J∆S Engineering Suite

Module Guide: Ventilation Design (ASHRAE 62.1-2022)

Version 1.2 — April 2026
JS Engineering Solutions

Version: 1.1 **Last Updated:** February 2026 **Applicable Standard:** ASHRAE Standard 62.1-2022, *Ventilation and Acceptable Indoor Air Quality in Buildings* **Published by:** JS Engineering Solutions

Table of Contents

1. Opening the Module

1.1 Launching the J∆S Engineering Suite

To access the Ventilation Design module, you must first launch the J∆S Engineering Suite application.

1. **Start the application.** Double-click the desktop shortcut labeled "J∆S Engineering Suite" or run `python launcher.py` from the installation directory. The login dialog appears.
2. **Authenticate.** Enter your username and password. If two-factor authentication (2FA) is enabled on your account, you will be prompted for the six-digit TOTP code from your authenticator app. Click **Login**.
3. **Dashboard.** After successful authentication, the main dashboard loads. The dashboard displays a 4x3 grid of module tiles organized by category: HVAC Design, Compliance, Reports, AI Assistant, Collaboration, and others.

1.2 Navigating to the Ventilation Module

From the dashboard, there are two ways to open the Ventilation Design module:

Method A — Sidebar Navigation:

1. Look at the left sidebar. It lists all available module categories in a collapsible tree view.
2. Expand the **HVAC Calculations** category by clicking the arrow or the category name.
3. Within HVAC Calculations, expand the **Ventilation & IAQ** subcategory.
4. Click **ASHRAE 62.1 Ventilation**. The module opens in the main content area.

Method B — Dashboard Tile:

1. On the main dashboard, locate the **HVAC Design** tile (typically in the top-left quadrant).
2. Click the tile to open the HVAC module launcher.
3. From the list of available HVAC tools, select **ASHRAE 62.1 Ventilation**.

Method C — Search:

1. Click the search bar at the top of the dashboard (or press `Ctrl+K`).
2. Type "ventilation" or "62.1".
3. Select **ASHRAE 62.1 Ventilation** from the search results dropdown.

1.3 Module Interface Overview

When the Ventilation Design module opens, you will see:

- **Top toolbar:** Buttons for New Project, Open, Save, Export (PDF/Excel/TXT), and Print.
- **Left panel — Zone List:** A table listing all zones in the current project. If you have already entered zones in the load calculation module (`engine.py`), they appear here automatically with their areas and occupancy data pre-filled.
- **Center panel — Zone Detail:** When a zone is selected in the left panel, the center panel displays all ventilation parameters for that zone: occupancy category (dropdown), zone area, zone population, Rp, Ra, Ez, and calculated Vbz and Voz values.
- **Right panel — System Summary:** Shows the system-level calculation including AHU assignment, diversity factor, system ventilation efficiency (Ev), and total outdoor air intake (Vot).
- **Bottom panel — Compliance Status:** A color-coded status bar showing PASS (green), WARNING (yellow), or FAIL (red) for each zone and the overall system.

1.4 Integration with Load Calculations

The Ventilation Design module is tightly integrated with the J∆S Engineering Suite load calculation engine. When you have an active project with zones defined in the load calculation module:

- **Zone areas (Az)** are pulled automatically from the room/zone definitions.
- **Zone populations (Pz)** are pulled from occupancy inputs in the load calculation.
- **Occupancy categories** are mapped from the space type selected in the load calculation. For example, if you defined a zone as "Open Office" in the load calculation, the ventilation module automatically assigns the "Office - Open Plan" occupancy category with Rp = 5 CFM/person and Ra = 0.06 CFM/SF.
- **Supply airflows (Vpz)** are pulled from the cooling load calculation results, enabling the automatic system-level multi-zone calculation.

You can override any auto-populated value. Overrides are flagged with a small icon so you can track which values are user-modified versus auto-populated.

1.5 Starting a Standalone Ventilation Calculation

If you want to use the ventilation module without a full load calculation project:

1. Click **New** in the toolbar (or `Ctrl+N`).

2. Enter a project name and location (city/state for weather data and altitude correction).

3. Click **Add Zone** to create zones manually.

4. For each zone, enter: Zone Name, Area (SF), Occupancy Category (dropdown), Population (number of people), and Air Distribution type (dropdown for Ez selection).

5. The module calculates Vbz, Voz, and system-level values in real time as you enter data.

2. Why Ventilation Matters

2.1 Indoor Air Quality and Human Health

Humans spend approximately 90% of their time indoors. The quality of indoor air directly impacts occupant health, cognitive performance, and well-being. Inadequate ventilation leads to the buildup of indoor air pollutants including:

• **Carbon dioxide (CO2):** Exhaled by occupants. At concentrations above 1,000 ppm, occupants report stuffiness, headaches, and difficulty concentrating. At concentrations above 2,500 ppm, cognitive performance measurably declines. Outdoor air is typically 400-420 ppm.

• **Volatile organic compounds (VOCs):** Emitted by building materials (paint, carpet, adhesives, furniture), cleaning products, and office equipment (printers, copiers). VOCs include formaldehyde, benzene, toluene, and hundreds of other compounds. Many are known carcinogens or irritants.

• **Particulate matter (PM2.5, PM10):** Generated by occupant activity, cooking, printing, and infiltration from outdoor sources. Fine particles (PM2.5) penetrate deep into the lungs and are linked to cardiovascular and respiratory disease.

• **Bioaerosols:** Bacteria, viruses, mold spores, and allergens. Adequate ventilation with appropriate filtration is the primary engineering control for reducing airborne infectious disease transmission.

• **Carbon monoxide (CO):** From combustion appliances, attached garages, and outdoor vehicle exhaust. CO is odorless and potentially lethal.

• **Radon:** A naturally occurring radioactive gas that enters buildings through foundation cracks. Radon is the second leading cause of lung cancer in the United States.

• **Ozone:** Generated by photocopiers, laser printers, and some electronic air cleaners. Ozone is a respiratory irritant.

2.2 The Business Case for Good Ventilation

Research consistently demonstrates that improved ventilation produces measurable returns:

• **Productivity:** A landmark Harvard T.H. Chan School of Public Health study (the COGfx Study, 2015) found that cognitive function scores were 61% higher in green buildings with enhanced ventilation (40 CFM/person) compared to conventional buildings (20 CFM/person). Decision-making performance improved by over 100% in some cognitive domains.

• **Absenteeism:** The EPA estimates that improved IAQ reduces sick leave by 10-30%. For a 100-person office with an average salary of $75,000, even a 10% reduction in sick days represents approximately $150,000 in annual savings.

• **Liability:** Building owners and employers face legal liability for IAQ-related health complaints. Sick Building Syndrome (SBS) lawsuits have resulted in multi-million-dollar settlements. Documenting compliance with ASHRAE 62.1 is a primary legal defense.

• **Tenant satisfaction and retention:** In commercial real estate, IAQ is increasingly a differentiator. WELL Building Standard and Fitwel certifications, which require ventilation rates meeting or exceeding ASHRAE 62.1, command rental premiums of 4-10%.

2.3 Code Requirements and Legal Obligations

Ventilation is not optional. It is required by building codes:

• **International Mechanical Code (IMC):** Section 403 requires mechanical ventilation in accordance with ASHRAE 62.1 for most commercial buildings. The IMC is adopted (with local amendments) by 49 of 50 US states.

• **California Mechanical Code (CMC):** Title 24, Part 4 requires ventilation rates that reference or exceed ASHRAE 62.1 values. California Title 24 energy standards (Part 6) impose additional requirements for demand-controlled ventilation and energy recovery.

• **ASHRAE 90.1 (Energy Standard):** While primarily an energy standard, ASHRAE 90.1-2022 contains ventilation-related requirements including DCV (Section 6.5.3.7), energy recovery (Section 6.5.6), and exhaust air energy recovery (Section 6.5.6.1). These are mandatory when ASHRAE 90.1 is the referenced energy code.

• **Local amendments:** Many jurisdictions (New York City, Seattle, Denver, etc.) have local amendments that increase ventilation requirements beyond the base code. The J∆S Engineering Suite allows custom overrides to accommodate local requirements.

2.4 Post-Pandemic Considerations

The COVID-19 pandemic dramatically increased awareness of indoor air quality and ventilation. Key post-pandemic developments relevant to ASHRAE 62.1 include:

• **ASHRAE 241-2023:** A new standard specifically addressing control of infectious aerosols. While separate from 62.1, it references 62.1 ventilation rates as a baseline and adds requirements for equivalent clean air delivery during infection risk management mode.

• **Increased filtration expectations:** Many building owners and jurisdictions now expect MERV 13 filtration as a minimum, up from the traditional MERV 8 minimum in ASHRAE 62.1.

• **Upper-room UVGI:** Ultraviolet germicidal irradiation as a supplement to ventilation. The J∆S Engineering Suite includes a separate module for UVGI design.

• **Portable air cleaners:** HEPA and carbon filtration units as supplements in spaces where increasing outdoor air is impractical.

2.5 The Engineer's Responsibility

The mechanical engineer of record is responsible for:

1. **Calculating** the minimum ventilation rates per ASHRAE 62.1 for every occupied zone in the building.
2. **Designing** the HVAC systems to deliver those rates under all operating conditions (full load, part load, economizer, morning warmup/cooldown).
3. **Documenting** the ventilation design in the construction documents, including a ventilation schedule showing all zones, their occupancy categories, and calculated outdoor air rates.
4. **Specifying** controls that maintain minimum outdoor air rates, including airflow measuring stations, CO2 sensors for DCV zones, and building pressure controls.
5. **Verifying** during commissioning that the installed system delivers the design outdoor air rates.

The J∆S Engineering Suite automates steps 1-4 and generates the documentation needed for step 5.

3. ASHRAE 62.1-2022 Overview

3.1 Scope of the Standard

ASHRAE Standard 62.1-2022, titled *Ventilation and Acceptable Indoor Air Quality in Buildings*, applies to:

- All spaces intended for human occupancy within buildings, except those within dwelling units covered by ASHRAE 62.2 (residential).
- New buildings, additions to existing buildings, and changes to existing buildings that are subject to plan review (e.g., tenant improvement projects that modify the HVAC system).
- All occupancy types: commercial office, retail, healthcare, education, hospitality, industrial (occupied areas), assembly, and institutional.

The standard does **not** apply to:

- Single-family homes, duplexes, townhouses, and multifamily dwelling units (covered by ASHRAE 62.2).
- Spaces used solely for manufacturing processes where ventilation is governed by OSHA or other industrial hygiene standards.
- Vehicles, aircraft, and ships.
- Smoking lounges specifically designated for smoking (these require separate analysis per Section 5.18).

3.2 Compliance Pathways

ASHRAE 62.1-2022 provides three compliance pathways. The designer must select one pathway for each ventilation zone (different zones in the same building may use different pathways, though this is uncommon in practice):

3.2.1 Ventilation Rate Procedure (VRP) — Section 6.2

The VRP is the **prescriptive** compliance pathway and is by far the most commonly used method. It specifies minimum outdoor air ventilation rates based on:

- The occupancy category of each zone (which determines Rp and Ra values from Table 6.2.2.1).
- The design population of each zone.
- The floor area of each zone.
- The air distribution effectiveness of the supply system configuration.
- The system ventilation efficiency for multi-zone systems.

Advantages of the VRP:

- Straightforward, deterministic calculation.
- Well-understood by plan reviewers and code officials.
- Directly supported by the J∆S Engineering Suite with full automation.
- Provides a clear, auditable compliance path.

Limitations of the VRP:

- Does not account for specific contaminant sources beyond the generic Rp and Ra values.
- May over-ventilate or under-ventilate for unusual occupancies or contaminant sources not covered by Table 6.2.2.1.
- Does not allow credit for air cleaning (except filtration as addressed in Section 6.2.1.2 of the 2022 edition).

The J∆S Engineering Suite provides **full support** for the VRP, including all steps from zone-level breathing zone outdoor airflow through system-level multi-zone calculations.

3.2.2 Indoor Air Quality Procedure (IAQP) — Section 6.3

The IAQP is a **performance-based** compliance pathway. Instead of prescribing outdoor air rates, it requires the designer to:

1. Identify all contaminants of concern for each zone.

2. Determine acceptable concentration limits for each contaminant (using references such as OSHA PELs, EPA guidelines, or ASHRAE-published concentration limits).

3. Perform a mass-balance analysis to determine the outdoor air rate (and/or air cleaning capacity) needed to maintain each contaminant below its acceptable concentration.

4. Document the analysis and maintain ongoing monitoring to verify compliance.

Advantages of the IAQP:

- Can result in lower outdoor air rates when specific contaminant analysis shows that prescriptive rates are unnecessarily high.
- Allows credit for air cleaning technologies (activated carbon, photocatalytic oxidation, bipolar ionization, etc.).
- More flexible for unusual occupancies.

Limitations of the IAQP:

- Requires detailed contaminant source identification and emission rate data, which may not be available.
- More complex to document and defend during plan review.
- Requires ongoing monitoring and maintenance of air cleaning systems.
- Few plan review authorities are comfortable reviewing IAQP-based designs.

The J∆S Engineering Suite provides **partial support** for the IAQP (reporting and contaminant tracking), but the VRP remains the recommended compliance pathway for most projects.

3.2.3 Natural Ventilation Procedure — Section 6.4

The Natural Ventilation Procedure allows compliance through operable windows and other natural ventilation openings, without mechanical ventilation, provided:

- Operable openings are provided with a total free area of at least 4% of the net occupiable floor area.
- The openings are located to provide cross-ventilation (openings on opposite sides of the space) or stack-effect ventilation (openings at different heights).
- No zone is more than 25 feet from an operable opening (measured along the airflow path).
- The space is not required to have mechanical cooling (or if mechanical cooling is provided, the natural ventilation system must be engineered to work independently of the mechanical system).
- The local climate supports natural ventilation for a sufficient portion of the year.

In practice, most commercial buildings in the United States use the VRP with mechanical ventilation. Natural ventilation is more common in mild climates (coastal California, Pacific Northwest) and in buildings pursuing LEED or Living Building Challenge credits for natural ventilation.

The J∆S Engineering Suite does **not** directly calculate natural ventilation airflows (which require computational fluid dynamics or wind tunnel analysis) but does provide guidelines for hybrid systems where natural ventilation supplements mechanical ventilation during favorable weather conditions.

3.3 Key Definitions

The following definitions from ASHRAE 62.1 are essential for understanding the ventilation calculations performed by the J∆S Engineering Suite:

Term	Definition
Breathing zone	The region within an occupied space between 3 and 72 inches above the floor and more than 2 feet from walls or fixed air-conditioning equipment. This is where occupants actually breathe.
Occupiable space	An enclosed space intended for human activities, excluding spaces intended primarily for other purposes such as storage, mechanical equipment, or circulation (corridors).
Outdoor air	Air taken from the outdoors and not previously circulated through the building. Also called "outside air" or "fresh air" (though the latter is discouraged as outdoor air may contain pollutants).
Recirculated air	Air removed from a space and reused as supply air, typically after passing through filters and heating/cooling coils.
Supply air	The total air delivered to a zone by the HVAC system, consisting of a mixture of outdoor air and recirculated air.
Exhaust air	Air removed from a space and discharged to the outdoors. Exhaust air is not recirculated.
Transfer air	Air moved from one indoor space to another indoor space, typically through door undercuts, transfer grilles, or ductwork.

Term	Definition
Return air	Air removed from a space and returned to the air handling unit for reconditioning. Return air may be recirculated, exhausted, or a combination.
Ventilation rate	The rate at which outdoor air is delivered to a space, expressed in CFM (cubic feet per minute) or L/s (liters per second).
Zone	One or more rooms or spaces with similar ventilation requirements served by a common supply air duct terminal (VAV box, diffuser, etc.).
System	The air handling unit (AHU) and its associated ductwork, serving one or more zones.

3.4 Key Changes in the 2022 Edition

The 2022 edition of ASHRAE 62.1 includes several updates from the 2019 edition. The J∆S Engineering Suite implements all of the following changes:

1. **Revised air classification categories (Section 5.16):** Updated criteria for classifying recirculated air into Classes 1 through 4, with clarified requirements for which classes may be recirculated, transferred, or must be exhausted.
2. **Updated Table 6.2.2.1 rates:** Several occupancy categories have adjusted Rp and/or Ra values. Most changes are minor (within 10% of previous values), but designers updating projects from the 2019 edition should verify all rates.
3. **Clarified DCV requirements (Section 6.2.7):** More explicit guidance on CO2-based DCV calculation methods, sensor accuracy requirements, and control sequences.
4. **Filtration coordination with Addendum F:** Minimum filtration requirements for outdoor air intakes are now more explicitly stated, with MERV 8 as the absolute minimum and MERV 13 recommended for most commercial applications.
5. **Pandemic readiness (Informative Appendix):** A new informative appendix discusses design considerations for airborne infectious disease mitigation, including increased ventilation, enhanced filtration, and UVGI as supplemental strategies. While informative (not mandatory), many jurisdictions and owners now require these measures.
6. **Updated occupant density defaults:** Some space types have revised default occupant density values in Table 6.2.2.1, reflecting current usage patterns (e.g., increased density in open-plan offices due to hoteling/hot-desking trends).

