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Introduction to ASHRAE 205 – A New Standard for HVAC&R Performance Maps

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ABSTRACT

Heating, cooling, ventilation, and refrigeration accounts for about 55% of energy use in buildings in the US (about 21 quads in 2021), hence accurate performance data of HVAC&R equipment is important in using computer models to select HVAC&R equipment, design control systems, predict building energy use during design, and helping to diagnose equipment problems during operation. The information available about HVAC&R equipment performance is generally limited and is published in inconsistent formats. Software programs often differ in how they interpret the available data and how they then model the HVAC&R equipment performance. Software can differ greatly in their predictions of HVAC&R equipment performance outside of the specific conditions used in testing HVAC&R equipment for various certifications. To improve the accuracy of HVAC&R performance prediction and the consistency of modeling HVAC&R performance between different software packages, ASHRAE has been developing Standard 205: Representation of Performance Data for HVAC&R and Other Facility Equipment. Standard 205 defines a common data model and serialization format for facility equipment performance data, allowing consistent and automated exchange among data sources (equipment manufacturers), simulation models, and engineering applications. Standard 205 defines a human readable JSON Schema used for defining data models and formats and Concise Binary Object Representation (CBOR) as the serialization format for the actual data file. This paper introduces Standard 205, the general representation format, and walks through a specific example of implementation for a piece of HVAC equipment.

1. INTRODUCTION

In 2021, buildings accounted for about 38 quads and 39% of all energy use in the US and heating, cooling, ventilation, and refrigeration (HVAC&R) accounts for about 55% of that building energy use (about 21 quads) (EIA 2021). Designers trying to reduce energy use and carbon footprint of their building designs are increasingly using building energy modeling (BEM) as a part of their design process. Thus, the need for accurate and consistent modeling of HVAC&R equipment by BEM software is growing.

Manufacturers typically provide limited information about the performance of their equipment: standardized rating numbers (IPLV, SEER, etc.) and performance at only a few operating points as shown in Figure 1. As a result, two pieces of equipment with the same standardized rating might have very different full performance maps and might result in very different energy use when operated away from the operating points used to define the rating. This is especially true for ratings that use unrealistic operating points to define the rating metric (Geister and Thompson 2009). Sometimes the equipment has a rating or certification that generates a richer, but still incomplete performance map. Sometimes designers can obtain a more complete equipment performance map upon request from the manufacturer, but the data obtained will differ in content and format from manufacturer to manufacturer and even between differing equipment from the same manufacturer (Yang and Li, 2010). For example, some manufacturers may include fan and pump energy in their performance map while others break out fan and pump energy separately. Some manufacturers might give a performance map in SI units, others in IP units, and some in mixed units. The dependent and independent variables that the performance map describes might also vary from manufacturer to manufacturer or equipment to equipment.

