What's New in ASHRAE/IES Standard 90.1-2022—Mechanical Updates, Part II

Mechanical System Performance Rating Method

BY SUPRIYA GOEL, ASSOCIATE MEMBER ASHRAE; REID HART, P.E., LIFE MEMBER ASHRAE; MICHAEL ROSENBERG, FELLOW ASHRAE

ASHRAE/IES Standard 90.1-2022 introduces a new system performance approach—the Mechanical System Performance Rating Method—as a new pathway for HVAC compliance. This method and the metric developed to express the efficiency of the HVAC system—the total system performance ratio (TSPR)—are discussed here.

Benefits of System Performance

Energy codes in the U.S. evaluate HVAC systems at either a component level (prescriptive approach) or through a whole-building performance approach (the Performance Rating Method or Energy Cost Budget in Standard 90.1). Prescriptive evaluation of HVAC systems includes the equipment's rated efficiency to determine compliance with the code through metrics including coefficient of performance (COP), energy efficiency ratio (EER), seasonal energy efficiency ratio (SEER), integrated part load value (IPLV), heating seasonal performance factor (HSPF), annual fuel utilization efficiency (AFUE), etc.

Though excellent metrics for evaluating efficiency of system components at standard conditions, these ratings are not as effective in quantifying actual system performance under the range of part-load and environmental conditions that will actually occur for a specific building installation. These metrics also 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 evaluates 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 shorter-lived components such as HVAC equipment and controls.[1]

A more appropriate metric for isolating the efficiency

Supriya Goel is a senior research engineer at Pacific Northwest National Laboratory in San Francisco. Reid Hart, P.E., is a mechanical engineer at PowerWise Consulting, LLC, in Eugene, Ore. Michael Rosenberg is a chief scientist at Pacific Northwest National Laboratory in Eugene, Ore.

of an HVAC system would be one that analyzes the interactions of all components of the HVAC system; accounts for part-load performance, duct and piping design, system type, and system controls, normalizes for building loads, and does not allow for trade-offs between building systems with different equipment lives (*Figure 1*). The total system performance ratio (TSPR) metric (developed by Pacific Northwest National Laboratory [PNNL]) addresses all 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.[1]

With TSPR, systems using less overall energy each year to meet the building's annual thermal and ventilation loads are rated as more efficient. The TSPR metric does not reward improvements in other building systems (such as reduction in loads from a better performing envelope), and performance is demonstrated solely for the efficiency of HVAC systems in the building. The TSPR metric and the related calculation procedures are further discussed below.

The TSPR metric and the Mechanical System Performance Rating Method were first implemented in Appendix D of the Washington State Energy Code[2] and more recently in Appendix L of Standard 90.1-2022.[3]

Mechanical System Performance Rating Method

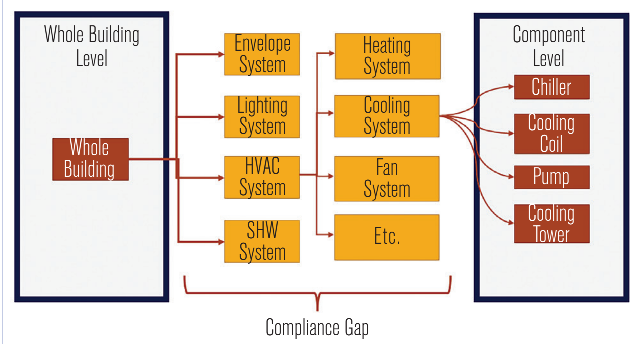
This section defines Standard 90.1-2022's Mechanical System Performance Rating Method and the total system performance ratio (TSPR) metric and provides an overview of the compliance approach. It provides additional details on the process used to calculate the mechanical performance factors (MPFs) and how these details factor into the compliance determination calculation.

TSPR: Definition and Calculation

Total system performance ratio (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 Mechanical System Performance Rating Method.

