STREAMLINING CODE COMPLIANCE THROUGH A FIXED BASELINE APPROACH AND AUTOMATED BASELINE MODEL GENERATION

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Abstract

Complying with ASHRAE Standard 90.1, through the 2013 edition, has been through either the prescriptive approach or the Energy Cost Budget (ECB) Method. Appendix G or the Performance Rating Method (PRM) within ASHRAE Standard 90.1 has been an approach used only to rate the energy performance of buildings for beyond code programs. However, ASHRAE 90.1-2016 (ASHRAE 2016), through addendum bm, modifies Appendix G to be a code compliance option (Rosenberg 2016), and makes other significant changes including fixing the stringency of the baseline to approximately 2004 levels. With each future update to Standard 90.1, the stringency of the baseline will remain unchanged but the level of improvement relative to this baseline will be increased.

The Performance Rating Method-Reference Manual (Reference Manual) (Goel et al 2016) expands on the requirements of the 2010 edition of the PRM by filling in gaps and providing additional modelling guidelines. A future updated version of the Reference Manual for Standard 90.1-2016 would provide similar guidance for the fixed baseline approach. The Reference Manual will also inform the development of an OpenStudio measure (OpenStudio 2016), which would apply the rules specified within the manual to automatically generate the baseline building model. This paper discusses the merits of the fixed baseline approach in Standard 90.1-2016, the technical approach used for the development of the Reference Manual for Standard 90.1-2016 and the development of the OpenStudio measure for automating the baseline model generation.

Introduction

ASHRAE Standard 90.1 is the most widely adopted standard for establishing minimum energy efficiency requirements for design, construction, operation and maintenance of all buildings except low-rise residential buildings in the United States (Energy Codes 2017). Many countries around the world, including India and Canada, have based their energy codes on a version of Standard 90.1 (Evans 2009, Shui 2009). Prior to the 2016 edition, Standard 90.1 had two paths for code compliance, the prescriptive path or the performance based Energy Cost Budget method (Figure 1). Compliance through the prescriptive path is achieved by designing each building component to meet a minimum efficiency level. The performance based compliance approach, the Energy Cost Budget Method, establishes compliance by comparing the simulated energy cost of proposed building design to a baseline building design. The ECB baseline building tracks the proposed design with each element in the baseline defined to be the same as the proposed; however, its efficiency is upgraded or downgraded to exactly meet the prescriptive code requirements.

ASHRAE Standard 90.1 provides another simulation based approach for determining building performance, known as the Performance Rating Method (PRM), commonly referred to by its location in the Standard, "Appendix G,". The PRM method is referenced by the Leadership in Energy Efficiency in Design (LEED) rating system and is cited by a number of standards and programs including ASHRAE/USGBC/IES Standard 189.1-2014, the International Green Construction Code (IgCC) and the Federal Energy Efficiency Standards.

Similar to the ECB approach, the PRM provides rules for the definition of the baseline building and compares the performance of the proposed building design against that of the baseline to determine the beyond code performance. However, the PRM provides more flexibility than the ECB method and offers credit for proper building orientation, window area, HVAC system type and other features not credited by the ECB method.

Until Standard 90.1-2016, the intent of the Appendix G approach was to credit beyond-code design strategies and the procedure was not used for code compliance. Addendum bm to ASHRAE Standard 90.1-2013 (as published in Standard 90.1-2016) modifies the PRM procedure and enables its use for code compliance. It also fixes the baseline at an efficiency level approximately equal to that in Standard 90.1-2004 and compliance is achieved by demonstrating a required level of improvement through energy modelling.

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The intent is that future versions of the standard will specify increasing levels of improvement over the baseline but that the stringency of the baseline requirements will remain essentially unchanged. The new approach defines a new metric called the Performance Cost Index (PCI), which is the ratio of the proposed building energy cost to the baseline building energy cost. A PCI of 1.0 means that the building is performing at a level equal to the baseline and a PCI of zero would characterize a building with zero energy cost. PCI targets for compliance are specified in the standard based on building type, climate zone and normalized for the amount of unregulated energy use in the proposed building. A proposed building is required to have a PCI less than the target in order to comply with the code.

