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VENTILATION

Office building update

HVAC cost changes

An Analysis

The HVAC costs of fresh air ventilation

Changes in annual energy operating costs resulting from increased minimum outside air ventilation

By Joseph H. Eto and Cecile Meyer
ASHRAE Member

ASHRAE Standard Project Committee 62-1981R is in the process of revising Standard 62-1981, "Ventilation for Acceptable Air Quality." The revisions will have far-reaching consequences for building owners and operators since the standards are likely to be incorporated into building codes at some point in the future [McNall 1984]. Currently, there are two methods of compliance: a prescriptive method, which is essentially a guideline for designing a building for acceptable indoor air quality, and a performance method, which relies on measurements of the completed building to determine indoor air quality. In this article, we focus on changes in annual energy use, annual energy operating costs, equipment sizing and first cost of the HVAC system that result from simulations of a building designed and operated to follow the guidelines in the prescriptive method. The interested reader is directed to Nero and Grimsrud [1984] for a general discussion of the performance method.

Under the prescriptive method, the standard is specified in terms of minimum outside air ventilation rates. That is, since energy-efficiency considerations dictate that commercial buildings recirculate as much indoor air as possible, except during economizer operation, a minimum outside ventilation rate must be maintained to ensure acceptable indoor air quality, in the absence of exceptional sources. The measure is units of outside airflow per inhabitant, cubic feet per minute per person (cfm/person).

The standard presently in effect recommends two separate *minimum* outside air ventilation rates that depend on whether smokers are present. In offices, ASHRAE recommends 5 cfm/person without smokers and 20 cfm/person with smokers [ASHRAE 1981]. The proposed standard does not distinguish the presence of smoking and simply recommends a minimum of 20 cfm/person [ASHRAE 1987]. Whether this new rate of outside air intake is sufficient to ensure acceptable indoor air quality remains a subject of debate (see, for example, Leader and Cain [1984] or Sterling and Sterling [1984]).

In 1982, Ross, Goodman and Birdsall published results from a similar study also using a building energy simulation program to estimate the impacts of different ventilation rates [Ross et al. 1982]. The present study is intended to complement this early work and extend the analysis in several new directions:

- The list of locations examined is expanded to include Canadian cities, as well as new U.S. locations.
- Actual current utility tariffs for each site are used for the annual operating energy costs.
- Changes in central plant equipment capacities are used to estimate the changes in HVAC system first costs.

Method of analysis

The method of analysis relies on 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—its structural, architectural, mechanical and electrical characteristics and its 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.

Four simulations were performed for each location, each with a different rate of minimum outside air ventilation. The lowest ventilation rate was 5 cfm/person increasing in increments of 5 cfm/person to 20 cfm/person. In normal operation, these ventilation rates are frequently exceeded when, for cooling purposes, additional outside air is taken in through an economizer cycle.

DOE-2 building energy analysis program: The program (version DOE-2.1C) was 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 tool for estimating building energy performance [Curtis 1984]. The DOE-2 program has been extensively validated [Diamond 1986].

Three features make DOE-2 particularly useful for a study of the energy and cost implications of increased ventilation rates in office buildings:

