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THE HVAC COSTS OF INCREASED FRESH AIR VENTILATION RATES IN OFFICE BUILDINGS, PART 2

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This study reports on predicted changes in annual energy operating costs that result from increased minimum outside air ventilation rates. The analysis is based on parametric DOE-2.1C simulations for typical small and medium office buildings in ten U.S. cities. In the simulations, minimum ventilation rates are increased from 5.0 liters per second per person (L/s.person)(10 cfm/person) to 17.5 L/s.person (35 cfm/person). Annual building energy costs are calculated using current electricity and natural gas tariffs for each location. The results suggest that, for the buildings, climates, and economic conditions examined, increasing minimum outside air ventilation rates, from the lowest level to that called for by the current ASHRAE Standard (10 L/s.person) will have small impacts on annual building energy costs. We found an average of 5% for the small office and 3% for the medium office. These results are due to the relatively small amount of energy used for HVAC purposes in typical office buildings and the operation of an economizer cycle, which has the effect of increasing outside air ventilation beyond the minimum for most operating hours.

INTRODUCTION

In 1989, ASHRAE adopted revisions to its Standard 62-1981, "Ventilation for Acceptable Air Quality" (1). The Standard offers two methods for compliance: a prescriptive method, which provides guidelines for designing a building for acceptable indoor air quality (through specification of minimum outside air ventilation rates), and a performance method, which relies on measurements of the completed building to determine indoor air quality. In this paper, we focus on changes in annual energy use and annual energy operating costs that result from simulations of typical office buildings operated to follow the guidelines of the prescriptive method.

In 1988, Eto and Meyer presented a similar study using a building energy simulation program to estimate the impacts of different ventilation rates for a large office building (2). They found that increasing minimum outside air ventilation rates from the lowest level of the earlier Standard (2.5 L/s.person, assuming no smokers) to the current Standard (10 L/s.person) would increase energy operating costs by no more than 5% and building first costs by no more than 1%. The current study is intended to complement this earlier analysis, by extending the range of building types and minimum outside air ventilation rates examined.

METHOD OF ANALYSIS

The method of analysis relies on a series of parametric building energy simulations in which all features of the building are held fixed, except the minimum outside air ventilation rate. The other aspects of the building description, including structural, architectural, mechanical, and electrical characteristics and hours of operation and temperature setpoints, remain unchanged, not only as the minimum ventilation rate changes for a given city, but also across cities. This latter step ensures that results can be compared, on a consistent basis, between cities as well as within them.

Six simulations are performed, each with a different rate of minimum outside air ventilation. The lowest ventilation rate was 5.0 L/s.person (10 cfm/person) increasing in increments of 2.5-L/s.person (5 cfm/person) to 17.5 L/s.person (35 cfm/person). In normal operation, these minimum ventilation rates are frequently exceeded when, for cooling purposes, additional outside air is taken in through an economizer cycle.

The DOE-2 building energy analysis program (version DOE-2.1C) is used to study the changes in energy use, energy costs, and equipment sizing that result from increasing minimum outside air ventilation rates. The DOE-2 program was developed for the Department of Energy to provide architects and engineers with a state-of-the-art tool for estimating building energy performance (3). The DOE-2 program has been extensively validated (4).

The two office building prototypes simulated are based on actual buildings of recent vintage, with modifications that make them representative of typical 1980s building construction practice. The prototypes were originally developed for the ASHRAE-sponsored evaluation of revisions to Standard 90 (5). In that evaluation, the building was slightly altered for each climate; for the present analysis, only one building was used (designed originally for the Washington, DC, climate) for each location. Operating schedules were taken from the Standard Building Operating Conditions developed for the Building Energy Performance Standards (6). The HVAC system for the medium office building was designed so that only electricity would be used for cooling and only natural gas would be used for heating (of course, electricity is also used for lighting, fans, pumps, etc.). For the small office building, electricity provides both heating and cooling. Major features of the office building prototypes are summarized in Table 1.

The simulations are performed using weather data and current utility tariffs from ten U.S. cities. The weather data are from either the Weather Year for Energy Calculation (WYEC) series developed for ASHRAE (7), or from the Typical Meteorological Year series developed by NOAA (8).

RESULTS

Table 2 summarizes the percentage changes in annual energy operating costs found for each minimum outside air ventilation rate and building type. The Table also presents the nominal annual operating cost (in $1987 per square meter) for each location and building type, at the base case ventilation rate of 5 L/s.person (10 cfm/person).

We find that increasing minimum outside air ventilation rates from the base case (5 L/s.person, 10 cfm/person) to the level called for by the new Standard (10 L/s.person, 20 cfm/person) increased energy operating costs by an average of 5% for the small office and 3% for the medium office. The greatest percentage increase in annual energy cost is found for the small office in Boston (9%) and Minneapolis (8%). For the medium office, the largest percentage increase is found in Miami (6%) followed by Washington (5%).

The findings for the small office are driven by the large heating requirements found in Minneapolis and Boston (5 MJ/m\s-2\u2\d\s+2 and 4 MJ/m\s-2\u2\d\s+2 at 5 L/s.person, respectively). The findings for the medium office in Miami are driven largely by increases in cooling energy of 13% from a base case of 0.8 kWh/m\s-2\u2\d\s+2. For the medium office in Washington, a moderate increase in heating energy use (up 5% from a base case of 2 MJ/m\s-2\u2\d\s+2), coupled with relatively large increase in cooling energy (up 12% from a base case of 0.4 kWh/m\s-2\u2\d\s+2) explains the increase in total costs.