TSPR Input Metric. TSPR is calculated as the ratio of the sum of a building's annual heating and cooling

FIGURE 1 Compliance paths and need for a system performance approach



load to some metric that represents the annual energy consumed by the building HVAC systems. The input metric representing energy consumption for Standard 90.1-2022 is energy cost using national average energy prices. This approach produces a consistent result that does not change based on region or serving utility. For specific applications, different metrics can be used based on local jurisdiction policy, and alternative metric MPFs for carbon emission, site energy and source energy are included in Informative Tables L5-3, L5-4 and L5-5, respectively, of Standard 90.1-2022.

The TSPR Concept: A larger TSPR indicates lower HVAC energy use to meet building loads; therefore, a system with a larger TSPR can be considered more efficient than one with a smaller TSPR. 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.

The annual HVAC system energy use of all system components (including auxiliary components) is included in TSPR 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. The impact of HVAC system controls, such as temperature and pressure resets 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.[1] Through this holistic approach to HVAC system evaluation, the TSPR metric is able to evaluate HVAC system performance to identify more efficient system configurations.

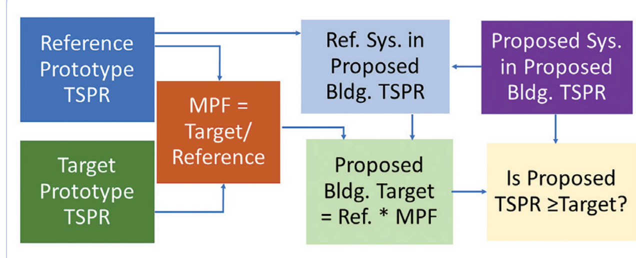
Standard 90.1-2022 Approach

Similar in concept to the Building Envelope Trade-Off Option in Standard 90.1, the Mechanical System Performance Rating Method is a discipline-specific performance approach rather than a whole-building approach.* It has been incorporated into Standard 90.1-2022 as an alternative to prescriptive compliance.

As with prescriptive performance, the mandatory HVAC requirements in Section 6.4 of the standard still apply for performance-based compliance under Section 6.6. Then, mechanical system performance is evaluated by comparing the proposed HVAC system design to a reference building system. As shown in *Figure 2*, this requires the user to calculate the TSPR of both systems. This involves a two-step process of first selecting the system components (*Table 1*) and second determining the resulting HVAC load to energy input ratio (i.e., the TSPR). This process is explained in greater detail throughout Section 6.6 and Appendix L of Standard 90.1-2022.

*The Building Envelope Trade-Off compliance path in the envelope discipline of Standard 90.1 that is supported by Appendix C is an example of a discipline performance rating path.

FIGURE 2 Using MPF to compare a proposed to a target HVAC system.



Computing the TSPR: Target systems define the minimum performance level required for compliance with this approach. Since target systems are changing with each code cycle, for simulation software stability, a stable reference system is used as a touchstone, with MPFs used to define the relationship between reference and target systems. Reference and target systems are summarized in *Table 1* and further detailed below.

Target systems are defined by the Standard 90.1 Standing Standards Project Committee for each climate zone and building type and represent minimum prescriptive levels of performance for a "good" HVAC system installation. The HVAC system selected for the

TABLE 1 Summary of reference and target systems by building type in Standard 90.1-2022.

