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Roadmap for the Future of Commercial Energy Codes

January 2015

M Rosenberg
R Hart
J Zhang
R Athalye

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract **DE-AC05-76RL01830**

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Executive Summary

Building energy codes have significantly increased building efficiency over the last 39 years, since the first national energy code was published in 1975.[1] The most commonly used path in energy codes, the prescriptive path, appears to be reaching a point of diminishing returns. The current focus on prescriptive codes has limitations including significant variation in actual energy performance depending on which prescriptive options are chosen, a lack of flexibility for designers and developers, the inability to handle optimization that is specific to building type and use, the inability to account for project-specific energy costs, and the lack of follow-through or accountability after a certificate of occupancy is granted. It is likely that an approach that considers the building as an integrated system will be necessary to achieve the next real gains in building efficiency. This report provides a high-level review of different formats for commercial building energy codes, including prescriptive, prescriptive packages, capacity constrained, outcome based, and predictive performance approaches. This report also explores a next generation commercial energy code approach that places a greater emphasis on performance-based criteria.

For commercial building energy codes to continue to progress as they have over the last four decades, the next generation of building codes will need to provide a path that is led by energy performance, ensuring a measurable trajectory toward net zero energy buildings. This report outlines a vision to serve as a roadmap for future commercial code development. That vision is based on code development being led by a specific approach to predictive energy performance combined with building-specific prescriptive packages that are designed both to be cost-effective and to achieve a desired level of performance. Compliance with this new approach can be achieved by either meeting the performance target, as demonstrated by whole building energy modeling, or by choosing one of the prescriptive packages. This review of the possible code formats (further described in Section 2.1) arrives at the following conclusions:

- Predictive performance with energy use index (EUI) targets falls short as a code mechanism, since it is difficult to match individual building use to broad EUI targets.
- Outcome-based codes–while an essential approach that should be applied to all buildings–are not a substitute for design and construction energy codes that focus on compliance at occupancy.
- For a design and construction code, a differential predictive performance method with a stable and independent baseline provides the best accuracy and potential for a highly automated approach that could eventually be applied to most buildings.
- Current performance codes that have a dependent and time-variable baseline should be replaced by a differential predictive performance method with a stable and independent baseline.
- At some point in the future, tools that demonstrate predictive performance compliance may become so simple that there will no longer be a need for any prescriptive path.
- As a bridge, prescriptive packages can provide a transition from the current component prescriptive approach to a performance only code, while providing flexibility and improved energy equivalency.

[1] The term "energy code" is used within this report as a generic term that includes ASHRAE 90.1 (a standard), the International Energy Conservation Code, and other forms of building energy standards, guidelines, laws, rules, etc.

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Michael Rosenberg
Pacific Northwest National Laboratory

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAV	constant air volume
COMnet	Commercial Buildings Energy Modeling Guidelines and Procedures
DOE	U.S. Department of Energy
DX	direct expansion
ECB	Energy Cost Budget
ECI	energy cost index
ECPA	Energy Conservation and Production Act
EER	energy efficiency ratio
EUI	energy use index
FC4P	four pipe fan coil
FEMP	Federal Energy Management Program
HVAC	heating, ventilation, and air-conditioning
IECC	International Energy Conservation Code
IgCC	International Green Construction Code
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
NA	not applicable
NBI	New Buildings Institute
NIBS	National Institute of Building Science
PNNL	Pacific Northwest National Laboratory
PRM	Performance Rating Method
RTU	rooftop unit
SSPC	Standing Standards Project Committee
VAV	variable air volume
VAV-RH	variable air volume reheat
VRF	variable refrigerant flow
WWR	window-to-wall ratio

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1.0 Introduction

Energy codes that influence the design and construction of commercial buildings offer one of the best opportunities for reducing energy use over the life of a building (Nelson 2012). While other factors affect energy use in buildings, including operation, maintenance, and the level of services provided, if a building does not start with an energy efficient infrastructure as required by an energy code, it will never achieve its full energy efficiency potential. Initial construction is the best time to significantly influence building energy efficiency; otherwise, there is a lost opportunity, as it is rarely as cost-effective to retrofit a building later (Nelson 2012).

This report discusses a number of possible energy code formats and looks at issues with the current prescriptive focused approach. Next, several alternatives to a traditional prescriptive approach are reviewed to suggest a path forward for the next generation of commercial building energy codes. Options discussed include:

- Predictive performance with energy use targets
- Predictive performance with a stable and independent baseline
- Prescriptive packages
- Outcome based codes

This report presents a direction for future commercial energy code development that, if realized, can significantly improve building energy performance. It goes a step further than previous work in this area by laying out a framework of actionable changes that can serve as a test bed for developing such a code. Necessary short-term, mid-term, and long-term actions needed to fulfill the recommendations of the proposed approach are identified as well as likely entities to lead each activity. While we recognize that adoption and enforcement are extremely important to achieve the goals of an energy code, they are only briefly addressed in this report to the extent that they are affected by the proposed code approach.

2.0 Background

Energy codes are intended to minimize energy use in buildings, resulting in cost savings for building owners and occupants, decreased power demands, and reduced environmental impacts. Current energy codes attempt to achieve this goal by focusing on providing minimum requirements for energy efficient design and construction of buildings, where the most cost-effective opportunities exist. While the value of preventing lost opportunities with energy codes is well recognized (Nelson 2012), leading to greater emphasis on code improvement over the last several code development cycles, there has also been growing sentiment that energy codes in their current form are getting too complex, change too often, limit design flexibility, don't achieve their desired outcomes, have reached a point of diminishing returns, and do not consider the building as an integrated system.

The first national building energy code, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90 (ASHRAE 1975) was published in 1975. In 1982 it was separated into non-residential (90.1) and residential (90.2) standards (ASHRAE 1989, 1993). Since its inception, the standard has been upgraded nine times, resulting in significant increases in building energy efficiency. Figure 2.1 shows the relative improvement in commercial energy efficiency for each version of ASHRAE Standard 90/90.1 through 2013. Component improvement based on changes in efficiency requirements is also shown for prescriptive type requirements.[1] A projection is shown with dotted lines based on maintaining the same rate of improvement that occurred from 2004 to 2013.[2] A conclusion that can be drawn from this data is that maintaining the same trend in component efficiency improvement (a lofty goal itself) will not result in net zero energy new construction by 2030, which has been a stated goal of many stakeholders in the buildings industry (ASHRAE 2008, Architecture 2030 2011). Adding requirements for on-site renewable energy will be necessary to achieve net zero, in addition to a more systems-based approach to energy efficiency.

The Energy Conservation and Production Act as modified by the Energy Policy Act of 1992 identifies ASHRAE Standard 90.1 as the national model energy standard for commercial and multi-family residential buildings over three floors (42 U.S.C. 6833(b)(1)). Although most states adopt a version of the International Energy Conservation Code (IECC), that code contains similar requirements to Standard 90.1, and allows Standard 90.1 to be used as an alternative compliance methodology (DOE 2014; ICC 2015). Because of its federal recognition, and since most other building energy codes are based on Standard 90.1, Standard 90.1 is used in this report as the framework for discussion.

[1] Heating and cooling use index based on weighted equipment efficiency requirement changes; envelope based on typical medium office steel frame wall and window areas with U-factor changes; lighting power based on building area allowances weighted for U.S. building floor area; overall Standard 90.1 progress based on PNNL's analysis.
[2] The simple projection is intended to show what savings will be produced by continuing the same rate of change from the last 9 years. It does not include a technical potential analysis, and actual achievement for each end use area will certainly be different.

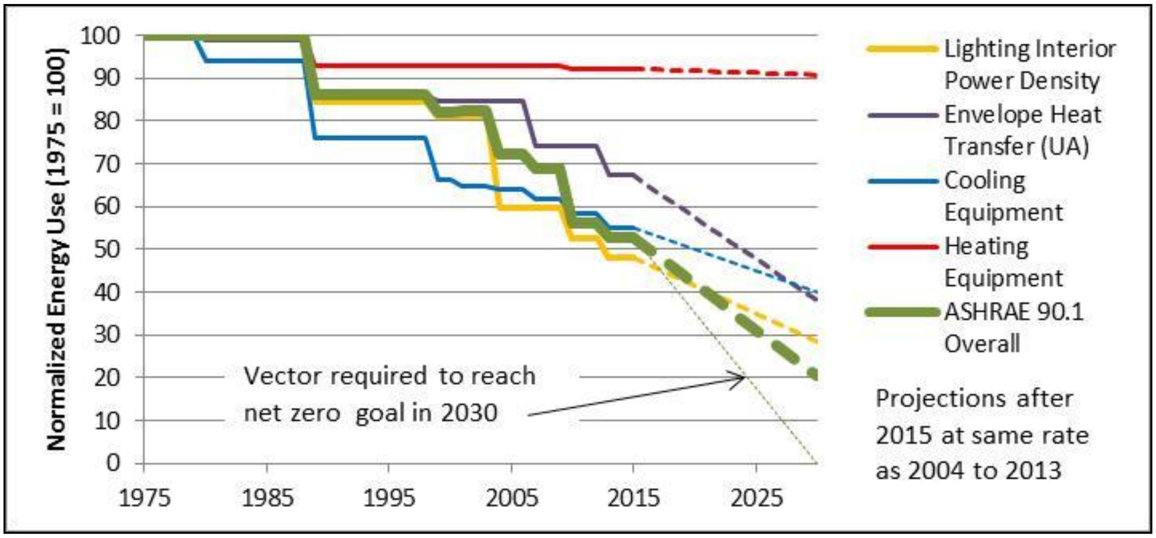

Figure 2.1. Improvement in ASHRAE Standard 90/90.1 (1975-2013) with Projections to 2030

2.1 Code Formats

Multiple building energy code formats are in use today or being contemplated for future codes. While other publications have provided more exhaustive descriptions of code formats (Conover et al. 2013; Spataro et al. 2011; Hogan 2013), the formats are summarized here for reference. 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. Enhanced mandatory requirements are suggested here for performance paths and discussed further in Section 3.74. Other approaches are based on energy use or capacity limits. These main formats or paths are described below and shown in Figure 2.2. Characteristics of the formats are summarized in Table 2.1.

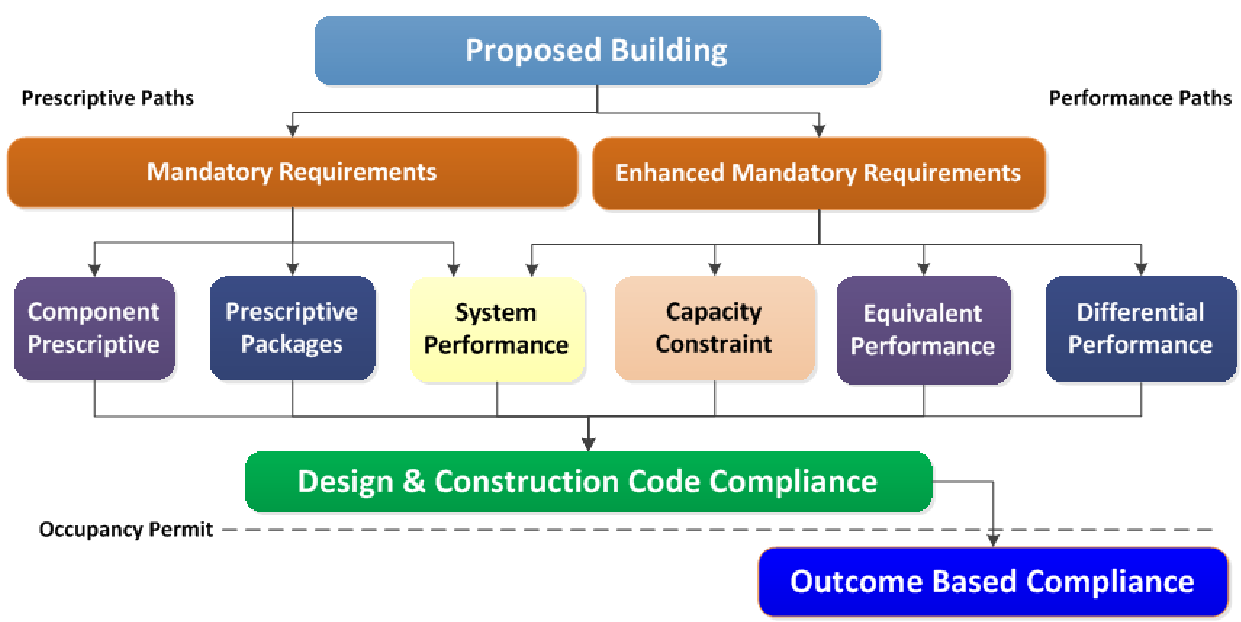

Figure 2.2. Code Compliance Paths

2.1.1 Component Prescriptive and System Performance

Strictly speaking, a prescriptive code requires a particular defined component quality, such as insulation R-value in a wall of a particular framing type. More generally, the prescriptive section of the code also contains component performance items like a required U-factor for wall assemblies or an energy efficiency ratio (EER) for an air conditioner. There may also be built-in trade-off approaches based on system or partial system performance such as an envelope trade-off that allows more insulation in one area to be traded for less in another (Hogan 2013).

For Standard 90.1, prescriptive criteria are usually set at the limit of cost-effectiveness using the scalar method establishing a discounted payback threshold (McBride 1995). Calculations use national average energy rates, equipment costs, and other economic assumptions as well as standard operational assumptions and selected climate locations. This results in criteria that are generally cost-effective on a national scale, but may not necessarily be for any individual building. This reality necessitates a relatively conservative approach to setting prescriptive requirements.

Another important issue affects the development of prescriptive criteria for products covered by federal efficiency regulations, such as some boilers, furnaces, service water heaters, air conditioners, motors, transformers, and refrigeration equipment. The Energy Conservation and Production Act (ECPA), as amended by the Energy Policy Act of 1992, prohibits states from establishing efficiency requirements in excess of federally established levels (preemption) (42 U.S.C. 6297). The rationale for this is that equipment manufacturers will have consistency in requirements across the country.

Generally, if all the mandatory and relevant prescriptive requirements are met, a building is considered to comply with the code. Standard 90.1 has historically been primarily prescriptive using this approach, although the exact nature of the prescriptions has changed over time.

2.1.2 Prescriptive Packages

A prescriptive package approach puts together packages of items that are intended to reach a desired minimum level of performance. An example might be a higher efficiency heating system in conjunction with either larger window areas or cathedral ceilings with less insulation. Rather than individual prescriptive requirements for individual components, packages of linked requirements that meet a pre-determined target performance level could be developed. In fact, these have been developed for some building types as part of the technical support documents developed by the U.S. Department of Energy (DOE) Commercial Building Initiative for building designs that are 50% better than ASHRAE Standard 90.1-2004.[1] A similar approach also has been previously presented to the Standing Standards Project Committee (SSPC) 90.1 as “Linked Criteria” in 2005 and 2009.[2]

EPCA also has requirements affecting prescriptive packages (42 U.S.C. 6297). If the code establishes one or more optional combinations of items deemed to comply, for every combination that includes a covered product with efficiency in excess of federal requirements, an additional combination must be

[1] A series of advanced energy design guides and their technical support documents are available at https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides . Accessed October 23, 2014.

[2] Jason Glazer, GARD Analytics and Chairman of the SSPC 90.1 Energy Cost Subcommittee developed a white paper and made presentations to SSPC 90.1, available at http://www.gard.com/lcs.zip. Accessed October 23, 2014.

available that includes efficiency exceeding the federal level by no more than 5%. In addition, at least one combination must include covered product efficiency that does not exceed federal levels.

Development of prescriptive packages is discussed in more detail in Section 3.4 and Appendix A.

2.1.3 Capacity Constraint

Capacity constraint refers to a code or standard that expresses its requirements as a limit on one or more service capacities (e.g., maximum capacity of the electric service panel (kilowatts) or natural gas service (therms/hour)). The capacity limit can be applied to equipment, like total heating or cooling capacity. An example common in commercial codes is a maximum lighting power density for each building type or space use. To be truly capacity constrained, the maximum lighting circuit capacity would be limited to the maximum allowed lighting power.

Like a performance based code (see below), the capacity constraints put limits on calculated values—the capacities one would calculate based on standard building load calculations and equipment sizing methods. Unlike a performance based code, however, a capacity constraint based code imposes very real limits on the actual building because it acts like a governor so that when the building is occupied the capability to use energy is limited. To some degree this is the opposite of a performance approach or outcome based approach (see below) in that instead of being based on amount of energy use over time with no specific limit on peak use, it addresses a limit on peak use without a specific limit on the timeframe over which that use occurs. Of importance to compliance verification, a limit on peak use or capacity can be easily addressed prior to occupancy, while a limit on use over time can only really be assessed in a post-occupancy situation. A significant drawback of capacity constraint based codes is that most building energy use occurs at part load conditions, and a capacity constraint only really addresses peak conditions that occur a few hours per year.

2.1.4 Predictive Performance

This refers to code compliance formats that are based on predicted building performance using energy simulation. A whole building predictive performance path allows some items to be less efficient in exchange for other items being more efficient than the prescriptive approach. It also provides additional flexibility as it allows the designer to use a variety of materials and approaches that may not meet prescriptive requirements. The typical goal of a performance approach is equivalent or better annual performance based on an hourly building energy simulation. In predictive performance approaches, a model of the proposed building is compared to either a hard target (such as energy use or energy cost index (ECI)) or a reference baseline. A target can be set by building type and climate or be adjusted based on building occupancy and requirements. The reference building approach is more common for reasons discussed in Section 3.2. Predictive performance allows for a compliant design solution that is more flexible than prescriptive solutions and can be optimized for a particular building's climate, operations, system interactions, and utility rate structure.

The performance metric might be expressed in terms of site energy, source energy, or energy cost. Energy cost tends to be the preferred metric within ASHRAE, as its use avoids long-standing debates over the proper calculation of source energy. However, source energy is more closely tied to emission and greenhouse gas reductions and is therefore favored in other arenas. For instance, California Title 24 (CEC

2013) has a performance path in their code that uses a site-source conversion factor for electric energy use. In addition, the IECC provides for cost, but jurisdictions are allowed to use site energy (ICC 2015). A reference baseline is a model similar to the proposed building with different parameters that are set by the performance rules. The baseline has characteristics in three dimensions (design parameters, time reference, and test criteria) as shown in Table 2.1.

Design indicates if the baseline design parameters are **dependent** on the proposed building design or follow an **independent** rule set.[1] A dependent design parameter in the baseline matches the proposed building but its efficiency is adjusted to meet prescriptive code values. An example would be maintaining the same heating, ventilation, and air-conditioning (HVAC) system type as in the proposed design, but adjusting efficiency to meet prescriptive requirements. An independent design parameter (often referred to as an asset) is defined in the baseline and may differ between baseline and proposed building models. Therefore, the energy impacts of those differences are captured in the comparison. An example of this approach would be setting the baseline HVAC system to a predetermined type based on the building program regardless of the HVAC system type in the proposed building. Both approaches exist in Standard 90.1. The Energy Cost Budget (ECB) method in Standard 90.1 is used for code compliance. It references a dependent baseline that tracks the design decisions in the proposed building. The second performance approach in Standard 90.1 is the Performance Rating Method (PRM), commonly referred to as Appendix G for its location in the Standard. The PRM is used for rating beyond-code energy performance for programs such the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED). The PRM tends to require a more independent baseline with parameters determined by the building program rather than the design solutions.

- **Time** indicates if the baseline parameters are updated to match the **current** code or based on a **stable** reference code, typically a historical or earlier version of the same code. A stable baseline allows easier tracking of code improvements, changes less often, and allows for easier development of automated software.
- **Test** indicates if the reference building must be **equivalent** to (no more energy use or cost than) the baseline or **differential**, meaning it must beat the baseline by an established percentage. A differential test is required when using a stable baseline from an earlier version of the same code.

