IAQ Building Education and Assessment Model (I-BEAM)

Text Modules: Indoor Air Quality and Energy Efficiency

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I-BEAM Text Modules

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Indoor Air Quality and Energy Efficiency (PDF, 14 pp, 79KB)

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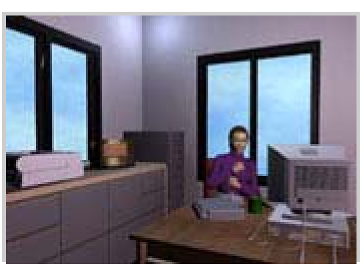
Indoor Air Quality (IAQ)

Energy Cost and IAQ Performance of Ventilation Systems and Controls



In 1999, EPA completed an extensive modeling study to assess the compatibilities and trade-offs between energy, indoor air quality, and thermal comfort objectives for HVAC systems and to help formulate strategies to simultaneously achieve superior performance on each objective. Much was learned as a result of this effort. The entire documentation of the study is contained in 7 individual reports plus an executive summary. All of the reports and the executive summary are available (See Energy Cost and IAQ Performance of Ventilation Systems and Controls Study EPA-4-2-S-01-001, January 2000)

Variations of Constant Volume (CV) and Variable Air Volume (VAV) systems were modeled in three different climates-hot and humid (Miami), temperate (Washington D.C.), and cold (Minneapolis) in an office building, school, and auditorium. Some of the key results are summarized below.

Energy and IAQ Compatibilities and Trade-Offs

How Did the Performance of CV and VAV Systems and Alternative Outdoor Air Control Strategies Compare? (Large Office Building)

- **Key Result: VAV systems saved energy**

  Explanation: The variable air volume systems provided $0.10 - $0.20 energy savings per square foot over constant volume systems modeled for a savings of 10% to 21% of HVAC energy cost. Since the modeled CV system is much more energy efficient than other CV systems, the results tend to underestimate the advantages of conversion from CV to VAV systems.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B

- **Key Result: VAV with fixed outdoor air fractions caused outdoor air flow problems**

  Explanation: VAV systems may require a different outdoor air control strategy at the air handler to maintain adequate outside air for indoor air quality than the constant volume predecessor. If the fixed outdoor damper strategy of the CV system, which is commonly used in the VAV systems, results in a fixed outdoor air fraction, the outdoor air delivery rate at the air handler may be cut to about one half to two thirds the design level during most of the year.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B

- **Key Result: Core zones received significantly less air than perimeter zones**

  Explanation: Both CV and VAV systems provided an unequal distribution of supply air and outdoor air to zones. The south zone received the highest and the core zone received the least outdoor air. The core zone received only about two thirds of the building average outdoor air flow.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: Core zones in VAV systems with a fixed outdoor air fraction received very little outdoor air**

  Explanation: The VAV system with fixed outdoor air fraction diminished the outdoor air delivery to the core zone to only about one third of the design level.. Even though the VAV with fixed outdoor air fraction is designed to deliver 20 cfm of outdoor air per occupant, the core zone received only 6-8 cfm per occupant, and only 2-3 cfm per occupant for a design level of 5 cfm per occupant. In some cases, this could contribute to higher indoor air quality complaint rates in the core relative to the perimeter zones.

  - Assessment of CV and VAV Ventilation Systems and Outdoor Air Control

Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: VAV with constant outdoor air control showed better outdoor air delivery without any meaningful energy penalty**

Explanation: A VAV system with an outdoor air control strategy that maintains the design outdoor air flow at the air handler all year round had slightly lower energy cost in the cold climate, and slightly more energy cost in the hot and humid climate. It is therefore comparable in energy cost, but preferred for indoor air quality.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: Economizers on VAV systems may be advantageous for both indoor air quality and energy in cold and temperate climates**

Explanation: By increasing the outdoor air flow when the outside air temperature (or enthalpy) is less than the return air temperature (or enthalpy), economizers can reduce cooling energy costs. For office buildings, economizers may operate to provide free cooling even at winter temperatures (e.g., at zero degrees Fahrenheit), provided that coils are sufficiently protected from freezing. Temperature economizers may need some mechanism to control humidity during warm weather. For the office building, energy savings of about $0.05 per square foot were experienced by the VAV system economizer over the non-economizer VAV system in cold and temperate climates. The economizer on the CV system was much less advantageous due to increases in heating energy costs for this particular system, and was actually more expensive under some utility rate structures.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

