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Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G – Performance Rating Method

March 2016

M Rosenberg
R Hart

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

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Michael Rosenberg
Pacific Northwest National Laboratory

Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BBP	baseline building performance
BBREC	baseline building regulated energy cost
BBUEC	baseline building unregulated energy cost
BECP	Building Energy Codes Program
BPF	building performance factor
DOE	U.S. Department of Energy
ECB	Energy cost budget
IgCC	International Green Construction Code
LEED	Leadership in Energy and Environmental Design
PCI	performance cost index
PNNL	Pacific Northwest National Laboratory
SSPC	Standing Standards Project Committee
USGBC	United States Green Building Council

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1.0 Introduction

ANSI/ASHRAE/IES Standard 90.1 (referred to as Standard 90.1) is the model energy standard upon which most non-residential energy codes in the United States are based (42 U.S.C. 6833(b)(1)). The standard includes two compliance paths (ASHRAE 2013).

- The prescriptive path establishes criteria for energy-related characteristics of individual building components such as minimum R-values of insulation, maximum lighting power allowance, occupancy sensor requirements for lighting control, and economizer requirements for HVAC systems.

- The performance path, known as the Energy Cost Budget (ECB) method, provides additional flexibility by allowing a designer to trade-off compliance by not meeting some prescriptive requirements if the impact on energy cost can be offset by exceeding other prescriptive requirements, as demonstrated through energy simulation modeling.

In addition to the ECB method, Standard 90.1 includes a second simulation-based performance approach, Appendix G, the Performance Rating Method. While similar to ECB, Appendix G is more flexible, but through publication of the 2013 edition of the standard, has not been an approved path for demonstrating compliance. Instead, it has been used to rate the performance of buildings that exceed the requirements of Standard 90.1 for beyond code[1] programs including United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) Rating System, ASHRAE's Green Building Standard 189.1, and the International Green Construction Code (IgCC) (USGBC 2014; ASHRAE 2014; ICC 2015).

A recent modification (Addendum *bm*) to Standard 90.1-2013 makes two significant changes for the 2016 edition, to be published in October of 2016 (Rosenberg 2013; ASHRAE 2015). First, it allows Appendix G to be used as a third path for compliance with the standard in addition to rating beyond code building performance. This prevents modelers from having to develop separate building models for code compliance and beyond code programs. Using this new version of Appendix G to show compliance with the 2016 edition of the standard, the proposed building design needs to have a performance cost index (PCI) less than targets shown in a new table based on building type and climate zone. The second change is the baseline design is now fixed at a stable level of performance set approximately equal to the requirements in the 2004 standard. Rather than changing the stringency of the baseline with each subsequent edition of the standard, compliance with new editions will simply require a reduced PCI (a PCI of zero is a net-zero building). Using this approach, buildings of any era can be rated using the same method. The intent is that any building energy code or beyond code program can use this methodology and merely set the appropriate PCI target for their needs. This report discusses the process used to set performance criteria for compliance with ASHRAE Standard 90.1-2016 and suggests a method for demonstrating compliance with other codes and beyond code programs.

[1] Beyond code programs generally refer to regulations, incentive programs, green building standards, and the like that require or incent building energy performance that exceeds the level required by a base energy code or standard.

2.0 Setting Performance Cost Index Targets

Using the Appendix G performance path baseline that is stable at the level of the 2004 edition of Standard 90.1 means that compliance with a newer edition of the standard can no longer be determined by simply designing a building with a lower predicted energy cost than a prescriptive baseline meeting that standard. Instead, to demonstrate compliance, the design would need to demonstrate a PCI below a target PCI (PCI_t). In other words the proposed design would need to exceed the performance (have a lower energy cost) compared to a stable (90.1-2004) baseline, by some amount. That amount is indicated by the PCI_t. Buildings qualifying for beyond code programs would need to exceed the compliance threshold for the appropriate edition of the code to whatever degree is prescribed by that program. This section discusses the method used to set the performance target compared to the baseline for Appendix G with Addendum *bm*.

