# Developing Commercial Code Precalculated Packages

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## ABSTRACT

Energy codes and standards have provided large increases in building efficiency since the first national building energy efficiency standard was published in late 1975; however, the most commonly used path in energy codes—the prescriptive path—appears to be reaching a point of diminishing returns. As the code matures, many basic requirements in the prescriptive path, such as wall insulation or equipment efficiency, reach their threshold cost-effective levels so achieving the next real gains in building efficiency will require the ability to save energy across multiple building elements. Performance paths are increasing in popularity; however, there remains a significant cost to design teams to follow this path using custom analysis—especially for simple buildings. An alternative approach is to develop precalculated packages that include trade-offs known to be commonly used by designers where energy performance is equivalent to a building following the prescriptive path. An efficient method is used to develop precalculated packages based on desired trade-off options: alternative package energy cost is determined based on limited runs of prototypical building models that are used to develop parametric regression models. A set of precalculated packages is selected for each climate zone based on equivalent energy cost. The approach is designed to be cost-effective and flexible for the design team while achieving a desired level of energy efficiency performance. An example of the approach—based on small- to medium-sized office buildings—is developed as an energy code proposal in multiple formats.

## Introduction

Most commercial energy codes in the United States are based on one of the two model energy codes: the International Energy Conservation Code (IECC) as developed by the International Code Council or ASHRAE Standard 90.1, although many state-specific amendments or codes exist (DOE 2016). Both of those model codes focus on prescriptive criteria as their main avenue for compliance. The prescriptive and performance paths in their current format result in a number of issues that compromise the goal of energy efficiency. These issues have been discussed in detail elsewhere (Rosenberg and Hart 2014, Rosenberg et al. 2014) and are summarized below to provide a context for pre-calculated packages:

- Variations in energy use occur in both the prescriptive and performance paths, due to multiple choices available to designers and the inherent energy use of different design options such as building materials, space layout, and HVAC system types.
- With changes in baseline for each code edition, it is difficult to track progress, or compare building energy performance.
- Updating performance path rules cannot keep pace with prescriptive changes in each edition of a code.
- There is a diminishing energy impact from new prescriptive changes, and codes have progressed close to the practical energy savings limit for a prescriptive approach.

- Efficient design selections are often not rewarded in current performance approaches.
- Current performance paths require significant design team analysis cost and lead to difficulties in quality control and building official review.
- Tenant infills often lack coordination between trades and would benefit from simplified tradeoff approaches.

There are multiple building energy code formats in use today or contemplated for future codes (Conover et al. 2013; Hogan 2013). In general, most codes have mandatory requirements that must always be met and prescriptive requirements that must be met as prescribed or that can be adjusted in a trade-off or predictive performance approach. Recognizing that standard prescriptive approaches have limitations, the authors explored precalculated packages (sometimes called prescriptive packages) to provide enhanced design flexibility while improving the consistency of energy codes. While many questions about package implementation will need to be addressed during the normal model code development processes, this paper is focused on exploring possible formats for precalculated packages, followed by a suggested process for developing the tradeoff options in precalculated packages.

## Target Performance Levels

For either a true performance path or precalculated package approach, an energy cost target is needed. To promote efficient building design and construction, a differential predictive performance method with a stable and independent baseline is recommended for future commercial codes, with precalculated packages for simple buildings included as a supplemental path (Rosenberg and Hart 2014). The *stable* and *independent baseline* improves the consistency of the energy performance path for buildings governed by codes. A *stable baseline* is from a fixed code edition, so that multiple standards can share a common performance improvement metric to demonstrate compliance with current codes or beyond-code standards. A stable baseline also makes development of automated performance software more attractive, as the market is broadened and the product shelf life is increased. With an *independent baseline* the baseline parameters for a performance analysis follow an independent rule set, rather than being dependent on the designed building. For example, a dependent baseline that uses the window to wall ratio (WWR) and heating, ventilation, and air-conditioning (HVAC) system of the proposed building gives no credit for optimizing WWR or improving overall HVAC system efficiency, while an independent baseline with a defined WWR and HVAC system does. The independent baseline has been established by a working group of the Standard 90.1 committee who selected typical good design practice for each of 16 prototype buildings used to track the progress of Standard 90.1 (Thornton et al. 2011). The efficiency levels of the prototype designs meet the current prescriptive path. Hence, those typical designs can be considered the *primary package* for creating performance targets.

