

Normative Appendix
Calculation of Total System Performance Ratio
Reference Section C403.1.1 in 2018 Washington State Energy Code

A.1 Scope. This appendix establishes criteria for demonstrating compliance using the *total system performance ratio* (TSPR) for office, retail, and education occupancies. For those occupancies, HVAC systems shall comply with Section C403 and this appendix as required by Section C403.1.1.

A.2 Compliance. Compliance based on *total system performance ratio* requires that the provisions of Section 403.3 are met and the *total system performance ratio* of the *proposed design* is less than or equal to the *total system performance ratio* of the *standard reference design*. The TSPR is calculated according to the following formula:

TSPR = annual heating and cooling load /annual carbon emissions from energy consumption of the building HVAC systems

Where:

Annual carbon emissions from energy consumption of the building HVAC systems = sum of the annual carbon emissions in pounds for heating, cooling, fans, energy recovery, pumps, and heat rejection calculated by multiplying site energy consumption by the carbon emission factors from Table A1

Annual heating and cooling load = the sum of the annual heating and cooling loads met by the building HVAC system in thousands of Btus.

Table C407.1 . Carbon Emissions Factors

Type	CO2e (lb/unit)	Unit
Electricity	0.55	kWh
Natural Gas	11.70	Therm
Oil	22.50	Gallon
Propane	12.40	Gallon

A.3 Simulation Program

A3.1 General.

A3.2 Calculation of the TSPR for the *Standard Reference Design*. The simulation program shall calculate the TSPR based only on the input for the *proposed design* and the requirements of this appendix. The calculation procedure shall not allow the user to directly modify the building component characteristics of the *standard reference design*.

A3.3 Specific approval. Performance analysis tools meeting the applicable subsections of Appendix A and tested according to ASHRAE Standard 140 shall be permitted to be *approved*. Tools are permitted to

be *approved* based on meeting a specified threshold for a jurisdiction. The *code official* shall be permitted to approve tools for a specified application or limited scope.

A.4. Climatic Data. The simulation program shall perform the simulation using hourly values of climatic data, such as temperature and humidity, using TMY3 data for the site as specified here.

<https://buildingenergyscore.energy.gov/resources>

A.5 Documentation. Documentation conforming to the provisions of this section shall be provided to the *code official*.

A.5.1 Compliance report. Building permit submittals shall include:

1. A report produced by the simulation software that includes the following.

1.1 Address of the building;

1.2 Name of individual completing the compliance report; and

1.3 Name and version of the compliance software tool.

1.4 The dimensions, floor heights and number of floors for each *block*.

1.5 By *block* the U-factor, C-factor, or F-factor for each simulated opaque and fenestration envelope component.

1.6 By *block* or by surface for each block, the fenestration area.

1.7 By *block* the lighting power density.

1.8 By *block* a list of the HVAC equipment simulated in the *proposed design* including the equipment type, fuel type, equipment efficiencies and system controls.

1.9 The *total system performance ratio* for both the *standard reference design* and the *proposed design*;

2. A mapping of the actual building HVAC component characteristics and those simulated in the *proposed design* showing how individual pieces of HVAC equipment identified above have been combined into average inputs as required by Section A.6.1.10 including;

1.1 fans

1.2 hydronic pumps

1.3 air handlers

1.4 packaged cooling equipment

1.5 furnaces

1.6 heat pumps

1.7 boilers

1.8 chillers

1.9 cooling towers

1.10 electric resistance coils

1.11 condensing units

1.13 motors for fans and pumps

1.14 energy recovery devices

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

1.1 equipment name or tag consistent with that found on the design documents

1.2 efficiency level

1.3 capacity

1.4 input power for fans and pumps

3. Floor plan of the building identifying how portions of the buildings are assigned to the simulated *blocks* and areas of the building that are not covered under the requirements of Section C403.1.1.

A.6 Calculation Procedure. Except as specified by this appendix, the *standard reference design* and *proposed design* shall be configured and analyzed using identical methods and techniques.

