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

J.H. Eto, P.E. **C. Meyer**
ASHRAE Member

ABSTRACT

This study reports on the changes in annual energy operating costs and in equipment sizing that result from increased minimum outside air ventilation rates. The analysis is based on parametric DOE-2.1C simulations for a large office building in 10 different U.S. and three Canadian locations. In the simulations, minimum ventilation rates are increased from 2.5 liters per second per person (L/s.person) or 5 cubic feet per minute per person (cfm/person) to 10.0 L/s.person or 20 cfm/person. Annual building energy costs are calculated using current electricity and natural gas tariffs for each location. The results suggest that, for the building and climates examined, higher minimum outside air ventilation rates will affect equipment-sizing decisions relatively more than they will affect annual building energy use. Increases in annual energy operating costs were small (less than 5%), because electricity is the dominant component of cost and electricity is used primarily for non-space-conditioning purposes. Estimates of the increase in HVAC first cost suggest that higher ventilation rates will have small effects (less than 0.5%) on total building construction costs.

INTRODUCTION

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 is 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 paper, we focus on changes in annual energy use, annual energy operating costs, equipment sizing, and first cost of the heating, ventilating, and air-conditioning (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 air ventilation rate must be maintained to ensure acceptable indoor air quality, in the absence of exceptional sources. The underlying assumption here is that outdoor ambient, "fresh air" conditions are superior to indoor, recirculated conditions. The measure is units of outside air flow per inhabitant, liters per second per person (L/s.person) or 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: 2.5 L/s.person (5 cfm/person) without smokers and 7.5 L/s.person (15 cfm/person) with smokers [ASHRAE 1981]. The proposed Standard does not distinguish the presence of smoking and simply recommends a minimum of 10 L/s.person (20 cfm/person) [ASHRAE 1987]. Whether this new rate of outside air intake is sufficient to ensure truly acceptable indoor air quality is a subject of debate (see, for example, Leaderer and Cain [1984] or Sterling and Sterling [1984]); however, for our purposes, it is the highest rate we evaluate.

Mr. Eto is a Staff Scientist in the Energy Analysis Program of the Lawrence Berkeley Laboratory. Ms. Meyer is a visiting researcher from the Ecole Polytechnique Feminine, Paris, France.

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, important 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.

Four sections follow this introduction. The next section provides background for the study with an overview of the methodology, including descriptions of the building energy simulation program, the building prototype, and the locations examined. The following section summarizes the findings for the changes in equipment sizing, energy use, energy costs, and HVAC system first costs. The next section discusses these findings briefly, and the final section is a summary.

BACKGROUND

This section describes the method of analysis and the building energy simulation program, the building prototype, and the cities used in the study.

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 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 2.5 L/s.person (5 cfm/person) increasing in increments of 2.5 L/s.person (5 cfm/person) to 10.0 l/s.person (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.

Several outputs of the program were saved from each simulation for use in the subsequent analyses. These outputs include annual energy use for heating, cooling, and ventilation/pumps; annual peak electrical demand; total annual cost of electricity and natural gas (including the cost of electricity used for lighting and other end uses, which do not change as minimum outside air ventilation rates increase); and the size of the chillers and boilers in the central plant.

DOE-2 Building Energy Analysis Program

The DOE-2 building energy analysis 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 state-of-the-art 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 entirely 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).

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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, DC, 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 made to some aspects of the HVAC system in order to make the building more representative of current design and operation practices. The modifications include a lower cooling setpoint, a higher economizer setpoint, and reverse-action thermostats. Major features of the office building prototype are summarized in Table 1.

Locations

The simulations were performed using weather data and utility tariffs from 10 U.S. cities 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 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. Table 2 identifies the weather tape used for each location and summarizes the annual heating and cooling degree-days found on each tape.

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. Tables 3a and 3b identify the utilities and rate schedules and describe briefly the type of rate used for each location.

RESULTS

This section reports on the results from simulations of the impacts of increased minimum outside air ventilation rates. We begin with the changes in central plant equipment capacities and annual energy use for space conditioning end uses resulting from different ventilation rates, and we conclude with the changes in annual energy operating and building HVAC system costs.