3.5 Relationship to Other Standards

ASHRAE 62.1 does not exist in isolation. The J∆S Engineering Suite considers the following related standards:

Standard	Relationship to 62.1
ASHRAE 90.1-2022	Energy standard. Requires DCV for high-density spaces (Section 6.5.3.7), energy recovery for high-OA systems (Section 6.5.6), and economizer operation. Ventilation rates from 62.1 are inputs to the 90.1 energy analysis.
ASHRAE 62.2-2022	Residential ventilation. Applies to dwelling units (apartments, condos, single-family homes). 62.1 applies to common areas of multifamily buildings (lobbies, corridors, fitness rooms).

Standard	Relationship to 62.1
ASHRAE 170-2021	Healthcare ventilation. Supersedes 62.1 for healthcare occupancies (hospitals, clinics, dental offices). Specifies higher ventilation rates, pressure relationships, and air change requirements.
ASHRAE 241-2023	Control of infectious aerosols. References 62.1 ventilation rates as baseline and adds requirements for equivalent clean airflow during pandemic/epidemic conditions.
ASHRAE 55-2023	Thermal comfort. Ventilation air must be conditioned to maintain thermal comfort. Supply air temperatures and velocities from the 62.1 ventilation design must satisfy 55 requirements.
NFPA 90A	Air conditioning and ventilating systems. Fire and smoke damper requirements, duct construction, and smoke control interact with ventilation system design.
IMC / CMC	Mechanical codes. Reference ASHRAE 62.1 for ventilation rates. May have additional or modified requirements.

4. Ventilation Rate Procedure (VRP) Step-by-Step

The Ventilation Rate Procedure is the primary calculation method implemented in the J∆S Engineering Suite. This section walks through every step of the VRP in exhaustive detail, from determining the occupancy category for a single zone through calculating the system-level outdoor air intake for a multi-zone VAV air handling unit.

The VRP consists of seven steps. Steps 1 through 5 are performed for every zone. Step 6 applies to single-zone systems only. Step 7 applies to multi-zone recirculating systems (VAV AHUs).

Step 1: Determine the Occupancy Category

Every ventilated zone must be assigned an occupancy category from ASHRAE 62.1-2022 Table 6.2.2.1. The occupancy category determines two rate values:

- **Rp** — The people outdoor air rate, in CFM per person. This rate addresses bioeffluents (CO_2, body odor, exhaled aerosols) generated by occupants.
- **Ra** — The area outdoor air rate, in CFM per square foot. This rate addresses contaminant emissions from the building itself: off-gassing from flooring, furniture, paint, adhesives, and cleaning products.

The J∆S Engineering Suite provides a dropdown selector for each zone pre-loaded with all occupancy categories from Table 6.2.2.1. When zones are imported from the load calculation module, the occupancy category is auto-mapped from the space type.

4.1.1 Common Occupancy Categories with Rp and Ra Values

The following table lists all commonly encountered occupancy categories. This is the most frequently referenced table in the entire ventilation design process.

Office and Administrative Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Office - Open Plan	5	0.06	5	Cubicle farms, open workstations, coworking areas
Office - Enclosed	5	0.06	5	Private offices, manager offices, single-occupant rooms
Conference / Meeting Room	5	0.06	50	High-density; strong DCV candidate
Break Room / Lounge	5	0.12	25	Higher Ra due to food odors and preparation
Lobby - Office Building	5	0.06	10	Main entry lobbies, atrium spaces
Lobby - Prefunction	5	0.06	30	Event prefunction areas, gathering spaces
Reception Area	5	0.06	30	Waiting areas, front desk zones
Corridor	0	0.06	0	No people component; area-based only
Storage / Warehouse	0	0.06	0	Ventilation for material off-gassing
Copy / Print Room	5	0.06	4	May also require exhaust for ozone

Education Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Classroom (ages 9+)	10	0.12	35	Standard K-12 and higher education
Classroom (ages 5-8)	10	0.12	25	Elementary school, lower density
Classroom (ages <5)	10	0.18	25	Daycare, pre-K; highest Ra in education
Lecture Hall / Auditorium	7.5	0.06	65	Very high density; DCV strongly recommended
Library - Reading Area	5	0.12	10	Quiet study areas, stacks
Library - Media Center	5	0.12	10	Computer labs within libraries
Science Laboratory	10	0.18	25	Supplemental exhaust may be required for fume hoods
Art Classroom	10	0.18	20	Higher Ra for art material emissions

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Music / Theater / Dance	10	0.06	35	Performance and rehearsal spaces
University / College Lab	10	0.18	25	Research and teaching labs

Healthcare Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Healthcare - Exam Room	5	0.06	10	Doctor's offices, outpatient exam
Healthcare - Patient Room	5	0.06	10	Inpatient room (ASHRAE 170 may supersede)
Healthcare - Waiting Room	7.5	0.06	30	Outpatient and emergency waiting
Healthcare - Physical Therapy	5	0.06	7	Rehabilitation spaces
Dental Office	5	0.06	10	Operatory, dental treatment rooms
Pharmacy	5	0.06	10	Retail and compounding areas

***Important:** For acute-care hospitals and certain healthcare occupancies, ASHRAE Standard 170-2021 supersedes ASHRAE 62.1. The J∆S Engineering Suite will flag zones with healthcare occupancy categories and prompt the user to confirm which standard applies.*

Retail and Commercial Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Retail Sales	7.5	0.12	15	Department stores, specialty retail
Mall Common Area	7.5	0.06	40	Shopping mall concourses
Grocery / Supermarket	7.5	0.06	8	Sales floor (bakery/deli may differ)
Barbershop / Beauty Salon	20	0.12	25	High Rp due to chemical vapors
Pet Shop	7.5	0.18	10	High Ra for animal odors
Auto Repair Workshop	7.5	0.18	7	Supplemental exhaust usually required

Food Service Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Restaurant Dining Room	7.5	0.18	70	Very high density + high Ra
Cafeteria / Fast Food Dining	7.5	0.18	100	Highest density food service
Bar / Cocktail Lounge	7.5	0.18	100	High density + food/beverage odors
Kitchen (Cooking)	7.5	0.12	20	Supplemental exhaust hoods required per IMC

Assembly and Recreation Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Auditorium (fixed seating)	5	0.06	150	Very high density; DCV essential
Places of Worship	5	0.06	120	Churches, mosques, synagogues, temples
Courtroom	5	0.06	70	High density, variable occupancy
Gymnasium / Arena (play area)	20	0.06	7	High Rp due to exertion (higher metabolic rate)
Gym / Health Club (exercise)	20	0.06	40	Weight rooms, cardio areas
Spectator Area (sports)	7.5	0.06	150	Bleachers, stadium seating
Swimming Pool (deck)	0	0.48	0	Very high Ra for chloramine control; no Rp
Bowling Alley (seating)	10	0.12	40	Combined recreation and food

Hospitality Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Hotel Bedroom / Living Room	5	0.06	10	Guest room
Hotel Lobby	7.5	0.06	30	Reception and waiting
Hotel Conference / Banquet	5	0.06	50	Similar to conference rooms
Hotel Bathroom	0	0	0	Exhaust-only

Mechanical and Service Spaces:

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)	Notes
Restrooms	0	0	0	Exhaust-only; ventilation per plumbing code
Server / Telecom Room	0	0	0	Cooling-driven; no IAQ OA requirement
Electrical Room	0	0.06	0	Ventilation for heat dissipation
Mechanical Room	0	0.12	0	Combustion air may apply separately
Janitor / Housekeeping Closet	0	0	0	Exhaust-only (chemical storage)
Parking Garage	0	0.12	0	CO-based ventilation; see IMC Section 404

4.1.2 How to Select the Right Occupancy Category

Selecting the correct occupancy category requires judgment. Follow these guidelines:

1. **Match the primary activity.** If a space is used for multiple activities, select the category that matches the primary (predominant) activity. If the space alternates between uses (e.g., a conference room that also serves as a training room), use the category with the higher ventilation requirement.
2. **When in doubt, use the higher rate.** If a space does not clearly fit any category, choose the category with the higher Rp or Ra value. Over-ventilation is preferable to under-ventilation from both a health and a code compliance perspective.
3. **Multi-use spaces.** For spaces with genuinely mixed uses (e.g., an open-plan office with a lounge area), consider splitting the space into separate zones, each with its own occupancy category. The J∆S Engineering Suite supports unlimited zones per project.
4. **Custom categories.** If a space does not fit any standard category (e.g., a medical marijuana grow facility or a 3D printing lab), the J∆S Engineering Suite allows you to enter custom Rp and Ra values. Document the basis for custom values in the project notes.

Step 2: Calculate Zone Population (Pz)

The zone population Pz is the largest number of people expected to occupy the zone during typical use. This is the **design occupancy** for ventilation, not the maximum emergency occupancy used for life safety calculations.

4.2.1 Using Default Occupant Densities

ASHRAE 62.1 Table 6.2.2.1 provides default occupant density values for each category, expressed in people per 1,000 square feet. When the actual anticipated population is unknown (speculative office space, retail shell, etc.), use the default density:

```
Pz = Default Density x Az / 1,000
```

Where:

- Pz = Zone population (people, round up to next whole number)

- Default Density = People per 1,000 SF from Table 6.2.2.1
- Az = Zone floor area (SF)

Example: A 2,000 SF open-plan office with default density of 5 people/1,000 SF:

```
Pz = 5 x 2,000 / 1,000 = 10 people
```

4.2.2 Using Actual Occupancy Counts

When the actual anticipated occupancy is known, use the actual count instead of the default density. This is appropriate for:

- Owner-occupied buildings with known headcounts per room.
- Conference rooms where the owner specifies the maximum seating (e.g., "this conference room is for 12 people").
- Restaurants where the seating layout is defined.

Best practice: If the actual count is lower than the ASHRAE default, use the actual count. If the actual count is higher than the ASHRAE default, use the actual count (you must ventilate for the people who are actually there, even if it exceeds the default density).

4.2.3 Diversified vs. Peak Populations

At the zone level, always use the peak (non-diversified) population Pz. Diversity is applied later at the system level (Step 7) to account for the fact that not all zones are at peak occupancy simultaneously.

Do not apply diversity at the zone level. Each zone must be designed to handle its full peak population independently.

Step 3: Calculate Breathing Zone Outdoor Airflow (Vbz)

The breathing zone outdoor airflow for each zone is the sum of two components:

```
Vbz = Rp x Pz + Ra x Az
```

Where:

- **Vbz** = Breathing zone outdoor airflow (CFM)
- **Rp** = People outdoor air rate (CFM/person) from Table 6.2.2.1
- **Pz** = Zone population (number of people) from Step 2
- **Ra** = Area outdoor air rate (CFM/SF) from Table 6.2.2.1
- **Az** = Zone floor area (SF)

4.3.1 Understanding the Two Components

The Vbz formula has two additive components that address different contaminant sources:

People component (Rp x Pz): This component dilutes bioeffluents generated by occupants. Bioeffluents include CO2 (exhaled at approximately 0.3 L/min per person at typical office activity), body odor (volatile organic compounds from skin and clothing), exhaled moisture, and exhaled bioaerosols (bacteria, viruses). The people component is proportional to the number of occupants and is zero for unoccupied spaces (corridors, storage).

Area component (Ra x Az): This component dilutes contaminant emissions from the building itself. Sources include:

- Formaldehyde and other VOCs from composite wood products (cabinetry, furniture, shelving).
- VOCs from carpet, vinyl flooring, and adhesives.
- VOCs from paint, stain, and finishes.
- Particles from deteriorating building materials.
- Cleaning product residuals.
- Off-gassing from new furniture and equipment.

The area component is always present, even for unoccupied spaces, because building material emissions occur regardless of occupancy. The only exceptions are spaces where both Rp and Ra are zero (restrooms, server rooms), which have no ASHRAE 62.1 outdoor air requirement and are typically ventilated by exhaust only.

4.3.2 Calculation Example

For an open-plan office zone with Az = 3,500 SF and Pz = 18 people:

```
People component = Rp x Pz = 5 x 18 = 90 CFM
Area component = Ra x Az = 0.06 x 3,500 = 210 CFM
Vbz = 90 + 210 = 300 CFM
```

In this example, the area component (210 CFM, 70%) dominates the people component (90 CFM, 30%). This is typical for low-density office zones. The ventilation requirement is driven more by the building size than by the number of occupants.

For a conference room with Az = 600 SF and Pz = 30 people:

```
People component = Rp x Pz = 5 x 30 = 150 CFM
Area component = Ra x Az = 0.06 x 600 = 36 CFM
Vbz = 150 + 36 = 186 CFM
```

In this high-density example, the people component (150 CFM, 81%) dominates the area component (36 CFM, 19%). The ventilation requirement is driven by occupancy, making this zone a strong candidate for demand-controlled ventilation.

Step 4: Determine Zone Air Distribution Effectiveness (Ez)

The zone air distribution effectiveness Ez accounts for how well the supply air delivery system mixes outdoor air within the breathing zone. Not all supply air configurations deliver outdoor air equally effectively to the region where occupants actually breathe (3 to 72 inches above the floor).

ASHRAE 62.1-2022 Table 6.2.2.2 provides Ez values for common supply air configurations:

Supply Air Configuration	Return/Exhaust Location	Ez Value	Description
Ceiling supply, cool air (supply temp below space temp)	Ceiling return	**1.0**	The most common commercial configuration. Cool air descends from ceiling diffusers, sweeps through the breathing zone, and returns to ceiling return grilles. Mixing is adequate.
Ceiling supply, cool air	Floor return	**1.0**	Cool air descends, passes through breathing zone, and exits at floor level. Good mixing.
Ceiling supply, warm air (>15 F above space temp)	Ceiling return	**1.0**	Warm air may stratify above the breathing zone, but ceiling return draws it back. Acceptable mixing.

Supply Air Configuration	Return/Exhaust Location	Ez Value	Description
Ceiling supply, warm air (>15 F above space temp)	Floor return	**0.8**	Warm air rises and stratifies above the breathing zone. Floor return draws air from below. The breathing zone receives less outdoor air. **20% penalty.**
Floor supply, cool air (underfloor air distribution)	Ceiling return	**1.2**	Displacement ventilation effect. Cool air enters at floor level, rises through the breathing zone as it is warmed by occupants and equipment, and exits at ceiling. **20% bonus — lower OA required.**
Floor supply, cool air	Floor return	**1.0**	Supply and return at same level, short-circuiting possible. No bonus.
Floor supply, warm air	Ceiling return	**1.0**	Warm air rises naturally, providing good mixing.
Floor supply, warm air	Floor return	**1.0**	Moderate mixing.
Makeup air drawn in on opposite side from exhaust/return	N/A	**0.8**	Cross-ventilation pattern with makeup air. Air may not fully sweep the breathing zone.
Makeup air drawn in on same side as exhaust/return	N/A	**0.5**	Short-circuiting. Makeup air may exit immediately without reaching the breathing zone. **50% penalty — significantly more OA required.**

4.4.1 Selecting the Correct Ez Value in the J∆S Engineering Suite

The J∆S Engineering Suite provides a dropdown selector for each zone with the following options:

1. **Ceiling Supply / Ceiling Return (Ez = 1.0)** — Default for most commercial spaces.
2. **Ceiling Supply / Floor Return (Ez = 1.0)** — Applies when supply air is at or below space temperature.
3. **Ceiling Warm Air / Floor Return (Ez = 0.8)** — Heating mode with floor return.
4. **Floor Supply (UFAD) / Ceiling Return (Ez = 1.2)** — Underfloor air distribution.
5. **Displacement Ventilation (Ez = 1.2)** — Low-velocity floor or low-wall displacement diffusers.
6. **Makeup Air Cross-Flow (Ez = 0.8)** — Transfer air or natural makeup from opposite wall.
7. **Makeup Air Same-Side (Ez = 0.5)** — Transfer air or natural makeup from same wall as exhaust.

Critical design consideration: In systems that provide both heating and cooling, the Ez value may change between modes. A ceiling supply system that delivers cool air in summer (Ez = 1.0) may deliver warm air in winter. If the return is at the ceiling, Ez remains 1.0 in both modes. If the return is at the floor (unusual but possible), Ez drops to 0.8 during heating. The J∆S Engineering Suite uses the **worst-case (lowest)** Ez value for sizing purposes unless the designer specifies seasonal adjustment with DDC controls.

4.4.2 Design Implications of Ez

The Ez value has a direct, proportional impact on the required outdoor air:

- **Ez = 1.2 (UFAD/displacement):** Reduces required OA by 17% compared to Ez = 1.0. This is a significant advantage for projects where minimizing outdoor air (and its associated energy penalty) is a priority. Displacement ventilation and UFAD systems are increasingly popular in green building design.
- **Ez = 0.8 (warm air/floor return or cross-flow makeup):** Increases required OA by 25% compared to Ez = 1.0. This penalty can significantly impact AHU sizing and energy consumption.
- **Ez = 0.5 (same-side makeup):** Doubles the required OA compared to Ez = 1.0. This configuration should be avoided in design whenever possible. It typically occurs in spaces with transfer air entering through a door undercut on the same wall as the exhaust grille.

Step 5: Calculate Zone Outdoor Airflow (Voz)

The zone outdoor airflow Voz is the minimum outdoor air that must reach the breathing zone, adjusted for distribution effectiveness:

```
Voz = Vbz / Ez
```

Where:

- **Voz** = Zone outdoor airflow (CFM). This is the outdoor air requirement at the zone level.
- **Vbz** = Breathing zone outdoor airflow (CFM) from Step 3.
- **Ez** = Zone air distribution effectiveness from Step 4.

4.5.1 Calculation Examples

Standard ceiling supply/return (Ez = 1.0):

```
Vbz = 300 CFM (from Step 3 example)
Voz = 300 / 1.0 = 300 CFM
```

No adjustment. Voz equals Vbz.

