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Operation and Maintenance for Indoor Air Quality: Implications from Energy Simulations of Increased Ventilation

J.A. Ventresca
Associate Member ASHRAE

ABSTRACT

To assess the impact of increasing the minimum outside air ventilation to 20 cfm/person upon both energy use and indoor air quality (IAQ), energy simulations were integrated with a real world case study building application. The simulations indicate that in temperate climates, high-rise office buildings with air economizers may experience very little energy increase, while some buildings, such as schools, may experience a heating energy increase of 20% or more. An important IAQ implication from the energy simulations is that many commercial buildings located in temperate climates, and requiring cooling all year with air economizers, should be operating on the economizer with more than 20 cfm/person outside air for the vast majority of operating hours throughout the extended fall, winter, and spring—if the economizer is working correctly. Improper economizer operation can cause inadequate ventilation and/or building overheating and associated IAQ complaints. This is a strong indication of the need for quality operation and maintenance (O&M) to ensure proper economizer operation.

INTRODUCTION

A study of the relationship between increasing the minimum outside air ventilation and the impacts upon energy use and indoor air quality was conducted by the City of Columbus, Ohio.

One of the best-documented simulation-based assessments of the energy impacts of increased minimum ventilation is the work of Eto and Meyer (1988). Their work examined energy operating costs and equipment sizing. Their methodology simulated one type of building in several climates as diverse as Miami, Florida, and Winnipeg, Canada. This provided for an assessment of the effect of weather upon increasing minimum outside air ventilation. The building type simulated was a large high-rise office building of 38 floors and 597,500 ft^2. This building was simulated with a variable-air-volume (VAV) air distribution system, perimeter radiation heating, and an air economizer. It was simulated with minimum outside air of 5 cfm/person and with step increases of 5 cfm/person up to 20 cfm/person minimum outside air. The simulated energy increases from increasing the minimum outside air from 5 to 20 cfm/person were as follows: heating energy increases of 0% to 8%, cooling energy increases of 1% to 14%, electric demand increases of 0.5% to 8%, insignificant fan energy increases, and total energy cost increases of less than 5%. To better understand the energy and IAQ impacts, it is valuable to examine the impacts on heating and cooling energy, not just total cost.

METHODOLOGY

The methodology involved energy simulations of increased minimum ventilation as part of a broader project that included (1) actual field measurement of increased electricity demand, (2) measurements of indoor air pollutants, and (3) many hours of observation of the HVAC systems in a case study high-rise office building in Columbus, Ohio. The case study building has a VAV air distribution system, with an air economizer and perimeter radiation heat. With a grant through the Urban Consortium Energy Task Force (UCETF), with DOE funding, theoretical simulations were integrated with a real world case study building application. This comprehensive approach, encouraged by the UCETF, was critical for gaining a better understanding of the nature of the energy *and* indoor air quality impacts of increasing minimum outside air ventilation.

The energy simulations assumed Columbus weather, with minimum outside air at 5 cfm/person, and then increased to 20 cfm/person. Several types and sizes of buildings were simulated. A commercially available hourly analysis program was used because we have used this program for a number of years to compare simulated performance to actual performance of energy retrofits. It incorporates the following essential features: (1) it utilizes the transfer function method of load calculation, (2) it models Columbus utility rates, and (3) it does hourly simulations for three representative days per month. For details of the energy simulations, see Ventresca and Shrack (1990) and the UCETF final project report available from PTI (see Acknowledgments for address).

RESULTS: ENERGY IMPACTS SUMMARY

The simulated energy increases from increasing the minimum outside air from 5 to 20 cfm/person, for a prototypical 100,000 ft^2, 10-story office building in Columbus, Ohio, were a 2.8% increase in heating energy and a 6.3% increase in cooling energy. This is in complete agreement with Eto and Meyer's simulation results for similar climates. We selected building charac-

Joseph A. Ventresca is Energy Coordinator, City of Columbus, Ohio.

have been diagnosed as suffering from "tight building syndrome" *should* be operating with outside air ventilation rates well above 20 cfm/person throughout the extended fall, winter, and spring.