For precalculated packages, one of the prototype buildings developed under the consensus process is used to arrive at a normalized Energy Cost Index (ECI)[1] for a primary package of building attributes. Many of the attributes are taken from the independent baseline used in the performance approach. For example the WWR is based on the rules of Appendix G of Standard 90.1-2013 (ASHRAE 2013) rather than the code maximum allowed for the proposed

[1] Alternative comparators could be used such as site or source energy use index; however ECI is currently the performance metric in both model codes.

building. That way a proposed building gets credit for reducing WWR, while the energy impact of a higher WWR must be offset by saving energy elsewhere. Figure 1 identifies the ECI of the primary package from among the distribution of energy costs for many prescriptive options for a medium office building in Climate Zone 5A.[2]

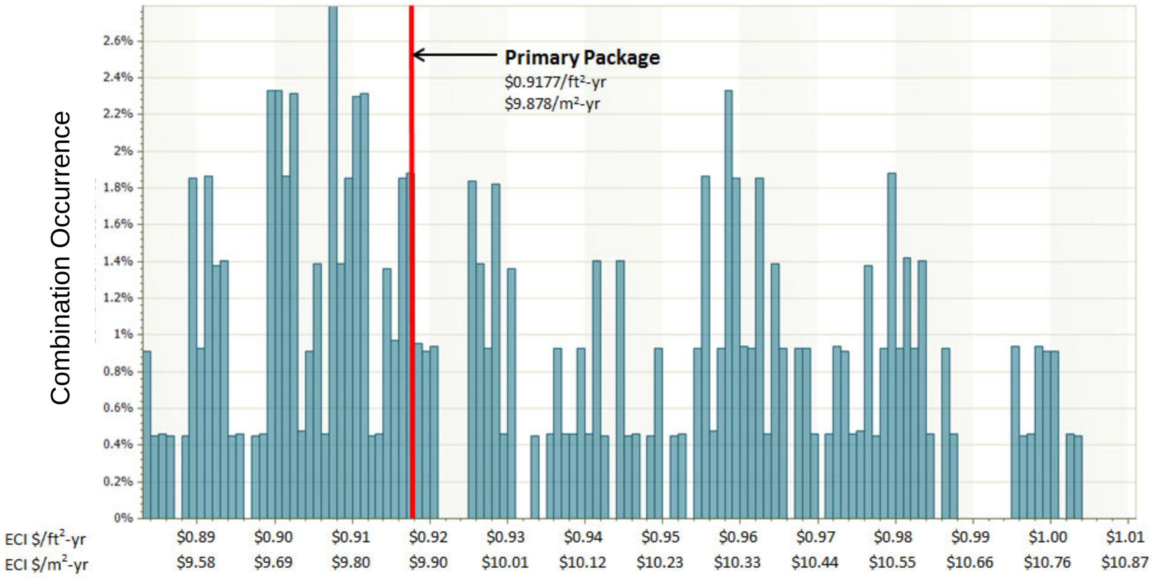


Figure 1. Primary package identified from within the distribution of energy costs for various combinations of prescriptive options for a prototypical medium office building in Climate Zone 5a.

The primary package includes energy efficient design options from the prescriptive path and generally lines up with many operational or fixed parameters for the independent baseline used in the performance path, along with mandatory and prescriptive requirements from the current code, like window and wall maximum U-factor or lighting power density. Any medium office in Climate Zone 5A that has parameters resulting in a prototype ECI that meets or is less than the ECI of the primary package would likely comply with the performance path. Under a precalculated package path the building would be deemed to comply with code without the need for custom building simulation.

The performance goal of using a stable and independent baseline rule set can be met one of three ways: 1) with a custom performance analysis, 2) through automated software, or 3) using precalculated packages. Custom performance analysis may always be needed for more complex buildings. Automated performance software that creates a baseline model from proposed building inputs will provide the most flexibility, but will likely require many years to fully develop. Precalculated packages provide an alternative for smaller or simple buildings that can be rolled out sooner than automated performance software.

