Designing and Testing Demand Controlled Ventilation Strategies

Erik Jeannette, P.E.

Co-Author
Tracy Phillips

Architectural Energy Corporation

Demand Controlled Ventilation – "DCV"

- Topics
  - Defining Demand Controlled Ventilation
  - Designing Systems that Utilize DCV
  - Energy Impacts of DCV
  - Commissioning Requirements of DCV

What is it?

- Demand Controlled Ventilation
  - Demand controlled ventilation is a control strategy that varies the minimum ventilation outdoor air based on occupancy
  - Use CO_2 sensors to determine occupancy
    - True counters would be better
  - There is a high percentage of time that our buildings are not fully occupied
    - Reduce the ventilation air provided to the space by implementing DCV.

What is it?

- Demand Controlled Ventilation
  - Carbon dioxide is measured in parts per million (ppm).
  - Outdoor air CO_2 is between 300 ppm and 500 ppm,
    - Indoor CO2 levels are rarely lower than the outdoor levels.
  - Indoor CO_2 levels range between 400 ppm and 900 ppm
    - Only rise above 1000 ppm during a high occupancy event, or when the ventilation system is not performing properly.
  - Re-circulated air at the AHU mixes CO_2 from one room to another
  - CO_2 does not travel through walls, floors or ceilings in noticeable concentrations

Why do it?

- Reduce over ventilating
- Provide only enough outside air to satisfy needs
  - Needs of people
  - Needs of odors
  - Needs of building pressure/ exhaust
- Reduce cooling and heating loads at AHU/ central plant
- Reduce exhaust fan energy (building pressure control)

- SAVE ENERGY!!

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Ventilation standard
    - Only a code when it is adopted by the local applicable code
- Title 24-2005
  - Non-Residential Energy code for California

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Calculate the minimum amount of fresh air that is needed to maintain a space at acceptable air quality conditions.
  - The calculation has two main components:
    - quantity of outside air based on the area of the space
    - maximum occupancy loading component

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Calculation of Minimum Outside Air

Total Min OA = Air_p *P + Air_a *A

Total Min OA= The total upper limit of outside air required (cfm)

Air_p= OA flow rate required per person per table 6-1 (cfm)

P= Zone population. Typically the largest quantity of people expected to occupy the space, or an average based on section 6.2.6.2

Air_a= Outdoor air flow rate required per unit area (cfm)

A= Zone floor area (ft^2)

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Example Calculation of Minimum Outside Air

    a typical office space has the following numbers:

    Air_p = 5 cfm/person

    Air_a = 0.06 cfm / ft^2

    Based on a typical occupant density of 5 people per 1,000 ft2
  - this results in 17 cfm / person.

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Variable Air Volume Systems
  - Requires the min OA airflow be met at all fan speeds
    - ♦Or, if the system is not capable, must meet min OA at lowest air flow
      - Need 2-point min OA damper calibration with SF speed!
      - or direct measurement of OA!

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Variable Air Volume Systems
  - Example
    - ♦A VAV system provides 10,000 cfm total, and needs to provide 1,000 cfm of OA
    - ♦The minimum outdoor air fraction should be 10%.

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Variable Air Volume Systems
  - Example
    - ♦However, since this fraction is not being adjusted based on total airflow, the minimum outdoor air fraction needs to be adjusted, so that the minimum outdoor air amount is still maintained at any supply airflow.

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Variable Air Volume Systems
  - Example
    - Thus, if the system is expected to modulate the supply airflow as low as 40%, or 4,000 cfm, the actual minimum outdoor air fraction that needs to be used is 1,000 cfm / 4,000 cfm, or 25% outside air, which results in 2500 cfm OA at max airflow.
    - 25% minimum OA instead of 10% OA!!

Designing Systems With DCV

- ASHRAE 62.1-2004
  - The human factor and carbon dioxide
  - "a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents."
  - Indoor CO_2 at 700 ppm above outdoor ambient

Designing Systems With DCV

- ASHRAE 62.1-2004
  - The human factor and carbon dioxide
  - "a substantial majority of visitors entering a space will be satisfied with respect to human bioeffluents."
  - Indoor CO_2 at 700 ppm above outdoor ambient

Designing Systems With DCV

- ASHRAE 62.1-2004
  - Because occupancy varies within a space, we can adjust the minimum outside air lower than the calculated minimum based on input from either an
    - occupant counter,
    - schedule,
    - CO_2 sensor
  - DCV!!

