise ID**	**Burltn VT**	**Chicago IL**	**Memphis TN**	**Houston TX**
Percent Total Savings	36.0%	42.3%	47.9%	43.9%	37.0%	39.5%	34.9%	29.9%
KWh/SqFt ECM Savings	**2.2**	**2.0**	**2.7**	**3.4**	**4.3**	**3.8**	**2.1**	**1.7**
Compare to 15 SEER savings	0.42	0.22	0.15	0.17	0.17	0.19	0.29	0.37
SqFt/Ton Cooling Installed	249	340	427	355	355	321	256	260
KWh/Ton ECM Savings	552.5	685.9	1,151.3	1,219.9	1,507.3	1,213.3	539.2	450.4
Annual savings for recast of heat pump heating to gas heating at 78% AFUE:								
KWh/SqFt, all measures	2.0	1.2	0.9	0.9	0.7	0.7	1.1	1.3
Therm/SqFt, all measures	0.012	0.047	0.102	0.139	0.200	0.171	0.057	0.024
ASHRAE Climate Zone	2	3	4	6	6	5	4	2
ASHRAE Moisture Area	Dry	Dry	Marine	Dry	Moist	Moist	Moist	Humid
East vs. West	West	West	West	West	East	East	East	East

Cost Effectiveness and Premium Ventilation Package

Measure cost effectiveness will vary by climate zone and building characteristics. The intent of this analysis is to demonstrate that potential savings exist. Individual measure results are shown in Table 5 as a range based on the greatest and smallest climate zone savings, along with an expected cost range. The basis is 1500 square feet per unit, as the measure cost is per rooftop unit. The payback range is fairly wide, indicating that measure packages should be developed for different climates. The average payback is reasonable for most measures, with the average package payback of less than five years.

There are significant advantages to incorporating the control measures into a "Premium Ventilation Package." This package includes all measures except the evaporative pre-cooler for the condenser. For example, economizer savings potential has been attractive, but unreliable unless commissioned. The payback on a small unit may not be attractive when the cost of commissioning was included. When multiple measures are combined—all of which require commissioning—the cost of commissioning is not much more than for one measure, so the overall cost for a combined measure with commissioning is much more attractive.

Table 5. Measure Savings, Cost & Simple Payback

Energy Conservation Measures	Savings Range kWh/Unit		Savings Range $/Unit/Year		Cost Range		Simple Payback Range, yr		Average Payback, years
Optimum start	250	850	$20	$119	$300	$450	2.5	22.5	5.4
OSA strip heat lockout	50	1,000	$4	$140	$250	$350	1.8	87.5	4.2
OSA warm-up lockout	250	1,950	$20	$273	$400	$650	1.5	32.5	3.6
Economizer control	600	1,950	$48	$273	$800	$1,200	2.9	25.0	6.2
Demand controlled ventilation	550	3,000	$44	$420	$500	$750	1.2	17.0	2.7
VSD fan control	900	1,100	$72	$154	$500	$750	3.2	10.4	5.5

Evap. condenser pre-cooling	150	1,100	$12	$154	$450	$650	2.9	54.2	6.6
Comprehensive Package	**2,600**	**6,400**	**$208**	**$896**	**$2,050**	**$3,050**	**2.3**	**14.7**	**4.6**
Premium Ventilation Package	**1,950**	**6,700**	**$156**	**$938**	**$1,700**	**$2,550**	**1.8**	**16.3**	**3.9**

Initial opinion of probable cost

There is a wide range of probable cost for this package of measures. The biggest variable is the pre-existence of a standard economizer. In this cost estimate the basis is that about one-third will require the addition of economizers and that 25% of the units will receive commissioning. The field test will be a very good opportunity to get good feedback about actual contractor costs for installing this set of measures. It may be that once actual costs are in hand, it makes sense to restrict the measure to units that are already equipped with outside air economizers.

Materials	**$**	**1,057**
Low voltage wiring	**$**	**125**
Installation	**$**	**405**
OH&P	**$**	**317**
Commissioning (25% sample)	**$**	**240**
Total	**$**	**2,144**

The parameters used to simulate each measure are shown in Table 3 along with non-interactive savings averaged across the eight climate zones. Individual measure results for each climate zone shown in Table 4.

