Pacific Northwest NATIONAL LABORATORY

PNNL-31571

HVAC System Performance for Energy Codes

Technical Brief

July 2021

S Goel
R Hart
M Tillou
M Rosenberg
J Gonzalez
K Devaprasad
J Lerond

U.S. DEPARTMENT OF ENERGY

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

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
the Office of Scientific and Technical
Information,
P.O. Box 62, Oak Ridge, TN 37831-0062
www.osti.gov
ph: (865) 576-8401
fox: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
email: info@ntis.gov
Online ordering: http://www.ntis.gov

PNNL-31571

HVAC System Performance for Energy Codes

Technical Brief

July 2021

S Goel
R Hart
M Tillou
M Rosenberg
J Gonzalez
K Devaprasad
J Lerond

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

Pacific Northwest National Laboratory
Richland, Washington 99354

Preamble

The U.S. Department of Energy (DOE) and Pacific Northwest National Laboratory (PNNL) are developing a series of technical briefs supporting national, state, and local initiatives update and advance building energy codes. These technical briefs represent a specific technologies, measures or practices that can be incorporated as module-based “plug-ins” via the national model energy codes, such as the International Energy Conservation Code (IECC) or ASHRAE Standard 90.1, or adopted directly by state and local governments pursuing advanced energy savings and greenhouse gas (GHG) emissions reductions. The collection of briefs is part of a larger effort to provide technical assistance supporting states and local governments, and to help them realize their policy goals.

This technical brief provides an additional heating, ventilation, and air conditioning (HVAC) System Performance path that goes beyond the prescriptive energy code. It provides a comprehensive performance-based approach for HVAC system evaluation and analysis. Potential building savings for the base package ranges from 23% to 58%, while the advanced package building savings ranges from 12% to 125%. The technical brief provides an overview of the Total System Performance Ratio (TSPR) metric, the performance-based evaluation methodology, and also includes code language that can be adopted by local jurisdictions for new buildings and major renovations. The code language included is an amendment to the 2021 International Energy Conservation Code, although it can be adapted to amend other codes.

Additional assistance may be available from DOE and PNNL to support states and local governments who are interested in adding Energy Credits and other “stretch” provisions to their building codes Assistance includes technical guidance, customized analysis of expected impacts (e.g., based on state-specific building stock, climate considerations, or utility prices), and further tailored code language to overlay state building codes or other standards. DOE provides this assistance in response to the Energy Conservation and Production Act (ECPA), which directs the Secretary of Energy to provide technical assistance “to support implementation of state residential and commercial building energy efficiency codes” (42 USC 6833). PNNL supports this mission by evaluating concepts for future code updates, conducting technical reviews and analysis of potential code changes, and assisting states and local jurisdictions who strive to adopt, comply with, and enforce energy codes. This helps to ensure successful implementation of building energy codes, as well as a range of advanced technologies and construction practices, and encourages building standards which are proven practical, affordable, and efficient.

DOE Building Energy Codes Program

The U.S. Department of Energy supports the advancement of building energy codes. Modern building codes and standards offer cost-effective solutions, contributing to lower utility bills for homes and businesses, and helping to mitigate the impacts of climate change. Learn more at energycodes.gov.

Executive Summary

The prescriptive path is likely the most widely used approach for commercial code compliance in the United States. Though easy to implement, the prescriptive approach does not discriminate between high-performing and poorly performing heating, ventilation, air conditioning (HVAC) system configurations that are both minimally compliant. To meet aggressive energy and carbon reduction goals, energy codes will need to transition from prescriptive to performance-based approaches, a transition that is riddled with several challenges. HVAC System Performance is a discipline performance path and provides a simpler solution to HVAC system evaluation compared to whole building performance, while keeping tradeoffs limited to specific building systems. The Total System Performance Ratio (TSPR) is a metric for evaluation of overall system efficiency instead of individual component efficiency, a solution that could also eventually facilitate the transition to a 100% performance-based code structure. TSPR is a ratio that compares the annual heating and cooling load of a building to the annual energy consumed by the building's HVAC system. A web-based calculation tool has been developed for determining a building's TSPR. Already incorporated into the 2018 Washington State Energy Code, this approach has also been evaluated by the ASHRAE Standard 90.1 Project Committee and has the potential to provide a comprehensive performance-based approach for HVAC system evaluation and analysis

This technical brief includes a sampled analysis of potential savings. For a base requirement case, the target HVAC performance requirements can save energy when compared to a minimum efficiency prescriptive system selection. For a jurisdiction with aggressive energy or emission policy goals, a more stringent HVAC performance requirement can increase savings. While impacts vary by building type and climate zone, national weighted impacts are expected to be in the following ranges:

- Base TSPR requirement: 20% to 58% HVAC energy savings when compared with a low-efficiency possible prescriptive system.
- Advanced TSPR requirement is recommended at a 12.5% HVAC energy savings above the base TSPR level; although a jurisdiction could set a higher bar, as potential savings range from 12% to 125%, depending on building type.

The range of potential system savings is summarized in Figure E.1. For the advanced TSPR requirements, savings are in addition to the base TSPR implementation.

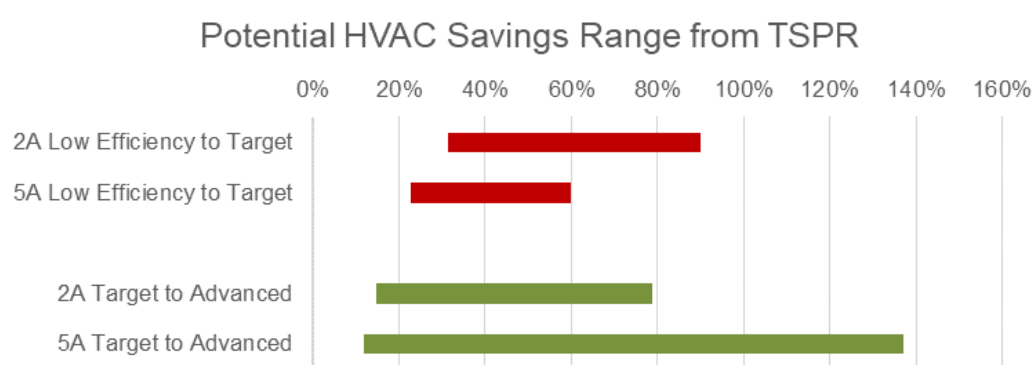

Figure E.1. Range of Possible TSPR HVAC Savings by Climate Type

Contents

Figures

Tables

1.0 HVAC System Performance

The HVAC System Performance Technical Brief provides an overview of the Total System Performance (TSPR) metric and the HVAC System Performance methodology, which can be adopted by a jurisdiction to encourage selection of efficient heating, ventilation, and air conditioning (HVAC) systems that meet their policy objectives and target higher than minimum prescriptive level of performance. The HVAC System Performance methodology is a discipline performance approach[1] that also paves the way for a transition to performance-based codes. Adoptable code language is been provided in Appendix A, which could be appended to the current building energy code adopted by the jurisdiction. This language is an overlay to the 2021 International Energy Conservation Code (IECC) (ICC 2021) and would need modification to be used with other energy codes.

The sections below provide an overview of why the transition to performance-based codes is critical to meet the aggressive energy and carbon reduction goals or meet policy objectives for electrification and decarbonization. It lays out the limitations associated with prescriptive path and the advantages and challenges associated with whole building performance path. The HVAC System Performance approach integrates the ease of use of the prescriptive path with the flexibility of the performance path by providing a simple approach that can be used for a system level analysis. Currently adopted by Washington State Energy Code (WSEC 2018) and under review for adoption as an addendum to ASHRAE Standard 90.1-2019 (ASHRAE 2019), this approach can be adopted through various formats that can be tailored to meet policy objectives, as discussed in Section 1.3.

1.1 Case for Performance Based Codes

Energy codes have traditionally contained *mandatory* and *prescriptive* items and an alternative *performance-based* compliance option. Mandatory measures must be complied with in all situations. Prescriptive paths establish minimum requirements for energy-related characteristics of individual building components such as minimum required R-values of insulation, solar heat gain coefficients of fenestration, occupancy sensors for lighting control, maximum fan power limits, and restrictions on window area, and others. Most whole-building performance paths on the other hand, allow buildings to trade-off some prescriptive requirements for improved performance in other building components and systems. The improved building performance is demonstrated through whole building energy simulation.

While easy to use and understand, the prescriptive path limits design flexibility and fails to acknowledge individual building characteristics as well as the interactive considerations that can optimize a building's energy performance with integrated solutions. Because prescriptive requirements are typically established at an individual component level and limited by cost effectiveness requirements, the rate of improvement of each subsequent code has slowed down based on economic considerations and limits of technological feasibility. In some cases, improvements in prescriptive requirements come at the expense of limitations in design flexibility. These are some of reasons that buildings choose the performance path over the prescriptive path to demonstrate compliance.

[1] An example of a discipline performance path is the Building Envelope Trade-Off Compliance Path in the envelope discipline of Standard 90.1 that is supported by Appendix C. There are current proposals under public review in Standard 90.1 for discipline performance paths for both lighting and HVAC disciplines.

It is also unlikely that energy codes largely dependent on prescriptive compliance will achieve aggressive savings policy goals. Figure 1 shows the rate of improvement in the prescriptive path of ASHRAE standards 90 and 90.1 since the first edition in 1975. It shows the rate of future improvement in three ways: (1) if the Standard continues to improve at the average rate it has since 1975, (2) if the Standard improves at the accelerated rate it has since 2004 (not likely, as described above), and (3) the rate at which it needs to improve if it is to reach net zero energy considering a reasonable amount of rooftop solar photovoltaics (Franconi et al. 2021). As indicated by this graph, the prescriptive improvements alone are not aggressive enough to pave the path to net zero energy for buildings. The HVAC Systems Performance path relies on a move to performance-based codes that treat the building as a system and encourage creative solutions more likely to lead to deep savings than the prescriptive alternative (Rosenberg et al. 2015).

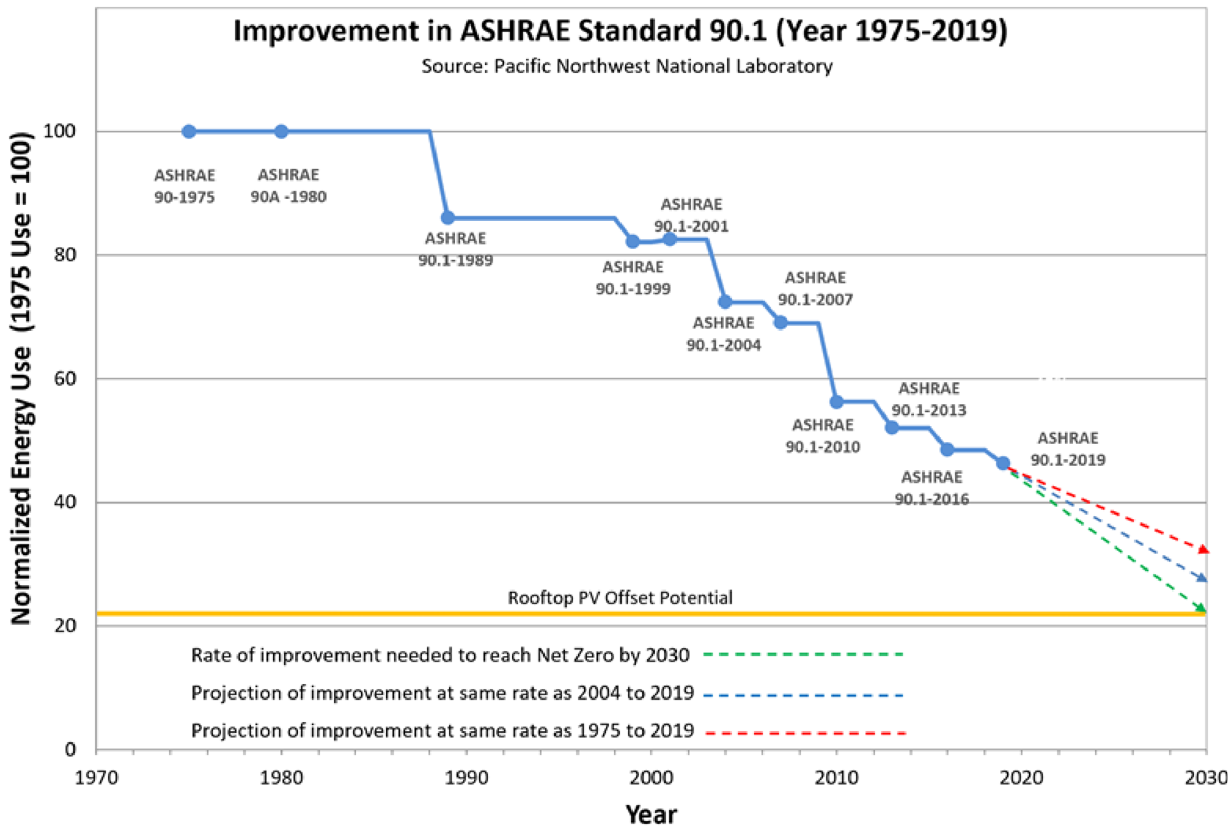

Figure 1. Past and Projected Savings from Prescriptive Code Compliance

1.2 System Performance Approach

Building energy performance has typically been evaluated at a whole-building level (energy use intensity, peak demand) or at an equipment level [e.g., chiller efficiency coefficient of performance (COP)] (Li et al. 2020). A whole building metric can be affected by the performance of any building system, including building envelope, lighting, HVAC, and service water heating, among others. Isolating the performance of individual building systems (for instance, reduced infiltration rate) using whole building metrics can be challenging. National model codes in the U.S. evaluate HVAC systems at either an equipment level (prescriptive approach) or through a whole building performance approach (the Performance Rating Method or Energy Cost Budget) (Rosenberg et al. 2020).

Prescriptive evaluation of HVAC systems includes the equipment's rated efficiency to determine compliance with the code. Commonly used HVAC system efficiency metrics include COP, energy efficiency ratio (EER), seasonal energy efficiency ratio (SEER), integrated part load value (IPLV), heating seasonal performance factor (HSPF) and annual fuel utilization efficiency (AFUE). Though excellent metrics for evaluating efficiency of system components at standard conditions, these ratings are not effective in quantifying actual system performance, which is affected by part load conditions. These metrics do not account for prescriptive requirements for associated HVAC system components such as energy recovery ventilation (ERV), economizers, and variable frequency drives on fans and pumps, as well as control requirements for things like temperature resets, fan speed control, and reheat limitations. While a whole building performance-based approach looks at the overall building performance, it is resource intensive, and distilling HVAC system performance from that analysis can be quite challenging. Additionally, whole building performance approaches allow trade-offs between long-lived components such as the building envelope and short-lived components such as HVAC equipment and controls (Jonlin et al. 2018a)

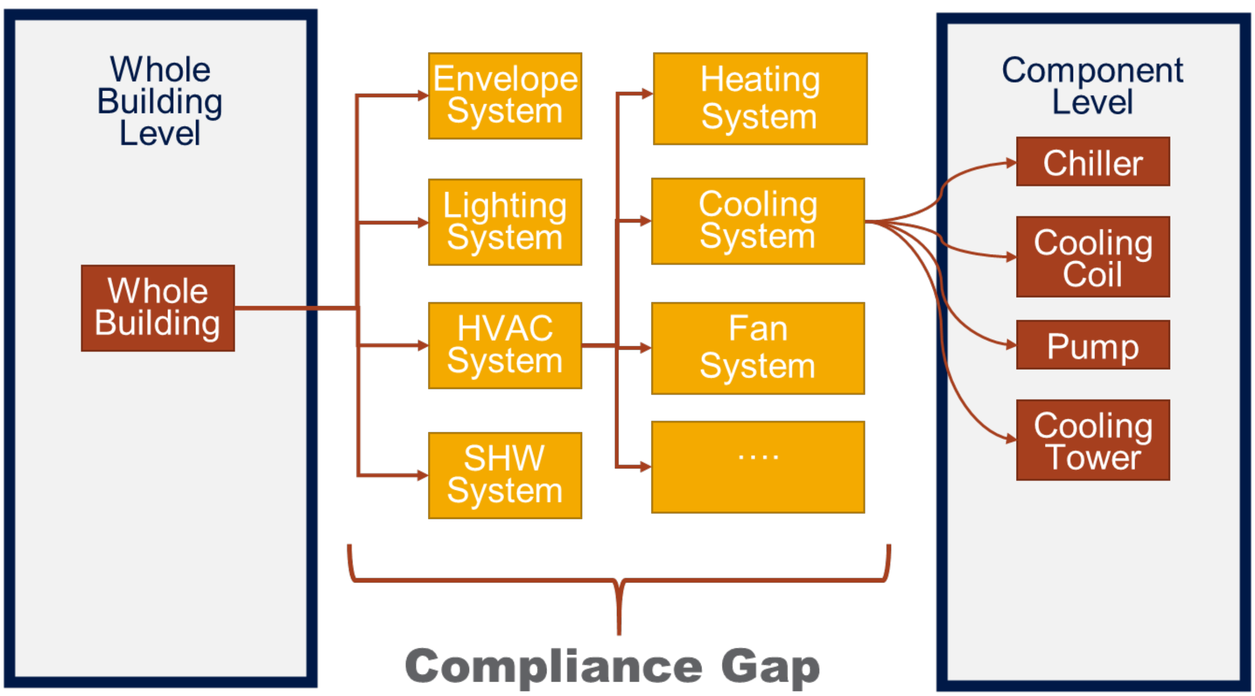

Figure 2. Compliance Paths and Need for a System Performance Approach (recreated from HPB 2019)

A more appropriate metric for evaluating an HVAC system would therefore be one that analyzes all components of the HVAC system, accounts for part load performance and system controls, normalizes for building loads and does not allow for trade-offs between different building systems (such as envelope and HVAC system) (Figure 2). The TSPR metric addresses all of these issues as it measures the amount of energy required to deliver each unit of heating and cooling to the building over the course of a typical year (Goel et al. 2014a; Jonlin et al. 2018b). Systems using less overall energy each year to meet the building's annual thermal and ventilation loads would be rated as more efficient. It does not allow trade-offs between different building systems and performance needs to be demonstrated through improvements within to the HVAC systems in the building. The TSPR metric and the related calculation procedures are further discussed in Section 2.0

The TSPR metric and the HVAC System Performance methodology are currently employed in Appendix D of the WSEC (WSEC 2018) and is currently undergoing public review as an addendum to ASHRAE Standard 90.1-2019. This approach has the advantage of encouraging increasing levels of performance while maintaining flexibility in allowing designers to optimize the most appropriate HVAC system based on the attributes of each particular project. The next section discusses the various ways this methodology could be adopted in code to meet different objectives.