2.1.5 Outcome Based

Outcome based is not really a building design and construction code, but more a method of compliance verification. It is based on verification of actual monitored energy consumption for a specified period after occupancy. Implicit in this approach is the assumption that the code is expressed in terms that can be verified by billing data (or other metered data), something not possible with a prescriptive code. An outcome based code could exist alone with a target developed based on building type and climate zone or layered on top of a performance based code with customized performance developed via building simulation. These two options are discussed in more detail in Section 3.2.

Unlike any of the other proposed approaches, an outcome based approach readily embraces existing building energy use and allows such a code to be readily applied to all buildings, not just new buildings.

[1] A mix of independent and dependent design parameters is typically required. For example, in Standard 90.1 Appendix G, the baseline window-to-wall ratio is independent of the proposed design while the shape of the building and number of floors is dependent on the proposed design.

Outcome based codes would require substantial new enforcement paradigms and infrastructures. The necessity of post-occupancy evaluations, uncertainties related to occupants and their habits, issues of building energy data confidentiality, and the potential requirement for corrective post-occupancy reconstructions makes this option difficult to envision in the near term for private sector buildings. An outcome based code has been in place in Sweden since 2006 (Wahlström 2010) and a pilot is in place in Seattle, Washington (SDPD 2012). An optional outcome based code has recently been proposed for the 2015 International Green Construction Code (IgCC).[1]

2.1.6 Summary of Code Formats

The many varied approaches to determining compliance are shown in

Table 2.1, with examples of particular applications. The strengths attributable to each approach are shown and discussed further under recommendations and shown in Table 3.2.

Table 2.1. Characteristics of Code Formats and Approaches

		Compliance		Baseline Dimensions					
		Basis		Design		Time		Test	
Code Approach	Examples	Reference Model Baseline Used	Energy Bills Used	Dependent	Independent	Current	Stable	Equivalent	Differential
Prescriptive Options:									
Prescriptive (with System Tradeoffs)	90.1; IECC; T24[(a)]	No	No	NA[(e)]	NA	NA	NA	NA	NA
Prescriptive Packages	Res. Envelope T24[(a)]	No	No	NA	NA	NA	NA	NA	NA
Predictive Performance Options:									
Equivalent to Current Dependent Baseline	90.1 Chapter 11	Yes	No	x		x		x	
Differential to Current Dependent Baseline	2012 IECC Performance	Yes	No	x		x			x
Equivalent to Current Independent Baseline	T24-2013[(a)]	Yes	No		x	x		x	
Differential to Current Independent Baseline	90.1 Appendix. G; LEED; 189.1[(b)]	Yes	No		x	x			x
Differential to Stable Independent Baseline	90.1 Addendum bm[(c)]	Yes	No		x		x		x
Equivalent to Energy Use Index (EUI) Target	Canadian Energy Code Green Globes; Seattle	Yes	No		x	x		x	
Outcome Performance Options:									
Outcome Based Code; EUI Target	Seattle; Sweden	No	Yes	NA	NA	NA	NA	NA	NA
Outcome Based Code; Differential to Stable Independent Baseline Prediction[(d)]	No current example	Yes	Yes		x		x		x

(a) T24 = California Title 24 (CEC 2013).
(b) A differential predictive performance approach has recently been approved for inclusion in ASHRAE Standard 189.1-2014.
(c) Addendum bm to Appendix G of Standard 90.1 (Rosenberg and Eley 2013).
(d) Outcome with predictive model could have other baselines with similar characteristics as predictive performance options.
(e) NA is not applicable.

[1] Final vote tallies are not yet released. The motion passed in preliminary voting.

2.2 Problems with the Current Approach to Commercial Codes

Most commercial energy codes in the United States are based on one of the two model energy codes: the IECC or Standard 90.1, though many state-specific amendments exist. Both of those model codes focus on prescriptive criteria as their main avenue for compliance. Although these codes include a performance compliance path, it is an equivalent predictive performance path with a dependent baseline established by the current prescriptive code as described above. This combination of formats results in a number of issues that compromise the goal of energy efficiency.

2.2.1 Variation in Energy Use

When establishing criteria in the prescriptive path, each component is judged independently, with the goal of requiring the most cost-effective level of efficiency of each component. The result is that two parallel prescriptive requirements don't necessarily guarantee equivalent energy performance. This adds design flexibility but means that decisions made by the design team can result in significant energy impacts. For example, the most cost-effective metal frame window has greater heat loss than the most cost-effective vinyl frame window, so at prescriptive code levels of efficiency, the metal frame window will result in greater energy use. There are parallels in most building systems. The selection of HVAC system type alone can result in variation of 25% to more than 100% of HVAC energy use based on multiple studies (Westphalen and Koszalinski 2001; Hart 2011; Perez-Lombard et al. 2004).

Normalized energy impact of variations in HVAC systems by climate zone from three studies is shown in Figure 2.3. HVAC system comparisons are normalized to identify relative range of energy use. Types include: four-pipe fan coil (FC4P), water loop heat pump (WLHP), packaged terminal air conditioner (PTAC), constant air volume central unit (CAV), packaged rooftop unit (RTU), variable air volume with reheat (VAV-RH), and variable refrigerant flow heat pump (VRF).[1] This demonstrates how given the same building, multiple HVAC systems choices can be made that all meet the prescriptive requirements, yet result in a wide range of energy use.

[1] These system comparisons used different values for fan static pressure and operations, so a direct system type comparison is elusive. The point of the comparison is simply to demonstrate the wide range that can occur for various system types, and the wide variation in energy use from one analysis to the next.

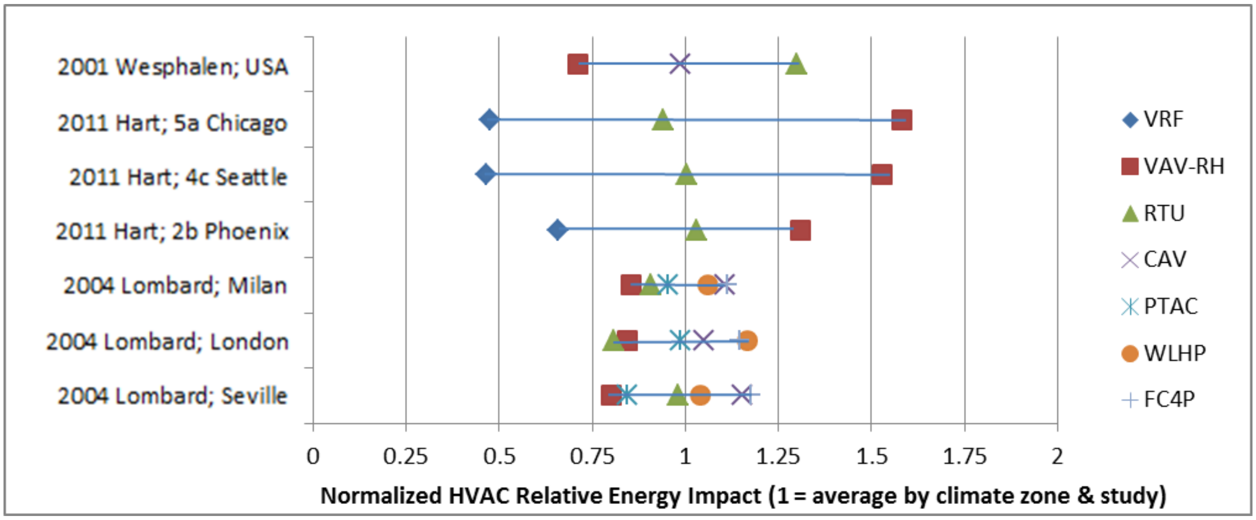

Figure 2.3. Range of Energy Use for Different System Types

To look at this issue across multiple building systems, Pacific Northwest National Laboratory (PNNL) analyzed the energy cost variation for a medium office building in Chicago (climate zone 5A) by selecting various combinations of options from the prescriptive path available in Standard 90.1-2013. Five building parameters were varied as shown in Table 2.2. Varying even these few parameters resulted in 216 possible combinations. Figure 2.4 shows the range of ECIs from \$0.883 to \$1.04/ft^2-yr (13% variation). That is a significant variation, equal to almost twice the energy savings attributed to Standard 90.1-2013 for the same building (Halverson et al. 2014). If additional parameters were varied (additional system types, building orientation, occupancy sensor verses sweep lighting controls, building area verses space-by-space lighting power compliance, etc.) the variation would be even greater.

Table 2.2. Alternative Designs for a Medium Office Building in Climate Zone 5A

	Alternative 1	Alternative 2	Alternative 3
HVAC System Type	Variable air volume (VAV) with direct expansion (DX) cooling and hydronic reheat	N/A	VAV with DX cooling and electric reheat
HVAC System Size[(a)]	135,000 Btu/h ≤ cooling capacity ≤ and 240,000 Btu/h EER = 10.8 Fan TSP = 4.46	N/A	135,000 Btu/h ≤ cooling capacity ≤ and 240,000 Btu/h EER = 9.8 Fan TSP = 5.58
Roof Type	Insulation below deck U-value = 0.021	N/A	Insulation above deck U-value = 0.032
Wall Construction	Wood framed U-value = 0.51	Steel framed U-value = 0.55	Mass wall U-value = 0.9
Window Construction	Non-metal frame U-value = 0.32	Metal frame fixed U-value = 0.45	Metal frame mixed operable[(b)] U-value = 0.46
Window-to-Wall Ratio	25%	33%	40%

(a) Compares serving the same building area with fewer large units to more small units. Smaller units are required to have higher efficiency and smaller duct runs result in reduced static pressure.
(b) Includes a mix of operable and non-operable windows.

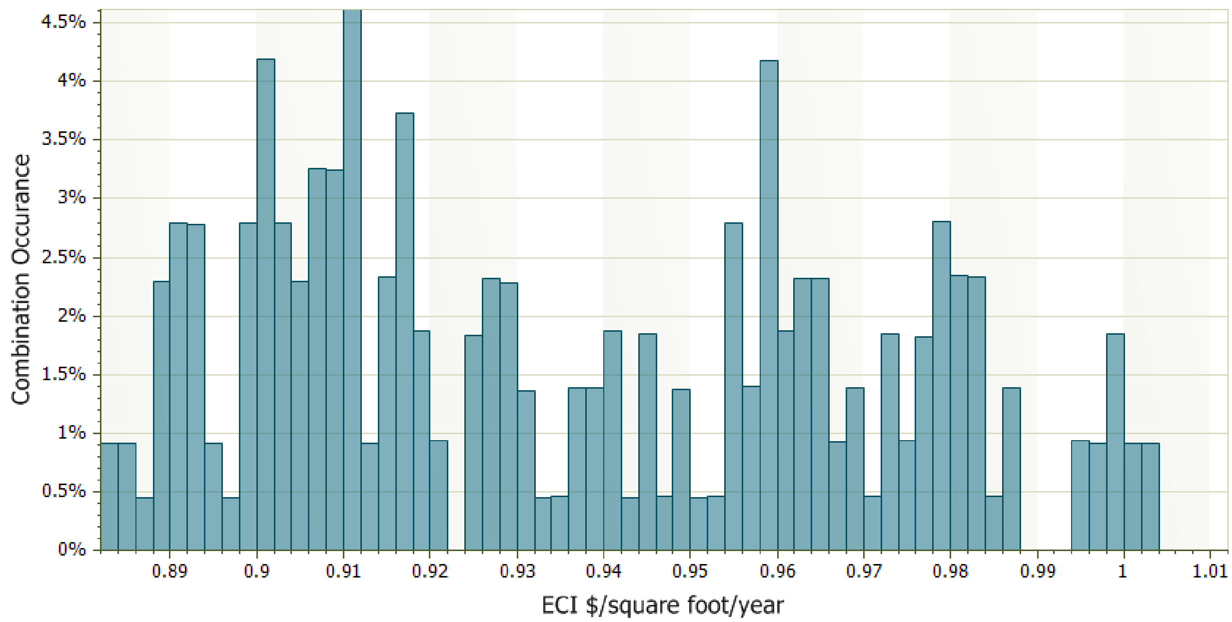

Figure 2.4. Distribution of Energy Costs for Prescriptive Options for Medium Office Building in Climate Zone 5A

Code development bodies have made efforts to address the variation in energy and energy cost of similar buildings having different prescriptive options. Recent attempts to eliminate some of the poorer energy performers from the prescriptive path have resulted in difficulty in reaching consensus, as required by the ASHRAE/American National Standards Institute (ANSI) process (ASHRAE 2014), as stakeholders dig in to protect market share and design flexibility. Recent examples include attempts to reduce limits on window area or require water cooled chillers in high cooling load applications.

The variation in energy use for similar code compliant buildings is not limited to those choosing the prescriptive path. Since the performance path is currently tracking a prescriptive baseline (dependent baseline), each proposed component's performance is adjusted to just meet the prescriptive code requirement when creating a dependent baseline reference model. This results in two similar buildings that have chosen different prescriptive options having very different performance targets.

2.2.2 Diminishing Returns

The approach of incrementally improving the efficiency of individual building components is reaching a point of diminishing returns. Figure 2.1 shows that simply increasing insulation or equipment efficiency will not achieve net zero energy targets and it is unlikely that cost-effective improvements can be applied at the same rate as in the past. For example, adding R-11 to an uninsulated wall decreases the heat loss by about 75% while adding an additional R-11 only adds an additional 11% reduction. In the case of HVAC equipment efficiency, there are concerns that the efficiencies of some classes of HVAC equipment are approaching practical and theoretical limits. For example, increasing air-conditioner or chiller efficiency requires larger heat exchangers with a similar diminishing return to adding insulation, and the cost of aluminum and copper continues to escalate (Hart et al. 2008).

Complicating the issue is that prescriptive criteria are usually set at the limit of cost-effectiveness using assumptions that must apply to wide range of buildings. Calculations use national average energy rates, equipment costs, and other economic assumptions as well as standard operational assumptions and selected climate locations. This results in criteria that are generally cost-effective on a national scale, but may not necessarily be for any individual building. This reality necessitates a relatively conservative approach to setting prescriptive requirements.

While the overall energy use progress shown in Figure 2.1 demonstrates some progress toward net zero in the future, it should be noted that many of the component use indices that have already been reduced close to their practical minimum. The projections are based on continuing past component efficiency progress into the future, and that may not be possible in all cases. Future progress will need to include on-site renewable energy and occur at an integrated system level that considers the specific building interactions of systems, utility rate structures, and operational parameters that are not easily regulated with current prescriptive approaches.

2.2.3 Limited Credit for Good Design Choices

As discussed above, neither the prescriptive component path nor the predictive performance path using a dependent baseline distinguish between high and low energy design choices that fall within the prescriptive allowances. Prescriptively, a building with a 40% window-to-wall ratio (WWR) and an air-cooled HVAC system is treated the same as one with a 30% WWR and a water-cooled HVAC system, even though the latter design choice is almost certain to result in less energy use. Similarly, even the performance path using a dependent baseline would give no tradeoff credit to the more efficient choices, as the baseline assumes the same system type and WWR. With an independent baseline, the WWR and system type are set, and differences in the proposed building would result in a credit or penalty. The dependent baseline (used in Standard 90.1 Chapter 11) doesn't credit energy efficient design. Other examples of energy reduction strategies that are not recognized by the current performance path include use of thermal mass to flatten heating and cooling loads, optimized orientation, "right sizing" of HVAC equipment, natural ventilation, and passive cooling.

2.2.4 Difficult to Track Progress

It is difficult to track the progress of energy codes in their current format. The problem is caused by the fact that the prescriptive baseline changes with each updated version of the code, making it a moving target. This makes it very difficult to compare the performance of buildings of different vintages, or to establish a deliberate improvement goal in performance requirements. How does a building 30% better than the 2004 version of Standard 90.1 compare to a building that is 15% better than the 2007 edition? Does the building that is 15% better than the 2007 Standard even comply with the 2010 Standard? How are codes progressing toward the ASHRAE and Architecture 2030 vision of net zero energy buildings by 2030 (ASHRAE 2008, Architecture 2030 2011). This issue is especially important in the United States, where state adoption of codes covers at least three editions of codes (DOE 2014).

2.2.5 Performance Path Rules Can't Keep Pace with Prescriptive Changes

With the growing charge to code development bodies to improve energy code performance, the pace of change has increased dramatically, from 32 addenda in Standard 90.1-2004 to 110 addenda in 90.1-

2013. In addition to the number of changes, the scope of regulated equipment has also increased. In the last two development cycles, Standard 90.1 has expanded coverage to include elevators, commercial refrigeration equipment, and computer room air conditioners. As each addendum is developed, it needs to be evaluated for impact on each performance path, with performance path changes often required. During the last several code cycles, the performance path has not been fully updated to match prescriptive requirements before publication of the standard. A review by the ECB subcommittee of Standard 90.1, after publication of the 2010 standard, identified 32 published addenda that were not accounted for in the performance methodologies[1]. These included such potentially impactful changes such as single-zone fan speed requirements, minimum skylight requirements and daylight dimming, exterior lighting control, and enhanced economizer requirements. These omissions create significant loopholes for projects using the performance approach in Standard 90.1.

Another problem occurs when, in the search for additional savings, prescriptive requirements become more complex. This is particularly problematic when a prescriptive requirement is not included in a proposed building design. Conventional and historical requirements such as wall insulation, lighting power, or heat recovery are straightforward. However, modeling some of the newer requirements has proven to be problematic. Defining the baseline building becomes a complex design problem, with many acceptable solutions. For example, Standard 90.1 now requires that large, high ceiling spaces have skylights and a daylight area equal to half the space area, with controls to automatically reduce electric lighting when daylight is available. There are many ways to meet these criteria, each providing potentially different levels of savings. Decisions need to be made regarding the size and layout of the skylights, the target illumination levels, the location of daylight sensors, and configuration of dimming controls. These are expensive exercises in design for a baseline building that will never be constructed. Other prescriptive requirements that are difficult to incorporate in the baseline building are building orientation, perimeter daylighting, and exterior shading.

2.2.6 Expected Savings May Not Be Realized

Projections of energy savings from codes are typically estimated by building energy modeling predicting the potential of the codes to save energy. These predictions assume the code is fully complied with, and that the operations and maintenance of building energy using systems are optimized, not only at occupancy, but throughout the life of the building. Studies have shown these assumptions may be overly optimistic (Turner and Frankel 2008). Figure 2.5 shows a comparison between modeled, predicted performance, and post occupancy energy use for a number of LEED-accredited buildings. The results show actual energy use varying between about 50% and 275% of predicted energy use. Stakeholders are demanding greater assurance of actual energy savings from codes than this data appears to support.

[1] Based on an internal review conducted by the ECB subcommittee.

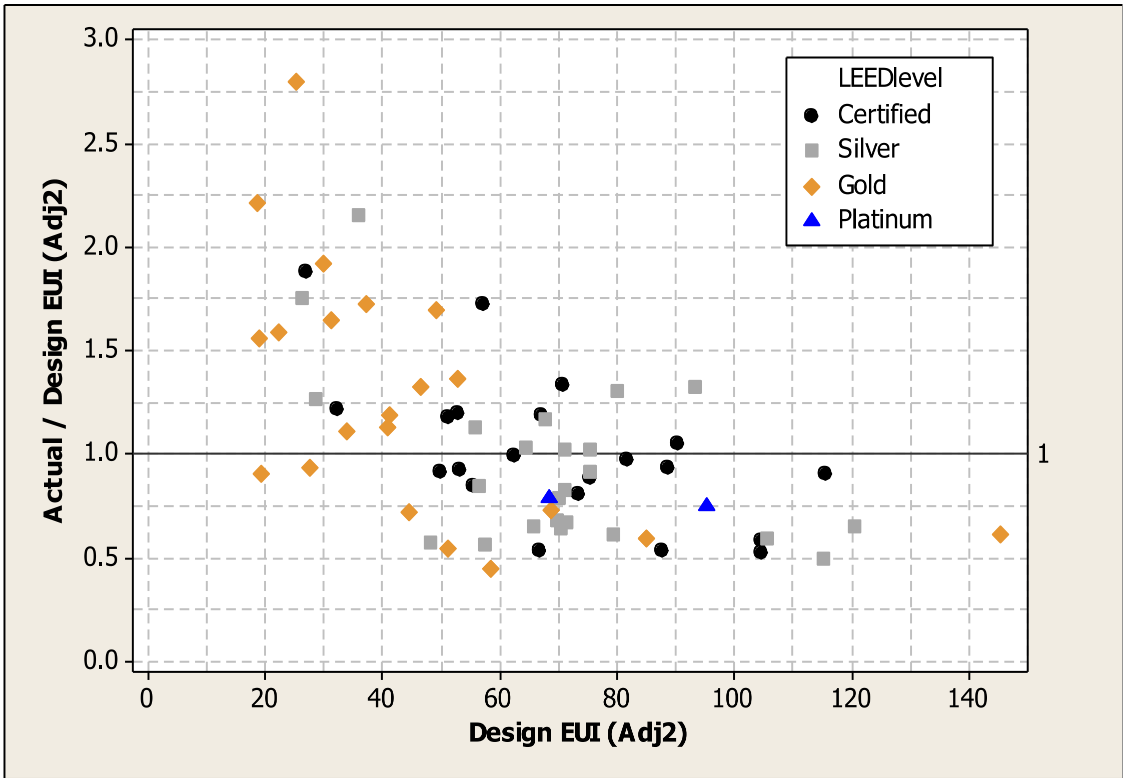

Figure 2.5. Predicted Performance Compareed to Actual Peforemance for LEED-Certified Buildings (Source: Turner and Frankel 2008. Used with permission.)