Underfloor air distribution (Ez = 1.2):

```
Vbz = 300 CFM
Voz = 300 / 1.2 = 250 CFM
```

The UFAD system requires 50 CFM less outdoor air than a ceiling supply system for the same zone. Over a large building with many zones, this reduction compounds into significant energy savings.

Warm air ceiling supply with floor return (Ez = 0.8):

```
Vbz = 300 CFM
Voz = 300 / 0.8 = 375 CFM
```

The poor mixing configuration requires 75 CFM more outdoor air. The AHU must deliver a higher OA fraction, increasing heating/cooling energy for conditioning the additional outdoor air.

Step 6: Single-Zone Systems — Vot = Voz

For single-zone systems (one AHU or packaged unit serving one zone), the system outdoor air intake equals the zone outdoor air:

```
Vot = Voz
```

No further calculation is needed. The outdoor air damper on the AHU is set (manually or by DDC control) to deliver Voz at design conditions.

Single-zone systems include:

- Rooftop packaged units (RTUs) serving a single open space.
- Split systems serving a single room.
- Dedicated outdoor air systems (DOAS) serving a single zone.
- Fan coil units with dedicated outdoor air connections (each fan coil is a single-zone system).

For single-zone systems, proceed to Section 5 (DCV) or Section 6 (Exhaust Air) as applicable. The multi-zone calculation in Step 7 does not apply.

Step 7: Multi-Zone Recirculating Systems — System Ventilation Efficiency (Ev)

For multi-zone recirculating systems (VAV air handling units serving multiple zones through a common supply duct), the system outdoor air intake Vot must be calculated using ASHRAE 62.1 Section 6.2.5.

4.7.1 Why Multi-Zone Systems Need a Special Calculation

In a single-zone system, the outdoor air fraction in the supply air can be set independently for the one zone it serves. In a multi-zone system, all zones receive supply air from the same AHU with the same outdoor air fraction. Each zone has a different Voz requirement and a different total supply airflow (Vpz). The zone with the highest ratio of required outdoor air to total supply air (Voz/Vpz) is the "critical zone" and drives the system outdoor air setpoint.

The problem: When the AHU delivers enough OA to satisfy the critical zone, all other zones receive more outdoor air than they need. The system ventilation efficiency Ev quantifies this over-ventilation and ensures the critical zone is not under-ventilated.

4.7.2 Step 7a: Determine Zone Primary Airflow (Vpz)

The zone primary airflow Vpz is the total design supply airflow to each zone. This value comes from the cooling load calculation. In the J∆S Engineering Suite, Vpz is automatically imported from the load calculation results.

Vpz includes both outdoor air and recirculated air. It is the total CFM delivered to the zone by the VAV terminal at design (peak cooling) conditions.

4.7.3 Step 7b: Calculate Zone Primary Outdoor Air Fraction (Zpz)

For each zone, calculate the primary outdoor air fraction:

```
Zpz = Voz / Vpz
```

Where:

- **Zpz** = Zone primary outdoor air fraction (dimensionless, between 0 and 1).
- **Voz** = Zone outdoor airflow (CFM) from Step 5.
- **Vpz** = Zone primary airflow (CFM) at design conditions.

Zpz represents the fraction of supply air that must be outdoor air for this zone. A high Zpz means the zone needs a large proportion of its supply air to be outdoor air (high ventilation need relative to cooling need). A low Zpz means the zone is cooling-dominated and needs relatively little outdoor air.

4.7.4 Step 7c: Identify the Critical Zone

The critical zone is the zone with the highest Zpz value:

```
Zd = MAX(Zpz for all zones served by the AHU)
```

Where Zd is the "design zone" primary outdoor air fraction. This zone drives the system outdoor air setpoint because it requires the highest outdoor air fraction.

4.7.5 Step 7d: Calculate Uncorrected Outdoor Air Intake (Vou)

The uncorrected outdoor air intake sums the people and area components across all zones, with the people component adjusted by a diversity factor:

```
Vou = D x SUM(Rp x Pz) + SUM(Ra x Az)
```

Where:

- **Vou** = Uncorrected outdoor air intake (CFM).
- **D** = Occupant diversity factor (between 0 and 1). D accounts for the fact that not all zones are at peak occupancy simultaneously. ASHRAE 62.1 requires that D be determined based on the expected peak simultaneous occupancy of all zones served by the AHU, divided by the sum of peak zone populations.
- **SUM(Rp x Pz)** = Sum of people components across all zones.
- **SUM(Ra x Az)** = Sum of area components across all zones.

Determining the diversity factor D:

D is calculated as:

```
D = Expected peak simultaneous occupancy / SUM(Pz for all zones)
```

Typical D values:

- **D = 1.0:** All zones at peak simultaneously. Conservative. Use for small systems (fewer than 5 zones) or buildings where all zones are likely fully occupied at the same time (e.g., a school during class hours).
- **D = 0.80-0.90:** Moderate diversity. Typical for office buildings with a mix of private offices, open plan areas, and some conference rooms.
- **D = 0.65-0.80:** High diversity. Typical for large office buildings with many conference rooms, some of which are usually empty.
- **D = 0.50-0.65:** Very high diversity. Hotels, convention centers, and buildings with highly variable occupancy.

The J∆S Engineering Suite calculates D automatically based on a diversity schedule if one is provided, or uses a user-entered D value. The default is D = 1.0 (conservative, no diversity credit).

4.7.6 Step 7e: Calculate System Ventilation Efficiency (Ev)

The system ventilation efficiency can be calculated using two methods: the simplified table method or the detailed Appendix A method.

Simplified Table Method (Table 6.2.5.2):

ASHRAE 62.1 Table 6.2.5.2 provides Ev values based on the maximum zone primary outdoor air fraction Zd:

Zd (Max Zpz) Range	Ev
Zd <= 0.15	1.0
0.15 < Zd <= 0.25	0.9
0.25 < Zd <= 0.35	0.8
0.35 < Zd <= 0.45	0.7
0.45 < Zd <= 0.55	0.6
Zd > 0.55	Use Appendix A method

Detailed Appendix A Method (Iterative):

The Appendix A method calculates Ev more precisely using the following approach:

1. Calculate the system outdoor air fraction at the AHU:

```
Xs = Vou / Vps
```

Where Vps = total system primary airflow = SUM(Vpz for all zones).

2. For each zone, calculate the zone ventilation effectiveness:

```
Evz = 1 + Xs - Zpz
```

3. The system ventilation efficiency is the minimum of all zone ventilation effectiveness values:

```
Ev = MIN(Evz for all zones) = MIN(1 + Xs - Zpz for all zones)
```

Since Zpz is maximized at the critical zone (Zd), this simplifies to:

```
Ev = 1 + Xs - Zd
```

4. However, Ev must be capped at 1.0 (it cannot exceed 100% efficiency):

```
Ev = MIN(1.0, 1 + Xs - Zd)
```

The Appendix A method typically yields a slightly higher (more favorable) Ev than the simplified table, resulting in a lower system OA requirement. The J∆S Engineering Suite implements both methods and defaults to the Appendix A calculation, displaying the Table 6.2.5.2 value for comparison.

4.7.7 Step 7f: Calculate System Outdoor Air Intake (Vot)

The total system outdoor air intake is:

```
Vot = Vou / Ev
```

Where:

- **Vot** = System outdoor air intake at the AHU (CFM). This is the minimum outdoor air that must enter the AHU at design conditions.
- **Vou** = Uncorrected outdoor air intake (CFM) from Step 7d.
- **Ev** = System ventilation efficiency from Step 7e.

4.7.8 Multi-Zone Calculation Summary

The complete multi-zone calculation flow is:

```
For each zone:
1. Assign occupancy category -> Rp, Ra
2. Determine Pz (population)
3. Vbz = Rp x Pz + Ra x Az
4. Select Ez
5. Voz = Vbz / Ez
6. Zpz = Voz / Vpz

For the system:
7. Zd = MAX(Zpz)
8. Vou = D x SUM(Rp x Pz) + SUM(Ra x Az)
9. Xs = Vou / SUM(Vpz)
10. Ev = MIN(1.0, 1 + Xs - Zd)
11. Vot = Vou / Ev
```

The J∆S Engineering Suite performs all 11 calculations automatically and displays the results in the Zone Summary table and System Summary panel.

5. Demand-Controlled Ventilation (DCV)

5.1 What is DCV?

Demand-Controlled Ventilation (DCV) is a ventilation control strategy that modulates the outdoor air ventilation rate in real time based on actual occupancy indicators rather than maintaining a fixed rate based on design (maximum) occupancy. The most common occupancy indicator is indoor carbon dioxide (CO_2) concentration, although occupancy sensors (PIR, ultrasonic, camera-based people counting) can also be used.

DCV reduces energy consumption by avoiding over-ventilation during periods of partial occupancy. A conference room designed for 30 people but typically occupied by 5-10 people does not need the full design outdoor air rate during most operating hours. DCV modulates the outdoor air damper (or VAV box minimum airflow setpoint) to match the actual ventilation need.

5.2 When DCV is Required by Code

Both ASHRAE 62.1-2022 and ASHRAE 90.1-2022 address DCV requirements. The code requirements are additive: if either standard requires DCV for a space, DCV must be provided.

5.2.1 ASHRAE 90.1-2022 Section 6.5.3.7 Requirements

ASHRAE 90.1-2022 requires DCV for spaces that meet **all** of the following criteria simultaneously:

1. The space is served by a mechanical ventilation system with an air-side economizer or with automatic modulating control of outdoor air.

2. The design occupant density is greater than or equal to **25 people per 1,000 SF**.

3. The design outdoor airflow rate for the space is greater than **750 CFM** (some earlier editions used 500 CFM; verify the adopted edition in your jurisdiction).

Spaces typically requiring DCV:

Space Type	Default Density (ppl/1,000 SF)	Density Threshold Met?	Typical Voz for 1,000 SF	Voz Threshold Met?	DCV Required?
Conference Room	50	Yes (>= 25)	310 CFM	No (if zone < ~2,500 SF)	Check both criteria
Lecture Hall	65	Yes	548 CFM	Depends on size	Usually Yes
Auditorium	150	Yes	810 CFM per 1,000 SF	Yes	Yes
Restaurant Dining	70	Yes	705 CFM per 1,000 SF	Depends on size	Usually Yes
Cafeteria	100	Yes	930 CFM per 1,000 SF	Yes	Yes
Gym / Exercise	40	Yes	860 CFM per 1,000 SF	Yes	Yes
Places of Worship	120	Yes	660 CFM per 1,000 SF	Depends on size	Usually Yes
Break Room	25	Borderline (= 25)	245 CFM per 1,000 SF	Often No	Check carefully
Open Office	5	No	55 CFM per 1,000 SF	No	No
Lobby	10	No	110 CFM per 1,000 SF	No	No
Classroom (ages 9+)	35	Yes	470 CFM per 1,000 SF	Depends on size	Check CFM threshold

5.2.2 ASHRAE 62.1-2022 Section 6.2.7 Requirements

ASHRAE 62.1-2022 permits (but does not require) DCV for any zone. When DCV is implemented, the standard specifies how the ventilation rate must be modulated:

- The ventilation rate must never drop below the area-based component (Ra x Az) during occupied hours, regardless of actual occupancy.
- The ventilation rate must be capable of reaching the full design Voz when the space is at design occupancy.
- The DCV system must use an approved sensing method (CO2 sensors meeting specified accuracy requirements, or occupancy counting systems with documented accuracy).

5.2.3 California Title 24 Requirements

California Title 24-2022 (Energy Code) requires DCV for spaces with design occupant density exceeding 25 people per 1,000 SF **and** where the design ventilation rate exceeds 1,500 CFM. This is a more stringent CFM threshold than ASHRAE 90.1, meaning fewer spaces trigger DCV in California. However, Title 24 also has additional DCV requirements for specific system types (e.g., VAV systems with economizers must have CO2-based DCV for zones over 25 ppl/1,000 SF regardless of CFM).

The J∆S Engineering Suite flags zones that trigger DCV requirements under both ASHRAE 90.1 and Title 24, based on the compliance path selected for the project.

5.3 CO2-Based DCV — Theory and Calculation

5.3.1 The CO2-Ventilation Relationship

CO_2 is a reliable proxy for human occupancy because:

- Humans generate CO_2 at a rate proportional to metabolic activity (approximately 0.31 L/min per person at typical office activity, 1.0 met).
- CO_2 is easily measured with commercially available sensors (accuracy +/- 75 ppm for standard NDIR sensors, +/- 50 ppm for premium sensors).
- At steady state, the indoor CO_2 concentration is directly related to the per-person ventilation rate and the CO_2 generation rate.

The steady-state mass balance for CO_2 in a zone is:

```
V_oa x (C_outdoor) + N x G = V_oa x (C_indoor)
```

Rearranging:

```
C_indoor - C_outdoor = N x G / V_oa
```

Where:

- C_indoor = Indoor CO_2 concentration (ppm)
- C_outdoor = Outdoor CO_2 concentration (ppm), typically 400-420 ppm
- N = Number of occupants
- G = CO_2 generation rate per person (CFM of CO_2)
- V_oa = Outdoor air ventilation rate (CFM)

5.3.2 CO2 Generation Rates by Activity Level

The CO_2 generation rate depends on metabolic activity level (met rate):

Activity Level	Met Rate	CO2 Generation (CFM CO2/person)	Typical Spaces
Seated, quiet	1.0 met	0.0084	Office, lecture hall, theater
Standing, light work	1.2 met	0.0101	Retail, reception
Light office work	1.1 met	0.0092	Typing, filing, desk work
Walking (2 mph)	2.0 met	0.0168	Corridors, lobbies
Moderate exercise	3.0 met	0.0252	Gym (light exercise)
Heavy exercise	6.0 met	0.0504	Gym (vigorous exercise)
Teaching	1.3 met	0.0109	Classroom (instructor)
Cooking	1.8 met	0.0151	Kitchen, break room

5.3.3 CO2 Setpoint Calculation

The target indoor CO2 concentration for a DCV zone is calculated from the mass balance equation. For an office space (1.0 met, Rp = 5 CFM/person):

```
Delta_CO2 = G / (Rp x K)
```

Where K is a unit conversion factor. Using the more intuitive form:

```
Delta_CO2 (ppm) = G (CFM CO2/person) x 10^6 / Rp (CFM OA/person)
```

For office activity:

```
Delta_CO2 = 0.0084 x 1,000,000 / 5 = 1,680 / 5 = ~700 ppm
```

Therefore:

```
CO2 setpoint = Outdoor CO2 + Delta_CO2 = 420 + 700 = ~1,120 ppm
```

This is the theoretical steady-state CO2 concentration when the ventilation rate exactly equals the ASHRAE 62.1 minimum (Rp = 5 CFM/person).

In practice, the J∆S Engineering Suite defaults to a CO2 setpoint of **1,000 ppm**, which provides a safety margin below the theoretical steady-state value and accounts for:

- Sensor accuracy tolerances (+/- 75 ppm).
- Control loop response time (CO2 may overshoot during rapid occupancy changes).
- Owner/occupant expectations (many building operators consider 1,000 ppm the maximum acceptable level).

The setpoint is configurable in the J∆S Engineering Suite. Common settings:

CO2 Setpoint	Implication
800 ppm	Premium IAQ. Higher energy cost but superior occupant satisfaction.
1,000 ppm	Standard. Good balance of IAQ and energy. J∆S default.
1,100 ppm	Code-minimum ventilation at steady state for office activity.
1,200 ppm	Below-minimum ventilation. Not recommended; may not comply with 62.1.

5.3.4 CO2 Sensor Placement Requirements

Proper CO2 sensor placement is critical for accurate DCV operation:

1. Height: Install sensors at breathing zone height (3 to 6 feet above floor). Wall-mounted sensors at 4 feet are most common.

2. Location: Mount on an interior wall, away from:

- Supply air diffusers (direct OA flow would read artificially low).
- Return air grilles (may read a mixed-zone average rather than the breathing zone concentration).
- Doors and windows (infiltration would dilute readings).
- Occupant breathing zones less than 3 feet away (localized exhaled CO2 would read artificially high).

3. Quantity: One sensor per DCV zone is the minimum. For large zones (> 5,000 SF), consider multiple sensors with averaging or worst-case logic.

4. Calibration: NDIR CO_2 sensors should be calibrated annually or use auto-calibrating (ABC logic) sensors that self-calibrate to outdoor baseline (~420 ppm) during unoccupied periods.

5. Outdoor reference: An outdoor CO_2 sensor is recommended (but not always required) to measure the actual outdoor baseline. Without an outdoor sensor, the system assumes a fixed outdoor concentration (420 ppm default in the J∆S Engineering Suite).

5.3.5 DCV Control Sequence

The J∆S Engineering Suite generates the following BACnet-compatible DCV control sequence:

Zone-Level DCV (for VAV systems):

1. Occupied mode, CO_2 below deadband (e.g., $CO_2 < 600$ ppm):

• VAV box minimum airflow setpoint = Area component only = Ra x Az.

• The OA delivered to the zone is minimized (building material ventilation only).

2. Occupied mode, CO_2 in proportional band (e.g., 600 ppm $< CO_2 <$ 1,000 ppm):

• VAV box minimum airflow setpoint = Ra x Az + proportional people component.

• The people component ramps linearly from 0 to (Rp x Pz) as CO_2 rises from the lower deadband to the setpoint.

• Example: At CO_2 = 800 ppm (50% through the band), the people component is 50% of design.