1.3 The Code Approach

The HVAC System Performance approach is a discipline performance approach rather than a whole building approach.[1] It can be adopted in code in several different ways depending on the objective of the energy code and the policy goal that it’s trying to meet.

1. **Alternative Approach.** As an alternative approach, System Performance provides an alternative to prescriptive or performance compliance. Mandatory requirements are still required to be met. This approach has been proposed as an addendum to Standard 90.1-2022 for HVAC systems.
2. **Reduce HVAC Exceptions.** This is an ancillary effect of the adoption of the HVAC performance path in any form, although it does require intentional changes to the prescriptive requirement exceptions of the code. Once TSPR can be used to establish the equivalence of system approaches, several exceptions could be eliminated. For example, a water-based economizer is an allowable exception to an air side economizer, even though it increases cooling energy use. This exception or alternative economizer approach could be eliminated from the prescriptive description once the TSPR software requirements are expanded to include a water-side economizer. Then it is up to the designer to use the HVAC performance path to demonstrate that the entire HVAC system uses equivalent energy to a system with an air economizer. This would require that other components of the system be more efficient than prescriptive to make up for the lost efficiency of the water-side economizer.
3. **HVAC System Minimum Efficiency.** The System Performance approach could be incorporated into the energy code as a minimum requirement, where a building would need to meet the mandatory requirements, the prescriptive requirement and comply via the System Performance approach. An alternative to this would be whole building performance path. This approach can be effective in encouraging efficient HVAC system design choices in every building that complies with the code. It ensures that a code compliant building has an HVAC system that is equivalent to or better than the target system that is used to define the minimum performance level. This is the approach that has been adopted by the 2018 edition of the WSEC (WSEC 2018).

[1] An example of a discipline performance path is the Building Envelope Trade-Off Compliance Path in the envelope discipline of Standard 90.1 that is supported by Appendix C. There are current proposals under public review in Standard 90.1 for discipline performance paths for both lighting and HVAC disciplines. The HVAC performance approach is similar to the TSPR approach proposed here.

4. **Advanced System HVAC Efficiency.** This approach builds on top of the “Minimum Efficiency” approach, and in addition to making System Performance a requirement for compliance, it adds a certain factor to the compliance margin to encourage better performance than the target system. This is the approach that has been adopted by Seattle Energy Code (SEC 2018).
5. **Energy Credits.** The System Performance approach has also been adopted into the Energy Credits approach (Hart et al. 2021). The Energy Credits approach, adopted in the 2021 IECC (ICC 2020), includes extra efficiency measures, and adequate measures must be selected to satisfy an “additional” efficiency requirement. The efficiency requirement is stated on a point scale, with each measure assigned points or energy credits based on percentage of reduction in total building cost. Energy credits representing a 5% reduction in HVAC energy input can be included in the list of energy credit measures. The HVAC System Performance approach can be used to demonstrate how the proposed system is more efficient overall than a target system. Then that improvement can be used to prorate the energy credit points. This approach has been proposed for the Energy Credits section of the 2022 WSEC (Hart 2021).

This technical brief focuses on the HVAC System Minimum Efficiency, Advanced HVAC System Efficiency, and Energy Credits approaches and provides adoptable code language for jurisdictions targeting any of those three. These approaches are of interest because they result in the most HVAC system savings.

1.4 Technical Considerations

How does the proposed measure compare to what’s required in current codes?

Existing energy codes already include System Performance approaches. Appendix C in Standard 90.1-2019 is an envelope system performance approach. The 2021 IECC has a similar envelope UA trade-off approach. The 2018 WSEC includes an HVAC System Performance approach that follows the “HVAC Minimum Efficiency” code approach outlined in Section 1.3. The HVAC System Performance approach has also been proposed for Standard 90.1-2022 and is currently under review.

The technical brief proposes a slightly different approach than the one what has been adopted by WSEC 2018 and proposed for Standard 90.1-2022. The proposed requirements are similar to approach in WSEC 2018, where HVAC System Performance is an additional requirement for compliance instead of an alternate to prescriptive compliance like the Standard 90.1 addendum AG that is under review. It also adopts the Mechanical Performance Factor (MPF) approach of the proposal to Standard 90.1-2022, which sets the reference performance level equivalent to Standard 90.1-2019 Appendix G baseline (ASHRAE 2019) that is based on 2004 prescriptive requirements. In the approach represented here, the target levels of performance, defined through the MPFs, could be updated with each code cycle. This is further discussed in Section 2.0.

Why is the System Performance approach superior to other approaches?

The System Performance approach incorporates the best of the prescriptive compliance path and the performance compliance path. It has the ease of use of the prescriptive path and the flexibility of the performance path. It can be adapted to use different metrics, which can support different policy objectives. For instance, the TSPR target could be set using carbon emissions, which supports the objective of electrification and decarbonization. Similarly, it could be set using site energy, source energy, or energy cost. Stringency (represented through the MPF) could be increased over time. As explained in Section 5.0, 23% to 37%% HVAC energy use savings is possible with the adoption of TSPR as a HVAC minimum efficiency option and an additional 12.5% savings of national HVAC energy use savings is possible if HVAC System Performance is adopted as an advanced code approach. All of these characteristics make the System Performance approach a highly viable option to facilitate the transition to performance-based codes and to meet aggressive energy efficiency goals.

What strategies are considered to minimize compliance burdens?

To achieve deeper savings in response to energy and carbon reduction policy goals, HVAC System Performance provides a much more expedient path as compared to the whole building performance path, which requires a detailed custom-building energy model. The HVAC System Performance ruleset, included in Appendix A of this document, requires several model simplifications to be implemented in the simulation software used to comply with this approach. For instance, the reference baseline model is required to be generated automatically and the compliance tool should be able to determine the compliance outcome. A standard output report documents all building inputs and simulation results to facilitate the review process. These requirements have been incorporated in the TSPR tool and implemented as an extension of DOE's Building Energy Asset Score Tool (Wang et al. 2015) and provide a simple web-based interface to demonstrate compliance using the HVAC System Performance approach.

Are there existing codes and standards that take a similar approach?

The outlined approach is a simple expansion of the requirements in the 2018 WSEC code. The Seattle Energy Code has also adopted the WSEC with additional amendments for a more stringent requirement by setting the compliance target to be a certain percentage higher that what is required in the WSEC. While not yet adopted, proposed addendum AG to Standard 90.1-2019 used the alternative tradeoff approach, and proposed addendums to the 2018 WSEC expand the building types covered by TSPR.

2.0 HVAC System Performance Methodology

This section defines the TSPR metric and provides an overview of the compliance approach. It provides additional details on the process used to calculate the MPFs and how these factor into the compliance determination calculation.

2.1 TSPR: Definition and Calculation

TSPR is a ratio of the annual heating and cooling provided for a building to the energy consumed for heating, cooling, and ventilating a building. The calculation is performed using whole building simulation, similar to whole building performance energy modeling, but using a simplified methodology as defined by the HVAC System Performance path.

2.1.1 TSPR Input Metric

TSPR is calculated as the ratio of the sum of a building's annual heating and cooling load to some metric that represents the annual energy consumed by the building HVAC systems. That input metric could be annual site energy, source energy, energy cost, or carbon emissions. The appropriate TSPR metric can be chosen based on the policy goals and priorities of the jurisdiction adopting the HVAC System Performance approach. There are several ways to evaluate energy input to an HVAC system. Among them are:

- Energy cost inputs, based on local or national average prices
- Site energy inputs, based on delivered (metered) energy measured in a consistent conversion to a common metric such as British thermal units (Btu) or gigajoules (GJ)
- Source energy inputs, which include adjustments to site energy inputs to reflect the conversion efficiency of electrical generation and drilling and distribution losses for natural gas
- Emissions resulting from energy inputs, usually expressed as carbon dioxide equivalent (CO_2e), which may be based on a national conversion rate, regional electric conversion rates, or various streams of future emission impact resulting in a range of possible results

For this analysis, the TSPR is based on an input value based on site energy conversions. This approach produces a consistent result that does not change based on region or serving utility considerations. For specific applications, different metrics can be used based on local jurisdiction policy.

Currently, different jurisdictions use different approaches:

- The State of Washington and City of Seattle use a carbon basis, with state-adopted carbon conversion factors.
- A proposal undergoing review for Standard 90.1-2022 uses a cost basis, with national average energy prices, although alternative metric options are included.
- The proposed code amendments in Appendix A use a site energy basis, with industry standard conversion factors that do not vary by region or policy.

The simplest representation of energy consumed by the HVAC system would use site energy (energy consumed at the site). The section below uses site energy input to explain the TSPR concept.

2.1.2 The TSPR Concept

A larger TSPR indicates lower HVAC energy use to meet the loads, and therefore can be considered a more efficient system. The annual heating and cooling loads include envelope loads, solar gains through fenestration, internal loads due to lights, equipment, and occupants, as well as ventilation and infiltration loads. This metric provides a single evaluation criterion that addresses all components of the HVAC systems used to move heat and air into, out of, and within a building. It includes distribution system effectiveness, considers both full and part load performance, and accounts for system controls. This differs from standard system efficiency ratings (such as SEER, COP, or kilowatt-hours per ton) that usually address part of a system and fail to account for all the system inefficiencies that may be present within a building as well as their interaction with building loads and ventilation requirements. In addition, such component efficiency ratings are based on standard rating conditions that may not reflect actual building conditions and the ambient conditions at the building site. The HVAC System Performance approach accounts for all of these parameters to provide a comprehensive evaluation of a building's HVAC system.

To calculate the TSPR, annual energy use of all system components, including auxiliary components, is included in calculations for a complete HVAC system evaluation. Hence, the total HVAC energy use includes fuel-fired and electric heating coils (including reheat coils), direct expansion cooling coils, boilers, chillers, heat rejection, energy recovery, and distribution system fans and pumps. $E_{Heating\text{-}elec}$ and $E_{Heating\text{-}gas}$ account for the energy use of all heating coils in a system, include the pre-heating coil, main heating coil, supplementary heating coil, and reheat coil. Similarly, E_{fan} includes the energy use of all fans in a system, including the supply fan, exhaust fan, return fan, and relief fan. E_{Pump} includes the energy use of all hot-water pumps, chilled water pumps, and condenser water pumps serving the system. The impact of HVAC system controls, such as fan static pressure and variable speed control, is accounted for through the energy use of that particular component. For example, the energy consumption of a fan in a variable air volume (VAV) system with static pressure reset will typically be lower than that for the same system without static pressure reset. Hence, the component E_{fan} accounts for the impact of system controls affecting fan energy use, similarly $E_{cooling}$ accounts for the impacts of economizer control and $E_{Heating}$ accounts for the impact of energy recovery.

$$HVAC\ Energy\ \text{Consumption}_{Total} = \left(E_{Heating-Elec} + E_{Heating-Gas} + E_{Heating-\text{Propane}} + E_{Heating-\text{Oil}} + E_{Cooling} + E_{Fan} + E_{Pump} + E_{Heat-Rejection} + E_{Heat-Recovery}\right)[kBtu] \quad (1)$$

where

$E_{Heating\text{-}elec}$ = heating electric energy consumption (kBtu)
$E_{Heating\text{-}gas}$ = heating gas energy consumption (kBtu)
$E_{Heating\text{-}propane}$ = heating propane energy consumption (kBtu)
$E_{Heating\text{-}oil}$ = heating oil energy consumption (kBtu)
$E_{Cooling}$ = cooling electric energy consumption (kBtu)
E_{Fan} = fan electric energy consumption (kBtu)
E_{Pump} = pump electric energy consumption (kBtu)
$E_{Heat\ Rejection}$ = heat rejection energy consumption (kBtu)
$E_{Heat\ Recovery}$ = heat recovery energy consumption (kBtu)

To determine the annual heating, cooling, and total loads for each building, the simulation uses a special HVAC system type available in DOE's EnergyPlus software called the Ideal Loads system (DOE 2018a). This system calculates the annual heating and cooling load (including ventilation load) for each zone in the building and supplies heating or cooling air to meet the setpoints as if the heating and cooling system efficiency was 100%. In other words, it finds how much heating and cooling service is actually delivered to each zone. This system includes setpoints for temperature and humidity control, and outdoor air quantity, so it truly represents the complete load on the HVAC system. Thus, the TSPR is calculated according to Eq. (2).

$$Total\ System\ Performance\ Ratio = \frac{Ideal\ annua\ heating\ load + Ideal\ annual\ cooling\ load\ (kBtu)}{(TotalElectricityConsumption + TotalGasConsumption\ )\ (kBtu)} \quad (2)$$

2.2 Compliance Calculations

The HVAC System Performance approach in energy codes follows a performance-based analysis with a minimum performance level identified through "target systems." Target systems are defined for each climate zone and building type and represent minimum prescriptive levels of performance for a "good" HVAC system. The HVAC system selected for the target attempts to strike a balance between the least efficient system configuration and a highly efficient system configuration by selecting a "good system," which is used to calculate the desired performance for each building type and climate zone. These are documented in Appendix A Table CD106.1(1-3) of this report. A "reference system" is also defined, which follows the Standard 90.1 Appendix G baseline configuration, which meets the Standard 90.1-2004 code (ASHRAE 2004) requirements and provides a stable baseline for comparison. The reference systems are listed in Table CD105.3.11(1-3), Appendix A of this report.

Similar to the Building Performance Factors (Rosenberg and Hart 2016) in Standard 90.1 Appendix G, Mechanical Performance Factors (MPF) are defined using the reference and target systems for each climate zone and building type. An MPF is simply the ratio of the reference TSPR to the target TSPR and represents the improvement in system output per cost for a target system ($TSPR_t$) compared to the reference system ($TSPR_r$). This allows the reference systems to remain stable in the simulation tool used to comply with HVAC System Performance path, with only a table of MPFs updated for each edition of code.

$$MPF = TSPR_r / TSPR_t \quad (3)$$

where

$TSPR_t$ = target TSPR
$TSPR_r$ = reference TSPR
MPF = Mechanical Performance Factor based on climate zone and building use type

The System Performance approach compares a proposed mechanical system ($TSPR_p$) with a reference mechanical system ($TSPR_r$) using the MPF. Proposed systems using the same or less overall annual energy as a selected target system to meet the building's annual thermal and ventilation loads would be rated as equivalent or more efficient. Then the improvement for the proposed system would need to be greater than or equal to the improvement for a target system ($TSPR_t$). So, efficiency equivalence is demonstrated where:

$$TSPR_p \geq TSPR_t \ OR \ \frac{TSPR_p}{TSPR_r} \geq \frac{TSPR_t}{TSPR_r} \ OR$$

$$\frac{TSPR_p}{TSPR_r} \geq MPF \qquad (4)$$

where:

$TSPR_t$ = *target TSPR*
$TSPR_r$ = *reference TSPR*
$TSPR_p$ = *proposed TSPR*
MPF = *Mechanical Performance Factor based on climate zone and building use type*

2.3 Reference HVAC Systems

The HVAC System Performance Approach establishes reference HVAC system specifications for five covered building types: office, retail, multifamily, hotel, and school. The reference systems have been separately defined for large offices (gross conditioned floor area >150,000 ft^2 or > 5 floors), medium offices (gross conditioned floor area 5000 to 150,000 ft^2 and ≤ 5 floors), and small offices (gross conditioned floor area ≤5000 ft^2 and ≤ 5 floors). Together, these five building types represent approximately 72% of new construction starts in the country for commercial buildings (Lei et al. 2020). The reference systems are climate zone specific, where warm climate zones, classified as climate zone 0 to 3A, have an electric system, such as packaged rooftop heat pump for the small office reference building or a packaged variable air volume system (P-VAV) with fan powered parallel induction units and electric resistance reheat for the large office buildings. The cold climate zones, classified as climate zones 3B, 3C, and 4-8, have gas fired systems, such as packaged rooftop gas furnaces for small office and VAV with hot water reheat systems for large office. Each of these systems are defined to represent a baseline level of performance, as prescribed by Standard 90.1-2019, Appendix G.

These systems are listed in Table CD105.3.11(1-3) within Appendix A of this document.

2.4 Target HVAC Systems

The target systems, defined through a consensus process within the Standard 90.1 committee, represent standard energy-efficient design practice. All aspects of the target system are defined to comply with the code. The system choice is meant to represent common practice for a particular use type and climate zone and has not been set to represent the most efficient HVAC system configuration nor the least efficient HVAC system configuration, as an attempt to provide a compliance path that is viable. This approach places a great deal of importance on the selection of the appropriate HVAC system type. The target systems are listed in Appendix A, Table CD106.1(1-3) of this document. In most cases, the target system is the same type as the reference (for example, the small office systems) and includes higher equipment efficiencies as required by the prescriptive energy code as well as additional HVAC system controls such as air-side economizers, ERV, or demand control ventilation (DCV), requirements for which have since been added to the code. For some use types, the system has been modified between the reference and target (as in the case of the multifamily use type) to represent more efficiency design choices that are more prevalent for that use type. This is seen in the case of the multifamily use type, where a reference system is defined using packaged terminal heat pumps (PTHPs) and packaged terminal air conditioners (PTACs) and the target system uses a single zone dedicated outdoor air system (DOAS) with ERV and split systems for heating and cooling.