## Precalculated Packages

While establishing a predictive performance goal supported by automated analysis software will ensure a minimum desired performance level, there will likely be a continued interest in maintaining prescriptive options for simple buildings. Precalculated packages provide

[2] Climate zones are as defined in the model codes. Climate Zone 5A covers a moderately northern band in the eastern U.S.

easily applied solutions while maintaining the desired level of performance. In the precalculated package approach, a building designer can choose from a number of packages with a pre-selected mix of parameters. Precalculated packages can be introduced as a third path along with prescriptive and performance.

The same primary package of prescriptive options that is used to create the performance target can establish the primary standard design package. Additional packages can be created based on prototype modeling. These packages will provide a minimum energy performance level within a reasonable range. There might be packages that allow more glazing area but have restrictions on other building parameters, like U-factors or lighting controls, to result in a similar desired energy performance level. Conversely, selection of less glazing area would allow more flexibility for other building components, such as increased lighting levels. As precalculated packages are added to the code, a number of different formats are possible:

1. **Limited Table.** Select a limited number of packages for each building type that cover the most common or desirable trade-offs. Tables can be in the main body of the code. While this may be viewed as simpler by users, it does limit flexibility in package selection.
2. **Extensive Table.** Include a broader range of packages in a normative appendix referenced in the body of the code. This allows for more flexibility, although the very large number of valid options (See Table 6) would need to be limited for a printed document with many building types and all climate zones.
3. **Package Database.** Develop a database of combination options, to allow the highest flexibility to the designer in selecting packages. The database would be web accessible, an e-book, or embedded in COMcheck.[3] This approach would be more appropriate with delivery of the code as an interactive document, and would require integration with automated electronic checklists to make inspection and compliance more streamlined.
4. **Point System.** Analyze the results of the precalculated package development and establish a point system that allows designers to trade-off positive and negative points to arrive at the target energy use. This would have the benefit of the most compact tables but would not fully account for interaction. Interaction effects could be accounted for by requiring excess above-code points.
5. **Formula Method.** Create a calculation method with the regression formulas to allow trade-offs. This would allow maximum flexibility and would be similar to the regression-based envelope trade-off in ASHRAE 90.1-2010 Appendix C (ASHRAE 2010).

### Fixed Package Formats

Packages can be developed that capture desired design options. These additional packages along with the standard design (primary) package will be available for design teams without the need for modeling. Table 1 shows an example of Format 1 (Limited Table) for Standard 90.1, with ten precalculated packages for a medium sized office building with variable air volume reheat systems in Climate Zone 5A. Package sets would be developed for other simple buildings, such as small offices, small retail, large retail with unitary systems, and motels with a similar format for IECC or other energy codes. After the primary package (package 1), each package has trade-offs that can provide energy equivalencies where the bold items are a relaxation of prescriptive requirements offset by shaded requirements that are more stringent.

[3] COMcheck is code compliance verification software; see: https://www.energycodes.gov/comcheck.

Table 1. Sample Precalculated Packages – Limited Table (Format 1)

**Precalculated Packages for Office Buildings 5,000 to 150,000 ft² (450 to 14,000 m²) in Climate Zone 5A**

Compliance with the Precalculated Package Path method requires that all parameters for one package in the table below be met in addition to the following:

1. All mandatory requirements of Standard 90.1-2013 must be met.
2. All prescriptive requirements not covered below must comply with Sections 5 to 10 of Standard 90.1-2013.
3. HVAC systems shall be VAV reheat and include economizers in compliance with Section 6.5.1 and energy recovery as required by Section 6.5.6.
4. Cooling source shall be direct expansion.