- **Key Result: VAV with constant outdoor air control and an economizer was overall the best, while VAV with constant outdoor air fraction (fixed outdoor damper) and no economizer was overall the worst system among those studied**

Explanation: Of all the ventilation systems and controls studied, the VAV system with constant outdoor air flow (variable outdoor air fraction), which in cold and temperate climates is combined with an economizer and proper freeze control and humidity control, provided the best overall performance considering outdoor air flow, thermal comfort and energy efficiency. The VAV system with a fixed outdoor air fraction (fixed damper) and no economizer provided the worst overall performance because it failed to deliver adequate outdoor air most of the time and had no energy benefit.

- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Outdoor Air Flow Rates and Energy Uses - (PDF 40 pp, 113KB) EPA Document number EPA-4-2-S-01-001B
- Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings -- Zonal Distribution of Outdoor Air and Thermal Comfort Control - (PDF 31 pp, 219KB) EPA Document number EPA-4-2-S-01-001C

What Kind of Energy Penalty was Associated with Raising Outdoor Air from 5 cfm to 20 cfm per Person? (Large Office Building)

- **Key Result: Raising outdoor air to meet ASHRAE Standard 62-1999 in most of the office buildings modeled resulted in very modest increases in energy costs**

Explanation: The main factor affecting the energy cost of raising outdoor air flow was occupant density, such that buildings with higher occupant density experienced higher energy cost increases. But for office buildings with 7 persons per thousand square feet, with moderate chiller and boiler efficiencies, and operating in daytime mode for 12 hours per work day, raising outdoor air flow from 5-20 cfm (2 - 9 L/s) per occupant raised HVAC energy costs by 2% - 10% (total energy costs by 1%-4%) depending upon system and climate variations. This is generally less than is commonly perceived and suggests that the issue needs a more careful examination by practitioners. The cooling cost increases in the summer months were counterbalanced by cooling cost savings during cooler weather. Cost increases were higher for economizer systems than systems without economizers because much of the cost savings from higher outdoor air flow rates during cooler weather was already captured by the economizer system. For buildings with occupant densities of 3 persons per thousand square feet, energy costs increases were less. By contrast, office buildings modeled with 15 persons per 1000 square feet experienced up to 21% increase in HVAC energy (or up to 8% increase in the total energy bill).

- Energy Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings - (PDF 22 pp, 94KB) EPA Document number EPA-4-2-S-01-001D

What Energy Penalty and Other Problems were Experienced when Outdoor Air was Increased in Schools and Auditoriums?

- **Key Result: VAV systems in education and auditorium required special adjustments for meeting the high outdoor air flow rates of ASHRAE 62-1999**

Explanation: In the education and auditorium buildings, the higher per occupant outdoor air requirements sometimes exceeded the total supply air needed to control thermal comfort. Even with the constant outdoor air damper control on the VAV system, the VAV box minimum settings had to be raised to what appear to be uncommonly high levels (e.g., 50% - 100% of peak flow), in order to maintain 15 cfm per occupant during part load.

- Potential Problems in IAQ and Energy Performance of HVAC Systems

When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

- **Key Result: Controlling humidity can be a problem for education buildings, auditoriums or other buildings with very high occupant densities where HVAC systems must deliver high outdoor air flow to meet ASHRAE Standard 62-1999**

Explanation: Relative humidity frequently exceeded 60% and occasionally exceeded 70% in all climates in the education buildings and the auditoriums even though the cooling coils were adequately sized to handle peak loads and the indoor temperatures were well controlled. Problems occurred at part load during mild weather when the outdoor relative humidity was high. The increased dominance of the outdoor air at 15 cfm per occupant meant that the heating and cooling system had to deal with wide ranges in the sensible to latent heat ratio, so that humidity as well as temperature had to be part of the control regime. Controlling humidity may be a subject of special concern in buildings with very high occupant densities which meet the outdoor air flow requirements of ASHRAE Standard 62-1999.