2.5 Defining the Proposed Building

To comply with the HVAC System Performance approach, the ratio of the TSPR of a proposed building design to that of the reference building design needs to be greater than the MPF for that building type and climate zone. Simulation software, which implements the HVAC System Performance ruleset and meets all the requirements outlined in the ruleset (Appendix A), would be used to analyze the proposed building. The simulation software is required to automatically generate the reference building and determine the proposed building TSPR and reference building TSPR.

The proposed building is required to be modeled in accordance with rules defined in the adoptable code language in Appendix A. These include a simplified modeling approach for the building geometry, envelope construction, interior loads, HVAC system specifications, and so on. The ruleset prescribes several simplifications that are required to be automatically applied to the proposed building by the simulation tool, including a simplified thermal zoning requirement, standard loads and schedules, prescribed envelope construction assemblies, and calculation of capacity weighted average equipment efficiencies for similar HVAC system types serving the building (Jonlin et al. 2018b). The user is required to create a simplified geometric representation of the building, define the use types, the thermal properties for each unique envelope construction, and the as-designed HVAC systems. The simulation tool workflow is discussed in additional detail in Section 3.0.

3.0 Analysis Tool

The adoptable code language provided (Appendix A) specifies the requirements for a simulation tool that can be used to demonstrate compliance with the HVAC System Performance Path. It outlines the requirements for defining the proposed building along with the necessary simplifications required to be implemented by the simulation tool. One of the key simplifications is a capability to automatically generate reference building model. It outlines all the capabilities a simulation tool would need to incorporate, including an output report with the compliance outcome that would need to be automatically generated by the tool. Any tool that implements these requirements could be used for compliance analysis for the HVAC System Performance path. The HVAC System Performance ruleset has been implemented into DOE's Building Energy Asset Score tool (Asset Score Tool), to provide a no-cost software tool that can used by jurisdictions interested in adopting this approach.

The following sections describe the simulation tool requirements, as outlined in HVAC System Performance Ruleset, software architecture of the Asset Score Tool, the various simplifications implemented within the tool to support the HVAC System Performance ruleset, and the compliance report generated by the tool.

3.1 Simulation Tool Requirements in the HVAC System Performance Path

The HVAC System Performance ruleset defines the requirements for a simulation tool implementing the ruleset. The defined approach employs several simplifications, which are required to be supported by the simulation tool for defining the proposed building design. The intent of these simplifications is to reduce the level of effort associated with developing an energy model by limiting the parameters that can be entered by the user, and using standard modeling defaults for parameters not available for the user to edit. Table CD105.2.10.2(1) in Appendix A outlines the required inputs for defining the proposed building HVAC system and also lists several defaults that are required to be implemented by the simulation tool. Building operation schedules and loads, including schedules of operation, plug loads, ventilation loads, equipment performance and operation, and more, are prescribed based on ASHRAE Standard 90.1 Appendix C and cannot be modified by the user (ASHRAE 2016).

As defined in Sections CD104 and CD105 in Appendix A, the simulation tool implementing the HVAC System Performance ruleset is required to automatically generate the standard reference design based on the user-specified proposed building design. The standard reference design should be specified to be the same as the proposed design except for the HVAC systems, which are modified as prescribed by the ruleset (Table CD105.3.11 (1-3) in Appendix A). The tool is then required to run annual simulations for the reference and proposed building to determine the annual HVAC energy use and annual heating and cooling loads. Compliance is determined by the simulation tool by calculating the proposed building TSPR, reference building TSPR and comparing its ratio against the required MPF for that climate zone and building type[1]. The simulation tool is also required to provide a compliance report that outlines the compliance outcome and additional details (Section CD104, Appendix A) including user-specified inputs, and simulation results, to facilitate the compliance review. Any simulation tool that which meets the requirements laid out in the HVAC System Performance ruleset in Appendix A can be used to determine compliance with this approach.

[1] An area weighted average MPF would be calculated for a mixed-use building.

3.2 Overview of Asset Score Tool

The Asset Score Tool, developed by Pacific Northwest National Laboratory (PNNL) for DOE, is a web-based tool to help building owners and managers assess the efficiency of a building's energy-related systems and to encourage investment in cost effective improvements (DOE 2018b; Wang 2015). Asset Score Tool uses EnergyPlus and OpenStudio to develop a whole building energy model of a building and provides an assessment of building systems based on the specified building characteristics (DOE 2018a; OpenStudio 2018). Its simplified interface allows a user to define their building characteristics and runs whole building energy simulation using standard operating assumptions to generate an Asset Score for the user's building. The tool also identifies upgrade opportunities for energy savings and a corresponding "potential" Asset Score. An additional module has been added to the Asset Score Tool for HVAC System Performance analysis that allows a user to define their proposed building design in accordance with the proposed code requirements and automatically generates the reference design following the rules defined in the code. The tool also applies the appropriate MPFs to the results to determine the compliance outcome, which is documented in the compliance report generated by the tool. The following sections explain the tool workflow for defining the proposed building and generating compliance results.

3.3 HVAC System Performance Analysis Workflow in Asset Score Tool

The Asset Score Tool provides a simplified interface for a user to define their proposed building design and automatically generates the reference building based on the rules defined in the HVAC System Performance ruleset for compliance analysis. Simulation runs generate a PDF report that includes the compliance results and additional details about the building for a code official to verify against design drawings. The tool itself is modular in design for a clean separation of functionalities, easier testing, and development. The core components of the Asset Score Tool application are functionally separated into the following four subsystems:

- User interface that allows a user to define the properties of the building
- Asset Score Application that stores all user inputs and additional code requirements (e.g., MPFs) in a database and translates this information into the Asset Score data model
- Modeling Engine that takes in the Asset Score data model and generates the corresponding OpenStudio models for simulation using EnergyPlus.
- Report Generator that post-processes the simulation results.

The TSPR module has been built on top of the Asset Score Tool structure and adds the capability to automatically generate the reference building based on the rules defined in the HVAC System Performance ruleset.

The Asset Score Application's web interface allows users to define their building geometry, envelope, HVAC, and lighting systems. For a TSPR analysis, certain values are prescribed and automatically defaulted based on the code requirement. For example, the code prescribes the lighting power density and infiltration rate, which are automatically added by the tool. User-specified values, in conjunction with the ruleset's default values, provide the required inputs for constructing an OpenStudio simulation model. The Asset Score Modeling Engine ingests these inputs to generate three separate analyses used to calculate a TSPR: the ideal loads run, the sizing run, and the annual run.

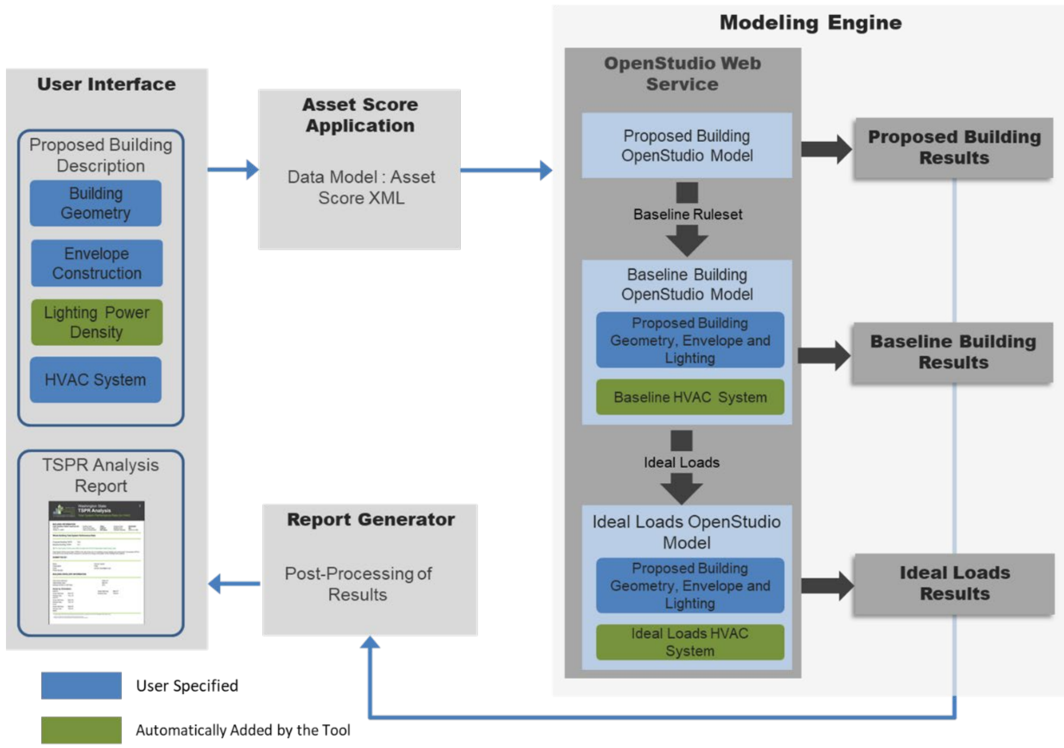

Figure 3. HVAC System Performance Tool Structure for HVAC System Performance Analysis

The ideal loads analysis calculates the annual heating and cooling loads of the building. The sizing run calculates the design system capacities and flow rates used to inform values for certain parameters in the annual run (e.g., cooling tower fan power, minimum airflow fraction for VAV with reheat terminals). Lastly, the annual run calculates the annual energy use by end use for the entire building. These three analyses are done for both the proposed building and the reference building. The proposed run represents a user's inputs as entered in the Asset Score Application. The reference building run is identical to the proposed building in terms of its geometry, envelope construction, internal loads, and ventilation loads, but with a code reference HVAC system in place of the user's HVAC system. The Report Generator ingests the simulation outputs and calculates the TSPR for the proposed and reference buildings. The Asset Score Application provides the required MPFs for the building based on its climate zone and building type(s) to determine the compliance outcome. Outputs are written to a PDF report documenting the calculated baseline and proposed TSPRs along with all model inputs defined by the user in the user interface. A sample report generated from the tool can be viewed here[1].

[1] https://buildingenergyscore.energy.gov/documents/TSPR_Analysis_Report_Example_1.pdf

4.0 System Comparisons: Validation of the TSPR Approach

PNNL used the TSPR tool to validate differences in HVAC system performance. The prototype building models (Goel et al. 2014b) for small office, medium office, and stand-alone retail were modified to include the HVAC System Performance path requirements for each of the respective use types. The ruleset includes several requirements for the proposed building (Appendix A, Section CD 105) such as schedules of operations, envelope construction type, lighting power densities, and so forth. It also requires averaging of HVAC equipment efficiency, fan power, pump power, and other parameters for similar system types to simplify the process for defining the energy model (Appendix A, Section CD105.2.10.2). All of these requirements have been implemented into the TSPR analysis tool, which was used to define the proposed building and automatically generate the reference building. Each of the prototypes were analyzed in climate zones 2A and 5A, with several different HVAC system configurations, including (i) reference HVAC system, (ii) target HVAC system, (iii) low-efficiency configuration that meets the Standard 90.1-2019 prescriptive code and is the least efficient system configuration that complies with the code, and (iv) several advanced system configurations that exceed the code requirement. These system configurations are summarized in the adoptable code language in Appendix A, Table 105.3.11(1-3). The target systems, summarized in Appendix A, Table 106.1.(1-3) include improved equipment performance (as required by minimum prescriptive code requirements in Standard 90.1-2019), lower fan power, and economizer control, if required by code.

A comparison of the target system (scenario 2) versus the low-efficiency configuration (scenario 3) demonstrates the additional savings that can result from adoption of the HVAC System Performance approach. Each of the advanced cases look at different system configurations, including variable refrigerant flow (VRF), water loop heat pumps, or ground source heat pump systems. Several advanced scenarios include DOAS systems with heat recovery and demand control ventilation. Section 5.0 of this report also summarizes the national average savings possible by the adoption of the HVAC System Performance path.

4.1 Small Office

The small office reference system is a packaged single zone heat pump for the warm climate zones (climate zones 0-3A) or a packaged single zone gas furnace for the cold climate zones (climate zones 3B, 3C, 4-8). Table 1 and Table 2 summarize the additional scenarios analyzed for climate zones 2A and 5A and Figure 4 and Figure 5 show the resulting TSPR-site for each of these scenarios.

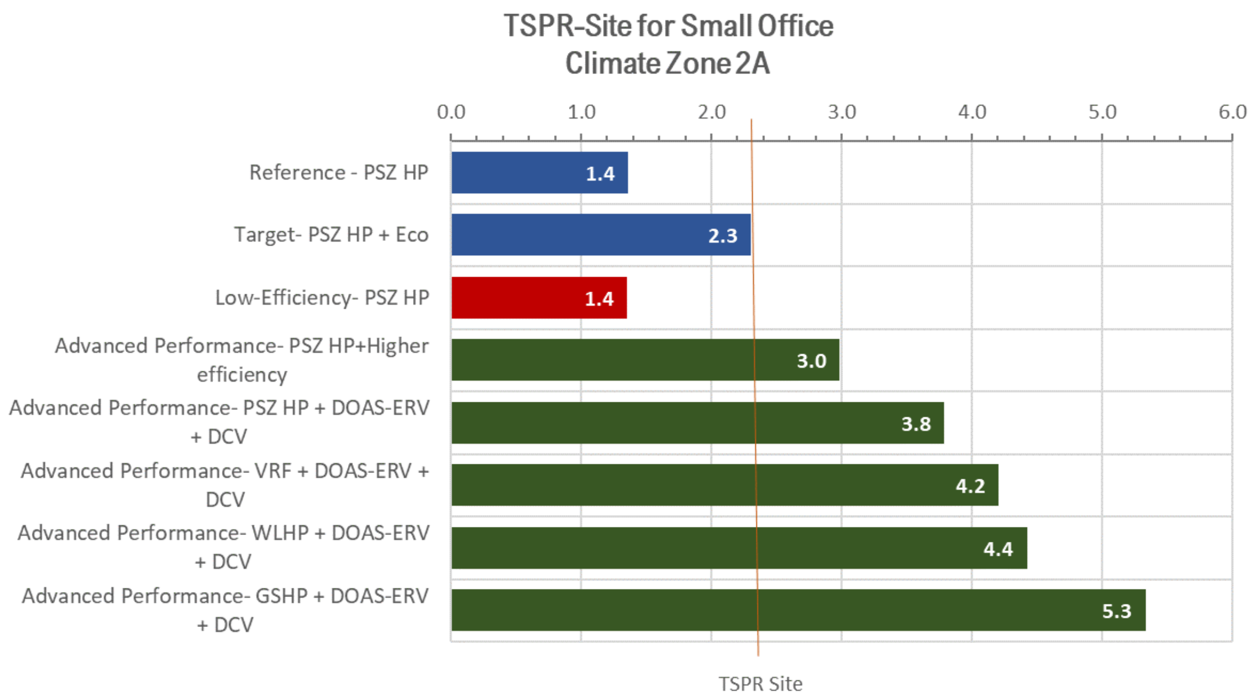

Figure 4. Small Office Results for Different System Configurations (Climate Zone 2A)

Table 1. Small Office System Configurations Analyzed for Climate Zone 2A

Run Description	Reference - PSZ HP	Target- PSZ HP + Eco	Low-Efficiency- PSZ HP	Advanced Performance- PSZ HP + Higher efficiency	Advanced Performance- PSZ HP + DOAS-ERV + DCV	Advanced Performance- VRF + DOAS-ERV + DCV	Advanced Performance- WLHP + DOAS-ERV + DCV	Advanced Performance- GSHP + DOAS-ERV + DCV
System Type	PSZ HP	PSZ HP	PSZ HP	PSZ HP	PSZ HP	VRF	WLHP	GSHP
Cooling Efficiency	3.0 COPnf	SEER 14	SEER 14	115% Target Efficiency	115% Target Efficiency	12.4 EER	16.8 EER	19.6 EER
Heating Efficiency	3.4 COPnf	HSPF 8.0	HSPF 8.0	115% Target Efficiency	115% Target Efficiency	3.65 COP	5.5 COP	3.8 COP
Fan Control	CAV	CAV	CAV	Two-Speed Fan	Cycling	Cycling	Cycling	Cycling
Fan Power	0.916 W/CFM	0.486 W/CFM	1.12 W/CFM	0.438 W/CFM	0.413 W/CFM	0.316 W/CFM	0.365 W/CFM	0.365 W/CFM
DOAS	No	No	No	No	Yes	Yes	Yes	Yes
ERV	No	No	No	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass
DCV	No	No	No	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area
Economizer	No	Yes	No	Yes	Yes	No	No	No

The low efficiency heat pump meets all Standard 90.1-2019 prescriptive requirements and yet has a TSPR which is equivalent to that of the reference building system and ~40% lower than the target. The 'advanced options' include WLHPs and VRF systems with DOAS for ventilation and cycling fans which provide conditioned air. The improvement in TSPR ranges from ~60% to over 130% over the target system for these configurations.