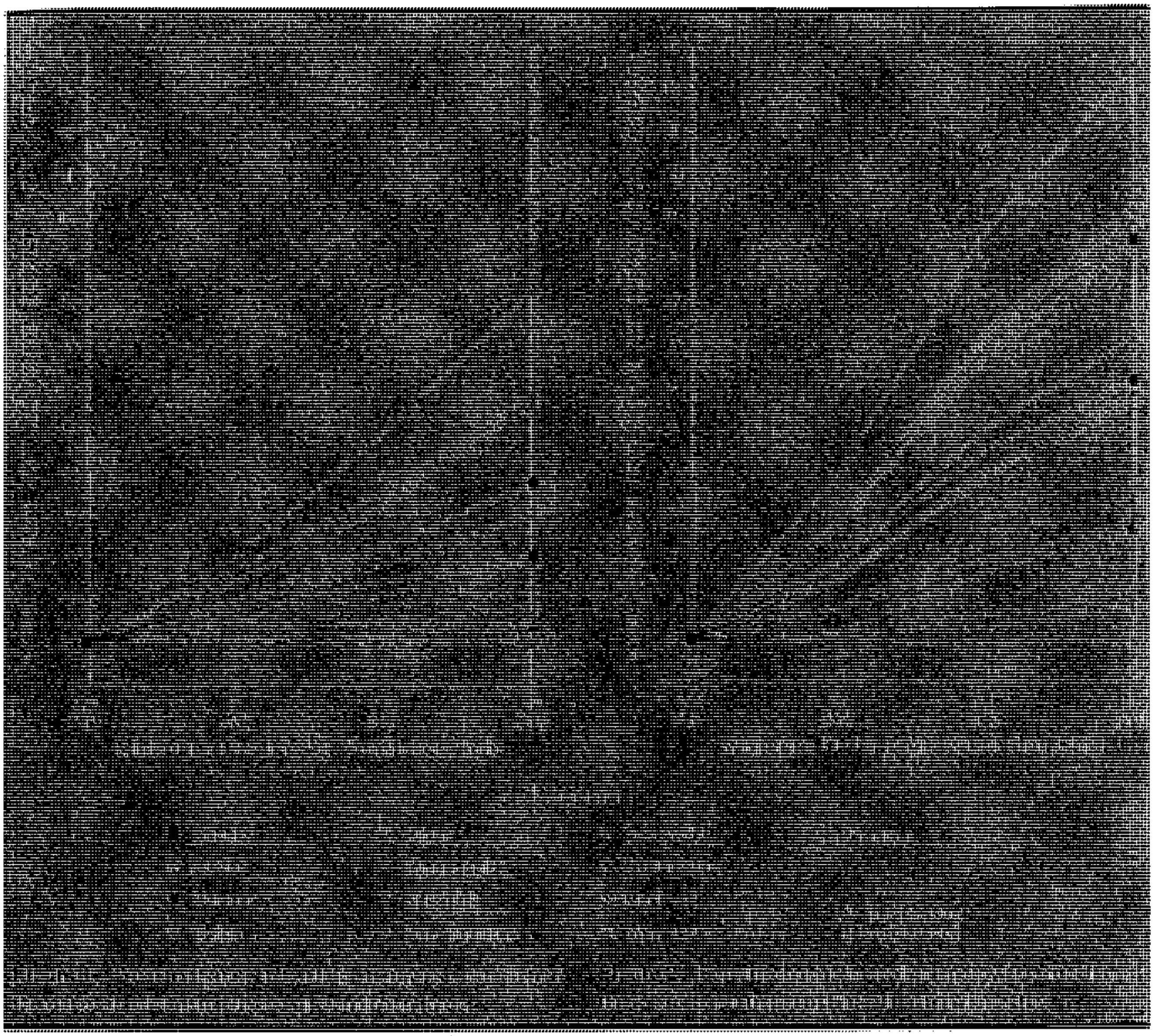
1. Heating and cooling loads are calculated on an hourly basis.
2. The structure and operation of a building can be specified by user inputs.
3. Version 2.1C of the program allows the user to model actual electricity and natural gas rate tariffs, including time-of-day prices for energy and demand charges, demand charges with sophisticated ratchets, and block rates with dynamic tier boundaries (i.e., boundaries that are a function of demand, as in kWh/kW).