| Package[1] | HVAC System[2] | Minimum Heating Source Efficiency[3] | Minimum Cooling Source Efficiency[4] | Maximum Window Wall Ratio (WWR) | Opaque Construction & Fenestration U-factor[5] | Maximum Fan Brake HP (input kW) for Each System[6] | Percent of Interior LPD (W/ft²) allowance[7] | Minimum Daylight Floor Area[8] | Minimum Occupancy Sensor Coverage Area |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HyRH | 100% | 100% | 33% | 100% | 100% | 100% | 21% | 53% |
| 2 | HyRH | 100% | 100% | **50%** | 100% | 100% | 100% | 41% | 53% |
| 3 | HyRH | 120% | 115% | **50%** | **125%** | 100% | 100% | 21% | 53% |
| 4 | HyRH | 100% | 100% | **40%** | **108%** | 100% | **122%** | 21% | 91% |
| 5 | HyRH | 110% | 110% | 33% | 100% | **135%** | 100% | 21% | 53% |
| 6 | **ELRH** | 100% | 120% | **40%** | **108%** | 100% | 80% | 21% | 91% |
| 7 | **ELRH** | 100% | 100% | **40%** | 83% | 100% | 100% | 41% | 91% |
| 8 | **ELRH** | 100% | 115% | 25% | 67% | 80% | **122%** | 21% | 91% |
| 9 | **ELRH** | 100% | 115% | 33% | 100% | **135%** | 100% | 41% | 91% |
| 10 | **ELRH** | 100% | 100% | 25% | **108%** | 100% | 100% | 41% | 91% |

[1]Package 1 is the *Primary Package* that sets target performance. Table values in bold are relaxed vs. primary package requirements; values with grey background are more stringent trade-offs.

[2]HyRH: Multiple zone variable air volume with hydronic reheat and natural gas boiler heating source; ELRH: Multiple zone variable air volume with electric reheat and central gas furnace.

[3] Percentage of required heating efficiency in Tables 6.8.1-5 & 6.8.1-6.

[4] Percentage of EER required efficiency in Table 6.8.1-1.

[5] Percentage of U-factor required in Table 6.5-5.

[6] Percentage of fan bhp (kW) calculated according to 6.5.3.1.1 Option 2.

[7] Percentage of building Lighting Power Density (LPD) Allowance.

[8] Daylight areas must include controls per Section 9.4.1.1 e and f.

*Table and section references are to Standard 90.1-2013*

Format 1 (Limited Table), as shown in the Table 1 example, requires about a half page per climate zone and building/system type, so it is necessarily limited in options for the designer. The same idea of fixed packages can be expanded to increase flexibility. More combinations and more intermediate parameter points can be offered; however the package listings get longer. Format 2 (Extensive Table) is just a longer version of Format 1 and would likely be a normative appendix where 30 to 100 possible combinations could be provided for each climate zone and building/system type. Format 3 (Package Database) follows the same concept, but could allow thousands of options that are selectable with filters; however, it would require that the code be accessed in an e-book or online format or that this option be accessed through COMcheck.

## Flexible Package Formats

The same precalculated package concept can be provided in more flexible formats. Format 4 (point system) is based on the same primary package and prototype analysis used for the fixed formats. Rather than selecting packages that result in a near-equivalent ECI, the impact of variation of each parameter is evaluated to arrive at appropriate unit points for each climate zone that will be applied to the percentage variation of the parameter. An example of unit points for three climate zones[4] is shown in Table 2 with an example application of the points in Table 3. The parameters, % change, and relevant prescriptive code sections would be defined in a precalculated package path code section. For this flexible format example, the applicable building type is smaller offices (≤ 50,000 $ft^2$) with simple packaged systems.

Table 2. Sample Precalculated Packages – Point System (Format 4)[a]

| **Package Parameters as Defined in Section ###.#.#** | **% of Building Area or % of Required factor or efficiency** | **Primary Code Base** | **Climate Zone Unit Points** | | |
|---|---|---|---|---|---|
| | | | **2B** | **4A** | **8** |
| Max Window Wall Ratio | % window area as a % of gross wall area | 30% | -14.9 | -16.4 | -4.1 |
| Envelope U-Factor | % of required average U-factor | 100% | -2.6 | -3.6 | -12.7 |
| HVAC System Type (Primary Base is Furnace & DX AC) | % building floor area ASHP | 0% | -0.1 | -1.5 | N/A |
| | % floor area VRF + DOAS | 0% | 4.1 | 3.9 | N/A |
| Heating Efficiency (area weighted if not all same) | % of table furnace Et, AFUE | 100% | N/A | 2.9 | 13.9 |
| | % of table HP HSPF | 100% | N/A | 0.4 | N/A |
| Cooling Efficiency (cfm weighted if not all same) | % of table IEER or EER | 100% | 4.9 | 2.7 | 0.6 |
| Fan Control (not allowed with VRF + DOAS) | % of total building supply cfm with advanced fan control | 0% | 5.1 | 4.9 | 4.7 |
| No Economizer Control | % of cooling supply air cfm without required economizer | 0% | -1.9 | -1.8 | -3.0 |
| Energy Recovery Ventilation | % of total building OA cfm with ERV where not required | 0% | N/A | 1.5 | 3.8 |
| Max Interior LPD ($W/ft^2$)[b] | % of required Building LPD, $W/ft^2$ | 100% | -33 | -31.7 | -28.1 |
| Minimum Daylight Area[b] | % floor area with daylight responsive controls | 15% | 6.8 | 7.9 | 7.4 |
| Minimum Occupant Sensor Coverage Area[b] | % floor area with occupancy sensor controls | 55% | 12.3 | 9.8 | 10.1 |