A.6.1 Simulation of the Proposed Building Design. The *proposed design* shall be configured and analyzed as specified in this section.

A.6.1.1 Utility Rates. For the purpose of calculating the TSPR the following simple utility rate determined by the Washington State Department of Commerce shall be used:

\$0.112/kWh of electricity

\$1.158/therm of fossil fuel

A.6.1.2 Block Geometry. The geometry of buildings shall be configured using one or more *blocks*. Each block shall define attributes including block dimensions, number of floors, floor to floor height and floor to ceiling height. Simulation software may allow the use of simplified shapes (such as rectangle, L shape, H Shape, U shape or T shape) to represent *blocks*. Where actual building shape does not match these pre-defined shapes, simplifications are permitted providing the following requirements are met.

1. The conditioned floor area and volume of each *block* shall match the proposed design within 10%.
2. The area of each exterior envelope component from Tables C402.14 is accounted for within ten percent of the actual design.
3. The area of vertical fenestration and skylights is accounted for within 10% percent of the actual design.
4. The orientation of each component in two and three above is accounted for within 45 degrees of the actual design.

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

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

A6.1.2.1 Number of Blocks. One or more *blocks* may be required per building based on the following restrictions.

1. Each *block* can have only one occupancy type (office, education, or retail). Therefore, at least one single *block* shall be created for each unique use type.
2. Each *block* can be served by only one type of HVAC system. Therefore, a single *block* shall be created for each unique HVAC system and use type combination. Multiple HVAC units of the same type may be represented in one *block*. Table A2 provides directions for combining multiple HVAC units or components of the same type into a single block.
3. Each *block* can have a single definition of floor to floor or floor to ceiling heights. Where floor heights differ by more than two feet, unique *blocks* should be created for the floors with varying heights.
4. Each *block* can include either above grade or below grade floors. For buildings with both above grade and below grade floors, separate *blocks* should be created for each. For buildings with floors partially above grade and partially below grade, if the total wall area of the floor(s) in consideration is $\geq 50\%$ above grade, then it should be simulated as a completely above grade *block*, otherwise it should be simulated as a below grade *block*.

5. Each wall on a façade of a *block* shall have similar vertical fenestration. The product of the proposed design U-factor times the area of windows (UA) on each façade of a given floor cannot differ by more than 15% of the average UA for that façade in each *block*. The product of the proposed design SHGC times the area of windows (USHGC) on each façade of a given floor cannot differ by more than 15% of the average USHGC for that façade in each *block*. If either of these conditions are not met, additional *blocks* shall be created consisting of floors with similar fenestration.

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

A.6.1.3 Thermal Zoning. Each floor in a *block* shall be modeled as a single thermal zone or as five thermal zones consisting of four perimeter zones and a core zone. Below grade floors shall be modeled as a single thermal *block*. If any façade in the *block* is less than 45' in length, there shall only be a single thermal zone per floor. Otherwise each floor shall be modeled with five thermal zones. A perimeter zone shall be created extending from each façade to a depth of 15'. Where facades intersect, the zone boundary shall be formed by a 45 degree angle with the two facades. The remaining area of each floor shall be modeled as a core zone with no exterior walls.

A.6.1.4 Occupancy.

A.6.1.4.1 Occupancy Type. The occupancy type for each *block* shall be consistent with the building area type as determined in accordance with C405.4.2.1. Portions of the building that are building area types other than office, school (education), or retail shall not be included in the simulation.

A.6.1.4.2 Occupancy Schedule, Density, and Heat Gain. The occupant density, heat gain, and schedule shall be for office, retail, or school as specified by ASHRAE Standard 90.1 Normative Appendix C.

A.6.1.5 Envelope Components.

A6.1.5.1 Roofs. Roofs will be modeled with insulation above a steel roof deck. The roof U-factor and area shall be modeled as in the proposed design. If different roof thermal properties are present in a single *block*, an area weighted U-factor shall be used. Roof solar absorptance shall be modeled at 0.70 and emittance at 0.90.

