ASHRAE 62.1 IAQP
Agenda

- The challenge: Energy, indoor air quality, outdoor air quality
- The opportunity: IAQP
- Compliance
- VRP versus DCV versus IAQP
- IAQP Methodology
The Challenge

Energy Efficiency

Ventilation leads to higher energy costs:
- Outside air is replaced 1-2 time per hour
- Outside air conditioning represents 30-50% of the total load on HVAC systems in most climates

- HVAC capacity
- Energy usage
- Water consumption
- Maintenance
Ventilation leads to higher energy costs:
100,000 ft² - 20,000 CFM of outside air:
- 380,000 kWh of cooling energy
- 1,340,000 kBTU of heating energy

### Energy Efficiency

<table>
<thead>
<tr>
<th>City</th>
<th>Electrical (kWh)</th>
<th>Gas/Steam (kBtu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boston</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>New York</td>
<td>14</td>
<td>85</td>
</tr>
<tr>
<td>Chicago</td>
<td>11</td>
<td>133</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Colorado</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Phoenix</td>
<td>26</td>
<td>1</td>
</tr>
<tr>
<td>Atlanta</td>
<td>29</td>
<td>11</td>
</tr>
<tr>
<td>Washington</td>
<td>19</td>
<td>67</td>
</tr>
<tr>
<td>San Antonio</td>
<td>48</td>
<td>4</td>
</tr>
<tr>
<td>New Orleans</td>
<td>56</td>
<td>2</td>
</tr>
<tr>
<td>Miami</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Baton Rouge</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>9</td>
<td>139</td>
</tr>
<tr>
<td>San Diego</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>San Juan</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>Nashville</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>Kansas</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Baltimore</td>
<td>19</td>
<td>78</td>
</tr>
<tr>
<td>Fort Smith</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Charlotte</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>Greenville</td>
<td>49</td>
<td>4</td>
</tr>
</tbody>
</table>
The Challenge
Indoor Air Quality (IAQ)

VOCs, CO\textsubscript{2}

Satish et al., LBL, 2012
Allen et al., Harvard School of Public Health, 2015

Elevated CO\textsubscript{2} has a direct and negative effect on productivity

Gain of $6,500 per year per employee
The Challenge
Outdoor Air Quality (OAQ)

Ventilation leads to increase of outdoor generated pollutants indoors, PM$_{2.5}$ - Ozone - CO - NOx - SOx

<table>
<thead>
<tr>
<th>Outside air ratings</th>
<th>American Lung Association</th>
<th>EPA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24-Hour Particle Pollution</td>
<td>Ozone Grade</td>
</tr>
<tr>
<td>Boston-Worcester-Providence, MA-RI-NH-CT</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>Chicago-Naperville, IL-IN-WI</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Dallas-Fort Worth, TX-OK</td>
<td>B</td>
<td>F</td>
</tr>
<tr>
<td>Houston-The Woodlands, TX</td>
<td>C</td>
<td>F</td>
</tr>
<tr>
<td>New York-Newark, NY-NJ-CT-PA</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Miami-Fort Lauderdale-Port St. Lucie, FL</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Washington-Baltimore-Arlington, DC-MD-VA-WV-PA</td>
<td>C</td>
<td>F</td>
</tr>
</tbody>
</table>
The Opportunity

Energy Efficiency, IAQ, and OAQ

→ Solution: IAQP + Air Cleaning

- IAQP + Air Cleaning:
  - Can be implemented as an energy conservation measure: less ventilation is needed to maintain IAQ
  - Decrease the intake of outdoor-generated pollutants indoors
Compliance
Compliance

ASHRAE Standard 62.1-2016
IAQP: Can be implemented as an energy conservation measure: less ventilation is needed to maintain IAQ

International Building Code (IBC) + ASHRAE 90.1
- Alternative Methods
- MD: 2015 versions of IMC and IECC/ASHRAE 90.1 2013
- VA and DC: 2012 versions of IMC and IECC/ASHRAE 90.1 2010

American Conference Of Governmental Industrial Hygienists (ACGIH) - 2016: Industrial Ventilation Manual
IAQP (including exhaust for IAQP)

USGBC
- Pilot: PC 68 – pre-requisite: EB & NC
- Pilot: Performance based indoor air assessment in Existing Buildings

WELL
6.2.7.1.1 For DCV zones in the occupied mode, breathing zone outdoor airflow ($q_{oA}$) shall be reset in response to current population.