Table 3: Measure Parameters and Potential Non-Interactive Savings

Technology	**Baseline Parameters**	**Measure Parameters**	**Average US Savings kWh/SF/yr**
Optimum start	Setpoint to Occupied 2 hours before occupancy; fan on	Setpoint ramps 33% during 3 hours before occupancy with fan cycling	322.9
OSA strip heat lockout	Strip heat operates as needed and during warm-up	Strip heat locked out above 30F OSA, heat pump compressor allowed to DOE2 default (10°F)	322.4
OSA vent lockout during morning warm-up with improved damper seals	Ventilation (31 cfm/person) begins 2 hours before occupancy with fan on; damper leakage at 8%.	OSA dampers closed before occupancy; at occupancy 31 cfm/person provided. Infiltration ACH/hr at DOE 2 defaults, Damper leakage at 4%.	619.4
Economizer control with integration and differential changeover control	No economizer; 31 cfm/person ventilation air during occupancy reflecting field discovered excess ventilation settings	Differential changeover (drybulb west 75°F high limit, enthalpy east 34 Btu/lb high limit) and 65% maximum air available on cooling demand. Ventilation to 20.5 cfm/person reflecting commissioned airflow setting	829.1
Demand controlled ventilation (DCV)	Ventilation at 31 cfm/person reflecting field discovered excess ventilation settings	Ventilation to 15 cfm/person to reflect typical occupancy below design; equivalent of maintaining 20 cfm/ actual person	968.9

VSD fan control for smaller rooftop packaged units.	Fan "ON" during occupied	Supply airflow reduced to 30% when heating or cooling not required; 15 cfm/person ventilation maintained	667.1
Evaporative assist condenser pre-cooling.	Air cooled evaporator at ambient dry-bulb	DOE2 standard measure, condenser type changed to evaporative	237.6

Table 4: Non-interactive Measure Savings by Climate

Energy Saving Technology	kWh/1000 sf/year savings, non-interactive							
	Phoenix AZ	Sac'to CA	Eugene OR	Boise ID	Burl'ton VT	Chicago IL	Memphis TN	Houston TX
Optimum start	219.0	235.0	309.0	403.0	551.5	449.0	241.0	175.5
OSA strip heat lockout	19.5	139.5	484.5	619.5	412.5	670.0	164.5	69.0
OSA warm-up lockout	153.0	292.0	590.0	857.0	1,311.0	1,058.5	444.0	249.5
Economizer control	595.0	766.0	905.5	1,101.5	1,315.5	1,025.0	515.5	409.0
Demand controlled ventilation	369.0	458.0	824.0	1,159.0	1,995.0	1,554.5	773.5	618.0
VSD fan control	726.0	614.0	654.5	636.0	726.0	659.5	660.0	661.0
Evap. condenser pre-cooling.	726.5	256.5	156.5	200.0	88.5	121.0	176.0	176.0
Package Interactive Savings	2,221.0	2,016.5	2,694.0	3,440.0	4,250.5	3,785.5	2,103.0	1,729.5

Appendix B: Western Premium Economizer Background

Important Pending Revision:

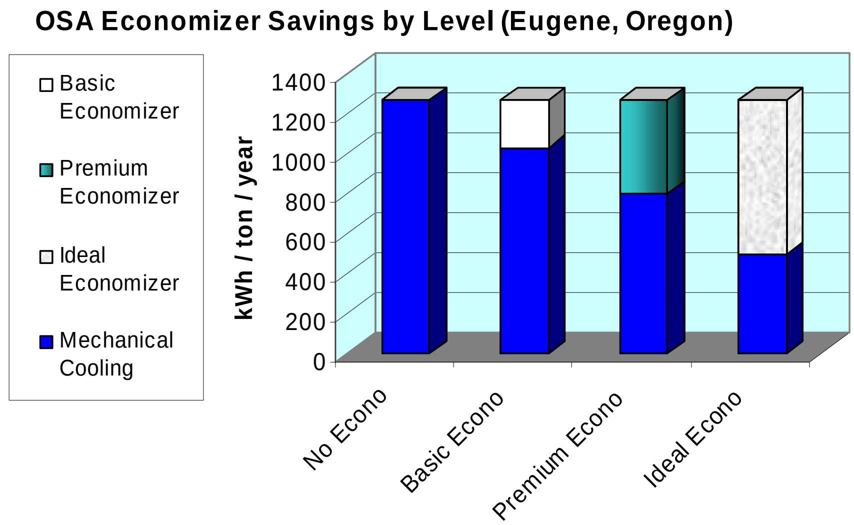
Since development of the Western Premium Economizer specification, problems have come to light with the dry-bulb sensors for the prime manufacturer.[6] As a result, this product is being replaced with a dry-bulb sensor with a smaller switching differential and more accuracy. As this new product will not operate in the comparative or differential changeover mode, the Western Premium Economizer specification is being revised to allow single point sensible changeover. In conjunction with a variable speed fan motor it is appropriate to run the fan at full speed in economizer mode only when the outside air is at least 5°F below return air.