2.2.7 Unregulated Loads Ignored

Although energy codes are expanding the coverage of unregulated building loads, a problem still exists and solutions using the current approaches are unlikely. It is difficult to regulate plug loads (computers, printers, coffee pots, task lighting, etc.) retail displays, signage, commercial processes, and any unusual use of energy. As we reduce the energy use of those building loads that are regulated by codes, the portion of unregulated energy increases, and further reductions are harder to achieve. Figure 2.6 shows the portion of unregulated loads increasing from 21% of average new commercial building energy cost in 2004 to 29% in 2013 (Hart and Xie 2014). It is unlikely that prescriptive building design and construction codes alone will ever regulate all building energy use.

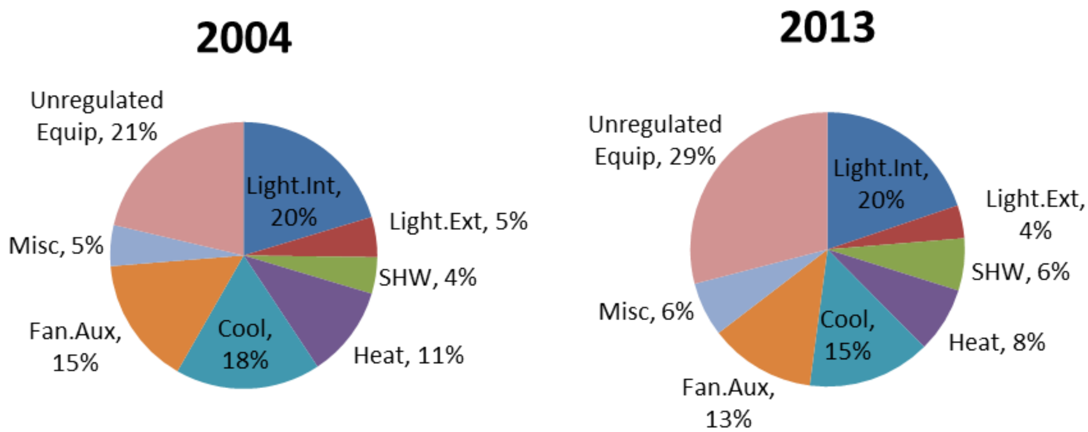

Figure 2.6. Nationally Weighted End Use Cost Breakdown for New Construction

2.2.8 Too Many Performance Approach Options

The two performance approaches in Standard 90.1 (discussed in Section 2.1) combined with the adoption and use of different versions has resulted in a multitude of building performance evaluation methods. One state's code references the 2001 version of ECB, three states reference the 2004 ECB, 27 states reference the 2007 ECB, and seven states references the 2010 ECB (DOE 2014). Each of the last three versions of the LEED rating system (two of which are still in effect) reference a different version of the PRM (USGBC 2005, 2009, 2014). The Federal Energy Management Program (FEMP) requires use of either the 2004, 2007, or the 2010 version of the PRM depending on the anticipated construction date (10 CFR 433). Table 2.3 summarizes the required performance methodologies for various codes and programs.

To make matters even more confusing, many of the codes or programs add their own modifications to the standards and modeling rules. For code compliance, Washington State and Florida use modified versions of the ECB (ICC 2011; WSEC 2012). ASHRAE Standard 189.1-2011 references Appendix G-2010 but adds three pages of modifications (ASHRAE 2011a). For federal tax incentives, the rules are really convoluted. The modeling must be completed in accordance with a mixture of the 2004 version of the PRM with some rules from the 2004 California Nonresidential Alternative Calculation Method Approval Manual, but the baseline building is defined by the prescriptive requirements of Standard 90.1-2001 (Deru 2007). Table 2.3 shows various uses for different vintages and modifications of the two performance paths in Standard 90.1.

By contrast, the test procedures for air conditioners, water heaters, boilers, and other equipment typically change very little as the standards for these equipment types become more stringent. Whole-building performance is far more complicated than that of individual pieces of equipment, yet we modify the whole-building test procedure almost continuously. This lack of standardization limits compliance software development and makes it very difficult for software developers and energy modelers to keep up with requirements. Software developers who want to automate the process of baseline-building creation have more than a dozen Standard 90.1 versions and performance options to deal with, making it cost-prohibitive to create software to serve all these purposes. This is probably one of the main reasons why the tools to implement the performance approaches of Standard 90.1 are so limited. Software developers are not the only members of the building industry burdened by these complex requirements. Building modelers and reviewers (code officials and program implementers) need to become experts on all the subtle differences of these approaches in order to judge compliance or award incentives. A single project that needs to achieve code compliance, LEED certification, utility incentives, and a federal tax incentive would need four separate baseline building models. For another perplexing example, envision a LEED project that demonstrates it is 30% better than Standard 90.1 using the PRM, but can't cite that as complying with the standard. It is difficult to explain these nuances to a building owner when trying to justify higher consulting fees.

Table 2.3. Applications of the Performance Methods in Standard 90.1

Use	Performance Method[a]
Energy Code Compliance for 1 State	2001 Energy Cost Budget
Energy Code Compliance for 3 States	2004 Energy Cost Budget
Energy Code Compliance for 27 States	2007 Energy Cost Budget
Energy Code Compliance for 7 States	2010 Energy Cost Budget
Florida Energy Code	2007 Energy Cost Budget (modified)
Washington State energy code	2010 Energy Cost Budget (modified)
LEED Version 2.2	2004 Performance Rating Method
LEED 2009	2007 Performance Rating Method
LEED Version 4	2010 Performance Rating Method
2012 International Green Construction Code	2010 Performance Rating Method (modified)
FEMP (Projects beginning before August 10, 2012)	2004 Performance Rating Method (modified)
FEMP (Projects beginning on or after August 10, 2012 before July 9, 2014)	2007 Performance Rating Method (modified)
FEMP (Projects beginning on or after July 9, 2014)	2010 Performance Rating Method (modified)
ASHRAE Standard 189.1-2009	2007 Performance Rating Method (modified)
ASHRAE Standard 189.1-2011	2010 Performance Rating Method (modified)
International Green Construction Code	2010 Performance Rating Method (modified)
Commercial Building Federal Tax Incentives	2004 Performance Rating Method (modified)

(a) States using the IECC can use Standard 90.1's ECB method as an option for compliance (ICC 2012, 2009, 2006).

3.0 Vision for a Future Commercial Building Energy Code

Effective building energy codes have many goals: comprehensiveness, flexibility, ease of administration, and high compliance rates all contribute to lower energy using buildings. Over the last several years, a number of papers and articles have been written discussing the limitations of current codes and a future vision for energy codes (Cohan et al. 2010; Eley et al. 2011; Denniston et al. 2011; CBC 2011; Rosenberg and Eley 2013). Interestingly, a number of commonalities are present in those visions:

- Future energy codes should ensure low performing design options are eliminated or balanced with high performing options.
- Energy codes should be developed with some level of overall building energy performance targeted.
- An energy code should consider the building as a system, accounting for building system and climate interactions.
- Energy codes based on performance (or predicted performance) should be supplemented by prescriptive compliance options where possible.
- The progress of energy codes should be measured on a fixed scale that can more easily track progress toward net zero energy buildings.
- The scope of energy codes should be expanded to cover post-occupancy energy use.
- Existing buildings need to be addressed by energy codes to ensure that, once constructed, buildings are maintained and operated efficiently.
- The scope of energy codes should be expanded to include those loads within a building that are not currently regulated such as cooking equipment, plug loads, industrial processes, computing equipment, etc.
- Buildings must be thoroughly tested and commissioned to ensure proper operation prior to occupancy.
- Enforcement and adoption should not be compromised as energy codes progress.
- Future codes should require or encourage on-site renewable energy to enable a path to zero net energy buildings.
- The progress of energy codes and building energy performance in general should be measured on a fixed scale that can more easily track progress toward zero net energy buildings.

3.1 Potential Solutions and Recommendations

One touchstone that can be applied in choosing from multiple code format options is that compliance paths for similar buildings should result in similar predicted maximum energy use. This is a shift from the current variation in energy use for prescriptive codes previously discussed. For example, if a lower performing HVAC system type is selected or WWR is increased, other high efficiency choices should make up the difference. If the goal is to achieve a standard of energy efficiency with energy codes, then multiple options in the code should provide a desired minimum energy performance level. Four potential solutions to the issues discussed above are reviewed here with pros and cons discussed:

1. Predictive performance with EUI targets
2. Differential predictive performance with a stable and independent baseline
3. Prescriptive packages
4. Outcome based codes

3.2 Predictive Performance with EUI Targets

One suggested approach to predictive performance code compliance is to establish fixed targets for energy use or energy cost based on building type, size, and climate zone instead of customizing the target based on specific building characteristics as is done with a reference building approach. EUI targets align well with management practices desiring clear and simple measurable goals. A model of the proposed design demonstrates that a building will use less energy than the target. In theory the approach has merit, but most previous attempts to use simple targets for commercial buildings have failed (Goldstein and Eley 2014). It is still too early to judge more recent attempts (CCBFC 2011; Wahlström 2010; SDPD 2012). Two major drawbacks to an EUI target approach are difficulty in setting an appropriate and fair target and difficulty in having a reliable prediction of building energy use.

Setting fair and appropriate targets can be a substantial challenge. EUI targets can be developed based on actual energy use of typical existing buildings or by using prototype building models normalized for climate. Unfortunately, few buildings are typical. Even simple buildings vary in function, number and frequency of occupants, plug and process loads, hours of operations, and other energy services. That makes fixed targets either too easy or too difficult to meet (Goldstein and Eley 2014). The difficulty in setting an EUI target can be demonstrated by simply viewing the wide range of energy results in any of the building energy datasets, even when adjustments are made for parameters like employees and operating hours (EPA 2012; LBNL 2014). True, those parameters can be modeled with standard assumptions—as is done in California’s Title 24 Alternate Compliance Methodology, but doing so negates one of the most important benefits of a performance based code—encouraging integrated design solutions that are customized for the actual loads and operation of the building. For example, a building with a very transient population might show the greatest benefit by investing in occupant based controls for HVAC and lighting. If that building is required to be simulated with fixed occupancy assumptions, the value of those controls will be severely underestimated, and savings from measures like reduced lighting power and energy recovery would over estimated.

Beyond setting the right target, there is substantial difficulty in having a reliable and accurate prediction, due to both the variation between modeling tools and difficulty controlling the many variables in a single model approach. An energy model is just a physics-based, simplified representation of an actual building. Some of those simplifications are determined by the software and some by the individual modeler. For example, how often are lights turned on and off manually in each space? Will the cleaning crew override sweep lighting controls for one hour, three hours, or all night? Will sleep modes on computers be implemented or overridden? How often will occupants open windows or raise or lower window shades? Each of these assumptions about how occupants use the building will affect the modeled energy use and thus compliance with the target.

It is well documented that different software programs can give widely different results when modeling the same building. A study for the California Energy Commission from Lawrence Berkeley National Laboratory comparing energy use of prototype building models used for California Title 24 development showed heating energy differences of over 100% and cooling energy differences of up to 20% for the same building when modeled in EnergyPlus and DOE2.1E (Huang et al. 2007). A study from Texas A&M University comparing the results of a house simulated in EnergyPlus and DOE2.1E showed EnergyPlus calculating as much as 25% higher cooling energy and 27% lower heating energy (Andolsun et al. 2010). This is for a home with relatively simple energy using systems, modeled by the same simulation team, trying to model the same house. Other studies have shown similar variations. ASHRAE Standard 140 (ASHRAE 2011b) provides a standard method of test for evaluating building energy simulation programs. A recent analysis by GARD Analytics for DOE used Standard 140 to compare results for 10 of the more commonly used simulation programs (Henninger and Witte 2013). There were significant differences found between the programs. Figure 3.1 shows the results on annual cooling load for high mass buildings with varying window configurations, temperature setback, and night ventilation. For example, there is more than a 50% difference in the annual cooling load for the south window case between TASE and DOE2.1e.

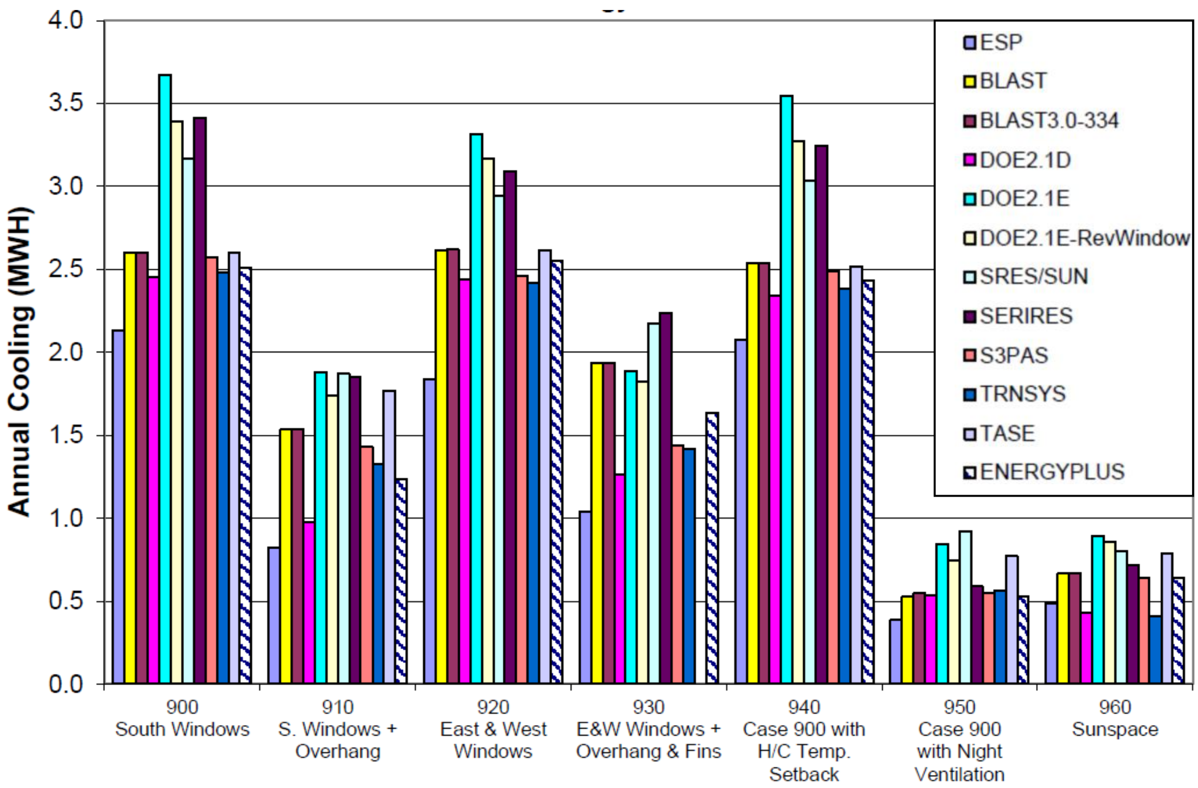

Figure 3.1. ASHRAE Standard 140 Comparison of High Mass Building Annual Cooling Loads (Source: Henninger and Witte 2013. Used with permission).

As far as the variables that go into any given building model, take the case of HVAC equipment performance curves. Even for a basic DX cooling coil simulation, as many as eight performance curves are required (Winkelmann et al. 1993). Not only is it extremely difficult to create those curves from manufacturer data, but often the detailed data needed is not readily available. Most simulation programs include default values for performance curves, but they differ from program to program, may be outdated, and can be overridden by the user. Small changes to these curves or many other simulation inputs can have a large influence on simulation results. When these types of changes are made in a single model that is compared with an EUI target, every model input must be scrutinized; otherwise, there will be wide variation in the predictions of the energy use of a particular building by multiple modelers. This is much less of an issue when a reference baseline is used or the model is calibrated to energy bills as discussed later.

With the single model vs. target approach, there is no true calibration, except as needed to meet the target. There are many "knobs" to turn in the model that really don't have a right or wrong value, yet each affects energy use. While a detailed modeling rule set can control many of the inputs, it is not practical to cover them all.

As discussed above, it is quite difficult to set a fair and appropriate EUI target and even more difficult to produce a consistent prediction of energy use for a particular building. Hence, the predictive performance with EUI target approach is not considered a good candidate as a code compliance method.

3.3 Differential Predictive Performance with a Stable and Independent Baseline

To avoid the issues raised previously regarding the problems of setting and maintaining a performance baseline that tracks the most recent prescriptive code, it is desirable to fix the baseline at some level of performance, and then apply a differential performance test as described previously. Improving the code then becomes simply a matter of incrementally increasing the differential in reference to that stable baseline. This approach is in development for Standard 90.1 as Addendum bm to Standard 90.1-2010 (Rosenberg and Eley 2013). In this approach, the rules for developing a baseline take prescriptive and mandatory requirements from the 2004 edition of Standard 90.1. Then significantly better performance is required for the proposed building.

There were two main reasons for settling on 2004 as the performance baseline. First, after 2004 the prescriptive requirements in Standard 90.1 started becoming too complex to develop clear rules that result in consistent modeling of the baseline (e.g., skylights and daylight dimming, as discussed previously). Second, the efficiency levels for lighting power and envelope components would make reasonable enhanced mandatory minimum requirements that can be used in conjunction with a performance or tradeoff path. Figure 3.2 shows how code and beyond code performance targets could progress toward and even beyond net zero energy buildings using a stable baseline approach.

An additional benefit of the stable baseline approach is that the same baseline and modeling rules can be used for both minimum code compliance and beyond code programs. The differential performance required is simply adjusted based on the purpose. Multiple uses for the same simulation ruleset make it more attractive for software developers to create reliable modeling tools with automated baselines. Consistent rulesets also increase the ability of building modeling professionals to produce consistent and comparable results. Such tools make the reference baseline predictive process much more reliable, less prone to gaming, and more likely to be acceptable to building officials.