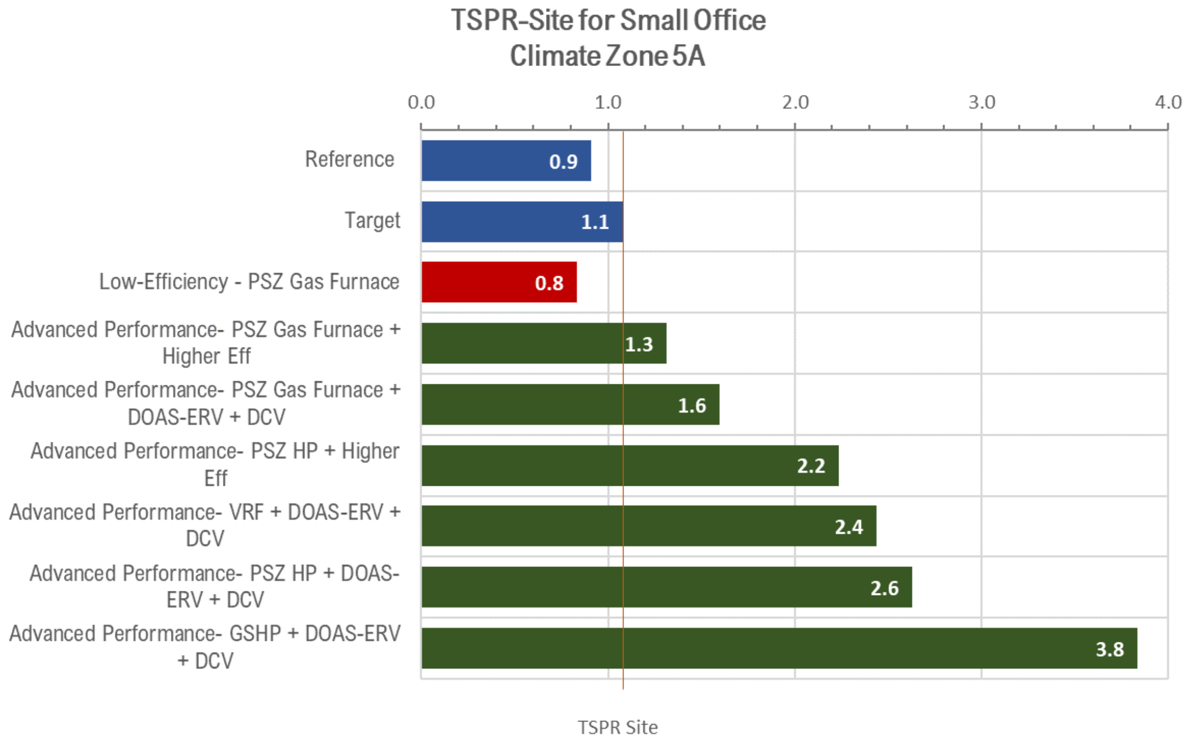

Figure 5. Small Office Results for Different System Configurations (Climate Zone 5A)

Table 2. Small Office System Configurations Analyzed for Climate Zone 5A

Run Description	Reference	Target	Low-Efficiency - PSZ Gas Furnace	Advanced Performance-PSZ Gas Furnace + Higher Eff	Advanced Performance-PSZ Gas Furnace + DOAS-ERV + DCV	Advanced Performance-PSZ HP + Higher Eff	Advanced Performance-VRF + DOAS-ERV + DCV	Advanced Performance-PSZ HP + DOAS-ERV + DCV	Advanced Performance-GSHP + DOAS-ERV + DCV
System Type	PSZ AC	PSZ AC	PSZ AC	PSZ AC	PSZ AC	PSZ HP	VRF	PSZ HP	GSHP
Cooling Efficiency	3.0 COPnf	SEER 14	SEER 14	115% Target Efficiency	115% Target Efficiency	115% Target Efficiency	12.4 EER	115% Target Efficiency	19.6 EER
Heating Efficiency	80% Et	81%Et	80% Et	93.5 Et	93.5 Et	115% Target Efficiency	3.65 COP	115% Target Efficiency	3.8 COP
Fan Control	CAV	CAV	CAV	Two-Speed Fan	Cycling	Two-Speed Fan	Cycling	Cycling	Cycling
Fan Power	0.916 W/CFM	0.486 W/CFM	1.12 W/CFM	0.438 W/CFM	0.438 W/CFM	0.438 W/CFM	0.316 W/CFM	0.365 W/CFM	0.365 W/CFM
DOAS	No	No	No	No	Yes	No	Yes	Yes	Yes
ERV	No	No	No	No	70% ERR ERV with Bypass	No	70% ERR ERV with Bypass	Yes, ERR=70%	70% ERR ERV with Bypass
DCV	No	No	No	No	Yes, 20% Area	No	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area
Economizer	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No

4.2 Medium Office

The medium office reference system is a packaged VAV with fan powered parallel induction units with electric resistance reheat for the warm climate zones (climate zones 0-3A) or a packaged VAV with hot-water reheat for the cold climate zones (climate zones 3B, 3C, 4-8). Table 3 and Table 4 summarize the additional scenarios analyzed for climate zones 2A and 5A and Figure 6 and Figure 7 show the resulting TSPR-site for each of these scenarios. In each case, the low-efficiency option, which meets Standard 90.1-2019 minimum prescriptive code requirements, has a significantly lower TSPR than the target.

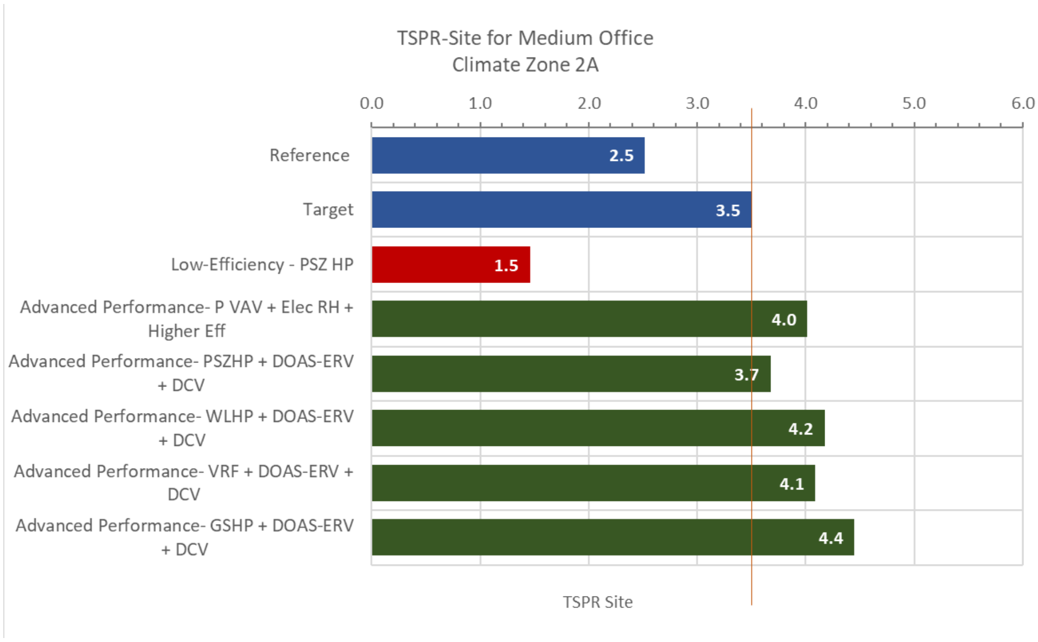

Figure 6. Medium Office Results for Different System Configurations (Climate Zone 5A)

Table 3. Medium Office System Configurations Analyzed for Climate Zone 5A

Run Description	Reference	Target	Low-Efficiency - PSZ HP	Advanced Performance - P VAV + Elec RH + Higher Eff	Advanced Performance - PSZHP + DOAS-ERV + DCV	Advanced Performance - WLHP + DOAS-ERV + DCV	Advanced Performance - VRF + DOAS-ERV + DCV	Advanced Performance - GSHP + DOAS-ERV + DCV
System Type	P-VAV with Elec RH PIU	P-VAV with Elec RH PIU	PSZ HP	P-VAV with Elec RH PIU	PSZ HP	WLHP	VRF	GSHP
Cooling Efficiency	3.4 COPnf	11.0 EER	11.0 EER	115% Target Efficiency	115% Target Efficiency	16.8 EER	12.4 EER	19.6 EER
Heating Efficiency	100% Et	100% Et	3.3 COP	100% Et	115% Target Efficiency	5.5 COP	3.65 COP	3.8 COP
Fan Control	VAV	VAV	CAV	VAV	Two-Speed Fan	Cycling	Cycling	Cycling
Fan Power	1.285 W/CFM	0.634 W/CFM	1.12 W/CFM	0.571 W/CFM	0.438 W/CFM	0.365 W/CFM	0.316 W/CFM	0.365 W/CFM
DOAS	No	No	No	No	Yes	Yes	Yes	Yes
ERV	No	No	No	No	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass
DCV	No	Yes, 20% Area	No	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area
Economizer	No	Yes	No	Yes	Yes	No	No	No

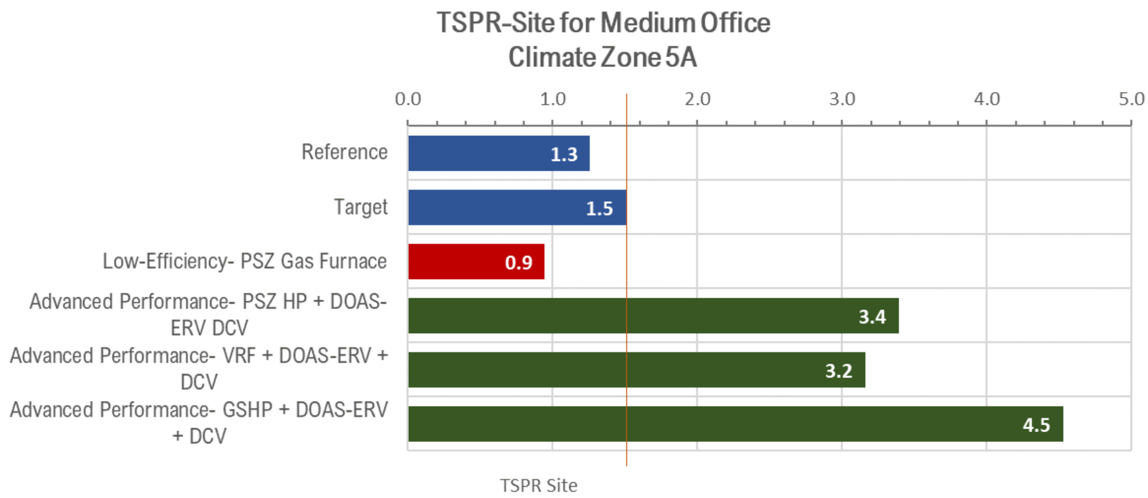

Figure 7. Medium Office Results for Different System Configurations (Climate Zone 5A)

Table 4. Medium Office System Configurations Analyzed for Climate Zone 5A

Run Description	**Reference**	**Target**	**Low-Efficiency- PSZ Gas Furnace**	**Advanced Performance- PSZ HP + DOAS-ERV DCV**	**Advanced Performance- VRF + DOAS-ERV + DCV**	**Advanced Performance- GSHP + DOAS-ERV + DCV**
System Type	P-VAV with HW RH	P-VAV with HW RH	PSZ AC	PSZ HP	VRF	GSHP
Cooling Efficiency	3.4 COPnf	11.0 EER	11.0 EER	115% Target Efficiency	12.4 EER	19.6 EER
Heating Efficiency	75% Et	81% Et	80% Et	115% Target Efficiency	3.65 COP	3.8 COP
Fan Control	VAV	VAV	CAV	Two-Speed Fan	Cycling	Cycling
Fan Power	1.285 W/CFM	0.634 W/CFM	1.12 W/CFM	0.438 W/CFM	0.316 W/CFM	0.365 W/CFM
DOAS	No	No	No	Yes	Yes	Yes
ERV	No	No	No	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass
DCV	No	Yes, 20% Area	No	Yes, 20% Area	Yes, 20% Area	Yes, 20% Area
Economizer	Yes	Yes	No	Yes	No	No

4.3 Mid-Rise Apartment

The midrise multifamily reference system is a PTHP for the warm climate zones (climate zones 0-3A) or a PTAC (with a gas-fired boiler) for the cold climate zones (climate zones 3B, 3C, 4-8). The target system adds a single zone DOAS with ERV for ventilation and the PTHP is replaced with a split heat pump for the warm climate zones and a split air conditioner for the cold climate zones. Table 5 and Table 6 summarize the additional scenarios analyzed for climate zones 2A and 5A and Figure 8 and Figure 9 show the resulting TSPR-site for each of these scenarios.

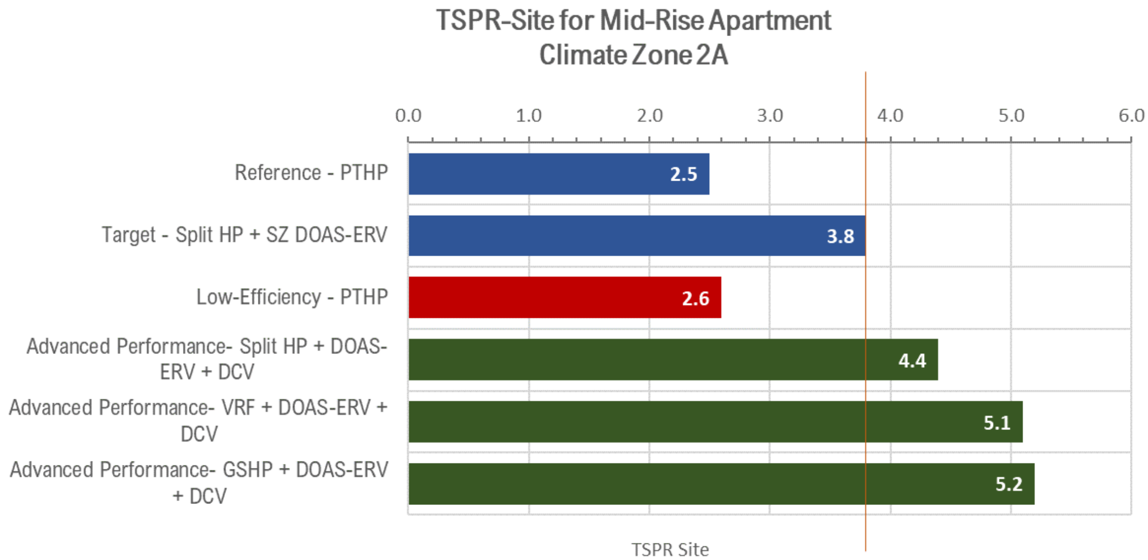

Figure 8. Mid-Rise Apartment Results for Different System Configurations (Climate Zone 2A)

Table 5. Mid-Rise Apartment System Configurations Analyzed for Climate Zone 2A

Run Description	Reference - PTHP	Target - Split HP + SZ DOAS-ERV	Low-Efficiency - PTHP	Advanced Performance- Split HP + DOAS-ERV + DCV	Advanced Performance- WLHP + DOAS-ERV + DCV	Advanced Performance- VRF + DOAS-ERV + DCV	Advanced Performance- GSHP + DOAS-ERV + DCV
System Type	PTHP	Split Heat Pump	PTHP	Split Heat Pump	WLHP	VRF	GSHP
Cooling Efficiency	3.1 COPnf	SEER 14	EER 11.3	SEER 14	16.8 EER	12.4 EER	19.6 EER
Heating Efficiency	3.1 COPnf	HSPF 8.2	3.232 COP	HSPF 8.2	5.5 COP	3.65 COP	3.8 COP
Fan Control	CAV	Cycling	CAV	Cycling	Cycling	Cycling	Cycling
Fan Power	0.3 W/CFM	0.246 W/CFM	0.3 W/CFM	0.246 W/CFM	0.185 W/CFM	0.148 W/CFM	0.185 W/CFM
DOAS	No	Yes	No	Yes	Yes	Yes	Yes
ERV	No	Single Zone ERV with no Bypass, 50% ERR	No	Single Zone ERV with no Bypass, 50% ERR	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass
DCV	No	No	No	No	Yes, 50% Area	Yes, 50% Area	Yes, 50% Area
Economizer	No	No	No	No	No	No	No

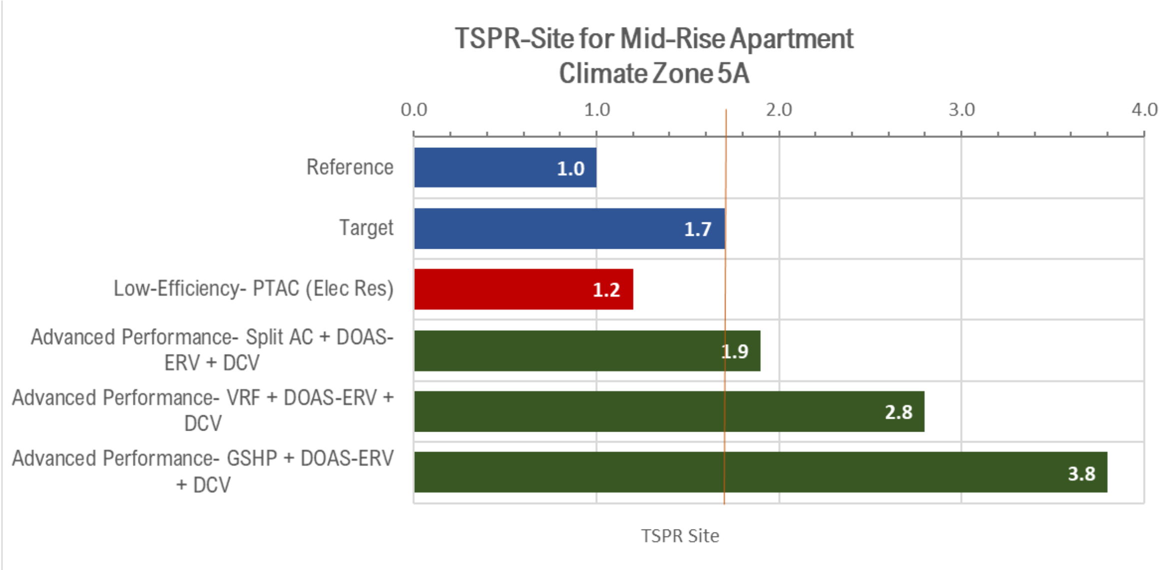

Figure 9. Mid-Rise Apartment Results for Different System Configurations (Climate Zone 5A)