The following specification has not been updated for this change in technology.

[6] Robison, D., R. Hart, W. Price, & H. Reichmuth. "Field Testing of Commercial Rooftop Units Directed at Performance Verification." *Proceedings of the ACEEE 2008 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy (ACEEE).

Western Premium Economizer Background

Why a *Western Premium Economizer*? Several field studies completed around the country have found that more than half of outside air economizers are not providing optimal savings, either because dampers or controls have failed, changeover is set incorrectly, or the improper type of controls for the local climate have been installed. The graph at the right shows the potential savings increase from upgrading an economizer to premium specifications. The following *Western Premium Economizer* requirements are designed to improve reliable operation and increase energy savings in the Pacific Northwest.



Outside Air Economizer Savings Principles. The basic idea behind an outside air economizer is to use cool outside air instead of mechanical cooling to cool the space. Where there are cooling loads at the same time outside air temperatures are cool, significant savings of 20% to 60% can be achieved. To work properly, the economizer must **coordinate** or **interlock** with the cooling so that it is only used when there is a call for cooling. An economizer is also equipped with some type of **changeover** control that returns the outside air damper to a minimum ventilation position when the outside air is too warm to provide cooling. An **integrated** economizer takes full advantage of outside air before mechanical cooling is used. Over the years, numerous ways to provide economizer controls have been created. The *Western Premium* outside air economizer uses readily available technology to provide a system that doubles the savings compared with a basic economizer that is typically provided in today's HVAC market place.

Understanding OSA Economizer Attributes. Many items can be adjusted to change the operation, effectiveness, cost, and potential savings of an outside air economizer. These can be grouped into five general attributes:

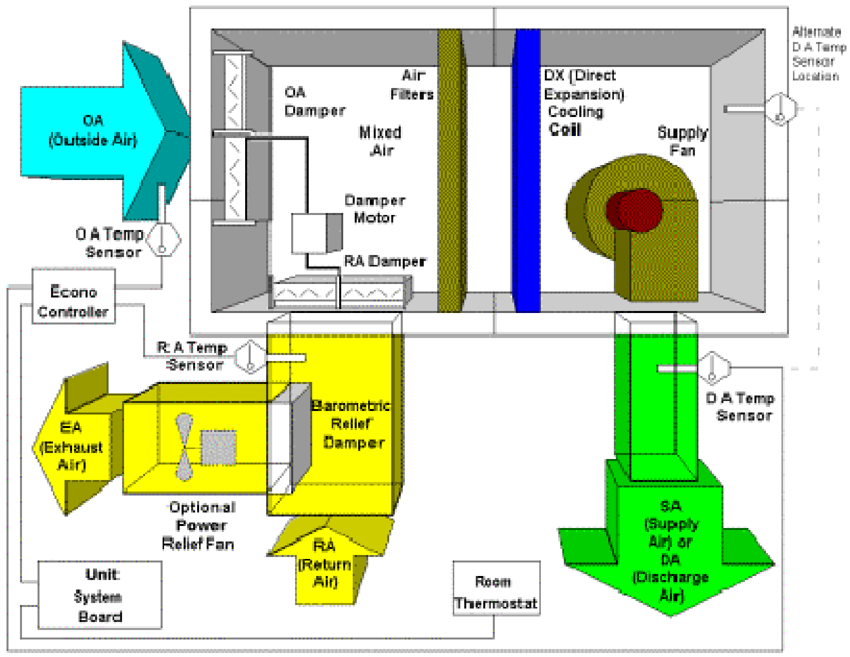
- Economizer configuration: How many dampers and what can they do?
- Economizer activation: When does the economizer come on?
- OSA high limit or "changeover" sequence: When is it too hot to economize?
- Level of Integration: Does mechanical cooling work together with free cooling?
- Minimum ventilation airflow amount and how activated.