3. Occupied mode, CO_2 at or above setpoint (e.g., CO_2 >= 1,000 ppm):

• VAV box minimum airflow setpoint = Full design Voz = (Rp x Pz + Ra x Az) / Ez.

• The zone receives full design ventilation.

4. Unoccupied mode:

• VAV box closes to minimum (or zero if night setback is active).

• No ventilation requirement during unoccupied hours per ASHRAE 62.1 Section 6.2.6.

System-Level DCV (for single-zone systems):

1. The OA damper modulates directly based on the zone CO_2 reading.

2. Minimum OA damper position corresponds to Ra x Az.

3. Maximum OA damper position corresponds to design Voz (or economizer full-open if economizer mode is active).

4. Proportional or PI control adjusts the damper position based on CO_2 error (setpoint minus actual).

5.3.6 BACnet Points for DCV

The J∆S Engineering Suite generates a BACnet point list for each DCV zone:

Point Name	Type	Units	Description
ZN-xxx-CO2	AI (Analog Input)	ppm	Zone CO2 sensor reading
ZN-xxx-CO2-SP	AV (Analog Value)	ppm	Zone CO2 setpoint (configurable)
ZN-xxx-CO2-DB	AV (Analog Value)	ppm	CO2 deadband (configurable, default 200 ppm)
ZN-xxx-DCV-EN	BV (Binary Value)	On/Off	DCV enable/disable

Point Name	Type	Units	Description
ZN-xxx-MIN-CFM	AV (Analog Value)	CFM	DCV minimum airflow (Ra x Az)
ZN-xxx-DES-CFM	AV (Analog Value)	CFM	DCV design airflow (Voz)
ZN-xxx-ACT-CFM	AI (Analog Input)	CFM	Actual zone airflow (from VAV box)
OA-CO2	AI (Analog Input)	ppm	Outdoor CO2 sensor (if provided)

5.4 Occupancy-Sensor-Based DCV

As an alternative or supplement to CO2-based DCV, occupancy sensors can be used:

- **Binary occupancy sensors (PIR, ultrasonic):** Detect presence/absence. When the zone is unoccupied, ventilation can be reduced to the area component (Ra x Az). When occupied, full design Voz is provided. This is a simple two-state control.
- **People counting sensors (camera-based, thermal, beam-break):** Count the actual number of occupants. The ventilation rate is calculated in real time as Vbz = Rp x (actual count) + Ra x Az. This provides proportional control similar to CO2-based DCV without the response time lag.

Advantages of occupancy sensors over CO2:

- Faster response time (CO2 takes 15-30 minutes to reach steady state after occupancy changes).
- No sensor calibration drift issues.
- Works in spaces with very low per-person ventilation rates where CO2 differential is small.

Disadvantages:

- Binary sensors cannot distinguish between 1 person and 30 people.
- People counting sensors are more expensive and may raise privacy concerns.
- CO2 sensors also detect non-human CO2 sources (combustion, fermentation) that occupancy sensors miss.

5.5 DCV Energy Savings Estimates

The energy savings from DCV depend on climate, occupancy patterns, and space type:

Space Type	Average Occupancy (% of Design)	Estimated OA Reduction with DCV	Annual HVAC Energy Savings
Conference Room	30-40%	50-60%	40-55% of OA conditioning load
Lecture Hall	50-70%	25-40%	20-35% of OA conditioning load
Restaurant Dining	40-60%	30-45%	25-40% of OA conditioning load
Gym / Exercise	30-50%	40-55%	35-50% of OA conditioning load
Auditorium	20-40%	55-70%	50-65% of OA conditioning load
Open Office	70-90%	10-25%	8-20% of OA conditioning load

The J∆S Engineering Suite 8760-hour energy simulation module can model DCV savings for specific projects by applying hourly occupancy schedules to the ventilation calculation.

6. Exhaust Air Requirements

6.1 Overview

Exhaust ventilation removes contaminated air directly from a space and discharges it to the outdoors. Unlike supply ventilation (which dilutes contaminants by introducing outdoor air), exhaust ventilation removes contaminants at the source before they can disperse into adjacent spaces.

ASHRAE 62.1 Table 6.5 and the International Mechanical Code (IMC) Table 403.3.2 specify minimum exhaust rates for spaces that generate contaminants requiring direct removal. The J∆S Engineering Suite calculates exhaust requirements for all applicable zones and ensures that the HVAC system provides adequate makeup air to replace exhausted air.

6.2 Restroom Exhaust (Table 6.5 / IMC Table 403.3.2)

Restrooms are classified as exhaust-only spaces with no outdoor air supply requirement under ASHRAE 62.1. All ventilation is provided by exhaust fans, with makeup air entering through door undercuts, transfer grilles, or ceiling transfer ducts from adjacent spaces.

Exhaust rates per fixture:

Fixture Type	Exhaust Rate	Code Reference	Notes
Water Closet (WC / Toilet)	50 CFM each	ASHRAE 62.1 Table 6.5	Per enclosed stall or compartment
Urinal	25 CFM each	ASHRAE 62.1 Table 6.5	Per urinal fixture

> ***Note on code variations:*** *Some jurisdictions and older code editions use different rates. The IMC and CPC historically used 75 CFM/WC and 50 CFM/urinal. ASHRAE 62.1-2022 uses the lower rates shown above. The J∆S Engineering Suite uses ASHRAE 62.1 rates by default but allows override for jurisdictions with different requirements. Always verify the rates required by your local Authority Having Jurisdiction (AHJ).*

Restroom exhaust calculation example:

Women's restroom with 4 water closets and 1 lavatory alcove:

```
Exhaust = 4 WC x 50 CFM/WC = 200 CFM
```

Men's restroom with 2 water closets, 3 urinals, and 1 lavatory alcove:

```
Exhaust = (2 WC x 50 CFM/WC) + (3 urinals x 25 CFM/urinal)
Exhaust = 100 + 75 = 175 CFM
```

Restroom exhaust design considerations:

- Exhaust grilles should be located near the ceiling (contaminated air is warm and rises) or near the floor (to capture heavier-than-air cleaning chemical vapors). Ceiling-mounted exhaust is most common.

• Door undercuts should provide at least 1 inch of clear opening for transfer air. For high-exhaust-rate restrooms, transfer grilles or ducted transfer air may be needed.

• Restroom exhaust must discharge to the outdoors. Recirculation of restroom air is prohibited.

• The restroom must be maintained at negative pressure relative to adjacent corridors and offices. The J∆S Engineering Suite verifies this by comparing exhaust air to transfer air/supply air.

6.3 Janitor and Housekeeping Closets

Janitor closets store cleaning chemicals that emit volatile organic compounds. ASHRAE 62.1 Table 6.5 requires:

Space	Minimum Exhaust Rate	Notes
Janitor Closet / Housekeeping Room	1 CFM/SF (minimum 25 CFM)	Continuous during occupied building hours

Example: A 100 SF janitor closet:

```
Exhaust = MAX(1.0 x 100, 25) = 100 CFM
```

A 15 SF supply closet:

```
Exhaust = MAX(1.0 x 15, 25) = 25 CFM (minimum governs)
```

6.4 Copy and Print Rooms

Copy rooms and print rooms contain equipment (laser printers, copiers, plotters) that emit ozone and toner particles. ASHRAE 62.1 Table 6.5 specifies:

Space	Minimum Exhaust Rate	Notes
Copy / Print Room	0.5 CFM/SF	May be combined with general return if space is open to office

Example: A 200 SF dedicated copy room:

```
Exhaust = 0.5 x 200 = 100 CFM
```

If the copy area is an alcove open to the general office (not enclosed), separate exhaust may not be required, but the J∆S Engineering Suite still recommends localized return air pickup near the equipment.

6.5 Kitchen and Food Preparation Areas

Commercial kitchen exhaust is governed by the International Mechanical Code (IMC) Section 507 and NFPA 96. ASHRAE 62.1 classifies kitchen air as Class 4 (highly objectionable fumes or gases) which must be exhausted directly and cannot be recirculated.

Space	Exhaust Requirement	Code Reference
Commercial Kitchen (with cooking hoods)	Per hood manufacturer and IMC 507	Typically 150-450 CFM per linear foot of hood
Residential-style Kitchen (break room)	0.7 CFM/SF or 2 ACH minimum	IMC Table 403.3.2
Dishwashing Room	30 CFM per linear foot of dishwasher	IMC Table 403.3.2

Commercial kitchen exhaust rates are specific to the hood type (Type I for grease-laden vapors, Type II for steam/heat), cooking equipment under the hood, and hood geometry. The J∆S Engineering Suite kitchen exhaust module handles these calculations separately and passes the exhaust rate to the ventilation module for makeup air calculations.

6.6 Parking Garages

Enclosed parking garages require ventilation to control carbon monoxide (CO) and nitrogen dioxide (NO2) from vehicle exhaust. ASHRAE 62.1 classifies parking garage air as Class 3 or Class 4.

Space	Exhaust Rate	Control Method
Parking Garage (continuous ventilation)	0.75 CFM/SF	Fixed rate
Parking Garage (CO-based DCV)	Variable, minimum 0.15 CFM/SF	CO sensors; increase to 0.75 CFM/SF when CO > 35 ppm

Example: A 50,000 SF underground parking garage:

```
Continuous exhaust = 0.75 x 50,000 = 37,500 CFM
DCV minimum = 0.15 x 50,000 = 7,500 CFM
DCV maximum = 0.75 x 50,000 = 37,500 CFM
```

CO-based DCV in parking garages offers substantial energy savings (80-90% fan energy reduction during low-traffic hours) and is strongly recommended by ASHRAE 90.1.

6.7 Laboratory Spaces

Laboratory exhaust is driven by fume hood requirements, chemical storage ventilation, and general lab air change rates. ASHRAE 62.1 defers to ANSI/AIHA Z9.5 and NFPA 45 for laboratory exhaust requirements.

Space	Typical Exhaust Rate	Standard
General Chemistry Lab	6-10 ACH	ANSI/AIHA Z9.5
Fume Hood (4-foot)	500-800 CFM per hood	ANSI/AIHA Z9.5
Fume Hood (6-foot)	750-1,200 CFM per hood	ANSI/AIHA Z9.5
Biological Safety Cabinet	200-500 CFM per cabinet	NSF 49
Radioisotope Lab	6-12 ACH	NRC guidelines

The J∆S Engineering Suite laboratory module calculates exhaust rates based on hood counts, types, face velocities, and room air change requirements, then passes the total exhaust to the ventilation module.

6.8 Other Exhaust Requirements (ASHRAE 62.1 Table 6.5)

Space	Minimum Exhaust Rate	Air Class	Notes
Locker Room / Shower	0.5 CFM/SF	Class 2	Moisture and odor control
Laundry Room	0.5 CFM/SF	Class 2	Lint, moisture, chemical vapors
Trash Room / Compactor	1.0 CFM/SF	Class 3	Decomposition odors

Space	Minimum Exhaust Rate	Air Class	Notes
Soiled Linen Room	1.0 CFM/SF	Class 3	Healthcare facilities
Paint Spray Booth	Per NFPA 33	Class 4	Dedicated exhaust system required
Welding Shop	1.0 CFM/SF minimum	Class 3	Local exhaust at welding stations
Nail Salon	0.6 CFM/SF	Class 2	Chemical vapors from nail products
Photo Processing (darkroom)	1.0 CFM/SF	Class 2	Chemical vapors
Swimming Pool (natatorium)	Per ASHRAE guidelines	Class 2	Chloramine control; dehumidification

6.9 Exhaust Air Classification Summary

ASHRAE 62.1 Section 5.16 classifies exhaust air into four classes that determine how the air may be handled:

Class	Description	Recirculation	Transfer	Examples
Class 1	Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor	Yes	Yes, to any space	Office, corridor, lobby, hotel room
Class 2	Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors	No	Limited (to Class 2 or 3 spaces only)	Restroom, break room, locker room, copy room
Class 3	Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odors	No	No	Lab, trash room, janitor closet, soiled linen
Class 4	Air with highly objectionable fumes or gases, or potentially dangerous particles, bioaerosols, or gases	No	No	Kitchen hood, paint booth, welding, autopsy

Key rule: Class 1 air can be recirculated or transferred to any space. Class 2-4 air must be exhausted to the outdoors and cannot be recirculated. Energy recovery from Class 2-4 exhaust is permitted (see Section 9) as long as the exhaust stream does not contaminate the supply air stream.

7. Transfer Air

7.1 What is Transfer Air?

Transfer air is air that moves from one indoor space to another, driven by pressure differentials created by the supply and exhaust system design. Transfer air is not outdoor air and is not recirculated air; it is air that has already been supplied to one zone and then flows to an adjacent zone before returning to the AHU or being exhausted.

Common transfer air paths:

- **Office to restroom:** The office is positively pressurized (more supply than return), and the restroom is negatively pressurized (exhaust only, no supply). Air transfers through the door undercut or transfer grille.
- **Office to corridor:** The office supply air exits through the door into the corridor, which has no dedicated supply. The corridor return grille collects the transfer air.
- **Pressurized zone to exhaust zone:** Any positively pressurized zone adjacent to a negatively pressurized zone will experience transfer air flow.

7.2 Transfer Air and Ventilation Credit

ASHRAE 62.1 allows a zone to count transfer air toward its outdoor air requirement under specific conditions:

1. **The source zone air must be Class 1.** Transfer air from a Class 2 or higher space (restroom, lab, kitchen) cannot be counted as ventilation for the receiving zone.
2. **The source zone must be adequately ventilated.** The source zone must have enough outdoor air to supply its own requirement plus the transfer air it provides to adjacent zones.
3. **The transfer air path must be reliable.** Door undercuts, transfer grilles, or transfer ducts must be properly sized to deliver the required airflow. Door undercuts are the least reliable (they depend on the door being closed) and should be verified with pressure drop calculations.

7.3 Transfer Air Calculation

The transfer airflow through a door undercut or grille is calculated using:

```
Q_transfer = Cd x A x SQRT(2 x rho x Delta_P) x 60 / rho
```

Or more practically, using the simplified formula:

```
Q_transfer (CFM) = 2,610 x A x SQRT(Delta_P)
```

Where:

- A = Free area of the opening (SF). A standard 36-inch-wide door with a 3/4-inch undercut has a free area of approximately 0.19 SF.
- Delta_P = Pressure differential across the opening (inches w.g.). Typical design differential for restroom transfer is 0.02-0.05 inches w.g.

Example: Transfer air through a 36-inch door with 3/4-inch undercut, 0.03 inches w.g. differential:

```
A = (36/12) x (0.75/12) = 3.0 x 0.0625 = 0.1875 SF
Q_transfer = 2,610 x 0.1875 x SQRT(0.03) = 2,610 x 0.1875 x 0.173 = 84.7 CFM
```

If the restroom exhaust requires 200 CFM, a single door undercut at 85 CFM is insufficient. Options include:

- Installing a transfer grille in the wall or door (larger free area).
- Installing a ducted transfer from the corridor to the restroom (above-ceiling duct with ceiling grille in restroom).
- Providing direct supply air to the restroom (less common, but allows precise control).

7.4 Transfer Air in the J∆S Engineering Suite

The J∆S Engineering Suite tracks transfer air in the system-level calculation:

1. For each exhaust-only zone (restroom, janitor closet, etc.), the module identifies adjacent supply zones that can provide transfer air.

2. The transfer air quantity is calculated based on the exhaust rate and the transfer path geometry.

3. The source zone's supply air is increased to account for the transfer air it must provide.

4. The system-level OA calculation (Section 4, Step 7) accounts for transfer air when calculating the total system outdoor air intake.

Users can view and modify transfer air assignments in the **Transfer Air** tab of the Ventilation Design module.

8. Makeup Air

8.1 What is Makeup Air?

Makeup air is outdoor air (or conditioned supply air) introduced into a building to replace air that has been exhausted. Without adequate makeup air, exhaust systems create negative building pressure, which causes:

- **Infiltration through the building envelope:** Uncontrolled outdoor air enters through cracks, gaps, door openings, and other envelope penetrations. This air is unfiltered, unconditioned, and uncontrolled — defeating the purpose of the HVAC system.
- **Exhaust fan performance degradation:** As building pressure becomes more negative, exhaust fan airflow decreases because the fan must work against a higher static pressure differential. The exhaust rate may drop below the design value.
- **Door operation problems:** Interior doors may be difficult to open (or slam shut) due to pressure differentials. Exterior doors may be difficult to open against wind pressure or may blow open.
- **Combustion appliance backdrafting:** Negative building pressure can cause flue gases from gas-fired water heaters, boilers, and furnaces to be drawn back into the building instead of exhausting through the flue. This is a life safety hazard (carbon monoxide poisoning).
- **Moisture problems:** In humid climates, negative building pressure draws hot, humid outdoor air through the envelope, causing condensation inside wall cavities and on cold surfaces.

8.2 Makeup Air Quantity

The total makeup air required for a building equals the total exhaust air minus the total return air that is exhausted at the AHU (relief air):

```
Makeup Air = Total Exhaust - AHU Relief Air
```

In most commercial buildings, the AHU handles both the supply and the return/exhaust. The outdoor air intake at the AHU provides the makeup air. The basic air balance equation is:

```
Supply Air = Return Air + Outdoor Air (at the AHU)
Exhaust Air (local) = Supply Air - Return Air (to AHU)
Therefore: Outdoor Air (at AHU) >= Local Exhaust Air (total)
```

The system outdoor air intake (Vot) calculated per Section 4 already includes enough outdoor air to replace the exhaust air, provided the system is properly balanced.