[a] Many of the building system acronyms in this table are defined in Table 5; others include: Air-Source Heat Pump (ASHP), Heating Ventilating and Air-Conditioning (HVAC), Air-Conditioning (AC), Variable Refrigerant Flow (VRF), Dedicated Outdoor Air System (DOAS), Annual Fuel Utilization Efficiency (AFUE), Heating Seasonal Performance Factor (HSPF), Energy Efficiency Ratio (EER), Integrated EER (IEER), Outside Air (OA), and Energy Recovery Ventilation (ERV).
[b] Where both LPD and control areas are changed, any incremental control area is multiplied by % of required LPD.

The point approach has the advantages of a compact presentation while allowing a wide range of flexibility for designers with parameter increments that are infinitely adjustable and allow any of the available options to be traded off, as long as negative impact points

[4] Climate zones are as defined in the model codes.

(representing below-code options) are offset by positive impact points (representing above-code options). Impact points are found for each parameter by first determining the incremental percentage difference between the proposed building and the primary base percentage, then multiplying that increment by the climate zone unit points. A sample worksheet is shown in Table 3. Drawbacks are that the point method requires simple calculations and interaction is not fully addressed. Interaction or extra efficiency improvements can be accounted for by requiring that there be a surplus of positive impact points, as shown in the example.

Table 3. Example of Applying a Precalculated Package Point System in Climate Zone 4A

| Item Differing from Primary Building Package | Proposed Building | Primary Base | Proposed Increment | CZ Unit Points | Impact Points |
|---|---|---|---|---|---|
| Window Wall Ratio | 35% | 30% | 5% | -16.4 | -82 |
| Envelope U-Factor | 85% | 100% | -15% | -3.6 | 54 |
| Furnace Efficiency | 117% | 100% | 17% | 2.9 | 50 |
| No Economizer Control | 100% | 0% | 100% | -1.8 | -180 |
| Interior LPD (W/ft$^2$) | 97% | 100% | -3% | -31.7 | 95 |
| Daylighting Control Area | 0% | 15% | -15% * 0.97 | 7.9 | -107 |
| Occupant Sensor Control Area | 80% | 55% | 25% * 0.97 | 9.8 | 237 |
| Total Impact Points | Proposed Building Package Complies with Code if ≥ 25 | | | | **67** |

Format 5 (Formula Method) is a fully flexible package approach that requires limited parameter entry by the user to calculate impact with regression coefficients for each building and system type. This could be a normative code appendix similar to the envelope trade-off in Appendix C of 90.1-2010 (ASHRAE 2010) and implemented in verification tools like COMcheck or design-integrated energy tools.

## Format Advantages and Disadvantages

Each of these formats has advantages and disadvantages, as listed in Table 4. While designers want flexibility, code official are interested in a high level of clarity and simplicity. Enforceability can be enhanced with automated checklists for the more complex formats.

