HVAC System Efficiency Calculations

Performance Analysis & Compliance Verification - ASHRAE Standards

Document: HVAC-EFF-2025-003 | **Standards:** ASHRAE 90.1, AHRI 550/590 | **Date:** November 2025

1. Chiller Performance Calculations

Coefficient of Performance (COP)

$$COP = Q_{cooling} / W_{electrical}$$

Where:

- $Q_{cooling}$ = Cooling capacity (kW)
- $W_{electrical}$ = Electrical power input (kW)

Magnetic Bearing Centrifugal Chiller Analysis:

Load Condition	Cooling Output (kW)	Power Input (kW)	COP	Efficiency (%)
100% Load	1,760	284	6.20	620%
75% Load	1,320	169	7.81	781%
50% Load	880	99	8.89	889%
25% Load	440	62	7.10	710%

IPLV Calculation (Integrated Part Load Value):
IPLV = 0.01(6.20) + 0.42(7.81) + 0.45(8.89) + 0.12(7.10)
IPLV = 0.062 + 3.280 + 4.001 + 0.852 = 8.195

Full Load COP: 6.20 | IPLV: 8.20
ASHRAE 90.1 Minimum: COP ≥ 5.5, IPLV ≥ 7.0
Status: COMPLIANT ✓

2. Heat Pump Performance

Heating Seasonal Performance Factor (HSPF)

$$\text{HSPF} = \text{Total Heating Output (Btu)} / \text{Total Electrical Input (Wh)}$$

$$\text{COP}_{\text{heating}} = \text{Heat Output (kW)} / \text{Power Input (kW)}$$

Variable Refrigerant Flow (VRF) System:

Heating Mode Performance:
- Heating Capacity: 45 kW @ 7°C outdoor
- Power Input: 12.8 kW
- $\text{COP}_{\text{heating}}$ = 45 ÷ 12.8 = 3.52
- Seasonal Average COP: 3.85

HSPF Calculation:
- Annual Heating Load: 125,000 kWh
- Annual Energy Input: 32,468 kWh
- HSPF = (125,000 × 3,412) ÷ (32,468 × 1,000)
- HSPF = 426,500,000 ÷ 32,468,000 = 13.1 Btu/Wh

Calculated HSPF: 13.1 Btu/Wh
ENERGY STAR Requirement: ≥ 10.0 Btu/Wh
Status: EXCEEDS STANDARD ✓

3. Air Handling Unit Efficiency

Fan Efficiency & Specific Fan Power

$$\text{Fan Efficiency} = (\text{Airflow} \times \text{Pressure}) / (\text{Power} \times 1000)$$

$$\text{SFP} = \text{Fan Power (W)} / \text{Airflow (L/s)}$$

Variable Air Volume (VAV) System Analysis:

Parameter	Design Value	Measured Value	Efficiency
Airflow Rate	15,000 CFM	14,850 CFM	99.0%
Static Pressure	2.5 in. w.g.	2.3 in. w.g.	108.7%
Fan Power	25 kW	22.1 kW	113.1%
Motor Efficiency	94.5%	95.2%	100.7%

Fan Efficiency Calculation:

- Airflow: 14,850 CFM = 7,008 L/s
- Pressure: 2.3 in. w.g. = 573 Pa
- Fan Efficiency = (7,008 × 573) / (22,100 × 1000)
- Fan Efficiency = 4,015,584 / 22,100,000 = 0.182 = 18.2%

Specific Fan Power:

SFP = 22,100 W ÷ 7,008 L/s = 3.15 W/(L/s)

ASHRAE 90.1 Limit: ≤ 4.0 W/(L/s)

Fan Efficiency: 18.2% | SFP: 3.15 W/(L/s)
Both parameters within acceptable limits ✓

4. Heat Recovery Systems

Heat Recovery Effectiveness

$$\text{Sensible Effectiveness} = (T_{supply} - T_{outdoor}) / (T_{exhaust} - T_{outdoor})$$

$$\text{Latent Effectiveness} = (W_{supply} - W_{outdoor}) / (W_{exhaust} - W_{outdoor})$$

Energy Recovery Ventilator (ERV) Performance:

Outdoor Air
-5°C
35% RH

Exhaust Air
22°C
45% RH

Supply Air
16°C
42% RH

Return Air
1°C
38% RH

Sensible Effectiveness:
$\eta_{sensible}$ = (16 - (-5)) / (22 - (-5))
$\eta_{sensible}$ = 21 / 27 = 0.778 = 77.8%

Latent Effectiveness (using humidity ratios):
• $W_{outdoor}$ = 1.2 g/kg, $W_{exhaust}$ = 7.8 g/kg, W_{supply} = 6.9 g/kg
η_{latent} = (6.9 - 1.2) / (7.8 - 1.2) = 5.7 / 6.6 = 0.864 = 86.4%

Sensible Effectiveness: 77.8%
Latent Effectiveness: 86.4%
ASHRAE 90.1 Minimum: ≥ 50% sensible
Status: EXCEEDS REQUIREMENTS ✓

5. Duct System Performance

Duct Leakage & Pressure Loss

$$\text{Duct Leakage Rate} = Q_{leak} / Q_{total} \times 100\%$$

$$\text{Pressure Loss} = f \times (L/D) \times (\rho V^2/2)$$

Where: f = friction factor, L = length, D = diameter, ρ = air density, V = velocity

Duct System Leakage Test Results:

Test Section	Test Pressure (Pa)	Measured Leakage (CFM)	System Airflow (CFM)	Leakage Rate (%)
Supply Ductwork	250	420	12,000	3.5%
Return Ductwork	125	180	11,500	1.6%
Total System	-	600	12,000	5.0%

Pressure Loss Calculation - Main Supply Duct:

- Duct: 24" diameter, 150 ft length
- Airflow: 8,000 CFM, Velocity: 1,592 FPM
- Friction factor: 0.018
- Pressure Loss = 0.018 × (150/2) × (0.075 × 1592²/2)
- Pressure Loss = 1.35 × 9,520 = 0.32 in. w.g.

Total Duct Leakage: 5.0%
ASHRAE 90.1 Limit: ≤ 6.0%
Pressure Loss: 0.32 in. w.g. (within design)
Status: COMPLIANT ✓

6. System Integration & Controls

Demand Control Ventilation (DCV)

$$\text{Required Ventilation} = \text{People} \times R_p + \text{Area} \times R_a$$

$$\text{CO2-based Control: } OA\% = (C_{space} - C_{outdoor}) / (C_{exhaust} - C_{outdoor})$$

Office Space Ventilation Control:

ASHRAE 62.1 Requirements:
- Occupancy: 150 people
- Floor Area: 15,000 ft²
- People component: 150 × 5 CFM/person = 750 CFM
- Area component: 15,000 × 0.06 CFM/ft² = 900 CFM
- Total Required: 750 + 900 = 1,650 CFM

CO_2-Based DCV Calculation:
- Outdoor CO_2: 400 ppm
- Space CO_2 setpoint: 1,000 ppm
- Exhaust CO_2 (design): 1,200 ppm
- Required OA% = (1,000 - 400) / (1,200 - 400) = 75%
- At 50% occupancy: OA% = (800 - 400) / (1,200 - 400) = 50%

Minimum Ventilation: 1,650 CFM
DCV Energy Savings: ~35% during low occupancy
Annual Energy Reduction: 45,000 kWh