A6.1.5.2 Above Grade Walls. Walls will be modeled as steel frame construction. The U-factor and area of above grade walls shall be modeled as in the proposed design. If different wall constructions exist on the façade of a *block* an area-weighted U-factor shall be used.

A6.1.5.2 Below Grade Walls. The C-factor and area of below grade walls shall be modeled as in the proposed design. If different slab on grade floor constructions exist in a *block*, an area-weighted C-factor shall be used.

A6.1.5.3 Above Grade Exterior Floors. Exterior floors shall be modeled as steel frame. The U-factor and area of floors shall be modeled as in the proposed design. If different wall constructions exist in the *block* an area-weighted U-factor shall be used.

A6.1.5.4 Slab on Grade Floors. The F-factor and area of slab on grade floors shall be modeled as in the proposed design. If different below grade wall constructions exist in a *block*, an area-weighted F-factor shall be used.

A6.1.5.6 Vertical Fenestration. The window area and area weighted U-factor and SHGC shall be modeled for each façade based the proposed design. Each exterior surface in a *block* must comply with A6.1.2.1(5). Windows will be combined in to a single window centered on each façade based on the area and sill height input by the user.

A6.1.5.7 Skylights The skylight area and area weighted U-factor and SHGC shall be modeled for each floor based the proposed design. Skylights will be combined in to a single skylight centered on the roof of each zone based on the area and sill height input by the user.

A.6.1.6 Lighting. Interior lighting power density shall be equal to the actual lighting power in the proposed design. The lighting schedule shall be for office, retail, or school as specified by ASHRAE Standard 90.1 Normative Appendix C. The impact of lighting controls is assumed to be captured by the lighting schedule and no explicit controls shall be modeled. Exterior lighting shall not be modeled.

A.6.1.7 Miscellaneous equipment. The miscellaneous equipment schedule power and shall be for office, retail, or school as specified by ASHRAE Standard 90.1 Normative Appendix C. The impact of miscellaneous equipment controls is assumed to be captured by the equipment schedule and no explicit controls shall be modeled.

A.6.1.8 Elevators. Elevators shall not be modeled.

A.6.1.9 SWH Equipment. SWH shall not be modeled.

A.6.1.10 On-site Renewable Energy Systems. On-site Renewable Energy Systems shall not be modeled.

A.6.1.10 HVAC Equipment. HVAC systems shall meet the requirements of Section C403 Mechanical Systems.

A6.1.10.1 Supported HVAC Systems. At a minimum, the HVAC systems shown in Table A1 shall be supported by the simulation program.

Table A1. Proposed Building HVAC Systems Supported by TSPR Simulation Software

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

A6.1.10.2 Proposed Building HVAC System Simulation. The HVAC systems shall be modeled as in the proposed design with clarifications and simplifications as described in Table A2. System parameters not described in the following sections shall be simulated to meet the minimum requirements of Section C403. All zones within a *block* shall be served by the same HVAC system type as described in Section A6.1.2.1 (2). Where multiple system components serve a *block*, average values weighed by the appropriate metric as described in this section shall be used. Heat loss from ducts and pipes shall not be modeled.