Table 4. Precalculated Package Format Comparison

| Format | Compact Presentation | Interaction Accounted for? | Design Flexibility | Clarity & Simplicity | Expandable Between Cycles |
|---|---|---|---|---|---|
| 1. Limited Table | Moderate | Yes | Limited | High | No |
| 2. Extensive Table | No | Yes | Moderate | Mod. High | No |
| 3. Package Database | Requires e-Book | Yes | High | Moderate | Yes |
| 4. Point System | Very | No | High | Mod. Low | No |
| 5. Formula Method | Moderate | Yes | Very High | Low | No |

Once an initial set of precalculated packages is developed, a process may be needed to add packages or parameters to the package calculators between code cycles. The most likely candidates are the code development bodies themselves. Alternatively, submission of packages could be made open to anyone, with the code bodies developing an acceptance procedure, possibly managed by a third-party. In theory, any proposed building design that demonstrates compliance via the performance path and using the same primary package could define a new precalculated package. However, code development bodies would likely require the use of standard prototypes and a high level of quality control for a package to be deemed acceptable for general use.

## Development of Precalculated Packages

For small- to medium-sized buildings without a high degree of complexity, analysis of a prototype building based on the primary package is expected to be representative of typical building energy use; therefore, other combinations or packages of prescriptive items can be selected so that the proposed building analyzed energy use will match or be less than the energy use of a building with the primary package. The primary package is representative of reasonable prescriptive options with a good level of energy performance. The sample package development process used by Pacific Northwest National Laboratory (PNNL) for the small- and mid-sized office building followed these steps:

- Identify commonly desired prescriptive options that affect energy operating cost.
- Identify above- and below-code parameters (e.g., efficiency or average U-factor) affecting energy cost for those options.
- Complete a limited set of interactive building model simulations for a prototype building.
- Use the simulation results to develop regressions where the parameter values are independent variables and gas and electric use and cost are dependent variables.
- Use the regressions with a decision analysis program to calculate all possible combinations and generate an ECI for all the combination packages.
- Review the results to select packages that have an ECI below—but close to—the primary package ECI, and that have trade-off items attractive to developers and designers.
- For validation, re-run a sample of packages with the EnergyPlus[5] simulation model to verify regressions.

The above steps apply to the fixed packages (Formats 1, 2, and 3) with variation in the number of packages made available for selection. For flexible packages, the same process is used to develop regressions. A range of packages is used to develop points for Format 4 and the regression models are used directly in a calculator for Format 5.

### Identify Options for Variation in Packages

To identify options for the packages, PNNL analysts selected items that would significantly affect energy use and be of interest to developers and designers. Ease of modeling was considered as well. For the Format 1 example shown in Table 1, two HVAC systems were selected; it would be desirable to include additional system types as final packages or points are developed for inclusion in codes or standards. For each option, a range of values was selected for the initial simulations, representing low-energy, code-level (primary package) energy, and high-energy cost. For some items, such as federally mandated equipment efficiency, the code level was the floor. The options and their relation to code are shown in Table 5. Each parameter option

[5] EnergyPlus is building simulation software; see: http://apps1.eere.energy.gov/buildings/energyplus/.

is assigned a parameter abbreviation used throughout the discussion, and many are established relative to a particular edition of Standard 90.1 (ASHRAE 2004; ASHRAE 2013).

Table 5. Parameter Options for Mid-sized Office Package Development

| Parameter Option | Primary Package (Typical) | High Energy Cost | Low Energy Cost |
|---|---|---|---|
| HVAC system type | Hydronic Reheat (HyRH) packaged direct expansion (DX) with variable air volume (VAV) | Electric Reheat (ELRH) packaged DX with VAV | N/A |
| Boiler thermal efficiency (Et) | 90.1-2013 requirement | N/A | 97% for condensing units (only with hydronic reheat) |
| Cooling energy efficiency ratio (EER) | 90.1-2013 requirement | N/A | 2013 efficiency + 10% |
| Fan power; total static pressure | 90.1-2013 requirement | 90.1-2013 req'mt + 35% | 90.1-2013 requirement - 20% |
| Window to wall ratio (WWR) | 33% | 50% | 20% |
| Opaque and fenestration U-factors (Regression input is average U-factor* (Uavg) for each WWR); windows based on weighted mix of types | 90.1-2013 requirement, U*: roof = 0.032 (0.182), wall = 0.055 (0.312), window = 0.45 (2.56) | 90.1-2004 requirement, U*: roof=0.063 (0.358), wall = 0.084 (0.477), window = 0.57 (3.23) | 90.1-2013 requirement - 20%, U*: roof=0.0256 (0.145), wall = 0.044 (0.250), window = 0.36 (2.04) |
| Lighting power density; LPD (w/sf) | 90.1-2013 requirement | 90.1-2004 requirement | 90.1-2013 requirement - 20% |
| Daylighting; percentage of floor area (Adl) | As required by 90.1-2013: ~21% of floor area daylit | None | All daylight zones: ~41% of floor area daylit |
| Open office light schedule; percentage floor area with occupancy sensors (Aos) | 90.1-2013: no open office controls or ~53% floor area with occupancy sensors | 90.1-2004 prototype occupancy sensors: ~7.5% floor area | Occupancy sensors almost everywhere: ~91% of floor area |