Results of the impacts of increased ventilation rates are reported as percentage changes from the values obtained for a base case. Percentage increases, by normalizing the increases to a base case, provide a better perspective than absolute increase because they facilitate comparisons across climates. Hence, we start by presenting the nominal values of the simulation results for the lowest ventilation rate, 2.5 L/s.person (5 cfm/person). Table 4 summarizes the central plant equipment capacities, the annual heating, cooling, and auxiliary HVAC energy, peak demand, and annual energy costs from our initial simulation for each location. Again, to facilitate comparison, the results have been divided by building area.

Figures 1 and 2 illustrate the impact of increased ventilation rates on boiler and chiller capacities, respectively. (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% 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%; the minimum is near 0%. 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

* We have determined that use of a single building for all locations, rather than a separate, slightly altered prototype for each location (as was done for the ASHRAE-sponsored research), does not materially affect the findings.

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 3, 4, and 5 present the percentage changes in annual heating, cooling, and auxiliary HVAC energy, respectively. Auxiliary HVAC energy includes both fan and pumping energy. The percentage changes in heating energy range from less than 1% to about 8%. The percentage changes in cooling energy range from less than 1% to nearly 14%. The changes for heating and cooling tend to parallel climatic severity. The percentage changes for HVAC auxiliary energy use are significantly smaller than those found for heating and cooling energy use. The maximum increase is less than 2%. 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 6 shows the percentage changes in electrical peak demand. The maximum increase is less than 8%. Since electricity is used for cooling, but not heating, the increases tend to parallel the severity of the cooling climate.

Figure 7 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%. The reason for the reduced impact is that the energy costs for space conditioning account for only a fraction of the total energy costs of operating the building. There are two reasons: First, the dominant component of annual energy cost is the cost of electricity (see Table 5). Second, electricity use for lighting and miscellaneous equipment is a fixed component that is not changed by increased ventilation rates (again, see Table 5).* For these reasons, the more severe cooling climates tend to exhibit the greatest percentage increases in energy costs.

To estimate the changes in first cost, we used the changes in boiler and chiller capacity as proxies for the increases in first cost of the HVAC system. That is, we assumed that the 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 \$9.5/MJ/h (\$10,000/Mbh) for increases in boiler capacity and \$32.3/MJ/h (\$600/ton) for increases in chiller capacity. These estimates are based on information contained in Saylor [1987].

Figure 8 shows our estimates of the changes in the first cost of HVAC systems resulting from the increased ventilation rates. Contrary to previous results, 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 \$1100/m^2 (\$100/ft^2) in 1987 dollars [Battelle 1983]. Thus, relative to this first cost, the percentage increases are less than 0.4%.

DISCUSSION

The results presented in the previous section indicate that, for the simulations performed, increased minimum outside air ventilation rates will have small effects on building annual energy and construction costs. In particular, the simulations do not support a one-to-one relationship between percentage increases in minimum outside air ventilation and increases in these costs. For example, a fourfold increase in the minimum ventilation rate corresponds to a maximum increase in annual energy costs of only 5%.

The primary reason for these small increases in energy cost is that energy use for heating, cooling, and auxiliary HVAC end uses represent 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 (see Table 1). Higher values for these end-uses would further decrease the impact of increased outside air ventilation rates.

The second reason for this result has to do with the operation of the HVAC system. 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 21.1°C or 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.

* In general, it is not possible to allocate electricity costs to individual end uses due to the nonlinear structure of electricity rate tariffs. (These same nonlinearities also result in nonlinear changes in annual energy costs.)

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This study focused on the greatest impacts due to increased minimum outside air ventilation rates. Specifically, results were calculated as increases from the lowest current recommended ventilation rate of 2.5 L/s.person (5 cfm/person). A less conservative evaluation would take current design practices, roughly 5 L/s.person (10 cfm/person), as the basis for evaluating changes. In this case, our results would suggest even smaller increases in both first and annual energy operating costs.

There are other reasons, not addressed in this study, why minimum outside air ventilation rates may have little effect on building energy costs. A primary one is that, either by design or by the limitations of outside air damper performance, many buildings are incapable of reducing outside air ventilation rates to the levels called for by the Standard. A recent study by Persily and Grot [1985] indicates that the measured performance of large office buildings frequently exceeds the levels called for by either the existing or the proposed Standard. The study did not, however, examine whether the measured minimum ventilation rates were the same as those designed.