Table A2 Proposed Building System Parameters

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
HVAC System Type	System Type	User Defined	Selected from Table A1	All
System Sizing	Design Day Information	Fixed	99.6% heating design and 1% dry-bulb and 1% wet-bulb cooling design	All
	Zone Coil Capacity	Fixed	Sizing factors used are 1.25 for heating equipment and 1.15 for cooling equipment.	All
	Supply Airflow	Fixed	Based on a supply-air-to-room-air temperature <i>set-point</i> difference of 20°F.	1-11
		Fixed	Equal to required outdoor air ventilation	12
Outdoor Ventilation Air	Outdoor Ventilation Air Flow Rate	Fixed	As specified in ASHRAE Standard 90.1 Normative Appendix C, adjusted for proposed DCV control ⁴	All
System Operation	Space temperature Setpoints	Fixed	As specified in ASHRAE Standard 90.1 Normative Appendix C	1-11
	Fan Operation – Occupied	User Defined	Runs continuously during occupied hours or cycled to meet load	1-11
	Fan Operation – Occupied	Fixed	Fan runs continuously during occupied hours	12
	Fan Operation - Night Cycle	Fixed	Fan cycles on to meet setback temperatures	1-11
Packaged Equipment Efficiency	DX Cooling Efficiency	User Defined	Cooling COP without fan energy calculated in accordance with ASHRAE Standard 90.1 Section 11.5.2c. ²	1, 2, 3, 4, 5, 7, 8, 9, 11, 12
	Heat Pump Efficiency	User Defined	Heating COP without fan energy calculated in accordance with ASHRAE Standard 90.1 Section 11.5.2c. ³	2, 4, 5, 7, 8
	Furnace Efficiency	User Defined	Furnace thermal efficiency ³	3,11
Heat Pump Supplemental Heat	Control	Fixed	Supplemental electric heat locked out above 40°F. Runs In conjunction with compressor between 40°F and 0°F.	2, 4
System Fan Power	Design Fan Power (W/cfm)	User Defined	Input electric power for all fans in required to operate <i>at fan system design conditions</i> divided by the supply airflow rate	All
	Single Zone System Fan	User Defined	W/cfm during deadband for VAV or multispeed single zone fans	3, 4, 5, 6, 7, 8

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
	Power During Deadband (W/cfm)			
Variable Air Volume Systems	Part Load Fan Controls	User Defined	VFD included. User specifies presence of static pressure reset.	9, 10, 11
	Supply Air Temperature Controls	User defined	If not SAT reset constant at 55°F. SAT reset results in 60°F SAT during low load conditions.	9, 10, 11
	Minimum Damper Position	User Defined	Average minimum damper position for <i>block</i> weighted by cfm	9, 10, 11
	Terminal Unit Heating Source	User Defined	Electric or hydronic	9, 10, 11
	Fan Powered Terminal Unit (FPTU) Type	User Defined	Series or parallel FPTU	11
	Parallel FPTU Fan	Fixed	Sized for 50% peak primary air at 0.35 W/cfm	11
	Series FPTU Fan	Fixed	Sized for 50% peak primary air at 0.35 W/cfm	11
Economizer	Economizer Presence	User Defined	Default to 100% economizer	3, 4, 9, 10, 11
	Economizer High Limit	Fixed	75°F fixed drybulb	3, 4, 9, 10, 11
Energy Recovery	Sensible Effectiveness	User Defined	Heat exchanger sensible effectiveness at design heating and cooling conditions	3, 4, 9, 10, 11, 12
	Latent Effectiveness	User Defined	Heat exchanger latent effectiveness at design heating and cooling conditions	3, 4, 9, 10, 11, 12
	Economizer Bypass	User Defined	If ERV is bypassed during economizer conditions	3, 4, 9, 10, 11, 12
	Energy Recovery Temp Control	User Defined	If bypass, target supply air temperature	3, 4, 9, 10, 11, 12
	Fan Power Reduction during Bypass (W/cfm)	User Defined	If ERV system include bypass, static pressure setpoint and variable speed fan, fan power can be reduced during economizer conditions.	3, 4, 9, 10, 11, 12
Demand Controlled Ventilation	DCV Application	User Defined	Percent of block floor area under DCV control	3, 4, 9, 10, 11, 12
DOAS	DOAS Fan Power W/cfm	User Defined	Fan input power in W/cfm of supply airflow ¹	12
	DOAS	User Defined	Heating source, cooling source	12