These buildings have the following characteristics: (1) internal heat generation requiring cooling all year; (2) cooling supplied via air economizers; (3) medium to large size, generally greater than 20,000 ft^2; and (4) located in temperate climates. Most buildings in this category have sealed windows and are incorrectly referred to in the popular literature as "sealed" buildings. If there is inadequate outside air ventilation in this type of building during temperate weather conditions, it is very likely that the central economizer is operating improperly and/or the terminal air distribution supply boxes and thermostats are operating improperly. This is a strong indication of the need for (1) maintenance to ensure proper air economizer operation and (2), once the central economizer is operating correctly, maintenance to ensure that terminal air supply boxes and thermostats are working correctly to deliver the outside air to the occupants.

Operation at Minimum Outside Air

The energy simulations show that for the subject group of buildings, in temperate climates, summer is the time when the buildings operate for an extended period with minimum outside air. This is because whenever the outside air contains more total heat than the return air, the building should be operated at minimum outside air for energy efficiency. For the simulations, minimum outside air was assumed whenever it was hotter than 70°F (simple dry-bulb control). Therefore, complaints of inadequate ventilation would be expected to peak in late July and August. Paradoxically, however, our experience with managing complaints in more than 70 buildings during the last 10 years and the experience of the Columbus Health Department is that complaints of inadequate ventilation and IAQ complaints in general peak in the spring and fall, at the time when outside air ventilation rates are the greatest from cooling with the air economizer. This is historically the time of year when temperature control problems peak, since even marginal temperature controls may provide satisfactory performance on full heating in the cold of winter or on full cooling in the heat of summer.

In contrast, we find that when outside air ventilation rates are their lowest, during hot weeks in the middle of summer, if the building temperatures are comfortable, there are rarely complaints of inadequate ventilation, even though outside fresh air is lower and CO_2 values are higher. This real world building experience agrees with the scientific documentation of Berglund and Cain (1989), who documented that cooler air is perceived as fresher: "Air was perceived to be fresher and less stuffy with decreasing temperature and relative humidity. The effect of temperature was linear and stronger than humidity."

IAQ Complaints Associated with Building Overheating

Improper economizer operation causes indoor air quality complaints by causing building overheating. There may be a winter pattern of building temperatures starting the day relatively cool, perhaps 67°F to 69°F, and rising to overheated temperatures of 77°F to 80°F on some afternoons. With improper operation of the economizer and temperature controls, by late afternoon the building's internal heat gains build up, and this, combined with warmer mid-day temperatures and low-angle penetrating passive solar gain, causes building overheating. We have documented repeated cases of complaints of stuffiness, inadequate ventilation, drowsiness, and eye and nose irritation on afternoons in the spring, winter, and fall, when the buildings were operating on economizer with maximum amounts of outside air. For example, IAQ complaints and complaints of "stuffiness" peaked in the areas of the case study building that were overheated (i.e., 77°F to 80°F) on winter afternoons when the HVAC system was operating on economizer with maximum amounts of outside air (i.e., 70 cfm/person or more as calculated from CO_2 values). Over the last seven years in Columbus buildings, we have experienced dramatic decreases in IAQ complaints by providing the occupants with thermostats that they control, to provide accurate temperature control. This experience agrees with the research of Seppanen and Jaakkola (1989), who found "there was a linear correlation between increase in (SBS) symptoms and rise in room temperatures." Providing accurate temperature control is not easy. It requires proper original HVAC controls design and continued operation and maintenance diligence.

Temperature measurement, while often taken for granted, is actually a sophisticated measurement that is proportional to the mean translational (kinetic) energy of the molecules of air (Forbrich and Nicolai 1974) and therefore is interactive with other indoor air quality parameters. Providing adequate cooling can often increase airflow and so improve ventilation effectiveness and pollutant removal. Raising temperatures during "bake-out" procedures increases the outgassing of volatile organic compounds (VOCs). Similarly, buildings that are operated 5°F to 10°F warmer than necessary may experience higher VOC outgassing rates. Temperature also greatly influences relative humidity. Overheated conditions of 79°F and 16% relative humidity are common on cold Ohio winter afternoons. The psychrometric chart shows that if the temperature is reduced by 7°F, to 72°F, the relative humidity rises by 4%. This 4% increase in relative humidity, from 16% to 20%, represents a 25% proportional increase because the initial relative humidity was so low.