6.2.7.1.2 For DCV zones in the occupied mode, breathing zone outdoor airflow ($q_{oA}$) shall not be less than the building component ($q_{BC}$) for the zone.

Exception: Breathing zone outdoor airflow shall be permitted to be reduced to zero for zones in occupied standby mode for the occupancy categories indicated in Table 6.2.2.1, provided that airflow is resumed to $q_{oA}$ whenever occupancy is detected.

6.2.7.1.3 Documentation. A written description of the equipment, methods, control sequences, sequences, and the intended operational functions shall be provided. A table shall be provided that shows the minimum and maximum outdoor intake airflow for each system.

6.2.7.2 Ventilation Efficiency. Variations in the efficiency with which outdoor air is distributed to the occupants under different ventilation system airflow rates and temperatures shall be permitted as an optional basis of dynamic reset.

6.2.7.3 Outdoor Air Fraction. A higher fraction of outdoor air in the air supply due to intake of additional outdoor air for free cooling or exhaust air makeup shall be permitted as an optional basis of dynamic reset.

6.3 Indoor Air Quality (IAQ) Procedure. Breathing zone outdoor airflow ($q_{oA}$) shall be determined in accordance with Sections 6.3.1 through 6.3.3.

6.3.1 Contaminant Sources. Each contaminant of concern for the purposes of the design shall be identified. For each contaminant of concern, indoor sources and outdoor sources shall be identified, and the emission rate for each contaminant of concern from each source shall be determined. Where two or more contaminants of concern target the same organ system, these contaminants shall be considered to be a contaminant mixture.

Informative Note: This section provides information for some potential contaminants of concern, including the organs they affect.

6.3.2 Contaminant Concentration. For each contaminant of concern, a concentration limit and its corresponding exposure period and an appropriate reference to a regulatory authority shall be specified. For each contaminant mixture of concern, the ratio of the concentration of each contaminant to its concentration limit shall be determined, and the sum of these ratios shall not be greater than one.

Exception: Consideration of odors in determining concentration limits shall not be required.

Informative Notes:
1. Odors are addressed in Section 6.3.4.2.
2. Informative Appendix E includes concentration guidelines for some potential contaminants of concern.

6.3.3 Perceived Indoor Air Quality. The design level of indoor air quality shall be defined in terms of the percentage of building occupants, visitors, or both expressing satisfaction with perceived IAQ.

6.3.4 Design Approach. Zone and system outdoor airflow rates shall be the larger of those determined in accordance with Section 6.3.4.1 and either Section 6.3.4.2 or 6.3.4.3, based on emission rates, concentration limits, and other relevant design parameters.

6.3.4.1 Mass Balance Analysis. Using a steady-state or dynamic mass balance analysis, the minimum outdoor airflow rates required to achieve the concentration limits specified in Section 6.3.2 shall be determined for each contaminant or contaminant mixture of concern within each zone served by the system.

Informative Notes:
1. Informative Appendix E outlines steady-state mass balance equations that describe the impact of air cleaning and outdoor air and recirculation rates for ventilation systems serving a single zone.
2. In the complete building model, a concentration or the concentration of contaminants or contaminant mixtures of concern may be used as a means of checking the accuracy of the design mass balance analysis, but such measurement is not required for compliance.

6.3.4.2 Subjective Evaluation. Using a subjective occupant evaluation conducted in the completed building, the minimum outdoor airflow rates required to achieve the level of acceptability specified in Section 6.3.3 shall be determined within each zone served by the system.

Informative Notes:
1. Informative Appendix C contains one approach to subjective occupant evaluation.
2. Level of acceptability often increases in response to increased outdoor airflow rates, increased level of indoor or outdoor air cleaning, or decreased indoor or outdoor contaminant emission rate.

6.3.4.3 Similar Zone. The minimum outdoor airflow rates shall not be less than those found in accordance with Section 6.3.4.2 for a substantially similar zone.

6.3.5 Combined IAQ Procedure and Ventilation Rate Procedure. The IAQ Procedure in conjunction with the Ventilation Rate Procedure shall be permitted to be applied to a zone or system. In this case, the Ventilation Rate Procedure shall be used to determine the required zone minimum outdoor airflow, and the IAQ Procedure shall be used to determine the additional outdoor air or air cleaning necessary to achieve the concentration limits of the contaminants and contaminant mixtures of concern.