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
	Supplemental Heating and Cooling			
	DOAS Supply Air Temperature Control	User Defined	SAT setpoint if DOAS includes supplemental heating or cooling and active temperature controls	12
Heating Plant	Boiler Efficiency	User Defined	Boiler thermal efficiency	1, 6, 7, 9, 10, 11, 12
	Heating Water Pump Power (W/gpm)	User Defined	Pump input W/gpm heating water flow	1, 6, 7, 9, 10, 11, 12
Chilled Water Plant	Chiller Compressor Type	User Defined	Screw/Scroll, Centrifugal or Reciprocating	6,10, 11, 12
	Chiller Condenser Type	User Defined	Air cooled or water cooled	6,10, 11, 12
	Chiller Full Load Efficiency	User Defined	Chiller COP	6,10, 11, 12
	Chilled Water loop Configuration	User Defined	Variable flow primary only, constant flow primary – variable flow secondary	6,10, 11, 12
	Chilled Water Pump Power (W/gpm)	User Defined	Pump input W/gpm chilled water flow	6,10, 11, 12
	Chilled Water Temperature Reset Included	User Defined	Yes/No	6,10, 11, 12
	Chilled Water Temperature Reset Schedule (if included)	Fixed	Outdoor air reset: CHW supply temperature of 44°F at 80°F outdoor air dry bulb and above, CHW supply temperature of 54°F at 60°F outdoor air dry bulb temperature and below, ramped linearly between.	6,10, 11, 12
	Condenser Water Pump Power (W/gpm)	User Defined	Pump input W/gpm condenser water flow	6,7, 8, 9, 10, 11, 12
	Condenser Water Pump Control	User Defined	Constant speed or variable speed	6,7, 10, 11, 12
	Cooling Tower Efficiency	User Defined	gpm/hp tower fan	6,10, 11, 12
Cooling Tower	Cooling Tower Fan Control	User Defined	Constant or variable speed	6,10, 11, 12
	Cooling Tower	User Defined	Design cooling tower approach and	6,10, 11,

Category	Parameter	Fixed or User Defined	Required	Applicable Systems
	Approach and Range		range temperature	12
Heat Pump Loop Flow Control	Loop flow and Heat Pump Control Valve	Fixed	Two position Valve with VFD on Pump. Loop flow at 3 gpm/ton	7, 8
GLHP Well Field		Fixed	Bore depth = 250'. Bore length 200'/ton for greater of cooling or heating load. Bore spacing = 15'. Bore diameter = 5". ¾" Polyethylene pipe. Ground and grout conductivity = 4.8 Btu-in/h-ft ² -°F.	8

¹ Where multiple fan systems serve a single *block* fan power is based on weighted average using on supply air cfm.

² Where multiple cooling systems serve a single *block*, COP is based on a weighted average using cooling capacity.

³ Where multiple heating systems serve a single *block*, thermal efficiency or heating COP is based on a weighted average using heating capacity.

A.6.2 Simulation of the Standard Reference Design. The *standard reference design* shall be configured and analyzed as specified in this section.

A.6.2.1 Utility Rates. Same as proposed.

A.6.2.2 Blocks. Same as proposed.

A.6.2.3 Thermal Zoning. Same as proposed.

A.6.2.4 Occupancy Type, Schedule, Density, and Heat Gain. Same as proposed.

A.6.2.5 Envelope Components. Same as proposed.

A.6.2.6 Lighting. Same as proposed.

A.6.2.7 Miscellaneous equipment. Same as proposed.

A.6.2.8 Elevators. Not modeled. Same as proposed.

A.6.2.9 SWH Equipment. Not modeled. Same as proposed.

A.6.2.10 On-site Renewable Energy Systems. Not modeled. Same as proposed.

A.6.1.11 HVAC Equipment. The *standard reference design* HVAC equipment consists of separate space conditioning systems and dedicated outside air systems as described in TableA3 for the appropriate building occupancies.