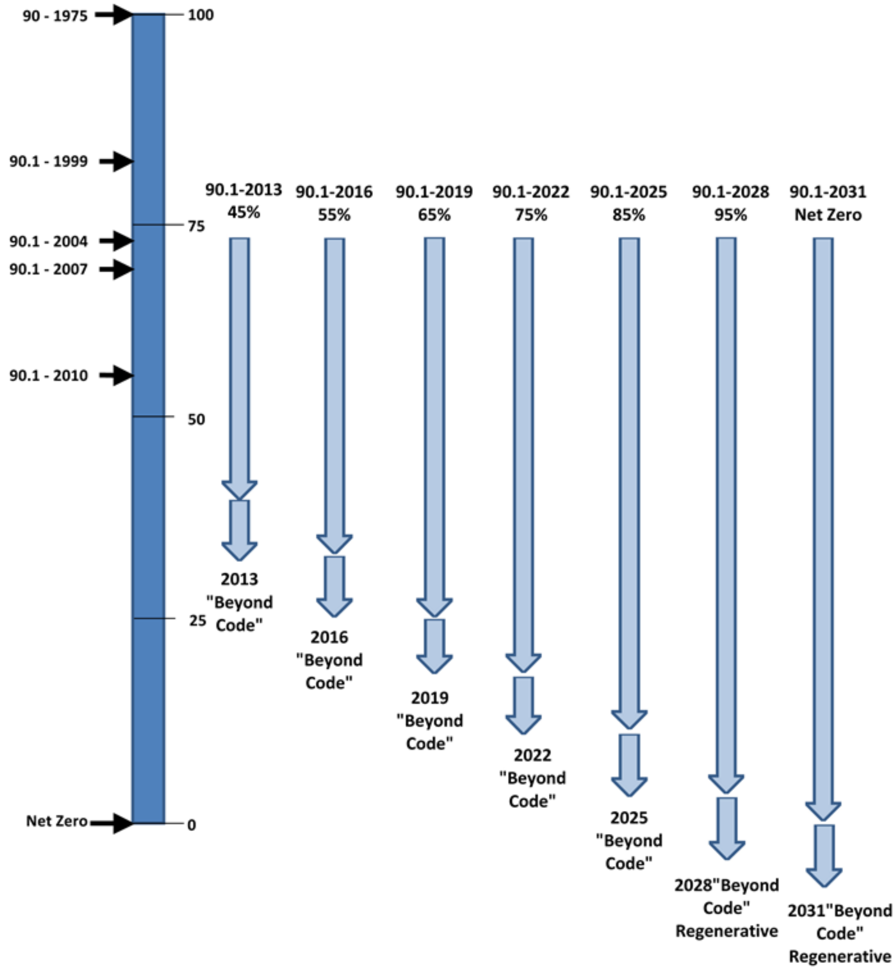

Figure 3.2. Example of a Path Forward for Standard 90.1 and "Beyond Code" Programs Following an Addendum bm Approach

Unlike the issues with a single model compared to an EUI target, having parallel baseline and proposed models is a great quality controller, avoiding the verification issues of a single model compared to an EUI target. With over a thousand inputs to an energy model, many of them critical, it requires a reference building comparison to reduce the inputs that need validation to a manageable level. When a proposed building is compared to a reference building, probably more than 80% of the inputs are neutral, e.g. they remain the same. The most important inputs are the remaining 20% that vary between the models. If one of the common inputs is wrong it likely won't affect the pass/fail outcome. One can compare files relatively easily to find and examine the changes made. Thus, quality control of accuracy can be achieved by focusing on a reasonable number of inputs.

The challenge with the differential performance approach with a stable baseline is in creating the appropriate differential target. The differential target can be established by comparing current prescriptive requirements to the stable baseline, but the range of prescriptive choices means the level of efficiency defined by the available prescriptive options varies considerably, as shown in Figure 2.4. Choices need to be made regarding which prescriptive options define the desired level of performance. What package of prescriptive options should define the target performance level? Fortunately, a working group of the

Standard 90.1 committee has selected from the prescriptive options what it considers typical good design practice for each of 16 prototype buildings used to track the progress of the standard (Thornton et al. 2011). For example, the large office building prototype in Chicago (climate zone 5A) includes 40% WWR, VAV HVAC systems, a water cooled chiller, natural gas boiler, and steel framed walls. The medium office building prototype, on the other hand, includes 35% WWR, packaged VAV HVAC units with DX cooling, and steel framed walls. The efficiency levels of all the building systems and components in these prototype designs meet the current prescriptive path, which has been developed using cost-effectiveness criteria. This enables those typical designs to be considered the “primary package” for creating cost-effective performance targets.

Comparing the primary package to the performance baseline defined in a performance ruleset can establish the differential performance target. Figure 3.3 identifies the ECI of the primary package from among the distribution of energy costs shown previously for several prescriptive options for a medium office building in climate zone 5A. Dividing the primary package ECI by the baseline package ECI provides a performance cost index target (PCI_t) for a medium office building in Climate Zone 5A. In this example, the baseline ECI is $1.235/ft^2-yr and the primary package ECI is $0.9177/ft^2-yr.

PCI_t = [Proposed Building Energy Cost] / [Baseline Building Energy Cost]

PCI_t = [$0.9177/ft^2-yr] / [$1.235/ft^2-yr]

$PCI_t = 0.743$

To summarize, the primary package is determined by the committee to include good design options from the prescriptive path. Then the primary package is compared to a baseline building determined from the rules of Appendix G. The differential performance from that comparison establishes the PCI target. If you now compare any proposed design to the Appendix G baseline design the resulting PCI needs to be less than the PCI target.

Any proposed medium office building design in climate zone 5A with a PCI less than or equal to 0.743 would comply. This PCI_t already normalized by climate zone and building type can then be further normalized for any specific building by the amount of unregulated loads in the building by creating a modified PCI_t for code compliance (as is done in Addendum bm). For beyond code programs that reward reductions in unregulated energy use (e.g., LEED), the PCI_t would not need to be modified. This means exactly the same procedure could be used to determine a buildings’ PCI for code and beyond code programs. Only the target changes. Another important benefit of this approach is that since unregulated loads are always included in the PCI calculation a building with a PCI of zero will truly be a net zero energy building.

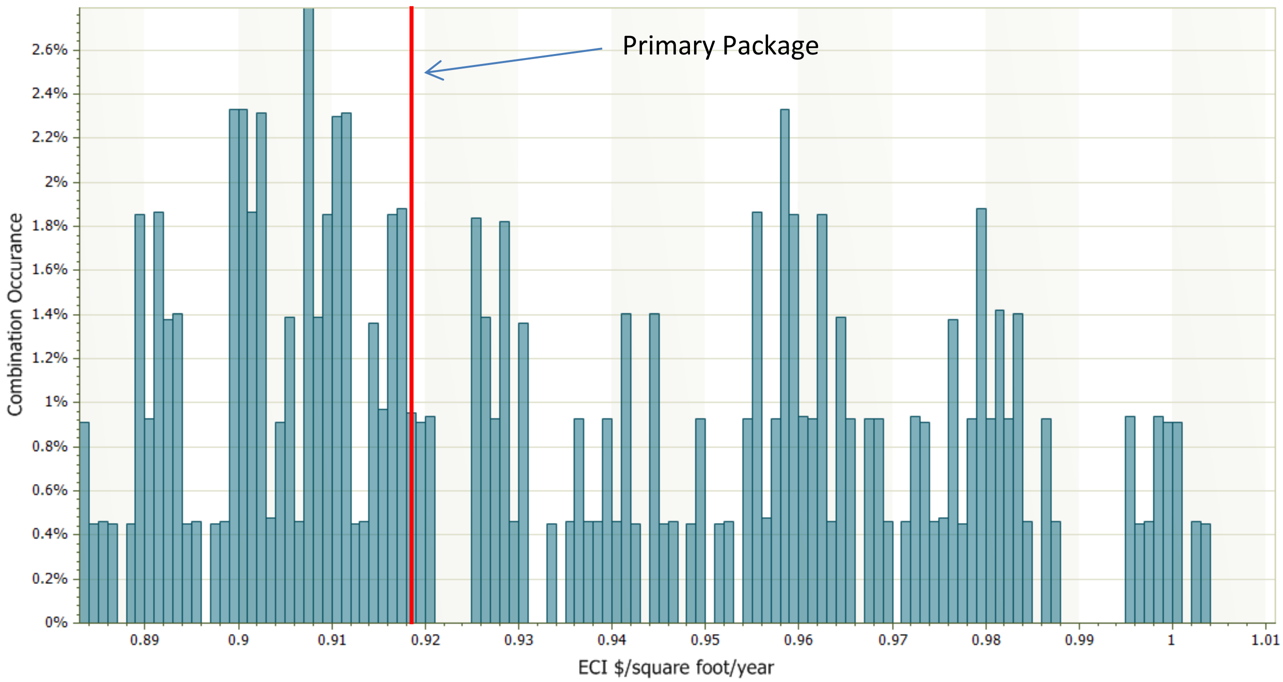

Figure 3.3. Primary Package Identified from within the Distribution of Energy Costs for Prescriptive Options for a Medium Office Building in Climate Zone 5A

In summary, a differential predictive approach with a stable and independent baseline allows a reliable comparison to a known baseline, normalizes the performance target to each specific building, enhances the ability to track improvement over time, requires that low efficiency prescriptive choices be offset with more efficient choices, rewards designers for optimization, paves the way for automated performance modeling, and markedly improves predictive accuracy.

3.4 Prescriptive Packages

Establishing a predictive performance goal ensures a minimum desired performance level, but there has also been a desire expressed to maintain prescriptive options for some buildings, particularly smaller or simpler buildings. Providing prescriptive options in the form of pre-defined packages provides turnkey solutions while maintaining the desired level of performance. In the prescriptive package approach, a building designer can choose from a number of packages or pre-selected combination options. While the long-term solution may be an automated stable and independent-baseline performance model that can be easily applied to any building, until there are simple and robust tools to demonstrate compliance by predictive performance, a good transition step can include prescriptive packages.

The same package of prescriptive options discussed above (primary package) that is used to create the performance target can establish the primary cost-effective, 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 and include a reasonable package for standard efficiency systems. There might be packages that allow a less efficient HVAC system type but have restrictions on other areas of the building, like envelope or lighting, to result in a similar desired energy performance level. Conversely, selection of a highly efficient HVAC system would allow more flexibility for other building components, such as a larger glazing area or increased lighting levels. Packages can be developed that capture the most common design choices. These additional packages along with the standard design package will be available for design teams without the need for modeling.

An important issue affects the development of prescriptive packages including products covered by federal efficiency regulations such as some boilers, furnaces, service water heaters, air conditioners, motors, transformers, and refrigeration equipment. EPCA requires that if the code establishes one or more optional combinations of items deemed to comply, for every combination that includes a covered product with efficiency in excess of federal requirements, an additional combination must be available that includes efficiency exceeding the federal level by no more than 5%. In addition, at least one combination must include covered product efficiency that does not exceed federal levels (42 U.S.C. 6297).

Once an initial set of prescriptive packages are developed, a process may be needed to add packages. The most likely candidates are the code development bodies themselves. Or perhaps, 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 could define a new prescriptive 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.

Until simplified and robust software is available so that any building can easily use a predictive performance approach, prescriptive packages can provide similar energy equivalency while keeping the code simple based on a selection matrix of prescriptive options. Table 3.1 shows an example of eleven prescriptive packages for a medium sized office building in climate zone 5A. Five of the packages include covered equipment with efficiencies in excess of the federal standard and six include efficiencies at the federal standard, meeting the EPCA requirements discussed above. Each of these packages ranges from 97% to 100% of the expected predicted energy cost of the primary prescriptive package. Further description of how prescriptive packages can be developed can be found in Appendix A. As prescriptive packages are added to the code, a number of different options are possible:

- Select a limited number of packages for each building type, included as tables in the main body of the code that cover the most common or desirable trade-offs. While this avoids an over-complicated impression of the packages and may be seen as more manageable by building officials, it does limit flexibility in package selection.
- Include a broader range of packages in a normative appendix referenced in the body of the code. This allows for more flexibility, although it should be noted that for the sample analysis performed for one building type (medium office building) in one climate zone (5A), 8,944 combinations of the 9 options included in the analysis were within 97% to 100% energy cost of the primary package. It is easy to see how this could quickly expand beyond the capability of a printed document when packages are created for a variety of building types and multiple climate zones.
- Develop an electronic database of combination options, to allow the highest flexibility to the developer or designer in selecting packages. This approach would be more appropriate with an electronic delivery of the code itself, and would require integration with automated electronic checklists to make inspection and compliance more streamlined.

Table 3.1. Sample Prescriptive Packages for Medium Office Building 5,000 to 50,000 ft^2 in Climate Zone 5A

Prescriptive Package Path Method for Office buildings from 5,000 to 50,000 square feet

Compliance with the Prescriptive 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 must be met.
2. All prescriptive requirements not covered below must comply with Sections 5 to 10 of Standard 90.1.
3. HVAC systems shall 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	HVAC System	Heating Source	Heating Source Efficiency[1.]	Min Cooling Source Efficiency[2.]	Max Window Wall Ratio	Opaque Construction U-Value[3.]	Fenestration U-Value[3.]	Fenestration SHGC[3.]	Maximum Fan Brake HP (each system)[4.]	Max Interior LPD (W/ft^2)	Minimum Daylight Area[5]	Minimum Occupancy Sensor Coverage Area
Package 1 (Primary)	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	33%	100%	100%	100%	100%	0.82	21%	53%
Package 2	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**50%**	100%	100%	100%	100%	0.82	**41%**	53%
Package 3	MZ VAV w/ hydronic Reheat	NG Boiler	**120%**	**115%**	**50%**	**125%**	**125%**	100%	100%	0.82	21%	53%
Package 4	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**40%**	**108%**	**108%**	100%	100%	**1.00**	21%	**91%**
Package 5	MZ VAV w/ hydronic Reheat	NG Boiler	**110%**	**110%**	33%	100%	100%	100%	**135%**	0.82	21%	53%
Package 6	MZ VAV w/ hydronic Reheat	NG Boiler	100%	100%	**40%**	**150%**	**150%**	100%	100%	0.82	21%	**91%**
Package 7	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**120%**	**40%**	**108%**	**108%**	100%	100%	**0.66**	21%	**91%**
Package 8	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	100%	**40%**	**83%**	**83%**	100%	100%	0.82	**41%**	**91%**
Package 9	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**115%**	**25%**	**67%**	**67%**	100%	**80%**	**1.00**	21%	**91%**
Package 10	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	**115%**	33%	100%	100%	100%	**135%**	0.82	**41%**	**91%**
Package 11	**MZ VAV w/ Electric Reheat**	**Central Gas Furnace w/ Electric Reheat**	100%	100%	**25%**	**108%**	**108%**	100%	100%	0.82	**41%**	**91%**

1. % of required heating efficiency in Table 6.8.1-6 of Standard 90.1
2. % of EER required efficiency in Table 6.8.1-1 of Standard 90.1
3. % of U-value required in Table 5.5-5 of Standard 90.1
4. % of fan BHP calculated according to 6.5.3.11 Option 2 of Standard 90.1
5. Daylight areas must include controls per Section 9.4.1.1.e and f of Standard 90.1
6. Values in bold differ from the primary package.

3.5 Outcome Based Codes

Outcome based codes provide the ultimate in confirmed energy performance. The actual energy use of the building is compared to the desired target. There is no question that benchmarking actual building energy use is a vital part of any energy management program and could become an extension of building energy codes. Studies have shown that buildings don't always achieve the results predicted by simulation (Turner and Frankel 2008), and measurement is necessary to take corrective action and demonstrate movement toward an energy goal. A major benefit of an outcome based code is that it considers all energy used by a building. Controlling the energy use of unregulated loads cannot simply be ignored. However, is an outcome based approach a valid replacement for a building design and construction energy code? Four issues stand in the way: timing, scope, appropriate targets, and impact of the energy service level.

Design and construction codes have their lever in the occupancy permit, and waiting until the performance is proven more than a year later can create issues for an outcome based code applied to new buildings. These issues may be resolved with performance bonds, punitive utility rates, or other performance insurance mechanisms, but no matter what the penalty, failure to meet the code results in a non-efficient building being added to the building stock.

An appropriate target is an issue, just as for the predictive performance EUI target approach, although for a building with measured energy use, a recently proposed methodology would allow creation of a more valid energy target by comparing post-occupancy building energy use to simulated energy performance calibrated for actual operating conditions (Goldstein and Eley 2014). This approach may prove to be a valuable way to create a customized target for an outcome based code.

If a building is not designed and constructed to minimize energy use, but must only comply with an outcome based approach, there may be undesired consequences. If the enforcement penalties are severe enough, building owners may be forced to reduce services (e.g., hours of operation) or amenities (e.g., appropriate lighting levels or ventilation control) to comply. This is surely not a desired outcome.

As discussed previously, outcome based codes would require substantial new enforcement paradigms and infrastructures. The necessity of post-occupancy evaluations, uncertainties related to occupants and their habits, and the potential requirement for corrective post-occupancy reconstructions makes this option difficult to envision in the near term for private sector buildings. Despite these hurdles, a great deal of work has been occurring to advance the prospects of outcome based codes. The New Buildings Institute (NBI) and the National Institute of Building Science (NIBS) have taken the lead in garnering support to advance outcome based codes. Those organizations recently held a summit in Seattle, bringing together experts and key stakeholders to help chart the course forward, which should be documented in an upcoming report.[1]

There is no reason why an outcome based code should apply only to newly occupied buildings. Future efforts in this area could focus on energy use requirements for all existing buildings, and be combined with a building design and construction code to ensure the building begins its life with the greatest possible potential for performing at low energy levels and continues to do so throughout its

[1] http://newbuildings.org/outcome-based-performance-summit

existence. The possible beginning of this approach is being seen with the development of operational rating systems and building energy disclosure laws.[1]

Therefore, while an outcome based code would be a valuable expansion of energy efficiency regulation for all buildings, it should not be a replacement for a design and construction energy code. Instead, an outcome based code should be coupled with a design and construction code, focused on the efficiency of the building infrastructure to ensure building energy use is minimized during the building life cycle.

3.6 Summary of Recommendations

Table 3.2 summarizes the various approaches for future codes considered here. It demonstrates that the predictive performance approach with a differential from a stable and independent baseline has the most beneficial qualities for a building design and construction code. It also indicates that a combination of approaches may be the best way to achieve the desired outcomes identified at the beginning of Section 3.0. Recommended options are shaded in green.

Table 3.2. Strengths of Potential Code Options

		Strengths of Approach						
Code Approach	Examples	Ensures energy efficient design and construction	Accounts for bldg. specific operation & service requirements	Promotes optimized design	Promotes energy equivalency	Simplicity; compliance & enforcement	Design Flexibility	Compliance enforced during occupancy for persistent savings
Prescriptive Options:								
Prescriptive (with System Tradeoffs)	90.1; IECC; T24	No	No	No	No	Yes	Some	No
Prescriptive Packages	Res. Envelope T24	Yes	No	Yes	Yes	Yes	More	No
Predictive Performance Options:								
Equivalent to Current Dependent Baseline	90.1 Chapter 11	No	Yes	No	No	No	Yes	No
Differential to Current Dependent Baseline	2012 IECC Performance	No	Yes	No	No	No	Yes	No
Equivalent to Current Independent Baseline	CA Title 24-2013	Yes	Yes	Yes	Yes	No	Yes	No
Differential to Current Independent Baseline	90.1 Appendix. G; LEED; 189.1	Yes	Yes	Yes	Yes	No	Yes	No
Differential to Stable Independent Baseline	90.1 Addendum bm	Yes	Yes	Yes	Yes	Yes[(c)]	Yes	No
Equivalent to EUI Target	Canada Energy Code	No	Might	Yes	Yes[(b)]	No	Yes	No
Outcome Performance Options:								
Outcome Based Code; EUI Target	Seattle; Sweden	No	No	No	Yes[(b)]	Yes	Yes	Yes
Outcome Based Code; Differential to Stable Independent Baseline Prediction[(a)]	No current example	No	Yes	Yes	Yes	Yes	Yes	Yes

(a) Outcome with predictive model could have other baselines with similar strengths as the predictive performance options.
(b) EUI targets make it difficult to fairly account for differences in building services and operation.
(c) Independent modeled performance with a stable baseline is more likely to encourage automated and integrated compliance software with detailed checklists.

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[1] Currently, two states, ten major cities and one county in the US have enacted building disclosure laws. http://www.imt.org/policy/building-energy-performance-policy

To ensure efficient building design and construction, a differential predictive performance method with a stable and independent baseline is recommended as the cornerstone of future commercial codes. To provide turn-key solutions for simpler buildings and for instances when modeling is neither desired nor needed, the performance method should be supplemented by prescriptive packages. To ensure reliable post-occupancy energy savings, outcome based codes for all existing buildings are recommended.