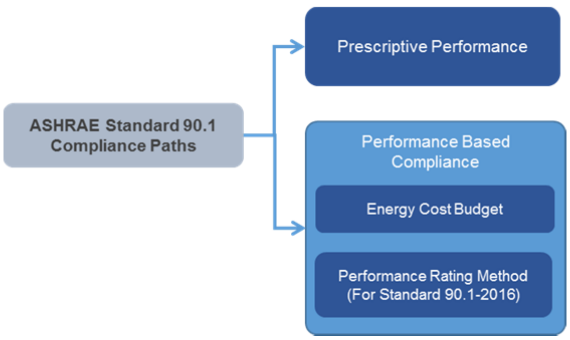

Figure 1: Compliance Paths for ASHRAE Standard 90.1

Comparison of Various Code Compliance Paths

The prescriptive based approach provides a convenient option where compliance for each building component can be individually met and enforced. This compliance option, however, is restrictive in nature, as it does not credit good building design such as optimally oriented windows or use of thermal mass. The prescriptive path has also reached the point of diminishing return as incrementally increasing component efficiency is unlikely to be cost-effective and will not achieve the net zero energy targets established by Architecture 2030 and adopted by some states and beyond code programs (Rosenberg 2014, Arent 2016, CEC 2015).

The two performance based options in Standard 90.1, ECB and PRM, are similar in the sense that a proposed building is compared against a baseline which meets the prescriptive code requirements, however the scope of prescriptive requirements addressed as well as the design features that can be credited for the proposed design differ between the two approaches. The ECB baseline building tracks the proposed design with each element in the baseline defined to the same as the proposed, however meeting the prescriptive and mandatory code requirements. The PRM approach significantly differs from the ECB approach as the baseline characteristics are defined by the method and to a large extent, are independent of the proposed building characteristics. The intent of the Appendix G approach is to recognize efficient design strategies whether or not those strategies are regulated by the prescriptive path. The PRM offers credit for proper building orientation by modelling the baseline building in the four cardinal orientations and using an average to establish the baseline performance. The PRM has window areas that depend on building type, whereas the ECB baseline has the same window area as the proposed design up to a limit of 40%. The HVAC system defined by the ECB procedure depends in large part on the system used for the proposed building, whereby the PRM specifies an HVAC system for the baseline building that is independent of the proposed design and based on the building type and climate zone. Creating the ECB baseline building is non-deterministic. The prescriptive standard has many exceptions and options and not all of these options achieve the same level of energy performance. Most of these problems are eliminated with the PRM since the baseline building is defined with less uncertainty.

PRM and Code Compliance

With ASHRAE 90.1 2016, the PRM can be used for both code compliance and beyond code programs. Besides being used for compliance with ASHRAE Standard 90.1, it is also used for compliance with the New York State Energy Code (NYS 2016). It is being piloted as an option for evaluations for U.S. Green Building Council's Leadership in Energy and Environmental Design® (LEED) (USGBC 2016). The fixed baseline approach has multiple advantages. It provides a solution where a single model can be used for both code compliance and beyond code assessment. With a baseline, whose performance requirements don't change every three years users can focus on development of technical expertise, software tools and verification systems instead of re-familiarizing themselves with a new set of rules for defining the baseline buildings. Previously, designers and engineers were required to generate separate models for code compliance and beyond code programs like LEED. Standard 90.1-2016 eliminates the need for this. The baseline building rules, based on ASHRAE Standard 90.1-2004 (ASHRAE 2004), also eliminate some of the more complicated code requirements introduced in later code editions, such as those for skylights and daylighting control. If these are not included in the proposed building design, but required in the baseline they are difficult to automate consistently and defining the baseline becomes a design problem with a number of solutions. 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 several ways in which these requirements can me modelled, each representing different levels of savings. Savings are also dependent on methodologies such as target illuminance levels or daylight sensor locations, which can be challenging to automate. Defining the baseline building becomes a design problem, with many acceptable solutions. Other prescriptive requirements that are difficult to incorporate in the baseline building are building orientation, perimeter daylighting, and exterior shading. Hence, Standard 90.1-2016 fixes the baseline to Standard 90.1-2004 where every new version of the code would now be a percentage improvement over the baseline.

This standardization and simplification of the baseline encourages the development of software tools that automate the process of generating the baseline building. It also streamlines the code development process where each new version of the standard can focus on refining existing ruleset and establishment of market viable improvement targets, rather than trying to align itself with the improved set of prescriptive requirements of the new standard (Rosenberg 2016).