Table 6. Mid-Rise Apartment System Configurations Analyzed for Climate Zone 5A

Run Description	**Reference**	**Target**	**Low-Efficiency-PTAC (Elec Res)**	**Advanced Performance-Split AC + DOAS-ERV + DCV**	**Advanced Performance-WLHP + DOAS-ERV + DCV**	**Advanced Performance-VRF + DOAS-ERV + DCV**	**Advanced Performance-GSHP + DOAS-ERV + DCV**
System Type	PTAC	Split AC	PTAC	Split AC	WLHP	VRF	GSHP
Cooling Efficiency	3.2 COPnf	SEER 13	EER 11.3	SEER 15.5	16.8 EER	12.4 EER	19.6 EER
Heating Efficiency	75% Et	80% AFUE	1	95% Et	5.5 COP	3.65 COP	3.8 COP
Fan Control	CAV	Cycling	CAV	Two-Speed	Cycling	Cycling	Cycling
Fan Power	0.3 W/CFM	0.271 W/CFM	0.3 W/CFM	0.217 W/CFM	0.197 W/CFM	0.163 W/CFM	0.203 W/CFM
DOAS	No	Yes	No		Yes	Yes	Yes
ERV	No	Single Zone ERV with no Bypass, 50% ERR	No	Single Zone ERV with no Bypass, 50% ERR	70% ERR ERV with Bypass	70% ERR ERV with Bypass	70% ERR ERV with Bypass
DCV	No	No	No	No	Yes, 50% Area	Yes, 50% Area	Yes, 50% Area
Economizer	No	No	No	No	No	No	No

5.0 Energy Savings Analysis

To estimate energy savings for this project, PNNL generated TSPR prototypes by modifying the prototype building models to follow the requirements prescribed by the HVAC System Performance path. The prototype building models are used for ASHRAE Standard 90.1 model code analysis process (Goel et al. 2014b) and were modified to include standard building operation assumptions, prescribed lighting power densities, envelope construction assembly types, and more as prescribed by the HVAC System Performance ruleset (Appendix A). The envelope thermal properties were based on ASHRAE Standard 90.1-2019. Prototypes used were mid-rise apartment, small office, medium office, and stand-alone retail. Several scenarios were analyzed using the TSPR prototypes, including (i) reference HVAC system scenario, (ii) target HVAC system scenario, (iii) low-efficiency case scenario, and (iv) advanced case scenario. The following process was used:

- A reference TSPR model was created with the general building parameters matching the Standard 90.1 prototypes. The reference TSPR prototypes have parameters based on Standard 90.1 Appendix G modeling requirements, which are documented in Table CD105.3.11(1-3).
- Several additional models were created for each TSPR prototype with a range of efficiencies, including one “target” model that matched a reasonably good system that met prescriptive requirements for Standard 90.1-2019.
- One “advanced” model was selected that included reasonable (85th percentile) efficiency improvements along with reasonable control measures like demand controlled ventilation, central DOAS allowing fan cycling, and an energy recovery system to reduce conditioning of outdoor air.
- One of the additional models was selected based on being a low-efficiency case that can still meet prescriptive requirements. This model had the lowest efficiencies possible, highest allowable fan power, and the least efficient operation of fan and ventilation cycles.
- The models were run in climate zones 2A and 5A to represent a range of heating and cooling impacts.
- The TSPR improvement from low efficiency to target and from target to advanced were evaluated for each modeled building type. The percentage improvements were disaggregated based on energy cost to heating, cooling, and auxiliary end uses. Office values were weighted based on construction data (Lei 2020) to represent the office group, whose values were also used as a proxy for school.
- The disaggregated percentage end use savings were applied across climate zones using adjustment by heating degree days (HDD65) for heating, cooling degree days (CDD50) for cooling, and an averaging technique for fan and pump auxiliaries.
- These percentage impacts were applied to HVAC end use breakdowns from the Standard 90.1-2019 performance indicator analysis (Nambiar et al. 2021).

5.1 TSPR Improvement Benefits

Implementing a base TSPR minimum requirement for HVAC systems in relevant buildings will result in savings when the least common denominator systems allowed under the prescriptive path are required to make some change to improve efficiency in line with a reasonably good prescriptive system. Such changes might include efficiency improvements, better duct design that reduces fan power, or the inclusion of options like economizers, demand controlled ventilation, or energy recovery that might be excepted for the particular situation. The HVAC System performance path looks at the performance of all the systems in the building, so smaller systems do not necessarily need to meet higher requirements.

Implementing an advanced TSPR requirement calls for a 12.5% increase in overall system effectiveness. This selection allows for reasonable selection in all building types considered. The advanced TSPR approach may be selected by jurisdictions that have a policy initiative to reduce energy use or related emissions. The expected HVAC savings based on the TSPR analysis is shown in Table 7.

Table 7. TSPR Improvement and HVAC Benefit

TSPR Savings for various system selections	**TSPR Improvement HVAC Benefit**			
	Low Efficiency to Target		**Target to Advanced**	
Climate Zone:	2A	5A	2A	5A
Apartment	32%	29%	16%	12%
Med Office	58%	37%	15%	125%
Small Office	41%	23%	64%	48%
Retail	35%	34%	31%	18%
Average	42%	31%	31%	51%
2nd Quartile	34%	28%	16%	16%
Minimum	32%	23%	15%	12%
Based on these results, use for advanced MPF across the board				**12.5%**

5.2 National Benefits Analysis

The results from the TSPR benefits analysis are applied to individual climate zones to capture differences in heating and cooling. Annual savings from adopting either the base level or the advanced level are shown. These are based on applying the percentage reductions listed in Table 7 to end use HVAC energy use and cost data (Nambiar et al. 2021) and multiplying by total expected 2022 commercial construction (Tyler et al. 2021) with climate zone and building type weighting (Lei 2020).

Note that adequate data are not available for the various selections of prescriptive HVAC systems, so a potential or total consumer savings is shown, assuming a low-efficiency case selection would always exist for the "Improve Low Efficiency" case and the "Adopt Advanced" case would always achieve full improvement compared to the target system. Then an estimate of 20% average impact is applied to provide a likely estimate of national annual savings. Note that these savings would continue year after year once the improved system is installed. Results are shown in Table 8.

Table 8. National Annual Benefits of TSPR

Overall US TSPR Annual Benefit	Improve Low Efficiency	Adopt Advanced
Annual consumer cost savings	$66,300,000	$59,650,000
20% of maximum Impact	$13,500,000	$12,000,000
Annual site million Btu savings	2,480,000	2,240,000
20% of maximum Impact	495,000	450,000

6.0 Sample Code Language

The sample code language provided here is designed to amend the 2021 IECC. If another code is amended, then adaptations in format and section references will be required.

Modify Section C403 as follows (For clarity, all language is new and not shown underlined):

C403.1.1 HVAC total system performance ratio (*HVAC TSPR*).

For systems serving office (including medical office) (occupancy group B), retail (occupancy group M), library (occupancy group A-3), education (occupancy group E), and hotel/motel occupancies (occupancy group R-1) and the *dwelling units* and residential common areas within occupancy group R-2 multifamily buildings, the *HVAC total system performance ratio* (*HVAC TSPR*) of the *proposed design* HVAC systems shall be greater than or equal to the *HVAC TSPR* of the *standard reference design* divided by the applicable mechanical performance factor (MPF) from Table CD103.1. *HVAC TSPR* shall be calculated in accordance with Appendix CD, Calculation of HVAC Total System Performance Ratio.

Exceptions:

1. Buildings with conditioned floor area less than 5,000 square feet.
2. HVAC systems using district heating water, chilled water or steam.
3. HVAC systems not included in Table CD105.2.10.1
4. HVAC systems included in table CD105.2.10.1 with parameters in Table CD105.2.10.2, not identified as applicable to that HVAC system type.
5. HVAC systems with chilled water supplied by absorption chillers, heat recovery chillers, water to water heat pumps, air to water heat pumps, or a combination of air and water cooled chillers on the same chilled water loop.
6. HVAC system served by heating water plants that include air to water or water to water heat pumps.
7. Underfloor air distribution and displacement ventilation HVAC systems.
8. Space conditioning systems that do not include mechanical cooling.
9. Alterations to existing buildings that do not substantially replace the entire HVAC system and are not serving initial build-out construction
10. HVAC systems meeting or exceeding all the requirements of the applicable Target Design HVAC System described in Tables CD105.4(1) through CD105.4(3) ,
11. HVAC systems serving laundry rooms, elevator rooms, mechanical rooms, electrical rooms, data centers, and computer rooms.
12. Buildings or areas of medical office buildings that comply fully with ASHRAE Standard 170, including but not limited to surgical centers, or that are required by other applicable codes or standards to provide 24/7 air handling unit operation
13. HVAC systems serving laboratories with fume hoods
14. Locker rooms with more than 2 showers
15. Natatoriums and rooms with saunas
16. Restaurants and commercial kitchens with total cooking capacity greater than 100,000 Btu/h
17. Areas of buildings with commercial refrigeration equipment exceeding 100 kW of power input.

18. Cafeterias and dining rooms.

Modify Section 406 as follows. If also adopting the PNNL Advanced Energy Credits language described in a separate Technical Brief do not include these changes and instead use the TSPR language changes described in the Advanced Energy Credits Technical Brief.

C406.13 HVAC Performance (TSPR).

For systems required to comply with Section C403.1.1, the *HVAC TSPR* shall exceed the minimum requirement by 5 percent. If improvement is greater, credits in Tables C406.1(1) through C406.1(5) are permitted to be prorated up to a 20 percent improvement using Equation 4-16. Energy credits for C406.13 may not be combined with energy credits from any of the HVAC measures described in Section C406.2.

$$\text{HVAC TSPR energy credit} = \text{base energy credit from Table 406.1} \times \frac{\text{TSPR\%}}{5\%} \qquad \text{(Equation 4-14)}$$

Where:

TSPR% = Percentage by which TSPR of proposed design exceeds minimum TSPR requirement. The value of TSPR% cannot exceed 20% for purposes of calculating H01 energy credits.

Append Tables C406.1(1) through C406.1(5) as follows to include credits for TSPR. For brevity the entire table is not shown.

Table C406.1(1) Additional Energy Efficiency Credits for Group B Occupancies

Sub-section / Climate Zone:	0A &1A	0B &1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
C406.13 *HVAC TSPR*	8	8	7	7	6	6	4	6	6	4	6	6	4	6	6	6	6

Table C406.1(2) Additional Energy Efficiency Credits for Group R and I Occupancies

Sub-section / Climate Zone:	0A &1A	0B &1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
C406.13 *HVAC TSPR*	8	8	8	7	6	6	5	6	6	4	6	5	4	6	6	6	7

Table C406.1(3) Additional Energy Efficiency Credits for Group E Occupancies

Sub-section / Climate Zone:	0A &1A	0B &1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
C406.13 *HVAC TSPR*	11	11	10	9	8	8	6	8	7	6	7	7	6	8	7	8	8

Table C406.1(4) Additional Energy Efficiency Credits for Group M Occupancies

Sub-section / Climate Zone:	0A &1A	0B &1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
C406.13 *HVAC TSPR*	11	11	10	9	8	8	6	8	8	7	8	8	6	9	8	9	10

Table C406.1(5) Additional Energy Efficiency Credits for Other[a] Occupancies

Sub-section / Climate Zone:	0A &1A	0B &1B	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
C406.13 *HVAC TSPR*	7	8	7	6	6	5	3	6	5	4	7	6	4	8	7	8	8

Add Appendix CD as follows (For clarity, all language is new and not shown underlined):

APPENDIX CD - CALCULATION OF HVAC TOTAL SYSTEM PERFORMANCE RATIO

SECTION CD101

GENERAL

CD101.1 Purpose

This appendix establishes criteria for demonstrating compliance with the requirements of C403.1.1, *HVAC total system performance ratio (HVAC TSPR)*

CD101.2 Scope.

This appendix applies to new HVAC systems that are not excluded from using *HVAC TSPR* by any of the exceptions to C403.1.1, and

1. serve office (including medical office), retail, library, hotel/motel, and education occupancies, or.
2. serve *dwelling units* and common areas within multifamily buildings.

All applicable HVAC systems shall comply with Section C403 and the requirements of this appendix.

CD101.2.1 Core & Shell / Initial Build-Out, and Future System Construction Analysis

Where the building permit applies to only a portion of the HVAC system in a building and the remaining components will be designed under a future building permit or were previously installed, the future or previously installed components shall be modeled as follows:

1. Where the HVAC zones that do not include HVAC systems in the current permit will be or are served by independent systems, then the block including those zones shall not be included in the model.
2. Where the HVAC zones that do not include complete HVAC systems in the permit are intended to receive HVAC services from systems in the permit, their proposed zonal systems shall be modeled with equipment that meets, but does not exceed, the requirements of C403.
3. Where the zone equipment in the permit receives HVAC services from previously installed systems that are not in the permit, the previously installed systems shall be modeled with equipment matching the certified value of what is installed or equipment that meets the requirements of C403.
4. Where the central plant heating and cooling equipment is completely replaced and HVAC zones with existing systems receive HVAC services from systems in the permit, their proposed zonal systems shall be modeled with equipment that meets, but does not exceed, the requirements of Section C403.

Note to adopting jurisdictions: Consider including the following informative note to clarify the requirements of CD101.2.1

Informative Note:

1. Examples of *HVAC systems* that are intended to receive HVAC services from *systems* in the permit include future zonal water source heat pumps that will receive loop water that is heated by a *boiler* or cooled by a cooling tower included in the permit, any *system* that will receive outdoor *ventilation* air from a dedicated *outdoor air system* included in the permit, and

future zone terminal units that will be connected to a central *VAV system* included in the permit.

2. An initial build-out with heating coils served from a previously installed *system* with a high-*efficiency* condensing *boiler* would use the installed *efficiency* if it exceeded the current requirements. If the installed *boiler* had a lower *efficiency* than the current requirements, the current requirement would be used.
3. A partial central plant upgrade (e.g. chiller, but not *boiler* replacement) cannot use this method.

SECTION CD102

DEFINITIONS

CD102.1 Definitions

The definitions contained in this section supplement or modify the definitions in the *International Energy Conservation Code*.

BLOCK. A generic concept used in energy simulation. It can include one or more thermal zones. It represents a whole building or portion of a building with the same use type served by the same HVAC system type.

HVAC TOTAL SYSTEM PERFORMANCE RATIO (HVAC TSPR). The ratio of the sum of a building's annual heating and cooling load in thousands of Btus to the sum of annual site energy consumption of the building HVAC systems in BTU.

PROPOSED DESIGN. A description of the proposed building used to estimate annual energy use for determining compliance based on total building performance and *HVAC total system performance ratio*.

STANDARD REFERENCE DESIGN. A version of the proposed design that meets the minimum requirements of this code and is used to determine the maximum annual energy use requirement for compliance based on total building performance and *HVAC total system performance ratio*.

SECTION CD103

HVAC TSPR COMPLIANCE

CD103.1 Compliance.

Systems required to use *HVAC TSPR* in accordance with C403.1.1 shall comply with all of the following:

1. Systems shall meet the applicable provisions of Section C403
2. The *HVAC TSPR* of the *proposed design* shall be greater than or equal to the *HVAC TSPR* of the *standard reference design* divided by the mechanical performance factor (MPF) using Equation CD-1 .

$$. TSPRp > TSPRr / MPF \qquad \text{Equation CD-1}$$

Where:

TSPRp = *HVAC TSPR* of the *proposed design* calculated in accordance with Sections CD103, CD104 and CD105.

TSPRr = *HVAC TSPR* of the *reference building design* calculated in accordance with Sections CD103, CD104 and CD105.

MPF = Mechanical Performance Factor from Table CD103.1 based on climate zone and building use type

Where a *building* has multiple *building* use types, MPF shall be area weighted using Equation CD-2

$$MPF = (A_1 * MPF_1 + A_2 * MPF_2 + . . . + A_n * MPF_n) / (A_1 + A_2 + . . . + A_n) \qquad \text{Equation CD-2}$$

Where:

MPF_1, MPF_2 through MPF_n = Mechanical Performance Factors from Table CD103.1 based on climate zone and *building* use types 1,2, through n

A_1, A_2 through A_n = Conditioned *floor* areas for *building* use types 1, 2, through n

Table CD103.1 Mechanical Performance Factors

Climate Zone: *Building* type	**Ocp. Group**	**0A**	**0B**	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**	**3C**	**4A**	**4B**	**4C**	**5A**	**5B**	**5C**	**6A**	**6B**	**7**	**8**
Office (small and medium)[a]	B	0.75	0.75	0.74	0.74	0.72	0.69	0.75	0.70	0.69	0.73	0.70	0.71	0.76	0.72	0.72	0.78	0.75	0.79	0.81
Office (Large)[a]	B	0.91	0.93	0.94	0.93	0.88	0.94	0.80	0.88	0.95	0.77	0.95	0.82	0.82	0.89	0.82	0.81	0.84	0.79	0.77
Retail	M	0.61	0.59	0.52	0.56	0.48	0.47	0.43	0.46	0.62	0.53	0.60	0.73	0.57	0.68	0.75	0.60	0.60	0.57	0.52
Hotel/Motel	R-1	0.62	0.62	0.63	0.63	0.62	0.68	0.61	0.69	0.73	0.59	0.66	0.65	0.55	0.59	0.68	0.51	0.54	0.47	0.40
Multi-Family/ Dormitory	R-2	0.64	0.63	0.67	0.63	0.65	0.64	0.59	0.60	0.54	0.59	0.57	0.52	0.58	0.53	0.48	0.57	0.53	0.55	0.52
School/ Education and Libraries	E (A-3)	0.89	0.89	0.89	0.87	0.83	0.82	0.79	0.80	0.80	0.75	0.85	0.77	0.84	0.83	0.73	0.86	0.82	0.83	0.78

[a] large office (gross conditioned floor area >150,000 ft^2 (14,000 m^2) or > 5 floors); all other offices are small or medium

CD103.1.1 HVAC TSPR

HVAC TSPR is calculated according to Equation CD-3:

$$\text{HVAC TSPR} = \frac{\text{annual heating and cooling load}}{\text{annual energy consumption of the building HVAC systems}} \qquad \text{Equation CD-3}$$

Where:

Annual energy consumption of the building HVAC systems	=	sum of the site energy consumption for heating, cooling, fans, energy recovery, pumps, and heat rejection in thousands of Btus.
Annual heating and cooling load	=	sum of the annual heating and cooling loads met by the building HVAC system in thousands of Btus.