Informative Note: The improvement of indoor air quality through the use of air cleaning or provision of additional outdoor air in conjunction with minimum ventilation rates may be quantified using the IAQ Procedure.

6.3.6 Documentation. Where the IAQ Procedure is used, the following information shall be included in the design documentation: the contaminants and contaminant mixtures of concern considered in the design process, the sources and emission rates of the contaminants of concern, the concentration limits and exposure periods, and the references for these limits, and the analytical approach used to determine ventilation airflow rates.
Indoor Air Quality Procedure (§6.3)
The Indoor Air Quality Procedure (IAQP) may be used as an alternative to the Ventilation Rate Procedure (VRP). While the VRP is a prescriptive procedure that determines minimum outdoor air ventilation rates for typical applications, the IAQP is a performance-based design approach that determines minimum outdoor airflow rates and air cleaning necessary to control the concentrations of contaminants to certain levels and maintaining a specified percentage of occupant or visitor satisfaction. The VRP is an indirect solution to achieving acceptable IAQ. The IAQP is a more direct approach to the goal, but it requires very different methods, knowledge, evaluations, decisions, and documentation than those of the VRP.

While the VRP allows (and in some cases requires) that recirculated air be cleaned, the specified outdoor ventilation rates may not be reduced. On the other hand, the IAQP allows any method to be used to achieve the contaminant concentration limits, including source control, air cleaning, or dilution of indoor contaminants with outside air.

The performance of the HVAC system in maintaining good air quality is based upon two requirements:

- Maintaining concentrations of specific contaminants below concentration limits, and
- Achieving a design target level of perceived indoor air quality acceptability.

Sometimes meeting the concentration limits will result in perceived acceptability and sometimes not. For instance, the human nose is very sensitive to odors that may or may not be addressed by the contaminant concentration limits. On the other hand, meeting only the perceived acceptability targets is not sufficient since some contaminants cannot be sensed even if target levels are reached (for instance radon and carbon monoxide).

Sometimes meeting the concentration limits for each individual contaminant will result in perceived acceptability and sometimes not. Since odors may add (see "Two Component Approach and Additivity" in Section 6.2), the outdoor air needed to dilute odorous contaminants might be the sum of the outdoor air needed to dilute each odorous contaminant.

The IAQ Procedure requires the building and its ventilation system to be designed to achieve both objective and subjective criteria. The IAQ allows ventilation air to be reduced below rates that would have been required by the VRP, if it can be reliably demonstrated that the resulting air quality meets the required criteria described in §6.3.4.

The IAQP may allow for a more cost-effective solution to providing good air quality since all design strategies may be considered and compared, including:

- Dilution ventilation and the commensurate added energy costs of conditioning greater volumes of outdoor air;
- Controlling contaminants at the source by specifying low-emissions carpets, wall coverings, paints, adhesives and furnishings;
- Air cleaning strategies; and
- Source control of HVAC air supplies and/or visitor satisfaction based on perceived air quality in similar buildings or through post-occupancy evaluation.

Many of these strategies involve added construction and maintenance costs, but can have the benefit of conditioning less outdoor air. They can also result in higher levels of perceived acceptability by building occupants and/or visitors. The IAQP may also be used to achieve better air quality than the VRP (lower contaminant levels and/or higher perceived acceptability) with or without increasing first cost or maintenance cost.

Compliance Requirements
Designing for compliance using the IAQP Procedure requires four steps:
ASHRAE Standard 62.1
ASHRAE Standard 62.1 Overview

- **ASHRAE Std. 62.1: Ventilation Rate Procedure (VRP)**
  - **PRESCRIPTIVE**

- **ASHRAE Std. 62.1: Indoor Air Quality Procedure (IAQP) – since 1979**
  - **PERFORMANCE-BASED**
  - Pollutant control ventilation (PCV)
  - Cleaning efficiency
  - Compliance report
  - Occupant survey

* Since 2006, the International Mechanical Code (IMC) allows for an engineered solution showing control of contaminant concentrations (IAQP).
ASHRAE Standard 62.1–2016

Ventilation Rate Procedure (VRP)