A related problem with measuring the costs of increased outside air ventilation rates in real buildings is the signal-to-noise problem, which suggests that other aspects of building operation will mask or otherwise obscure the impact of increased ventilation rates. A notable and uncontrollable influence is weather-induced fluctuations in energy use and costs, which can easily overwhelm the impact of increased minimum ventilation rates.

Similarly, we have made generous assumptions regarding the increased first cost of compliance. It is possible that the combination of the building industry's traditional practice of oversizing designs for safety and the availability of HVAC equipment in a limited number of finite sizes (which often results in even greater oversizing) may mean no increase in first cost. Thus, there is also a question as to whether the first cost of compliance will result in measurable increases in first cost.

All simulation-based analyses must, of course, be evaluated according to how well their results match reality. A simulation-based analysis requires a detailed description of a single building and a specific mode of operation. To make our results as representative as possible, we have chosen a prototypical large office building and simulated its performance in many locations with a well-documented and extensively validated simulation program. Nevertheless, recent work demonstrates that real buildings rarely perform as simulated, which, often, is to say that real buildings are rarely operated by the assumptions used in the simulation [Piette 1986].

On the other hand, simulations provide a controlled environment in which changes in ventilation rates can be studied in a consistent manner that cannot be duplicated easily in the real world. Hence, in recognition of these limitations and advantages of simulations, our analyses have focused on relative changes rather than on absolute values, which depend on specific building conditions. We maintain that relative changes from simulations yield important insights into the magnitude of the impacts of ventilation standards on the building industry.

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 current standard, 2.5 L/s.person (5 cfm/person), was the basis for comparison of ventilation rates up to the proposed level of 10 L/s.person (20 cfm/person). Economics were evaluated with actual and current utility rate tariffs and with generous HVAC equipment cost assumptions.

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

- Central plant capacities may increase up to 20% for chillers and up to around 10% for boilers in the most severe heating and cooling climates.
- Annual energy use for heating may increase up to 8%. Annual energy use for cooling may increase up to 14%. Annual auxiliary HVAC energy use is largely unaffected with a maximum increase of less than 2%.
- Annual energy operating costs will increase by less than 5%.
- HVAC first costs may increase by, at most, $3.6/m^2 ($0.35/ft^2).

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TABLE 1

Summary of Office Building Characteristics

Size	55,530 m^2 (597,500 ft^2)
Shape	38 floors, 2 basement levels, flattened hexagon in cross section, approximately 1,670 m^2/floor (18,000 ft^2)
Construction	Steel frame, limestone cladding
Glazing	25% of wall area
Operation	8am - 6pm weekdays, with some evening work, 30% occupancy on Saturday, closed Sundays and Holidays
Thermostat Settings	24.4°C (76°F) Cooling 22.2°C (72°F) Heating (night and weekend setback 12.8°C (55°F)
Internal Loads	25.8 W/m^2 (2.4 W/ft^2) lighting 7.7 W/m^2 (0.8 W/ft^2) equipment
HVAC Air-side	2 VAV systems zoned separately for perimeter (w/terminal reheat) and core (no reheat), dry bulb economizer set at 21.1°C (70°F)
Heating Plant	2 Gas-fired hot water generators (eff. = 75%)
Cooling Plant	2 Hermetic centrifugal chillers w/cooling tower (chiller COP = 4.3)

TABLE 2

Summary of Climatic Conditions

City	Weather Tape	Annual Heating Degree-Days[1] °C	(°F)	Annual Cooling Degree-Days[1] °C	(°F)
Atlanta	WYEC[2]	1675.8	(3016.5)	877.2	(1579.0)
Boston	WYEC	3163.6	(5694.5)	401.7	(723.0)
Chicago	WYEC	3424.4	(6164.0)	543.9	(979.0)
Dallas	WYEC	1320.3	(2376.5)	1412.8	(2543.0)
Miami	WYEC	126.1	(227.0)	2225.0	(4005.0)
Minneapolis	WYEC	4483.6	(8070.5)	416.9	(750.5)
New York	WYEC	2745.0	(4941.0)	574.4	(1034.0)
San Francisco	TMY[3]	1808.9	(3256.0)	39.7	(71.5)
San Diego	TMY	714.2	(1285.5)	365.0	(657.0)
Washington	WYEC	2353.3	(4236.0)	791.7	(1425.0)
Montreal	WYEC	4580.0	(8244.0)	192.2	(346.0)
Vancouver	WYEC	3185.3	(5733.5)	18.3	(33.0)
Winnipeg	WYEC	6041.1	(10874.0)	136.1	(245.0)