Performance Rating Method Reference Manual

A Performance Rating Method Reference Manual has been developed to support compliance with the PRM for Standard 90.1-2010 (Goel et al 2016). This Reference Manual includes an expanded set of rules and guidelines that provides the modelling approach for defining the baseline and proposed building in accordance to Standard 90.1-2010 PRM. Its purpose is to improve the accuracy and confidence in energy modelling. It is based on a variety of sources including the Commercial Energy Service Network (COMnet) Modeling Guidelines and Procedures (MGP), the California NonResidential Alternative Calculation Manual (NACM) and the Energy Cost Budget (ECB) Compliance Supplement developed by Standing Standard Projects Committee (SSPC) 90.1 ECB Subcommittee (COMnet 2014), (CEC 2013), (ECB 1999). As a comprehensive modelling guideline, it provides a resource for modellers, designers, energy analysts and software developers. The Reference Manual for Standard 90.1-2010 was also used to guide the development of the Standard 90.1-2010 OpenStudio measure for automatically generating the baseline. A future updated version of the Reference Manual for Standard 90.1-2016 will provide similar guidance for Standard 90.1-2016. It will inform the development of an updated OpenStudio (OpenStudio 2016) measure, which would apply the rules specified within the manual to automatically generate the baseline building model. Both of these activities are under development by the authors.

The Reference Manual for 2016 will provide more certainty for standardizing the building energy modelling process for compliance that uses the Appendix G methodology. The 2016 PRM-Reference Manual will be coordinated with the (COMNET) Modeling Guidelines and Procedures (MGP), which already include modelling rules for the 2016 Appendix G procedure. (COMNET 2016).

Energy Modeling Guidelines

PRM Reference Manual is a methodology document developed by the Pacific Northwest National Laboratory. The purpose of this manual is to standardize building energy modelling by creating consistent baselines according to the requirements of ASHRAE Standard 90.1 Appendix G's Performance Rating Method. The Reference Manual comprises of a set of rules and guidelines that provides the standardization for specific modelling inputs in the baseline building as well as restrictions for the corresponding input for the proposed building. It provides default values for basic modelling assumptions such as schedules of operation, plug loads, ventilation loads, equipment performance and operation, etc., providing a reliable and consistent default values for the baseline and proposed designs where actual values are not available.

It also provides details for converting the PRM requirements into energy modelling inputs. For instance, Standard 90.1-2010 specifies pump power for chilled water, condenser water and hot water pumps. However, this specification (a W/gpm value) cannot be directly analysed using most energy modelling tools and needs to be converted into values that can be entered into simulation tools (pump head and impeller and motor efficiency).

Clarifications to Code Requirements

In addition to the modelling guidelines, the Reference Manual provides clarifications to the rules defined in Appendix G. These clarifications have been made in consultation with experts such as energy modellers, members of the ECB Subcommittee of Standard 90.1 and LEED reviewers. Some clarifications have also paved way for code change proposals for future version of Appendix G. One such example of a clarification provided by the Reference Manual includes the rules for specifying the maximum fenestration area. Where Standard 90.1-2010 Appendix G requires the fenestration area to be a maximum of 40% of above-grade wall area for the baseline building, the Reference Manual clarifies this requirement to be individually applicable for each space conditioning category (residential, non-residential and semi-heated). The Reference Manual underwent an extensive peer review process prior to its publication, providing greater quality assurance and validation to its interpretations and modelling guidelines.

PRM Reference Manual 2016

The new version of the Reference Manual for ASHRAE Standard 90.1-2016 is under development and will be published in 2017. Similar to the Reference Manual for Standard 90.1-2010, this document would provide the modelling guidelines and procedures for modelling the proposed building design and the baseline building in accordance to ASHRAE Standard 90.1-2016, following the fixed baseline approach. The fixed baseline approach is being piloted by LEED as an alternative to the 2010 PRM for Energy and Atmosphere Credit 1, Optimize Energy Performance. The Reference Manual for Standard 90.1-2010 plays a substantial role in providing guidance for modelling in accordance to Standard 90.1-2010 PRM. The manual for Standard 90.1-2016 would play a key role in understanding the PCI approach and all additional requirements that have changed between Standard 90.1-2010 PRM and Standard 90.1-2016 PRM.

The section below explains the technical approach for the development of the manual and explains the structure followed for its development.