8.3 Building Pressurization

The building should be maintained at a slight positive pressure relative to the outdoors to prevent uncontrolled infiltration. The recommended building pressure differential is:

Building Type	Recommended Positive Pressure	Notes
Standard commercial office	0.05 to 0.10 inches w.g.	Prevents infiltration
Hospital / healthcare	0.03 to 0.05 inches w.g.	Specific pressure relationships between zones per ASHRAE 170
Cleanroom	0.03 to 0.05 inches w.g. (cascade)	Each cleanliness level pressurized relative to the next
Laboratory	Negative relative to corridors	Laboratories are kept negative; corridors positive
Data center	0.01 to 0.03 inches w.g.	Positive to prevent dust infiltration

The J∆S Engineering Suite calculates building pressurization by comparing total supply air to total return plus exhaust air. The difference (supply minus return minus exhaust) represents the air that exfiltrates through the envelope, creating positive pressure. This exfiltration quantity is controlled by the OA/RA damper settings.

8.4 Makeup Air Units (MAUs)

For buildings with large exhaust systems (commercial kitchens, laboratories, industrial facilities), the exhaust air volume may exceed the outdoor air capacity of the main AHU(s). In these cases, a dedicated Makeup Air Unit (MAU) is required.

MAU design considerations:

• **Heating:** The MAU must temper the outdoor air to at least 55-65 F before delivering it to the building, to avoid occupant discomfort and condensation. Gas-fired MAUs, hot water coils, and electric heaters are common.

• **Cooling:** In hot climates, the MAU should also cool the outdoor air. DX cooling or chilled water coils are used.

• **Filtration:** The MAU should include at least MERV 8 filtration (MERV 13 recommended) to protect indoor air quality.

• **Humidity control:** In humid climates, the MAU should dehumidify the outdoor air to prevent moisture problems.

• **Delivery:** Makeup air can be delivered directly to the exhaust zone (e.g., a kitchen MAU supplying air directly to the kitchen), to the building plenum, or to the general supply ductwork. Direct delivery is preferred for large exhaust volumes to avoid overloading the main AHU.

8.5 Makeup Air in the J∆S Engineering Suite

The J∆S Engineering Suite calculates makeup air requirements as follows:

1. **Sum all local exhaust** (restrooms, kitchens, labs, janitor closets, etc.) for the entire building.

2. **Sum all AHU outdoor air intakes** (Vot for each AHU).

3. Compare: If total AHU OA >= total local exhaust, the building is positively pressurized (assuming return air is balanced). No additional makeup air unit is needed.

4. If total AHU OA < total local exhaust, the deficit must be provided by a dedicated MAU or by increasing the OA capacity of the existing AHUs.

5. Building pressure check: The module verifies that total supply > total return + total exhaust by a margin sufficient to maintain 0.05-0.10 inches w.g. positive pressure.

The makeup air calculation is displayed in the **Building Air Balance** tab of the Ventilation Design module, showing:

- Total supply air (all AHUs combined)
- Total return air (all AHUs combined)
- Total local exhaust (all exhaust fans combined)
- AHU outdoor air intake (all AHUs combined)
- AHU relief/exhaust air (AHU-level exhaust)
- Net building pressurization airflow (CFM)
- Estimated building pressure (inches w.g., based on envelope leakage area)

9. Energy Recovery

9.1 Overview

Energy recovery ventilation (ERV) or heat recovery ventilation (HRV) captures energy from the exhaust air stream and transfers it to the incoming outdoor air stream. This pre-conditions the outdoor air, reducing the heating and cooling load on the HVAC system. In climates with extreme temperatures or high humidity, energy recovery can reduce the outdoor air conditioning penalty by 50-80%.

Energy recovery is particularly important in ventilation design because ASHRAE 62.1 mandates minimum outdoor air rates that cannot be reduced (absent DCV). The outdoor air must be conditioned to supply air temperature, representing a significant energy cost. Energy recovery mitigates this cost without reducing ventilation.

9.2 When Energy Recovery is Required

ASHRAE 90.1-2022 Section 6.5.6 requires exhaust air energy recovery for systems meeting specific thresholds. The requirements depend on the climate zone, the percentage of outdoor air at design conditions, and the design supply airflow:

9.2.1 ASHRAE 90.1-2022 Section 6.5.6.1 Thresholds

Energy recovery is required when the system has a design outdoor air intake rate exceeding the values in Table 6.5.6.1. The thresholds vary by climate zone:

Climate Zone	OA CFM Threshold (% OA >= 30%)	OA CFM Threshold (% OA >= 40%)	OA CFM Threshold (% OA >= 50%)	OA CFM Threshold (% OA >= 60%)	OA CFM Threshold (% OA >= 70%)	OA CFM Threshold (% OA >= 80%)
3B, 3C, 4B, 4C, 5B	>= 5,500	>= 5,500	>= 5,500	>= 5,500	>= 5,500	>= 5,500
1B, 2B, 5C	>= 2,500	>= 2,500	>= 2,500	>= 2,500	>= 2,500	>= 2,500
1A, 2A, 3A, 4A, 5A, 6A, 6B, 7, 8	>= 1,500	>= 1,000	>= 500	>= 500	>= 500	>= 500

Simplified rule of thumb: *In cold or humid climates (Climate Zones 4A-8), energy recovery is effectively required for any system with more than 1,500 CFM of outdoor air. In mild climates (Climate Zones 3B, 3C, 4B, 4C, 5B), the threshold is 5,500 CFM.*

9.2.2 Minimum Recovery Effectiveness

When energy recovery is required, ASHRAE 90.1-2022 specifies minimum recovery effectiveness:

Climate Zone	Minimum Enthalpy Recovery Ratio	Minimum Sensible Recovery Ratio
1A, 2A, 3A, 4A (humid)	50% enthalpy recovery	N/A (enthalpy governs)
5A, 6A, 7, 8 (cold)	N/A (sensible governs)	50% sensible recovery
All others	50% (either enthalpy or sensible, as appropriate)	50% (either)

9.2.3 California Title 24 Requirements

California Title 24-2022 has its own energy recovery requirements that differ from ASHRAE 90.1. In general, Title 24 requires energy recovery for systems with outdoor air rates exceeding 30% of total supply air and 1,500 CFM of outdoor air in Climate Zones 1-16 (California-specific zones). The J∆S Engineering Suite automatically applies the correct energy recovery requirements based on the selected compliance path (ASHRAE 90.1 or Title 24).

9.3 Energy Recovery Device Types

The J∆S Engineering Suite supports the following energy recovery technologies:

9.3.1 Enthalpy Wheel (Total Energy Wheel)

Description: A rotating wheel with a desiccant-coated heat transfer matrix. The wheel slowly rotates between the exhaust and supply air streams, transferring both sensible heat (temperature) and latent heat (moisture). The desiccant absorbs moisture from the humid air stream and releases it into the dry air stream.

Performance:

- Sensible effectiveness: 70-85%
- Latent effectiveness: 60-80%
- Total (enthalpy) effectiveness: 65-82%
- Pressure drop: 0.5-1.5 inches w.g. per air stream

Advantages:

- Highest total energy recovery of any device type.
- Transfers both sensible and latent energy (ideal for humid climates).
- Compact footprint relative to capacity.

Disadvantages:

- Small amount of cross-contamination between exhaust and supply air (1-5% carryover). Not suitable for Class 3 or Class 4 exhaust without purge section.
- Moving parts (wheel motor, bearings) require maintenance.
- Desiccant may degrade over time, reducing latent effectiveness.

J∆S Engineering Suite modeling: The module models enthalpy wheel performance using manufacturer-published effectiveness data at design conditions, with corrections for face velocity, wheel speed, and entering air conditions.

9.3.2 Flat Plate Heat Exchanger (Plate HX)

Description: A fixed, non-moving device consisting of multiple parallel plates that separate the exhaust and supply air streams. Heat transfers through the plates from the warm stream to the cold stream. Standard plate HX transfers sensible heat only. Membrane plate HX can also transfer moisture (latent heat).

Performance:

- Sensible effectiveness: 55-80%
- Latent effectiveness: 0% (standard plates), 40-65% (membrane plates)
- Pressure drop: 0.5-2.0 inches w.g. per air stream

Advantages:

- No moving parts (except bypass dampers).
- No cross-contamination between air streams (supply and exhaust are completely separated by the plates).
- Suitable for all exhaust air classes including Class 3 and Class 4.
- Low maintenance.

Disadvantages:

- Standard plates recover only sensible heat (no moisture transfer). Membrane plates recover both but are more expensive.
- Larger footprint than enthalpy wheels for the same capacity.
- Condensate drain required in cold climates (condensation on cold-side plates).

9.3.3 Heat Pipe

Description: Sealed tubes containing a refrigerant that evaporates on the warm side and condenses on the cold side, transferring heat through phase change. The tubes are arranged in rows, with the supply and exhaust air streams flowing across opposite ends of the tubes.

Performance:

- Sensible effectiveness: 45-65%
- Latent effectiveness: 0% (sensible only)

- Pressure drop: 0.3-0.8 inches w.g. per air stream

Advantages:

- No moving parts at all.
- No cross-contamination.
- Very low maintenance.
- Can be tilted to control capacity (gravity-assisted operation).

Disadvantages:

- Sensible heat only (no moisture transfer).
- Lower effectiveness than enthalpy wheels or plate HX.
- Higher cost per unit of capacity.
- Refrigerant charge must be precisely matched to operating conditions.

9.3.4 Runaround Loop (Glycol Loop)

Description: Two finned-tube coils (one in the exhaust stream, one in the supply stream) connected by a piping loop circulating a glycol-water solution. A pump circulates the glycol between the two coils, transferring heat from the warm stream to the cold stream.

Performance:

- Sensible effectiveness: 40-60%
- Latent effectiveness: 0% (sensible only)
- Pressure drop: 0.5-1.5 inches w.g. per air stream (coil pressure drop)

Advantages:

- Supply and exhaust air streams do not need to be adjacent. The coils can be located anywhere in the building, connected by piping. Ideal for retrofit applications where supply and exhaust ducts are remote from each other.
- No cross-contamination (completely separate air streams).
- Suitable for all exhaust air classes.

Disadvantages:

- Lowest effectiveness of all device types.
- Pump energy consumption offsets some of the energy savings.
- Glycol requires freeze protection and periodic concentration testing.
- Two coils, piping, pump, expansion tank, and controls add significant cost and complexity.

9.4 Frost Control

In cold climates (outdoor design temperature below approximately 20 F), moisture in the exhaust air stream can condense and freeze on the cold surfaces of the energy recovery device. Frost buildup reduces airflow, increases pressure drop, and can damage the device.

Frost control strategies:

• **Exhaust preheat:** A small preheat coil in the exhaust air stream raises the exhaust air temperature just enough to prevent freezing on the energy recovery device. This reduces net energy recovery but prevents frost.

• **Face and bypass:** A bypass damper diverts a portion of the outdoor air around the energy recovery device, mixing warm bypass air with cold air leaving the device. The mixed temperature stays above freezing.

• **Defrost cycle:** Periodically, the supply air is bypassed and warm exhaust air melts any accumulated frost. The device then returns to normal operation. Typical defrost cycles are 5-10 minutes per hour during extreme cold.

• **Wheel speed modulation (enthalpy wheels):** Reducing the wheel speed reduces the heat transfer rate, raising the exhaust-side surface temperature above freezing.

The J∆S Engineering Suite automatically checks for frost conditions based on the project location's winter design temperature and recommends the appropriate frost control strategy.

9.5 Energy Recovery in the J∆S Engineering Suite

The J∆S Engineering Suite energy recovery module:

1. **Determines if energy recovery is required** per ASHRAE 90.1 or Title 24 based on the system OA rate, OA percentage, and climate zone.
2. **Selects the appropriate device type** based on exhaust air class, climate (sensible vs. latent recovery needs), and system layout.
3. **Calculates the recovered energy** (BTU/hr) at design heating and cooling conditions.
4. **Adjusts the coil loads:** The AHU heating coil and cooling coil loads are reduced by the recovered energy.
5. **Calculates annual energy savings** using the 8760-hour simulation engine.
6. **Generates equipment schedules** with manufacturer-specific models from Greenheck, Carrier, Trane, and other manufacturers.

10. Natural Ventilation

10.1 Overview

Natural ventilation uses wind pressure and thermal buoyancy (stack effect) to drive outdoor air through a building without the use of fans. ASHRAE 62.1-2022 Section 6.4 provides requirements for buildings that rely on natural ventilation as the sole ventilation strategy.

10.2 When Natural Ventilation is Allowed

Natural ventilation may be used as the sole ventilation strategy when all of the following conditions are met:

1. **Operable openings** (windows, louvers, doors) are provided with a total free area of at least **4% of the net occupiable floor area** of the naturally ventilated zone.
2. **No zone is more than 25 feet** from an operable opening, measured along the shortest airflow path from the opening to the most remote point in the zone.

3. The openings are permanently accessible to occupants. Openings that are sealed, locked, or blocked by furniture do not qualify.

4. Exhaust requirements are met independently. Spaces with exhaust requirements (restrooms, kitchens) must still have mechanical exhaust, even if the building uses natural ventilation for supply.

5. The local climate supports natural ventilation for a reasonable portion of the year. ASHRAE 62.1 does not define a specific climate threshold, but most engineers interpret this as requiring acceptable outdoor conditions (temperature, humidity, air quality) for at least 80% of occupied hours. In hot-humid or very cold climates, natural ventilation alone is rarely viable.

10.3 Hybrid (Mixed-Mode) Ventilation

Hybrid or mixed-mode ventilation combines natural ventilation with mechanical ventilation. There are three primary hybrid strategies:

Changeover (either/or): The building operates in natural ventilation mode when outdoor conditions are favorable (typically 55-75 F, low humidity, acceptable air quality) and switches to mechanical ventilation when conditions are unfavorable. Operable windows are closed during mechanical mode to prevent over-pressurization or under-pressurization.

Concurrent (both simultaneously): Natural ventilation through operable windows supplements the mechanical ventilation system. The mechanical system provides a base level of ventilation and filtration, while operable windows allow occupants to bring in additional outdoor air. This is common in green building design (LEED, WELL) and in mild climates.

Zoned: Some zones use natural ventilation (perimeter offices near operable windows) while other zones use mechanical ventilation (interior conference rooms, server rooms). This requires careful pressure management to prevent uncontrolled airflow between naturally and mechanically ventilated zones.

10.4 Natural Ventilation in the J∆S Engineering Suite

The J∆S Engineering Suite provides the following natural ventilation tools:

- **Opening area calculator:** Verifies that the 4% free area requirement is met for each zone.
- **25-foot distance check:** Verifies that no point in the zone exceeds 25 feet from an operable opening.
- **Climate suitability analysis:** Using the project weather data, calculates the percentage of occupied hours when outdoor conditions are within acceptable ranges for natural ventilation. If the percentage is below 80%, the module recommends a hybrid system.
- **Hybrid mode control sequence:** Generates a control sequence for changeover operation, including interlocks between operable window sensors and the mechanical ventilation system.

10.5 Limitations

Natural ventilation has significant limitations that the engineer must consider:

- **No filtration:** Outdoor air entering through operable windows is unfiltered. In locations with poor outdoor air quality (urban areas, wildfire-prone regions), natural ventilation exposes occupants to unfiltered particulate matter and pollutants.
- **No humidity control:** In humid climates, natural ventilation introduces uncontrolled moisture, which can cause condensation, mold growth, and thermal discomfort.

- **Security concerns:** Operable windows on ground floors may present security risks. Upper floors may have safety concerns (fall protection).
- **Noise:** Operable windows admit exterior noise, which may be unacceptable in offices, healthcare facilities, or schools near busy roads.
- **Unpredictable airflow:** Wind speed and direction are variable, making it difficult to guarantee minimum ventilation rates through natural means alone.

11. Filtration

11.1 Overview

Filtration removes particulate matter, bioaerosols, and (with appropriate media) gaseous contaminants from the air. While filtration is not a substitute for ventilation (dilution), it is an essential complement that improves the quality of both outdoor air and recirculated air.

ASHRAE 62.1-2022 specifies minimum filtration requirements for outdoor air intakes, and ASHRAE Standard 52.2 defines the MERV (Minimum Efficiency Reporting Value) rating system used to classify filter performance.

11.2 MERV Ratings Explained

The MERV rating system classifies filters by their ability to capture particles in three size ranges:

MERV Rating	Particle Size Range	Capture Efficiency	Typical Application
MERV 1-4	> 10.0 microns	< 20% for 3-10 micron	Minimal filtration, window AC units
MERV 5-8	3.0 - 10.0 microns	20-70% for 3-10 micron	Residential, light commercial
MERV 8	3.0 - 10.0 microns	70-85% for 3-10 micron	**ASHRAE 62.1 minimum for OA**
MERV 9-12	1.0 - 3.0 microns	50-90% for 1-3 micron	Superior commercial, hospital ancillary
MERV 13	0.3 - 1.0 microns	50-75% for 0.3-1.0 micron	**Recommended minimum; captures most bacteria, mold, sneeze droplets**
MERV 14	0.3 - 1.0 microns	75-85% for 0.3-1.0 micron	General surgery, superior commercial
MERV 15-16	0.3 - 1.0 microns	85-95% for 0.3-1.0 micron	Hospital inpatient, cleanroom prefilter
MERV 17-20 (HEPA)	0.3 microns	99.97%+ for 0.3 micron	Cleanrooms, isolation rooms, BSL-3 labs

11.3 ASHRAE 62.1 Filtration Requirements

ASHRAE 62.1-2022 requires the following minimum filtration:

Location in Air Path	Minimum MERV Rating	Notes
Outdoor air intake (before mixing with return)	**MERV 8**	Minimum. Protects AHU coils and ductwork from outdoor particles.
Recirculated air (if the AHU recirculates air)	**MERV 8**	Same minimum for return air filtration.
Systems serving healthcare occupancies	**MERV 14** or higher	Per ASHRAE 170. Two-stage filtration (MERV 8 prefilter + MERV 14 final).