- Breathing zone outdoor airflow: use Table 6.2.2.1 rates (pages 12-15)

\[ V_{bz} = R_p P_z + R_a A_z \]

Definition: Breathing zone is the region within an occupied space between planes 3-72 in. above the floor and more than 2 feet from the walls.
Based on CO₂ concentrations as a surrogate for human occupancy

\[ V_{bz} = R_p P_z + R_a A_z \]

- Minimum CFM/Person
- Actual Zone Population
- Zone Floor Area Constant
- Minimum CFM/ft²
Example Calculation of Outside Air Requirement using VRP and DCV

Office Building
Area = 80,000 ft$^2$
# People/1,000 ft$^2$ = 5
  # People = 400
Supply/Return Location = Ceiling
Zone Air Distribution Effectiveness = 0.8

People Outside Rate = 5 CFM/person
Area Outside Rate = 0.06 CFM/ft$^2$
### Example Calculation of Outdoor Air Requirement using VRP and DCV

<table>
<thead>
<tr>
<th>VRP</th>
<th>Building Component – Min. Outside Air (CFM)</th>
<th>People Component – Min. Outside Air (CFM)</th>
<th>Total Outdoor Air (CFM)</th>
</tr>
</thead>
<tbody>
<tr>
<td># People = 400</td>
<td>6,000</td>
<td>2500*</td>
<td>8,500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VRP + DCV</th>
<th>Building Component – Min. Outside Air (CFM)</th>
<th>People Component – Min. Outside Air (CFM)</th>
<th>Total Outdoor Air (CFM)</th>
</tr>
</thead>
<tbody>
<tr>
<td># People = 300</td>
<td>6,000</td>
<td>1,875</td>
<td>7,875</td>
</tr>
<tr>
<td># People = 200</td>
<td>6,000</td>
<td>1,250</td>
<td>7,250</td>
</tr>
<tr>
<td># People = 100</td>
<td>6,000</td>
<td>625</td>
<td>6,625</td>
</tr>
</tbody>
</table>

*For office buildings, DCV can save a maximum of 29% of total Design Outside Air intake.
VRP and DCV Drawbacks

- **VRP**
  - Leads to unnecessary energy consumption (prone to over-ventilation)
  - Does not control outdoor-generated pollutants

- **DCV**
  - Does not control outdoor-generated pollutants
  - Does not account for pollutants generated indoors that are independent of human activities
    - Nine literature studies* documented the above statements by testing formaldehyde, total volatile organic compounds (TVOC), and radon
  - Requires CO$_2$ sensor for each ventilation zone; sensors must be calibrated every ~6 months for proper operation.
  - For certain spaces, such as offices, portion of ventilation related to “people” component is low (29% in case of offices), leaving little margin to save energy using this methodology

*(Gabel et al., 1986; Donnini et al., 1991; Carpenter, 1996; Enermodal, 1995; Persily et al., 2003; Chao & Hu, 2004; Jeong et al., 2010; Mui & Chan, 2006; Herberger & Ulmer 2012)
IAQP Methodology

The IAQP allows compliance based on:
1. Objective Evaluation (contaminants concentrations)
2. Subjective Evaluation (survey)

- Design
  - Contaminants and/or mixtures, sources, and emissions
    - 32 VOCs
    - 5 inorganics
    - Include top 10 contaminants if not included in the above
  - Concentration limits
  - Identify air cleaning solution and efficiency
    - ASHRAE Standard 52.2 Particulate Filtration
    - ASHRAE Standard 145.2 Gaseous Filtration
    - ONLY Sorbent
  - Use mass balance equation

- Verification
  - IAQ Testing
  - Survey
    - Locations at breathing level
    - EPA methods

ASHRAE + LEED
IAQP Methodology: Design Phase

Outside Concentration, $C_0$

Supply Air, $V_S$

Emissions, $N$

Indoor Concentration, $C_{bz}$
IAQP Methodology: Design Phase

Outside Concentration, $C_0$

$V_{ot}$ Outside Air

Return Air Duct or Plenum

Air Cleaning Efficiency, $E_f$

$Q_{HLR}$

Supply Air, $V_S$

Emissions, $N$

Indoor Concentration, $C_{bz}$

$CO_2$, $VOC$
IAQP Methodology: Design Phase

Outside Concentration, $C_0$

Return Air Duct or Plenum

Supply Air Duct

Supply Air, $V_S$

Emissions, $N$

Indoor Concentration, $C_{bz}$

Air Cleaning Efficiency, $E_f$
IAQP: Objective Evaluation Steps

Mass Balance Analysis

\[ V dC_{bz} = \frac{\text{Dilution}}{V_{ot} C_{o} dt} - \frac{\text{Cleaning}}{Q_{HLR} E_f C_{bz} dt} \]