3.7 Other Considerations

Many other considerations are important for effective energy codes. At a minimum, these include more widespread adoption of model codes, improving compliance rates, appropriate commissioning or acceptance testing of installed equipment and systems, expanding code scope to cover currently unregulated building energy uses, more in-depth modeling rules for performance paths, accredited modeling professionals, and the development of automated software to allow easier compliance with a performance path. While detailed discussion of these important items is beyond the scope of this paper, they are briefly described below.

3.7.1 Performance Metric

An important decision is what metric to use for building performance. There are a number of options including site energy use, source energy use, energy cost, and greenhouse gas emissions. In the past, it has been challenging to reach consensus on this question due to long-standing disagreements between the natural gas and electric industries. At this time, the public process used to develop model codes has embraced energy cost as the preferred metric.

3.7.2 Cost-effectiveness

Energy code requirements are expected to be cost-effective. Ideally, the set of packages for a particular building type should include several packages that are cost-effective overall. That does not mean that all packages should be required to be cost-effective. For example, a package that allows 50% glazing area (above the 40% prescriptive limit), but requires a higher-cost high-efficiency HVAC system and added opaque wall insulation, is a viable option for a building with a larger glazing area, even if the incremental cost of high efficiency options is not cost-effective. As long as there are reasonable paths through the code that are cost-effective, the code as a whole should be deemed cost-effective.

Many in the building and energy policy sectors subscribe to the goal of net zero building energy use; however, baring a significant drop in the price of renewable energy generation or some unforeseen improvement in building system technology, it is unlikely that a broad range of net zero buildings can be constructed and still meet current cost-effectiveness criteria. A major reason for this is that the current approaches to cost-effectiveness have not considered environmental externalities or non-energy benefits such as green market value. It may not be possible to achieve significant further reductions in energy codes—eventually reaching net zero—if these factors are not brought into the cost effectiveness equation.

3.7.3 Impact of Measure Life on Performance Trade-offs

A valid concern that has been expressed about trade-offs is that a shorter-life high-efficiency item could be traded for a reduction in efficiency of a long-life item. An example is a condensing furnace or advanced lighting controls traded for lesser wall insulation. One fact ignored by the concern is that when shorter-life equipment is replaced in the future, efficiency standards are likely to be higher, so the impact would not be as great as a replacement with today's lowest efficiency equipment. However, it is possible that some equipment (for example advanced lighting controls) may not be replaced at all at the end of its useful life. Allowing trade-offs has benefit for design, and as long as trade-offs are subject to enhanced mandatory standards as discussed below, the benefit is likely to outweigh disadvantages.

3.7.4 Enhanced Mandatory Requirements

Enhanced mandatory requirements are desirable for performance trade-offs or outcome based codes, because, while tradeoffs make sense based on energy equivalency, allowing any trade-off can have unintended consequences. For example, tradeoffs could be made that would result in an equivalent energy use with single pane glazing; however, there are impacts on comfort from single pane glazing that would likely result in the space temperature setpoint being increased during the heating season under actual operation. Mandatory standards are more important with a defined (independent) performance baseline that expands the range of design options that are available for trade-off credit. An example of an enhanced mandatory requirement might be requiring that insulation levels not be traded off below the baseline level for the performance path. While the earlier code level would not match the current requirements, it provides a reasonable backstop that is already defined in the performance approach.

3.7.5 Compliance

Updates to the energy code need to consider the impact on compliance. A more performance-based code could negatively impact compliance verification if it is left to a code official to have to verify modeling. Code officials don't usually possess this level of expertise and it is not likely that they will attain it. Better solutions could include either approved software that automates the process of creating a baseline building, or third party expert verification. Again, focusing on a stable differential and independent baseline for the performance path allows for investment in development of long-term code compliance software based on a predictive performance approach. As that software is developed, it will be possible to incorporate code compliance checklists that are automatically generated in the performance compliance process.

Once there is more confidence in the accuracy of the simulation, the process of plan review and inspection should not be much more complicated than for prescriptive requirements. After all, each building that pursues a performance path will in effect define a specific set of prescriptive values applicable to the candidate building. The code official performs review for those prescriptive values, the same as they do currently, just using a software generated list that will vary more from project to project. This process could be greatly improved in both the current and proposed scenarios by requiring energy code compliance experts to perform plan review and inspections. These experts could be building officials who focus on energy code compliance or an approved third party. Either scenario would be a vast improvement over today's approaches, which generally rely on a building official whose main priorities are life safety issues while compliance with the energy code is often an afterthought that they are not adequately prepared for or given proper resources to complete.

3.7.6 Building Alterations

While the approaches laid out in this report work well for new construction, it is a different story for minor alterations and retrofits. Replacement of worn out equipment, energy related changes associated with cosmetic improvements, lighting upgrades, and other renovation or alteration work will require that some prescriptive component requirements remain in the code. Prescriptive requirements for alterations and renovations can be separately addressed in a section of the code that clarifies what is required for these situations that are different from new construction.

3.8 Conclusions

For commercial building energy codes to continue to progress as they have over the last 40 years, the next generation of building codes will need to provide a path that is led by energy performance, ensuring a measurable trajectory toward net zero energy buildings.

Predictive performance with EUI targets falls short as a code mechanism, and outcome based codes—while an essential approach that should be applied to all buildings—are not a substitute for design and construction energy codes that focus on compliance at occupancy. For a design and construction code, a differential predictive performance method with a stable and independent baseline provides the best accuracy and potential for a highly automated approach that could eventually be applied to most buildings. At some point in the future, tools that demonstrate predictive performance compliance may become so simple that a prescriptive path is no longer needed. As a bridge, prescriptive packages can provide a transition from the current component prescriptive approach, while providing flexibility and improved energy equivalency

4.0 Path Forward

If the code is to transition to achieve the recommendations in Section 3.6, many activities will need to occur. This section discusses those activities, provides a potential time-frame for their implementation, and identifies current or potential champions of each activity when known. Appendix B presents a series of logic model diagrams identifying the needed activities, interdependencies, barriers to implementation, impacted stakeholders and final outcomes. While the logic models attempt to outline a broad range of code activities, the core of code transformation activities require development of the performance path. Figure 4.1 shows an excerpt of the performance path logic model, with core activities in dark green.

4.1 Short-Term Activities (2014-2016)

A list of short-term activities needed to move the proposed roadmap forward follows, with potential actors for the different activities identified. PNNL's involvement is specifically identified.

- **Refine predictive performance based code option with a stable and independent baseline.** This activity is currently underway, being advanced by PNNL as Addendum bm to Standard 90.1 through the ASHRAE process. Once accepted into Standard 90.1 this approach will need to be proposed to other codes and beyond code programs. PNNL should take the lead on this activity.
- **Expand the scope of regulated energy use covered by codes.** This activity has been ongoing since the expansion of the scope of Standard 90.1 in 2010 allowing the regulation of commercial and industrial processes. Immediately after that change, computer room air conditioning, elevators, and refrigeration were regulated, but other processes have been slow to follow. PNNL and others could accelerate activity in this area, but there is no specific champion.
- **Develop sample prescriptive packages.** PNNL has developed a set of sample prescriptive packages for medium office buildings in climate zone 5A. The process used to create the packages and the packages themselves are presented in Appendix A. One potential approach is to try to get the sample packages accepted into Standard 90.1 as an equivalent alternative.
- **Develop increased mandatory minimums for performance based code.** Addendum bm includes increased mandatory minimums for lighting power allowances set approximately equal to those required by the 2004 edition of Standard 90.1. Enhanced envelope requirements also set at 2004 levels were also included in the original version of Addendum bm, but were removed during the process of establishing consensus. Consensus on enhanced envelope requirements at some reduced level of stringency may be achievable. This should be pursued by PNNL.
- **Develop software and modeler acceptance criteria for performance codes to help ensure accuracy.** Currently most predictive performance based codes require testing with ASHRAE Standard 140. However, none of those codes has set acceptance criteria; testing alone is all that is required. A proposal was presented to SSPC 90.1 to require credentialed modeling professionals for performance based compliance, but that was not accepted. The Commercial Buildings Energy Modeling Guidelines and Procedures (COMnet) has established acceptance testing for simulation software used for code compliance. PNNL participates in the COMnet advisory group, and DOE should explore ways to support the acceptance of COMnet or similar protocols.
- **Continue to enhance prescriptive requirements where necessary**. This is being done via SSPC 90.1, the IECC, and various state codes. In addition to PNNL, various other organizations are

championing this effort, including regional energy organizations, advocates, design professionals, code officials, and manufacturers.

- **Review Code Cost-Effectiveness Policies.** A clear barrier to attaining net zero buildings is the limitation of current cost-effectiveness policies. A review of cost-effectiveness policies to determine what options exist for inclusion of factors like environmental externalities and non-energy benefits such as productivity improvements and green market value should be pursued. This can be followed by an analysis of what level of efficiency can be achieved under which policies. Such a survey and analysis would help policy makers choose appropriate cost-effectiveness approaches for both advanced codes and minimum codes. PNNL is equipped to conduct such a survey and perform the analysis, but this work is currently not scoped.
- **Gain acceptance of performance based ruleset with a stable and independent baseline for various codes and beyond code programs**. It was anticipated that PNNL would already have begun this process, but with the delay in acceptance of Addendum bm, this may be pushed to mid-term. PNNL should champion this activity.
- **Initiate meaningful commissioning requirements in Standard 90.1**. Meaningful commissioning requirements have been implemented in the IECC and various state codes and beyond code programs. Standard 90.1 continues to lag behind in this respect. The mechanical subcommittee of SSPC 90.1 recently agreed to PNNL's request to establish a commissioning technical working group to consider the options and develop a proposal.
- **Develop 2016 new building performance targets**. This has been done and included in Addendum bm, but will be re-examined near the end of the Standard 90.1-2016 development cycle. PNNL will provide the target updates near the end of the 2016 cycle.
- **Create more robust and defined modeling ruleset**. There are two related activities occurring in this area. Both COMnet and PNNL are creating detailed modeling rulesets meant to be implemented in automated compliance simulation software. PNNL participates in the COMnet advisory group, and DOE should explore ways to support the acceptance of COMnet or similar protocols.
- **Plan needed infrastructure for existing building/outcome based code.** NBI (with assistance from NIBS) has taken the lead on advancing outcome based codes. They have introduced an optional outcome based path in the IgCC that is likely to be approved. They have also hosted brainstorming sessions with stakeholders to help develop a path forward. They will be issuing a report on future activities they will undertake to advance outcome based codes.

4.2 Mid-Term Activities (2019-2022)

A continuation set of activities into the mid-term time frame is identified below, with potential actors for the different activities identified. PNNL's involvement is specifically identified.

- **Update the standard design packages and 2019 performance target**. As the code progresses, each cycle will require an update to the standard design package for each building type and climate zone from which performance targets are derived. This is expected to become a major activity of SSPC 90.1, with assistance from PNNL.
- **Establish a more independent baseline.** The current Addendum bm performance approach is not completely independent in that baseline design is still dependent on the proposed building shape,

zoning, and number of stories. Modifications to the simulation ruleset and software that automates the creation of the baseline will be required. Further, the performance path in Chapter 11 has a highly dependent baseline. Once Appendix G, as amended by Addendum bm, is accepted as a valid performance path, phasing out the Chapter 11 path will improve the independence of the performance approach. Similar activity will be needed for the IECC. This activity should be completed by SSPC 90.1 with assistance from PNNL.

- **Expand code training for code officials and designers.** Expanding current code training to emphasize performance based codes will make those methods more reliable in producing equivalent buildings. Such a training program should be developed in conjunction with development of improved and automated performance based analysis software. Modeling training is available, but most of it does not focus on the subtleties of performance based code analysis.
- **Incorporate requirements for renewable energy sources**. As renewable energy sources become cost-effective, they should be incorporated into the standard design package from which performance targets are derived. It is unlikely that the PNNL codes program can influence cost-effectiveness of renewables, but it can introduce code requirements when cost-effective.
- **Expand the scope of regulated energy use covered by codes.** Build on short-term activities in this area. PNNL and others should accelerate activity in this area.
- **Expand meaningful commissioning requirements in 90.1.** Build on short-term activities in this area. PNNL and SSPC 90.1 should continue this activity.
- **Complete the prescriptive packages for all appropriate building types**. Following the approach used for creating sample packages, expand the effort to cover most buildings and all climate zones. It is likely that these packages will only be applicable to a subset of the more simple building types (e.g., small to medium offices, retail, fast food, warehouse), but that would cover most construction activity. Performance based modeling is likely to be more appropriate for complex buildings. PNNL has established a methodology to develop these packages and has the computing infrastructure to develop them. Or perhaps another model will take shape where vested interests provide packages that are then vetted and approved by code bodies. Additional resources should be allocated to expand the sample to the additional building prototypes and climate zones.
- **Develop methodology for existing building (outcome based) code targets.** This is a complex task that will balance stringency and applicability for a range of buildings. An alternative would be to create custom targets for each individual building that are dynamic over the building's life. Significant thought is needed in this area. PNNL should explore options for outcome based codes in future work.
- **Begin to establish infrastructure for existing building (outcome based) code**. Based on lessons learned from optional implementation of outcome based codes, establish the needed infrastructure and support to enable outcome based code to apply to all existing buildings. NBI is likely to continue efforts in this area, but additional supporters are needed for this fundamental change, which may require legislative action. If this is to move forward, a detailed action plan is likely needed.
- **Enhance Cost-Effectiveness Methods.** Based on the earlier review of cost-effectiveness policies, develop methods that include factors like environmental externalities and other non-energy benefits. PNNL currently develops the DOE cost-effectiveness methodology for codes and is

equipped to develop such methods and work with code development bodies for both minimum and advanced codes to adopt appropriate levels of cost-effectiveness criteria.

- **Create automated software for implementing updated performance approach**. PNNL has already begun this activity for the 2010 version of Appendix G and is likely to continue as Appendix G becomes approved for code compliance. Others including the California Energy Commission, Florida Solar Energy Center, and Bentley Systems have pursued similar approaches and are likely to continue.
- **Require third party code enforcement or dedicated Building Official.** Most knowledgeable observers continue to believe that commercial code compliance is poor at worst and enforced sporadically at best. Recent audits by New York City indicated that 90% of building plans examined failed to meet the energy code (Anuta 2014). Like existing building energy codes, this enforcement infrastructure change may require legislation. If this is to move forward, a detailed action plan is likely needed.

4.3 Long-Term Activities (2025-2030)

A final set of activities needed to achieve the vision is identified below, with potential actors for the different activities identified. PNNL's involvement is specifically identified.

- **Update standard design package and performance targets.** Continue previous efforts in this area. The ultimate goal is a net zero energy target, so provisions for renewable energy will be needed. Many organizations have targeted the year 2030 for this goal.
- **Enhance automated software for simple buildings**. Continue development of automated performance software, so that simpler buildings can develop an easy path toward flexible performance selection. Include integration with code inspection and compliance activities. PNNL is involved in development of compliance software (COMcheck) and anticipates that it can be integrated with flexible performance software. Other makers of performance software will likely participate.
- **Remove current component prescriptive approach from code**. Once new performance and package approaches are operational and field tested, remove current component prescriptive approach from code to ensure performance targets are met. PNNL can propose changes, but support will be needed from those voting on code changes.
- **Include all loads in regulated energy use**. As more unregulated loads are brought under the purview of the energy codes those remaining will be offset by renewable energy. PNNL can propose changes, but support will be needed from those voting on code changes.
- **Establish outcome based codes for all existing buildings**. This will likely require legislative action. Current activities in mandatory building benchmarking may set the stage for future outcome based codes.

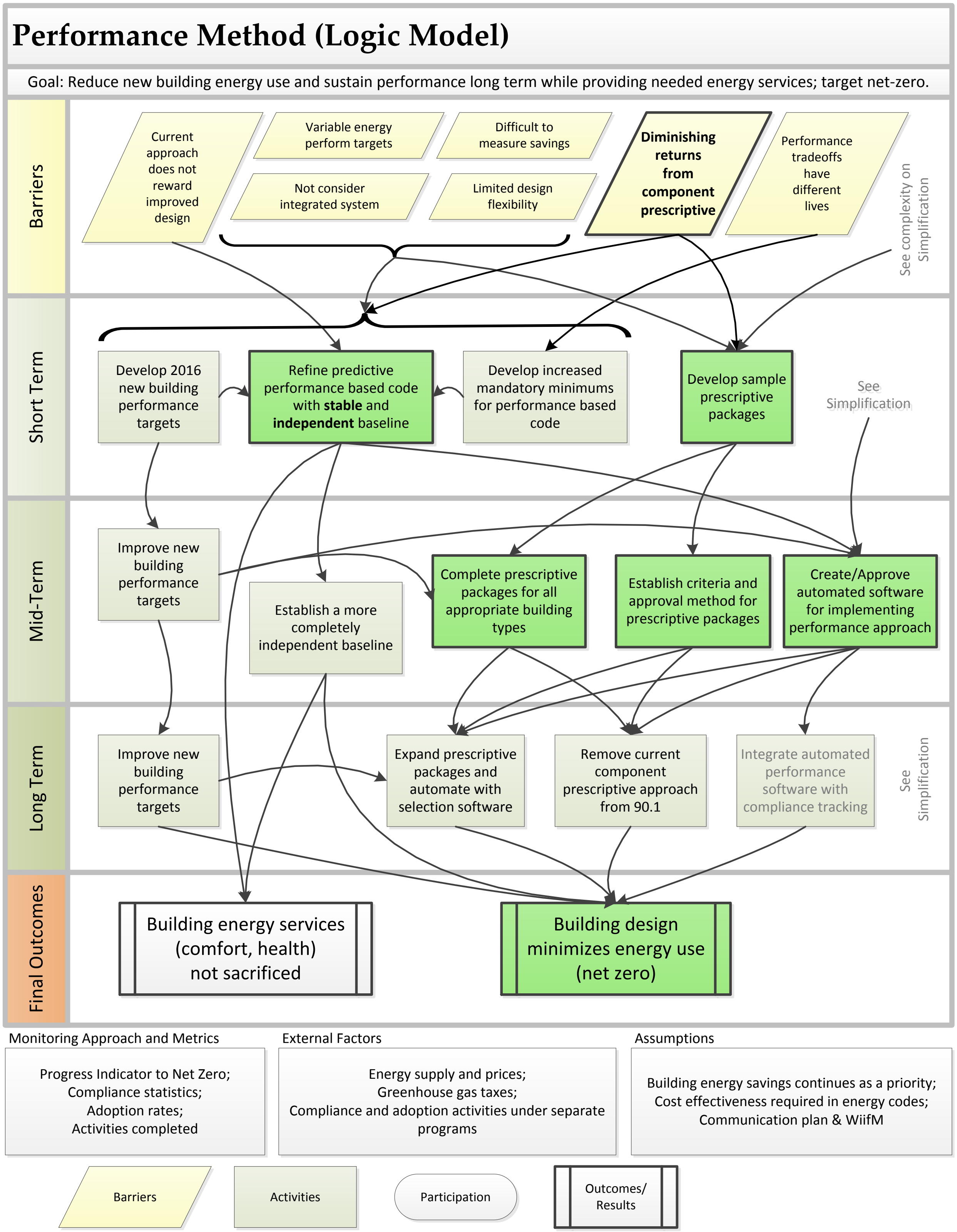

Figure 4.1. Core of Activities in Performance Path Development

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Appendix A

Development of Prescriptive Packages

Appendix A

Development of Sample Prescriptive Packages

The basic concept of prescriptive packages is to follow the guiding principles in the performance path without requiring a customized simulation model of each building. Prescriptive packages are envisioned for simpler buildings. Complex buildings such as hospitals or laboratories are not likely to fit the package approach due to complexity and variation from one building to the next. For small- to medium-sized buildings without a high degree of complexity, the prototype buildings are expected to be representative of the energy use; therefore, a generic set of prescriptive items can be packaged together so that the subject building's energy use will match or be less than the energy use of a primary package equipped building. A primary package for each of 16 prototype buildings has been selected by a working group of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 committee and has been used as the basis to track the progress of the standard (Thornton et al. 2011). These requirements have been selected as representative of reasonable prescriptive options with a good level of energy performance. At an outline level, the sample package development process used by Pacific Northwest National Laboratory (PNNL) for the mid-sized office building described in Section 3.4 and below followed these steps:

- Identify prescriptive options that affect energy cost and are commonly desired alternatives to the options in the primary package.
- Identify levels of efficiency or energy cost impact for those options, both above- and below-code levels (although mandatory requirements such as equipment efficiencies governed by preemption do not allow a below-code level).
- Complete a limited set of building model simulations for a prototype building, covering a range of levels for the variable options to capture multiple interactive situations.
- Use the results of these runs to develop regressions where the option values are independent variables and gas and electric use and cost are dependent variables.
- Use the regressions in a decision analysis program that allow calculation of all possible combinations of different discrete levels of options, including intermediate values that were not included in the original runs. This approach is much more efficient than completing full simulation runs for all alternatives.
- Use the endpoint results to generate an energy cost index (ECI) for all the combinations from the electric and gas regression results. Compare these to the primary package to determine a percentage of primary ECI.
- Review the results to select packages that have an ECI below 100% of the primary package, but are close to the primary package ECI, and that have tradeoff items attractive to developers and designers.
- For validation, re-run the selected packages with the EnergyPlus simulation model to obtain final results. The final results were all within ±2% of total energy cost of the regression results.