Table A3 Standard Reference Design HVAC Systems

Parameter	Building Type			
	Large Office ¹	Small Office and Libraries ¹	Retail	School
System Type	Water-source Heat Pump	Packaged air-source Heat Pump	Packaged air-source Heat Pump	Packaged air-source Heat Pump
Fan control ²	Cycle on load	Cycle on load	Cycle on load	Cycle on load
Space condition fan power (W/cfm)	0.528	0.528	0.522	0.528
Heating/Cooling sizing factor ³	1.25/1.15	1.25/1.15	1.25/1.15	1.25/1.15
Supplemental heating availability	NA	<40°F	<40°F	<40°F
Modeled cooling COP (Net of fan) ⁴	4.46	3.83	4.25	3.83
Modeled heating COP (Net of fan) ⁴	4.61	3.81	3.57	3.81
Cooling Source	DX (heat pump)	DX (heat pump)	DX (heat pump)	DX (heat pump)
Heat source	Heat Pump	Heat Pump	Heat Pump	Heat Pump
OSA Economizer ⁵	No	No	Yes	Yes
Occupied ventilation source ⁶	DOAS	DOAS	DOAS	DOAS
DOAS Fan Power (W/cfm of outside air)	0.819	0.819	0.730	0.742
DOAS temperature control ^{7,8}	Bypass	Wild	Bypass	Bypass
ERV efficiency (sensible only)	70%	70%	70%	70%
WSHP Loop Heat Rejection	Cooling Tower ⁹	NA	NA	NA
WSHP Loop Heat Source	Gas Boiler ¹⁰	NA	NA	NA
WSHP Loop Temperature Control ¹¹	50°F to 70°F	NA	NA	NA
WSHP circulation Pump W/gpm ¹²	16	NA	NA	NA
WSHP Loop Pumping Control ¹³	HP Valves & pump VSD	NA	NA	NA

¹ Offices <50,000 ft² use “Small Office” parameters; otherwise use “Large Office” parameters.

² Space conditioning system shall cycle on to meet heating and cooling setpoint schedules as specified in ASHRAE Standard 90.1 Normative Appendix C. One space conditioning system is modeled in each zone. Conditioning system fan operation is not necessary for ventilation delivery.

³ The equipment capacities (i.e. system coil capacities) for the *standard reference design* building design shall be based on design day sizing runs and shall be oversized by 15% for cooling and 25% for heating.

- ⁴ COPs shown are direct heating or cooling performance and do not include fan energy use. See 90.1 appendix G (G3.1.2.1) for separation of fan from COP in packaged equipment for units where the efficiency rating includes fan energy (e.g., SEER, EER, HSPF, COP).
- ⁵ Economizer on space conditioning systems shall be simulated when outdoor air conditions allow free cooling. Economizer high limit shall be based on differential drybulb control. DOAS system continues to operate during economizer mode.
- ⁶ Airflow equal to the outside air ventilation requirements is supplied and exhausted through a separate DOAS system including a supply fan, exhaust fan, and sensible only heat exchanger. No additional heating or cooling shall be provided by the DOAS. A single DOAS system will be provided for each *block*. The DOAS supply and return fans shall run whenever the HVAC system is scheduled to operate in accordance with ASHRAE Standard 90.1 Normative Appendix C.
- ⁷ “Wild” DOAS control indicates no active control of the supply air temperature leaving the DOAS system. Temperature will fluctuate based only on entering and leaving conditions and the effectiveness of ERV.
- ⁸ “Bypass” DOAS control includes modulating dampers to bypass ERV with the intent to maintain supply air temperature at a maximum of 60 deg. F. when outside air is below 75°F. Once outside air is above 75°F bypass dampers will be fully closed.
- ⁹ Includes a single axial fan cooling tower with variable-speed fans at 40.2 gpm per/hp, sized for an approach of 10°F and a range of 10°F.
- ¹⁰ Includes a single natural draft boiler with 80% E_t .
- ¹¹ Loop boiler and heat rejection shall be controlled to maintain loop temperature entering heat pumps between 50°F and 70°F.
- ¹² Pump motor input power shall be 16 W/gpm.
- ¹³ Loop flow shall be variable with variable speed drive pump and unit fluid flow shutoff at each heat pump when its compressor cycles off.