11.3.1 MERV 13 Recommendation

While ASHRAE 62.1 requires only MERV 8 as a minimum, ASHRAE has issued guidance (and many jurisdictions now require) MERV 13 as the recommended minimum for most commercial applications. The rationale:

- MERV 13 captures particles in the 0.3-1.0 micron range, which includes most bacteria (0.5-5.0 microns), mold spores (2-10 microns), and respiratory droplets/droplet nuclei (0.5-5.0 microns).
- MERV 13 provides meaningful protection against airborne infectious disease transmission. CDC and ASHRAE both recommend MERV 13 as a minimum for buildings where infectious disease mitigation is a concern.
- The pressure drop penalty for MERV 13 compared to MERV 8 is modest (typically 0.15-0.30 inches w.g. additional initial pressure drop) and modern AHUs can easily accommodate this.

The J∆S Engineering Suite defaults to MERV 13 filtration for all new projects and displays a warning if the user selects a lower rating.

11.4 Pressure Drop Impact

Higher-efficiency filters have higher pressure drops, which increase fan energy consumption. The engineer must balance filtration effectiveness against energy use.

Typical initial pressure drops by MERV rating (at 500 FPM face velocity):

MERV Rating	Initial Pressure Drop (inches w.g.)	Final Pressure Drop at Changeout (inches w.g.)
MERV 8 (2-inch pleated)	0.20 - 0.35	0.80 - 1.00
MERV 8 (4-inch pleated)	0.15 - 0.25	0.60 - 0.80
MERV 11 (4-inch pleated)	0.25 - 0.40	0.80 - 1.00
MERV 13 (4-inch pleated)	0.35 - 0.50	1.00 - 1.30
MERV 14 (12-inch rigid cell)	0.30 - 0.50	1.00 - 1.50
MERV 16 (12-inch rigid cell)	0.40 - 0.60	1.20 - 1.80
HEPA (6-inch deep pleat)	1.00 - 1.40	1.80 - 2.50

Design best practice: Size the AHU and fan for the final (dirty) filter pressure drop, not the initial (clean) pressure drop. The J∆S Engineering Suite includes filter pressure drop in the system static pressure calculation, using the average of initial and final pressure drop as the design value (or the value at the recommended changeout point, typically 2x initial).

11.5 Filter Selection in the J∆S Engineering Suite

The J∆S Engineering Suite filter selection module:

1. Determines the minimum required MERV rating based on the occupancy type, code requirements, and owner's project requirements (OPR).

2. Calculates the filter face area based on the AHU airflow and the recommended face velocity (typically 300-500 FPM for standard pleated filters, 250-350 FPM for high-efficiency rigid cell filters).

3. Selects filter size and configuration from standard sizes (12x24, 20x24, 24x24, 20x20, etc.) to match the AHU filter rack dimensions.

4. Calculates pressure drop at design airflow using manufacturer data.

5. Estimates filter life based on the outdoor air quality (particulate loading), recirculated air quality, and ASHRAE 52.2 dust-holding capacity.

6. Generates a filter schedule for inclusion in the construction documents, listing filter location, size, quantity, MERV rating, manufacturer/model, initial pressure drop, and replacement interval.

11.6 Two-Stage Filtration

For applications requiring high-efficiency filtration (MERV 14+), two-stage filtration is recommended:

- **Stage 1 (prefilter):** MERV 8 pleated filter. Captures large particles, extending the life of the downstream high-efficiency filter.
- **Stage 2 (final filter):** MERV 13-16 rigid cell or bag filter. Captures fine particles for IAQ.

Two-stage filtration reduces operating costs because the inexpensive prefilter absorbs most of the particle loading, and the expensive final filter lasts longer.

11.7 Gaseous Contaminant Filtration

Standard particulate filters (MERV-rated) do not remove gaseous contaminants (VOCs, ozone, NO2, SO2). For applications where gaseous contaminant removal is needed, supplemental gas-phase filtration is required:

Technology	Target Contaminants	Effectiveness	Common Applications
Activated carbon	VOCs, ozone, odors	80-99% (initially)	Office near highways, airports, industrial areas
Permanganate-impregnated alumina	Formaldehyde, H2S, SO2, NOx	70-95%	Healthcare, museums, archives
Photocatalytic oxidation (PCO)	VOCs, bacteria, viruses	Variable (30-90%)	Supplemental IAQ improvement
Bipolar ionization	Particles, some VOCs, pathogens	Variable (controversial)	Supplemental IAQ; verify UL 2998 ozone compliance

The J∆S Engineering Suite includes gas-phase filtration in the IAQ analysis module when the IAQP compliance pathway is used or when the outdoor air quality at the project location indicates elevated gaseous contaminant levels.

12. Worked Examples

The following three comprehensive examples demonstrate the full Ventilation Rate Procedure as implemented in the J∆S Engineering Suite. Each example includes every intermediate calculation so the reader can verify the methodology and reproduce the results manually.

12.1 Example 1: Multi-Zone VAV Office Building (10 Zones)

Project: A three-story office building in Denver, Colorado (Climate Zone 5B, altitude 5,280 feet). The first floor is served by AHU-1, a variable air volume (VAV) air handling unit with ceiling supply diffusers and ceiling return grilles. The system serves 10 zones.

System Configuration:

- Supply air distribution: Ceiling supply, cool air during cooling; ceiling supply, warm air during heating (heating supply temperature 90 F, less than 15 F above space temperature of 72 F, so Ez = 1.0 in both modes).
- Return air: Ceiling return.
- Ez = 1.0 for all zones.
- Occupant diversity factor: D = 0.80 (estimated 80% simultaneous peak).

12.1.1 Zone Data

Zone	Space Type	Occupancy Category	Az (SF)	Pz (people)	Rp (CFM/person)	Ra (CFM/SF)	Vpz (CFM)
101	Open Office	Office - Open Plan	3,200	16	5	0.06	1,500
102	Open Office	Office - Open Plan	2,800	14	5	0.06	1,300
103	Private Offices	Office - Enclosed	1,600	8	5	0.06	700
104	Conference Room A	Conference/Meeting	600	20	5	0.06	400
105	Conference Room B	Conference/Meeting	450	15	5	0.06	350
106	Break Room	Break Room/Lounge	800	20	5	0.12	500
107	Lobby	Lobby - Office	1,200	12	5	0.06	550
108	Corridor	Corridor	1,500	0	0	0.06	400
109	Copy Room	Copy/Print Room	250	1	5	0.06	200
110	Storage	Storage/Warehouse	500	0	0	0.06	150
Total			**12,900**	**106**			**6,050**

12.1.2 Step-by-Step Zone Calculations

Zone 101 — Open Office (3,200 SF, 16 people):

```
Vbz = Rp x Pz + Ra x Az
Vbz = (5 x 16) + (0.06 x 3,200)
Vbz = 80 + 192 = 272 CFM

Voz = Vbz / Ez = 272 / 1.0 = 272 CFM

Zpz = Voz / Vpz = 272 / 1,500 = 0.181
```

Zone 102 — Open Office (2,800 SF, 14 people):

```
Vbz = (5 x 14) + (0.06 x 2,800)
Vbz = 70 + 168 = 238 CFM

Voz = 238 / 1.0 = 238 CFM

Zpz = 238 / 1,300 = 0.183
```

Zone 103 — Private Offices (1,600 SF, 8 people):

```
Vbz = (5 x 8) + (0.06 x 1,600)
Vbz = 40 + 96 = 136 CFM

Voz = 136 / 1.0 = 136 CFM

Zpz = 136 / 700 = 0.194
```

Zone 104 — Conference Room A (600 SF, 20 people):

```
Vbz = (5 x 20) + (0.06 x 600)
Vbz = 100 + 36 = 136 CFM

Voz = 136 / 1.0 = 136 CFM

Zpz = 136 / 400 = 0.340
```

Zone 105 — Conference Room B (450 SF, 15 people):

```
Vbz = (5 x 15) + (0.06 x 450)
Vbz = 75 + 27 = 102 CFM

Voz = 102 / 1.0 = 102 CFM

Zpz = 102 / 350 = 0.291
```

Zone 106 — Break Room (800 SF, 20 people):

```
Vbz = (5 x 20) + (0.12 x 800)
Vbz = 100 + 96 = 196 CFM

Voz = 196 / 1.0 = 196 CFM

Zpz = 196 / 500 = 0.392
```

Zone 107 — Lobby (1,200 SF, 12 people):

```
Vbz = (5 x 12) + (0.06 x 1,200)
Vbz = 60 + 72 = 132 CFM

Voz = 132 / 1.0 = 132 CFM

Zpz = 132 / 550 = 0.240
```

Zone 108 — Corridor (1,500 SF, 0 people):

```
Vbz = (0 x 0) + (0.06 x 1,500)
Vbz = 0 + 90 = 90 CFM

Voz = 90 / 1.0 = 90 CFM

Zpz = 90 / 400 = 0.225
```

Zone 109 — Copy Room (250 SF, 1 person):

```
Vbz = (5 x 1) + (0.06 x 250)
Vbz = 5 + 15 = 20 CFM

Voz = 20 / 1.0 = 20 CFM

Zpz = 20 / 200 = 0.100
```

Zone 110 — Storage (500 SF, 0 people):

```
Vbz = (0 x 0) + (0.06 x 500)
Vbz = 0 + 30 = 30 CFM

Voz = 30 / 1.0 = 30 CFM

Zpz = 30 / 150 = 0.200
```

12.1.3 Zone Summary Table

Zone	Space	Az (SF)	Pz	Rp	Ra	Vbz (CFM)	Ez	Voz (CFM)	Vpz (CFM)	Zpz
101	Open Office	3,200	16	5	0.06	272	1.0	272	1,500	0.181
102	Open Office	2,800	14	5	0.06	238	1.0	238	1,300	0.183
103	Private Offices	1,600	8	5	0.06	136	1.0	136	700	0.194
104	Conference A	600	20	5	0.06	136	1.0	136	400	0.340
105	Conference B	450	15	5	0.06	102	1.0	102	350	0.291
106	Break Room	800	20	5	0.12	196	1.0	196	500	0.392
107	Lobby	1,200	12	5	0.06	132	1.0	132	550	0.240
108	Corridor	1,500	0	0	0.06	90	1.0	90	400	0.225
109	Copy Room	250	1	5	0.06	20	1.0	20	200	0.100
110	Storage	500	0	0	0.06	30	1.0	30	150	0.200
Total		**12,900**	**106**			**1,352**		**1,352**	**6,050**	

12.1.4 System-Level Calculation

Step 7a: Identify the critical zone:

```
Zd = MAX(Zpz) = 0.392 (Zone 106 - Break Room)
```

The Break Room is the critical zone because it has the highest ratio of required outdoor air to supply air. This makes sense: the Break Room has a high ventilation requirement (elevated Ra due to food odors, plus high occupancy) relative to its supply air (moderate cooling load).

Step 7b: Calculate the people component sum:

```
SUM(Rp x Pz) = 80 + 70 + 40 + 100 + 75 + 100 + 60 + 0 + 5 + 0 = 530 CFM
```

Step 7c: Calculate the area component sum:

```
SUM(Ra x Az) = 192 + 168 + 96 + 36 + 27 + 96 + 72 + 90 + 15 + 30 = 822 CFM
```

Step 7d: Calculate uncorrected outdoor air (Vou) with diversity:

```
Vou = D x SUM(Rp x Pz) + SUM(Ra x Az)
Vou = 0.80 x 530 + 822
Vou = 424 + 822
Vou = 1,246 CFM
```

Note: The diversity factor D = 0.80 is applied only to the people component, not the area component. This is because building materials emit contaminants regardless of occupancy (area component is constant), but not all zones are at peak occupancy simultaneously (people component can be diversified).

Step 7e: Calculate system primary airflow:

```
Vps = SUM(Vpz) = 6,050 CFM
```

Step 7f: Calculate system outdoor air fraction:

```
Xs = Vou / Vps = 1,246 / 6,050 = 0.206
```

Step 7g: Calculate system ventilation efficiency (Appendix A method):

```
Ev = MIN(1.0, 1 + Xs - Zd)
Ev = MIN(1.0, 1 + 0.206 - 0.392)
Ev = MIN(1.0, 0.814)
Ev = 0.814
```

Cross-check with Table 6.2.5.2 (simplified method): Zd = 0.392, which falls in the range 0.35 < Zd <= 0.45, giving Ev = 0.7 from the table.

The Appendix A method yields Ev = 0.814, which is significantly higher (more favorable) than the table value of 0.7. The Appendix A method is more precise and results in a lower system OA requirement. The J∆S Engineering Suite uses the Appendix A method by default.

Step 7h: Calculate system outdoor air intake (Vot):

```
Using Appendix A: Vot = Vou / Ev = 1,246 / 0.814 = 1,530 CFM
Using Table: Vot = Vou / Ev = 1,246 / 0.7 = 1,780 CFM
```

Result: AHU-1 requires a minimum outdoor air intake of **1,530 CFM** (Appendix A method) at design conditions.

OA percentage of total supply:

```
OA% = Vot / Vps = 1,530 / 6,050 = 25.3%
```

DCV check:

- Zone 104 (Conference A): 20 people / (600 SF / 1,000) = 33.3 ppl/1,000 SF. **DCV required** (density > 25).
- Zone 105 (Conference B): 15 people / (450 SF / 1,000) = 33.3 ppl/1,000 SF. **DCV required** (density > 25).

- Zone 106 (Break Room): 20 people / (800 SF / 1,000) = 25.0 ppl/1,000 SF. **DCV required** (density >= 25, borderline).
- All other zones: Below 25 ppl/1,000 SF. DCV not required.

Energy recovery check (ASHRAE 90.1, Climate Zone 5B): System OA = 1,530 CFM. For Climate Zone 5B with OA% = 25.3% (less than 30%), the threshold is 5,500 CFM. Since 1,530 < 5,500, **energy recovery is not required** by ASHRAE 90.1 for this system.

12.2 Example 2: Healthcare Exam Room with Exhaust Requirements

Project: An outpatient medical clinic in Houston, Texas (Climate Zone 2A). The clinic contains 8 exam rooms, a waiting room, reception, staff lounge, restrooms, and clean/soiled utility rooms. This example focuses on a single exam room and its associated exhaust requirements.

Zone Data — Exam Room 3:

Parameter	Value
Space Type	Healthcare - Exam Room
Occupancy Category	Healthcare - Exam Room
Area (Az)	120 SF
Population (Pz)	2 (1 patient + 1 provider)
Rp	5 CFM/person
Ra	0.06 CFM/SF
Ez	1.0 (ceiling supply / ceiling return)
Supply Air (Vpz)	150 CFM (from cooling load calculation)

12.2.1 Breathing Zone Outdoor Airflow

```
Vbz = Rp x Pz + Ra x Az
Vbz = (5 x 2) + (0.06 x 120)
Vbz = 10 + 7.2
Vbz = 17.2 CFM
```

12.2.2 Zone Outdoor Airflow

```
Voz = Vbz / Ez = 17.2 / 1.0 = 17.2 CFM
```

12.2.3 ASHRAE 170 Cross-Check

For outpatient exam rooms, ASHRAE Standard 170-2021 (which supersedes 62.1 for healthcare) requires:

Parameter	ASHRAE 170 Requirement	ASHRAE 62.1 Result	Governing Value
Minimum total ACH	6 ACH	N/A	6 ACH
Minimum OA ACH	2 ACH	17.2 CFM = 1.1 ACH*	2 ACH
Pressure relationship	Negative or Neutral	N/A	Negative

*ACH calculation: ACH = (CFM x 60) / Volume. Volume = 120 SF x 9 ft ceiling = 1,080 CF. ACH from 62.1 = (17.2 x 60) / 1,080 = 0.96 ACH.

ASHRAE 170 requires 2 OA ACH minimum:

```
OA CFM (170) = 2 ACH x 1,080 CF / 60 = 36 CFM
```

ASHRAE 170 governs: The exam room requires **36 CFM** of outdoor air (ASHRAE 170), which is more than double the ASHRAE 62.1 requirement of 17.2 CFM.

Total supply air at 6 ACH:

```
Total CFM (170) = 6 ACH x 1,080 CF / 60 = 108 CFM
```

The cooling load calculation produced Vpz = 150 CFM, which exceeds the 6 ACH minimum. Use Vpz = 150 CFM.

12.2.4 Exhaust Requirements

ASHRAE 170 requires that exam rooms be at **negative pressure** relative to the corridor. This means exhaust must exceed supply within the exam room:

```
Exhaust = Supply + Transfer In
```

If the exam room has no direct exhaust (exhaust is at the AHU), the negative pressure is achieved by ensuring the return airflow from the exam room exceeds the supply airflow minus any intentional transfer to the corridor.