	Building Type Parameter	Large Office	Medium Office	Small Office	Retail	School	Hotel	Apartment
Reference	System Type (Warm CZ)	VAV/RH Water-Cooled Chiller (0.576 kW/ton)/ Elec RH	Packaged VAV/RH DX Cool (COP 3.4)/Elec RH	Packaged Air-Source Heat Pump (Cooling COP 3.0, Heating COP 3.4)	Packaged Air-Source Heat Pump (COP 3.4)	VAV/RH Water-Cooled Chiller (0.718 kW/ton); Elec RH	Packaged Terminal Air-Source Heat Pump (Cooling and Heating COP 3.1)	Packaged Terminal Air-Source Heat Pump (Cooling and Heating COP 3.1)
Target	System Type (Warm CZ)	VAV/RH Water-Cooled Chiller (0.576 kW/ton)/ Elec RH	Packaged VAV/RH DX Cool (COP 3.83)/ Elec RH	Packaged Air-Source Heat Pump (Cooling COP 3.82, Heating COP 3.81)	Packaged Air-Source Heat Pump (Cooling COP 3.76, Heating COP 3.54)	VAV/RH Water-Cooled Chiller (0.68 kW/Ton); Elec RH	Packaged Terminal Air-Source Heat Pump (Cooling COP 3.83, Heating COP 3.44)	Split Air-Source Heat Pump (Cooling COP 3.82, Heating COP 3.86)
Reference	System Type (Cold CZ)	VAV/RH Water-Cooled Chiller (0.576 kW/ton)/Gas Boiler (80% AFUE)	Packaged VAV/RH DX Cool (COP 3.4)/ Gas Boiler (75% E_t)	Packaged Air-Source AC (COP 3.0)/Furnace (80% E_t)	Packaged Air-Source AC (COP 3.5)/Furnace (80% E_t)	VAV/RH Water-Cooled Chiller (0.718 kW/Ton); Gas Boiler (80% AFUE)	Packaged Terminal AC (COP 3.2)/ Furnace (75% E_t)	Packaged Terminal AC (COP 3.2)/ Furnace (75% E_t)
Target	System Type (Cold CZ)	VAV/RH Water-Cooled Chiller (0.576 kW/ton)/ Gas Boiler (90% E_t)	Packaged VAV/RH DX Cool (COP 3.83)/Gas Boiler (81% E_t)	Packaged Air-Source AC (COP 3.82)/ Furnace (81% E_t)	Packaged Air-Source AC (Cooling COP 3.76)/Furnace (81% E_t)	VAV/RH Water-Cooled Chiller (0.68 kW/Ton); Gas Boiler (80% E_t)	Packaged Terminal AC (COP 3.83)/ Furnace (80% E_t)	Split Air-Source AC (COP 3.65) Gas Furnace (80% AFUE)

Elec RH – Electric Reheat; VAV – Variable Air Volume; DX – Direct Expansion; AC – Air Conditioner;
COP – Coefficient of Performance; E_t – Thermal Efficiency; AFUE – Annual Fuel Utilization Efficiency

target attempts to strike a balance between the least efficient prescriptively allowed 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. "Good systems" are set at the applicable minimum efficiency levels listed in Tables 6.8.1-2 through 6.8.1-21 of Standard 90.1-2022.

A "reference system" is also defined, which follows the Standard 90.1 Appendix G baseline configuration, which meets the Standard 90.1-2004 code requirements for efficiency levels, controls, fan power, economizers, energy recovery, etc., and provides a stable baseline for comparison.

Mechanical Performance Factors: To demonstrate compliance, the proposed system TSPR must be greater than a reference system TSPR divided by a mechanical performance factor (MPF). Section 6 of Standard 90.1-2022 includes a table of MPFs for various building types in each climate zone. The reference systems are based on those defined in the Standard 90.1-2022 Appendix G baseline, which are set roughly at the efficiency levels of Standard 90.1-2004. The MPFs are analogous to building performance factors in Appendix G and establish the improvement over the stable 2004 baseline required to meet the current code. MPFs were developed based on a target level of performance considering current code requirements and are intended to be updated with each code cycle. *Figure 2* shows how MPFs are initially generated with prototype buildings. Then the real-time run of the proposed building is used with both proposed and reference systems. The reference system in the proposed building TSPR is multiplied by the MPF to generate a target for the proposed building. The proposed system passes if its TSPR is greater than the **calculated** target.

Designers may want to use TSPR to avoid some prescriptive requirements in these situations:

- For some systems, an outdoor air economizer might not be desirable even though prescriptively required. Using TSPR the designer could show that the energy savings of an economizer could be offset by lower fan energy and higher cooling efficiency.
- In some buildings, the fan power limits might be difficult to achieve. Where higher fan power is desired, the higher fan energy use could be offset through better heating and cooling system efficiency.

Analysis Tool

Although a web-based tool to implement the Mechanical System Performance Rating Method has been developed by PNNL, any simulation tool meeting the requirements laid out in the Mechanical System Performance Rating Method in Normative Appendix L of Standard 90.1-2022 and approved by the code official can be used to determine compliance with this approach.

The following paragraphs describe the simulation tool requirements, as outlined in Standard 90.1-2022 Appendix L; software architecture of the tool; the various simplifications implemented within the tool to support the Mechanical System Performance Rating Method; and the compliance report generated by the tool.

Simulation Tool Requirements: The simulation tool must operate within the parameters defined in Table L2.2.3 of Appendix L, where each system component will have either fixed or user-defined characteristics within a specified range. The intent of these simplifications is to maintain consistency and reduce the level of effort associated with developing an energy model by both limiting the parameters that can be entered by the user and using standard modeling defaults for parameters not available for the user to edit. Some of the key requirements for the tool include:

- Ability to limit user inputs to those required for defining the proposed building HVAC system as defined by the ruleset in accordance with Appendix L;
- Implement defaults for schedules, loads and additional strategies such as fan curves, pump curves and demand-controlled ventilation in accordance with Appendix L.
- Automatically generate the standard reference design based on the user-defined proposed building.
- Run annual simulations for the reference and proposed buildings to determine the annual HVAC energy use and annual heating and cooling loads.
- Determine compliance by calculating the proposed building TSPR and reference building TSPR and comparing its ratio against the required MPF for that climate zone and building type.†
- Generate a compliance report that outlines the compliance outcome and additional details including

†An area-weighted average MPF would be calculated for a mixed-use building.

FIGURE 3 Medium office results for different system configurations (Climate Zone 2A).

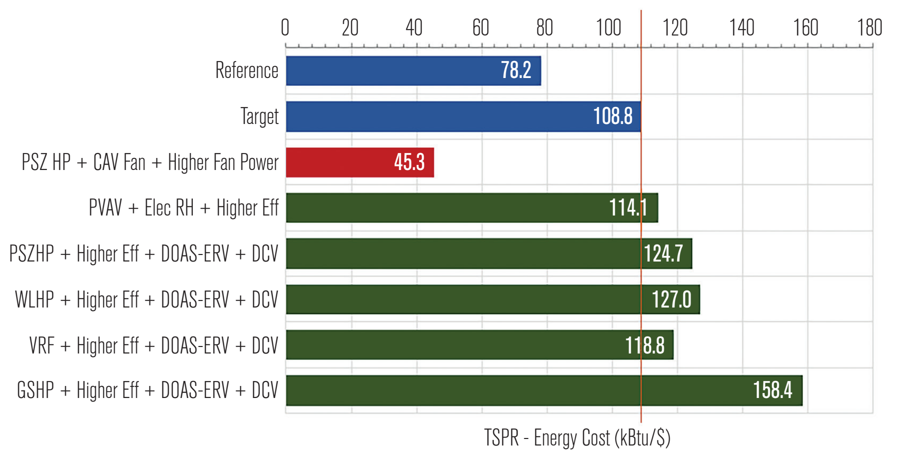
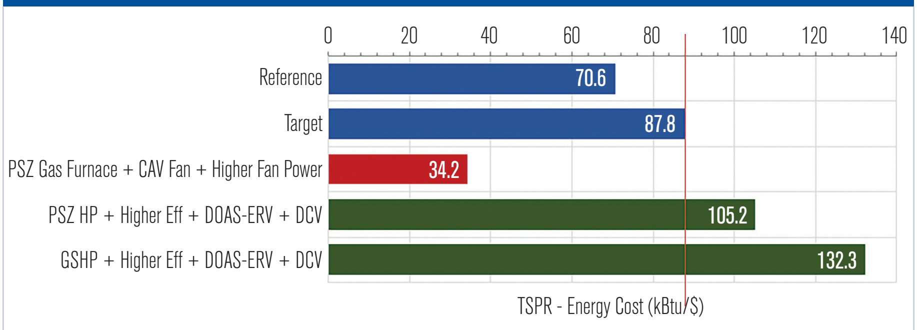


FIGURE 4 Medium office results for different system configurations (Climate Zone 5A).



user-specified inputs, and simulation results, to facilitate the compliance review, as required by the ruleset.