SECTION CD104

GENERAL REQUIREMENTS

CD104.1 Simulation Program

CD104.1.2 Calculation of the HVAC TSPR for the *Standard Reference Design*.

The simulation program shall calculate the *HVAC TSPR* based only on the input for the *proposed design* and the requirements of this appendix. The calculation procedure shall not allow the user to directly modify the building component characteristics of the *standard reference design*.

CD104.1.2 Specific approval.

Performance analysis tools meeting the applicable subsections of Appendix CD and tested according to ASHRAE Standard 140 shall be permitted to be *approved*. Tools are permitted to be *approved* based on meeting a specified threshold for a jurisdiction. The *code official* shall be permitted to approve tools for a specified application or limited scope.

CD104.2 Climatic data.

The simulation program shall perform the simulation using hourly values of climatic data, such as temperature and humidity, using TMY3 data for the site as specified here:

https://buildingenergyscore.energy.gov/resources

CD104.3 Documentation.

Documentation conforming to the provisions of this section shall be provided to the *code official*.

CD104.3.1 Compliance report.

Building permit submittals shall include:

1. A report produced by the simulation software that includes the following:
   1.1 Address of the building.
   1.2 Name of individual completing the compliance report.
   1.3 Name and version of the compliance software tool.
   1.4 The dimensions, floor heights and number of floors for each *block*.
   1.5 By *block,* the U-factor, C-factor, or F-factor for each simulated opaque envelope component and the U-factor and SHGC for each fenestration component.
   1.6 By *block* or by surface for each block, the fenestration area.
   1.7 By *block,* a list of the HVAC equipment simulated in the *proposed design* including the equipment type, fuel type, equipment efficiencies and system controls.
   1.8 Annual site HVAC energy use by end use for the proposed and baseline building
   1.9 Annual sum of heating and cooling loads for the baseline building.
   1.10 The HVAC total system performance ratio for both the *standard reference design* and the *proposed design*.
2. A mapping of the actual building HVAC component characteristics and those simulated in the proposed design showing how individual pieces of HVAC equipment identified above have been combined into average inputs as required by Section CD105.2.10 including:
   2.1 Fans
   2.2 Hydronic pumps
   2.3 Air handlers
   2.4 Packaged cooling equipment
   2.5 Furnaces
   2.6 Heat pumps
   2.7 Boilers
   2.8 Chillers
   2.9 Cooling towers
   2.10 Electric resistance coils
   2.11 Condensing units
   2.12 Motors for fans and pumps
   2.13 Energy recovery devices

   For each piece of equipment identified above include the following as applicable:

   1. Equipment name or tag consistent with that found on the design documents.
   2. Rated Efficiency level.
   3. Rated Capacity.
   4. Electrical input power for fans and pumps (before any speed or frequency control device) at design condition and calculation of input value (W/cfm or W/gpm)
3. Floor plan of the building identifying:
   3.1 How portions of the buildings are assigned to the simulated blocks
   3.2 Areas of the building that are not covered under the requirements of Section C403.1.1.

SECTION CD105

CALCULATION PROCEDURES

CD105.1 General.

Except as specified by this appendix, the *standard reference design* and *proposed design* shall be configured and analyzed using identical methods and techniques.

CD105.2 Simulation of the proposed building design.

The proposed design shall be configured and analyzed as specified in this section.

CD105.2.1 Block geometry.

The geometry of buildings shall be configured using one or more *blocks*. Each *block* shall define attributes including *block* dimensions, number of floors, floor to floor height and floor to ceiling height. Simulation software may allow the use of simplified shapes (such as rectangle, L shape, H Shape, U shape or T shape) to represent *blocks*. Where actual building shape does not match these pre-defined shapes, simplifications are permitted providing the following requirements are met:

1. The *conditioned floor area* and volume of each *block* shall match the proposed design within 10 percent.
2. The area of each exterior envelope component from Table C402.1.4 is accounted for within 10 percent of the actual design.
3. The area of vertical fenestration and skylights is accounted for within 10 percent of the actual design.
4. The orientation of each component in 2 and 3 above is accounted for within 45 degrees of the actual design.

The creation of additional *blocks* may be necessary to meet these requirements.

Exception: Portions of the building that are unconditioned or served by systems not covered by the requirements of Section C403.1.1 shall be omitted.

CD105.2.1.1 Number of blocks.

One or more *blocks* may be required per building based on the following restrictions:

1. Each *block* can have only one occupancy type (multifamily *dwelling unit*, multifamily common area, office, library, education, hotel/motel or retail). Therefore, at least one single *block* shall be created for each unique use type.
2. Each *block* can be served by only one type of HVAC system. Therefore, a single *block* shall be created for each unique HVAC system and use type combination. Multiple HVAC units of the same type may be represented in one *block*. Table D601.10.2 provides directions for combining multiple HVAC units or components of the same type into a single *block*.
3. Each *block* can have a single definition of floor to floor or floor to ceiling heights. Where floor heights differ by more than two feet, unique *blocks* should be created for the floors with varying heights.
4. Each *block* can include either above grade or below grade floors. For buildings with both above grade and below grade floors, separate *blocks* should be created for each. For buildings with floors partially above grade and partially below grade, if the total wall area of the floor(s) in consideration is greater than or equal to 50 percent above grade, then it should be simulated as a completely above grade *block*, otherwise it should be simulated as a below grade *block*.
5. Each wall on a façade of a *block* shall have similar vertical fenestration. The product of the proposed design U-factor times the area of windows (UA) on each façade of a given floor cannot differ by more than 15 percent of the average UA for that façade in each *block*. The product of the proposed design SHGC times the area of windows (SHGCA) on each façade of

a given floor cannot differ by more than 15 percent of the average SHGCA for that façade in each *block*. If either of these conditions are not met, additional *blocks* shall be created consisting of floors with similar fenestration.

6. For a building model with multiple *blocks*, the *blocks* should be configured together to have the same adjacencies as the actual building design.

CD105.2.2 Thermal zoning.

Each floor in a *block* shall be modeled as a single thermal zone or as five thermal zones consisting of four perimeter zones and a core zone. Below grade floors shall be modeled as a single thermal *block*. If any façade in the *block* is less than 45 feet in length, there shall only be a single thermal zone per floor. Otherwise each floor shall be modeled with five thermal zones. A perimeter zone shall be created extending from each façade to a depth of 15 feet. Where facades intersect, the zone boundary shall be formed by a 45 degree angle with the two facades. The remaining area or each floor shall be modeled as a core zone with no exterior walls.

CD105.2.3 Occupancy.

CD105.2.3.1 Occupancy type.

The occupancy type for each *block* shall be consistent with the building area type as determined in accordance with C405.4.2.1. Portions of the building that are building area types other than multifamily *dwelling unit*, multifamily common area, office, school (education), library, or retail shall not be included in the simulation. Surfaces adjacent to such building portions shall be modeled as adiabatic in the simulation program.

CD105.2.3.2 Occupancy schedule, density, and heat gain.

The occupant density, heat gain, and schedule shall be for multifamily, office, retail, library, hotel/motel or school as specified by ASHRAE Standard 90.1 Normative Appendix C.

CD105.2.4 Envelope components.

CD105.2.4.1 Roofs.

Roofs will be modeled with insulation above a steel roof deck. The roof U-factor and area shall be modeled as in the proposed design. If different roof thermal properties are present in a single *block*, an area weighted U-factor shall be used. Roof solar absorbtance shall be modeled at 0.70 and emittance at 0.90.

CD105.2.4.2 Above grade walls.

Walls will be modeled as steel frame construction. The U-factor and area of above grade walls shall be modeled as in the proposed design. If different wall constructions exist on the façade of a *block* an area-weighted U-factor shall be used.

CD105.2.4.3 Below grade walls.

The C-factor and area of below grade walls shall be modeled as in the proposed design. If different slab on grade floor constructions exist in a *block*, an area-weighted C- factor shall be used.

CD105.2.4.4 Above grade exterior floors.

Exterior floors shall be modeled as steel frame. The U-factor and area of floors shall be modeled as in the proposed design. If different wall constructions exist in the *block* an area-weighted U-factor shall be used.

CD105.2.4.5 Slab on grade floors.

The F-factor and area of slab on grade floors shall be modeled as in the proposed design. If different below grade wall constructions exist in a *block*, an area-weighted F- factor shall be used.

CD105.2.4.6 Vertical fenestration.

The window area and area weighted U-factor and SHGC shall be modeled for each façade based the proposed design. Each exterior surface in a *block* must comply with Section D601.2.1 item 5. Windows will be combined into a single window centered on each façade based on the area and sill height input by the user. When different U values, SHGC or sill heights exist on a single facade, area weighted average for each shall be input by the user.

CD105.2.4.7 Skylights.

The skylight area and area weighted U-factor and SHGC shall be modeled for each floor based the proposed design. Skylights will be combined in to a single skylight centered on the roof of each zone based on the area input by the user

CD105.2.4.8 Exterior Shading.

Permanent window overhangs shall be modeled. When windows with and without overhangs or windows with different overhang projection factors exist on a façade, window width weighted projection factors shall be input by the user as follows.

$$P_{avg} = \frac{A_1 \times L_{o1} + A_2 \times l_{o2} \ldots\ldots A_n \times L_{on}}{L_{w1} + L_{w2} \ldots. + L_{wn}} \qquad \text{Equation CD-4}$$

Where,

P_{avg} = Average overhang projection modeled in the simulation tool

A = Distance measured horizontally from the furthest continuous extremity of any overhang, eave, or permanently attached shading device to the vertical surface of the glazing.

L_o = Length off the overhang

L_w = Length of the window

CD105.2.5 Lighting.

Interior lighting power density shall be equal to the allowance in Table C405.4.2(1) for multifamily, office, retail, library, or school. The lighting schedule shall be for multifamily, office, retail, library, or school as specified by ASHRAE Standard 90.1 Normative Appendix C. The impact of lighting controls is assumed to be captured by the lighting schedule and no explicit controls shall be modeled. Exterior lighting shall not be modeled.

CD105.2.6 Miscellaneous equipment.

The miscellaneous equipment schedule and power shall be for multifamily, office, retail, library, or school as specified by ASHRAE Standard 90.1 Normative Appendix C. The impact of miscellaneous equipment controls is assumed to be captured by the equipment schedule and no explicit controls shall be modeled.

Exceptions.

1. Multifamily dwelling units shall have a miscellaneous load density of 0.42 W/ft^2
2. Multifamily common areas shall have a miscellaneous load density of 0 W/ft^2

CD105.2.7 Elevators.

Elevators shall not be modeled.

CD105.2.8 Service water heating equipment.

Service water heating shall not be modeled.

CD105.2.9 On-site renewable energy systems.

On-site Renewable Energy Systems shall not be modeled.

CD105.2.10 HVAC equipment.

HVAC systems shall meet the requirements of Section C403 Mechanical Systems.

CD105.2.10.1 Supported HVAC systems.

At a minimum, the HVAC systems shown in Table CD105.2.10.1 shall be supported by the simulation program.

Table CD105.2.10.1 PROPOSED BUILDING HVAC SYSTEMS SUPPORTED BY HVAC TSPR SIMULATION SOFTWARE

System No.	System Name	System Abbreviation
1	Packaged Terminal Air Conditioner	PTAC
2	Packaged Terminal Air Heat Pump	PTHP
3	Packaged Single Zone Gas Furnace	PSZGF
4	Packaged Single Zone Heat Pump (air to air only)	PSZHP
5	Variable Refrigerant Flow (air cooled only)	VRF
6	Four Pipe Fan Coil	FPFC
7	Water Source Heat Pump	WSHP
8	Ground Source Heat Pump	GSHP
9	Packaged Variable Air Volume (DX cooling)	PVAV
10	Variable Air Volume (hydronic cooling)	VAV
11	Variable Air Volume with Fan Powered Terminal Units	VAVFPTU
12	Dedicated Outdoor Air System (in conjunction with systems 1-8)	DOAS

CD105.2.10.2 Proposed building HVAC system simulation.

The HVAC systems shall be modeled as in the proposed design with clarifications and simplifications as described in Tables CD105.2.10.2(1) and CDS105.10.2(2). System parameters not described in the following sections shall be simulated to meet the minimum requirements of Section C403. All zones within a *block* shall be served by the same HVAC system type as described in Section CD105.2.1.1 item 2. Heat loss from ducts and pipes shall not be modeled.

For packaged single-zone air conditioners (cooling only), water-loop heat pumps, ground-source heat pumps and packaged rooftop heat pumps, heating COP and cooling COP, exclusive of fan power, shall be determined using the following equations:

For Table CD105.2.10.1 Systems 4, 7, and 8 heating efficiency

$$COP_{nfheating} = 1.48E\text{-}7 \times COP_{47} \times Q + 1.062 \times COP_{47}$$ Equation CD-5

For Table CD105.2.10.1 System 3 heating efficiency

$$COP_{nfheating} = -0.0296 \times HSPF^2 + 0.7134 \times HSPF$$ Equation CD-6

For Table CD105.2.10.1 System 4, 7, 8, and 9 cooling efficiency

$$COP_{nfcooling} = 7.84E\text{-}8 \times EER \times Q + 0.338 \times EER$$ Equation CD-7

For Table CD105.2.10.1 System 1 and 2 cooling efficiency

$$COP_{nfcooling} = -0.0076 \times SEER^2 + 0.3796 \times SEER \quad \text{Equation CD-8}$$

For Table CD105.2.10.1 System 1 and 2 cooling efficiency

$$COP_{nfcooling} = 0.3322 \times EER - 0.2145 \quad \text{Equation CD-9}$$

For Table CD105.2.10.1 System 2 heating efficiency

$$COP_{nfheating} = 1.1329 \times COP - 0.214 \quad \text{Equation CD-10}$$

Where:

EER, SEER, COP and HSPF shall be at AHRI full load test conditions

Q = AHRI rated cooling capacity in BTU/h. If Q > 760,000BTU/h use 760,000 in the calculation

Note to adopting authority*: The following equations are the SI version of Equations CD-5 - CD11 and shall be used when adopting an SI version of the IECC.*

$$(COP_{nfheating} = 5.05E\text{-}4 \times COP_{H8.3} \times Q + 1.062 \times COP_{H8.3}) \quad \text{Equation CD-5 (SI)}$$

$$(COP_{nfheating} = -0.3446 \times SCOP_H^2 + 2.434 \times SCOP_H) \quad \text{Equation CD-6(SI)}$$

$$(COP_{nfcooling} = 9.13E\text{-}4 \times COP_C \times Q + 1.15 \times COP_C) \quad \text{Equation CD-7(SI)}$$

$$(COP_{nfcooling} = -0.0885 \times SCOP_C^{\,2} + 1.295 \times SCOP_C) \quad \text{Equation CD-8(SI)}$$

$$(COP_{nfcooling} = 9.13E\text{-}4 \times COP_C \times Q + 1.15 \times COP_C) \quad \text{Equation CD-9(SI)}$$

$$(COP_{nfheating} = 1.1329 \times COP - 0.214) \quad \text{Equation CD-10(SI)}$$

$$COP_{nfcooling} = 0.3322 \times EER - 0.2145 \quad \text{Equation CD-11(SI)}$$

Where:

EER, SEER, COP and HSPF shall be at AHRI full load test conditions

Q = AHRI rated cooling capacity in BTU/h. If Q > 760,000BTU/h use 760,000 in the calculation

Where multiple system components serve a *block*, average values weighed by the appropriate metric as described in this section shall be used.

1. Where multiple fan systems serve a single block, fan power shall be based on weighted average using the design supply air cfm
2. Where multiple cooling systems serve a single block, COP shall be based on a weighted average using cooling capacity. DX coils shall be entered as multi-stage if more than 50% of coil capacity serving the block is multi-stage with staged controls.
3. Where multiple heating systems serve a single block, thermal efficiency or heating COP shall be based on a weighted average using heating capacity.
4. Where multiple boilers or chillers serve a heating water or chilled water loop, efficiency shall be based on a weighted average for using heating or cooling capacity.
5. When multiple cooling towers serving a condenser water loop are combined, the cooling tower efficiency, cooling tower design approach and design range are based on a weighted average of the design water flow rate through each cooling tower.
6. Where multiple pumps serve a heating water, chilled water or condenser water loop, pump power shall be based on a weighted average for using design water flow rate.
7. When multiple system types with and without economizers are combined, the economizer maximum outside air fraction of the combined system shall be based on weighted average of

100% supply air for systems with economizers and design outdoor air for systems without economizers.

8. Multiple systems with and without ERVs cannot be combined.
9. Systems with and without supply air temperature reset cannot be combined.
10. Systems with different fan control (constant volume, multi-speed or VAV) for supply fans cannot be combined.

CD105.2.10.3 Demand Control Ventilation:

Demand Controlled Ventilation (DCV) shall be modeled using a simplified approach that adjusts the design outdoor supply air flow rate based on the area of the building that is covered by DCV.