Designing Systems With DCV

- Title 24-2005
  - California's energy code
  - Similar to ASHRAE 62.1-2004
    - Important differences...

Designing Systems With DCV

- Title 24-2005, Section 121
  - DCV is required in
    - single zone HVAC spaces that have an economizer and serve a space with a design occupant density of 25 people per 1,000 ft2 or greater
      - with a few exceptions:
      - Classrooms, spaces with high exhaust, garage spaces, food service prep, etc

Designing Systems With DCV

- Title 24-2005, Section 121
  - The indoor CO_2 setpoint is 600 ppm above outdoor ambient
  - If outdoor CO_2 is not measured, then the outdoor CO_2 level is assumed to be equal to 400 ppm

Designing Systems With DCV

- Title 24-2005, Section 121
- Important!
  - During normal occupied hours, the ventilation rate is not allowed to drop below the values listed in table 121-A, multiplied by the floor area of the conditioned space.
  - The ventilation rate found in this table for a typical office building is 0.15 cfm / ft2, which results in 15,000 cfm of minimum outside air for the typical 100,000 ft2 office building

Designing Systems With DCV

- Title 24-2005, Section 121
- Comparison of Spaces and Codes
  - 100,000 ft^2 building => 100,000 cfm supply air

Code/ Standard	DCV Applicable Building Area	Building Type	Lower Min OA Airflow	Upper Min OA Airflow	Percent OA Reduction
ASHRAE 62-2004	100,000 ft^2	Office	6,000 cfm	8,500 cfm	29%
Title 24-2005	100,000 ft^2	Office	15,000 cfm	15,000 cfm[1]	0%
ASHRAE 62-2004	100,000 ft^2	K-12 School	12,000 cfm	47,000 cfm	74%
Title 24-2005	100,000 ft^2	K-12 School	15,000 cfm	67,500 cfm	78%

Designing Systems With DCV

One more standard.....

- ASHRAE 90.1 -2004 Energy Standard (section 6.4.3.8)
- requires spaces with a design occupancy density greater than 100 people per 1000 ft^2 incorporate DCV in the HVAC design.
  - (i.e.: lecture halls, auditoriums, lobbies)

Designing Systems With DCV

- LEED 2.2
- USGBC, LEED Buildings
- Indoor Environmental Quality: IEQ Credit 1
  - When the indoor CO2 levels rise 10% above the ASHRAE 62.1-2004 requirements, then the mechanical control system shall send an alarm to the occupants (BAS) so that they will be informed and can take corrective action.

Designing Systems With DCV

- LEED 2.2
- Indoor Environmental Quality: IEQ Credit 1
- Spaces included
  - densely populated areas with a design occupant density greater than or equal to 25 people per 1,000 ft2.
    - Classrooms, restaurants, conference rooms, auditorium, courtrooms, gymnasiums, etc

Designing Systems With DCV

- Important Design Info
  - The Upper and Lower Limits of Min OA
  - Cooling and Heating coil design
    - Based on "minimum" OA
  - "Open the OA damper if CO_2 is high"...NO!!
  - Only open for DCV as much as the coil can handle!!

Designing Systems With DCV

- Important Design Info
  - The Upper and Lower Limits of Min OA
  - Upper limit of "Minimum OA"
  - Lower Limit of "Minimum OA"
  - DCV Modulation is between upper and lower limits

Designing Systems With DCV

- Important Design Info
  - The Upper and Lower Limits of Min OA
  - Economizer is active
    - DCV is active
    - DCV has priority to open further than the Economizer
  - DCV saves energy when Economizer is not active

Designing Systems With DCV

- Important Design Info
  - The Upper and Lower Limits of Min OA
    - Outdoor air entering through an air handler is filtered, and conditioned - Good
    - Maintain positive building pressure to prevent uncontrolled infiltration
      - Keeps moisture from entering through walls
    - Removing CO_2 from the air with filters or scrubbers is not allowed.

CO_2 Sensors

- Sensor Location and Quantity
  - How many do we need?
  - Where do we put them?