1. Economizer configuration includes the number and relationship of dampers and relief/exhaust air characteristics, as well as the type of mixed air or discharge air temperature control. The basic questions are: "How many dampers does the economizer control?" and "What damper control options do I have?" Damper Control options include:

- Number of dampers. Typically, smaller units have outside and return air dampers. Exhaust or relief can be omitted, provided by barometric dampers or motor controlled exhaust air dampers. On larger units, a relief fan can be added to assist exhaust. Smaller units have parallel blade or single dampers. On larger units, opposed blade dampers with seals improve control.

- Damper movement can be manual, two-position with only open or closed positions; three-position with full, minimum, and closed positions; or fully modulating with the ability to locate to any percentage open position.
- Fully modulating automatic dampers are typically controlled by a primary sensor or low limit temperature control. Usually the proportional controller maintains air between 50^{o}F and 56^{o}F. The sensor can be located in either the mixed air (MA) position or the discharge air (DA) position. One point of confusion is that this is often called a “mixed air” sensor by manufacturers. Mixed air is the proper primary sensor location for fully modulating chilled water coils, but to maintain comfort and avoid coil icing with a direct-expansion cooling system, the primary economizer sensor should typically be located downstream of the cooling coil in the discharge air position.

Packaged Unit (DX cooling) Outside Air Economizer



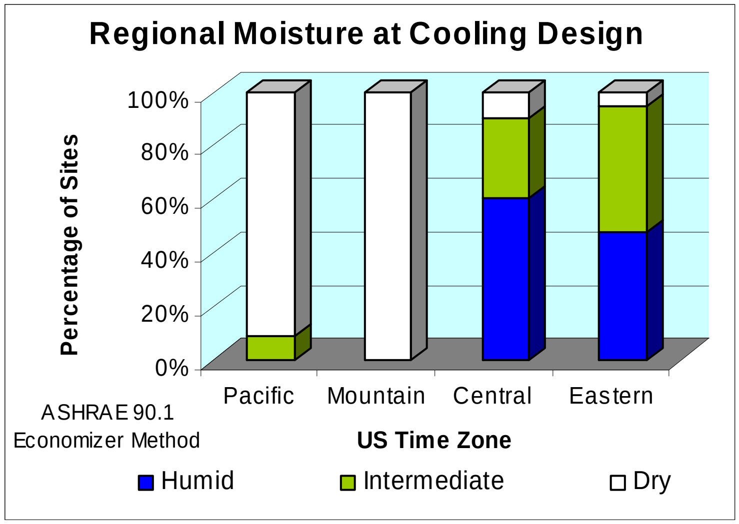
2. Economizer activation includes how or if the economizer operation is interlocked with cooling call. The basic question is: When does the economizer turn on? Activation of the economizer can be:

- “Wild” or full open. This can be manual or automatic. Automatic operation usually includes a lock-out that closes the economizer if OSA is too cold.
- Fixed mixed air cycle that always maintains a set mixed air temperature (55^{o}F typical).
- Coordinated or interlocked with a call for cooling. Activation on an actual call for cooling is preferred, as other methods can result in excessive heating costs.

3. OSA high limit or “changeover” sequence determines when is it too hot outside to use the economizer. Changeover type is distinguished by both choice of mode and sensor type. The sensor type should match the climate. Three types of sensors are available:

- Dry-bulb sensors measure temperature only.
- Enthalpy sensors adjust for the heat energy of moisture content in air.
- Separate dry-bulb and humidity sensors measure moisture more accurately and are also referred to as enthalpy control.

The graph shows the share of humid vs. dry climate cities by time zone in the U.S. In the western half of the country, there are no humid climate sites and dry-bulb sensors will do the job at a lower cost with better reliability.