TABLE CD105.2.10.2(1) PROPOSED BUILDING SYSTEM PARAMETERS

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
HVAC System Type	System Type	User Defined	Selected from Table CD105.2.10.1	All
System Sizing	Design Day Information	Fixed	99.6% heating design and 1% dry-bulb and 1% wet-bulb cooling design	All
	Zone Coil Capacity	Fixed	Sizing factors used are 1.25 for heating equipment and 1.15 for cooling equipment	All
	Supply Airflow	Fixed	Based on a supply-air-to-room-air temperature *set-point* difference of 20°F or	1-11
		Fixed	Equal to required outdoor air ventilation	12
Outdoor Ventilation Air	Portion of supply air with proposed Filter ≥MERV 13	User-defined	Percentage of supply air flow subject to higher filtration (Adjusts baseline Fan Power higher. Prorated)	All
	Outdoor Ventilation Air Flow Rate	Fixed	As specified in ASHRAE Standard 90.1 Normative Appendix C, adjusted for proposed DCV control	All
	Outdoor *Ventilation* Supply Air Flow Rate Adjustments	Fixed	Based on ASHRAE Standard 62.1 Section 6.2.4.3 System Ventilation Efficiency (Evs) is 0.75	9-11
		Fixed	System Ventilation Efficiency (Evs) is 1.0	1-8, 12
		Fixed	Basis is 1.0 Zone Air Distribution Effectiveness	All
System Operation	Space temperature Set points	Fixed	As specified in ASHRAE Standard 90.1 Normative Appendix C, except multifamily which shall use 68 deg. F heating and 76 deg. F cooling setpoints	1-11
	Fan Operation – Occupied	User Defined	Runs continuously during occupied hours or cycles to meet load. Multispeed fans reduce airflow related to thermal loads.	1-11
	Fan Operation – Occupied	Fixed	Fan runs continuously during occupied hours	12
	Fan Operation – Night Cycle	Fixed	Fan cycles on to meet setback temperatures	1-11
Packaged Equipment Efficiency	DX Cooling Efficiency	User Defined	Cooling COP without fan energy calculated in accordance with Section CD105.2.10.2	1, 2, 3, 4, 5,7, 8, 9, 11,12
	DX Coil Number of Stages	User-defined	Single Stage or Multistage	3, 4, 9
	Heat Pump Efficiency	User Defined	Heating COP without fan energy calculated in accordance with Section CD105.2.10.2	2, 4, 5, 7, 8
	Furnace Efficiency	User Defined	Furnace thermal efficiency[c]	3, 11
Heat Pump Supplemental Heat	Control	Fixed	Supplemental electric heat locked out above 40°F. Runs In conjunction with compressor between 40°F and 0°F.	2, 4

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
System Fan Power and Controls	Part-load Fan Controls	User-defined	Constant volume or two speed	1-8
	Part-load Fan Controls[a]	User-defined	Constant volume or variable air volume	12
	Part-load Fan Controls[a]	Fixed	Variable air volume. VFD with static pressure reset	9-11
	Design Fan Power (W/cfm)	User Defined	Input electric power for all fans in required to operate at fan system design conditions divided by the supply airflow rate This is a "wire to air" value including all drive, motor *efficiency* and other losses.	All
	Low-speed fan power	User Defined	Low speed input electric power for all fans required to operate at low speed conditions divided by the low speed supply airflow rate. This is a "wire to air" value including all drive, motor *efficiency* and other losses.	1-8
Variable Air Volume Systems	Supply Air Temperature (SAT) Controls	User defined	If not SAT reset then constant at 55°F. Options for reset based on outside air temperature (OAT) or warmest zone. If warmest zone, then the user can specify the minimum and maximum temperatures. If OAT reset, SAT is reset higher to 60°F at outdoor low of 50°F. SAT is 55°F at outdoor high of 70°F.	9, 10, 11
	Minimum Terminal Unit airflow percentage	User Defined	Average minimum terminal unit airflow percentage for *block* weighted by cfm or minimum required for outdoor air ventilation, whichever is higher.	9, 10, 11
	Terminal Unit Heating Source	User Defined	Electric or hydronic	9, 10, 11
	Dual *set point* minimum *VAV* damper position	User-defined	Heating maximum airflow fraction	9,10.
	Fan Powered Terminal Unit (FPTU) Type	User Defined	Series or parallel FPTU	11
	Parallel FPTU Fan	Fixed	Sized for 50% peak primary air at 0.35 W/cfm	11
	Series FPTU Fan	Fixed	Sized for 50% peak primary air at 0.35 W/cfm	11
Economizer	Economizer Presence	User Defined	Yes or No	3, 4, 9, 10,11
	Economizer Control Type	Fixed	Differential dry-bulb	3, 4, 9, 10,11
Energy Recovery	Sensible Effectiveness	User Defined	Heat exchanger sensible effectiveness at design heating and cooling conditions	3, 4, 9, 10, 11, 12
	Latent Effectiveness	User Defined	Heat exchanger latent effectiveness at design heating and cooling conditions	3, 4, 9, 10, 11, 12
	Economizer Bypass	User Defined	If ERV is bypassed during economizer conditions	3, 4, 9, 10, 11, 12
	Bypass SAT Setpoint	User Defined	If bypass, target supply air temperature	3, 4, 9, 10, 11, 12
	Fan Power Reduction during Bypass (W/cfm)	User Defined	If ERV system include bypass, static pressure set point and variable speed fan, fan power can be reduced during economizer conditions	3, 4, 9, 10, 11, 12
Demand Controlled Ventilation	DCV Application	User Defined	Percent of block floor area under DCV control	3, 4, 9, 10, 11, 12
DOAS	DOAS Fan Power W/cfm	User Defined	Fan electrical input power in W/cfm of supply airflow[a]	12
	DOAS Supplemental Heating and Cooling	User Defined	Heating source, cooling source	12
	Maximum SAT Set point (Cooling)	User-defined	SAT set point if DOAS includes supplemental cooling	12

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
	Minimum SAT Set point (Heating)	User-defined	SAT set point if DOAS includes supplemental heating	12
Heating Plant	Boiler Efficiency~~d~~	User Defined	Boiler thermal efficiency	1, 6, 7, 9, 10, 11, 12
	Heating Water loop Configuration[a]	User-defined	Constant flow primary only; Variable flow primary only; Constant flow primary – variable flow secondary	1, 6, 7, 9, 10, 11, 12
	Heating Water Primary Pump Power (W/gpm)	User-defined	Heating water primary pump input W/gpm heating water flow	1, 6, 7, 9, 10, 11, 12
	Heating Water Secondary Pump Power (W/gpm)	User-defined	Heating water secondary pump input W/gpm heating water flow (if primary/secondary)	1, 6, 7, 9, 10, 11, 12
	Heating Water Loop Temperature	Fixed	180°F supply, 130°F return	1, 6, 9, 10,11
	Boiler Type	Fixed	Non-condensing boiler where input thermal efficiency is less than 86%; Condensing boiler otherwise	1, 6, 7, 9, 10, 11, 12
Chilled Water Plant	Chiller Compressor Type	User Defined	Screw/Scroll, Centrifugal or Reciprocating	6,1 0, 11, 12
	Chiller Condenser Type	User Defined	Air cooled or water cooled	6, 10, 11, 12
	Chiller Full Load Efficiency~~d~~	User Defined	Chiller COP	6, 10, 11, 12
	Chilled Water loop Configuration[a]	User Defined	Variable flow primary only, constant flow primary – variable flow secondary	6, 10, 11, 12
	Chilled Water Primary Pump Power (W/gpm)	User-defined	Primary pump input W/gpm chilled water flow	6, 10, 11,12
	Chilled Water Secondary Pump Power (W/gpm)	User-defined	Secondary Pump input W/gpm chilled water flow (if primary/secondary)	6, 10, 11,12
	Chilled Water Temperature Reset Included	User Defined	Yes/No	6, 10, 11,12
Chilled Water Plant (cont.)	Chilled Water Temperature Reset Schedule (if included)	Fixed	Outdoor air reset: CHW supply temperature of 44°F at 80°F outdoor air dry bulb and above, CHW supply temperature of 54°F at 60°F outdoor air dry bulb temperature and below, ramped linearly between	6, 10, 11,12
	Condenser Water Pump Power (W/gpm)	User Defined	Pump input W/gpm condenser water flow	6, 7, 8, ~~,~~10, 11, 12
	Condenser Water Pump Control	User Defined	Constant speed or variable speed	6, 7, 8, 10, 11,12
	Cooling Tower Efficiency	User Defined	gpm/hp tower fan	6, 7, 10, 11,12
	Cooling Tower Fan Control	User Defined	Constant or variable speed	6, 7, 10, 11,12
	Cooling Tower Approach and Range	User Defined	Design cooling tower approach and range temperature	6, 7, 10, 11,12
Heat Pump Loop Flow Control	Loop flow and Heat Pump Control Valve	Fixed	Two position Valve with VFD on Pump. Loop flow at 3 gpm/ton	7, 8
Heat Pump Loop Temperature Control		Fixed	Set to maintain temperature between 50°F and 70°F	7
GLHP Well Field		Fixed	Bore depth = 250’ Bore length 200’/ton for greater of cooling or heating load Bore spacing = 15’ Bore diameter = 5” ¾” Polyethylene pipe Ground and grout conductivity = 4.8 Btu-in/h-ft^{2}-^{0}F	8

a. Part load fan power and pump power modified in accordance with Table CD105.2.10.2(2)

Table CD105.2.10.2(2) Fan and Pump Power Curve Coefficients

Equation Term	Fan Power Coefficients	Pump Power Coefficients	
	VSD + SP reset	Ride Pump Curve	VSD + DP/valve reset
b	0.0408	0	0
x	0.088	3.2485	0.0205
x^2	-0.0729	-4.7443	0.4101
x^3	0.9437	2.5295	0.5753

CD105.3 Simulation of the standard reference design.

The standard reference design shall be configured and analyzed as specified in this section.

CD105.3.1 Utility rates.

Same as proposed.

CD105.3.2 Blocks.

Same as proposed.

CD105.3.3 Thermal zoning.

Same as proposed.

CD105.3.4 Occupancy type, schedule, density, and heat gain.

Same as proposed.

CD105.3.5 Envelope components.

Same as proposed.

CD105.3.6 Lighting.

Same as proposed.

CD105.3.7 Miscellaneous equipment.

Same as proposed.

CD105.3.8 Elevators.

Not modeled. Same as proposed.

CD105.3.9 Service water heating equipment.

Not modeled. Same as proposed.

CD105.3.10 On-site renewable energy systems.

Not modeled. Same as proposed.

CD105.3.11 HVAC equipment.

The *reference building design* HVAC equipment consists of separate space conditioning systems as described in Table CD105.3.11(1) through Table CD105.3.11(3) for the appropriate building use types. In these tables, ‘Warm’ refers to climate zones 0 to 2 and 3A and ‘Cold’ refers to climate zones 3B, 3C, and 4 to 8.

Table CD105.3.11(1) Reference Building Design HVAC Complex Systems

Building Type Parameter	Large Office (warm)	Large Office (cold)	School (warm)	School (cold)
System Type	*VAV*/ RH Water-cooled Chiller/ Electric Reheat (PIU)	*VAV*/ RH Water-cooled Chiller/ Gas *Boiler*	*VAV*/ RH Water-cooled Chiller/ Electric Reheat (PIU)	*VAV*/ RH Water-cooled Chiller/ Gas *Boiler*
Fan control	VSD	VSD	VSD	VSD
Main fan power (W/CFM (W·s/L) Proposed ≥ MERV13	1.165 (2.468)	1.165 (2.468)	1.165 (2.468)	1.165 (2.468)
Main fan power (W/CFM (W·s/L) proposed < MERV13	1.066 (2.259)	1.066 (2.259)	1.066 (2.259)	1.066 (2.259)
Zonal fan power (W/CFM (W·s/L))	0.35 (0.75)	NA	0.35 (0.75)	NA
Minimum zone airflow fraction	1.5* Voz	1.5* Voz	1.2* Voz	1.2 * Voz
Heat/cool sizing factor	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Outdoor air economizer	No	Yes except 4A	No	Yes except 4A
Occupied OSA (= proposed)	Sum(Voz)/0.75	Sum(Voz)/0.75	Sum(Voz)/0.65	Sum(Voz)/0.65
Energy recovery ventilator *efficiency* ERR (Enthalpy Recovery Ratio) ERV bypass SAT *set point*	NA	NA	50% No Bypass	50% 60°F except 4A
DCV	No	No	No	No
Cooling Source	(2) Water-cooled Centrifugal Chillers	(2) Water-cooled Centrifugal Chillers	(2) Water-Cooled Screw Chillers	(2) Water-Cooled Screw Chillers
Cooling *COP* (net of fan)	Path B for profile	Path B for profile	Path B for profile	Path B for profile
Heating source (reheat)	*Electric resistance*	Gas *Boiler*	*Electric resistance*	Gas *Boiler*
Furnace or *boiler efficiency*	1.0	75% Et	1.0	80% Et
Condenser heat rejection	Cooling Tower	Cooling Tower	Cooling Tower	Cooling Tower
Cooling tower *efficiency* (gpm/fan-hp (L/s·fan-*kW*))	38.2 (3.23)	38.2 (3.23)	38.2 (3.23)	38.2 (3.23)
Tower turndown (> 300 ton (1060 *kW*))	50%	50%	50%	50%
Pump (constant flow/variable flow)	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range
Tower approach	25.72 – (0.24 x WB), where WB WB is the 0.4% evaporation design wet-bulb temperature (°F)			
Cooling condenser *pump* power (W/gpm (W·s/L))	19 (300)	19 (300)	19 (300)	19 (300)
Cooling primary *pump* power (W/gpm (W·s/L))	9 (142)	9 (142)	9 (142)	9 (142)
Cooling secondary *pump* power (W/gpm (W·s/L))	13 (205)	13 (205)	13 (205)	13 (205)
Cooling coil chilled water delta-T, °F (°C)	12 (6.7)	12 (6.7)	12 (6.7)	12 (6.7)
Design chilled water supply temperature, °F (°C)	44 (6.7)	44 (6.7)	44 (6.7)	44 (6.7)
Chilled water supply temperature (CHWST) reset *set point* vs OAT, °F (°C)	CHWST/OAT: 44-54/ 80-60 (6.7-12.2/ 26.7-15.6)	CHWST/OAT: 44-54/ 80-60 (6.7-12.2/ 26.7-15.6)	CHWST/OAT: 44-54/ 80-60 (6.7-12.2/ 26.7-15.6)	CHWST/OAT: 44-54/ 80-60 (6.7-12.2/ 26.7-15.6)
CHW cooling loop *pump*ing control	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD
Heating *pump* power (W/gpm (W·s/L))	16.1 (254)	16.1 (254)	19 (254)	19 (254)

Building Type Parameter	Large Office (warm)	Large Office (cold)	School (warm)	School (cold)
Heating oil HW dT. °F (°C)	50 (10)	50 (10)	50 (10)	50 (10)
Design HWST. °F (°C)	180 (82)	180 (82)	180 (82)	180 (82)
HWST reset *set point* vs OAT, °F (°C)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)
Heat loop *pumping* control	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD

Table CD105.3.11(2)

TSPR Reference Building Design HVAC Simple Systems

Building Type Parameter	Medium Office (warm)	Medium Office (cold)	Small Office (warm)	Small Office (cold)	Retail (warm)	Retail (cold)
System type	Package *VAV* - Electric Reheat	Package *VAV* - Hydronic Reheat	PSZ-HP	PSZ-AC	PSZ-HP	PSZ-AC
Fan control	VSD	VSD	Constant Volume	Constant Volume	Constant Volume	Constant Volume
Main fan power (W/CFM (W·s/L)) proposed ≥ MERV13	1.285 (2.723)	1.285 (2.723)	0.916 (1.941)	0.916 (1.941)	0.899 (1.905)	0.899 (1.905)
Main fan power (W/CFM (W·s/L)) proposed < MERV13	1.176 (2.492)	1.176 (2.492)	0.850 (1.808)	0.850 (1.801)	0.835 (1.801)	0.835 (1.801)
Zonal fan power (W/CFM (W·s/L))	0.35 (0.75)	NA	NA	NA	NA	NA
Minimum zone airflow fraction	30%	30%	NA	NA	NA	NA
Heat/cool sizing factor	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Supplemental heating availability	NA	NA	<40°F (<4.4°C) OAT	NA	<40°F (<4.4°C) OAT	NA
Outdoor air economizer	No	Yes except 4A	No	Yes except 4A	No	Yes except 4A
Occupied OSA source	Packaged unit, occupied damper, all *building* use types					
Energy recovery ventilator	No	No	No	No	No	No
DCV	No	No	No	No	No	No
Cooling source	DX, multi-stage	DX, multi-stage	DX, 1 stage (heat pump)	DX, single stage	DX, 1 stage (heat pump)	DX, single stage
Cooling *COP* (net of fan)	3.40	3.40	3.00	3.00	3.40	3.50
Heating source	*Electric resistance*	Gas *Boiler*	Heat Pump	Furnace	Heat Pump	Furnace
Heating *COP* (net of fan) / furnace or *boiler efficiency*	1.0	75% E_t	3.40	80% E_t	3.40	80% E_t

Table CD105.3.11(3)-

TSPR Reference Building Design HVAC Simple Systems

Building Type Parameter	**Hotel (warm)**	**Hotel (cold)**	**Multifamily** (warm)	**Multifamily** (cold)
System type	*PTHP*	*PTAC*	*PTHP*	*PTAC*
Fan control	Constant Volume	Constant Volume	Constant Volume	Constant Volume
Main fan power (W/CFM (W·s/L))	0.300 (0.636)	0.300 (0.636)	0.300 (0.636)	0.300 (0.636)
Heat/cool sizing factor	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Supplemental heating availability	<40°F (<4.4°C)	NA	<40°F (<4.4°C)	NA
Outdoor air economizer	No	No	No	No
Occupied OSA source	Packaged unit, occupied damper	Packaged unit, occupied damper	Packaged unit, occupied damper	Packaged unit, occupied damper
Energy recovery ventilator	No	No	No	No
DCV	No	No	No	No
Cooling source	DX, 1stage (heat pump)	DX, 1 stage	DX, 1 stage (heat pump)	DX, 1 stage
Cooling *COP* (net of fan)	3.10	3.20	3.10	3.20
Heating source	*PTHP*	(2) Hydronic *Boiler*	*PTHP*	(2) Hydronic *Boiler*
Heating *COP* (net of fan) / furnace or *boiler efficiency*	3.10	75% E_t	3.10	75% E_t
Heating *pump* power (W/gpm (W·s/L))	NA	19 (300)	NA	19 (300)
Heating coil heating water delta-T, °F (°C)	NA	50 (27.8)	NA	50 (27.8)
Design HWST, °F (°C)	NA	180 (82.2)	NA	180 (82.2)
HWST reset *set point* vs OAT, °F (°C)	NA	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	NA	HWST/OAT: 180/150 20/50 (82-65.6/ -6.7-10)
Heat loop *pump*ing control	NA	2-way Valves & ride *pump* curve	NA	2-way Valves & ride *pump* curve

SECTION CD106

REFERENCE TABLES

CD106.1 Target Design HVAC Systems.