Note 1: calculated to base 18.3°C (65°F)
Note 2. Weather Year for Energy Calculation
Note 3: Typical Metereological Year

TABLE 3a

U.S. Utility Rate Schedules

City/Utility*	Schedule	Type
Atlanta		
Georgia Power Co.	PL-6	Declining block no demand charge
Atlanta Gas Co.	N-2	Declining block
Boston		
Boston Edison Co.	T-2	Time of use
Boston Gas Co.	No. 3	Declining block
Chicago		
Commonwealth Edison Co.	6L	Time of use
Peoples Gas	No. 2	Flat rate
Dallas		
Texas Utilities Electric Co.	G	Declining block w/demand charge
Lone Star Gas Co.	No. 951	Declining block
Miami		
Florida Power and Light Co.	GSLDT-2	Time of use
Peoples Gas System	GSLV	Flat rate
Minneapolis		
Northern States Power Co.	Gen. TOD	Time of use
Northern States Power Co.	C&I Svc.	Time of use
New York		
Consolidated Edison Co.	No. 9	Time of use
Consolidated Edison Co.	No. 2	Declining block
San Diego		
San Diego Gas and Electric Co.	AO-TOU	Time of use
San Diego Gas and Electric Co.	GN-1	Flat rate
San Francisco		
Pacific Gas and Electric Co.	E-20	Time of use
Pacific Gas and Electric Co.	G-50	Declining block w/demand charge
Washington		
Potomac Electric Power Co.	DC-GT	Time of use
Washington Gas Light Co.	Sch. 2	Flat rate

* For each city, the electric utility is listed first, followed by the gas utility.

TABLE 3b

Canadian Utility Rate Schedules

City/Utility*	Schedule	Type
Montreal		
Hydro-Quebec	Rate M	Declining block
Gaz Metroplitain	Rate 1	Declining block
Vancouver		
BC Hydro and Power Auth.	GS	Declining block w/demand charge
BC Hydro and Power Auth.	GS	Declining block
Winnipeg		
Winnipeg Hydro	Pwr. Std.	Declining block w/demand charge
ICG Utilities	Other	Declining block

* For each city, the electric utility is listed first, followed by the gas utility.

TABLE 4

Summary of Baseline Simulations at 2.5 l/s.person (5 cfm/person)