The intent of the manual is to provide energy modelling guidelines for modelling buildings for code compliance or beyond code programs. The manual elaborates on the requirements for ASHRAE Standard 90.1-2016 PRM and explains how they apply to both baseline and proposed building. It comprises of five chapters, where:

- Chapter 1 gives an overview of the document and its purpose as well as the types of projects it can be used for.
- Chapter 2 provides general modeling procedures. It defines a space, thermal zone and thermal block as well as the guidelines for classifying a building into these three components. It defines the rules for baseline equipment sizing as well as rules related to unmet load hours for the baseline and proposed building. It addresses some of the ambiguous requirements in Standard 90.1-2016 concerning dealing with unconditioned spaces, handling of semi-heated spaces and well as modeling requirements for special space types including parking garages, crawlspaces and attics. It explains the process for calculating the PCI for proposed buildings to determine compliance.
- Chapter 3 documents specific code requirements as applicable to the baseline and proposed buildings. These are done using 'building descriptors'. A building descriptor addresses code requirements that need to be defined in the energy model for the baseline or proposed building. Some building descriptors are not code requirements but are provided as modeling guidelines to improve consistency between energy models. For example, the Standard 90.1-2016 Reference Manual will provide defaults for equipment performance curves, internal loads and schedules of operation, which are not prescribed by the standard but can be used if the design value is not known.
- Chapter 4 of the document summarizes the process used for defining energy cost data, including default values for annual state average energy costs as well as the guidelines for defining custom utility data using tariffs, energy, demand charges and ratchets.
- Chapter 5 provides the requisite content and format of the standard output reports required by PRM-RM, following requirements specified by the Standard 90.1-2016 Appendix G as well as LEED V4. The standard output reports provide a means for the rating authorities to view building information written out by the software tool, eliminating human errors or inconsistent interpretation of requirements.

There have been significant revisions between the 2010 and 2016 editions of Standard 90.1, including definition of the baseline HVAC systems. The 2010 PRM based the baseline HVAC system type on the building function, size, number of floors and proposed building heating fuel source. The 2016 edition (and the 2013 edition) has added another distinction based on climate zone. Additional details added include the specified window-to-wall (WWR) for the baseline building and the baseline service hot water system fuel source, which vary based on the use type of the building. Additional requirements have been added for computer rooms with respect to baseline HVAC system selection (Section G3.1.1(g)), elevators (Table G3.1.16), commercial refrigeration systems (Table G3.1.17), economizer control (Section G3.1.2.6.1) and equipment schedules (G3.1.3.15). The modelling and implementation of all these new requirements would be more efficient and less prone to varying interpretations through the Reference Manual for Standard 90.1-2016. Fixing the baseline has many advantages that have already been discussed. The change also allows one energy model or workflow to be used for multiple purposes: code compliance, LEED points, utility incentive programs, etc. It would allow for a more streamlined adoption of this standard as a compliance option by providing additional guidance and clarifications regarding the intent and modelling approach for each requirement.

Automated Baselines

With the ever-changing code requirements, much of the investment in developing modelling processes and QA/QC process for each code cycle are rendered obsolete by the next code cycle, which provides a new set of minimums for the baseline and revises the rules, which govern the baseline model development. Standard 90.1-2016 addresses this issue by fixing the minimum to 2004 levels making automated baselines a more viable option.

Several software tools have developed partial capabilities for automatically generating the baseline building model for Standard 90.1-2010 (IES 2016, DesignBuilder 2016, OpenStudio 2016, Bentley Systems 2016). Due to the complexity of the rules that define the characteristics of the baseline building, and the limited market short lifespan for these tools, none of these capabilities can automatically generate a 100% complete baseline building (IES 2016, DesignBuilder 2016) . In addition, with the new 2016 standard, these rules would need to be defined yet again to generate a baseline compliant with the Standard 90.1-2016 requirements. Such capability is being developed by PNNL using OpenStudio Measures. OpenStudio Measures are discussed in more detail below.

OpenStudio Measures

OpenStudio is open source software for whole building energy modelling using the EnergyPlus simulation engine (US DOE 2015) and advanced daylight analysis using Radiance. (Guglielmetti 2011). OpenStudio Measures are scripts written in the Ruby scripting language, which are executed against an OpenStudio input file to make a controlled change. Measures can be used for actions affecting specific components or systems of a building like modifying the WWR of a building or adding controls to a HVAC system.

Measures can also be used at the whole building level, for instance, to automatically generate a baseline-building model based on the user defined proposed building model.

A measure by National Renewable Energy Laboratory (NREL) has been developed, which takes in the proposed building model and partially creates the corresponding ASHRAE 90.1 PRM Appendix G baseline (EERE 2016). Most of the functionality is complete for ASHRAE Standards 90.1-2010 and 90.1-2013 and is under development for Standard 90.1-2016 PRM by PNNL. The Reference Manual for Standard 90.1-2010 has been used in the development of the OpenStudio measure for automating the baseline model for Standard 90.1-2010 and the Reference Manual for Standard 90.1-2016 will be used for in the development of the measure for automating the baseline model generation for Standard 90.1-2016.