A.1.1 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 package users. Ease of modeling was considered as well. For this sample, two heating, ventilation, and air-conditioning (HVAC) systems were selected; additional system types could be necessary for final package development. For each option, a range of values was selected for the initial simulations, representing low-energy, code-level energy, and high-energy cost. The options and their relation to code are shown in Table A.1. Each variable option is assigned a variable abbreviation used throughout the discussion, and many are established relative to a particular edition of Standard 90.1.

Table A.1. Variable Options for Package Development

Variable Option	Primary Package (Typical)	Low Energy Impact	High Energy Impact
HVAC system type	Packaged direct expansion (DX) with variable air volume (VAV) and hydronic reheat with dual max 20% box minimum damper position	Packaged DX with VAV and electric reheat with parallel fan powered terminal unit, 30% minimum damper position	N/A
Boiler thermal efficiency (Et)	90.1-2013 requirement (2013 dependent on size)	N/A	Condensing (93%) only run with hydronic reheat
Cooling energy efficiency ratio (EER)	90.1-2013 requirement	N/A	90.1-2013 efficiency + 10%
Fan power; total static pressure (TSP)	90.1-2013 requirement	90.1-2004 requirement + 20%	90.1-2013 requirement - 20%
Window (WWR)	33%	50%	20%
Opaque and fenestration UA; average U-factor (Uavg)	90.1-2013 requirement (roof=0.032, wall = 0.055, windows based on mix of types) at 33% WWR	90.1-2004 requirement (roof=0.0630, wall = 0.084, windows are based on mix of types) at 33% WWR	90.1-2013 requirement - 20% (roof=0.0256, wall = 0.044, windows are based on mix of types) at 33% WWR
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)	Per 90.1-2013 (no open office controls ~53% floor area with occupancy sensors)	90.1-2004 occupancy sensor requirements	Occupancy sensors everywhere (91% of floor area)

A.1.2 EnergyPlus Simulation

The medium office prototype building model simulations were completed, including runs[1] for variable options set at the typical or prescriptive level, varying the level for each option to its high and low energy impact condition while maintaining the other options at their typical levels, interactive runs with all options at high or low levels, and additional runs with a mixture of option levels that are expected to be highly interactive. The inputs and results for the runs are shown in Table A.2 for the primary VAV reheat system with hydronic heating and in Table A.3 for the VAV electric reheat system.

[1] Completing a full factorial set of runs that includes all combinations requires excessive resources and is not necessary. The simplified approach used has provided good results in the past. Using a design of experiments selection process in the future for the selection of mixed value option runs may improve the results or make the process more efficient.

Table A.2. EnergyPlus Runs for Packaged DX with VAV and Hydronic Reheat

Purpose	Boiler thermal efficiency	Cooling unit EER	Total Fan Static Pressure, in w.g.	Window Wall Ratio	Area weighted average U	Area weighted average	% of floor Area Daylit	% of floor Area Occ Sensors	Run Results (Independent Variable)		
Variable:	*Et*	*EER*	*TSP*	*WWR*	*Uavg*	*LPD*	*Adl*	*Aos*	*Electric EUI*	*Gas EUI*	*ECI*
Nom	80%	9.8	5.578	33%	0.115	0.82	21%	53%	7.783	0.118	$ 0.9174
Hi Et	93%	9.8	5.578	33%	0.115	0.82	21%	53%	7.783	0.103	$ 0.903
Hi EER	80%	12	5.578	33%	0.115	0.82	21%	53%	7.576	0.118	$ 0.896
Hi TSP	80%	9.8	4.462	33%	0.115	0.82	21%	53%	7.688	0.119	$ 0.909
Hi WWR	80%	9.8	5.578	20%	0.087	0.82	21%	53%	7.616	0.114	$ 0.896
Hi Uavg	80%	9.8	5.578	33%	0.092	0.82	21%	53%	7.792	0.110	$ 0.911
Hi LPD	80%	9.8	5.578	33%	0.115	0.656	21%	53%	7.390	0.122	$ 0.881
Hi Adl	80%	9.8	5.578	33%	0.115	0.82	41%	53%	7.418	0.120	$ 0.882
Hi Aos	80%	9.8	5.578	33%	0.115	0.82	21%	91%	7.242	0.122	$ 0.866
Lo TSP	80%	9.8	7.5813	33%	0.115	0.82	21%	53%	7.964	0.116	$ 0.934
Lo WWR	80%	9.8	5.578	50%	0.152	0.82	21%	53%	8.020	0.117	$ 0.941
Lo Uavg	80%	9.8	5.578	33%	0.162	0.82	21%	53%	7.794	0.137	$ 0.937
Lo LPD	80%	9.8	5.578	33%	0.115	1	21%	53%	8.215	0.111	$ 0.956
Lo Adl	80%	9.8	5.578	33%	0.115	0.82	0%	53%	8.194	0.112	$ 0.954
Lo Aos	80%	9.8	5.578	33%	0.115	0.82	21%	8%	8.072	0.116	$ 0.945
All Hi	93%	10.78	4.462	20%	0.070	0.656	41%	91%	6.422	0.098	$ 0.758
All Lo	80%	9.8	7.5813	50%	0.206	1	0%	8%	9.629	0.108	$ 1.098
Mix Env. 1	80%	9.8	5.578	20%	0.127	0.82	21%	53%	7.638	0.133	$ 0.918
Mix Env. 2	80%	9.8	5.578	50%	0.121	0.82	21%	53%	8.036	0.108	$ 0.934
Mix Load 1	80%	9.8	7.5813	50%	0.121	1	21%	8%	9.075	0.092	$ 1.025
Mix Load 2	80%	9.8	7.5813	33%	0.092	0.656	21%	8%	7.815	0.110	$ 0.913
Mix Load 3	80%	9.8	4.462	20%	0.127	0.656	0%	91%	6.974	0.141	$ 0.857
Mix Load 4	80%	9.8	5.578	33%	0.115	1	41%	91%	7.216	0.119	$ 0.860
Mix Load 5	80%	9.8	5.578	33%	0.115	0.656	0%	8%	7.999	0.118	$ 0.940
Mix Load 6	80%	9.8	5.578	33%	0.115	1	0%	91%	7.934	0.108	$ 0.923

Table A.3. EnergyPlus Runs for Packaged DX with VAV and Electric Reheat

Purpose	Boiler thermal efficiency	Cooling unit EER	Total Fan Static Pressure, in w.g.	Window Wall Ratio	Area weighted average U	Area weighted average	% of floor Area Daylit	% of floor Area Occ Sensors	Run Results (Independent Variable)			
Variable:	*Et*	*EER*	*TSP*	*WWR*	*Uavg*	*LPD*	*Adl*	*Aos*	*Electric EUI*	*Gas EUI*		*ECI*
Nom	n/a	9.8	5.578	33%	0.115	0.82	21%	53%	9.247	0.027	$	0.979
Hi EER	n/a	12	5.578	33%	0.115	0.82	21%	53%	9.023	0.027	$	0.955
Hi TSP	n/a	9.8	4.462	33%	0.115	0.82	21%	53%	9.135	0.028	$	0.968
Hi WWR	n/a	9.8	5.578	20%	0.087	0.82	21%	53%	8.930	0.030	$	0.949
Hi Uavg	n/a	9.8	5.578	33%	0.092	0.82	21%	53%	9.188	0.026	$	0.972
Hi LPD	n/a	9.8	5.578	33%	0.115	0.656	21%	53%	8.822	0.029	$	0.936
Hi Adl	n/a	9.8	5.578	33%	0.115	0.82	41%	53%	8.850	0.028	$	0.939
Hi Aos	n/a	9.8	5.578	33%	0.115	0.82	21%	91%	8.758	0.028	$	0.928
Lo TSP	n/a	9.8	7.5813	33%	0.115	0.82	21%	53%	9.457	0.026	$	0.999
Lo WWR	n/a	9.8	5.578	50%	0.152	0.82	21%	53%	9.695	0.024	$	1.021
Lo Uavg	n/a	9.8	5.578	33%	0.162	0.82	21%	53%	9.552	0.030	$	1.013
Lo LPD	n/a	9.8	5.578	33%	0.115	1	21%	53%	9.716	0.026	$	1.025
Lo Adl	n/a	9.8	5.578	33%	0.115	0.82	0%	53%	9.691	0.026	$	1.023
Lo Aos	n/a	9.8	5.578	33%	0.115	0.82	21%	8%	9.513	0.027	$	1.006
All Hi	n/a	10.78	4.462	20%	0.070	0.656	41%	91%	7.613	0.033	$	0.816
All Lo	n/a	9.8	7.5813	50%	0.206	1	0%	8%	11.617	0.023	$	1.218
Mix Env. 1	n/a	9.8	5.578	20%	0.127	0.82	21%	53%	9.275	0.033	$	0.987
Mix Env. 2	n/a	9.8	5.578	50%	0.121	0.82	21%	53%	9.645	0.023	$	1.015
Mix Load 1	n/a	9.8	7.5813	50%	0.121	1	21%	8%	10.739	0.021	$	1.125
Mix Load 2	n/a	9.8	7.5813	33%	0.092	0.656	21%	8%	9.187	0.027	$	0.972
Mix Load 3	n/a	9.8	4.462	20%	0.127	0.656	0%	91%	8.683	0.035	$	0.928
Mix Load 4	n/a	9.8	5.578	33%	0.115	1	41%	91%	8.729	0.027	$	0.925
Mix Load 5	n/a	9.8	5.578	33%	0.115	0.656	0%	8%	9.434	0.028	$	0.998
Mix Load 6	n/a	9.8	5.578	33%	0.115	1	0%	91%	9.544	0.025	$	1.007

A.1.3 Regression Development

The results of the EnergyPlus runs were used to develop regressions[1] where the option 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. (A separate calculation is performed for electric and gas energy use, then rates are applied to arrive at the ECI for the combination.)
- All options are retained as independent variables in at least one of the energy type equations, even if their significance is low. For the regressions for the non-primary energy type (e.g., the gas equation for interaction with lighting changes), insignificant variables would be dropped. (If the significance is very low for the primary energy regression, it indicates the option might be better excluded from consideration as a variable option, because low significance indicates a low impact on energy use and cost.)
- 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[2] or the R-correlation[3] of the equation.

The parameters for the four regression models are shown in Table A.4. The R correlation or Multiple R^2 are quite high for all the regressions, and when regression coefficients were used to calculate the ECI results, the comparison was very close, with the ECI errors ±0.75% for the hydronic reheat system and ±1.5% for the electric reheat system.

Table A.4. Parameters for the Regression Models

System	VAV, Hydronic Reheat		VAV, Electric Reheat	
Output	Elec.EUI	Gas.EUI	Elec.EUI	Gas.EUI
Multiple R^2	*0.9976*	*0.9639*	*0.9954*	*0.982*
Intercept	6.3634	0.1928	6.2604	0.0414
Et	0	-0.1256	0	0
EER	-0.0820	0	-0.0996	0
TSP	0.0953	-0.0027	0.1189	-0.0006
WWR	-0.4019	0.0547	1.4087	-0.0315
Uavg	-5.1783	0.7724	5.2286	0.0519
LPD	3.1560	-0.0344	3.6786	-0.0091
Adl	-1.7408	0.0216	-1.9289	0.0049
Aos	1.0626	0	1.5701	0
LPD:Aos	-1.5206	0	-2.2876	0
Aos^2	-0.8690	0	-0.6322	0
WWR*Uavg	14.4242	-1.1130	0	0

[1] Unlike a typical regression development process where the goal is to reduce a large population of data to the most simple explanatory equation that can give meaning to general trends, the regression equations developed have the goal of predicting the energy impact on the prototype model of each option value and the interaction with other options as accurately as possible.
[2] For example, including the Aos*LPD interactive term had the result of the EER term becoming significant at the p=0.01 level rather than not significant.
[3] For example, including the Aos^2 term changed the multiple R^2 from 0.9904 to 0.9954.

A.1.4 Decision Analysis Model Development

A model of the interaction of variable options was developed and is shown both as an influence diagram in Figure A.1 and as a decision tree in Figure A.2. The diagrams establish interaction between WWR and Uavg and allow more efficient analysis by restricting Et to the primary system.

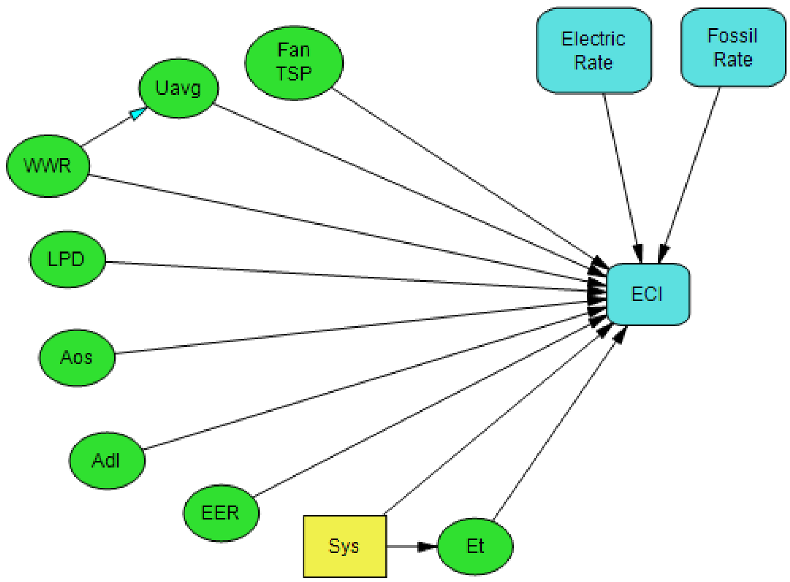


Figure A.1. Influence Diagram for Medium Office Package Development

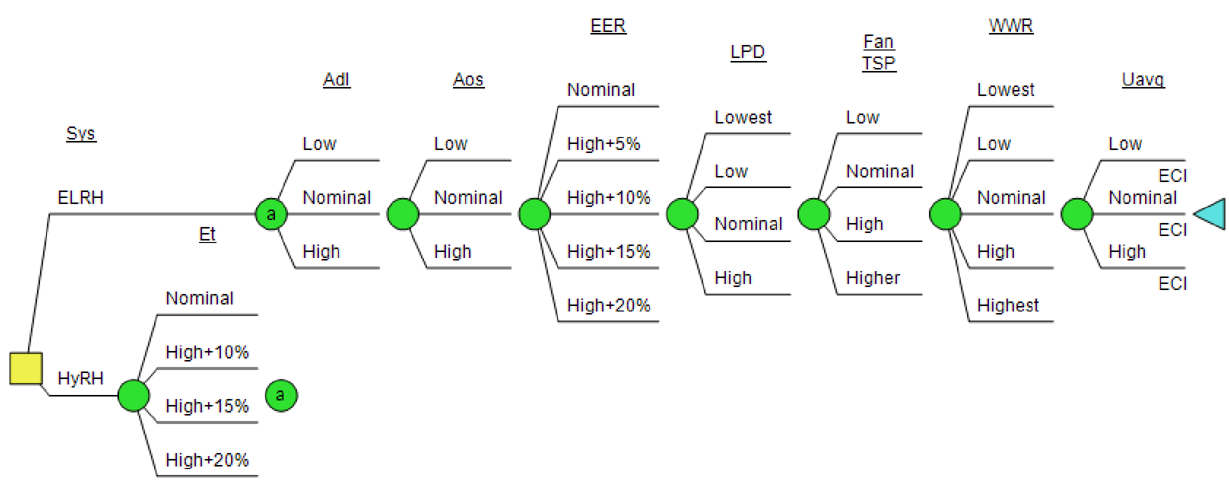


Figure A.2. Decision Tree for Medium Office Package Development

Once the decision logic was developed and values were assigned to the various states for each node, an Excel model using the regression coefficients and energy rates to calculate total building ECI was connected to the decision analysis model. The impact of each of the variable option levels on energy use can be determined, as shown in the tornado diagram in Figure A.3. In this diagram, the width of each bar represents the range of impact of each variable when the other variables are held at the typical level.

Separate tornados are shown for each HVAC system, the primary VAV reheat system with hydronic heating (HyRH) and the VAV electric reheat system (ELRH). The vertical line for each system represents the expected value of ECI based on an equal likelihood of all states of each of the variable options occurring. Three of the variables have a high level of ECI impact on both systems: lighting power density (LPD), Occupancy sensor area (Aos), and daylighted area (Adl).

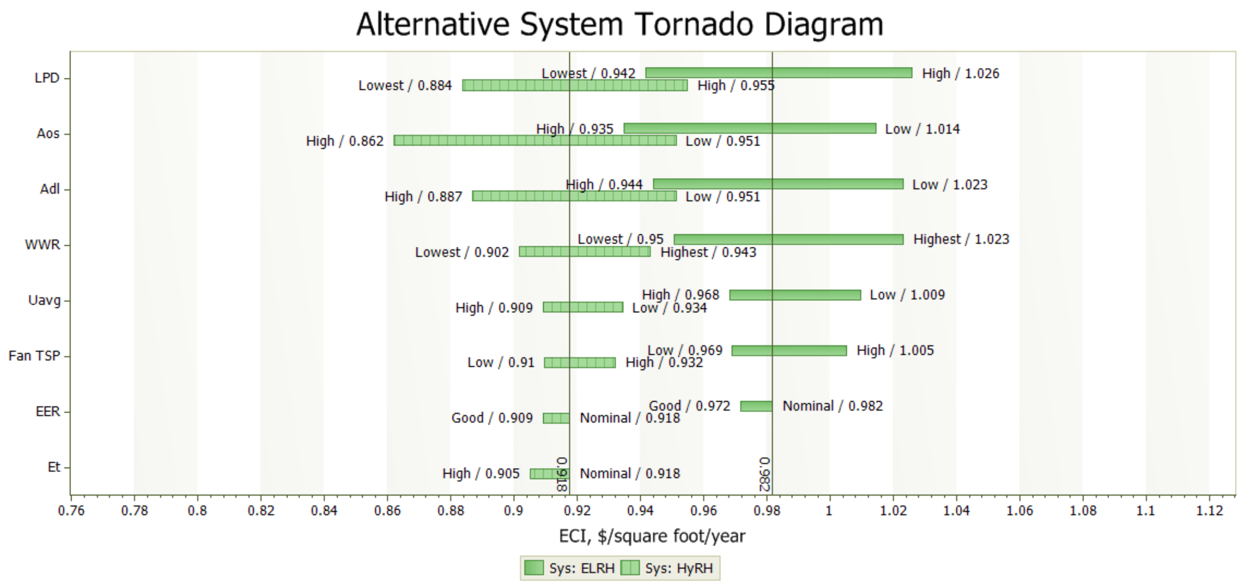


Figure A.3. Tornado Diagram showing ECI Impact of Variable Options for Medium Office Packages

Using the decision analysis model, the ECIs for all combinations of variable options were calculated. The distribution of results for each system can be seen in Figure A.4. The electric reheat system has a much higher possible ECI than the hydronic reheat option.