CO_2 Sensors

- Sensor Location and Quantity
  - Single Zone AHU
  - Gymnasium, auditorium, lobby
    - 1 sensor in the space

      or
    - 1 sensor in the return air
      - What is more representative?
    - 1' to 6' AFF (Title 24)
      - 6' is best to keep people from breathing on them
      - 8' is better

CO_2 Sensors

- Sensor Location and Quantity
  - Multizone AHU
  - VAV system with multiple zones
  - Good Question!!

CO_2 Sensors

- Sensor Location and Quantity
  - Multizone AHU
  - VAV system with multiple zones
    - 1 sensor in the return air?....No
    - 1 sensor in the conference room?...No
    - Multiple sensors....Yes
      - Common areas
      - Conference rooms
      - A sample of representative spaces

CO_2 Sensors

- Sensor Location and Quantity
  - Multizone AHU
  - VAV system with multiple zones
    - Drop the setpoint in Return air
    - 600 ppm, 500 ppm (700 ppm)
    - Need very similar occupancy patterns
      - K-12 classrooms

CO_2 Sensors

- Sensor Location and Quantity
  - Multizone AHU
  - VAV system with multiple zones
    - $SACO_2$
    - Supply Air CO_2 Control
      - Presented in ASHRAE Journal, October 2004
      - Measure AHU supply air CO_2, control to maintain $SACO_2$ at setpoint
      - Setpoint based on worst case zone OA/ SA airflow conditions
      - Does it meet the codes/ standards? Unclear....

DCV Sequences

- DCV Sequences of Operation
- Write sequences that are robust
  - Include DCV and economizer control integration
  - Upper and lower min OA setpoints/ control
    - Do not wait for CO2 to rise above setpoint before reacting
  - Reset schedule of min OA based on CO2
    - Don't wait for a problem – use a reset to react early

Space CO_2	Outdoor Airflow Setpoint
100 ppm above ambient	Lower minimum OA cfm
700 ppm above ambient	Upper minimum OA cfm

DCV Sequences

- DCV Sequences of Operation
  - Open the VAV damper for more airflow first
  - After many zones call for more OA based on DCV, open the OA damper more at the AHU

DCV Sequences

- DCV Sequences of Operation
- Write sequences that are robust
  - Include DCV and economizer control integration
  - Upper and lower min OA setpoints/ control

DCV Sequences

- DCV Sequences of Operation
  - Economizer Control:
  - When the outdoor air conditions allow for economizer operation to occur, the mixed air damper shall modulate as needed to maintain the supply air temperature setpoint, and shall be subject to maintaining at least the minimum outside air setting. When the outdoor air conditions do not meet the economizer mode criteria, then the outside air damper shall be at its minimum setting. (see below for a definition of "minimum setting").

DCV Sequences

- DCV Sequences of Operation
  - 1) Minimum Outside Air Setting (Simplified):
  - If the CO2 sensor input is less than the setpoint, then the OA damper shall be at the lower minimum setting. If the CO2 reading rises above the setpoint, then the OA damper shall modulate open as needed to bring the CO2 back down below the setpoint. The CO2 control routine shall not be allowed to open the OA damper beyond the upper minimum ventilation rate as specified in the mechanical schedule.
  - This has an inherent Time-lag of response

DCV Sequences

- DCV Sequences of Operation
  - 2) Minimum Outside Air Setting (with direct measurement of OA):
  - The outside air damper shall modulate to maintain the minimum outdoor airflow setpoint, which is a value between the lower minimum and upper minimum quantities, based on the following linear reset schedule:

Space CO_2	Outdoor Airflow Setpoint
100 ppm above ambient	Lower minimum OA cfm
700 ppm above ambient	Upper minimum OA cfm

CO_2 Sensors

- CO2 Sensors
- HVAC grade sensors range between $350 and $450
  - installed cost of a CO2 sensor is between $1,500 and $2,500

CO_2 Sensors

- CO2 Sensors
- Below is a list of CO2 sensor specifications that are appropriate for the HVAC industry:
  - Range: 0-2,000 ppm
  - Accuracy: +/- 50 ppm
  - Stability: <5% Full Scale for 5 years
  - Linearity: +/- 2% Full Scale
  - Manufacturer recommended minimum calibration frequency: 5 years

CO_2 Sensors

- CO2 Sensors
- Other considerations:
  - duct mounted or wall mounted
  - outdoor rated
  - alarm dry contact relay is needed
  - Ease of calibration
  - LED display should be considered
  - located between 3' and 6' above the floor when mounted indoors.