2.1 Appendix G Performance Metric

The new metric to rate building performance used by Appendix G is called the Performance Cost Index (PCI). The PCI of a proposed building design is calculated as follows:

$$Performance\ Cost\ Index = \frac{Proposed\ Building\ Performance}{Baseline\ Building\ Performance} \qquad \text{(Eq. 1)}$$

Where:

Proposed Building Performance = The annual energy cost for a proposed design calculated according to Standard 90.1, Appendix G

Baseline Building Performance = The annual energy cost for a baseline design calculated according to Standard 90.1, Appendix G

This results in a PCI of 1.0 for a building designed at the energy cost level of 90.1-2004, and a PCI of zero for a net-zero energy cost building. The maximum PCI (PCI target) required for compliance with any edition of Standard 90.1 can be determined based on the energy cost of a typical building designed to the mandatory and prescriptive requirements of that standard compared to a similar building designed to the mandatory and prescriptive requirements of 90.1-2004.

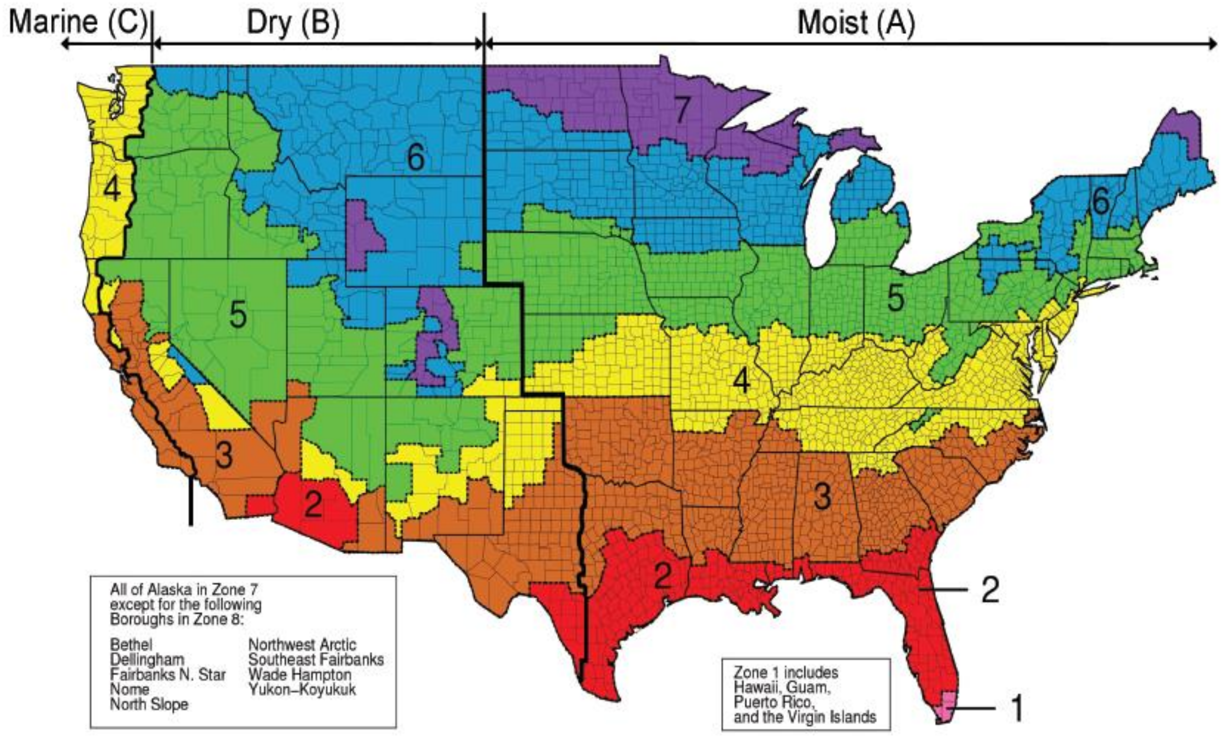
2.2 Use of Prototype Buildings

To determine the savings impact from various editions of Standard 90.1, Pacific Northwest National Laboratory (PNNL) developed prototype commercial building models using the EnergyPlus building simulation program (DOE 2013). These prototypes and the procedure for quantifying the progress of Standard 90.1 have previously been described in detail (Thornton et al. 2011, Goel et al. 2014). As described in these reports, PNNL developed a suite of 16 prototype buildings covering the majority of the commercial building stock and mid-rise to high-rise residential buildings that are listed in Table 2.1. Each of the 16 prototype buildings are simulated in a representative city for each of 17 climate zones, 15 of which are located in the United States. Figure 2.1 shows the United States climate zone map and lists the representative climate locations. Climate zones for international locations are available Standard 90.1 (ASHRAE 2013).