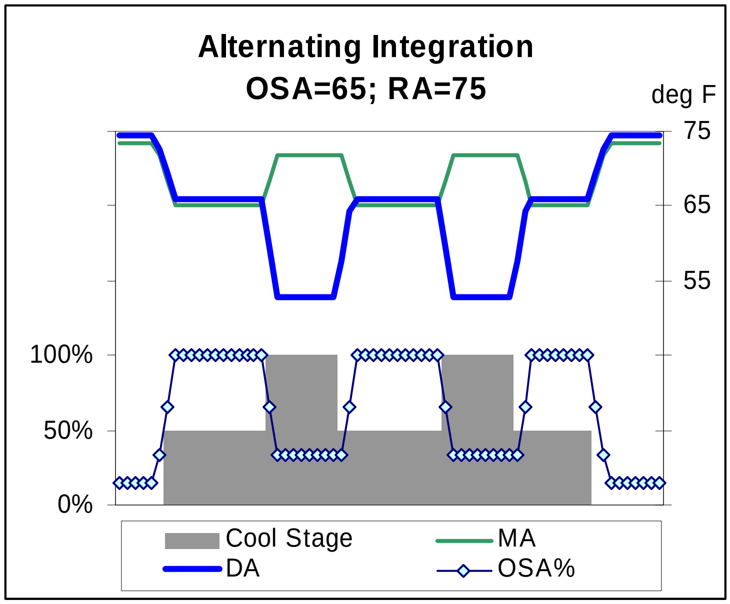


The mode of control can be a single (OSA only) fixed (snap disc) sensor for dry-bulb, a single (OSA only) adjustable (analog) sensor for either sensor type, or a set of differential or comparative (OSA vs. RA) sensors. A differential changeover uses outside air until it is warmer or contains more energy than return air. Differential changeover allows the economizer to take better advantage of integration strategies discussed below. Some will advocate using a single OSA sensor with a higher setpoint, but the assumed return air temperature will be a guess at best. Even a good guess will fail when the return air temperature varies or the cooling setpoint is changed. So, with single-sensor changeover, there will be times when either (a) the economizer is not used when it could be or (b) the economizer operates when outside air is too warm. Differential changeover takes the guesswork out of field adjustments and provides a more reliable economizer changeover. Most economizer controllers are typically equipped with the logic for differential control and it just takes a return air sensor to achieve this superior changeover method.

4. Level of integration determines if the economizer operates in conjunction with the cooling coil or separately. The first two options can use a single-stage cooling thermostat, while the final three require a dedicated thermostat stage for economizer:

- **Non-integrated or exclusive operation**: Below the changeover temperature, only the economizer operates. Above the changeover setting, only the cooling coil operates. They never operate at the same time. To maintain comfort, a non-integrated economizer changeover is usually set for OSA above 50^{o}F or 55^{o}F, although with experimentation, some spaces can achieve comfort with changeover settings around 60^{o}F.
- **Time-delay integration**: On a call for cooling, the economizer operates for a set time (usually 5 minutes). Then if there is still a need for cooling, the cooling coil operates and the economizer modulates to near minimum to keep discharge air from getting too cold. When the cooling call is satisfied, both the coil and economizer are off and the dampers return to the minimum ventilation position. This strategy can be implemented with differential changeover or a higher single-sensor changeover setting.

- **Alternating integration**: This is the best integration that can be achieved with a single-stage direct-expansion cooling unit. As shown in the graph, the first cooling stage from the thermostat activates the economizer. When the temperature rises further, the second thermostat stage is activated and the cooling compressor operates. With the coil on and the primary sensor in the discharge air position, the economizer controller modulates the outside air dampers closed (usually to or near the minimum ventilation position) to keep discharge air from getting too cold for comfort and to prevent coil icing. When the space temperature drops and the second stage is satisfied, the compressor stops and the economizer opens again to provide maximum outside air economizing until the first stage of cooling is satisfied or the second stage is activated again. Note that in the graph example, the OSA damper does not close all the way to the minimum position; if the OSA were cooler or the return air warmer, it would.



- **Partial integration**: With a multiple-stage direct-expansion cooling unit, integration is improved. Operation is similar to alternating integration, except that when the second stage of cooling is called for, the partial cooling provides only a 5- or 10-degree temperature drop from mechanical cooling. The economizer is able to do more of the cooling with outside air while maintaining a comfortable discharge temperature. When the second stage cooling call is satisfied, the economizer returns to full outside air similar to the alternating integration. For a two-stage cooling unit, partial integration can be achieved with a two-stage thermostat:
    - o below the changeover setting, stage one is the economizer and stage two is the first stage of compressor cooling, and
    - o above the changeover setting, stage one is the first stage of compressor cooling economizer and stage two is the second stage of compressor cooling.
- **Full integration**: A hydronic chilled-water cooling coil can be modulated to any cooling output. This allows the economizer to be fully open when outside air is above the discharge air setpoint (usually 55°F) and add only the amount of mechanical cooling that is actually needed. For full integration to be achieved, a differential changeover strategy is required.