DISCUSSION

The results presented in the previous section indicate that, for the simulations performed, increased minimum outside air ventilation rates will have relatively small effects on annual building energy costs. In particular, the simulations do not support a one-to-one relationship between percentage increases in minimum outside air ventilation and increases in annual energy costs. For example, a doubling in the minimum ventilation rate from the lowest value examined to that called for by the current Standard, corresponds to an average increase in annual energy costs of about 5% for the small office.

The primary reason for small increases in energy costs is that energy use for heating, cooling, and auxiliary HVAC end uses represents only a fraction of the total energy operating costs of modern office buildings. Energy use for lighting and miscellaneous equipment constitutes a large, fixed component of energy costs that is unchanged by increased outside air ventilation rates.

A second reason for our findings has to due with the operation of modern HVAC systems. In all of our simulations, we assume that an economizer is able to introduce outside air in excess of the minimum ventilation rate whenever the outside air temperature is less than a given value (specifically, we have used a drybulb setpoint of 19°C or 66°F. For most office buildings, normal operation of the economizer means that outside air ventilation rates will generally exceed the minimum rates called for in the Standard. That is, increased minimum ventilation rates can only increase energy use when the supply air temperature would otherwise be higher (in the heating mode) or lower (in the cooling mode), but for this minimum rate. In most office buildings, this circumstance only occurs at the extremes of the temperature scale, i.e., only at very low or very high outside air temperatures. Consequently, for a large number of operating hours, the Standard has no effect on energy use.

SUMMARY

We have performed a simulation-based analysis of the increases in energy use and energy costs that result from building operation at different minimum outside air ventilation rates. The analysis relied on parametrically increasing minimum outside air ventilation rates for a medium and small prototypical office building in 10 U.S. cities. A minimum outside air ventilation rate from the previous Standard, 5.0 L/s.person (10 cfm/person), was the basis for comparison to both the current Standard of 10 L/s.person (20 cfm/person) and several higher minimum rates. Economics were evaluated with actual and current utility rate tariffs.

The results suggest, for the prototypes, climates, and economic conditions examined, that the increased minimum outside air ventilation rates called for by the new Standard: 1. May increase annual energy operating costs on average between 3% and 5% (for medium and small office buildings, respectively); 2. May increase energy costs relatively more for smaller buildings located in colder climates; and, 3. May increase energy costs relatively more for larger buildings located in warmer climates.

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Table 1. Summary of Building Characteristics

	Medium Office	Small Office
Size	4,524 m^2 (48,680 ft^2)	209 m^2 (2,250 ft^2)
Shape	3 floors, rectangular	1 floor, square
Construction	steels frame superstructure, 4" precast concrete walls	wood frame, brick veneer
Glazing	36% of wall area, equally distributed	50% north and south, 10% west, 3% east
Operation	8 am - 6 pm weekdays, with some evening work, 30% occupancy on Saturday, closed Sundays and holidays	identical to medium office
Thermostat Settings	24°C (76°F)cooling 22°C (72°F) heating (night and weekend setback) 17°C (62°F)	identical to medium office
Internal Loads	26 W/m^2 (2.4 W/ft^2) lighting 5.4 W/m^2 (0.5 W/ft^2) equipment	identical to medium office
Occupancy	13.7 m^2/person (148 ft^2/person)	11.0 m^2/person (118 ft^2/person)
HVAC Air-Side	dual-duct system with variable speed fan; dry bulb economizer set at 19°C (66°F)	variable air volume, direct expansion, rooftop unit; dry bulb economizer set at 19°C (66°F)
Heating Plant	gas-fired hot water boiler (eff.=75%)	baseboard electric
Cooling Plant	air-cooled, hermetic reciprocating chiller (COP = 2.4)	direct expansion (COP=2.8)

Table 2. Annual Energy Operating Cost Impacts

	5 L/s.person ($1987\$/m^2$)	Percentage Increase from 5 L/s.person				
		7.5 L/s.person	10 L/s.person	12.5 L/s.person	15 L/s.person	17.5 L/s.person
Small Office						
Atlanta	0.16	2.0	4.0	6.4	8.7	11.3
Boston	0.35	3.8	8.5	14.0	19.0	25.3
Chicago	0.41	1.3	2.8	5.4	8.0	10.9
Dallas	0.13	1.9	3.7	5.8	8.3	11.3
Miami	0.21	1.9	3.5	5.4	7.1	9.0
Minneapolis	0.14	3.6	7.4	11.9	16.0	20.6
New York	0.27	2.7	5.8	9.5	13.1	17.4
San Diego	0.17	1.3	2.5	3.8	5.0	6.5
Seattle	0.06	2.9	6.2	10.2	14.3	19.1
Washington	0.25	1.2	2.3	3.7	5.0	6.5
Medium Office						
Atlanta	0.13	2.1	4.1	6.2	8.2	10.4
Boston	0.13	1.6	3.2	4.9	6.8	9.2
Chicago	0.13	1.6	3.1	4.8	6.8	9.1
Dallas	0.14	2.1	4.2	6.4	8.6	10.8
Miami	0.14	2.8	5.7	8.7	11.8	14.9
Minneapolis	0.14	1.2	2.9	5.0	7.5	10.2
New York	0.13	1.8	3.5	5.2	7.3	9.6
San Diego	0.12	0.9	1.7	2.5	3.3	4.2
Seattle	0.12	0.6	1.1	2.0	2.8	3.8
Washington	0.13	2.3	4.6	7.0	9.5	12.0