For this design:

- Supply: 150 CFM
- Return: 160 CFM (10 CFM more than supply to create negative pressure)
- Net pressure: Negative (10 CFM flows into the exam room from the corridor through the door undercut)

12.2.5 Additional Clinic Exhaust Spaces

Space	Exhaust Rate	Basis
Patient Restroom (1 WC)	50 CFM	ASHRAE 62.1 Table 6.5
Staff Restroom (1 WC, 1 urinal)	75 CFM	50 + 25 per fixture
Soiled Utility	10 ACH	ASHRAE 170 Table 7-1
Clean Utility	N/A (positive pressure)	ASHRAE 170
Janitor Closet (50 SF)	50 CFM	1 CFM/SF (min 25 CFM)
Total Clinic Exhaust	**275+ CFM**	Sum of all exhaust zones

The clinic AHU must provide at least 275 CFM more outdoor air than recirculated air to make up for the exhaust, plus additional air for building pressurization.

12.2.6 Key Takeaway

In healthcare applications, ASHRAE 170 almost always supersedes ASHRAE 62.1 and requires significantly higher ventilation rates. The J∆S Engineering Suite automatically flags healthcare occupancy categories and applies the more stringent ASHRAE 170 requirements when the user confirms the space is a healthcare occupancy.

12.3 Example 3: Restaurant with High Ventilation and Kitchen Exhaust

Project: A 4,500 SF full-service restaurant in Chicago, Illinois (Climate Zone 5A). The restaurant contains a dining room, bar, commercial kitchen, restrooms, and an entry vestibule. AHU-1 serves the dining room, bar, and vestibule. The kitchen has a dedicated makeup air unit (MAU-1).

12.3.1 Zone Data

Zone	Space Type	Occupancy Category	Az (SF)	Pz (people)	Rp (CFM/person)	Ra (CFM/SF)	Ez	Vpz (CFM)
R-1	Dining Room	Restaurant Dining	2,400	120	7.5	0.18	1.0	4,800
R-2	Bar / Lounge	Bar/Cocktail Lounge	800	50	7.5	0.18	1.0	1,600
R-3	Entry Vestibule	Lobby - Office	200	5	5	0.06	1.0	250
R-4	Kitchen	Kitchen (Cooking)	900	10	7.5	0.12	1.0	MAU
R-5	Restrooms (M)	Restrooms	150	0	0	0	N/A	Exhaust only
R-6	Restrooms (F)	Restrooms	200	0	0	0	N/A	Exhaust only

12.3.2 Zone Calculations (AHU-1 Zones: R-1, R-2, R-3)

Zone R-1 — Dining Room (2,400 SF, 120 people):

```
Vbz = (7.5 x 120) + (0.18 x 2,400)
Vbz = 900 + 432
Vbz = 1,332 CFM

Voz = 1,332 / 1.0 = 1,332 CFM

Zpz = 1,332 / 4,800 = 0.278
```

The dining room has an exceptionally high ventilation requirement. The people component (900 CFM, 68%) dominates due to the high occupancy (120 people at Rp = 7.5 CFM/person), and the area component (432 CFM, 32%) is also significant due to the elevated Ra = 0.18 CFM/SF (food odors, cooking byproducts).

Zone R-2 — Bar / Lounge (800 SF, 50 people):

```
Vbz = (7.5 x 50) + (0.18 x 800)
Vbz = 375 + 144
Vbz = 519 CFM

Voz = 519 / 1.0 = 519 CFM

Zpz = 519 / 1,600 = 0.324
```

Zone R-3 — Entry Vestibule (200 SF, 5 people):

```
Vbz = (5 x 5) + (0.06 x 200)
Vbz = 25 + 12
Vbz = 37 CFM

Voz = 37 / 1.0 = 37 CFM

Zpz = 37 / 250 = 0.148
```

12.3.3 System-Level Calculation (AHU-1)

Zone summary for AHU-1:

Zone	Voz (CFM)	Vpz (CFM)	Zpz
R-1 Dining	1,332	4,800	0.278
R-2 Bar	519	1,600	0.324
R-3 Vestibule	37	250	0.148

Critical zone:

```
Zd = MAX(Zpz) = 0.324 (Zone R-2 - Bar)
```

People component sum:

```
SUM(Rp x Pz) = 900 + 375 + 25 = 1,300 CFM
```

Area component sum:

```
SUM(Ra x Az) = 432 + 144 + 12 = 588 CFM
```

Diversity factor: For a restaurant, most seating is occupied during meal periods. Use D = 0.85.

Uncorrected outdoor air:

```
Vou = D x SUM(Rp x Pz) + SUM(Ra x Az)
Vou = 0.85 x 1,300 + 588
Vou = 1,105 + 588
Vou = 1,693 CFM
```

System primary airflow:

```
Vps = SUM(Vpz) = 4,800 + 1,600 + 250 = 6,650 CFM
```

System outdoor air fraction:

```
Xs = Vou / Vps = 1,693 / 6,650 = 0.255
```

System ventilation efficiency (Appendix A):

```
Ev = MIN(1.0, 1 + Xs - Zd)
Ev = MIN(1.0, 1 + 0.255 - 0.324)
Ev = MIN(1.0, 0.931)
Ev = 0.931
```

System outdoor air intake:

```
Vot = Vou / Ev = 1,693 / 0.931 = 1,818 CFM
```

OA percentage:

```
OA% = 1,818 / 6,650 = 27.3%
```

12.3.4 Kitchen Exhaust and Makeup Air

The commercial kitchen has a Type I grease hood over the cooking line:

Equipment	Hood Length	Exhaust Rate (CFM/LF)	Exhaust CFM
Charbroiler + Fryer	10 LF	400 CFM/LF	4,000
Range + Oven	8 LF	300 CFM/LF	2,400
Total Kitchen Exhaust			**6,400 CFM**

The kitchen exhaust (6,400 CFM) is far larger than the kitchen ventilation requirement from ASHRAE 62.1:

```
Kitchen Vbz = (7.5 x 10) + (0.12 x 900) = 75 + 108 = 183 CFM
```

The kitchen exhaust is driven by the hood requirements (IMC Section 507), not by ASHRAE 62.1. The kitchen requires a dedicated Makeup Air Unit (MAU-1) to replace the exhausted air.

MAU-1 sizing:

```
Makeup Air = Kitchen Exhaust - Transfer Air from Adjacent Zones
```

Assume 400 CFM of transfer air enters the kitchen from the dining room (through the pass-through window and swinging doors):

```
MAU-1 = 6,400 - 400 = 6,000 CFM
```

MAU-1 must deliver 6,000 CFM of tempered, filtered outdoor air to the kitchen.

12.3.5 Restroom Exhaust

Men's restroom (2 WC, 2 urinals):

```
Exhaust = (2 x 50) + (2 x 25) = 100 + 50 = 150 CFM
```

Women's restroom (3 WC):

```
Exhaust = 3 x 50 = 150 CFM
```

Total restroom exhaust: 300 CFM

12.3.6 Building Air Balance

Air Stream	CFM	Notes
AHU-1 Supply	6,650	Dining, bar, vestibule
AHU-1 Outdoor Air	1,818	27.3% OA
AHU-1 Return	4,832	6,650 - 1,818 = 4,832 recirculated
MAU-1 Supply (all OA)	6,000	Kitchen makeup
Kitchen Exhaust	6,400	Hood exhaust
Restroom Exhaust	300	Direct exhaust
Total Supply	**12,650**	AHU-1 + MAU-1
Total Exhaust	**6,700**	Kitchen + restrooms

Air Stream	CFM	Notes
Net Pressurization	**+5,950**	Supply - exhaust (before AHU return/relief)

The building is positively pressurized. The AHU-1 relief damper exhausts excess return air as needed to maintain building pressure at 0.05-0.10 inches w.g.

12.3.7 DCV Check

- Zone R-1 (Dining): 120 people / (2,400/1,000) = 50 ppl/1,000 SF. Voz = 1,332 CFM > 750 CFM. **DCV required.**
- Zone R-2 (Bar): 50 people / (800/1,000) = 62.5 ppl/1,000 SF. Voz = 519 CFM < 750 CFM. **DCV required** (density > 25, check local code for CFM threshold).
- Zone R-3 (Vestibule): 5 people / (200/1,000) = 25 ppl/1,000 SF. Not required.

12.3.8 Energy Recovery Check

AHU-1 OA = 1,818 CFM. Climate Zone 5A, OA% < 30%. Per ASHRAE 90.1 Table 6.5.6.1, threshold is 1,500 CFM for Climate Zone 5A at OA% < 30%. Since 1,818 > 1,500, **energy recovery is required** for AHU-1.

MAU-1 OA = 6,000 CFM (100% OA). For 100% OA systems in Climate Zone 5A, energy recovery is required for systems above 500 CFM. Since 6,000 >> 500, **energy recovery is required** for MAU-1. However, kitchen exhaust is Class 4 (grease-laden), which limits recovery options. A runaround glycol loop or plate HX with grease-resistant coatings may be used. Enthalpy wheels are not suitable for grease-laden exhaust.

13. Common Code Violations

The following are the most frequently encountered ASHRAE 62.1 code violations in commercial HVAC design. The J∆S Engineering Suite includes automated checks for each of these violations and flags them in the Compliance Status panel.

13.1 Undersized Outdoor Air

Violation: The system outdoor air intake (Vot) is less than the calculated minimum.

How it happens:

- The OA damper minimum position is set too low during commissioning.
- The OA intake louver, ductwork, or filter is undersized, restricting airflow below the design value.
- The AHU economizer damper linkage is improperly adjusted.
- The building operator reduced the OA damper position to save energy (common but illegal if it drops below the ASHRAE 62.1 minimum).

Detection: An airflow measuring station at the OA intake is the most reliable detection method. Without a measuring station, OA flow can be estimated from mixed air temperature calculations, but this method is less accurate.

J∆S check: The module verifies that the AHU OA intake capacity (based on louver free area, filter face velocity, and duct sizing) can physically deliver the calculated Vot.

13.2 Missing or Improperly Located CO_2 Sensors

Violation: DCV-required zones (>= 25 ppl/1,000 SF and > 750 CFM OA) lack CO_2 sensors, or sensors are improperly located.

How it happens:

- The engineer specifies DCV in the sequence of operations but does not include CO_2 sensors on the equipment schedule.
- CO_2 sensors are installed in the return air duct instead of the zone. Return air sensors read an average of all zones on the AHU, not the specific DCV zone concentration.
- Sensors are installed directly in front of supply air diffusers, reading low due to dilution by outdoor air.
- Sensors are installed at ceiling height instead of breathing zone height (3-6 feet above floor).

J∆S check: The module flags all zones that require DCV and includes CO_2 sensor requirements in the equipment schedule and control sequence.

13.3 Missing Exhaust for Required Spaces

Violation: Restrooms, janitor closets, copy rooms, or other exhaust-required spaces lack dedicated exhaust systems.

How it happens:

- The engineer relies on general return air from the AHU to ventilate the restroom, instead of providing dedicated exhaust. This violates ASHRAE 62.1 because restroom air is Class 2 and must be exhausted, not recirculated.
- Janitor closets are overlooked because they are small and seem insignificant.
- Copy rooms in open-plan offices are not enclosed and the engineer assumes general office ventilation is sufficient (which may be true if the copy area is open, but not if it is enclosed).

J∆S check: The module identifies all exhaust-required spaces and verifies that dedicated exhaust fans and ductwork are specified.

13.4 Incorrect Ez Value Selection

Violation: Using Ez = 1.0 for all air distribution configurations, even when the actual configuration warrants Ez = 0.8 or Ez = 0.5.

How it happens:

- The engineer does not consider the heating mode supply air temperature. A ceiling supply system delivering cool air (Ez = 1.0 in cooling mode) may deliver warm air 15 F+ above space temperature during heating mode. If the return is at the floor, Ez drops to 0.8 during heating.
- Transfer air / makeup air configurations are not evaluated for Ez. A space receiving makeup air from the same side as the exhaust (Ez = 0.5) can be dramatically under-ventilated if Ez = 1.0 is assumed.

J∆S check: The module prompts the user to confirm the supply air configuration for each zone and selects the worst-case Ez value for sizing.

13.5 Failure to Apply Multi-Zone Ev Correction

Violation: For multi-zone VAV systems, summing zone Voz values and using the sum as the system Vot without applying the system ventilation efficiency (Ev) correction.

How it happens:

- The engineer calculates Voz correctly for each zone but simply sums them: Vot = SUM(Voz). This is only valid for 100%-outdoor-air (DOAS) systems. For recirculating VAV systems, the Ev correction is required.
- The simple sum approach may actually over-ventilate the system (providing more total OA than needed) while simultaneously under-ventilating the critical zone. This is counterintuitive but occurs because the OA fraction at the AHU is the same for all zones, and the critical zone (highest Zpz) may not receive enough OA even though the total OA exceeds the sum of Voz values.

J∆S check: The module automatically applies the Ev correction for any AHU serving more than one zone and displays both the simple sum and the Ev-corrected Vot for comparison.

13.6 Not Accounting for Transfer Air in Air Balance

Violation: The building air balance does not account for transfer air from supply zones to exhaust zones, resulting in negative building pressure.

How it happens:

- The restrooms and janitor closets exhaust 500 CFM total, but the AHU outdoor air intake does not include an additional 500 CFM to replace the exhausted air.
- The engineer sizes the AHU OA based on the ventilation calculation only, without adding the exhaust makeup.

J∆S check: The module performs a complete building air balance showing supply, return, exhaust, outdoor air, and transfer air for all zones, and verifies that the building is at positive pressure.

13.7 Using Ventilation Air for Exhaust Makeup Only

Violation: The OA intake provides enough air to replace exhaust but less than the ASHRAE 62.1 minimum Vot.

How it happens:

- In a building with 300 CFM of restroom exhaust and a calculated Vot of 800 CFM, the engineer provides only 300 CFM of OA (enough for exhaust makeup but far short of the ventilation requirement).

J∆S check: The module verifies that Vot is the greater of the ventilation calculation result and the exhaust makeup requirement.

13.8 Failure to Ventilate During Occupied Hours

Violation: The ventilation system is turned off during occupied hours (e.g., during morning warmup/cooldown, or manually shut off by building operators).

How it happens:

- The AHU morning warmup sequence closes the OA damper to heat the building faster. If occupants arrive before warmup is complete, the building is occupied but not ventilated.

• Building operators turn off the ventilation system (or close the OA damper) to reduce energy costs or eliminate complaints about cold drafts.

J∆S check: The module generates a control sequence that maintains minimum OA during all occupied hours, with an explicit note prohibiting OA damper closure during occupied mode.

13.9 Ignoring Altitude Corrections for Supply Air Calculations

Violation: Using sea-level air density factors (1.08 sensible heat factor, 4,840 latent heat factor) for buildings at significant altitude.

How it happens:

• The standard sensible heat equation (Q = 1.08 x CFM x Delta_T) uses 1.08, which assumes sea-level air density (0.075 lb/CF). At 5,280 feet (Denver), air density is approximately 0.062 lb/CF, and the factor drops to about 0.90.

• While ASHRAE 62.1 ventilation rates are in volumetric terms (CFM) and are not directly affected by altitude, the supply air temperature calculations that depend on air density must be corrected. Under-ventilating at altitude is possible if the supply air temperature difference is calculated using sea-level density.

J∆S check: The module automatically applies altitude corrections based on the project location elevation.

14. Troubleshooting

14.1 "The OA Rate Seems Too High"

Symptoms: The calculated Vot appears unreasonably high compared to similar projects or the engineer's experience.

Possible causes and solutions:

1. **Incorrect occupancy category.** Verify that each zone has the correct occupancy category. A zone mistakenly assigned "Cafeteria" (Ra = 0.18, density = 100) instead of "Break Room" (Ra = 0.12, density = 25) will have dramatically inflated ventilation requirements. **Solution:** Review and correct all occupancy category assignments.

2. **Over-estimated zone population.** If Pz is set too high (e.g., using fire code maximum occupancy instead of design occupancy), the people component will be inflated. **Solution:** Use ASHRAE 62.1 default densities or actual anticipated occupancy, not maximum occupancy per life safety codes.

3. **Low Ev (poor system ventilation efficiency).** A system with one high-Zpz zone (like a conference room on a VAV system) will have a low Ev, dramatically increasing Vot. **Solution:** Consider placing the high-Zpz zone on a separate single-zone system (dedicated split system or packaged unit), which eliminates the Ev penalty for the main system.

4. **Ez = 0.8 or 0.5 applied to many zones.** If the air distribution configuration results in low Ez values for multiple zones, the total OA increases significantly. **Solution:** Redesign the air distribution to achieve Ez = 1.0 or higher (e.g., switch from floor return to ceiling return during heating mode).

5. **No diversity factor applied.** If D = 1.0 (no diversity), all zones are assumed to be at peak occupancy simultaneously. For large buildings with many zones, applying an appropriate diversity factor (D = 0.7-0.85) can significantly reduce Vot. **Solution:** Calculate or estimate the actual peak simultaneous occupancy and apply an appropriate D factor.

14.2 "The Building Pressure is Negative"

Symptoms: Doors are hard to open (wind effect pulls doors shut), noticeable drafts at exterior walls, infiltration complaints, higher-than-expected heating/cooling loads.

Possible causes and solutions:

1. Exhaust exceeds outdoor air intake. Total exhaust CFM (restrooms, kitchen, lab, janitor closets) exceeds total AHU outdoor air CFM. **Solution:** Increase AHU OA or add a dedicated MAU to replace exhausted air.

2. Kitchen hood exhaust not balanced by makeup air. A commercial kitchen hood exhausting 6,000 CFM without a dedicated MAU will pull 6,000 CFM through the rest of the building, creating severe negative pressure. **Solution:** Install a MAU sized to replace kitchen exhaust.