- Potential Problems in IAQ and Energy Performance of HVAC Systems When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

- **Key Result: The outdoor air requirements of ASHRAE Standard 62-1999 for education buildings, auditoriums and other buildings with very high occupant densities can create a significant energy burden**

Explanation: When outdoor air ventilation rates were raised from 5 to 15 cfm per occupant in the education building and the auditorium, HVAC energy costs for the school rose by 15% - 32% (5% - 14% of total energy cost), and by 26% - 67% (9% - 25% of total energy cost) in the auditorium. These results include all adjustments to insure adequate outdoor air flow at part load, and the control of relative humidity to 60% or below.

- Potential Problems in IAQ and Energy Performance of HVAC Systems When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings - (PDF 41 pp, 140KB) EPA Document number EPA-4-2-S-01-001F

How Were Peak Loads and Downsizing Potential Affected by Raising Outdoor Air Flow Rates? (All Buildings)

- **Key Result: Peak loads, and therefore equipment capacity requirements, may be significantly impacted when outdoor air ventilation rates are raised**

Explanation: Raising the rate from 5 to 20 cfm per occupant in office buildings often raised peak coil requirements by 15% - 25%, and created preheat requirements where none had previously existed. Raising the outdoor air flow rate from 5 to 15 cfm increased peak loads by 25%-35% in the education building, and by 35% - 40% in the auditorium. This could provide real limits to downsizing strategies which are often part of an energy efficiency strategy, and calls for specific steps to reduce peak loads without sacrificing outdoor air requirements. It also suggests that indoor air consultants advising clients of existing buildings to raise outdoor air flow rates in order to reduce indoor air quality complaints, should first consider the potential need to either increase capacity or reduce peak loads. Buildings without sufficient capacity may find themselves unable to maintain thermal comfort in the face of these higher outdoor ventilation rates, or in the worst scenario, may experience coil damage.

- Peak Load Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings - (PDF 17 pp, 74KB) EPA Document number EPA-4-2-S-01-001E

Can Energy Recovery Systems Solve the Energy and Humidity Problems of Higher Outdoor Air Flow in Schools and Auditoriums?

- **Key Result: Energy recovery technologies may potentially reduce or eliminate the humidity control, energy cost and sizing problems associated with ASHRAE Standard 62-1999 in education buildings, auditoriums, and other buildings with very high occupant density**

Explanation: Available literature and other modeling studies suggest that both latent and sensible energy recovery systems may significantly reduce or eliminate the associated problems of controlling thermal comfort, reducing energy costs, and downsizing equipment needs while meeting the outdoor air requirements of ASHRAE Standard 62-1999 in high occupant density buildings. Corroborating research could be of great value. Cost issues would include the capital cost of the energy recovery equipment, capital cost savings from downsizing, and the annual energy savings from the energy recovery system.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G
- Software tools to assess the potential for humidity control, outdoor air control, and economic viability of energy recovery systems in schools are available, see www.epa.gov/iaq/schooldesign/saves.html

Was Protecting IAQ a Hindrance to Achieving Energy Reductions During Energy Efficiency Projects? (Office, School)

- **Key Result: Protecting or improving indoor air environmental quality during energy efficiency retrofit projects need no hamper energy reduction goals**

Explanation: Many energy efficiency measures with the potential to degrade indoor environmental quality appear to require only minor adjustments to protect the indoor environment. When energy efficiency retrofit measures (including lighting upgrades), which were adjusted to either enhance or not degrade indoor environmental quality, were combined with measures to meet the outdoor air requirements of ASHRAE Standard 62-1999, total energy costs were cut by 42% - 43% in the office building and by 22% - 37% in the education building . The IAQ measures included raising outdoor air flow from 5 to 20 cfm per occupant in the office building and from 5 cfm to 15 cfm in the education building, installing a constant outdoor air flow control, and controlling humidity to 60% maximum. When measured against the base building energy costs, these IAQ measures meant that only 2%-3% of energy savings in the office building, and 3% - 9% in the education building were foregone. However, an energy recovery ventilation system would be expected to significantly reduce or eliminate these penalties in the education building. There appears to be demonstrable compatibility between indoor environmental goals and energy efficiency goals, when energy saving measures and retrofits are applied wisely.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G

- **Key Result: Operational measures that are compatible with IAQ save far more energy than operational measures that are incompatible with IAQ**

Explanation: Operational measures compatible with indoor environmental quality are expected to cut total energy costs by 10%-15% or more. These principally include preventive maintenance and tune-up of the HVAC, and reducing lighting use during unoccupied hours. By contrast, avoiding operational measures that degrade indoor environmental quality such as wider temperature control bands and reduction in operating hours meant that total energy reductions of only 3%-5% in the office building, and 7%-10% in the education building were foregone. It may make little sense to pursue energy reduction activities that compromise IAQ and run the risk and potential liability of IAQ related illnesses and complaints, when the energy saving potential for compatible measures is so much greater in comparison.