* U-factor in Btu/h·ft$^2$·°F (W/m$^2$·K)

## EnergyPlus Simulation

The small and medium office prototype building models were simulated with runs for parameters options set at the typical prescriptive level (primary package). Then each option was run at its high and low energy impact condition while maintaining the other options at their typical levels. Finally, interactive runs included all options at high or low levels and runs with a mixture of option levels expected to be highly interactive. The inputs for the high and low energy impact values are shown in Table 5.

## Regression Development

The EnergyPlus results were used to develop regressions where the parameter values are independent variables and gas and electric use are dependent variables, with the following rules:

- Separate regression equations are developed for each HVAC system type.
- Separate regression equations are developed for each energy type with some separation by end use: general electric; cooling and auxiliary HVAC electric; electric or gas heat; and other gas are all separate regression equations. This was found necessary to maintain significance and keep results comparative between different heating types.
- All option parameters are retained as independent variables in at least one of the energy type equations, even if their significance is low. In regressions for the non-primary energy type (e.g., the gas interaction with lighting), insignificant variables are dropped.

- Included parameters are maintained in parallel for different HVAC system types, so that the same inputs were used across all system types, even if significance was low for some.
- Interactive variables or second-order variables are included where there is a logical justification, they are significant, and they improve either the significance of other variables or the R-correlation.

The R correlations (Multiple $R^2$) are quite high, ranging from 0.964 to 0.998 for the mid-sized office and from 0.904 to 0.999 for the small office. When regression coefficients were used to calculate the ECI results from inputs for the simulation runs, the comparison was very close, with the maximum (absolute average) ECI errors ±0.7% (0.3%) for the hydronic reheat system and ±1.3% (0.4%) for the electric reheat system.

### Decision Analysis Model Development

A model of the interaction of parameter options was developed and is shown as a decision tree in Figure 2 (See Table 5 for definitions of parameter names). The decision model also established interaction between WWR and Uavg and was set up to allow more efficient analysis by restricting thermal efficiency ($E_t$) to the Hydronic Reheat (HyRH) system.