Workflow for the Automated Baseline

The automated baseline approach reads the proposed building model and generates the baseline-building model on the basis of the same. Based on the specified standard (ASHRAE Standard 90.1-2010, 90.1-2013, or 90.1-2016), the proposed model is modified in accordance to rules specified in the corresponding standard to generate the baseline building model. For example, it is modified to have the appropriate construction types and properties, appropriate WWR, skylight to roof ratio (SRR), HVAC system based on the building type and heating fuel source and design supply air temperatures. A sizing run is carried out post these modifications to determine space loads, equipment capacities and design airflows. On the basis of the calculated space loads, envelope constructions might be modified, if a space is classified as semi-heated. The heating, cooling capacities and design airflows trigger requirements for economizer controls, energy recovery ventilation, equipment efficiency, etc. All these inputs inform the annual run for the baseline building. This entire process for the sizing run and annual run is then repeated for all four orientations by rotating the building by 90° each time (Figure 2).

Standard Outputs

The process of code compliance or certification can be further streamlined by providing standard outputs that meet the compliance or certification requirement. Capabilities can be added that would automatically read the output for the four baseline runs, average the results and calculate the percentage improvement of the proposed building for Standard 90.1-2010 or the PCI for Standard 90.1-2016. Chapter 5 of the Reference Manual for Standard 90.1-2010 (Goel et al 2016) provides a list of standard reports that could be provided by software tools automatically generating the baseline, in addition to the performance rating. The standard outputs would include basic building information (like floor area, use types, number of floors), building performance results (such as energy use by end use and fuel type), a summary of model inputs for both baseline and proposed design, and standard diagnostic messages like unmet load hours and simulation error messages and warnings. The standard output reports have the potential of streaming both the compliance and verification process if incorporated into the automated baseline workflow.

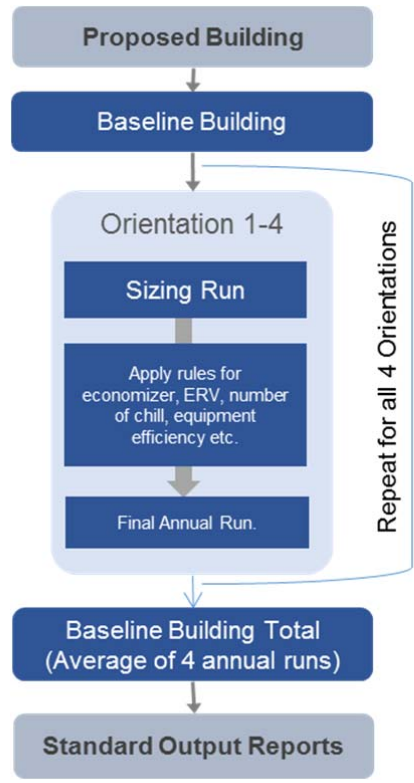

Figure 2: Automatic Baseline Model Generation Process

Vision for a Complete Workflow

This paper has outlined a vision for a complete workflow, allowing for a consistent, standard and streamlined process for code compliance. Standard 90.1-2016 provides the PRM as a new code compliance option and fixes the baseline at 2004 efficiency levels, allowing each new code to specify a performance cost index target improvement over the previous version. The Reference Manual would guide the process of defining the proposed building model and inform the development of software tools for automating baseline model generation. These software tools would write out standard outputs that could be used for specific programs, hence providing greater quality assurance and improving the efficiency of the entire workflow. Use of a standard output schema has the potential of further streamlining this entire workflow by removing redundancy for energy modellers associated with filling out output forms for different programs. This complete workflow has the potential for streamlining the modelling process for the PRM with workflows that are well understood, documented and implemented.

Conclusion

ASHRAE Standard 90.1-2016 PRM proposes a completely new approach to code compliance and hence, provides a solution where a single model can be used for both code compliance and beyond-code programs such as LEED. It significantly reduces the complexity of modelling efforts required for design teams and provides a consistent benchmark for building owners. The stable baseline encourages software developers to add features to automate the process of generating the baseline building. Aided through the Reference Manual and automated baseline model generation capability through OpenStudio and other tools, this approach would facilitate the entire process for code compliance and analysis for beyond code programs. Industry wide adoption of the additional details provided by the document will pave the way for more consistent energy modelling including the automation of consistent baseline building generation. This will lead to more cost effective and accurate modelling. Review periods will be significantly reduced. With the adoption of the fixed baseline approach in Standard 90.1-2016, it will be more conducive for software tools to invest in the automated baseline process, as a single model will be useful for many different purposes.

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