Outside Concentration, \( C_o \)

Return Air Duct or Plenum

Supply Air, \( V_s \)

Emissions, \( N \)

Indoor Concentration, \( C_{bz} \)

Air Cleaning Efficiency, \( E_f \)

\( V_{ot} \) Outside Air

\( Q_{HLR} \)
Example Calculation of Outside Air Requirement using VRP, DCV, IAQP

Office Building
Area = 80,000 ft²
# People/1,000 ft² = 5
  # People = 400
Supply/Return Location = Ceiling
Zone Air Distribution Effectiveness = 0.8
Outside Air Requirements Comparison

*ASHRAE Standard 62.1-2016*

<table>
<thead>
<tr>
<th>Method</th>
<th>Office</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRP (CFM)</td>
<td>8,500</td>
</tr>
<tr>
<td>DCV (CFM) - # People = 80</td>
<td>7,875</td>
</tr>
<tr>
<td>DCV (CFM) - # People = 50</td>
<td>7,250</td>
</tr>
<tr>
<td>DCV (CFM) - # People = 20</td>
<td>6,625</td>
</tr>
<tr>
<td>IAQP (CFM)</td>
<td>1,992</td>
</tr>
</tbody>
</table>

*Outside air requirements will be the max between IAQP and exhaust*
<table>
<thead>
<tr>
<th>Contaminant of Concern</th>
<th>Contaminant Source</th>
<th>Contaminant Strength</th>
<th>Contaminant Target Concentration</th>
<th>Perceived IAQ</th>
<th>Design Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Identify and list)</td>
<td>(Identify and list)</td>
<td>(Determine and list)</td>
<td>(List)</td>
<td>(List)</td>
<td>(List)</td>
</tr>
</tbody>
</table>

Outside Air Requirements = X CFM

Number of HLR Modules = Qty. Y
Summary of ASHRAE Testing Standards

- ASHRAE Standard 145.2:
  - Laboratory Test Method for Assessing the Performance of Gas-Phase Air Cleaning Systems: Air Cleaning Devices
    - Applies to sorbent testing only (excludes electronic air cleaning)
    - Gases: VOCs, aldehydes, ozone, basic and acidic gases

- ASHRAE Standard 52.2:
  - Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
Sorbent-based Air Cleaning Performance

- Air cleaning certification data according to ASHRAE Standards is needed to apply the Indoor Air Quality Procedure (IAQP) and LEED IAQP

- Third party certifications according to ASHRAE Standard 145.2 and 52.2 for sorbent-based cartridges from Research Triangle Institute (RTI)

Example: Ozone test data from RTI:
- Efficiency = 70%
- By-product VOCs and ozone concentrations = 0 ppb
## IAQP Use Cases

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor air is non-attainment for NAAQS or polluted</td>
<td>Reduces burden of ambient sources of particulate and gaseous pollutants</td>
</tr>
<tr>
<td></td>
<td>Reduces frequency of PM filter replacement</td>
</tr>
<tr>
<td>Buildings with existing capacity limitations (aging of HVAC equipment, re-purpose of the space, adding more people)</td>
<td>Enables compliance with the code using existing equipment with adding additional HVAC capacity</td>
</tr>
<tr>
<td>Identified COC concentrations are high, requiring additional ventilation</td>
<td>Enables better indoor air quality</td>
</tr>
<tr>
<td>New buildings with limited HVAC capacity (e.g., geothermal projects)</td>
<td>Engineers or owners gain from the economic advantages of the IAQP</td>
</tr>
<tr>
<td>Building is located in cold or hot/humid climates</td>
<td>Allows reduction in kWh and operating peak demand</td>
</tr>
<tr>
<td>LEED buildings</td>
<td>Allows earning LEED points related to energy, indoor air quality, and innovation.</td>
</tr>
</tbody>
</table>