Energy Impacts of DCV

- Energy Model Predictions
- DOE2, Equest, Visual DOE
  - Major Factors when Modeling DCV:
    - Occupancy schedule
    - Space heating and cooling loads
    - Ambient temperatures and humidity
    - HVAC system type
    - Amount of time the system economizes
  - Note:
    - DCV is only helpful when it is very cold, or warm (or humid)

Energy Impacts of DCV

Building Type	Spaces DCV Applied	Location	Cost Savings per ft^2 / Year
Elementary Schools (8 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.09 - \$0.33
Middle Schools (6 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.05 - \$0.20
High Schools (4 schools)	Gyms, large classrooms, media centers, auditoriums, cafeterias	Colorado Springs, CO	\$0.05 - \$0.14
University Building	Large classrooms, offices	Boulder, CO	\$0.31
University Building	Large classrooms, offices	Boulder, CO	\$0.34
University Building	Large classrooms, offices, lobby, conference room	Denver, CO	\$0.23
Ice Rink	Ice rink	Edmonton, Canada	\$0.04
University[1]	Lecture halls	Indiana	\$0.14 - \$0.23
High-rise Office[2]	Open office	Oregon	\$0.11
Convention Center[2]	Convention halls	Oregon	\$0.10

Commissioning DCV

- **Commissioning Issues**
  - **Things to look for at all phases of the project**

Commissioning DCV

- **Design Phase Issues**
  - Verify that the commissioning specification is present and appropriate for the scope
  - Verify that the upper and lower min OA values are specified on the mechanical schedule
  - Verify that the sequences are properly written
  - Verify that the CO_2 sensor requirements are clearly and properly specified
  - Verify that the CO_2 sensors are located on plans, and the mounting height is clearly marked

Commissioning DCV

- **Submittal Phase Issues**
  - Verify that the submitted CO_2 sensor meets the specification requirements
  - Verify that the appropriate sensors have been selected for outdoor use, duct mount or space mount
  - Verify that the control submittal reflects design requirements and all sensors have been incorporated into the engineered control submittal drawings
  - Verify that the "packaged" mechanical equipment factory wiring is compatible with submitted sensor

Commissioning DCV

- **Construction Phase**
  - Verify that the submitted (and approved) sensors have been installed in the correct locations, and have proper covers or guards as needed

Commissioning DCV

- **Acceptance Phase**
  - Perform a calibration check by recording readings on all sensors early in the morning. All sensors should read within 50-70ppm or should be calibrated.
  - Functionally test all DCV related sequences, including the worst case scenario of minimum flow, and then verify proper building pressurization is still maintained.
  - Ensure that the owner's maintenance staff is aware of how to calibrate the sensors (calibration generally is not necessary on new sensors)

Commissioning DCV

- **Seasonal Testing / Short-Term Monitoring**
  - Take trend data (1-2 weeks) on the CO2 sensor signal, the damper operation of air handler and terminal units, exhaust fans status and building pressure to validate proper operation under normal occupied operating conditions
  - Generate a report or memo with plots indicating proper operation of the DCV strategy

Conclusion

- Verify applicable codes
- Apply DCV properly
- Use upper and lower limits in design
- Specify clearly
- Functionally test thoroughly
- Energy savings vary based on applicable code, building type, occupancy, spaces served and climate

Audience Participation

- Time Permitting…
  - Who has a DCV application / story to discuss?
  - Did I miss any topics on DCV?
  - SACO_2 applied?
  - Multi-point sampling CO_2 sensor?

Thanks for Listening!

Erik Jeannette, P.E.

Architectural Energy Corporation
San Francisco, California
Boulder, Colorado
Nashville, Tennessee

ejeannette@archenergy.com
www.archenergy.com
303-444-4149

ARCHITECTURAL ENERGY CORPORATION
Integrated Engineered Solutions