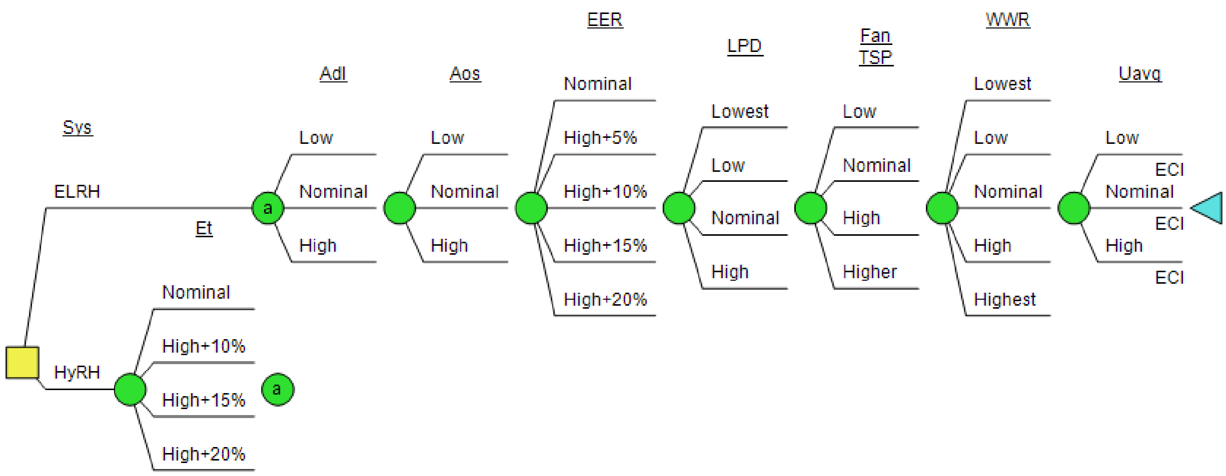


Figure 2. Decision Tree for Medium Office Package Development

Once the decision logic was developed and values were assigned to the various states for each node, a spreadsheet model using the regression coefficients and energy rates to calculate total building ECI was connected to the decision analysis model. The decision analysis model then calculated the ECIs for all combinations of parameter options. The distribution of results was similar to that shown in Figure 1, except wider for this analysis that includes above and below code parameters, ranging from an ECI of \$0.74 to \$1.23 per $ft^2$.

The selected packages were re-run with the EnergyPlus simulation model to validate the regressions and obtain final results. The final results for the 11 selected packages were all within ±1.5% of total energy cost predicted by EnergyPlus as compared to the regressions. While this is a small sample, the tight range of result difference suggests that it may be acceptable to use the regressions directly for final results with just spot verification by interactive simulation in the future, rather than just for the process of narrowing package selection.

The endpoint results from the decision analysis were used to generate an ECI for all the combinations from the electric and gas regression results. These were compared to the primary package to determine a percentage of primary package energy cost. The total number of analyzed packages is shown in Table 6, grouped by the relation of package ECI to the primary package. It is encouraging that for both the primary HVAC system (HyRH) and the alternative system (ELRH), there are a large number of energy equivalent packages to choose from, even with a tight tolerance of within 1% equivalent energy cost, where 5% of the possible combination packages are available as potential energy equivalent packages.

Table 6. Counts of Analyzed Packages Related to ECI of the Primary Package

| Package Count | Hydronic Reheat VAV | Electric Reheat VAV | Total Packages | |
|---|---|---|---|---|
| Total Package Combinations | 43,200 | 10,800 | 54,000 | 100% |
| From 90% to 100% ECI | 22,838 | 2,079 | 24,917 | 46% |
| From 97% to 100% ECI | 7,789 | 1,115 | 8,944 | 16% |
| From 99% to 100% ECI | 2,493 | 426 | 2,919 | 5% |

The options were reviewed to select desired packages, focusing on packages that have an ECI below 100% of the primary package but are close to the primary package ECI. A range of 97% to close to 100% was used to narrow down the packages considered for manual package selection. During manual selection, the following considerations were applied:

- Energy cost of the package was between 100% and 97% of that of the primary package.
- Options selected represented trade-offs that developers have expressed interested in at energy code feedback meetings.
- In each package, the high efficiency trade-offs to offset a low efficiency desired item were limited to as few as necessary.
- Enough packages with equipment that just meets minimum efficiency requirements were included to be in compliance with EPCA requirements to include minimum efficiency equipment choices in code options for products covered by federal efficiency regulations (42 U.S.C. 6297(f)(3)(E)).
- The number of packages was limited to avoid having too many options.

## Conclusions and Acknowledgments

A predictive performance approach with a stable and independent baseline provides valid code flexibility with equivalent energy cost; however, the design overhead of custom performance analysis for each building is high. After sample package development was conducted for small- and medium-sized office buildings, it was found:

- There are a large number of potential packages (combinations of option values) that have an ECI close to the selected primary or code-compliant package.
- Multiple packages with reasonable trade-offs can be created that allow more design flexibility without costly custom performance analysis for each building.
- For the building type and systems modeled, the combination regression results were all within ±1.5% of total energy cost predicted by EnergyPlus, allowing direct development of a large database of valid packages (Format 3) or a package calculator (Format 5).

- There are adequate packages with minimum efficiency equipment to meet EPCA code option requirements.
- Precalculated packages can provide flexible energy cost equivalent options until simplified and robust software is available so that any building can easily use a predictive performance approach.

The authors would like to acknowledge support from the U.S. Department of Energy Building Energy Codes Program and YuLong Xie and Bing Liu from PNNL for their contributions.

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