PNNL has created versions of the prototypes for each edition of Standard 90.1 published since 2004 including the 2004, 2007, 2010, and 2013 editions. This combination of prototypes, climate locations, and standard editions results in 1,088 individual building models which are available for download (BECP 2012). Energy and energy cost details for each of the 1,088 models are also available online (PNNL 2014). PNNL's process of using prototypes to quantify the improvement of Standard 90.1 compared to previous editions is referred to as the Progress Indicator. Using the energy cost data for each of these models it is possible to develop PCI targets for each edition of Standard 90.1 compared to the 2004 baseline for each building type and climate zone. When creating the compliance targets for Standard 90.1, the SSPC decided to combine the results of similar prototype buildings resulting in eight general building types as shown in Table 2.1, and the savings for the related prototype buildings were averaged to develop the building type savings.

Table 2.1 ASHRAE Commercial Prototype Building Models

Building Type	Prototype building
Office	Small Office
	Medium Office
	Large Office
Retail	Stand-Alone Retail
	Strip Mall
School	Primary School
	Secondary School
Healthcare/hospital	Outpatient Health Care
	Hospital
Lodging/hotel	Small Hotel
	Large Hotel
Warehouse	Warehouse
Restaurant	Fast Food Restaurant
	Sit-Down Restaurant
Apartment (Multi-family)	Mid-Rise Apartment
	High-Rise Apartment



- 1A: Miami, Florida (very hot, humid)
- 1B: Riyadh, Saudi Arabia (very hot, dry)
- 2A: Houston, Texas (hot, humid)
- 2B: Phoenix, Arizona (hot, dry)
- 3A: Memphis, Tennessee (warm, humid)
- 3B: El Paso, Texas (warm, dry)
- 3C: San Francisco, California (warm, marine)
- 4A: Baltimore, Maryland (mixed, humid)
- 4B: Albuquerque, New Mexico (mixed, dry)
- 4C: Salem, Oregon (mixed, marine)
- 5A: Chicago, Illinois (cool, humid)
- 5B: Boise, Idaho (cool, dry)
- 5C: Vancouver, B.C. Canada (cool, marine)
- 6A: Burlington, Vermont (cold, humid)
- 6B: Helena, Montana (cold, dry)
- 7: Duluth, Minnesota (very cold)
- 8: Fairbanks, Alaska (subarctic)

Figure 2.1 United States Climate Zone Map and Representative Cities

2.3 Performance Cost Index Targets for Compliance with Various Editions of Standard 90.1

Using the results of the Progress Indicator analysis, PCI targets have been developed for compliance with Standards 90.1-2010, 2013, and 2016. When doing this for Standard 90.1-2016, the Standing Standards Project Committee (SSPC) 90.1 took the approach of normalizing the PCI target for the amount of unregulated energy use in a proposed building model.[1] When using Appendix G for compliance, those