Location	Boiler Capacity kJ/hr.m^2	Boiler Capacity (Btu/hr.ft^2)	Chiller Capacity kJ/hr.m^2	Chiller Capacity (Tons/1000 ft^2)	Heating Energy MJ/m^2	Heating Energy (kBTU/ft^2)	Cooling Energy kWh/m^2	Cooling Energy (kWh/ft^2)	HVAC Aux. Energy kWh/m^2	HVAC Aux. Energy (kWh/ft^2)	Peak Demand W/m^2	Peak Demand (W/ft^2)	Energy Cost 1987 U.S.$/m^2	Energy Cost (1987 U.S.$/ft^2)
Atlanta	459.7	(40.5)	369.2	(2.7)	159.6	(14.1)	35.6	(3.3)	32.2	(3.0)	78.1	(7.3)	14.0	(1.3)
Boston	610.7	(53.8)	354.2	(2.6)	297.1	(26.2)	20.9	(1.9)	30.6	(2.8)	75.0	(7.0)	26.5	(2.5)
Chicago	581.8	(51.3)	377.3	(2.8)	311.2	(27.4)	24.1	(2.2)	33.2	(3.1)	78.3	(7.3)	19.8	(1.8)
Dallas	410.5	(36.2)	403.2	(3.0)	153.6	(13.5)	40.5	(3.8)	35.2	(3.3)	80.4	(7.5)	11.8	(1.1)
Miami	194.1	(17.1)	378.7	(2.8)	31.1	(2.7)	58.2	(5.4)	35.8	(3.3)	79.4	(7.4)	14.7	(1.4)
Minneapolis	739.1	(65.1)	367.8	(2.7)	370.5	(32.6)	19.7	(1.8)	30.9	(2.9)	74.8	(6.9)	10.5	(1.0)
New York	493.1	(43.4)	344.6	(2.5)	247.9	(21.8)	24.0	(2.2)	29.8	(2.8)	75.1	(7.0)	25.6	(2.4)
San Francisco	374.4	(33.0)	299.7	(2.2)	152.8	(13.5)	19.0	(1.8)	29.3	(2.7)	67.5	(6.3)	15.8	(1.5)
San Diego	232.6	(20.5)	339.2	(2.5)	88.3	(7.8)	33.0	(3.1)	32.2	(3.0)	72.4	(6.7)	23.8	(2.2)
Washington	457.3	(40.3)	365.1	(2.7)	214.1	(18.9)	29.3	(2.7)	31.6	(2.9)	77.7	(7.2)	13.1	(1.2)
Montreal	614.5	(54.1)	405.9	(3.0)	362.9	(32.0)	18.9	(1.8)	30.3	(2.8)	76.0	(7.1)	8.9	(0.8)
Vancouver	476.4	(42.0)	301.0	(2.2)	246.2	(21.7)	12.9	(1.2)	27.4	(2.5)	67.9	(6.3)	6.7	(0.6)
Winnipeg	761.4	(67.1)	382.8	(2.8)	504.6	(44.5)	15.4	(1.4)	30.7	(2.8)	77.8	(7.2)	7.2	(0.7)

TABLE 5

Electricity and Utility Cost Breakdown

	Cooling and Aux. HVAC Electricity as a fraction of Total Electricity (%)	Electricity Costs as a fraction of Total Energy Costs (%)
Atlanta	40.8	93.8
Boston	34.3	94.3
Chicago	36.8	97.8
Dallas	43.4	94.5
Miami	48.8	99.3
Minneapolis	33.9	87.8
New York	35.3	94.5
San Francisco	32.9	96.6
San Diego	39.8	97.7
Washington	38.2	87.7
Montreal	33.3	81.9
Vancouver	29.1	88.7
Winnipeg	31.9	82.1