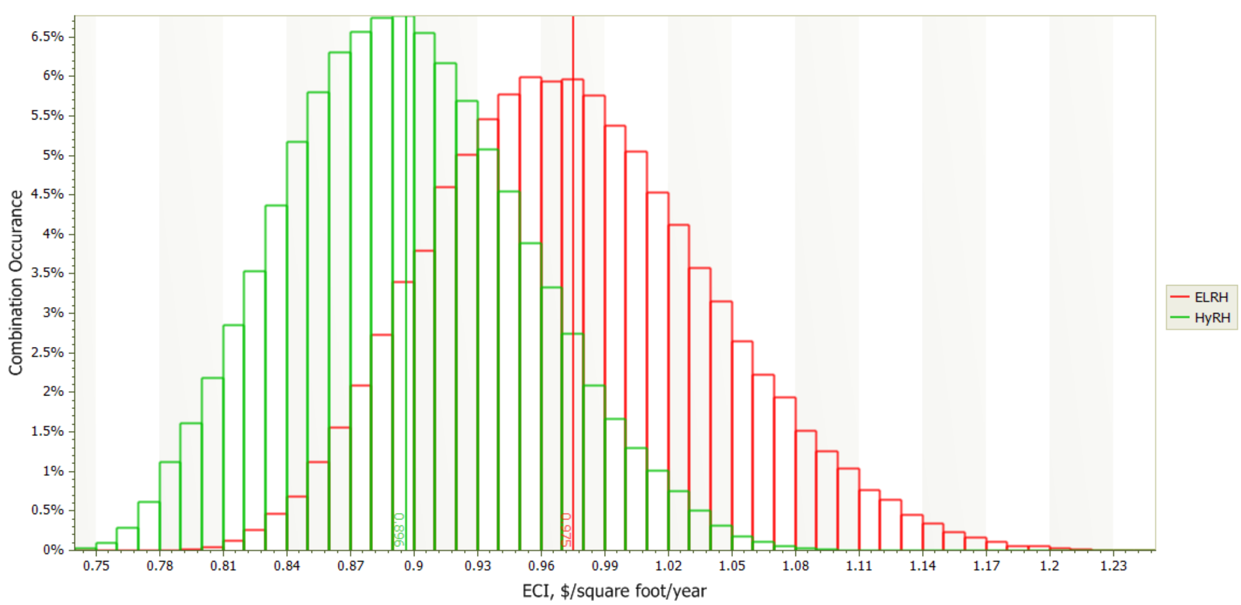


Figure A.4. Histograms Showing Distribution of ECI Results for All Combinations of Variable Options

The same data can be displayed as a cumulative probability curve that better shows the comparison between the two system selections. In addition to the expected value (the vertical line, this time calculated with more precision than in the tornado diagram and again, based on an equal likelihood of all states of each of the variable options occurring) the values for 10%, 50%, and 90% probability are also shown. From these curves, shown in Figure A.5, it is clear that the electric reheat system has a wider impact on ECI than the hydronic reheat system.

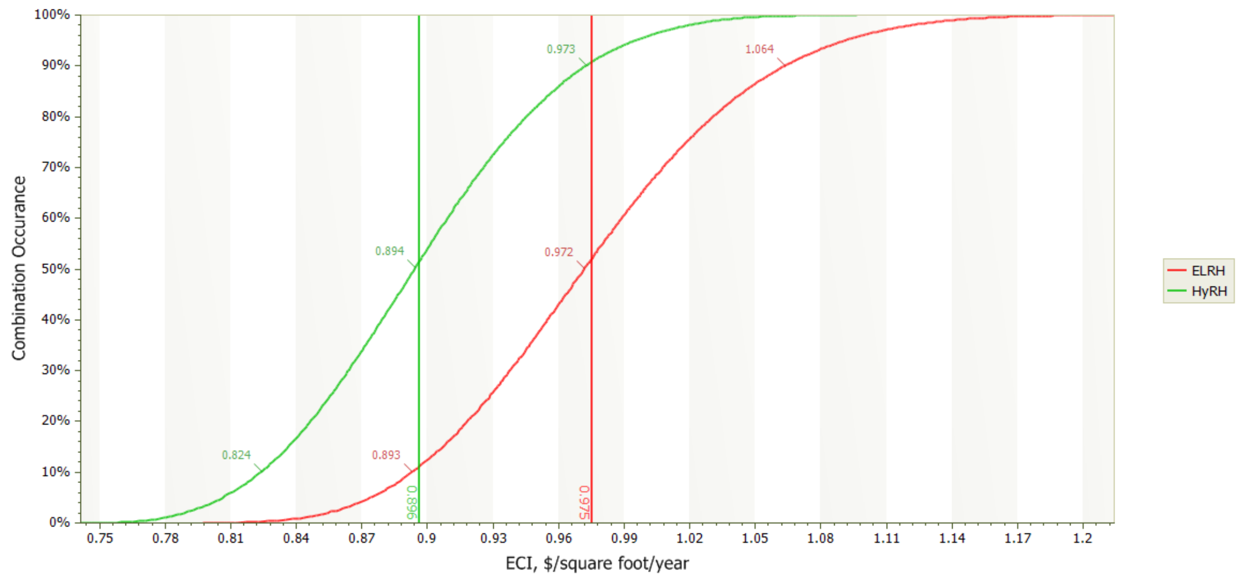


Figure A.5. Cumulative Probability of ECI Results for All Combinations of Variable Options

A.1.5 Compile Results and Select Packages

The endpoint results from the decision analysis were used to generate an energy cost index for all the combinations from the electric and gas regression results. These were compared to the primary package to determine a percentage of primary use. Count statistics of the analyzed packages are shown in Figure A.5. What is encouraging is that with both the primary or standard 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 packages are available for consideration.

Table A.5. Result Count Statistics of the Analyzed Packages

Package Count	Hydronic Reheat VAV	Electric Reheat VAV	Total Packages	
Total Combinations	43,200	10,800	54,000	100%
Combinations Related to ECI of Primary Package				
From 90% to 100%	22,838	2,079	24,917	46%
From 97% to 100%	7,789	1,115	8,944	16%
From 99% to 100%	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 selection, the following considerations applied:

- Energy use of the package was at or below that of the primary package.
- Options selected represented trade-offs that developers were most likely interested in.
- 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 (discussed further in Section 3.4).
- The number of packages was limited to avoid overwhelming the selector with too many options.

The selected packages were presented in the body of the report in Table 3.1.

A.1.6 Validation of Regression Results

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 ±2% of total energy cost predicted by EnergyPlus as compared to the regressions, as shown in Figure A.6.

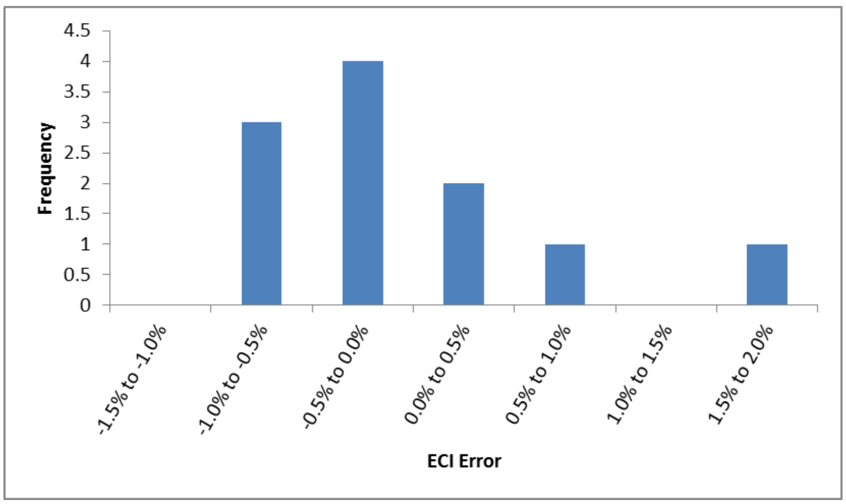


Figure A.6. Histogram of ECI Error, Regression Results vs. EnergyPlus Results

Appendix B

Logic Model for Commercial Energy Code Development Roadmap

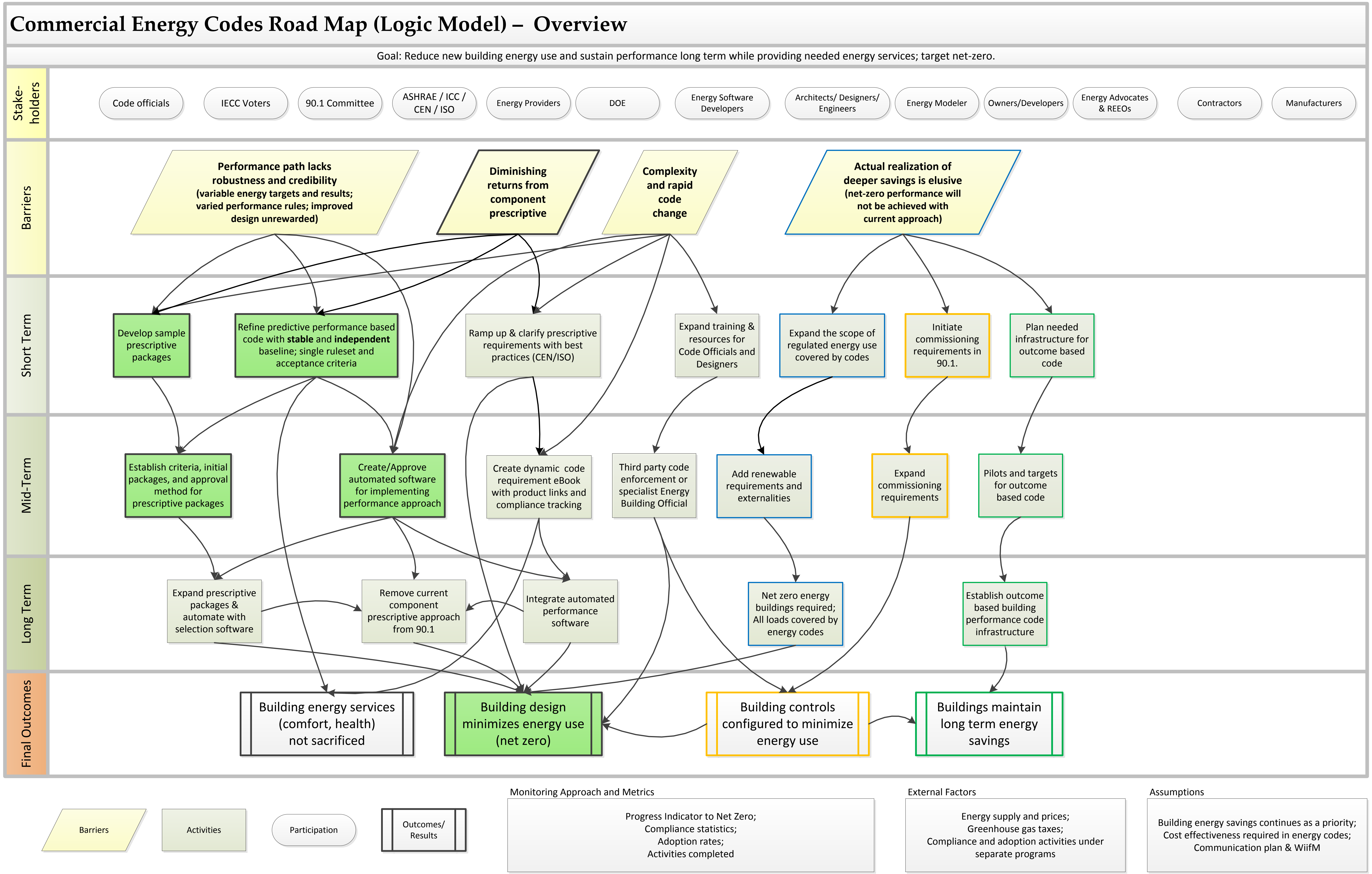
Appendix B

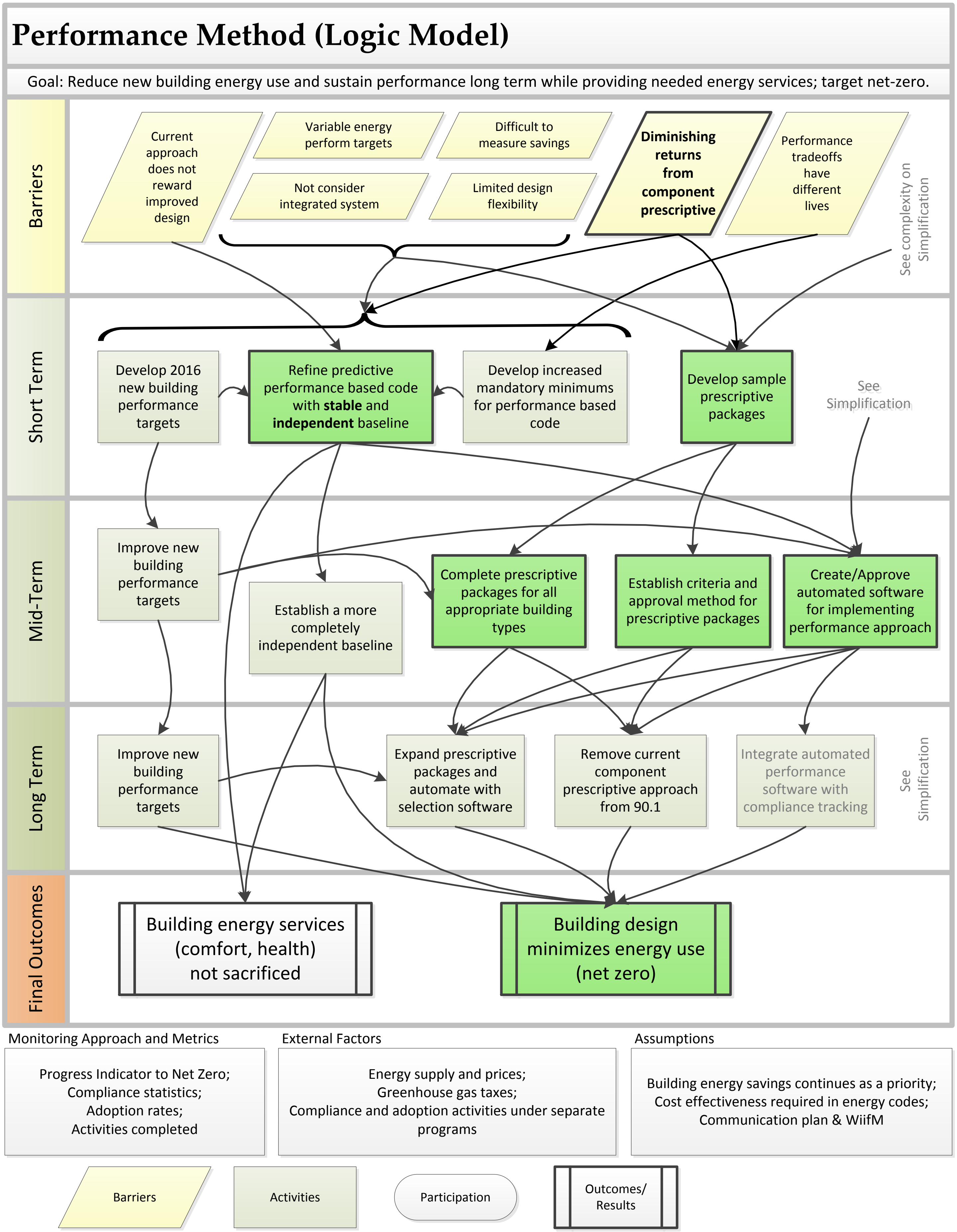
Logic Model for Commercial Energy Code Development Roadmap

This appendix presents a logic model that identifies barriers in the current commercial energy code to minimizing building energy use and identifies activities at the short-term, mid-term, and long-term phases over the next several years to overcome those barriers. Section 4.0 identifies entities (including Pacific Northwest National Laboratory) that could potentially engage the different activities. Since this is a large undertaking, the first logic model presents a high level overview of all the barriers, activities, and desired outcomes in the big picture roadmap. Following that, a more detailed logic model is presented, split into four major activity groups of the overall roadmap:

- Performance method (interacts with simplification)
- Simplification (interacts with performance method)
- Achieving deeper savings
- Commissioning and outcome based performance

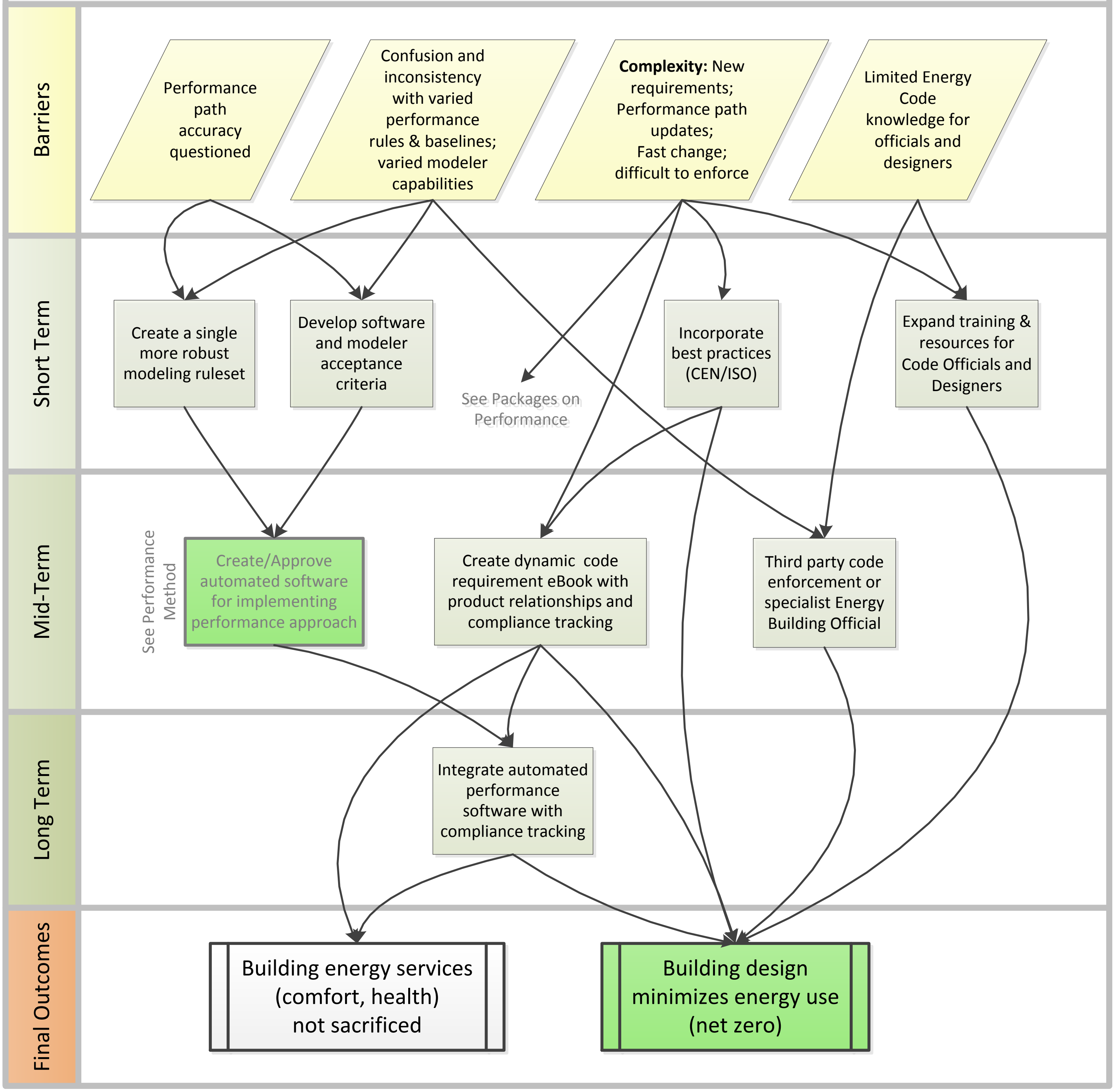
Finally, a detailed view is presented that includes all the barriers and activities on one sheet. Note that the logic model does not identify every task and interaction necessary to achieve the final outcomes, but is a starting place that identifies major activities and can assist with more detailed planning.


Commercial Energy Codes Road Map (Logic Model) – Overview
Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.
Stake-holders
Code officials
IECC Voters
90.1 Committee
ASHRAE / ICC / CEN / ISO
Energy Providers
DOE
Energy Software Developers
Architects/ Designers/ Engineers
Energy Modeler
Owners/Developers
Energy Advocates & REEOs
Contractors
Manufacturers
Barriers
Performance path lacks robustness and credibility (variable energy targets and results; varied performance rules; improved design unrewarded)
Diminishing returns from component prescriptive
Complexity and rapid code change
Actual realization of deeper savings is elusive (net-zero performance will not be achieved with current approach)
Short Term
Develop sample prescriptive packages
Refine predictive performance based code with stable and independent baseline; single ruleset and acceptance criteria
Ramp up & clarify prescriptive requirements with best practices (CEN/ISO)
Expand training & resources for Code Officials and Designers
Expand the scope of regulated energy use covered by codes
Initiate commissioning requirements in 90.1.
Plan needed infrastructure for outcome based code
Mid-Term
Establish criteria, initial packages, and approval method for prescriptive packages
Create/Approve automated software for implementing performance approach
Create dynamic code requirement eBook with product links and compliance tracking
Third party code enforcement or specialist Energy Building Official
Add renewable requirements and externalities
Expand commissioning requirements
Pilots and targets for outcome based code
Long Term
Expand prescriptive packages & automate with selection software
Remove current component prescriptive approach from 90.1
Integrate automated performance software
Net zero energy buildings required; All loads covered by energy codes
Establish outcome based building performance code infrastructure
Final Outcomes
Building energy services (comfort, health) not sacrificed
Building design minimizes energy use (net zero)
Building controls configured to minimize energy use
Buildings maintain long term energy savings
Barriers
Activities
Participation
Outcomes/ Results
Monitoring Approach and Metrics
Progress Indicator to Net Zero;
Compliance statistics;
Adoption rates;
Activities completed
External Factors
Energy supply and prices;
Greenhouse gas taxes;
Compliance and adoption activities under separate programs
Assumptions
Building energy savings continues as a priority;
Cost effectiveness required in energy codes;
Communication plan & WiifM


Performance Method (Logic Model)
Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.
Barriers
Current approach does not reward improved design
Variable energy perform targets
Difficult to measure savings
Not consider integrated system
Limited design flexibility
Diminishing returns from component prescriptive
Performance tradeoffs have different lives
See complexity on Simplification
Short Term
Develop 2016 new building performance targets
Refine predictive performance based code with stable and independent baseline
Develop increased mandatory minimums for performance based code
Develop sample prescriptive packages
See Simplification
Mid-Term
Improve new building performance targets
Establish a more completely independent baseline
Complete prescriptive packages for all appropriate building types
Establish criteria and approval method for prescriptive packages
Create/Approve automated software for implementing performance approach
Long Term
Improve new building performance targets
Expand prescriptive packages and automate with selection software
Remove current component prescriptive approach from 90.1
Integrate automated performance software with compliance tracking
See Simplification
Final Outcomes
Building energy services (comfort, health) not sacrificed
Building design minimizes energy use (net zero)
Monitoring Approach and Metrics
Progress Indicator to Net Zero; Compliance statistics; Adoption rates; Activities completed
External Factors
Energy supply and prices; Greenhouse gas taxes; Compliance and adoption activities under separate programs
Assumptions
Building energy savings continues as a priority; Cost effectiveness required in energy codes; Communication plan & WiifM
Barriers
Activities
Participation
Outcomes/ Results

Code Simplification (Logic Model)

Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.



Monitoring Approach and Metrics

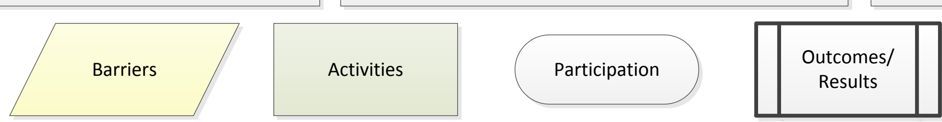
Progress Indicator to Net Zero;
Compliance statistics;
Adoption rates;
Activities completed

External Factors

Energy supply and prices;
Greenhouse gas taxes;
Compliance and adoption activities under separate programs

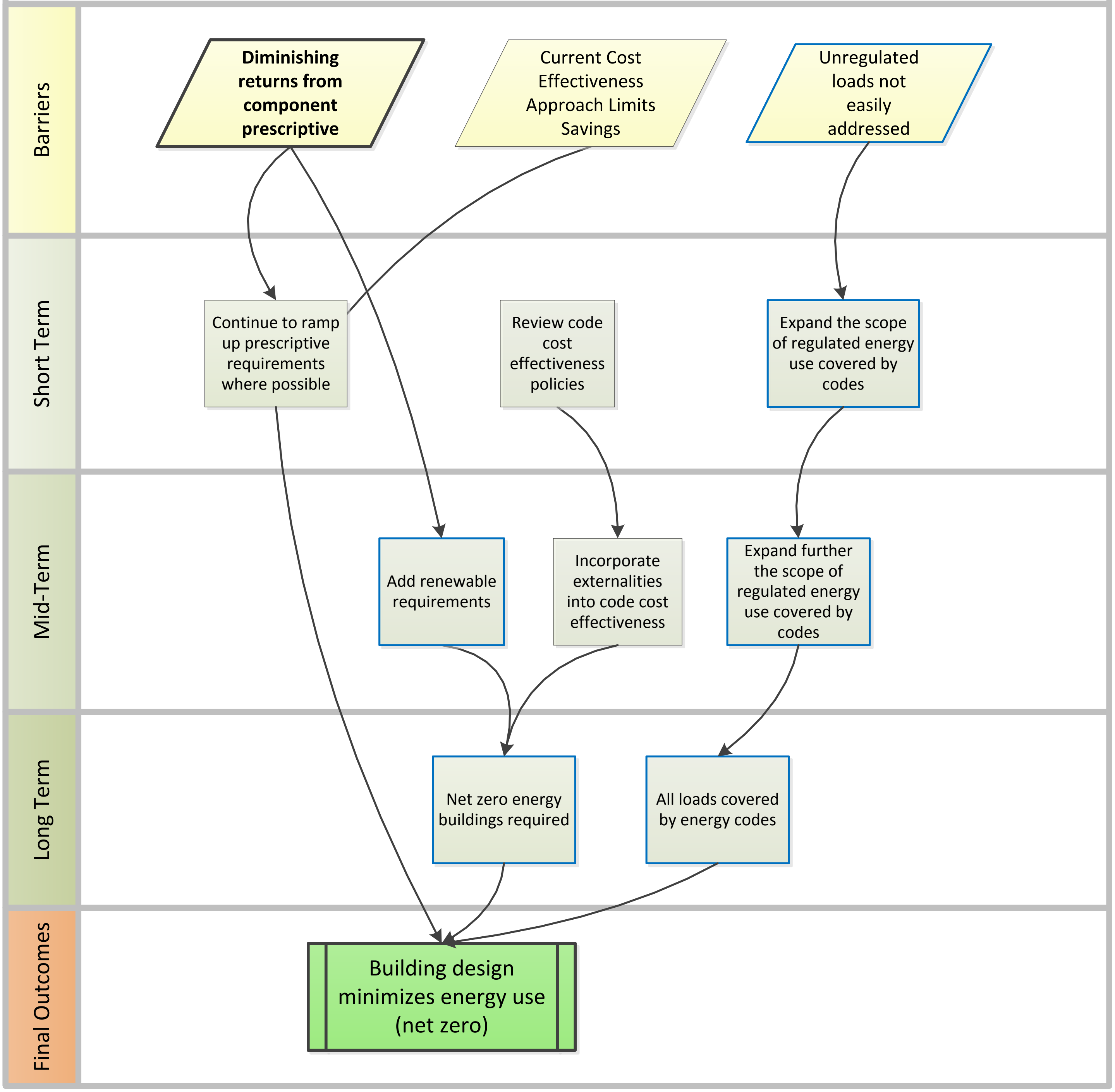
Assumptions

Building energy savings continues as a priority;
Cost effectiveness required in energy codes;
Communication plan & WiifM

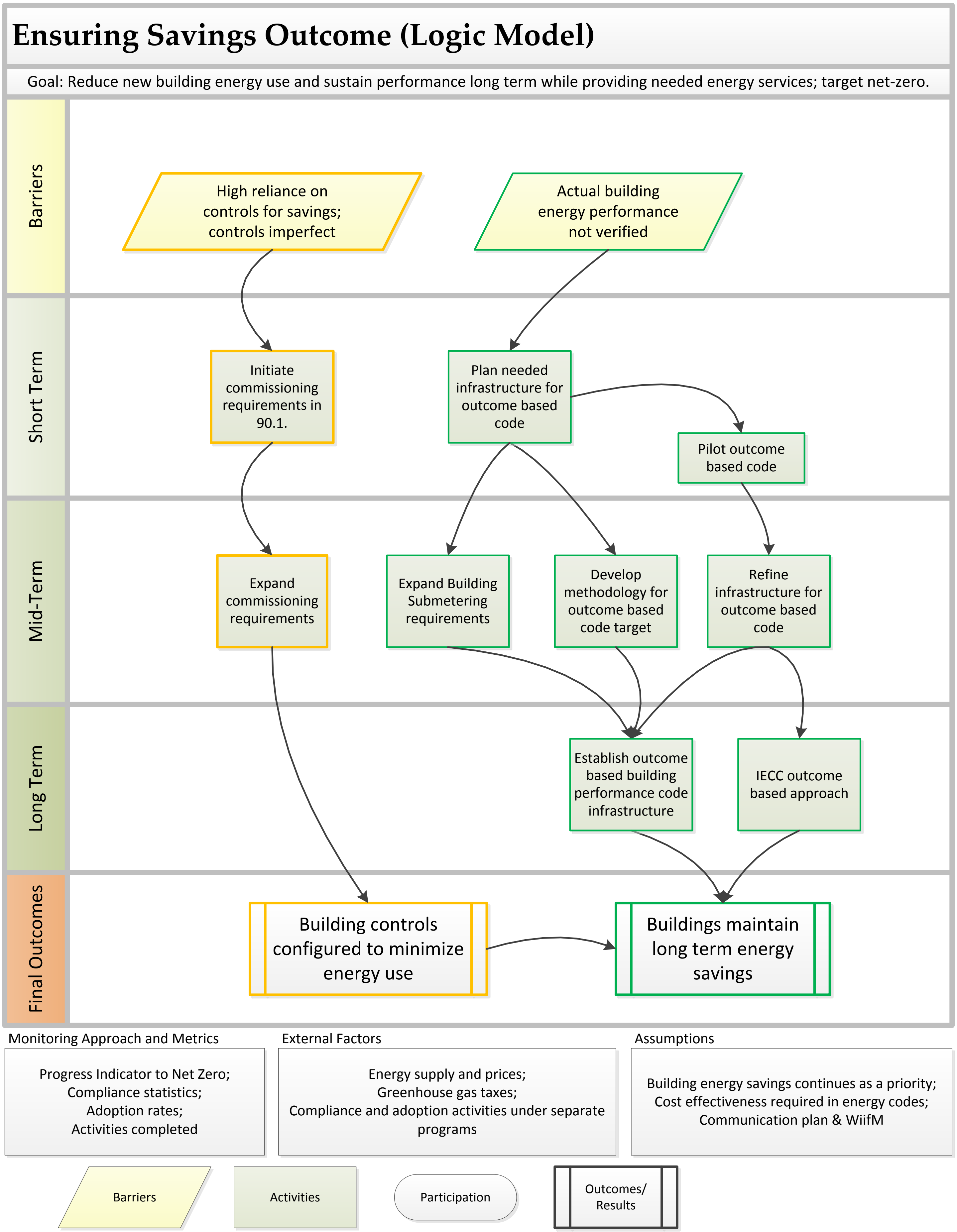


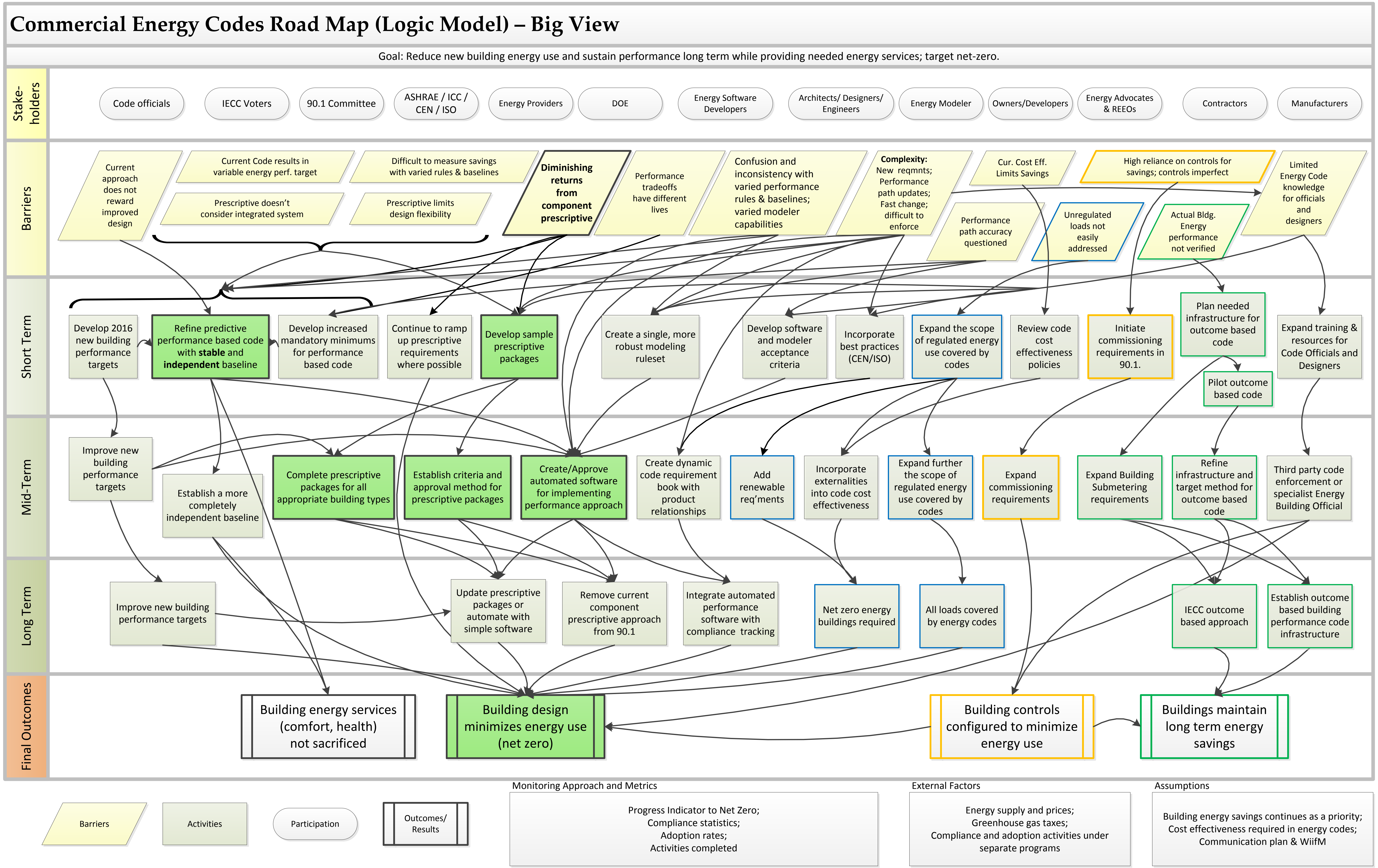
Achieving Deeper Savings (Logic Model)

Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.



Monitoring Approach and Metrics	External Factors	Assumptions
Progress Indicator to Net Zero; Compliance statistics; Adoption rates; Activities completed	Energy supply and prices; Greenhouse gas taxes; Compliance and adoption activities under separate programs	Building energy savings continues as a priority; Cost effectiveness required in energy codes; Communication plan & WiifM


Ensuring Savings Outcome (Logic Model)
Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.
Barriers
Short Term
Mid-Term
Long Term
Final Outcomes
High reliance on controls for savings; controls imperfect
Actual building energy performance not verified
Initiate commissioning requirements in 90.1.
Plan needed infrastructure for outcome based code
Pilot outcome based code
Expand commissioning requirements
Expand Building Submetering requirements
Develop methodology for outcome based code target
Refine infrastructure for outcome based code
Establish outcome based building performance code infrastructure
IECC outcome based approach
Building controls configured to minimize energy use
Buildings maintain long term energy savings
Monitoring Approach and Metrics
Progress Indicator to Net Zero; Compliance statistics; Adoption rates; Activities completed
External Factors
Energy supply and prices; Greenhouse gas taxes; Compliance and adoption activities under separate programs
Assumptions
Building energy savings continues as a priority; Cost effectiveness required in energy codes; Communication plan & WiifM
Barriers
Activities
Participation
Outcomes/ Results


Commercial Energy Codes Road Map (Logic Model) – Big View
Goal: Reduce new building energy use and sustain performance long term while providing needed energy services; target net-zero.
Stake-holders
Code officials
IECC Voters
90.1 Committee
ASHRAE / ICC / CEN / ISO
Energy Providers
DOE
Energy Software Developers
Architects/ Designers/ Engineers
Energy Modeler
Owners/Developers
Energy Advocates & REEOs
Contractors
Manufacturers
Barriers
Current approach does not reward improved design
Current Code results in variable energy perf. target
Prescriptive doesn't consider integrated system
Difficult to measure savings with varied rules & baselines
Prescriptive limits design flexibility
Diminishing returns from component prescriptive
Performance tradeoffs have different lives
Confusion and inconsistency with varied performance rules & baselines; varied modeler capabilities
Complexity: New reqmnts; Performance path updates; Fast change; difficult to enforce
Cur. Cost Eff. Limits Savings
Performance path accuracy questioned
Unregulated loads not easily addressed
High reliance on controls for savings; controls imperfect
Actual Bldg. Energy performance not verified
Limited Energy Code knowledge for officials and designers
Short Term
Develop 2016 new building performance targets
Refine predictive performance based code with stable and independent baseline
Develop increased mandatory minimums for performance based code
Continue to ramp up prescriptive requirements where possible
Develop sample prescriptive packages
Create a single, more robust modeling ruleset
Develop software and modeler acceptance criteria
Incorporate best practices (CEN/ISO)
Expand the scope of regulated energy use covered by codes
Review code cost effectiveness policies
Initiate commissioning requirements in 90.1.
Plan needed infrastructure for outcome based code
Pilot outcome based code
Expand training & resources for Code Officials and Designers
Mid-Term
Improve new building performance targets
Establish a more completely independent baseline
Complete prescriptive packages for all appropriate building types
Establish criteria and approval method for prescriptive packages
Create/Approve automated software for implementing performance approach
Create dynamic code requirement book with product relationships
Add renewable req'ments
Incorporate externalities into code cost effectiveness
Expand further the scope of regulated energy use covered by codes
Expand commissioning requirements
Expand Building Submetering requirements
Refine infrastructure and target method for outcome based code
Third party code enforcement or specialist Energy Building Official
Long Term
Improve new building performance targets
Update prescriptive packages or automate with simple software
Remove current component prescriptive approach from 90.1
Integrate automated performance software with compliance tracking
Net zero energy buildings required
All loads covered by energy codes
IECC outcome based approach
Establish outcome based building performance code infrastructure
Final Outcomes
Building energy services (comfort, health) not sacrificed
Building design minimizes energy use (net zero)
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