[illegible]

Office building prototype: The office building prototype simulated is based on an actual building of recent vintage with modifications to ensure compliance with ASHRAE Standard 90-1975 [ASHRAE 1975]. This prototype was originally developed for the ASHRAE-sponsored evaluation of revisions to Standard 90 [Battelle 1983]. 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, D.C., climate) for each location.* Operating schedules were taken from the Standard Building Operating Conditions developed for the Building Energy Performance Standards [DOE 1979]. The HVAC system 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.). Slight modifications also were made to some aspects of the HVAC system in order

* We have found that use of a single building for all locations, rather than a separate, slightly altered prototype for each location, does not materially affect the findings.

[illegible]



to make the building more representative of current design and operation practices. The modifications include a lower cooling setpoint (76 F), a higher economizer setpoint (70 F) and reverse-action thermostats. Major features of the office building prototype are summarized in *Table 1*.

The simulations were performed using weather data and utility tariffs from 10 U.S. and three Canadian cities. The variables considered in selecting the locations included climatic variation, office building population, and utility rate types and levels.

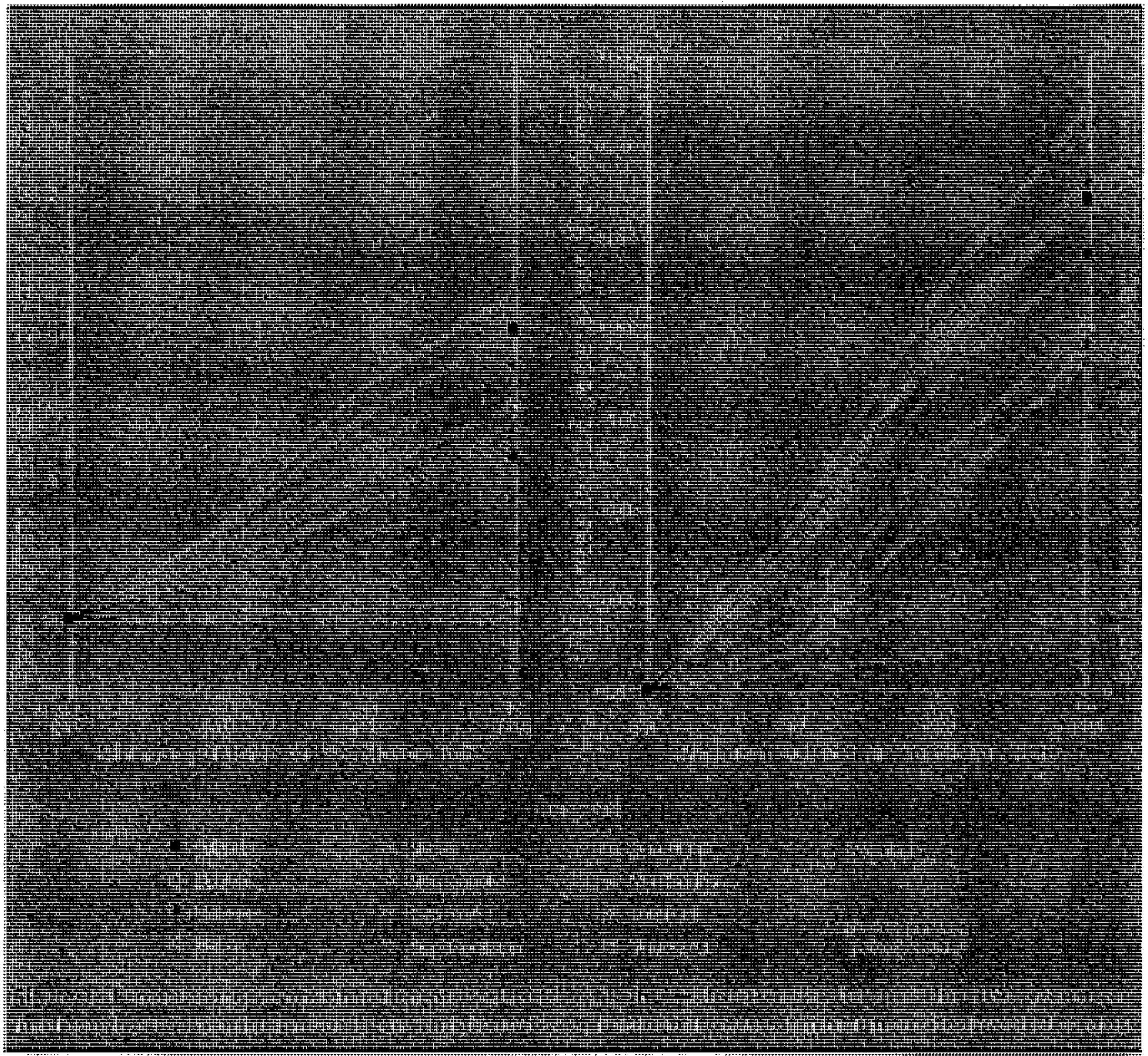
The weather data were from either the Weather Year for Energy Calculation (WYEC) series developed for ASHRAE [Crow 1981] or from the Typical Meteorological Year series developed by the National Oceanic and Atmospheric Administration (NOAA) [NCC 1981]. Both series are intended to be representative of typical conditions in a given location. Where both were available for a given location, the WYEC series was chosen.