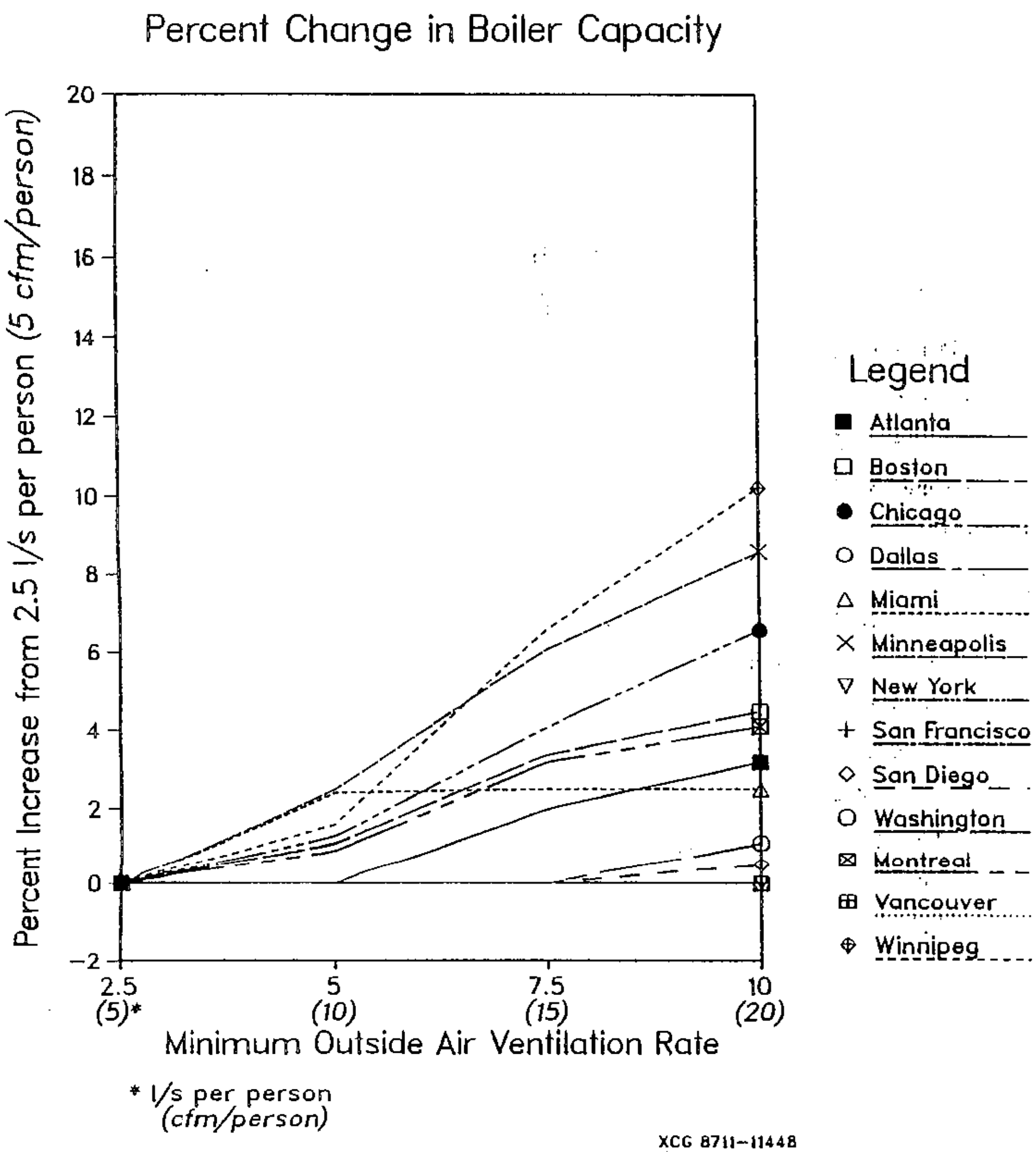

Figure 1 *Percent change in boiler capacity as a function of increases in minimum outside air ventilation rates*