3. Leaky return air ductwork. If return ductwork runs through a ceiling plenum and has significant leaks, some return air is lost to the plenum and exhausted through ceiling penetrations. The AHU receives less return air than expected and cannot maintain positive building pressure. **Solution:** Seal return air ductwork or provide additional OA.

4. Wind effects. Sustained wind on the leeward side of the building can create localized negative pressure at some outdoor air intakes, reducing OA flow. **Solution:** Locate OA intakes on multiple sides of the building or in protected locations. Use OA airflow measuring stations with control feedback to maintain minimum OA regardless of wind conditions.

5. Stack effect. In tall buildings during cold weather, warm air rises and exits through upper-floor openings (elevator shafts, stairwells, mechanical penetrations), drawing cold outdoor air in at lower floors. This creates negative pressure at lower floors and positive pressure at upper floors. **Solution:** Seal vertical penetrations, provide vestibule doors at ground-floor entries, and balance the HVAC system to counteract stack effect.

14.3 "Occupants Complain About Stuffy Air"

Symptoms: Occupants report feeling stuffy, drowsy, or experiencing headaches, particularly in the afternoon.

Possible causes and solutions:

1. OA damper not delivering design airflow. The OA damper may be partially closed, the OA ductwork may be obstructed, or the filter may be clogged, reducing actual OA flow below design. **Solution:** Measure actual OA flow at the AHU. Install an OA airflow measuring station if one is not present.

2. DCV not functioning. In DCV zones, the CO2 sensor may be malfunctioning (reading artificially low), causing the controller to deliver minimum OA even when the space is fully occupied. **Solution:** Verify CO2 sensor calibration. Compare sensor reading to a portable CO2 monitor.

3. Inadequate ventilation for the actual occupancy. The zone may be occupied by more people than the design population. A conference room designed for 12 people but regularly used by 20 people will be under-ventilated. **Solution:** Verify actual occupancy and recalculate Voz. Consider adding DCV if not already provided.

4. Recirculation of contaminants. If the AHU return air picks up contaminants from a poorly maintained space (moldy ductwork, dirty coils) and recirculates them, IAQ complaints will occur even with adequate OA flow. **Solution:** Inspect AHU coils, drain pans, and ductwork for biological growth. Clean or replace as needed.

5. CO2 above comfort threshold. Measure indoor CO2. If concentrations exceed 1,000 ppm during occupied hours, ventilation is likely insufficient. **Solution:** Increase OA or address the specific cause (failed damper, sensor, etc.).

14.4 "Temperature Complaints in Zones Near the OA Intake"

Symptoms: Zones near the AHU or OA intake experience cold drafts in winter or hot/humid air in summer.

Possible causes and solutions:

1. Insufficient OA tempering. The AHU preheat coil may be undersized or malfunctioning, allowing cold OA to enter the mixing plenum and be delivered to nearby zones without adequate heating. **Solution:** Verify preheat coil capacity and operation. Consider adding a dedicated OA preheat coil upstream of the mixing section.

2. OA damper hunting. If the OA damper modulates rapidly (hunting), zones near the AHU experience alternating blasts of cold/warm air. **Solution:** Tune the OA damper control loop (reduce proportional gain, increase integral time). Consider a fixed minimum OA damper position instead of modulating control.

3. Poor mixing of OA and return air. If the mixing section of the AHU is too short, OA and return air do not fully mix before reaching the coil and fan. This creates stratified air with cold streaks that are delivered to specific zones. **Solution:** Add mixing baffles to the mixing section. Consider an OA preconditioning coil to reduce the temperature differential before mixing.

14.5 "Energy Bills Are Higher Than Expected"

Symptoms: Heating and/or cooling energy consumption is significantly higher than the energy model predicted.

Possible causes and solutions related to ventilation:

1. OA damper stuck open. The OA damper may be stuck at a position higher than the minimum (possibly full open if the economizer control failed in the open position). This introduces far more OA than needed, dramatically increasing conditioning energy. **Solution:** Verify OA damper position and operation. Inspect the damper actuator, linkage, and controller.

2. DCV not reducing OA during low occupancy. If DCV is not functioning (sensor failure, controller programming error), the system delivers full design OA at all times, even when zones are lightly occupied. **Solution:** Verify DCV operation by observing VAV box minimum airflow setpoints during low-occupancy periods.

3. Energy recovery not functioning. If the energy recovery device (enthalpy wheel, plate HX) is bypassed, offline, or degraded (fouled, frost-damaged), the full OA conditioning penalty applies. **Solution:** Verify energy recovery device operation. Check wheel rotation, glycol pump operation, frost control, and effectiveness (measure entering/leaving air temperatures on both streams).

4. Excessive infiltration. Negative building pressure (see Section 14.2) draws in unconditioned outdoor air through the envelope, bypassing the AHU filtration and conditioning. **Solution:** Correct building pressure. Seal envelope leaks.

15. Complete Reference Tables

15.1 ASHRAE 62.1-2022 Table 6.2.2.1 — Minimum Ventilation Rates in Breathing Zone (Complete)

The following is a comprehensive listing of occupancy categories from ASHRAE 62.1-2022 Table 6.2.2.1 as implemented in the J∆S Engineering Suite.

15.1.1 Correctional Facilities

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Booking / Waiting	7.5	0.06	50
Cell	5	0.12	25
Dayroom	5	0.06	30
Guard Station	5	0.06	15
Laundry (within facility)	5	0.12	10

15.1.2 Education

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Art Classroom	10	0.18	20
Classroom (ages 5-8)	10	0.12	25
Classroom (ages 9+)	10	0.12	35
Computer Lab	10	0.12	25
Daycare (through age 4)	10	0.18	25
Lecture Hall (fixed seats)	7.5	0.06	65
Library - Media Center	5	0.12	10
Library - Stacks	5	0.12	10
Multiuse Assembly	7.5	0.06	100
Music / Theater / Dance	10	0.06	35
Science Laboratory	10	0.18	25
University / College Lab	10	0.18	25
Wood / Metal Shop	10	0.18	20

15.1.3 Food and Beverage

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Bar / Cocktail Lounge	7.5	0.18	100
Cafeteria / Fast-Food Dining	7.5	0.18	100
Kitchen (Cooking)	7.5	0.12	20
Restaurant Dining Room	7.5	0.18	70

15.1.4 General

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Break Room	5	0.12	25

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Coffee Station	5	0.12	20
Conference / Meeting Room	5	0.06	50
Corridor	0	0.06	0
Occupiable Storage	0	0.12	0
Restrooms	0	0	0

15.1.5 Hotels, Motels, Resorts, Dormitories

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Barracks / Sleeping Bay	5	0.06	20
Bedroom / Living Room	5	0.06	10
Laundry Room (common)	5	0.12	10
Lobby / Prefunction	7.5	0.06	30
Multipurpose Assembly	5	0.06	120

15.1.6 Miscellaneous Spaces

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Bank Vault / Safe Deposit	5	0.06	5
Computer (not printing)	5	0.06	4
Electrical / Mechanical Room	0	0.06	0
Elevator	0	0	0
Pharmacy (prep area)	5	0.18	10
Photo Studio	5	0.12	10
Shipping / Receiving	0	0.12	0
Sorting / Packing / Light Assembly	0	0.12	0
Telephone Closet	0	0	0
Transportation Waiting	7.5	0.06	100
Warehouse	0	0.06	0

15.1.7 Office Building

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Lobby	5	0.06	10
Main Entry Lobby	5	0.06	10

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Office - Enclosed	5	0.06	5
Office - Open Plan	5	0.06	5
Reception Area	5	0.06	30
Telephone / Data Entry	5	0.06	60

15.1.8 Public Assembly

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Auditorium (fixed seating)	5	0.06	150
Courtroom	5	0.06	70
Legislative Chamber	5	0.06	50
Museum / Gallery	7.5	0.06	40
Places of Religious Worship	5	0.06	120

15.1.9 Retail

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Barbershop / Beauty Salon	20	0.12	25
Coin-Operated Laundry	7.5	0.12	20
Mall Common Area	7.5	0.06	40
Pet Shop	7.5	0.18	10
Retail Sales (except below)	7.5	0.12	15
Supermarket	7.5	0.06	8

15.1.10 Sports and Entertainment

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Bowling Alley (seating)	10	0.12	40
Casino (gaming area)	7.5	0.18	120
Disco / Dance Floor	20	0.06	100
Gym / Arena (play area)	20	0.06	7
Health Club / Aerobics Room	20	0.06	40
Health Club / Weight Room	20	0.06	10
Spectator Area	7.5	0.06	150
Swimming Pool (pool deck)	0	0.48	0

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Swimming Pool (natatorium)	0	0.48	0

15.1.11 Vehicles and Auto Repair

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Auto Repair Workshop	7.5	0.18	7
Parking Garage	0	0.12	0

15.1.12 Healthcare (ASHRAE 62.1 categories; ASHRAE 170 may supersede)

Occupancy Category	Rp (CFM/person)	Ra (CFM/SF)	Default Density (ppl/1,000 SF)
Dental Office / Operatory	5	0.06	10
Exam / Treatment Room	5	0.06	10
Medical Procedure Room	5	0.06	20
Operating Room	5	0.06	20
Patient Room	5	0.06	10
Physical Therapy	5	0.06	7
Recovery Room	5	0.06	10
Waiting Room (outpatient)	7.5	0.06	30

15.2 ASHRAE 62.1-2022 Table 6.2.2.2 — Zone Air Distribution Effectiveness (Ez)

Config #	Supply Air Configuration	Return / Exhaust Location	Supply Temp vs. Space Temp	Ez
1	Ceiling supply	Ceiling return	Cool (below space temp)	1.0
2	Ceiling supply	Floor return	Cool (below space temp)	1.0
3	Ceiling supply	Ceiling return	Warm (>= 15 F above space temp)	1.0
4	Ceiling supply	Floor return	Warm (>= 15 F above space temp)	0.8
5	Floor supply (UFAD)	Ceiling return	Cool (below space temp)	1.2
6	Floor supply	Floor return	Cool (below space temp)	1.0
7	Floor supply	Ceiling return	Warm (above space temp)	1.0
8	Floor supply	Floor return	Warm (above space temp)	1.0

Config #	Supply Air Configuration	Return / Exhaust Location	Supply Temp vs. Space Temp	Ez
9	Makeup air from opposite side of room	Exhaust on far wall	N/A	0.8
10	Makeup air from same side of room	Exhaust on same wall	N/A	0.5

Notes on Table 6.2.2.2:

- Config 5 (UFAD with ceiling return, cool supply) provides an Ez of 1.2, which is the most favorable value. This means the zone requires 17% less outdoor air than a standard ceiling supply system. The improved effectiveness is due to the displacement ventilation effect: cool air enters at floor level, rises through the breathing zone as it absorbs heat from occupants and equipment, and exits at the ceiling. Contaminants are carried upward and away from the breathing zone.
- Config 10 (makeup air from same side as exhaust) has the worst effectiveness (Ez = 0.5), requiring twice the outdoor air of a standard system. This configuration short-circuits the ventilation air, with makeup air potentially exiting the room immediately without reaching the breathing zone. Avoid this configuration in design.
- For systems that operate in both heating and cooling modes, use the worst-case (lowest) Ez value for sizing unless the control system dynamically adjusts the minimum outdoor air based on operating mode.

15.3 ASHRAE 62.1-2022 Table 6.5 — Minimum Exhaust Rates

Space / Application	Exhaust Rate	Air Class	Notes
Art Room	0.7 CFM/SF	2	Solvent and material emissions
Auto Repair Workshop	1.5 CFM/SF	3	Vehicle exhaust, solvents
Barber Shop	0.5 CFM/SF	2	Hair treatment chemicals
Beauty / Nail Salon	0.6 CFM/SF	2	Nail polish, acetone, hair chemicals
Copy / Print Room	0.5 CFM/SF	2	Toner, ozone
Darkroom	1.0 CFM/SF	2	Photo chemicals
Educational Science Lab	1.0 CFM/SF	2	Chemical vapors (fume hoods separate)
Janitor Closet	1.0 CFM/SF (min 25 CFM)	3	Cleaning chemical storage
Kitchen (commercial)	Per IMC 507 / hood calc	4	Type I hoods for grease; Type II for steam/heat
Kitchen (residential style)	0.7 CFM/SF (min 2 ACH)	2	Break room with cooking appliances
Laundry (commercial)	0.5 CFM/SF	2	Lint, moisture, chemical vapors
Laundry (coin-operated)	0.5 CFM/SF	2	Lint, moisture
Locker / Dressing Room	0.5 CFM/SF	2	Moisture, body odors
Paint Spray Booth	Per NFPA 33	4	Solvent vapors, paint particles

Space / Application	Exhaust Rate	Air Class	Notes
Parking Garage (enclosed)	0.75 CFM/SF	3	CO, NO2 from vehicles
Pet Shop	0.9 CFM/SF	3	Animal odors, dander, ammonia
Restroom (per WC)	50 CFM/fixture	2	Per water closet
Restroom (per urinal)	25 CFM/fixture	2	Per urinal
Shower Room	20 CFM/head + 0.5 CFM/SF	2	Moisture control
Soiled Linen Storage	1.0 CFM/SF	3	Healthcare facilities
Swimming Pool (natatorium)	Per dehumidification calc	2	Chloramine vapors
Trash Room / Compactor	1.0 CFM/SF	3	Decomposition odors
Welding Shop	1.0 CFM/SF minimum	3	Welding fumes (local exhaust at source)
Woodworking Shop	0.5 CFM/SF	2	Sawdust, finish vapors

15.4 ASHRAE 62.1-2022 Table 6.2.5.2 — System Ventilation Efficiency (Ev) — Simplified

Maximum Zone Primary OA Fraction (Zd)	System Ventilation Efficiency (Ev)
Zd <= 0.15	1.0
0.15 < Zd <= 0.25	0.9
0.25 < Zd <= 0.35	0.8
0.35 < Zd <= 0.45	0.7
0.45 < Zd <= 0.55	0.6
Zd > 0.55	Use Appendix A calculation

When to use Appendix A instead of the table:

- When Zd > 0.55 (the table does not provide values above 0.55).
- When the table method produces an overly conservative (low) Ev and the designer wants a more precise result. The Appendix A method typically yields a higher Ev than the table, resulting in a lower Vot.
- For complex systems with many zones and widely varying Zpz values.

The J∆S Engineering Suite always calculates Ev using both the table method and the Appendix A method and displays both values, using the Appendix A result as the design value.

16. Abbreviations

Abbreviation	Definition
ACH	Air Changes per Hour
AHJ	Authority Having Jurisdiction
AHU	Air Handling Unit
AI	Analog Input (BACnet point type)
AV	Analog Value (BACnet point type)
Az	Zone floor area (SF)
BACnet	Building Automation and Control Networks (ASHRAE 135)
BSL	Biosafety Level
BTU	British Thermal Unit
BV	Binary Value (BACnet point type)
CFM	Cubic Feet per Minute
CMC	California Mechanical Code
CO	Carbon Monoxide
CO2	Carbon Dioxide
CPC	California Plumbing Code
CRAC	Computer Room Air Conditioner
CRAH	Computer Room Air Handler
D	Occupant diversity factor
DCV	Demand-Controlled Ventilation
DDC	Direct Digital Control
DOAS	Dedicated Outdoor Air System
DX	Direct Expansion (refrigeration)
ERV	Energy Recovery Ventilator
Ev	System ventilation efficiency
Evz	Zone ventilation effectiveness (Appendix A method)
Ez	Zone air distribution effectiveness
FPM	Feet Per Minute (air velocity)
HEPA	High-Efficiency Particulate Air (filter)
HRV	Heat Recovery Ventilator
HX	Heat Exchanger
IAQ	Indoor Air Quality
IAQP	Indoor Air Quality Procedure

Abbreviation	Definition
IMC	International Mechanical Code
L/s	Liters per second
MAU	Makeup Air Unit
MERV	Minimum Efficiency Reporting Value
NDIR	Non-Dispersive Infrared (CO2 sensor type)
NFPA	National Fire Protection Association
NO2	Nitrogen Dioxide
OA	Outdoor Air
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PI	Proportional-Integral (control method)
PIR	Passive Infrared (occupancy sensor)
PM2.5	Particulate Matter, 2.5 microns and smaller
PM10	Particulate Matter, 10 microns and smaller
ppm	Parts per million
Pz	Zone population (number of people)
Ra	Area outdoor air rate (CFM/SF)
Rp	People outdoor air rate (CFM/person)
RTU	Rooftop Unit
SF	Square Feet
UFAD	Underfloor Air Distribution
UVGI	Ultraviolet Germicidal Irradiation
VAV	Variable Air Volume
Vbz	Breathing zone outdoor airflow (CFM)
VOC	Volatile Organic Compound
Vot	System outdoor air intake (CFM)
Vou	Uncorrected outdoor air intake (CFM)
Voz	Zone outdoor airflow (CFM)
Vpz	Zone primary airflow (CFM)
Vps	System primary airflow (CFM)
VRP	Ventilation Rate Procedure
WC	Water Closet (toilet fixture)

Abbreviation	Definition
Xs	System outdoor air fraction (Vou/Vps)
Zd	Design zone primary OA fraction (max Zpz)
Zpz	Zone primary outdoor air fraction (Voz/Vpz)

This guide is part of the J∆S Engineering Suite documentation series, version 1.1. For questions, feedback, or technical support, contact JS Engineering Solutions.