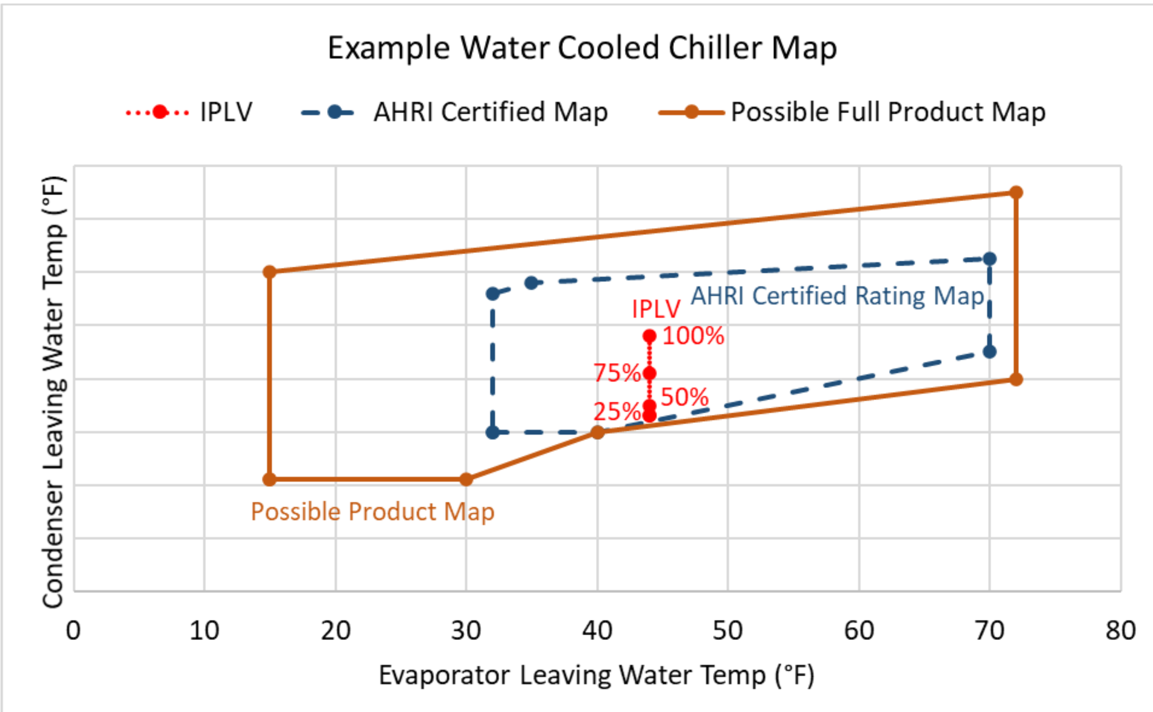

Figure 1: Example of performance data maps for a limited rating, for a more complete certification, and for the full operating range of the equipment.

Once the necessary performance data for the equipment are obtained, the modeler then needs to convert that data to the proper format for the BEM model, often in the form of curve fitting data extracted from the performance map to the internal model. Some models are physics based, trying to describe system operation with a set of linear or non-linear differential equations while some models are empirical, consisting of curve fits (often biquadratic) to some portion of measured data and others are machine learning models. To speed simulation, detailed physics models often get simplified (google the term "simplified cooling coil model" to see just how many simplified models have been proposed). Each of these models will result in differing simulation results, especially if the model is simulating performance in regimes that are "far away" from any specific data point given by the manufacturer.

A comparison of ten empirical steady-state models for liquid chillers by Swider (2002) showed R^2 values ranging from 0.40 to 0.95. A comparison of eleven empirical models for variable speed, variable flow water chillers by Lee, Liao and Lu (2012) showed coefficient of variation of root mean square (CVRMSE) values ranging 1.9% to 12.9%. Such variations in predictions are annoying at best but potentially "design killing" at worst because even small variations in energy savings prediction could be the difference between a design passing or failing a performance rating method such as ASHRAE 90.1 Appendix G (ASHRAE, 2019).

In addition to differing results from differing software, a designer who is using different software packages for different parts of the design would likely need to convert the performance map multiple times. Each stage of data manipulation, reformatting, and curve fitting is time consuming and provides an opportunity for an error to occur. As a result, designers limit the range of equipment they select, especially newer and more efficient equipment for which the process has not yet been done, thus limiting the ultimate performance of the system design.

ASHRAE Standard 205: Representation of Performance Data for HVAC&R and Other Facility Equipment is a new standard common data model and serialization format for facility equipment performance data that allows for consistent and automated data exchange among data sources (equipment manufacturers), simulation models, and engineering applications. Because ASHRAE 205 calls for a complete performance map with a high density of points, equipment performance simulation can directly read the performance map and use linear interpolation to estimate performance between adjacent performance map points, avoiding the need to perform any curve fitting and ensuring accuracy of the simulation and consistency of performance estimation across software packages.

This paper presents a summary of the ASHRAE 205 standard, explains the general data format, and discusses the future plans for development.

2. ASHRAE 205 DEVELOPMENT HISTORY

Development of ASHRAE 205 began with the formation of ASHRAE SPC 205 in the Fall of 2010 with the first meeting at the Las Vegas ASHRAE meeting in 2011. Development of 205 continued in spurts from 2011 through late 2018 when a first full draft of the standard emerged. The first publication public review (PPR) of 205 began in March of 2019 with 130 public comments. The standard was updated and modified to address the comments and a second draft (PPR2) was released for public review in May 2020. That draft received 56 public comments which were resolved over the next year and a third draft (PPR3) was submitted for public review in June 2021 and it received 19 public comments. Those comments are currently being resolved and since modifications to PPR3 are expected to be minor, they will undergo Independent Substantive Change (ISC) review of only changed elements rather than a full public review of the entire document sometime in 2022.

After creation of an SPC, the first task in creating a new ASHRAE standard is to develop the Title, Purpose, and Scope (TPS) of the standard. This seemingly simple step is not always as easy as it sounds, especially when it comes to clearly stating the scope of the standard.

As of April 2022, the ASHRAE 205 TPS is the following:

> **TITLE**: Representation of Performance Data for HVAC&R and Other Facility Equipment
>
> **PURPOSE**: To facilitate automated sharing of equipment performance characteristics by defining data models and data serialization formats.
>
> **SCOPE**: This standard applies to performance data for any HVAC&R or other facility system, equipment, or component

The current standard is about 100 pages long, the bulk of which are the Representation Specifications (RS) which describe the required and optional informative, descriptive, and performance data for that equipment. The format of the RS is described more in Section 3.

3. ASHRAE 205 DATA MODEL AND SERIALIZATION FORMAT

The main body of the standard provides rules and definitions used for a generating reference specification (RS) which is a human readable document that defines the required and optional documentation, the data model, and verification rules. The actual 205 data file is a Concise Binary Object Representation (CBOR) file that conforms to a JSON Schema defined by an RS. The overall structure of 205 and how it relates to equipment manufacturers and application software is shown in Figure 2.

In contrast to many other ASHRAE standards, ASHARE 205 is not dual-unit, and uses only SI units within specifications. In the context of automated data exchange, the use of dual-units would introduce ambiguity and complicate implementation.

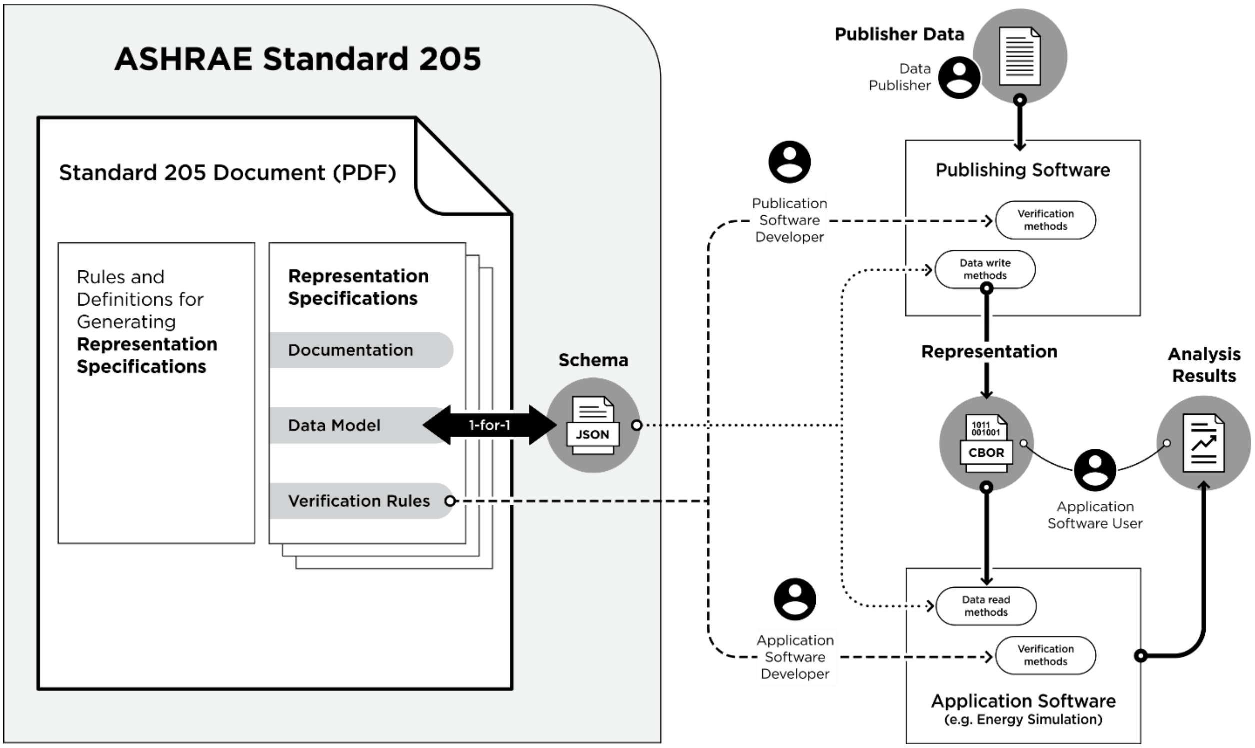

Figure 2: ASHRAE Standard 205 Structure

3.1 Representation Specification (RS)

Each RS has a standardized format consisting of the following:

- Identification and History: This section includes an identifier the format of RSXXXX (where XXXX is a four-digit number), a version history table including a version number, date, and notes where changes between version are explained. The four-digit XXXX number is assigned by SPC 205 when the RS is ready for public review.
- Scope and Description: This section provides information that defines the applicability (i.e., description of covered equipment) and exclusions (description of equipment not covered but that someone might think is covered).
- Embedded Representations: This section lists any component elements in the system that have their own RS, such as a fan, motor, or drive assembly.
- Referencing Representations: This section is a list of any other RS which reference this particular RS.
- Schematic: One or more schematics providing a visual representation of the equipment. These are typically simple line drawings designed to help users understand the basic energy flows of the equipment.
- Data Model: This section specifies the data groups, elements and enumerations that identify the system performance, i.e., these are the performance maps.

As of April 2022, the 205 draft has seven RSs as described in Table 1. Other RS currently are under development include Water Source Heat Pumps, Energy Recover Ventilators, Fan Coil Units, and Variable Refrigerant Flow Outdoor Units.

Table 1: Current Representation Specifications in ASHRAE 205

Designation	Title	Applicability
RS0001	Liquid-Cooled Chiller	Electrically driven vapor compression liquid-chilling packages that include one or more hermetic or open drive compressors (centrifugal, screw, scroll, reciprocating, rotary or other types) and are equipped with a liquid-cooled condenser
RS0002	Unitary Cooling Air-Conditioning Equipment	Air cooled direct expansion cooling air conditioners, including those with single speed, staged, or variable speed compressor(s). This representation specification applies to both unitary and packaged systems.
RS0003	Fan Assembly	Fans within a packaged assembly. An "assembly" describes the context of static pressure values provided in a conforming representation. An assembly shall include any number of components in addition to the fan that are accounted for in the representation's static pressure values. An assembly shall contain no additional components if no other components are accounted for in the representation's static pressure values
RS0004	Air-to-Air Direct Expansion Coil System	Direct expansion vapor compression refrigerant coil systems with two coils (one evaporator and one condenser) both exchanging heat with air streams to provide cooling
RS0005	Motor	Electric motors
RS0006	Electronic Motor Drive	Electronic motor drives
RS0007	Mechanical Drive	Mechanical drives used to transmit mechanical power from one shaft to another through belts, gears, or chains.

3.2 Serialization Format

The serialization format is the implementation of encoding the data model for storage and transmission. In other words, it's the actual file format for the single file that contains all the descriptive data and the actual performance maps. While the RS is described at a high level using YAML, JSON, and Markdown, one could use JSON itself as the final serialization format but as an ASCII readable/editable file, that format is more susceptible to accidental or deliberate modification. For example, loading a file to an editor and resaving without typing anything can often introduce changes to the file in the form of linefeed character insertion/removal, tab insertion/removal, word wrapping, and other seemingly benign modifications that alter the size of the file and make it difficult to determine if substantial changes to the file have been made. Additionally, using a text-based format means both the file size and speed of reading in the data file itself can start to become excessive in some larger pieces of equipment.

For these reasons and others, SPC 205 decided that a binary format of some sort was best for serialization. Luckily, there is a standard binary serialization format already developed for JSON called Concise Binary Object Representation or CBOR, and so CBOR has been adopted as serialization format for an ASHRAE 205 Reference Specification (Bormann and Hoffmann, 2020). CBOR also has a standard method of encryption (Schaad and Cellars, 2017) manufacturers who wish to use encryption as a method of limiting data access to authorized users and/or ensuring data integrity.

3.3 Equipment Performance Map

The key data within the representation is the equipment performance map (or maps) which is basically a multidimensional data lookup table. The purpose of ASHRAE 205 is to give manufacturers a standard way to organize a complete performance map for each type of equipment thus eliminating the need for BEM software to "guess" at an equipment's operating performance, either by assuming a specific model of operation or extrapolating performance from a limited performance map. ASHRAE 205 requires that the data in the performance map dense enough that linear interpolation can accurately estimate the performance between any adjacent points in the performance map.