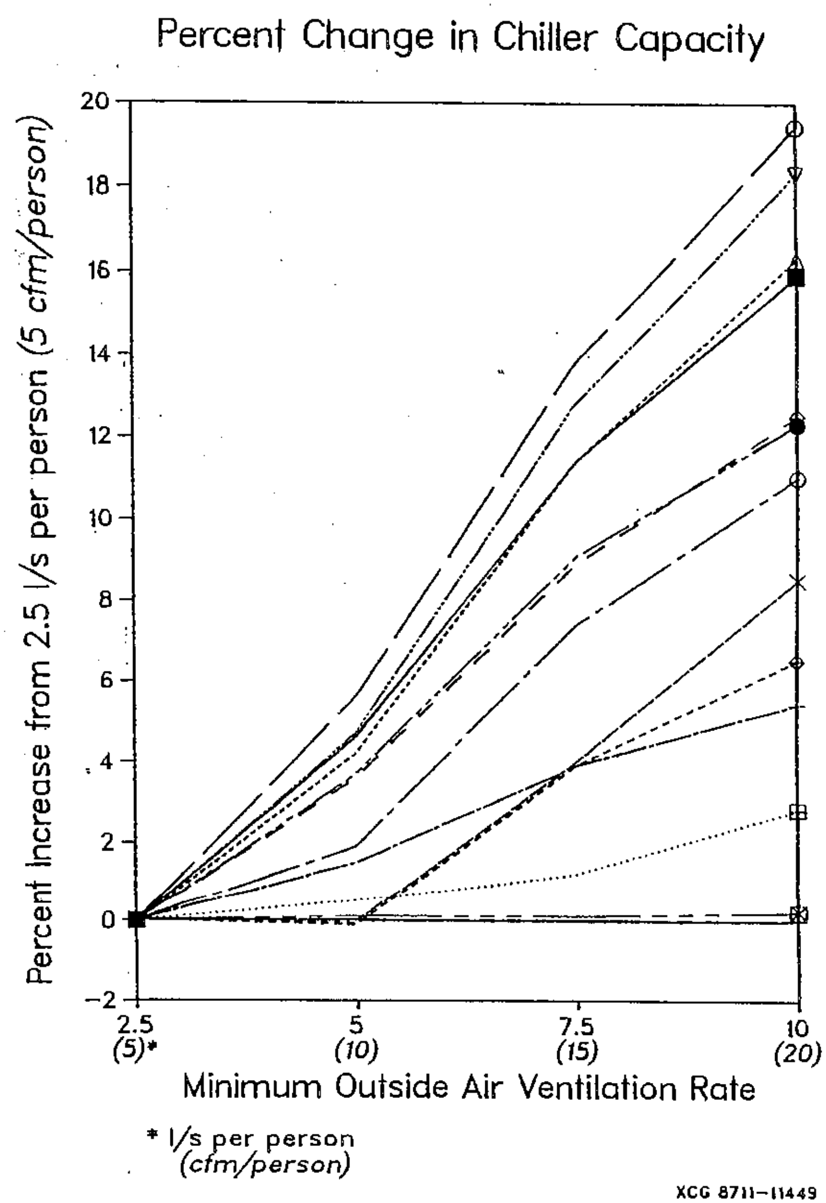

Figure 2 *Percent change in chiller capacity as a function of increases in minimum outside air ventilation rates*