- The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings - (PDF 20 pp, 80KB) EPA Document number EPA-4-2-S-01-001G

Energy Retrofit Measures and IAQ

Retrofit Measures Compatible with IAQ

Most energy retrofit measures are generally compatible with IAQ provided that they are instituted with certain IAQ protections.. Staged energy retrofits that include provisions to protect IAQ and that provide additional outdoor air to meet the ventilation requirements of ASHRAE Standard 62-1999 can result in substantial energy saving. Some compatible measures and the steps needed to protect IAQ are discussed below.

Improving Energy Efficiency of the Building Shell

Tightening the building shell will reduce infiltration. Therefore, mechanically supplied outdoor air may need to be increased to insure applicable ventilation standards are met, and that there is sufficient make up air to satisfy exhaust ventilation requirements.

Reducing Internal Loads Such as Lighting and Office Equipment Upgrades

Reduced internal loads will reduce supply air requirements in VAV systems. Therefore, the outdoor air flow may need to be increased to meet applicable ventilation standards. Lighting must be sufficient for general lighting and task lighting needs.

Upgrading Fans, Motors, and Drives

All upgrades are compatible with IAQ and need no special IAQ protections.

Upgrading Chillers and Boilers

All upgrades are compatible with IAQ. Installation must be done so as to provide good access for cleaning and maintenance. Sufficient air must be supplied to boilers to support combustion and the proper exhaust of flue gasses. The boiler room should be under positive pressure. A dedicated outdoor air supply to support combustion is desirable if possible.

Energy Recovery Ventilation (ERV) Systems

Energy recovery ventilation systems provide excellent opportunities for saving energy, controlling humidity, and providing sufficient outside air to promote IAQ in high occupant density buildings. ERV systems also increase the potential for downsizing other HVAC components. EPA's software for assessing the IAQ and energy and economic potential of ERV systems for schools is available to interested parties.

Equipment Downsizing

Prudent avoidance of over-sizing equipment reduces first costs and energy costs. However, capacity must be sufficient for thermal and outdoor air requirements during peak loads in both summer and winter.

Latent load should not be ignored when sizing equipment in any climate. Inadequate humidity control has resulted in thermal discomfort and mold contamination so great as to render some buildings uninhabitable.

Energy recovery systems may enable chillers and boilers to be further downsized by reducing the thermal loads from outdoor air ventilation.

Retrofit Measures That Are Incompatible With IAQ

Most retrofit measures are compatible with IAQ provided that the precautions identified above are adhered to. Perhaps the most critical issue is downsizing. Often, equipment is downsized, without considering the ventilation requirements of ASHRAE 62-1999. In such cases, if IAQ problems occur because of inadequate ventilation, the system would be incapable of solving the problem.

Operational Measures for Energy and IAQ

Operational Measures That Are Compatible With IAQ

Most energy conservation measures are compatible with IAQ or can be made compatible as long as actions are taken to protect against potentially adverse IAQ effects. This section delineates measures that are compatible and, where they occur, identifies the potentially adverse effects to be avoided.

Preventive Maintenance (PM) of HVAC

Preventive maintenance will improve IAQ and reduce energy use by removing contaminant sources (e.g. clean coils/drain pans), and insuring proper calibration and efficient operation of mechanical components (e.g. fans, motors, thermostats, and controls). Data from many buildings throughout the United States show that a properly commissioned building with controls and equipment functioning properly can save 5%-15% in total building energy cost.

Air-Side Economizer

Economizers use outdoor air to provide free cooling. Economizers potentially improve IAQ when economizer is operating by helping to insure that the outdoor air ventilation rate meets IAQ requirements.

Economizers are not practical or advisable in hot-humid climates. Except in dry climates, moisture control must be incorporated. For example:

- On/off set points could be calibrated to both the temperature and moisture conditions of outdoor air to avoid indoor humidity problems.
- Outdoor air may be dried using desiccants prior to entering the indoor space.
- Economizer may shut down when a preset outdoor air temperature is exceeded.