Target system descriptions described in Tables CD105.4(1) through CD105.4(3) are provided as reference for Section C403.1.1 Exception 10. The target systems are used for developing MPF values and do not need to be programmed into TSPR software.

Table CD106.1(1) Target Building Design Criteria HVAC Complex Systems

Building Type Parameter	Large Office (warm)	Large Office (cold)	School (warm)	School (cold)
System Type	*VAV*/ RH	*VAV*/ RH	*VAV*/ RH	*VAV*/ RH
	Water-cooled Chiller/	Water-cooled Chiller/	Water-cooled Chiller/	Water-cooled Chiller/
	Electric Reheat (PIU)	Gas *Boiler*	Electric Reheat (PIU)	Gas *Boiler*
Fan control	VSD	VSD	VSD	VSD
Main fan power (W/CFM (W·s/L) Proposed ≥ MERV13	1.127 (2.388)	1.127 (2.388)	1.127 (2.388)	1.127 (2.388)
Zonal fan power (W/CFM (W·s/L))	0.35 (0.75)	NA	0.35 (0.75)	NA
Minimum zone airflow fraction	1.5* Voz	1.5* Voz	1.2* Voz	1.2 * Voz
Heat/cool sizing factor	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Outdoor air economizer	*Yes except 0-1*	Yes	*Yes except 0-1*	Yes
Occupied OSA (= proposed)	Sum(Voz)/0.75	Sum(Voz)/0.75	Sum(Voz)/0.65	Sum(Voz)/0.65
Energy recovery ventilator *efficiency* ERR	NA	NA	50%	50%
(Enthalpy Recovery Ratio)			No Bypass	60°F except 4A
ERV bypass SAT *set point*				
DCV	Yes	Yes	Yes	Yes
% Area Variable Control	15%	15%	70%	70%
% Area On/Off Control	65%	65%	20%	20%
Cooling Source	(2) Water-cooled Centrif Chillers	(2) Water-cooled Centrif Chillers	(2) Water-Cooled Screw Chillers	(2) Water-Cooled Screw Chillers
Cooling *COP* (net of fan)	Path B for profile	Path B for profile	Path B for profile	Path B for profile
Heating source (reheat)	*Electric resistance*	Gas *Boiler*	*Electric resistance*	Gas *Boiler*
Furnace or *boiler efficiency*	1.0	90% Et	1.0	80% Et
Condenser heat rejection	Cooling Tower	Cooling Tower	Cooling Tower	Cooling Tower
Cooling tower *efficiency* (gpm/hp (L/s·*kW*))—See G3.1.3.11	40.2 (3.40)	40.2 (3.40)	40.2 (3.40)	40.2 (3.40)
Tower turndown (> 300 ton (1060 *kW*))	50%	50%	50%	50%
Pump (constant flow/variable flow)	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range	Constant Flow; 10°F (5.6°C) range
Tower approach	G3.1.3.11	G3.1.3.11	G3.1.3.11	G3.1.3.11
Cooling condenser *pump* power (W/gpm (W·s/L))	19 (300)	19 (300)	19 (300)	19 (300)
Cooling primary *pump* power (W/gpm (W·s/L))	9 (142)	9 (142)	9 (142)	9 (142)
Cooling secondary *pump* power (W/gpm (W·s/L))	13 (205)	13 (205)	13 (205)	13 (205)

Building Type Parameter	Large Office (warm)	Large Office (cold)	School (warm)	School (cold)
Cooling coil chilled water delta-T, °F (°C)	18 (10)	18 (10)	18 (10)	18 (10)
Design chilled water supply temperature, °F (°C)	42 (5.56)	42 (5.56)	42 (5.56)	42 (5.56)
Chilled water supply temperature (CHWST)	CHWST/OAT:	CHWST/OAT:	CHWST/OAT:	CHWST/OAT:
reset *set point* vs OAT, °F (°C)	44-54/ 80-60	44-54/ 80-60 (6.7-12.2/ 26.7-15.6) (see Apx G)	44-54/ 80-60 (6.7-12.2/ 26.7-15.6) (see Apx G)	44-54/ 80-60 (6.7-12.2/ 26.7-15.6) (see Apx G)
	(6.7-12.2/ 26.7-15.6) (see Apx G)			
CHW cooling loop *pump*ing control	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD
Heating *pump* power (W/gpm (W·s/L))	16.1 (254)	16.1 (254)	19 (254)	19 (254)
Heating HW dT. °F (°C)	50 (27.78)	20 (11.11)	50 (27.78)	20 (11.11)
Design HWST. °F (°C)	180 (82)	140 (60)	180 (82)	140 (60)
HWST reset *set point* vs OAT, °F (°C)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)
Heat loop *pumping* control	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD	2-way Valves & *pump* VSD

Table CD106.1(2) Target Building Design Criteria HVAC Simple Systems

Building Type Parameter	Medium Office (warm)	Medium Office (cold)	Small Office (warm)	Small Office (cold)	Retail (warm)	Retail (cold)
System type	*Package VAV - Electric Reheat*	*Package VAV - Hydronic Reheat*	*PSZ-HP*	*PSZ-AC*	*PSZ-HP*	*PSZ-AC*
Fan control	*VSD*	*VSD*	*Constant Volume*	*Constant Volume*	*2-speed*	*2-speed*
Main fan power (W/CFM (W·s/L)) proposed ≥ MERV13	*0.634 (1.343)*	*0.634 (1.343)*	*0.486 (1.03)*	*0.486 (1.03)*	*0.585 (1.245)*	*0.585 (1.245)*
Zonal fan power (W/CFM (W·s/L))	*0.35 (5.53)*	*NA*	*NA*	*NA*	*NA*	*NA*
Minimum zone airflow fraction	1.5* Voz	1.5* Voz	*NA*	*NA*	*NA*	*NA*
Heat/cool sizing factor	*1.25/1.15*	*1.25/1.15*	*1.25/1.15*	*1.25/1.15*	*1.25/1.15*	*1.25/1.15*
Supplemental heating availability	*NA*	*NA*	*<40°F (<4.4°C) OAT*	*NA*	*<40°F (<4.4°C) OAT*	*NA*

Building Type / Parameter	Medium Office (warm)	Medium Office (cold)	Small Office (warm)	Small Office (cold)	Retail (warm)	Retail (cold)
Outdoor air economizer	*Yes except 0-1*	Yes	*Yes except 0-1*	*Yes*	*Yes except 0-1*	*Yes*
Occupied OSA source	*Packaged unit, occupied damper, all building use types*					
Energy recovery ventilator	*No*	*No*	*No*	*No*	*Yes, in 0A, 1A, 2A, 3A*	*Yes all A, 6,7,8 CZ*
ERR					*50%*	*50%*
DCV	Yes	Yes	No	No	*Yes*	*Yes*
% Area Variable Control	15%	15%			*80%*	*80%*
% Area On/Off Control	65%	65%			*0%*	*0%*
Cooling source	*DX, multi-stage*	*DX, multi-stage*	*DX, 1 stage (heat pump)*	*DX, single stage*	*DX, 2 stage (heat pump)*	*DX, 2 stage*
Cooling COP (net of fan)	*3.83*	*3.83*	*3.82*	*3.8248*	*3.765*	*3.765*
Heating source	*Electric resistance*	*Gas Boiler*	*Heat Pump*	*Furnace*	*Heat Pump*	*Furnace*
Heating COP (net of fan) / furnace or boiler efficiency	*100%*	*81% E_t*	*3.81*	*81% E_t*	*3.536*	*81% E_t*
Heating coil HW dT. °F (°C)	*NA*	20 (11.11)	*NA*	*NA*	*NA*	*NA*
Design HWST. °F (°C)	*NA*	140 (60)	*NA*	*NA*	*NA*	*NA*
HWST reset *set point* vs OAT, °F (°C)	NA	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	NA	NA	*NA*	*NA*
Heat loop *pump*ing control	NA	2-way Valves & ride *pump* curve	NA	NA	*NA*	*NA*
Heating pump power (W/gpm (W·s/L))	NA	16.1	*NA*	NA	*NA*	*NA*

Table CD106.1(3) Target Building Design Criteria HVAC Simple Systems

Building Type / Parameter	Hotel (warm)	Hotel (cold)	Multifamily (warm)	Multifamily (cold)
System type	*PTHP*	*PTAC with Hydronic Boiler*	*Split HP*	*Split AC*
Fan control	Cycling	Cycling	Cycling	Cycling
Main fan power (W/CFM (W·s/L))	0.300 (0.638)	0.300 (0.638)	0.246 (0.523)	0.271 (0.576)
Heat/cool sizing factor	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Supplemental heating availability	<40°F (<4.4°C)	NA	<40°F (<4.4°C)	NA
Outdoor air economizer	Only CZ 2, 3	No	No	No
Occupied OSA source	DOAS	DOAS	DOAS	DOAS except 3C

Energy recovery ventilator	NA	NA	Yes	Yes except 3C
DCV	Yes	Yes	No	No
% Area Variable Control	70%	70%		
% Area On/Off Control	0%	0%		
Cooling source	DX, 1stage (heat pump)	DX, 1 stage	DX, 1 stage (heat pump)	DX, 1 stage
Cooling *COP* (net of fan)	3.83	3.83	3.823	3.6504
Heating source	*Heat Pump*	(2) Hydronic *Boiler*	*Heat Pump*	Furnace
Heating *COP* (net of fan) / furnace or *boiler efficiency*	3.44	81% E_t	3.86	80% AFUE
Heating *pump* power (W/gpm (W·s/L))	NA	16.1	NA	NA
Heating coil heating water delta-T, °F (°C)	NA	20 (11.11)	NA	NA
Design HWST, °F (°C)	NA	140 (60)	NA	NA
HWST reset *set point*	NA	HWST/OAT: 180-150/ 20-50 (82-65.6/ -6.7-10)	NA	NA
vs OAT, °F (°C)				
Heat loop *pump*ing control	NA	2-way Valves & ride *pump* curve	NA	NA

7.0 References

42 USC 6833. ECPA, Public Law 94-385, as amended. Available at http://www.gpo.gov/fdsys/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf. Also see https://www.energycodes.gov/about/statutory-requirements.

ASHRAE. 2004. ANSI/ASHRAE/IESNA Standard 90.1-2004. *Energy Efficient Design of New Low-Rise Residential Buildings*. Atlanta, GA

ASHRAE. 2016. ANSI/ASHRAE/IES Standard 90.1-2016. *Energy Efficient Design of New Low-Rise Residential Buildings*. Atlanta, GA

ASHRAE. 2019. *ASHRAE/ANSI/IES Standard 90.1-2019: Energy Standard for Buildings except Low-Rise Residential Buildings*. Atlanta, GA.

DOE. 2018a. EnergyPlus Energy Simulation Software. U.S. Department of Energy, Washington, D.C. https://energyplus.net/

DOE. 2018b. Building Energy Asset Score. U.S. Department of Energy, Washington, D.C. https://www.energy.gov/eere/buildings/building-energy-asset-score

EIA. 2020 U.S. Energy Information Administration. 2020. Annual Energy Outlook 2020. Energy Information Administration of U.S. Department of Energy, Washington, D.C. https://www.eia.gov/outlooks/aeo/

Franconi E, XYZ. 2021. Feasibility XYZ. Richland, WA. PNNL-XXXX (Pending)

Hart R, C Nambier, M Tyler, Y Xie, and J Zhang. 2019. "Relative Credits for Extra Efficiency Code Measures; Technical Brief." Pacific Northwest National Laboratory, Richland, WA. https://www.osti.gov/servlets/purl/1490280.

Hart R. 2021. "Revision of Section C406." Pacific Northwest National Laboratory, Richland, WA. https://www.sbcc.wa.gov/sites/default/files/2021-06/C406-PNNL-Code%20Change_21i.pdf

Hart R, J McNeill, M Tillou, C Cejudo, C Nambiar, H Nagda, D Maddox, J Lerond, and M Rosenberg,. 2021. *Energy Credits for Energy Codes.* Pacific Northwest National Laboratory, Richland WA.

Hart R and B Liu. 2015. *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.* PNNL-23923, Rev. 1, Pacific Northwest National Laboratory for U.S. Department of Energy Office Energy Efficiency & Renewable Energy. https://www.energycodes.gov/development/commercial/methodology.

HPB. 2019. System Level Key Performance Indicators. http://www.hpbmagazine.org/System-Level-Key-Performance-Indicators/. Accessed July 2021.

Goel S, N Wang, M Rosenberg, and V Mendon. 2014a. "Performance-Based Building System Evaluation for DOE Energy Asset Score." Presented at the ASHRAE Annual Conference, Atlanta, GA, June 28-July 2.

Goel S., R.A. Athalye, W. Wang, J. Zhang, M.I. Rosenberg, Y. Xie, and R. Hart, et al. 2014b. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. PNNL-23269. Richland, WA: Pacific Northwest National Laboratory.

ICC. *2021 International Energy Conservation Code (IECC)*. 2020. International Code Council, Inc., Country Club Hills, IL.

Jonlin D, B Thornton, and MI Rosenberg, 2018a. "Can High Performance Equipment Lead to a Low-Performing Building?" In *Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings* 3:1–13. Washington, DC: ACEEE.

Jonlin D, MI Rosenberg, and S Goel. 2018b. "TSPR: The Total System Performance Ratio as a Metric for HVAC System Efficiency." In *Proceedings of the 2018 ACEEE Summer Study on Energy Efficiency in Buildings*. Asilomar, CA.

Lei X, JB Butzbaugh, Y Chen, J Zhang, and MI Rosenberg. 2020. *Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018)*. PNNL-29787, Pacific Northwest National Laboratory, Richland, WA. https://www.energycodes.gov/sites/default/files/documents/Commercial_Weighting_Factors_2003_to_2018_20200730.pdf

Li H, T Hong, S H Lee, and M Sofos. 2020. *System Level Key Performance Indicators for Building Performance Evaluation*. Lawrence Berkeley National Laboratory, Berkeley, CA. https://eta-publications.lbl.gov/sites/default/files/system-level_key_performance_indicators.pdf

Nambiar C, R Hart, Y Xie, and J Zhang. 2021. End Use Data from Performance Indicator Analysis of 90.1-2019. 2021. Pacific Northwest National Laboratory, Richland, WA. https://www.energycodes.gov/sites/default/files/documents/2019EndUseTables.zip

OpenStudio. (2018). https://openstudio.net

Rosenberg M and R Hart. 2016. *Developing Performance Cost Index Targets for ASHRAE Standard 90.1 Appendix G*. PNNL-25202, Rev. 1, Pacific Northwest National Laboratory, Richland, WA.

Rosenberg M, R Hart, J Zhang, and R Athalye. 2015. *Roadmap for the Future of Commercial Energy Codes*. PNNL-24009, Pacific Northwest National Laboratory, Richland, WA.

Rosenberg M, S Goel, and M Tillou. 2020. "Paving the Way for Net Zero Energy Codes through Performance Based Approaches." *In Proceedings 2020 ACEEE Summer Study on Energy Efficiency in Buildings*, Asilomar, CA.

SEC. 2018. *Seattle Energy Code*. http://www.seattle.gov/sdci/codes/codes-we-enforce-(a-z)/energy-code#2018seattleenergycode

Tyler M, D Winiarski, M Rosenberg, and B Liu. 2021. *Impacts of Model Building Energy Codes – Interim Update*. PNNL-31437, Pacific Northwest National Laboratory, Richland, WA. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-31437.pdf

Wang N, S Goel, V Srivastava, and A Makhmalbaf. 2015. *Commercial Building Energy Asset Score System: Program Overview and Technical Protocol (Version 1.2)*. PNNL-22045, Rev. 1.2, Pacific Northwest National Laboratory, Richland, WA.

WSEC. 2018. *Washington State Energy Code, 2018*. Washington State Building Code Council, Olympia, WA. https://sbcc.wa.gov/sites/default/files/2020-04/2018%20WSEC_C%202nd%20print.pdf

Appendix A –Code Language for Advanced Package

Appendix A includes the code language adjustments necessary if a more aggressive advanced requirement for the HVAC System Performance path is desired by the Jurisdiction. To use the advanced package, simply replace the table CD103.1 in Section 6 with the following:

Table CD103.1 Mechanical Performance Factors

Climate Zone: *Building* type	**Ocp. Group**		**0A**	**0B**	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**	**3C**	**4A**	**4B**	**4C**	**5A**	**5B**	**5C**	**6A**	**6B**	**7**	**8**
Office (small and medium)[a]	B		0.66	0.66	0.64	0.65	0.63	0.60	0.66	0.61	0.63	0.73	0.65	0.71	0.76	0.70	0.73	0.77	0.75	0.78	0.79
Office (Large)[a]	B		0.80	0.81	0.82	0.81	0.77	0.82	0.70	0.77	0.81	0.62	0.77	0.62	0.65	0.69	0.61	0.67	0.66	0.65	0.63
Retail	M		0.53	0.52	0.46	0.49	0.42	0.41	0.38	0.40	0.56	0.44	0.58	0.70	0.45	0.67	0.69	0.47	0.46	0.42	0.37
Hotel/Motel	R-1		0.54	0.54	0.55	0.55	0.54	0.60	0.53	0.60	0.64	0.39	0.52	0.46	0.33	0.41	0.45	0.31	0.33	0.27	0.23
Multi-Family/ Dormitory	R-2		0.56	0.55	0.59	0.55	0.57	0.56	0.52	0.53	0.48	0.46	0.44	0.39	0.47	0.41	0.33	0.48	0.44	0.45	0.41
School/ Education Library	E (A-3)		0.78	0.78	0.78	0.76	0.73	0.72	0.69	0.69	0.68	0.70	0.74	0.68	0.80	0.74	0.62	0.84	0.78	0.78	0.72

[a] large office (gross conditioned floor area >150,000 ft^2 (14,000 m^2) or > 5 floors); all other offices are small or medium

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov