Pacific Northwest
NATIONAL LABORATORY

PNNL-34990-Rev. 2

Service Water Heating System Performance Approach for Energy Codes

Technical Brief

January 2025

C Cejudo
J Lerond
M Tillou
S Goel

U.S. DEPARTMENT OF ENERGY

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

DISCLAIMER

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;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

PNNL-34990 Rev. 2

Service Water Heating System Performance Approach for Energy Codes

Technical Brief

January 2025

C Cejudo
J Lerond
M Tillou
S Goel

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 to update and advance building energy codes. These technical briefs represent specific technologies, measures or practices that can be incorporated as module-based “plug-ins” to the national model energy codes, such as the International Energy Conservation Code (IECC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1. Model energy codes are adopted directly by state and local governments, and the availability of higher efficiency “plug-in” options may be used by jurisdictions pursuing advanced energy savings and 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 Service Water Heating (SWH) System Performance path that goes beyond the prescriptive energy code by outlining a comprehensive performance-based approach for SWH system evaluation and analysis. The components of this brief include an overview of the SWH System Performance Ratio (SWHPR) metric, the performance-based evaluation methodology, and model code language that can be adopted by local jurisdictions for new buildings and major renovations. The proposed code language is specifically designed as an overlay to ASHRAE Standard 90.1-2022, although it can be adapted for other national, state, or local energy codes.

Additional assistance may be available from DOE and PNNL to support states and local governments who are interested in adding, into their building codes, innovative and resilient building solutions that are both flexible and affordable. 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 in effectively implementing energy codes. This helps to ensure benefits are fully realized through 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 building a more resilient future. Learn more at energycodes.gov.

Executive Summary

Energy codes and standards include mandatory requirements that all buildings must fulfill, and a choice between a set of prescriptive measures or a more flexible whole-building or system based performance compliance approach, enabling greater design flexibility. The prescriptive path, which is typically the simplest approach, is the most widely used approach for commercial code compliance in the United States. This pathway is also predominantly used in smaller, less complex building types. However, due to its relative simplicity the prescriptive pathway has limitations and can result in equipment specifications that meet minimum code requirements but may not be designed and optimized for efficiency across the entire system, such as a service water heating (SWH) system. One solution is to pursue a whole-building energy modeling compliance approach; however, this may not be possible in all situations, due to the time, resources and expertise needed to conduct this type of modeling. A simpler, yet still effective, approach is to limit the performance assessment exclusively to the SWH system – inclusive of the equipment, piping distribution layout, part load conditions, and controls – providing a more robust metric to assess and appropriately credit higher performing service water heating (SWH) systems in the code. This technical brief outlines a SWH System Performance approach which includes a simple metric, the Service Water Heating System Performance Ratio (SWHPR), for evaluating overall SWH system efficiency instead of individual component efficiency.

SWHPR is a ratio of the annual service water heating load of a building to the annual energy input of the building's SWH system, which can be expressed in units of energy, cost, or greenhouse gas (GHG) emissions. Section 1.0 of this report describes the SWH System Performance approach. Section 2.0 outlines the methodology used to develop a target for SWH system performance requirements, which can save energy when compared to a more prescriptive approach based solely on equipment efficiency. For a jurisdiction with ambitious energy or emission policy goals, use or adoption of a SWH system performance requirement can help achieve goals and increase energy cost savings for building owners and operators. Section 3.0 describes the software tool requirements for calculating compliance with the SWH System Performance approach, while Section 4.0 outlines the next steps in development of this novel compliance approach.

Section 5.0 provides the necessary code language, written as an overlay to ASHRAE Standard 90.1-2022, that jurisdictions can adopt into their current energy code. It includes the equations, supporting data and requirements needed to calculate performance metrics and demonstrate compliance. Where amending an energy code other than ASHRAE Standard 90.1-2022, some additional modifications may be required.

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASPE	American Society of Plumbing Engineers
BTO	Building Technology Office
CO_{2e}	carbon dioxide emissions
COP	coefficient of performance
DOE	U.S. Department of Energy
ECPA	Energy Conservation and Production Act
EF	energy factor
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	Energy Protection Agency
GHG	greenhouse gas
HPWH	heat pump water heater
HVAC	heating, ventilation, air conditioning
iHPWH	integrated heat pump water heater
IECC	International Energy Conservation Code
IES	Institute of Education Sciences
LRMER	long-run marginal emissions rate
MEC	Model Energy Codes
PNNL	Pacific Northwest National Laboratory
POU	point-of-use
PNNL	Pacific Northwest National Laboratory
RE	recovery efficiency
SBL	standby losses
SWH	service water heating
SWHPR	Service Water Heating Performance Ratio
TSPR	Total System Performance Ratio
TE	thermal efficiency
UEF	uniform energy factor

Contents

Tables

Figures

1.0 Service Water Heating Performance Approach

This technical brief introduces the Service Water Heating (SWH) System Performance Approach for building energy code compliance. This system performance-based approach allows jurisdictions to adopt a simplified, system-based compliance approach for SWH systems. The benefits of this approach include the ability to establish specific SWH performance targets, allowing prescriptive tradeoffs and providing greater user flexibility than the standard whole building performance compliance path. The SWH System Performance Approach integrates the ease of use of the prescriptive path with the flexibility of the performance path.

Figure 1 outlines the major building energy systems (envelope, lighting, HVAC, and SWH) and shows how the SWH system is made up of many individual components that impact overall energy use (equipment, piping, controls, etc.). This depiction helps demonstrate how a systems-based SWH compliance approach helps to bridge the whole building performance-based and component based prescriptive compliance approaches. Comparing a proposed SWH design to a target SWH system, representing good design practice for considerations like system selection, distribution and temperature maintenance, allows designers greater flexibility than component based prescriptive compliance and less effort than complicated whole building performance-based compliance. A system performance approach for the building envelope has been in the Model Energy Code since 1999 and a system performance approach for HVAC systems was added in 2022.

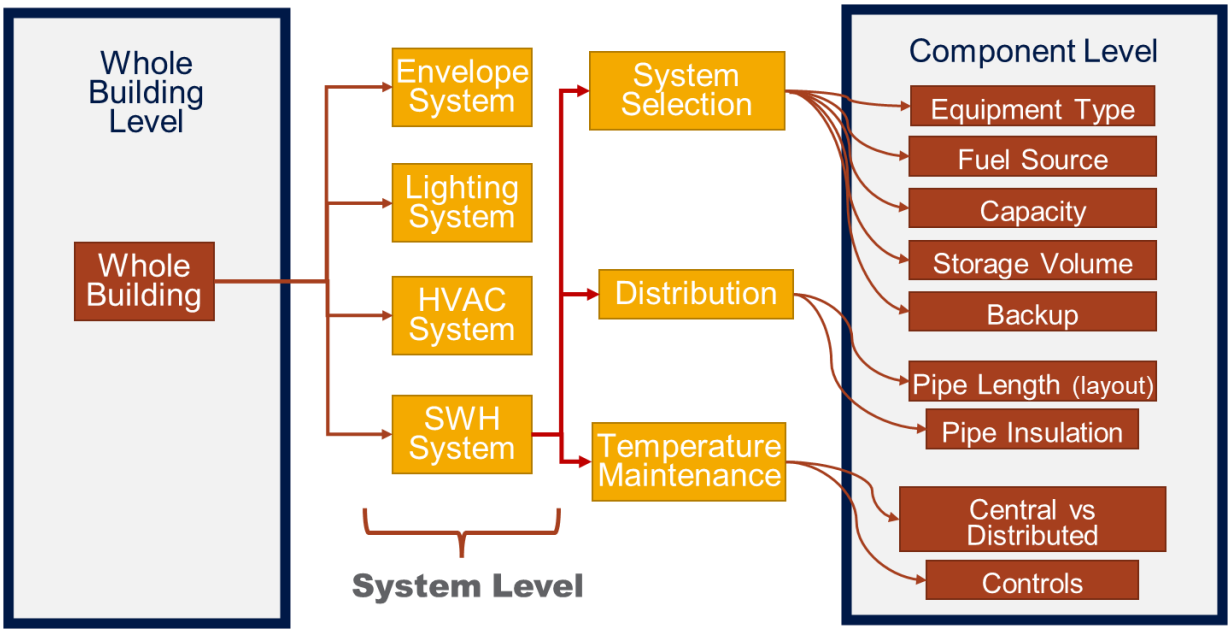

Figure 1: Major Building Energy Systems and SWH Components (recreated from HPB 2019)

This technical brief describes using the SWH System Performance Ratio (SWHPR) metric for compliance, the considerations which define the SWH target system selection, and the simulation procedure and requirements for compliance software calculations. Having the ability to incorporate different performance-based approaches into building energy codes is critical to meet states and jurisdictions' ambitious energy and emission reduction goals and policy objectives for electrification and decarbonization.

1.1 Scope

The benefit of evaluating SWH system performance independently from other building systems and components is greater energy efficiency and system flexibility without the expense of a complicated whole-building analysis. This SWH system performance approach is intended to offer a simple performance-based compliance solution as an alternative to current prescriptive and whole building compliance pathways. As such the approach is not intended to be applicable to all SWH systems in all building types. The proposed application is for buildings, multifamily buildings greater than three stories and commercial buildings of all occupancy types and sizes, with simple standalone SWH systems.

The SHW System Performance Approach is applicable to proposed SWH systems in six covered building types: office, retail, food service, multifamily, hotel, and schools. Together, these six building types represent approximately 74% of new construction starts in the country for commercial buildings (Lei et al. 2020).

Complex SWH systems, such as those that serve healthcare buildings, or large end uses such as commercial laundries and natatoriums, are not compatible with this proposed compliance pathway. Similarly, systems that use district heating, or heat recovery from HVAC processes are outside the scope of this compliance path since the underlying assumptions of SWH design and use are not consistent with these types of systems. Such buildings should use the prescriptive or whole building performance paths to demonstrate compliance.

Importantly, the proposed methodology does not consider energy interactions between other building systems, such as a building's envelope, lighting, and/or mechanical systems. For users interested in considering interactions among different building systems, the existing whole-building performance approach (e.g., ASHRAE 90.1 Appendix G) can be used instead.

1.2 Evaluating SWH Performance

Building energy performance for energy code compliance has traditionally been evaluated at a whole building level through performance-based evaluations or at a component level [e.g., chiller efficiency coefficient of performance (COP)] through prescriptive code requirements (Li et al. 2020, Goel et. al 2021). A whole building metric can be affected by the performance of any building system, including building envelope, lighting, HVAC, and SWH, among others. This approach can be resource intensive, and isolating the performance of individual building systems, such as the envelope or SWH system using whole building metrics can be challenging.

Prescriptive compliance uses a rated efficiency metric, either thermal efficiency (Et), energy factor (EF), or uniform energy factor (UEF), based on the size and type of SWH equipment. Though excellent metrics for evaluating efficiency of individual system components at standard conditions, these ratings are not effective in quantifying overall system performance, which includes additional considerations like part load conditions, piping distribution layout, and controls.

A more robust metric for evaluating overall SWH system performance has been developed for the SWH systems performance approach. This new metric, Service Water Heating Performance

Ratio (SWHPR), assesses all components of the SWH system collectively and provides the following benefits:

- Accounts for part load performance and system controls,
- Is normalized using the buildings SWH loads making it easier to compare the performance of different system configurations.
- Eliminates the impact of trade-offs between different building systems (such as envelope and HVAC system).

The SWHPR metric is the ratio of the sum of a building's annual service water heating load to the sum of the annual energy input of the service water heating systems, thereby providing an intermediate solution which combines the simplicity and ease of the prescriptive approach with the flexibility, and optimization that can be achieved through performance-based approaches.

2.0 Service Water Heating System Performance Methodology

This section describes the Service Water Heating Performance Ratio (SWHPR) metric and provides an overview of how, using SWHPR, SWH system compliance is achieved. It also provides additional details on the SWH system characteristics and how they factor into evaluating overall system compliance.

2.1 Service Water Heating Performance Ratio: Definition and Calculation

The SWHPR metric is the ratio of the sum of the total annual SWH load to the calculated annual energy input of a SWH system designed to meet those loads. The SWHPR metric is similar to the Total System Performance Ratio (TSPR) used for heating, ventilation, air conditioning (HVAC) system evaluation (Goel et al. 2021). The equation for calculating SWHPR is shown below.

$$SWHPR = \frac{\sum_{i=0}^{n} L}{E_{primary\_heating} + E_{temperature\_maintenance}}$$

Where:

- n is the number of simulated timesteps in a year. At a minimum, n shall be equal to 8760, representing an hourly timestep. Where a sub-hourly timestep is used, the primary system load L shall be adjusted accordingly

- L is the primary system load for a particular simulation time step (in Btu/h). L can be calculated as follows: $L = 8.02 \times \rho \times q \times Cp \times (T_{supply} - T_{mains})$ where ρ is the density of water (in lb/ft^3), q is the hot water volumetric flow rate (in gal/min), Cp is the specific heat of hot water (in Btu/lb. F), T_{supply} is the SWH supply water temperature (in deg. F), T_{mains} is the mains temperature (in deg. F) and 8.02 is a conversion factor (in ft^3.min.gal^{-1}.h^{-1})

- $E_{primary\_heating}$ is the total annual energy input associated with the SWH system converted to units of equivalent CO_2 emissions in lbs of CO_2.

- $E_{temperature\_maintenance}$ is the annual energy input associated with the required SHW system temperature maintenance (recirculation heating and pumping energy) converted to units of equivalent CO_2 emissions in lbs of CO_2. If a target or proposed SWH system is decentralized then $E_{temperature\_maintenance}$ = 0 (i.e., system does not use temperature maintenance re-circulation).

The annual SWH load should be the sum of SWH loads calculated at a minimum on an hourly basis. A sub-hourly time step may also be used. Where a sub-hourly timestep is used, the primary system load L shall be adjusted accordingly. The sample code language in Section 5.0 uses total equivalent carbon dioxide (CO_2e) emissions as the compliance metric for annual energy input. However, annual energy input may also be expressed in units of energy consumption or cost, depending on the intended goals of a jurisdiction adopting SWH System

Performance. Section 2.4 describes the methodology, and Tables X5-1 and X5-2 in Section 5.0 summarize the emissions factors necessary to derive total CO_2e from the calculated annual energy input.

2.2 Compliance

When using SWHPR for compliance, the SWHPR of a target SWH system is compared to the SWHPR of a proposed SWH system The proposed and target SWH designs are modeled following the rules in Section 2.5 and using software compatible with the requirements in Section 3.0.

Compliance is demonstrated if the SWHPR of the proposed SWH system is greater than or equal to the SWHPR of the target SWH system.

$$SWHPR_p \geq SWHPR_t$$

Where:

$SWHPR_p$ = the SWHPR of the proposed SWH system

$SWHPR_t$ = the SWHPR of the target SWH system

2.3 Metric: Equivalent SWH Emissions

CO_2 equivalent emissions is the recommended metric for determining compliance with the SWH System Performance Approach. The emissions are calculated as the sum of emissions from the grid electricity, specific for each Emissions and Generation Resource Integrated Database (eGRID) region, and fuels burned on site. The delivered fossil fuel factors are U.S. averages based on 2019 Energy Information Administration (EIA) and Environmental Protection Agency (EPA) data and are shown in Table X.5-1 of the sample code language in Section 2.0. The electricity conversion factors are 2022 Cambium long-run marginal emission rates (LRMER)[1], and are shown in Table X.5-2 of the sample code language in Section 2.0. The values are consistent with those published in ASHRAE Standard 90.1 Addendum l based on 2021 Cambium data (ASHRAE 2024b). The electricity data are site end-use values for the Cambium mid-case scenario, based on a 20-year levelized analysis period, zero discount rate, and a 20-year greenhouse gas global warming period. The Cambium eGRID subregions are based on US grid-balancing areas and do not completely align with EPA eGRID subregion, which are based on utility service territory. Look up tables that indicate $eGRID_c$ subregions by zip code or county are included in the published Cambium 2022 LRMER workbooks[2]. More details on the Cambium input assumptions and methodology are described in the documentation report[3].

[1] https://www.nrel.gov/analysis/cambium.html
[2] https://data.nrel.gov/submissions/206
[3] https://www.nrel.gov/docs/fy23osti/84916.pdf

2.4 SWH Proposed System Characteristics

SWH system performance is intended as an alternative compliance approach for a proposed SWH system that is easy to use. To help keep the methodology simple the application has been limited to six covered building types: office, retail, food service, multifamily, hotel, and schools. SWH systems in these building types are generally well understood and lend themselves to this type of simplified compliance approach. SWH systems excluded from this path are those serving more complex applications and building types such as healthcare buildings (including hospitals, outpatient care and nursing homes), standalone commercial laundry facilities, and natatoriums or rooms with saunas.

SWH system performance has been developed as a compliance path for the most common SWH equipment types including point of use (POU) water heaters, instantaneous water heaters, and storage water heaters (both consumer and commercial rated). SWH performance has also been developed to account for all the associated SWH equipment (including temperature maintenance), the differences between central and distributed (localized) SWH systems, and the potential impacts of different piping configurations serving hot water demand loads of end-use devices (fixtures, appliances, etc.). The specific requirements and exclusions for proposed SWH systems are listed in Section 5.0, subsection X1 General of this document. SWH demand loads and categories are defined in section 5.0, subsection X2.2.1.

2.5 SWH Target System Characteristics

The SWH 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 building type and represent the minimum prescriptive levels of performance needed to demonstrate compliance. The selected target SWH system designs represent “good design practice” and attempt to strike a balance between the least efficient system configuration and a highly efficient system configuration and were developed with input from industry stakeholders.

The SWH Target system characteristics have been determined based on the following considerations:

- The approach for SWH Target system selection is defined to be independent of the proposed SWH design and is instead identified based on the SWH loads.
- SWH Target systems have been defined to give credit to system designs that favor equipment energy efficiency, optimal pipe sizing, and system compactness design.
- Target systems have been selected to result in low greenhouse gas emissions.

Seven target systems have been identified by numeric values as follows:

(1) Small consumer rated electric instantaneous water heater, distributed equipment without temperature maintenance.
(2) Small consumer rated electric integrated storage water heater, distributed equipment without temperature maintenance.
(3) Small consumer rated electric integrated storage heat pump water heater (iHPWH), distributed equipment without temperature maintenance.
(4) Medium consumer rated electric iHPWH distributed equipment without temperature maintenance.

(5) Medium consumer rated electric iHPWH, with centralized equipment and temperature maintenance.
(6) Medium commercial rated electric heat pump water heater (HPWH), with centralized equipment and temperature maintenance.
(7) Medium commercial rated electric heat pump water heater (HPWH), with centralized equipment, gas backup and temperature maintenance.

Table 1 summarizes the key parameters of each target system. Sections 2.5.1 through Section 2.5.7 describe the parameters in more detail.

Table 1: SWH Target Systems

System Type ID	System Size	Fuel Type	Equip. Storage Capacity	Equip. Input Capacity	Additional Storage Volume	Equip. Type	Equip. Efficiency	Location	Temp. Maint. Included
(1)	Small	Electric	<2	≤12 kW	0 gal	Instantaneous	Table F-2 of Standard 90.1-2022	Distributed	No
(2)	Small	Electric	≥20 gal and ≤55 gal	≤12 kW	0 gal	Storage	Table F-2 of Standard 90.1-2022	Distributed	No
(3)	Small	Electric	≤55 gal	≤12 kW	0 gal	iHPWH	UEF 2.3[1]	Distributed	No
(4)	Medium	Electric	>55 gal and ≤120 gal	≤12 kW	0 gal	iHPWH	Table F-2 of Standard 90.1-2022	Distributed	No
(5)	Medium	Electric	>55 gal and ≤120 gal	≤12 kW	per Table 2	iHPWH	Table F-2 of Standard 90.1-2022	Centralized	Yes
(6)	Large	Electric	N/A	<6 kW	per Table 2	Commercial HPWH	COP 3.0	Centralized	Yes
(7)	Large	Hybrid Gas and Electric	N/A	>12 kW	per Table 2	Commercial HPWH with Gas Backup	COP 3.0	Centralized	Yes

Note: Equip.: Equipment; Temp. Maint.: temperature maintenance); HPWH: heat pump water heater; iHPWH: Integrated HPWH; COP: Coefficient of Performance

2.5.1 System Size

The size of a SWH system is dependent on the hot water loads served. For example, a few localized lavatories in a small office may be served by a single small volume point of use (POU) water heater, or several distributed instantaneous water heaters. In comparison a high-rise apartment may be served by a large centralized system consisting of multiple water heaters, storage tanks and temperature maintenance components.

2.5.2 Fuel Type

Two target systems (1 and 2) are applicable to small SWH loads where energy use and the associated greenhouse gas emissions for water heating will be very small and thus use electric resistance heat is an inexpensive and reasonable fuel use. In four of the SWH Target systems (3, 4, 5, and 6) the heat source is an electric heat pump water heater (HPWH) with electric resistance backup. In most electric grid regions this will result in the lowest emissions over the

[1] Energy Conservation Standards for Consumer Water Heaters, Final Rule. May 6, 2024. 88 FR 37778-37946. Available at https://www.regulations.gov/document/EERE-2017-BT-STD-0019-1426..

life of the system. System type (7) is also a heat pump water heater, but with natural gas backup. The gas backup is chosen in this target system for larger applications to keep the additional storage volume at a reasonable size.

2.5.3 Storage Capacity

Because peak hot water load draw rates can vary widely in both magnitude and time distribution, storage capacity is used as a "battery" to store thermal energy, which helps offset SWH equipment recovery heating rate. The storage capacity referred to in the SWH Target systems are based on ANSI/ASHRAE/IES Standard 90.1-2022 Table 7.1-1 Performance Requirements for Water-Heating Equipment and engineering best practices. The additional storage capacity for SWH Target systems 5, 6 and 7 is included for these larger systems to keep the storage capacity at a reasonable size. Table 2 lists the target system volume by specific building use type based on the ASHRAE Handbook: HVAC Applications, Chapter 51 Service Water Heating (ASHRAE 2019). Figure 2 illustrates and example of the relationship between recovery and storage capacity for a Hotel/Motel application. Note that the data used for figures 16-23 in the Handbook predate low-flow fixtures and appliances, therefore Table 2 reflects recent research and engineering best practices for appropriately sized SHW systems.

Table 2: SWH Target System Assumptions by Building Use Type

Primary SWH Demand Load Category	Description	Fixtures Included	Category Description	Recovery Rate	Total Storage Capacity
A	General Residential	Shower, Lavatory, Kitchen Sink, Residential Dishwasher, Residential Clothes Washer	4 - 50 units	7 GPH per unit	14 gal per unit
			51 - 100 units	5 GPH per unit	
			> 100 units	3 GPH per unit	
B	Hotel (including Motel)	Shower, Lavatory, Kitchenette	<20 rooms	3 GPH per room	8 gal per room
			21 - 60 rooms	2 GPH per room	
			> 60 rooms	1.5 GPH per room	
C	General Commercial (Office, Retail)	Public Restrooms, Kitchenette, Service Sinks	All	0.2 GPH per person	0.75 gal per person
D	Commercial Kitchen	3-compartment Sinks, Service Sinks, Commercial Dishwasher	Sit down Service	1.0 GPH per max meals per hour	2 gal per max meals per hour
			Fast Service	0.25 GPH per max meals per hour	
E	Fitness / Gym	Multiple Showers	All	0.35 GPH per person	1.5 GPH per person

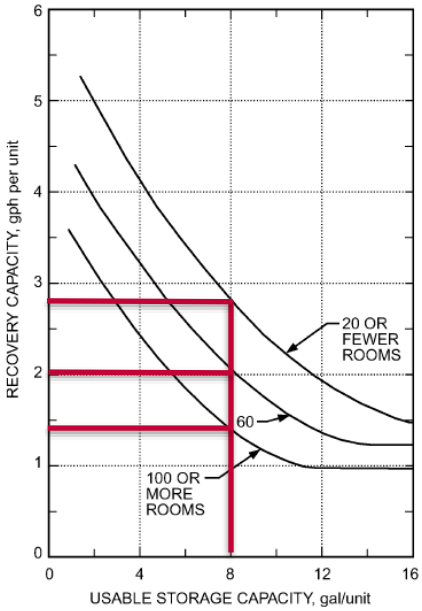

Figure 2: Relationship between recovery and storage capacity for Hotel/Motel (modified from Figure 17 in ASHRAE Handbook: HVAC Applications, Chapter 51 Service Water Heating)

2.5.4 Input Capacity, Equipment Type

When sizing a SWH system, the recovery rate of the equipment is considered along with the storage capacity. The higher the recovery rate, the less storage capacity is required (ASHRAE 2019). SWH equipment input rates in the Target Systems table follow the defined values listed in ANSI/ASHRAE/IES Standard 90.1-2022 Table 7.4-1 Performance Requirements for Water-Heating Equipment and ANSI/ASHRAE/IES Standard 90.1-2022 Table F-2 Minimum Energy Efficiency Requirements for Water Heaters and Pool Heaters.

2.5.5 Equipment Efficiency

SWH measured equipment efficiencies (e.g., UEF, Et, or COP) are the rated efficiency of a water heater when operated in accordance with the U.S. Department of Energy (DOE) test procedures found in 10 CFR 431.106 and Appendix A-E of Subpart G for commercial and industrial water heating equipment and 10 CFR 430 Appendix E for consumer water heaters and residential-duty commercial water heaters[1]. Other than target system (3) described below, the equipment efficiency values are based on ASHRAE Standard 90.1-2022. Because DOE standards undergo continuous updates, minimum efficiency values will be incorporated into the SWH System Performance analysis tool as appropriate.

While DOE issues standards for consumer electric storage water heaters above 55 gallons which result in requiring HPWH technology, currently DOE standards do not require HPWH technology for consumer storage water heaters 55 gallons or under. However, there are many ≤55 gallon models available on the market that use integrated HPWH technology (aka iHPWH) and future federal standards have been finalized that will essentially require HPWH-level

[1] For more information refer to the recently published Notice of Proposed Rulemaking (NOPR) here: https://www.federalregister.gov/documents/2022/01/11/2021-27004/energy-conservation-program-test-procedure-for-consumer-water-heaters-and-residential-duty

performance for certain consumer storage water heater products in the ≥20 gallon and ≤55 gallon storage volume range by 2029. Target system (3) is developed to represent the use of much smaller volume equipment. This Technical Brief proposes a Target System UEF of 2.3 for this type of system consistent with these future standard levels.

DOE does not have a minimum efficiency requirement for commercial/central HPWHs, although there is a DOE test procedure and a COP metric. EPA's ENERGY STAR program is currently considering revising its specification requirements for central/commercial heat pump water heaters.[1,2] However, as of this writing these specifications have not been finalized. For the Target Systems assuming commercial (not consumer/residential) HPWHs (6 and 7), a COP of 3.0 is specified, consistent with EnergyStar commercial water heater specification 2.0, with COP measured in accordance with the current DOE test procedure.[3]

2.5.6 Location

The location of the SWH system is either distributed or centralized. A distributed SWH design utilizes multiple SWH systems, each located in close proximity to the hot water demand loads they serve. A centralized design, most often, has one SWH system that serves demand loads spread out across a building's area.

2.5.7 Temperature Maintenance Inclusion

A SWH distribution system should be properly designed to deliver adequate hot water flow at an appropriate temperature, in accordance with building requirements and local codes and standards, and within an acceptable time period. According to the American Society of Plumbing Engineers (ASPE 2003), a reasonable wait time for delivery of hot water is 0-10 seconds from when the valve is opened. A delay of 11-30 seconds is possibly acceptable, and a delay over 30 seconds is considered unacceptable.

In a distributed design, as discussed above, piping distances are short and thus the wait time for hot water delivery would not require temperature maintenance. A centralized design can have significant piping lengths requiring a dedicated temperature maintenance system to provide hot water to the furthest fixture served within an acceptable time frame.

[1] For more information refer to the EnergyStar website: Commercial Water Heaters Specification Version 3 | ENERGY STAR
[2] Refer to the ENERGY STAR Draft 1 Test Method for Central Heat Pump Water Heater Systems - December 5, 2024 here: https://www.energystar.gov/commercial-water-heaters-specification-version-3
[3] Refer to current ENERGY STAR® Program Requirements for Commercial Water Heaters Partner Commitments here: energystar.gov/sites/default/files/asset/document/Program Requirements_Commercial Water Heaters_Final Version 2.0_12 29 17.pdf

3.0 Analysis Tool

The adoptable code language provided in Section 5.0 specifies the requirements for a simulation tool that can be used to demonstrate compliance with the SWH System Performance Approach. It outlines the requirements for defining the proposed building along with the necessary assumptions required to be implemented by the simulation tool. It outlines the capabilities a simulation tool would need to incorporate, including an automatically generated compliance report with necessary information specified. Any tool that implements these requirements that is approved by the building official could be used for compliance analysis for the SWH System Performance approach.

3.1 Simulation Program

The simulation program used to demonstrate compliance with the SWH System Performance Approach should be capable of simulating the SWH system equipment and controls outlined in Section 2.3 and have the capability to automatically simulate the target SWH design based on the user defined SWH loads and proposed SWH design parameters. The program should be able to carry out hourly, and/or sub-hourly annual (8760 hours) simulation of the SWH equipment and loads. The simulation software should be able to extract the necessary information used to calculate the SWHPR for both the proposed SWH design and the target SWH design and automatically generate the required compliance report. While the required analysis focuses on SWH systems, the simulation tool doesn't have to be limited to this usage, i.e., a whole building energy modeling software such as EnergyPlus can be used for this type of analysis.

4.0 Next Steps

Service water heating energy use is second only to space conditioning in most residential buildings and can be a significant end use in many commercial buildings (ASHRAE 2019). As the American Society of Plumbing Engineers (ASPE) Design Guide states, “Generally, current ‘standard [design] methods' are of concern as they usually result in oversizing. Using these methods, engineers rarely have a complaint about too much hot water. However, unaccounted for are the additional costs an owner must pay to provide such a system" (ASPE 2003).

As building envelope, lighting, and HVAC systems become increasingly efficient over time through building code and equipment efficiency improvements, achieving similar improvements on SWH system efficiency will be necessary to help states and jurisdictions achieve their energy and emissions reduction goals. Additionally, model energy code bodies could benefit from adopting a SWH system efficiency approach. For example, the ASHRAE 90.1 standard committee established a goal of achieving net zero energy operational emissions in the Standard by 2031. Incorporating a SWH system efficiency proposal could help further reduce energy consumption to drive towards that goal.

Energy efficiency is a key aspect of the SWH Performance Approach. PNNL is working on several projects through the support of DOE’s Building Technology Office (BTO), to overcome barriers to market adoption of all energy-efficient water heating technologies, including HPWHs, gas-fired HWPHs, and condensing water heating systems. In addition, ASHRAE recently approved a new Guideline Project Committee (GPC) 47 *Design Guide for Central Service Water Heating Systems Using Electric Heat Pump Water Heaters in Multifamily Buildings* (anticipated publication end of 2025). Lessons from this and other ongoing work in SWH system sizing, equipment specification and performance analysis will be incorporated into the modeling rules used to ensure the (SWH) system performance approach can help designers bring flexibility to building code compliance.

5.0 Sample Code Language

This section provides modifications to Standard 90.1-2022 to implement the Service Water Heating System Performance Approach. The SWH System Performance approach can be adopted in code in several ways depending on the objective of the energy code and the policy goal that it's trying to meet:

- Alternative Approach: The SWH System Performance Approach provides an alternative to prescriptive or performance compliance. Mandatory requirements are still required to be met. This approach that has been adopted by the HVAC System Performance approach in Standard 90.1-2022 for HVAC systems (ASHRAE 2022).

- SWH System Minimum Efficiency: The SWH System Performance approach is incorporated into the energy code as a minimum requirement, where a building must meet the mandatory requirements, the prescriptive requirement and comply via the SWH System Performance approach. This approach can be effective in encouraging efficient SWH system design choices and would ensure that a code compliant building has SWH systems that is equivalent to or better than the target system. This approach that has been adopted by the HVAC System Performance approach in the Washington State Energy Code (WESC 2024).

- SWH Energy Efficiency Credits: The Energy Credits approach, adopted in the ASHRAE Standard 90.1-2022 (ASHRAE 2022), 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 annual energy cost. Similar to the energy credits for HVAC TSPR, energy credits for SWH System Performance is included in the list of energy credit measures. The SWH 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 is included in the Energy Credits section of the 2021 Washington State Energy Code (WSEC) (WESC 2024) and Addendum j to Standard 90.1-2022 (ASHRAE 2024a). Note that SWH System Performance can be used for energy credits in combination with either the *alternative approach* or the *minimum efficiency* approach described above.

Foreword

(This foreword is not part of the modified code language. It is merely informative and does not contain requirements necessary for conformance to the code.)

The modification below includes a new Normative Appendix to Standard 90.1-2022 that modifies Sections 3, and Section 7. This modified code language allows for an alternate method for compliance with Section 7 of the Standard. Currently users can opt to use one of three prescription options or a whole-building modeling-based method to demonstrate service water heating compliance.

Code Change Language

Add new definitions and abbreviations to Chapter 3 Definitions, Abbreviations and Acronyms as follows:

3.2 Definitions

service water heating system performance ratio (SWHPR): ratio of the sum of a *building's* annual service water heating load in kBtu to the sum of annual *energy* input of the service water heating *systems,* where the units are in accordance with Section X5.

proposed SWH design: a computer representation of an actual proposed *building SWH* design used as the basis for calculating the *service water heating performance ratio* in accordance with Section 7.6.2.

target SWH design: a computer representation of a hypothetical *SWH* design based on modifications to the *proposed SWH design* in accordance with Section X4.3. This representation is used as the basis for calculating the *service water heating performance ratio* for determining alternative service water heating *system* performance in accordance with Section 7.6.2.

SWH peak demand load: the highest amount of hot water usage (Btu/h, or kW) measured for a building or facility in a selected time frame.

SWH end-use: a point of connection (shower, faucet, lavatory, appliance, etc.) with flow and temperature requirements met by the SWH *system.*

SWH demand load: the demand for service hot water for a building (or part of a building). SWH demand load is characterized by a design SWH flow rate and design SWH supply water temperature.

SWH demand load category: a representative group of SWH demand loads for a given building use type.

SWH demand load profiles: a collection of ratios of a demand load's average peak hot water flow rate to the maximum peak daily hot water flow rate.

3.3 Abbreviations and Acronyms

SWH	*service water heating*
SWHPR	*service water heating performance ratio*
$SWHPR_p$	*SWHPR* of the *proposed SWH design*
$SWHPR_t$	*SWHPR* of the *target SWH design*

Modify Section 7 to as follows:

7.2 Compliance Paths. *Service water heating systems* and *equipment* shall comply with Sections 7.2.1 and 7.2.2.

7.2.1 Requirements for All Compliance Paths. *Service water heating systems* and *equipment* shall comply with Sections 7.1, "General"; 7.4, "Mandatory Provisions"; 7.7, "Submittals"; and 7.8, "Product Information."

7.2.2 Additional Requirements to Comply with Section 7. Service water heating systems and equipment shall comply with one of the following

a. Section 7.5, "Prescriptive Compliance Path."

b. Section 7.6 Service Water Heating System Performance

7.6 Alternative Compliance Path

7.6.1 Service Water Heating (SWH) System Performance Approach

7.6.1.1 Scope. The SWH Performance Approach is an optional path for compliance where the following conditions are met:

c. All *SWH systems* in the building that meet the criteria in Section X1.1.1 shall comply with Section 7.6.1.2.

d. All other SWH systems shall comply with the applicable requirements in Section 7.5.

7.6.1.2 Criteria. SWH systems in new buildings, additions, or alterations shall comply with the requirements in Section X2, "Service Water Heating System Performance Approach." The SWH performance ratio of the *proposed SWH design* (*SWHPRp*), using this method, shall be greater than or equal to the SWH performance ratio of the *target SWH design* (*SWHPRt*) when calculated in accordance with the following:

$$SWHPR_p \geq SWHPR_t$$

Where:

$SWHPR_p$ = *SWHPR* of the *proposed SWH design* calculated in accordance with Normative Appendix X

$SWHPR_t$ = *SWHPR* of the *target SWH design* calculated in accordance with Normative Appendix X

Informative Note: The Service Water Heating System Performance Approach is a simplified performance trade-off approach for SWH *systems* that does not require using the whole-building trade-off approaches in Section 12 or Normative Appendix G. SWH *systems* that are allowed to use this approach will not need to comply with all of the prescriptive requirements in Section 7.5. This approach does not allow SWH *system* efficiency trade-offs with building envelope, power, HVAC systems, or lighting systems.

Add Normative Appendix X as follows. Renumber references to X to reflect appropriate Normative Appendix letter designation:

NORMATIVE APPENDIX X

SERVICE WATER HEATING SYSTEM PERFORMANCE APPROACH

X1. GENERAL

X1.1 Scope. This appendix offers an alternative path of compliance for *service water heating (SWH) systems* in accordance with Section 7.6.1. This appendix establishes the requirements for *SWH systems* that use the SWH System Performance Approach and requirements for calculating *SWHPRp* and *SWHPRt* to demonstrate compliance in accordance with Section 7.6.1.2. Not all *SWH systems* are allowed to use the SWH System Performance Approach as described in Section X1.1.1.

X1.1.1 Allowable SWH Systems. *SWH systems* are allowed to use the SWH System Performance Approach if they comply with all the following criteria:

a. The *SWH system* uses point of use water heaters, instantaneous water heaters, storage water heaters, or commercial water heaters. Refer to Table 7.4 for further information.
b. The *SWH system* serves a *building* use type included in Section X1.1.1.1.
c. The *SWH system* is not excluded by Section X1.1.1.2.
d. The *SWH system* is powered by grid-delivered electricity, renewable electricity, natural gas, propane, renewable thermal *energy*, or distillate *fuel* oil.
e. The *SWH system*, at the time of permit, is a complete design including all equipment, piping and end-use devices.

Informative Notes:

1. The intent of the scope is to allow most of the *building* to use the *SWHPR* path and have portions of the *buildings* that cannot use the *SWHPR* path use the prescriptive path.

2. The allowed *system* types may not be supported by all *simulation program* versions. The *simulation program* is required to support the target *systems* for the *building* types modeled, and the proposed *system* type(s) must be supported by the *simulation program*.

X1.1.1.1 Allowable Building Use Types. *SWH systems* that serve the following *building* use types are allowed to use the SWH System Performance Approach:

a. Office
b. Retail
c. Food service (including fast-food and sit-down restaurant)
d. Multifamily (4 stories and more, including dormitory, and common laundry uses)
e. Hotel (including motel)
f. School (including K through 12 and university)
g. Other *building* use types that are <1000 ft2 and <10% of the *building* conditioned floor area unless specifically excluded by Section X1.1.1.2(a)

X1.1.1.2 Excluded SWH Systems. The following *SWH systems* are excluded from using the SWH System Performance Approach:

a. *SWH systems* serving any of the following excluded *building* areas or *loads*:
    1. Healthcare, including Hospitals, Outpatient Care and Nursing Homes
    2. Standalone commercial laundry facilities.
    3. Natatoriums or rooms with saunas or spas.
b. Existing *SWH systems* that are not replaced in their entirety as part of an alteration.
c. Existing *SWH systems altered to serve* a new addition.
d. Where the *building* permit applies to only a portion of the *SWH system* in a *building*, and the remaining components will be designed under a future *building* permit. (e.g. Core and Shell/Initial Build-Out Construction)
e. *SWH systems* serving portions of the building that are also served in parallel by *SWH systems* not allowed to use the SWH System Performance Approach
f. *SWH systems* using any of the following:
    1. *Systems* using district heating or cooling.
    2. *Systems* with a common heating source serving both HVAC and service water heating equipment.
    3. *Systems* using recovered heat from HVAC *systems* for service water heating.

Exception to X1.1.1.2

Portions of the building or systems which are excluded from the SWH system performance approach are permitted to comply with the requirements in Section 7.5 and the included portion of the buildings and systems shall comply with the requirements in Section 7.6
Informative Note: The intention of the scope is to allow most of the building to use the SWH System Performance path and have portions of the buildings that cannot use the SWH System Performance path use the prescriptive path (Section 7.5).

X2. SERVICE WATER HEATING SYSTEM PERFORMANCE APPROACH

X2.1 Compliance

X2.1.1 Mandatory Requirements. All *SWH systems* in the proposed *building* design that are included in the *proposed SWH design* shall comply with the requirements in Section 7.2.1.

Informative Note: *Buildings* using the SWH System Performance Approach are required to meet all mandatory provisions in Section 7.4 in accordance with Section 7.2.1.

X2.1.2 SWH System Performance Approach Requirements. All *SWH systems* using the SWH System Performance Approach shall demonstrate compliance using *SWHPRp* and *SWHPRt* in accordance with Section 7.6.1 and the following requirements:

a. *SWHPRp* and *SWHPRt* shall be calculated in accordance with Section X2.1.3, "Calculating SWHPR," and the requirements of Sections X1, X3, X4, and X5.
b. Alterations that include replacement of the entire *SWH system* shall be modeled the same as a new building.
c. Compliance documentation and supplemental information shall be submitted in accordance with Sections 4.2.2 and X2.1.4 "*SWHPR Submittals*."

X2.1.3 Calculating SWHPR. *SWHPR* shall be calculated according to Equation X-1:

$$SWHPR = \frac{\sum_{i=0}^{n} L}{E_{ph} + E_{tm}} \quad \text{(X-1)}$$

Where:

n = the number of simulated timesteps in a year. At a minimum, n shall be equal to 8760, representing an hourly timestep.

E_{ph} = the total annual primary heating energy input associated with the *SWH system* converted to units of equivalent CO_2 emissions in lbs of CO_2 in accordance with Section X5.

E_{tm} = the annual energy input associated with the required *SHW system* temperature maintenance (heating and pumping energy) converted to units of equivalent CO_2 emissions in lbs of CO_2. If a target or proposed *SWH system* is decentralized then $E_{tm} = 0$ (i.e., system does not use temperature maintenance re-circulation)

L = the primary system *SWH* load in Btu/h for a particular simulation time step calculated in accordance with equation X-2

$$L = 8.02 \times \rho \times q \times Cp \times \left(T_{supply} - T_{mains}\right) \quad \text{(X-2)}$$

Where:

ρ is the density of water (in lb/ft^3),

q is the hot water volumetric flow rate (in gal/min),

Cp is the specific heat of hot water (in Btu/lb. F),

T_{supply} is the *SWH* supply water temperature (in deg. F), and

T_{mains} is the mains temperature (in deg. F).

Informative Note: The annual *SWH energy* inputs calculated using the SWH System Performance Approach are not predictions of *service water heating system energy* consumption for an actual proposed *building* after *construction*. Actual experience will differ from these calculations due to variations such as occupancy, *building* operation and maintenance, weather, *energy* use of *systems* and *building* areas not covered by this procedure, and the precision of the calculation tool.

X2.1.4 SWHPR Submittals. Where *SWHPRp* and *SWHPRr* are used to demonstrate compliance in accordance with Section 7.6.1, documentation shall be provided to the *building official* including the following:

a. A compliance report, as outlined in Section X3.4, automatically generated by the simulation program.

b. A mapping of the actual *building SWH* component characteristics and those simulated in the proposed design showing how individual pieces of *SWH* equipment identified above have been combined into average inputs as required by the simulation program, including (but not limited to) the following:
   1. Water heaters
   2. Storage tanks
   3. Circulation pumps
   4. Temperature maintenance equipment
   5. Temperature control equipment

c. For each piece of equipment identified in item (b), include the following along with the units specified in Table X3.1 as applicable:
   1. Equipment name or tag consistent with that found on the design documents
   2. Rated efficiency level as rated in Section 7.8
   3. Rated capacity
   4. Where not provided by the simulation program report in item (a), documentation of the calculation of any weighted equipment efficiencies input into the program.
   5. Electrical input power for circulation pumps (before any speed or frequency control device) at design condition and calculation of input value (W/gpm)

d. A floor plan of the building identifying which portions of the building are assigned to the simulated *SWH demand loads* (See Section X2.2.1) and are using Section 7.6.1 for compliance and which areas of the building are served by *SWH systems* required to meet the prescriptive requirements of Section 7.5 in accordance with Section 7.6.1.1(b).

Informative Note: The items listed under items (b) and (c) may either be included in the report generated by the *simulation program* or submitted separately.

X2.2 Proposed Building Information Required. The simulation of *SWH systems* and the *SWH demand loads* they serve shall be modeled based on *building* information required by this section.

X2.2.1 Simplified SWH Loads Approach. The *SWH loads* of *buildings* shall be categorized into one or more *SWH demand loads*.

X2.2.1.1 *SWH Demand Loads*. Each *SWH demand load* is defined by the building areas served including building use type, the design SWH flow rate and the design SWH supply water temperature. The *gross conditioned floor area* assigned to each *SWH demand load* shall match the actual proposed *building* design within 5%. The user shall create multiple *SWH demand loads*, if necessary, to meet these requirements. Each *SWH demand load* will be assigned a primary SHW usage profile and up to three additional SWH usage profiles in accordance with Section X4.1.2.

X2.2.1.2 Number of SWH Demand Loads One or more *SWH demand loads* shall be created per *building* based on the *proposed SWH design* in the *building* and the following restrictions:

a. Each *SWH demand load* shall have only one primary *building* use type. At least one *SWH demand load* shall be created for each unique *building* use type, including where one *SWH system* serves two different *building* use types. The applicable building use types and criteria are defined in Section X.1.1.1.1.

b. A single *SWH demand load* shall be created for each unique *SWH system* type and *building* use type combination in the *SWH* design of the proposed *building*. The unique *SWH system* types are listed in X1.1.1(a). Multiple *SWH systems* of the same type are permitted to be represented with one *SWH demand load* in accordance with Section X2.2.3.1.

X2.2.1.3 Building Demand Load Type Components. The *SWH load type* characteristics used in the *proposed* SWH design shall be based on the actual SWH design of the proposed *building* using documented user-defined values.

X2.2.2 SWH Demand Load Category. *SWH demand load categories* described in Table X2.2.2 shall be used to design the usage of each *SWH demand load*.

Table X2.2.2 Proposed Design *SWH Demand Load* Categories

Demand Load Category	Description	Fixtures Included
A	General Residential	Shower, Lavatory, Kitchen Sink
B	Hotel (including Motel)	Shower, Lavatory, Kitchenette
C	General Commercial	Public Restrooms, Kitchenette, Service Sinks
D	Commercial Kitchen	3—Compartment Sink, Service Sinks, Commercial Dishwasher
E	Fitness / Gym	Multiple Showers

X2.2.2.1 SWH Demand Load Category by Building Type. Each *SWH demand load category type* in the *proposed SWH design* shall be associated with *a SWH demand load* category. Allowable *SWH demand load categories* for each *building* use type and *SWH demand load* are summarized in Table X2.2.2.1. Each *SWH demand load* in the *proposed SWH design load* shall be modeled based on the actual *SWH system* design in the proposed *building* using inputs described in Section X3.1.

Table X2.2.2.1 Allowable SWH Demand Load Category by Building Use Type

Building Use Type	Primary SWH Demand Load Category	Additional SWH Demand Load Category 1	Additional SWH Demand Load Category 2	Additional SWH Demand Load Category 3
Multifamily	A	B	C	D
Hotel (including Motel)	A	B	C	-
Small office	C	D	-	-
Large office	C	D	E	-
Food service	D	C	-	-
Primary school	C	E	-	-
Secondary school	C	E	D	-
Retail	C	D	-	-
Other	C	-	-	-

X2.2.3 SWH System Components. The *SWH system* parameters shall be provided for the *proposed SWH design* at *design conditions* unless otherwise stated with clarifications and simplifications as described in Table X3.1 and as follows:

a. Each *SWH demand load* shall be served by only one type of *SWH system* in the *proposed SWH design.*

b. Where multiple *SWH systems*, of the same type, serve a *SWH demand load*, average values weighted by the appropriate metric as described in Section X2.2.3.1 shall be used.

c. The Table X2.2.3 parameter requirements are based on input of full-load *equipment efficiencies* with adjustment using part-load curves integrated in the *simulation program*. Where other approaches to part-load adjustment are used, it is permitted for specific input parameters to vary.

Informative Note: Table X3.1 includes both user-defined parameters and parameters that are fixed in the *simulation program* and may not be changed by the user. They are maintained in one table here so related items can be viewed together in context.

X2.2.3.1 Proposed Building SWH System Aggregation. Projects using the SWH System Performance Approach shall comply with all the following requirements.

a. Where multiple *SWH systems*, of the same type, serve a single *SWH demand load*, system performance shall be based on weighted average using the design peak flow rate in gallons per hour (gph) of each *system*.

b. Where multiple *SWH systems*, of the same type, serve a single *SWH demand load*, thermal *efficiency* or SWH efficiency shall be based on a weighted average using SWH capacity.

c. Where multiple *pumps* serve a SWH loop, *pump* power shall be based on a weighted average using design water flow rate.

X3. SIMULATION PROGRAM

The *simulation program* shall be capable of accounting for the following SWH system parameters:

Table X3.1 Proposed Design SWH System Parameters

Category	Parameter	Fixed or User Defined	Required	Applicable Systems	Applicable Loads
SWH System Type	*Building* Use Type	User Defined	Selected from Section X1.1.1.1	All	All
	System type	Fixed	Selected from Section X1.1.1	All	All
	Centralized or Decentralized	Fixed	Selected from Table X.1.1.2	All	All
	Area of primary loads served	User Defined	Number of stories, gross conditioned floor area, average floor-to-floor height	All	All
System Sizing	Primary Equipment Fuel Type	User Defined	Electric resistance, fuel fired or renewable source energy	All	All
	Primary Equipment Capacity	User Defined	Recovery rate in gallons per hour (GPH)	All	All
	Primary Equipment Efficiency	User Defined	As defined in ANSI/ASHRAE/IES Standard 90.1-2022 Table 7.4-1 Performance Requirements for Water-Heating Equipment and Table F-2 Minimum Energy Efficiency Requirements for Water Heaters and Pool Heaters.	All	All
	Primary Equipment Storage Volume	User Defined	Include any storage, not solely of the primary equipment	All	All
	Hot Water Delivered Temperature	User Defined	Temperature of hot water provided at *SWH end-uses.*	All	All
	Hot Water Stored Temperature	User Defined	Temperature of stored hot water in equipment or additional storage volume upstream of delivered temperature.	All but instantaneous	All
	Outlet Temperature Control	User Defined	Default 105 deg F for public lavatories.	All	Public lavatories
	Temperature Control	User Defined	Per ANSI/ASHRAE/IES Standard 90.1-2022	Centralized systems	All

Category	Parameter	Fixed or User Defined	Required	Applicable Systems	Applicable Loads
	Peak supply flow rate	User Defined	In gallons per minute (GPM)	All	All
System Sizing	Backup Equipment Fuel Type	User Defined	Electric resistance, fuel fired or renewable source energy	Centralized systems	All
	Backup Equipment Capacity	User Defined	In gallons per hour (GPH)	Centralized systems	All
	Backup Equipment Efficiency	User Defined	As defined in ANSI/ASHRAE/IES Standard 90.1-2022 Table 7.4-1 Performance Requirements for Water-Heating Equipment and Table F-2 Minimum Energy Efficiency Requirements for Water Heaters and Pool Heaters.	Centralized systems	All
	Number of Storage Tanks	User Defined	Quantity of dedicated storage tanks per system	Centralized systems	All
	Additional Storage Volume	User Defined	In gallons	All but instantaneous	All
	Storage Tank Insulation	User Defined	In R-value	All but instantaneous	All
	Designed standby losses	User Defined		All but instantaneous	All
Temperature Maintenance	Temperature Maintenance Included	User Defined	Yes or No	Centralized systems	All
	Temperature Maintenance System Type	User Defined	Circulation, Heat Trace or other	Centralized systems	All
	Temperature Maintenance System Equipment Efficiency	User Defined	In UEF, Et or COP	Centralized systems	All
	Circulation pump controls	User Defined		Centralized systems	All
	Circulation pump efficiency (W/gpm)	User Defined		Centralized systems	All
	Return temperature setpoint	User Defined		Centralized systems	All
	Temperature Maintenance Controls	Fixed		Centralized systems	All
Distribution Piping	Piping Main length to furthest fixture	User Defined		All	All
	Piping Main Diameter	User Defined		All	All
	Piping Insulation	User Defined	In R-value	All	All

X3.1 Calculation of the SWHPR. The *simulation program* shall calculate both the *SWHPRp* and *SWHPRr* based only on the input for the *proposed SWH design* and the requirements of this Appendix. The calculation procedure shall not allow the user to directly modify either the *building* component characteristics of the *target SWH design* or the *SWH* parameters identified as fixed input in Table X3.1.

X3.2 SWHPR Simulation Program. All components of the *proposed SWH design* for SWH demand loads served by *SWH systems* using this method shall be explicitly modeled by the *simulation program*. The *code official* shall be permitted to approve a *simulation program* for a specified application or limited scope.

X3.2.1 Minimum Capability. The *simulation program* shall be approved by the *code official* and shall, at a minimum, have the ability to explicitly model all of the following:

a. 8760 hours per year

b. Part-load performance curves or other part-load adjustment methods for *SWH system* equipment

c. Capacity and efficiency correction curves or other part-load adjustment methods for SWH heating and pumping equipment

d. The energy use of all *SWH system* types included in the analysis and energy impact from all related fixed and user inputs in Table X3.1

e. Ability to automatically generate the *target SWH design.*

X3.2.2 SWHPR Determination. The *simulation program* shall have the ability to either directly determine the *SWHPRp* and *SWHPRr* or produce hourly and annual reports of *energy* use by each *energy* source suitable for determining the *SWHPRp* and *SWHPRr* using a separate calculation.

X3.2.3 Equipment Sizing Calculations. *Equipment* sizing shall be performed for both the *proposed design* and *SWHPR target building design* in accordance with *generally accepted engineering standards* and handbooks acceptable to the *adopting authority (*e.g., *ASHRAE Handbook – HVAC Applications).*

X3.3 Climatic Data. The *simulation program* shall perform the simulation using hourly values of climatic data, including temperature, humidity, solar radiation, and wind speed and direction from representative climatic data, for the *site* in which the *proposed SWH design* is to be located. For locations for which several climatic data sources are available or weather data are not available, the designer shall select available weather data that best represent the climate at the *construction site*. The selected weather data shall be approved by the *rating authority*.

X3.4 Compliance Report. The *simulation program* shall generate a report that includes the following:

a. Address of the building

b. Name of individual completing the compliance report

c. Name and version of the compliance simulation program and the edition of Standard 90.1 the simulation program method complies with.

d. The floor area, story heights, and number of stories for each SWH demand load

e. By SWH demand load, a list of the *SWH equipment* simulated in the proposed design, including the *equipment* type, fuel type, rated *equipment* efficiencies, rated capacities, and system control parameters

f. Annual site *SWH* energy use by end use and energy type for the *proposed SWH design* and *target SWH design*

g. Annual sum of hourly *SWH demand loads* of the *proposed SWH design*.

h. *SWHPRp, SWHPRt* and compliance result in accordance with Section 7.6.1.2

Informative Note: The *simulation program*, at a minimum, will report compliance with the *SWHPR* based on the compliance criteria in Section 7.6.1.2. The compliance report required by Section X3.4 includes the composite *systems* entered into the program for the different *SWH demand loads*. These may differ from actual *systems* and may be based on capacity *efficiency* weighting per Section X2.2.3.1. The *simulation program* may allow input of individual actual *systems* and perform the weighting, or it may require the user to perform that weighting separately and input the weighted *efficiencies*. In the second case, the weighted *efficiency* calculation would be included. Should a jurisdiction adopt other compliance criteria, then a separate calculation of *SWHPRp and SWHPRt* using the alternate compliance criteria may be necessary.

X4. CALCULATION PROCEDURE

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

X4.1 Simulation of the Proposed Design SWH Loads. The *proposed SWH design* load calculation shall be configured and analyzed as specified in this section.

X4.1.1 **SWH Demand Loads:** The *simulation program* shall model the *SWH systems* using one or more *SWH demand loads*, described in Section X2.2.1. The *simulation program* shall provide for simplified input described in Section X2.2 and allow for the simulation of multiple *SWH demand loads*.

X4.1.2 SWH Demand Load Categories. The simulation program shall be able to represent the hourly the SWH usage profiles described in Section X2.2.2.

X4.1.3 Design SWH flow rates. The design SWH flow rate of each *SWH demand load* in the *proposed SWH design* shall be modeled based on the actual *SWH* design in the proposed *building* using inputs described in Section X3.1.

X4.1.4 Design SWH Temperatures. The *design SWH* storage temperature and the *design SWH* fixture temperature of each SWH demand load in the *proposed SWH design* shall be modeled based on the actual *SWH* design in the proposed *building* using inputs described in Section X3.1.

X4.1.5 SWH Schedules. The design *SWH* flow rate of each SWH demand load shall be adjusted using a hourly *SWH* load schedule for the applicable *building* use type in accordance with Table X4.1.5.

X4.1.6 Mains Temperature Profile. The average monthly cold water supply temperature for each climate zone shall be modeled in accordance with Table X4.1.6.

Table X4.1.5 SWH Demand Load Profiles

Main Occupancy Type	Space Type	Day of Week	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
Office	All	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.19	0.35	0.38	0.39	0.47	0.57	0.54	0.34	0.33	0.44	0.26	0.21	0.15	0.17	0.08	0.05	0.05
Office	All	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.11	0.15	0.21	0.19	0.23	0.20	0.19	0.15	0.13	0.14	0.07	0.07	0.00	0.00	0.00	0.00	0.00
Office	All	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.06	0.06	0.09	0.06	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Retail Standalone	All	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.23	0.32	0.41	0.57	0.62	0.61	0.50	0.45	0.46	0.47	0.42	0.34	0.33	0.00	0.00	0.00
Retail Standalone	All	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.24	0.27	0.42	0.54	0.59	0.60	0.49	0.48	0.47	0.46	0.44	0.36	0.29	0.22	0.00	0.00
Retail Standalone	All	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.29	0.31	0.36	0.36	0.34	0.35	0.37	0.34	0.25	0.00	0.00	0.00	0.00	0.00
Retail Strip mall	All	Mon - Thu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.18	0.27	0.38	0.52	0.62	0.61	0.52	0.45	0.47	0.47	0.44	0.34	0.11	0.08	0.04
Retail Strip mall	All	Fri, Sat	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.21	0.26	0.39	0.50	0.62	0.60	0.51	0.47	0.48	0.42	0.16	0.11	0.11	0.08	0.04
Retail Strip mall	All	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09	0.18	0.30	0.33	0.37	0.35	0.35	0.36	0.36	0.08	0.09	0.07	0.05	0.05	0.03
School Primary	All (Study Periods)	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.60	0.63	0.72	0.79	0.83	0.61	0.65	0.10	0.10	0.19	0.25	0.00	0.00	0.00	0.00
School Primary	All (Study Periods)	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Primary	All (Study Periods)	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Primary	All (Summer Holiday)	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	0.25	0.00	0.00	0.00	0.00
School Primary	All (Summer Holiday)	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Primary	All (Summer Holiday)	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Secondary	All (Study Periods)	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.60	0.63	0.72	0.79	0.83	0.61	0.65	0.10	0.10	0.19	0.25	0.00	0.00	0.00	0.00
School Secondary	All (Study Periods)	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Secondary	All (Study Periods)	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Main Occupancy Type	Space Type	Day of Week	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
School Secondary	All (Summer Holiday)	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	0.25	0.00	0.00	0.00	0.00
School Secondary	All (Summer Holiday)	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
School Secondary	All (Summer Holiday)	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hotel Small	Guest Rooms	Mon - Fri	0.20	0.15	0.15	0.15	0.20	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.55	0.40	0.40	0.60	0.45	0.25
Hotel Small	Guest Rooms	Sat	0.20	0.15	0.15	0.15	0.20	0.25	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.25	0.30	0.40	0.40	0.40	0.60	0.35
Hotel Small	Guest Rooms	Sun	0.20	0.15	0.15	0.15	0.20	0.25	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.25	0.30	0.40	0.40	0.40	0.60	0.35
Hotel Small	Laundry Room	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hotel Small	Laundry Room	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hotel Small	Laundry Room	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hotel Large	Guest Rooms	Mon - Fri	0.20	0.15	0.15	0.15	0.20	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.20	0.30	0.55	0.40	0.40	0.60	0.45	0.25
Hotel Large	Guest Rooms	Sat	0.20	0.15	0.15	0.15	0.20	0.25	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.25	0.30	0.40	0.40	0.40	0.60	0.35
Hotel Large	Guest Rooms	Sun	0.20	0.15	0.15	0.15	0.20	0.25	0.35	0.60	0.80	0.55	0.40	0.30	0.20	0.20	0.20	0.20	0.20	0.25	0.30	0.40	0.40	0.40	0.60	0.35
Hotel Large	Kitchen	Mon - Fri	0.20	0.15	0.15	0.15	0.20	0.25	0.50	0.60	0.55	0.45	0.40	0.45	0.40	0.35	0.30	0.30	0.30	0.40	0.55	0.60	0.50	0.55	0.45	0.25
Hotel Large	Kitchen	Sat	0.20	0.15	0.15	0.15	0.20	0.25	0.40	0.50	0.50	0.50	0.45	0.50	0.50	0.45	0.40	0.40	0.35	0.40	0.55	0.55	0.50	0.55	0.40	0.30
Hotel Large	Kitchen	Sun	0.25	0.20	0.20	0.20	0.20	0.30	0.50	0.50	0.50	0.55	0.50	0.50	0.40	0.40	0.30	0.30	0.30	0.40	0.50	0.50	0.40	0.50	0.40	0.20
Warehouse	Office	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.40	0.50	0.50	0.70	0.90	0.80	0.70	0.80	0.30	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Warehouse	Office	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.40	0.50	0.50	0.70	0.90	0.80	0.70	0.80	0.30	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Warehouse	Office	Sun	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Fast-food Restaurant	All	Mon - Fri	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.33	0.13	0.10	0.72	0.31	0.98	0.92	0.22	0.31	0.23	0.16	0.10	0.40	0.42	0.43	0.15

Main Occupancy Type	Space Type	Day of Week	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
Fast-food Restaurant	All	Sat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.10	0.72	0.60	0.98	0.92	0.25	0.25	0.23	0.16	0.10	0.40	0.42	0.43	0.00
Fast-food Restaurant	All	Sun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.10	0.72	0.60	0.98	0.92	0.25	0.25	0.23	0.16	0.10	0.40	0.42	0.43	0.00
Sit-down Restaurant	All	Mon - Fri	0.20	0.00	0.00	0.00	0.00	0.00	0.15	0.60	0.55	0.45	0.40	0.45	0.40	0.35	0.30	0.30	0.30	0.40	0.55	0.60	0.50	0.55	0.45	0.25
Sit-down Restaurant	All	Sat	0.20	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.50	0.45	0.50	0.50	0.45	0.40	0.40	0.35	0.40	0.55	0.55	0.50	0.55	0.40	0.30
Sit-down Restaurant	All	Sun	0.25	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.50	0.50	0.40	0.40	0.30	0.30	0.30	0.40	0.50	0.50	0.40	0.50	0.40	0.20
Midrise Apartment	All	Mon - Fri	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.61	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29
Midrise Apartment	All	Sat	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.61	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29
Midrise Apartment	All	Sun	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.61	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29
Highrise Apartment	All	Mon - Fri	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.61	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29
Highrise Apartment	All	Sat	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.61	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29
Highrise Apartment	All	Sun	0.08	0.04	0.01	0.01	0.04	0.27	0.94	1.00	0.96	0.84	0.76	0.6	0.53	0.47	0.41	0.47	0.55	0.73	0.86	0.82	0.75	0.61	0.53	0.29

Table X4.1.6 – Mains Temperature (in deg. F) by Climate Zones

Climate Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0A	85.5	85.8	86.7	87.8	88.9	89.6	90.0	89.6	88.7	87.6	86.5	85.6
0B	76.8	78.6	82.8	88.3	93.9	97.9	99.1	97.3	93.0	87.4	81.9	77.9
1A	76.5	77.2	79.0	81.7	84.6	86.7	87.6	87.1	85.1	82.4	79.5	77.4
1B	69.6	71.1	75.6	82.0	88.7	93.7	95.7	94.3	89.6	83.1	76.6	71.6
2A	68.9	69.4	72.0	76.1	80.4	84.0	85.8	85.3	82.6	78.4	73.9	70.5
2B	65.7	66.4	69.8	75.2	81.1	86.0	88.3	87.6	84.0	78.6	72.7	67.8
3A	56.7	56.7	59.4	64.4	70.3	75.7	79.0	79.2	76.3	71.2	65.1	59.9
3B	59.4	59.4	62.2	67.3	73.2	78.3	81.1	81.1	78.3	73.0	67.3	62.2
3C	63.3	63.3	64.0	65.7	67.5	69.3	70.2	70.3	69.4	67.8	66.0	64.4
4A	50.0	49.1	51.3	55.6	61.5	66.9	70.7	71.6	69.6	65.1	59.2	53.8
4B	52.3	51.6	53.8	58.3	63.9	69.3	72.7	73.4	71.2	66.7	61.0	55.8
4C	52.7	52.0	53.1	55.4	58.5	61.5	63.7	64.2	63.3	61.0	57.7	54.9
5A	45.1	43.9	45.1	48.7	54.0	59.2	63.0	64.4	63.1	59.4	54.1	49.1
5B	47.3	46.2	47.7	51.1	55.9	60.8	64.4	65.7	64.2	60.6	55.6	50.9
5C	50.5	50.0	50.5	52.3	54.5	56.8	58.6	59.2	58.6	56.8	54.7	52.3
6A	39.7	37.8	38.7	42.6	48.4	54.3	59.0	61.2	60.1	56.1	50.5	44.4
6B	41.7	40.1	41.0	44.6	49.8	55.2	59.4	61.3	60.3	56.5	51.3	45.9
7	35.4	33.1	33.4	36.7	41.7	47.5	52.3	54.9	54.3	51.1	45.9	40.1
8	32.0	32.0	32.0	32.0	32.7	36.7	40.5	43.0	43.2	41.4	37.9	33.6

Table X4.1.7 – Unconditioned Space Temperature (in deg. F) by Climate Zones

Climate Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0A	26.5	27.2	27.7	28.2	28.1	28	27	27.2	27.2	26.8	26.7	26.2
0B	22.1	23	24.5	26.6	29.6	30.6	31.9	32	30.3	28.4	26	23.2
1A	22.2	23.1	23.5	25.1	26.5	27.3	27.6	27.5	27.2	26.5	24.8	22.7
1B	18.4	20.7	24	28.2	30.6	31	29.8	28.8	28	25.7	22.3	19.1
2A	18.5	19.7	20.7	23.3	26.8	27.2	27.5	27.1	26.4	25.2	21.9	19.9
2B	19.3	18	19.7	24.6	26.4	29.5	29	28.6	27.3	23.1	19.7	17.5
3A	12.6	15.1	18.7	20.8	23.1	25.5	26.3	26.6	24.1	20.1	17.5	14.9
3B	15.2	16.5	17.9	22.1	24.9	27.4	27.2	26.4	24.6	21.5	17.1	14.3
3C	18.3	18.4	18	19.6	19.8	21.1	22.2	22.3	21.6	21.8	19	18.6
4A	10.9	10	13.6	16.9	20.1	23.6	25.7	25.5	22.5	18.8	14.7	12.2
4B	11.7	12.8	15.6	18.8	21.2	24.5	26	25.1	22.8	18.6	14.4	11.4
4C	12.9	13.7	15.3	16.9	18.2	19.8	21.1	21.8	19.5	17.2	15.1	13.5
5A	8	7.5	11.8	14.8	18.6	21.7	23.8	23	20.4	16.2	13.9	8.8
5B	10.7	10	13.1	13.9	18.6	23.9	24.2	23.6	21.6	14.5	12	9.5
5C	12.7	12.8	13.8	15.7	16.3	18.4	19.4	19.8	18.5	15.9	14.3	12.7
6A	2.3	5.4	10.3	14.5	18.9	22	23.1	22.6	19.7	14.7	10.1	5.4
6B	4.7	8.8	10.3	14.3	16.4	20.3	22.9	22	19.2	15.5	11.9	7.6
7	-0.3	3	6.3	12.6	18.5	21.3	22.3	21.3	17.8	13.5	8.9	1.1
8	-0.8	0.6	3.8	10.6	16.7	20	20.6	19	14.3	8.2	-0.8	-1.8

X4.2 Simulation of the Proposed Design. The *proposed design SWH systems* shall be configured and analyzed as specified in this section.

X4.2.1 SWH Equipment. The *simulation program* shall analyze the control parameters that meet the mandatory requirements of Section 7.4 and the parameters provided by the user or specified as fixed in Table X3.1 as applicable for each *SWH system* included in the *proposed design*.

X4.2.2 Supported SWH Systems. The *SWH systems* included in the *proposed SWH design* and the *target building design* shall be supported by the *simulation program*. *SWH systems* permitted are limited to those allowed in accordance with Section X.1.1.1. The *simulation program* shall support multiple *SWH demand loads* being served by one central *SWH system*.

X4.2.3 Proposed Building SWH System Simulation. The *SWH systems* shall be modeled as in the *proposed design* with clarifications and simplifications as described in Table X3.1 and the following rules:

a. *System* parameters not described in Table X3.1 and the following sections shall be simulated to meet the minimum requirements of Section 7.4.
b. Where multiple *system* components serve a *SWH* load, average values weighed by the appropriate metric as described in Section X2.2.3.1 shall be used.
c. Heat loss from pipes shall not be modeled.
d. The *simulation program* shall model part-load SWH *equipment* performance using either
    1. full-load *efficiency* and typical part-load performance adjustments for the proposed *equipment* using the part load performance curves described in Tables X4.2.3-1 and X4.2.3-2 ;
    2. part-load adjustments based on input of both full-load and part-load metrics, or
    3. *equipment*-specific adjustments based on performance data provided by the *equipment manufacturer* for the proposed *equipment*.
e. Where required by the *simulation program* the *SWH* equipment thermal efficiency and shell UA shall be calculated in accordance with Tables X4.3.2-3 and Tables X4.3.2-4.
f. Part-load variable-speed *pump* power shall be calculated using a cubic function with coefficients as shown in Table X4.2.3. The independent variable shall be the fraction of design water flow rate for *pumps* as shown in Figure X4.2.3.

Table X4.2.3 Pump Power Curve Coefficients

Equation Term	Pump Power Coefficients	
	Ride Pump Curve	VSD + Differential Pressure/Valve Reset
b	0	0
x	3.2485	0.0205
x2	–4.7443	0.4101
x3	2.5295	0.5753

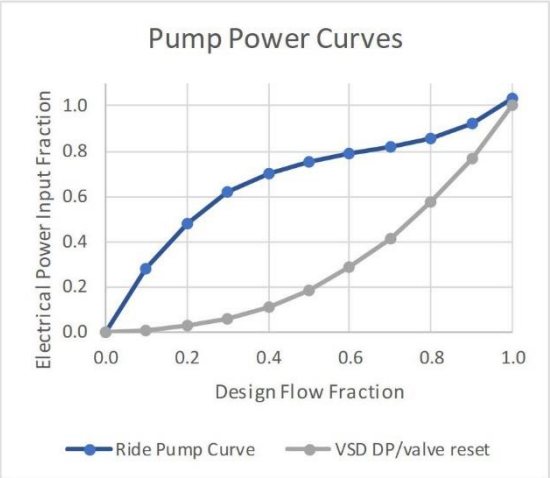

Figure X4.2.3 Pump power performance as a function of design water flow.

Table X-4.2.3-1 SWH Equipment Performance Curves References

SWH Type	Output Variable [a]	Curve Type [b]	*X* [c]	*Y* [c]	Minimum/ Maximum Value for *X* (I-P °F)	Minimum/ Maximum Value for *Y* (I-P °F)
HPWH	CAP-f-T	T1	ZAT	EWT	30/90	35/125
HPWH	COP-f-T	T1	ZAT	EWT	30/90	35/125
Condensing Fuel Fired WH	EIR_C-f-T	T2	PLR	EWT	0/1	70/160
Non-Condensing Fuel Fired WH	EIR_{NC}-f-T	T3	PLR	-	0/1	NA

a. COP-f-T is the coefficient of performance modifier as a function of temperatures; CAP-f-T is the capacity modifier as a function of temperatures, EIR_C-f-T is the efficiency modifier for condensing fuel fired equipment as a function of Part Load Ratio and Entering Water Temperature, EIR_{NC}-f-T is the efficiency modifier for noncondensing fuel fired equipment as a function of Part Load Ratio. .

b. T1: Output = Coeff1 + Coeff2 × X + Coeff3 × X^2 + Coeff4 × Y + Coeff5 × Y^2 + Coeff6 × X × Y
T2: Output = Coeff1 + Coeff2 × X + Coeff3 × X^2 + Coeff4 × Y + Coeff5 × Y^2 + Coeff6 × X × Y+ Coeff7 × X^3 + Coeff8 × Y^3 + Coeff9 × X^2 × Y + Coeff10 × X × Y^2
T3: Output = Coeff1 + Coeff2 × X + Coeff3 × X^2 + Coeff4 × X^3

c. EWT : entering-water temperature ZAT: zone-air dry-bulb temperature: PLR: Part Load Ratio

Table X-4.2.3-2 Target Equipment Performance Curves Coefficients (Simulation Input Required in I-P units)

Set	Description	Output Variable	Coeff 1	Coeff 2	Coeff 3	Coeff 4	Coeff 5	Coeff 6	Coeff 7	Coeff 8	Coeff 9	Coeff 10
A	Heat Pump Water Heater	CAP-f-T	0.369827	0.043341	-0.00023	0.000466	0.000026	-0.00027	NA	NA	NA	NA
		COP-f-T	1.19713	0.077849	-0.0000016	-0.02675	0.000296	-0.00112	NA	NA	NA	NA
B	Condensing Fuel Fired WH	EIR-f-T	0.946581	0.22541	-3.1E-15	0.00904	-0.00029	-0.00176	-0.3203	2.15E-16	0.000827	1.4047E-5
C	Non-Condensing Fuel Fired WH	EIR-f-T	0.732	2.26	-5.8729	6.2469	2.3668	NA	NA	NA	NA	NA

Table X-4.2.3-3 SWH Equipment Efficiency Adjustments

Equipment Type	Typical Modeling Input	Calculation
Consumer Gas-Fired Water Heater	• Thermal efficiency (TE) • Shell UA	$EF = 0.9066 * UEF + 0.0711$ Use Table X4.2.3-4 to find the corresponding, RE and TE, based on the EF. $UA = (TE - RE) * \frac{IN}{67.5}$
Consumer Electric Water Heater (Electric Resistance)	• TE • UA	$EF = 2.4029 * UEF - 1.2844$ $EF = minimum(0.96, EF)$ $UA = 41094 \frac{(\frac{1}{EF} - 1)}{(24 \times 67.5)}$ $TE = 1$
Consumer Electric Water Heater (Heat-Pump)	• COP • UA	$EF = 1.2101 * UEF - 0.6052$ $UA = 41094 \frac{(\frac{1}{EF} - 1)}{(24 \times 67.5)}$
Instantaneous Gas-Fired Water Heater	• TE • UA • SBL	$EF = UEF$ $EF = maximum(EF, 1.0)$ $SBL = 0$ $TE = EF$ $UA = 0$
Instantaneous Electric Water Heater	• TE • UA • SBL	$EF = UEF$ $EF = maximum(EF, 1.0)$ $SBL = 0$ $TE = 1.0$ $UA = 0$
Residential-Duty Commercial Gas-Fired Water Heater	• TE • UA • SBL	$EF = 1.0005 * UEF + 0.0019$ $RE = UEF$ $IN = OUT \; / \; RE$ $MAIN_{VOL} = maximum(100, VOL)$ $SEC_{VOL} = minimum(0, VOL - 100)$ $SBL_{main} = IN \; / \; (800 + 110 * (VOL)^{0.5})$ $SBL_{sec} = 70.053446021 + 1.24483165 * SEC_{VOL} - 0.0005644955 * SEC_{VOL}^2$ $SBL = SBL_{main} + SBL_{sec}$ $UA = SBL * RE \; / \; 70$ $TE = \frac{UA * 70 + IN * RE}{IN}$
Residential-Duty Commercial Electric Instantaneous Water Heater	• TE • UA	$EF = 1.0219 * UEF - 0.0025$ $EF = minimum(EF, 1.0)$ $TE = EF$ $SBL = 0$ $UA = SBL \; / \; 70$

Table X4.2.3-4 – Thermal Efficiency (TE) and Recovery Efficiency (RE) for Consumer Gas-Fired Water Heater based on Energy Factor (EF)

EF	TE	RE	EF	TE	RE
0.5	0.82	0.802	0.75	0.82	0.817
0.51	0.82	0.803	0.76	0.82	0.818
0.52	0.82	0.804	0.77	0.82	0.818
0.53	0.82	0.805	0.78	0.82	0.819
0.54	0.82	0.806	0.79	0.82	0.819
0.55	0.82	0.806	0.8	0.82	0.819
0.56	0.82	0.807	0.81	0.82	0.82
0.57	0.82	0.808	0.82	0.82	0.82
0.58	0.82	0.809	0.83	0.82	0.82
0.59	0.82	0.809	0.84	0.82	0.821
0.6	0.82	0.81	0.85	0.82	0.821
0.61	0.82	0.81	0.86	0.82	0.821
0.62	0.82	0.811	0.87	0.82	0.822
0.63	0.82	0.812	0.88	0.95	0.948
0.64	0.82	0.812	0.89	0.95	0.948
0.65	0.82	0.813	0.9	0.95	0.949
0.66	0.82	0.813	0.91	0.95	0.949
0.67	0.82	0.814	0.92	0.95	0.949
0.68	0.82	0.814	0.93	0.95	0.949
0.69	0.82	0.815	0.94	0.96	0.959
0.7	0.82	0.815	0.95	0.97	0.97
0.71	0.82	0.816	0.96	0.98	0.98
0.72	0.82	0.816	0.97	0.99	0.99
0.73	0.82	0.817	0.98	1	1
0.74	0.82	0.817			

X4.3 Simulation of the Target SWH Design. The *target SWH design* shall be configured and analyzed as specified in this section.

X4.3.1 SWH Load Inputs. *SWH demand load*s, schedules, design SHW flow rates and design SHW supply temperatures shall be modeled the same as in the *proposed SWH design.*

X4.3.2 SWH Equipment. The *target SWH design* SWH equipment shall be modeled in accordance with the assigned *target SWH system* type in Table X4.3.2-1 and the SWH System Type descriptions in Table X4.3.2-2. The sizing of the SWH Target Systems shall be in accordance with the design parameters, by occupancy type, in Table X4.3.2-3.

Table X4.3.2-1 Assigned Target SWH System Type

Building Use Type	Assigned Target System Type
Multifamily mid rise (4-10 stories)	3
Multifamily high rise (10+ stories)	6
Large hotel	6
Motel	5
Small office	4
Large office	5
Food Service	4
Primary school	4
Secondary school	5
Standalone retail	1
Strip mall retail	3
Warehouse	1
Other	2

Table X4.3.2-2 SWH Target Systems

System Type	System Size	Fuel Type	Equip. Storage Capacity	Equip. Input Capacity	Additional Storage Volume	Equip. Type	Equip. Efficiency	Location	Temp. Maint. Included
(1)	Small	Electric	<2	≤12 kW	0 gal	Instantaneous	Table F-2 of Standard 90.1-2022	Distributed	No
(2)	Small	Electric	≥20 gal and ≤55 gal	≤12 kW	0 gal	Storage	Table F-2 of Standard 90.1-2022	Distributed	No
(3)	Small	Electric	≤55 gal	≤12 kW	0 gal	iHPWH	UEF 2.3	Distributed	No
(4)	Medium	Electric	>55 gal and ≤120 gal	≤12 kW	0 gal	iHPWH	Table F-2 of Standard 90.1-2022	Distributed	No
(5)	Medium	Electric	>55 gal and ≤120 gal	≤12 kW	per Table 2	iHPWH	Table F-2 of Standard 90.1-2022	Centralized	Yes
(6)	Large	Electric	N/A	<6 kW	per Table 2	Commercial HPWH	COP 3.0	Centralized	Yes
(7)	Large	Hybrid Gas and Electric	N/A	>12 kW	per Table 2	Commercial HPWH with Gas Backup	COP 3.0	Centralized	Yes

Note: Equip.: Equipment; Temp. Maint.: temperature maintenance); HPWH: heat pump water heater; iHPWH: Integrated HPWH; COP: Coefficient of Performance

Table X4.3.2-3 Allowable SWH Target System Usage Profiles by Building Use Type

Primary SWH Demand Load Category	Description	Fixtures Included	Category Description	Target System Recovery Capacity	Target System Storage Volume
A	Residential	Shower, Lavatory, Kitchen Sink, Residential Dishwasher, Residential Clothes Washer	4 - 50 units	7 GPH per unit	14 gal per unit
			51 - 100 units	5 GPH per unit	
			> 100 units	3 GPH per unit	
B	Hotel	Shower, Lavatory	<20 rooms	3 GPH per room	8 gal per room
			21 - 60 rooms	2 GPH per room	
			> 60 rooms	1.5 GPH per room	
C	General Commercial	Public Restrooms, Kitchenette, Janitorial Sinks	All	0.2 GPH per person	0.75 gal per person
D	Commercial Kitchen	3-compartment Sinks, Service Sinks, Commercial Dishwasher	Sitdown Service	1.0 GPH per max meals per hour	2 gal per max meals per hour
			Fast Service	0.25 GPH per max meals per hour	
E	Fitness / Gym	Multiple Showers	All	0.35 GPH per person	1.5 GPH per person

X5. SWHPR METRIC FOR ANNUAL SWH ENERGY INPUT

For purposes of calculating *SWHPRp and SWHPRt*, the calculated annual SWH *energy* input of each *building* project *energy* source shall be converted to greenhouse gas emissions using the *greenhouse gas* emission factors from ASHRAE 90.1-2022 Appendix M (Published in Addendum L to Standard 90.1-2022)[1]. The greenhouse gas emissions factors associated with electricity shall be selected based on the eGRID subregion and year the *building* will go into service.

[1] Addendum L to Standard 90.1-2022 can be found at https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/90_1_2022_l_20240430.pdf

6.0 References

ASHRAE. 2019. “Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings.” ASHRAE, Atlanta, GA.

ASHRAE. 2019. “ASHRAE Handbook – HVAC Applications, Chapter 51 Service Water Heating.” ASHRAE, Atlanta, GA.

ASHRAE. 2022. “Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings.” ASHRAE, Atlanta, GA.

ASHRAE. 2024a. “Addendum j to Standard 90.1-2022” ASHRAE, Atlanta, GA. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/90_1_2022_j_20240229.pdfASHRAE. 2024b. “Addendum l to Standard 90.1-2022” ASHRAE, Atlanta, GA. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/90_1_2022_l_20240430.pdf

ASPE. 2003. *Domestic Water Heating Design Manual, 2nd ed.* ASPE, Rosemont, IL.

DOE. 2015. Energy Conservation Program for Consumer Products. *Code of Federal Regulations* 10 CFR 430. U.S. Department of Energy, Washington, D.C.

DOE. 2015. Energy Efficiency Program for Certain Commercial And Industrial Equipment. *Code of Federal Regulations* 10 CFR 431. U.S. Department of Energy, Washington, D.C.

Goel, S.; Rosenberg, M.; Gonzalez, J.; Lerond, J. *Total System Performance Ratio—A Systems Based Approach for Evaluating HVAC System Efficiency.* Energies 2021, 14,5108. https://doi.org/10.3390/en14165108

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

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

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.pnnl.gov/main/publications/external/technical_reports/PNNL-29787.pdf

WSEC. 2024. *Washington State Energy Code, 2021*. Washington State Building Code Council. https://sbcc.wa.gov/sites/default/files/2024-01/2021_WSEC_C_2ndEd_012824.pdf

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

www.pnnl.gov