Economizer may need to be disengaged during significant outdoor air pollution episodes if that is a problem, or an air cleaning capability could be applied to the outdoor air prior to entering the occupied space. Economizers may be expected to reduce annual HVAC energy costs in cold or temperate climates.

Night Pre-Cooling

Cool outdoor air at night may be used to pre-cool the building while simultaneously exhausting accumulated pollutants. This is called building flush. However, the cool outdoor air may also have a high moisture content and could humidify the building at night, so caution is suggested. In addition to preventing microbiological growth, controls should stop pre-cooling operations if the dew point of the outdoor air is high enough to cause condensation on equipment.

Reducing Demand Charges

Night pre-cooling and sequential startup of equipment to eliminate demand spikes are examples of strategies that are compatible with IAQ. Load shedding strategies, which are potentially incompatible with IAQ, may involve changing the space temperature set points, or reducing outdoor air ventilation during occupancy. These can create IAQ problems and complaints.

Supply Air Temperature Reset

Supply air temperature may sometimes be increased to reduce chiller energy use in VAV systems. However, fan energy will increase because more air is required to provide the same cooling. Higher (lower) supply air temperatures in a VAV system will increase (decrease) supply airflow - this may increase (decrease) outdoor airflow in systems that provide a constant percentage of outdoor air. A higher supply air temperature also reduces dehumidification potential and could create excess indoor humidity.

CO_2 Controlled Ventilation

CO_2 controlled ventilation varies the outdoor air supply in response to CO_2 which is used as an indicator of occupancy. CO_2 controls may be useful for reducing energy use for general meeting rooms, studios, theaters, educational facilities, etc., where occupancy is highly variable, and irregular.

A typical system will increase outdoor air when CO_2 levels rise to 600-800 PPM to insure that maximum levels do not exceed 1,000 PPM. The system should incorporate a minimum outside air setting to dilute building related contaminants during low occupancy periods. CO_2 sensors must be calibrated periodically and set points may need to be adjusted based on outdoor CO_2 levels around the building.

Reduce Light Usage During Unoccupied Hours

Reducing light usage during unoccupied hours saves considerable energy, is easy to administer, and is compatible with IAQ.

IAQ Incompatible Operational Measures

Attempts in the past to save energy have needlessly compromised IAQ and resulted in occupant complaints and/or serious illness. This section delineates those measures to avoid, and demonstrates that the potential energy loss from avoiding these measures is not significant.

Reducing Outdoor Air Ventilation below Standards

Applicable ventilation standards usually specify a minimum continuous outdoor airflow rate per occupant, and/or per square foot, during occupied hours. Standards are designed to insure that pollutants in the occupied space are sufficiently diluted with outdoor air. Reducing outdoor airflow below applicable standards can degrade IAQ and has low energy saving potential relative to other energy saving options.

Reducing HVAC Operating Hours

Delayed start-up or premature shutdown of the HVAC can evoke IAQ problems and occupant complaints. The loss in energy savings from avoiding this strategy is not significant in a well-run building.

- An insufficient lead-time prior to occupancy can result in thermal discomfort and pollutant-related health problems. IAQ problems can last for several hours, as the HVAC system must overcome the loads from both the nightly setbacks and from current occupancy. This is a particular problem when equipment is downsized.
- Shutting equipment down prior to occupants leaving may sometimes be

acceptable provided that fans are kept operating to insure adequate ventilation.

Relaxing Temperature / Humidity Set Points Below Standards

Occupant satisfaction and productivity is highly sensitive to temperature and humidity conditions. In addition, even a slight thermal discomfort can exacerbate pollution-related problems when they occur compounding the complexity and cost of diagnosis and remediation. The loss in energy savings from avoiding this strategy is not significant in a well-run building.

International Performance Measurement and Verification Protocol (IPMVP)

This document discusses procedures to quantify energy conservation measure (ECM) performance and energy savings in buildings. An appendix covering indoor environmental issues has also been developed. Download a PDF version of the December 1997 protocols (DOE/EE-0157) (PDF, 192 pp, 647KB)

Calculating Energy Saving Potential of Upgrades

EPA's Energy Star Program encourages building owners and managers to upgrade their equipment to save energy. A number of technical assistance packages are available to Energy Star Partners and to others on the WEB. Browse through the Energy Star website to take advantage of this assistance.