To detect building overheating on the economizer cycle, it is necessary to monitor the temperature continuously in order to determine the temperature pattern. Instantaneous temperature measurement may not reveal many cases of poor temperature control. While much attention has been given to proper measurement for other indoor air parameters requiring integrated measurement, accurate integrated temperature measurement is often overlooked.

Operation and Maintenance Conditions That Cause Improper Economizer Operation

The following five operation and maintenance conditions that cause improper economizer operation and overheating were identified:

1. HVAC control problems. Overheating in the economizer mode occurs when the economizer is not totally broken but it isn't working accurately either. Maintenance, adjustment, and calibration of the economizer controls are needed. Then, after the central economizer controls are operating correctly, adjustment and calibration of the terminal air supply boxes and thermostats are needed.

2. Outside air damper closing from freeze stat signal. Outside air dampers were observed to be closed at temperatures of 32°F and colder. Even at these temperatures, considerable amounts of outside air (i.e., 55% at 30°F) are needed to provide 55°F air for cooling building internal heat. However, the cold air may stratify and hit the coil freeze stat, which then closes the O.A. damper completely. This can occur on a considerable number of winter days in temperate climates. The solution requires ductwork/damper modifications to provide proper air mixing.

3. Chiller water towers that are inoperable in the winter. On warmer winter afternoons, the chillers are needed to further cool the outside air. However, if the chillers are inoperable because the

water towers have been drained to protect them from freezing, the result we have experienced is IAQ complaint calls to the local health department.

4. Improper tracking of supply and return air fans. Even if the outside air damper is open, outside air will not be drawn into the building unless the supply air fan pulls it in. If the return air fan is running too fast, then inadequate outside air intake and negative building pressurization will occur. The solution will depend upon the type of airflow volume control equipment in the particular building, i.e., inlet vane control, outlet damper control, variable-speed drives, fan-tracking control, building pressure sensing control, etc.

5. Return air damper malfunction. At 100% outside air, the return air damper should be fully closed and well sealed. Otherwise, return air is recirculated, which can cause overheating. The solution requires "maintenance" but not in the usual sense of the word, such as lubrication, etc. Economizer maintenance is "system" maintenance, to ensure that the economizer system is working optimally to maintain the required supply air temperature. This requires expertise and experience in pneumatics, in DDC, and in troubleshooting, testing, and optimizing the entire HVAC controls system.

Columbus energy management experience over the last 10 years has shown that one, two, or all of these conditions exist in many buildings. Correcting them should be a first step toward improved indoor air quality (Ventresca 1989).

CONCLUSION

An important implication from the energy simulations for indoor air quality is that many commercial buildings located in temperate climates and requiring cooling all year with air economizers should be operating on the economizer with more than 20 cfm/person outside air whenever the temperature is between about 20°F and 70°F. This assumes the air economizer is operating properly, which is critical. Experience with the case study building revealed that improper economizer operation may cause inadequate ventilation and/or building overheating and associated IAQ complaints. This is a strong indication of the need for quality operation and maintenance (O&M) in "healthy buildings" to ensure proper economizer operation and accurate temperature control.

ACKNOWLEDGMENT/DISCLAIMER

The statements and conclusions contained herein are those of the grantee. Neither the United States nor DOE nor the Urban Consortium for Technology Initiatives and its Energy Task Force makes any warranty, express or implied, or assumes any responsibility for the accuracy or completeness of the information herein.

The comprehensive final report on this UCETF project is available from Public Technology, Inc. (PTI), c/o D. dePercin, 1301 Pennsylvania Ave., N.W., Washington, DC 20004.

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