Overview of Mechanical System Performance Tool: The Mechanical System Performance tool (MSP tool, also known as the TSPR analysis tool), developed by PNNL for DOE, is a web-based tool to provide a simplified interface for HVAC system evaluation. It uses EnergyPlus and OpenStudio to develop a simplified whole-building energy model of a building and provides an assessment of building systems based on the specified building characteristics. The tool implements the Mechanical System Performance ruleset and includes a simplified block schema to represent the building's geometry rather than a detailed building architectural description. This allows for rapid input, with a completed analysis in four to 12 hours rather than 40 to 120 hours of professional time.

The tool 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 tool can be found at https://energycode.pnl.gov/HVACSystemPerformance.

System Comparisons: Validation of the TSPR Approach

PNNL used the MSP tool to validate differences in HVAC system performance. Prototype building models were modified to include the Mechanical System Performance Rating Method requirements for each respective use type. This section shows the results for the medium office, analyzed in Climate Zones 2A and 5A, with several different HVAC system configurations, including (1) the reference HVAC system, (2) the target HVAC system, (3) a base-efficiency configuration that meets the Standard 90.1-2022 prescriptive code and that is the least efficient system configuration that complies with the code and (4) several advanced system configurations that exceed the code requirement. Additional comparison results and details can be found in a PNNL technical report.[4]

Each of the advanced cases looks at different system types, including variable refrigerant flow (VRF), water-loop heat pumps (WLHPs) or ground-source heat pump (GSHP) systems. Several advanced scenarios include dedicated outdoor air systems (DOAS) with energy recovery ventilation (ERV) and demand-controlled ventilation (DCV).

For each of the building type and climate zone comparisons, the TSPR results are color coded in the figures in the following subsections as follows:

- Reference and target system TSPRs are shown in blue. The target TSPR for the building needs to be exceeded to meet the TSPR compliance criteria, and a red line is drawn for that threshold.
- System configurations that do not meet the target TSPR are shown with red bars.

- Alternative system configurations that meet or exceed the target TSPR are shown in green. These systems qualify as passing the Mechanical System Performance Rating Method.

Medium Office

The medium office reference system is a packaged variable air volume (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). The section below summarizes the additional scenarios analyzed for Climate Zones 2A and 5A, and *Figure 3* and *Figure 4* show the resulting TSPR-cost for each of these scenarios. In each case, the base-efficiency option, which meets Standard 90.1-2022 minimum prescriptive code requirements, has a significantly lower TSPR than the target. A lower TSPR than the target indicates more HVAC energy use to meet the same loads as compared to the target, hence reflects a lower-efficiency system.

The following HVAC systems were analyzed for Climate Zone 2A:

1. **Reference System:** Packaged variable air volume (PVAV) with electric reheat and fan-powered induction units (PIU) based on the requirements defined in Standard 90.1-2022 for the specific use type and climate zone.
2. **Target System:** PVAV with electric reheat PIU, based on the requirements defined in Standard 90.1-2022 for the specific use type and climate zone.
3. **PSZ HP + CAV Fan + Higher Fan Power:** Packaged single-zone heat pump (PSZ HP) meeting prescriptive code requirements with a constant air volume (CAV) fan with fan power higher than the target system.
4. **PVAV + Elec RH + Higher Eff:** Packaged variable air volume (PVAV) with electric reheat with higher efficiency for the cooling system, DCV and economizer control.
5. **PSZ HP + Higher Eff + DOAS-ERV + DCV:** Packaged single-zone heat pump (PSZ HP) with higher efficiency (than code minimum), with DOAS, ERV and DCV.