[1] In Standard 90.1, regulated energy use is defined as *energy used by building systems and components with requirements prescribed in Sections 5 through 10. This includes energy used for HVAC, lighting, service water heating, motors, transformers, vertical transportation, refrigeration equipment, computer-room cooling equipment, and other building systems, components, and processes with requirements prescribed in Sections 5 through 10*. Unregulated energy use is *energy used by building systems and components that is not regulated energy use.*

loads that are unregulated by the standard are kept the same between the proposed and baseline building models, so the PCI target can be adjusted, keeping the stringency the same between buildings with different amounts of unregulated load. When using Appendix G for quantifying building performance for beyond code programs that allow credit for improvements in unregulated loads, a different approach is taken that is described in the next section. The following equation is used to develop the PCI targets when using Appendix G for compliance:

$$PCI_t = \frac{(BBUEC + (BPF \cdot BBREC))}{BBP} \quad \text{(Eq. 2)}$$

where:

PCI_t =	The maximum Performance Cost Index for a proposed design to comply with a particular edition of Standard 90.1.
BBUEC =	Baseline Building Unregulated Energy Cost. The portion of the annual energy cost of a baseline building design that is due to unregulated energy use.
BBREC =	Baseline Building Regulated Energy Cost. The portion of the annual energy cost of a baseline building design that is due to regulated energy use.
BPF =	Building Performance Factor (BPF) from Tables 2.2, 2.3, and 2.4. For building types not listed in those tables use “All Others.”[1] Where a building includes multiple building area types, the required BPF shall be equal to the area-weighted average of each building area type.
BBP =	Baseline Building Performance. The annual energy cost of the baseline building design including both regulated and unregulated energy use.

Building Performance Factors in Tables 2.2, 2.3, and 2.4 are developed according to the following equation:

$$BPF_{Year\ X} = \left(\sum \frac{Prototype\ Building\ Regulated\ Energy\ Cost_{Year\ X}}{Prototype\ Building\ Regulated\ Energy\ Cost_{2004}}\right) \Big/ N_p \quad \text{(Eq. 3)}$$

where:

Prototype Building Regulated Energy Cost $_{year\ x}$ =	The portion of annual energy cost due to regulated energy use from the PNNL prototype buildings for a given building prototype, climate zone and edition of Standard 90.1.
Prototype Building Regulated Energy Cost $_{2004}$ =	The portion of annual energy cost due to regulated energy use from the PNNL prototype buildings for a given building prototype, climate zone and the 2004 edition of Standard 90.1.
N_p =	Number of prototype buildings of a particular building type from Table 2.1

[1] The BPF values for “All Others” are developed for each climate zone except 1B and 5C using weighted average values for each prototype building using national construction weights. For 1B and 5C straight numerical averages are used instead, since those climate zones do not exist in the U.S., and there are no national construction weights.

Table 2.2 Building Performance Factors (BPF) for Compliance with Standard 90.1-2010

	Climate Zone																	
Building Type	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	**Building Type Average**
Office	0.74	0.77	0.73	0.76	0.72	0.76	0.66	0.70	0.73	0.70	0.72	0.73	0.70	0.71	0.72	0.70	0.75	0.72
Retail	0.71	0.75	0.68	0.71	0.68	0.74	0.75	0.69	0.74	0.75	0.69	0.73	0.76	0.69	0.74	0.66	0.69	0.72
School	0.68	0.68	0.64	0.67	0.63	0.67	0.68	0.63	0.67	0.64	0.63	0.63	0.63	0.63	0.62	0.61	0.64	0.65
Healthcare	0.72	0.75	0.70	0.70	0.69	0.72	0.64	0.66	0.73	0.66	0.69	0.70	0.66	0.69	0.68	0.69	0.71	0.69
Restaurant	0.76	0.73	0.71	0.72	0.72	0.72	0.78	0.70	0.71	0.76	0.74	0.72	0.75	0.75	0.74	0.78	0.79	0.74
Hotel	0.80	0.82	0.76	0.77	0.77	0.81	0.80	0.76	0.81	0.78	0.72	0.77	0.73	0.71	0.73	0.69	0.70	0.76
Warehouse	0.63	0.62	0.67	0.69	0.67	0.69	0.73	0.69	0.71	0.72	0.70	0.71	0.74	0.74	0.73	0.73	0.76	0.70
Apartment	0.92	0.91	0.88	0.86	0.87	0.87	0.80	0.90	0.93	0.92	0.88	0.92	0.92	0.88	0.91	0.83	0.89	0.89
All Others	0.81	0.76	0.70	0.71	0.69	0.74	0.72	0.71	0.73	0.73	0.69	0.72	0.73	0.69	0.70	0.67	0.67	0.72

Table 2.3 Building Performance Factors (BPF) for Compliance with Standard 90.1-2013

	Climate Zone																	
Building Type	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	**Building Type Average**
Office	0.63	0.67	0.62	0.67	0.65	0.69	0.59	0.63	0.65	0.63	0.65	0.66	0.63	0.66	0.66	0.62	0.66	0.65
Retail	0.57	0.63	0.58	0.63	0.59	0.67	0.65	0.60	0.65	0.65	0.60	0.64	0.66	0.60	0.63	0.58	0.58	0.62
School	0.51	0.58	0.52	0.58	0.54	0.57	0.55	0.54	0.55	0.54	0.55	0.55	0.55	0.54	0.55	0.52	0.56	0.55
Healthcare	0.69	0.61	0.65	0.61	0.65	0.61	0.59	0.62	0.58	0.60	0.64	0.57	0.60	0.62	0.57	0.61	0.61	0.61
Restaurant	0.67	0.67	0.63	0.66	0.65	0.65	0.66	0.63	0.60	0.65	0.67	0.63	0.65	0.68	0.65	0.70	0.73	0.66
Hotel	0.69	0.70	0.67	0.65	0.68	0.70	0.69	0.67	0.69	0.67	0.65	0.66	0.65	0.64	0.66	0.62	0.63	0.67
Warehouse	0.56	0.57	0.61	0.63	0.62	0.64	0.68	0.63	0.65	0.68	0.65	0.66	0.70	0.71	0.71	0.72	0.72	0.66
Apartment	0.78	0.78	0.76	0.74	0.79	0.78	0.73	0.83	0.86	0.86	0.81	0.85	0.86	0.81	0.84	0.79	0.85	0.81
All Others	0.67	0.66	0.60	0.62	0.61	0.66	0.64	0.63	0.62	0.66	0.62	0.62	0.66	0.61	0.61	0.58	0.57	0.63

Developing BPFs for Standard 90.1-2016 posed a challenge for SSPC 90.1. The challenge was the BPFs needed to be developed in parallel with other changes to the standard, making it impossible to know what the final Progress Indicator savings for the 2016 edition will be. Based on the addenda to the standard already approved and a knowledge of addenda that could potentially be approved, the SSPC decided on an estimated reduction of 5% of the 2004 regulated energy cost beyond that achieved in 2013 for the 2016 BPFs. Table 2.4 includes a reduction of 0.05 from the 2013 BPFs. Climate zones 0A and 0B were added to Standard 90.1 for 2016.

Table 2.4 Building Performance Factors (BPF) for Compliance with Standard 90.1-2016

	Climate Zone																	
Building Type	0A & 1A	0A & 1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8	**Building Type Average**
Office	0.58	0.62	0.57	0.62	0.60	0.64	0.54	0.58	0.60	0.58	0.60	0.61	0.58	0.61	0.61	0.57	0.61	0.60
Retail	0.52	0.58	0.53	0.58	0.54	0.62	0.60	0.55	0.60	0.60	0.55	0.59	0.61	0.55	0.58	0.53	0.53	0.57
School	0.46	0.53	0.47	0.53	0.49	0.52	0.50	0.49	0.50	0.49	0.50	0.50	0.50	0.49	0.50	0.47	0.51	0.50
Healthcare	0.64	0.56	0.60	0.56	0.60	0.56	0.54	0.57	0.53	0.55	0.59	0.52	0.55	0.57	0.52	0.56	0.56	0.56
Restaurant	0.62	0.62	0.58	0.61	0.60	0.60	0.61	0.58	0.55	0.60	0.62	0.58	0.60	0.63	0.60	0.65	0.68	0.61
Hotel	0.64	0.65	0.62	0.60	0.63	0.65	0.64	0.62	0.64	0.62	0.60	0.61	0.60	0.59	0.61	0.57	0.58	0.62
Warehouse	0.51	0.52	0.56	0.58	0.57	0.59	0.63	0.58	0.60	0.63	0.60	0.61	0.65	0.66	0.66	0.67	0.67	0.61
Apartment	0.73	0.73	0.71	0.69	0.74	0.73	0.68	0.78	0.81	0.81	0.76	0.80	0.81	0.76	0.79	0.74	0.80	0.76
All Others	0.62	0.61	0.55	0.57	0.56	0.61	0.59	0.58	0.57	0.61	0.57	0.57	0.61	0.56	0.56	0.53	0.52	0.58

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Example 1 shows how compliance with Standard 90.1-2013 would be determined for a mixed use building in climate zone 5A

Example 1. Code Compliance for a Mixed Use Building in Climate Zone 5A

The designer for a mixed use building in Chicago, climate zone 5A is trying to determine if the design complies with ASHRAE Standard 90.1-2013. The building is 50,000 ft^2 with 10,000 ft^2 of retail space and 40,000 ft^2 of residential apartments. Building simulation performed according to the rules of Appendix G-2013 result in the following:

Proposed building performance	=	\$32,000/year
Baseline building performance (BBP)	=	\$49,000/year
Baseline building regulated energy cost (BBREC)	=	\$34,000/year
Baseline building unregulated energy cost (BBUEC)	=	\$15,000/year

Question: Does the proposed building design comply with 90.1-2013?

Step 1. Determine Performance Cost Index from Equation 1:

$$Performance\ Cost\ Index\ = \frac{Proposed\ Building\ Performance}{Baseline\ Building\ Performance}$$

$$Performance\ Cost\ Index\ (PCI)\ = \frac{\$32{,}000/year}{\$49{,}000/year} = 0.65$$

Step 2. Determine Building Performance Factor from Table 2.3:

Since the project is a mixed use building, the BPF is the area-weighted average of the appropriate building type BPFs for climate zone 5A from Table 2.3.

$$Building\ Performance\ Factor\ (BPF) = \frac{40{,}000\ ft^2 * 0.81 + 10{,}000\ ft^2 * 0.60}{50{,}000\ ft^2} = 0.77$$

Step 3. Determine Performance Cost Index Target from Equation 2:

$$PCI_t = \frac{(BBUEC + (BPF \cdot BBREC))}{BBP}$$

$$PCI_t = \frac{(\$15{,}000 + (0.77 \cdot \$34{,}000))}{\$49{,}000} = 0.84$$

Answer: Yes, Performance Cost Index < Performance Cost Index Target (0.65 < 0.84)

2.4 Performance Cost Index Targets for Beyond Code Programs Referencing Various Editions of Standard 90.1

Beyond code programs reference a particular version of Standard 90.1 and offer financial incentives or other recognition for achieving a level of energy performance that is better than the referenced version. The United States Green Building Councils (USGBC) Leadership in Energy and Environmental Design (LEED) Version 4 for instance, references 90.1-2010 and offers credits for percent improvements over that standard. For example, LEED assigns eight points to a newly constructed building that demonstrates a 20% reduction in energy cost compared to the 2010 baseline. This threshold for credits can also be expressed in terms of PCI. Using the PCI approach, the same building would qualify for eight points by achieving a PCI 20% lower than the PCI_t calculated in accordance with Equation 2. This means that the same energy modeling procedure can be used for compliance with any code and also be used to earn incentives or credits, when a building is significantly better than the code baseline. The performance beyond code for a proposed building using this approach would be calculated as follows:

$$\% \text{ Improvement beyond code} = 100 * \frac{\mathrm{PCI_t} - \mathrm{PCI}}{\mathrm{PCI_t}} \qquad \text{(Eq. 4)}$$

The PCI needed to achieve any target percent improvement can be calculated as follows:

$$\mathrm{PCI} = PCI_t \times \left(1 - \frac{\%Improvement}{100}\right) \qquad \text{(Eq.5)}$$

where:

%Improvement	=	the target percent improvement over the edition of Standard 90.1 referenced by the program.
PCI	=	the Performance Cost Index needed to achieve the target percent improvement.
PCI_t	=	the Performance Cost Index Target calculated using Equation 2 for the appropriate standard, building type, and climate zone, and fraction of unregulated energy cost. For building types not listed in those tables use *All Others*. Where a building includes multiple building area types, the required PCI_t shall be equal to the area-weighted average of each building area type.

Example 2 shows how this approach could be used for a beyond code program that references Standard 90.1-2010 as the basis of comparison.

Example 2. Beyond Code Performance for a Mixed Use Building in Climate Zone 5A

The designer is trying to determine by what percentage the building described in Example 1 exceeds the minimum compliance requirements of Standard 90.1-2010 for use in a green building rating system.

Question: For this building, what is the percent improvement over the Standard 90.1-2010?

Step 1. Determine Performance Cost Index from Equation 1:
The Performance Cost Index is the same as was determined in Example 1.

$$Performance\ Cost\ Index\ (PCI)\ = \frac{\$32{,}000/year}{\$49{,}000/year} = 0.65$$

Step 2. Determine the Building Performance Factor from Table 2.2:
Since the project is a mixed use building, the BPF is the area-weighted average of the appropriate BPF for the building types and Climate Zone 5A from Table 2.2.

$$\text{Building Performance Factor (BPF)} = \frac{40{,}000\ ft^2 * 0.88 + 10{,}000\ ft^2 * 0.69}{50{,}000\ ft^2} = 0.84$$

Step 3. Determine the Performance Cost Index Target from Equation 2:

$$PCI_t = \frac{(BBUEC + (BPF * BBREC))}{BBP}$$

$$PCI_t = \frac{(\$15{,}000 + (0.84 * \$34{,}000))}{\$49{,}000} = 0.89$$

Step 4. Determine the percent improvement beyond 90.1-2010 from Equation 3:

$$\%\ Improvement\ beyond\ code = 100 * \frac{PCI_t - PCI}{PCI_t}$$

$$\%\ Improvement\ beyond\ 90.1\text{–}2010 = 100 * \frac{0.89 - 0.65}{0.89} = 27\%$$

Answer: The proposed design is 27% better than 90.1-2010

2.5 Customizing Performance Targets

The intent of the new stable baseline for Appendix G is that it can be used for any code or beyond code program, even those not based on an edition of Standard 90.1. The key is that if the baseline remains consistent with that described in Appendix G, a user can use the same baseline model for multiple purposes and take advantage of software tools that automate the process of creating the baseline model. This requires creation of custom PCI targets using the methodology described in this report. One approach to doing that would be modifying the PNNL prototype building models to be consistent with an alternative code or beyond code performance threshold, the numerator in equation 3 can be changed to produce the new PCI_ts.

The procedure can easily be adapted to use source energy or carbon emissions instead of energy cost. The modeling procedure is exactly the same. The only difference is source energy or emissions are summed and compared instead of cost. If source energy or emissions is used as the metric for comparison against the baseline building, Performance Cost Index is not the right term; another term should be used since cost is no longer the metric.

Programs that apply to a limited geographic area or to a limited number of building types can simplify the building performance factor tables to include just the climates or building types that are applicable. Or, instead of having climate zone specific PCI_t for each building type, the average BPF from tables 2.2, 2.3, or 2.4 can be used to consolidate the PCI_t, across all climate zones. If the program prescribes standard assumptions for schedules of operation, temperatures and unregulated energy use, then PCI_t targets can be pre-calculated for these conditions. Asset rating programs are an example of where operating conditions are prescribed so that the energy performance of different buildings can be compared to each other with a common operational basis, regardless of actual individual building operation.

3.0 References

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