To evaluate the energy costs of increased ventilation rates realistically, current electricity and natural gas tariffs were obtained from the appropriate utility in each location. For locations where consumers can choose service under more than one electricity tariff, we opted for the tariff with time-of-day prices.

Results

Results of the impacts of increased ventilation rates are reported as percentage changes from the values obtained for a base case. Percentage increases from a base case provide a better perspective than absolute increase because, by normalizing the increases to this base case, they facilitate comparisons across climates. For reference, the simulation results for the base case of 5 cfm/person are summarized in *Table 2*.

We first calculated the effects of increased ventilation rates on boiler and chiller capacities. (Fan sizes do not change, since their sizing is unaffected by outside air ventilation rates.) For both boilers and chillers, the percentage changes are generally in proportion to the severity of climate. The changes in boiler capacities range from almost no change to about a 10 percent increase. The largest increases occur in the colder climates and the smallest in milder ones. The maximum change in chiller capacity is somewhat greater, about 20 percent; the minimum is near 0 percent. The largest increases in chiller capacity are found in the climates with the greatest cooling requirements, but the trend is less uniform than that for boiler capacities. The most severe cooling climate (Miami), for example, does not have



the largest percentage increases. Note that boiler and chiller sizing is a function of the coincident loads of all zones within a building. Consequently, changes in minimum ventilation rates may result in monotonic yet nonlinear changes in sizing due to changes in the coincidence of zonal peak loads.

Figures 1 and *2* report the percentage changes in annual heating and cooling energy, respectively. The percentage changes in heating energy range from less than 1 percent to about 8 percent. The percentage changes in cooling energy range from less than 1 percent to nearly 14 percent. The changes for heating and cooling tend to parallel climatic severity; more severe heating/cooling climates show larger percentage increases in heating/cooling energy. The percentage changes for HVAC auxiliary energy use (fans and pumps) are significantly smaller than those found for heating and cooling energy use. The maximum increase is less than 2 percent. This result is not surprising since a significant component of the auxiliary HVAC energy use is fan energy use, which is largely unaffected (<<1%).

Figure 3 translates the annual energy use changes into dollars. The percentage changes are much less dramatic than those for annual heating or cooling energy use, with a maximum percentage increase of less than 5 percent. In general, energy costs for space conditioning account for only a fraction of the total energy costs of operating the building. Specifically, we found that the dominant component of annual energy cost is the cost of electricity (typically, 80 to nearly 100 percent of total costs). Of that electricity use, the unchanging fraction accounted for by lighting and miscellaneous equipment ranged from 30 to 40 percent of the total. For these reasons, the more severe cooling climates tend to exhibit the greatest percentage increases in energy costs.