6. WLHP + Higher Eff + DOAS-ERV + DCV: Water loop heat pumps with higher efficiency (than code minimum), with DOAS, ERV and DCV control.

7. VRF + Higher Eff + DOAS-ERV + DCV: Variable refrigerant flow (VRF) systems with higher efficiency (than code minimum) with DOAS, ERV and DCV control.

8. GSHP + Higher Eff + DOAS-ERV + DCV: Ground-source heat pumps (GSHP) with higher efficiency (than code minimum) with DOAS, ERV and DCV control.

The following HVAC systems were analyzed for Climate Zone 5A:

1. Reference System: PVAV with hot water (HW) reheat, based on the requirements defined in Standard 90.1-2022 for the specific use type and climate zone.

2. Target System: PVAV with hot water (HW) reheat, based on the requirements defined in Standard 90.1-2022 for the specific use type and climate zone.

3. PSZ Gas Furnace + CAV Fan + Higher Pan Power: PSZ gas furnace with minimum prescriptive efficiency with a CAV fan with fan power higher than the target system.

4. PSZ HP + Higher Eff + DOAS-ERV + DCV: Packaged single zone heat pump (PSZ HP) with higher efficiency (than code minimum) with DOAS, ERV and DCV.

5. GSHP + Higher Eff + DOAS-ERV + DCV: Ground-source heat pumps (GSHP) with higher efficiency (than code minimum) with DOAS, ERV and DCV control.

Conclusion

Until recently, energy codes relied on either the prescriptive compliance approach or the whole-building performance compliance approach to determine code compliance.

For the first time, the new Mechanical System Performance Rating Method gives the energy code a metric and a minimum standard for evaluating the overall efficiency of a building's HVAC system, without prescribing the technical means of achieving that level of efficiency. This approach can be tailored to meet goals and objectives of the adopting jurisdiction.

The stringency of TSPR metric thresholds can be set initially to eliminate only the least efficient systems from consideration and can then be strengthened over future code cycles to require progressively higher-performing systems.

This encourages an integrated design approach for the selection and analysis of HVAC systems and can potentially shift the focus of code compliance from that of simply complying with the prescriptive provisions to that of designing complete integrated systems that interact in a manner that provides the highest levels of efficiency.

The Mechanical System Performance Rating Method can be applied to any model energy code or beyond-code program.

Standard 90.1 is using energy cost as the TSPR evaluation metric, but this could just as well be carbon emissions, site energy use or source energy use based on the policy goals of the city, state or jurisdiction applying the Mechanical System Performance Rating Method. Informative material supporting the use of these alternative metrics is included in Standard 90.1-2022 Appendix L.

Aspects of a high-performance system design which, through the prescriptive approach to compliance, were not credited or recognized are now a critical aspect for system evaluation.

The simplified implementation of the Mechanical System Performance Rating Method through the MSP tool provides a mechanism for designers to perform quick analysis to identify how different system design strategies impact the overall performance of the HVAC system.

This approach is a critical step toward a systems-based approach for building design and evaluation.

The Mechanical System Performance Rating Method is a bridge between the prescriptive compliance path and the whole-building performance compliance path making it a highly viable option to facilitate the transition to performance-based codes and to meet aggressive energy efficiency goals.

References

1. Goel, S., R. Hart, J. Gonzalez, J. Lerond, et al. 2021. "Mechanical Performance Factor Development for HVAC System Performance." PNNL-32140. Technical Documentation. Pacific Northwest National Laboratory for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. https://tinyurl.com/yc54mf8m

2. WSEC. 2018. Washington State Energy Code. Washington State Building Code Council.

3. ANSIASHRAE/IES Standard 90.1-2022, *Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings*.

4. Goel, S., R. Hart, Tillou, M., M. Rosenberg, et al. 2021. "HVAC System Performance for Energy Codes." PNNL-31571. Technical Brief. Pacific Northwest National Laboratory for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. https://tinyurl.com/43tucm8t ■