The performance map itself is described as a set of data values relating *grid variable* (i.e., inputs) to *lookup variables* i.e., outputs). For each unique set of grid variables there is a corresponding set of lookup variables that are the system state (or performance) at the given combination of grid variables. A set of three grid variables can be thought of as a non-linear rectilinear grid as shown in Figure 3.

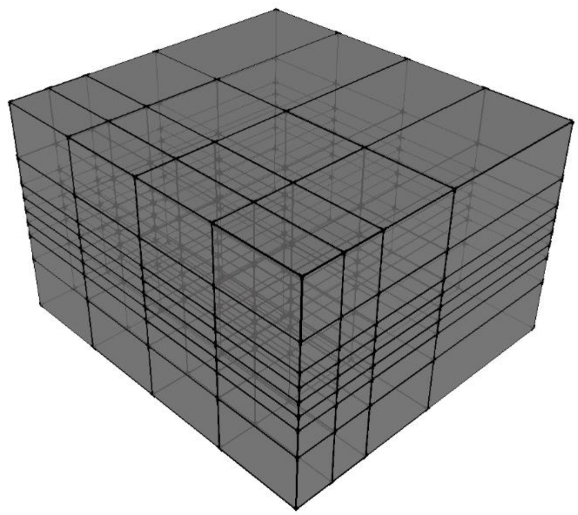

Figure 3: Example of a three-dimensional rectilinear grid

ASHRAE 205 does not define a required number of data points for each grid variable, or required density of lookup variable data points, but does recommend the data publisher provide a density high enough for "accurate" prediction by multidimensional linear interpolation. The standard also does not define "accurate" – that is a determination left to the manufacturer to decide. As one can imagine, defining a performance map for a system component with several grid variables, a wide range of operating conditions, and significant non-linearities could result in hundreds, to thousands, or even tens of thousands of data points, certainly far more data points that could be easily presented on a PDF data sheet, and far too many to expect engineers to individually create data tables by hand from the PDF sheet without error, hence reinforcing the need for a standard data file format.

4. PERFORMANCE MAP EXAMPLE

As an example of an ASHRAE 205 Performance Map consider the fictious example given in Appendix A of 205. This equipment provides a cooling power and capacity based upon an indoor temperature, and outdoor temperature and a volumetric flow rate. Grid variables for this example would be defined as in Table 2:

Table 2: Example Grid Variable Definition

Name	Data Type	Units	Constraints
outdoor_temperature	Numeric	K	≥ 0
indoor_temperature	Numeric	K	≥ 0
air_volumetric_flow_rate	Numeric	m^3/s	≥ 0

Lookup variables for this example would be defined as in Table 3.

Table 3: Example Lookup Variable Definition

Name	Data Type	Units	Constraints
power	Numeric	W	≥ 0
capacity	Numeric	W	≥ 0

Suppose for this example that the equipment has a limited operational space where the performance can be well defined with only 3 outdoor temperatures, 3 indoor temperatures and 2 volumetric flow rates. In that case the grid variable data group might consist of the following values:

outdoor_temperature = **[**302.59**,** 308.15**,** 313.71**]**
indoor_temperature **= [**295.37**,** 297.04**,** 298.71**]**
air_volumentric_flow_rate = [0.26, 0.34]

This example has two lookup variables, each of which has a value for all combinations of the grid variables, which means that for this example there are 3x3x2 = 18 data points. An example lookup variable data group might be:

Power **= [**2192.5**,** 2192.5**,** 2192.5**,** 2192.5**,** 2192.5**,** 2192.5**,** 2370**,** 2370**,**
2370**,** 2370**,** 2370**,** 2370**,** 2615**,** 2615**,** 2615**,** 2615**,** 2615**,** 2615**]**

Capacity **= [**8740**,** 9100**,** 8740**,** 9100**,** 8740**,** 9100**,** 8380**,** 8720**,** 8380**,**
8720**,** 8380**,** 8720**,** 8560**,** 8910**,** 8560**,** 8910**,** 8560**,** 8910**]**

These data can be put into a single 2-D table with each row corresponding to a unique combination of grid variables as shown in Table 4. These are the performance data that get encoded into the CBOR file that would be published by the manufacturer.