5. Minimum outside airflow for ventilation is typically controlled by the economizer controller. While not technically part of the economizer strategy for cooling, energy can be saved by paying attention to when and how much ventilation air is used. Excessive ventilation air increases heating and cooling use when the economizer is not active. Too little ventilation air results in odors or unhealthful conditions in the space. When the economizer controller is set up, the quantity of ventilation air can be determined one of four ways:

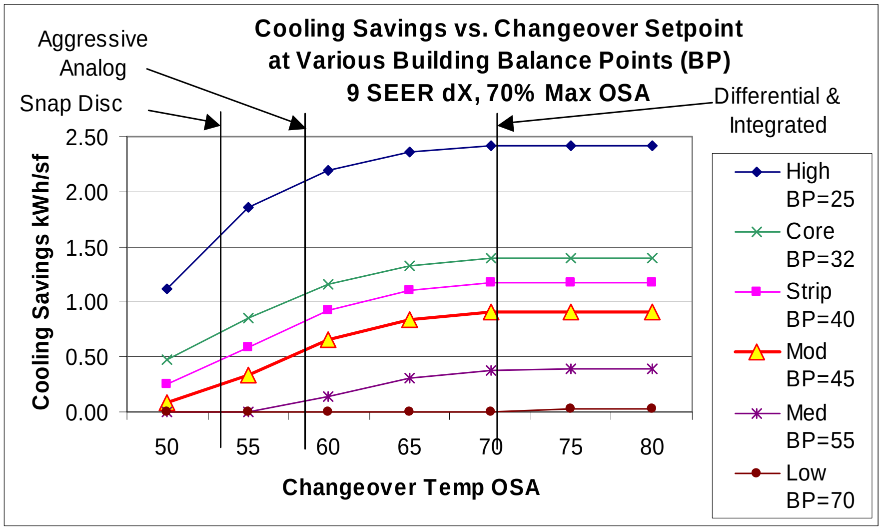
- Estimated by observed damper position
- Estimated by temperature measurement
- Flow measured with flow plate, velometer, or duct traverse
- Varied with demand controlled ventilation by CO_2 sensor

How the economizer controller is wired determines when the ventilation air is activated. Ventilation air dampers can be:

- Always open (no automatic control)
- Open whenever the fan is on
- Open when the fan is on and the return air is warm (>68 ^oF; called a warm-up cycle)
- Open with the "occupied" schedule in the thermostat
- Open when an occupancy sensor detects occupancy in the room
- Open with demand controlled ventilation

Economizer Integration. The major method to increase savings is to achieve some level of integration of the economizer with mechanical cooling. **Integration** means that the outside air is used to full advantage before mechanical cooling is used. With a modulating chilled-water cooling coil, full integration can be achieved. Outside-air dampers remain full open until outside air is warmer than return air (differential changeover) and only as much chilled-water cooling is used as is needed. With direct expansion cooling using multiple stages or a variable speed compressor, partial integration can be achieved. With a single stage direct expansion unit, alternating integration can be achieved. Basic economizers installed today are typically not integrated. They use single-sensor changeover, which means the economizer is turned off at a set outside air temperature when the technician thinks the compressor may be needed. This changeover is controlled by a snap disc set around 55 degrees or an adjustable sensor that may be set even lower. Single-sensor changeover economizers can save more by increasing the changeover setpoint to around 60 degrees (B+ on the A-D scale).

Getting as much integration as possible is important because there are many occupied hours during the year in the 55 to 70 degree range where integration applies. There is also a trend of reducing internal building loads. New lighting technologies and flat-screen computer displays put less heat into the space. This means that balance temperatures are increasing. The balance temperature is the outside air temperature when no cooling is required. The graph at right shows that most savings occur when the economizer is integrated and differential changeover is used.



***Western Premium Economizer* Designation.** To avoid confusion with manufacturers who may have different specifications for a "premium" economizer, EWEB uses the term *Western Premium* to specify an integrated economizer with a dry-bulb differential changeover.