To estimate increases in first cost, we used increases in boiler and chiller capacity as proxies for the increases in first cost of the HVAC system. That is, we assumed that increases in HVAC system cost would scale linearly with the increase in boiler and chiller capacity. This assumption is quite crude, and so we have attempted to derive the estimates very conservatively. Specifically, we assumed that HVAC first cost would increase $10,000/Mbh for increases in boiler capacity and $600/ton for increases in chiller capacity.

Figure 4 shows the resulting estimates of increases in the first cost of HVAC systems resulting from increased ventilation rates. These estimates are expressed as increases in costs per unit of building area rather than as percentage increases in total building first cost. For perspective, however, the total construction costs of the office building prototype were estimated to be approximately \$100/ft^2 in 1987 dollars [Battelle 1983]. Relative to this first cost, the percentage increases are less than 0.4 percent.

Discussion

There are two reasons why the simulations do not support a one-to-one relationship between percentage increases in minimum outside air ventilation and increases in these costs. (Recall that the fourfold increase in the minimum ventilation rate resulted in a maximum increase in annual energy costs of 5 percent.) The first reason is that energy use for heating, cooling and auxiliary HVAC end-uses represents only a fraction of the total energy costs for 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. In this respect, our assumption of relatively low levels of energy intensity for lighting and miscellaneous equipment has been conservative. Higher values for these end-uses would tend to decrease the impact of increased outside air ventilation rates.

The second reason is due to the operation of the economizer cycle. 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 setpoint of 70 F). For large office buildings, normal operation of an economizer dictates that outside air ventilation rates 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 large 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 the majority of operating hours, the standard will have no effect on energy use.

Finally, we mention an important real-world consideration that may affect application of our simulated results to measured performance. Our results were calculated as increases from the lowest current recommended ventilation rate of 5 cfm/person; this may be an unrealistic starting point for analysis. That is, either by design or by the limitations of outside air damper performance, many buildings are incapable of reducing outside air ventilation rates to this level. A recent study by Persily and Grot [1985] found that measured minimum outside air ventilation rates in large office buildings frequently exceed the levels called for by either the existing or the proposed standard. Hence, taking current design practices as the basis for evaluating changes, roughly 10 cfm/person, would suggest smaller increases in both first and annual energy operating costs.

Summary

We have performed a simulation-based analysis of the increases in energy use, energy costs, central plant equipment capacities and HVAC first costs that result from compliance with different minimum outside air ventilation rate design standards. The analysis relied on parametrically increasing minimum outside air ventilation rates for a prototypical large office building in 10 U.S. and three Canadian locations. The low end of the the current standard, 5 cfm/person, was the basis for comparison of ventilation rates up to the proposed level of 20 cfm/person. Economics were evaluated with actual and current utility rate tariffs and assumptions regarding incremental HVAC equipment cost as a function of boiler and chiller capacities.

The results indicate, for the prototype and climates examined, that with increased ventilation rates:

- Central plant capacities increase by up to 20 percent for chillers and up to around 10 percent for boilers in the most severe heating and cooling climates.
- Annual energy use for heating increases by up to 8 percent. Annual energy use for cooling increases by up to 14 percent. Annual auxiliary HVAC energy use is largely unaffected with a maximum increase of less than 2 percent.
- Annual energy operating costs increase by less than 5 percent.
- HVAC first costs increase by less than \$0.35/ft^2. ■

Acknowledgment

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About the authors

Joseph H. Eto is a staff scientist in the energy analysis program of Lawrence Berkeley Laboratory, Berkeley, California. He received an M.S. degree in energy and resources from the University of California at Berkeley. His research interests include commercial building energy use, utility planning and regulation, and energy demand forecasting.

Cecile Meyer is a student at the Ecole Polytechnique Feminine, Paris, France. In the summer of 1987, she was a visiting researcher at the Lawrence Berkeley Laboratory. Her interests include computers and telecommunications.