Table 4: Example Performance Map Data Group

outdoor_temperature (K)	**indoor_temperature (K)**	**air_volumetric_flow_rate (m^3/s)**	**power (W)**	**capacity (W)**
302.59	295.37	0.26	2192.5	8740.0
302.59	295.37	0.34	2192.5	9100.0
302.59	297.04	0.26	2192.5	8740.0
302.59	297.04	0.34	2192.5	9100.0
302.59	298.71	0.26	2192.5	8740.0
302.59	298.71	0.34	2192.5	9100.0
308.15	295.37	0.26	2370.0	8380.0
308.15	295.37	0.34	2370.0	8720.0
308.15	297.04	0.26	2370.0	8380.0
308.15	297.04	0.34	2370.0	8720.0
308.15	298.71	0.26	2370.0	8380.0
308.15	298.71	0.34	2370.0	8720.0
313.71	295.37	0.26	2615.0	8560.0
313.71	295.37	0.34	2615.0	8910.0
313.71	297.04	0.26	2615.0	8560.0
313.71	297.04	0.34	2615.0	8910.0
313.71	298.71	0.26	2615.0	8560.0
313.71	298.71	0.34	2615.0	8910.0

5. ASHRAE 205 FUTURE DEVELOPMENT

The proposed changes to the Public Review 3 draft will be sent public review by ASHRAE in a limited Independent Substantive Change (ISC) review which limits public review to only the listed changes and expected to have no public comments or comments that can be resolved with only editorial changes which do not require public review. It is expected that Standard 205 will be published as ASHRAE Standard 205 2022 sometime in the summer of 2022. At the time of publication, SPC 205 will request to change from a Standard Publication Committee (SPC) to a

Standing Standard Publication Committee (SSPC) and for ASHRAE 205 to become a standard undergoing continual maintenance (CM).

The core 205 development team is beginning development of extensions to the toolkit to allow the use of Heat Pump Design Model (HPDM), developed by Oak Ridge National Laboratory, to generate performance maps and automatically create ASHRAE 205 format files. Many manufacturers use versions of HPDM as an internal design tool and for creating performance maps for requests from the design industry so these extensions should make it easier for users of HPDM to easily generate ASHRAE 205 compliant files.

SPC 205 members are currently developing several RS for additional equipment including:

- Defrost (this is looking at a common way of representing defrost across various equipment)
- ERV
- Fan Coils
- Hot Water Heaters
- Unitary Heat Pumps
- VRF

For some of these equipment, point-by-point performance maps might become either too large or too difficult to generate. SPC 205 understands this and is thus considering the use standardized parameterizations or other alternative approaches to describing performance data.

The new RS will be added to ASHRAE 205 as Addenda as they are completed. SPC 205 welcomes new membership and encourages manufacturers to lead development of new RS for equipment not already covered. The core ASHRAE 205 development team will continue working with other SPC and industry members not only to maintain the standard but also continue development of the ASHRAE 205 toolkit with tools for both manufacturers and simulation developers and will with other SPC members to develop guides for the development of new RS as well as for use and integration of ASHRAE 205 tools into simulation software.

Recently the California Simulation Engine (CSE) demonstrated the ability to load and run a simple ASHRAE 205 file in place of the other internal equipment models. The development team hopes this demonstration will encourage other software developers to also begin incorporating the use of ASHRAE 205 files into their software.

Once ASHRAE 205 is published and as the equipment covered by 205 grows and software vendors begin to implement 205, SPC 205 and others will look to engage with other standards and certifications (ASHRAE 90.1, IECC, RESNET, LEED, etc.) to consider making use of ASHRAE 205 files a core part of those standards.

6. CONCLUSIONS

ASHARE 205 is a new ASHRAE standard describing a data model and file format for the performance data of HVAC&R and related equipment. When published, the standard is expected to provide the following benefits to the HVAC&R community:

- Increased publication of full performance maps by manufacturers
- Decreased errors generated when inputting equipment performance info into application software
- More consistent and accurate equipment performance simulation by BEM application

NOMENCLATURE

BEM	Building Energy Modeling
CBOR	Common Binary Object Representation
CM	Continual Maintenance
CSE	California Simulation Engine
CVRMSE	Coefficient of Variation of Root Mean Square Error
HPDM	Heat Pump Design Model

ISC	Independent Substantive Change
PPR	Publication Public Review
RS	Representation Specification
SPC	Standard Project Committee
SSPC	Standing Standard Project Committee
TPS	Title, Purpose, and Scope

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Interested parties can reach out to any of the authors for further information about joining SPC 205 and learning about the current state of ASHRAE 205 development. SPC 205 has regular meetings at ASHRAE conferences and usually at least one online meeting between conferences.