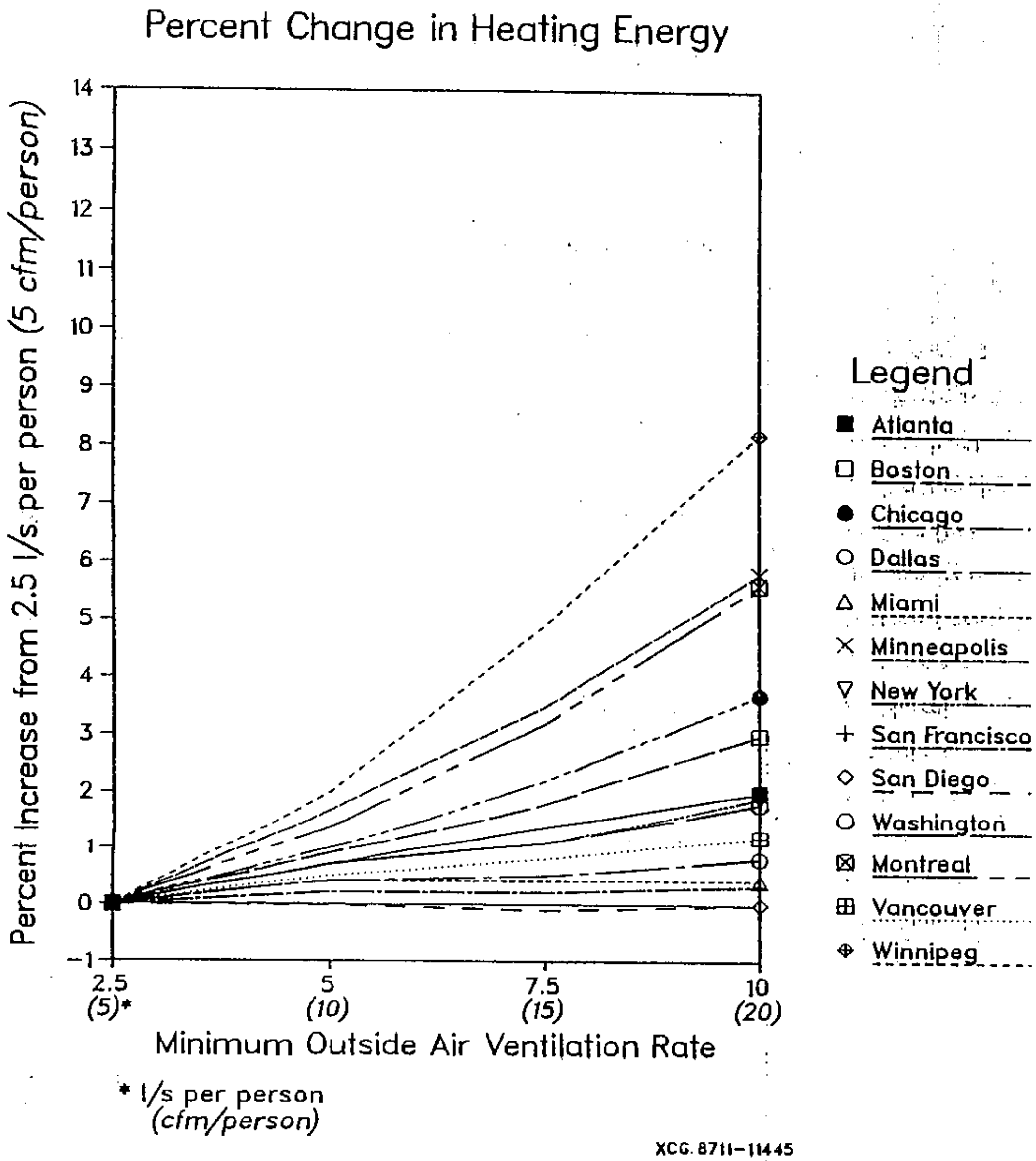

Figure 3 *Percent change in heating energy as a function of increases in minimum outside air ventilation rates*

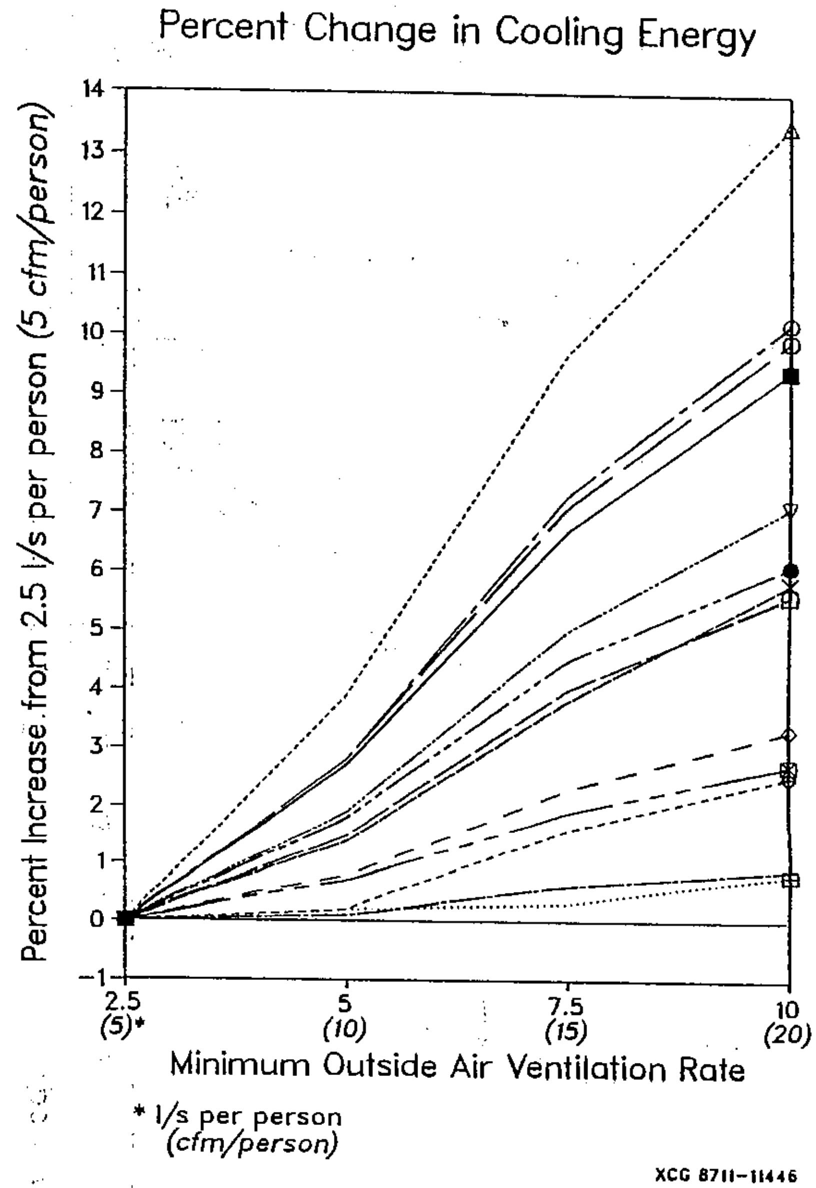

Figure 4 *Percent change in cooling energy as a function of increases in minimum outside air ventilation rates*

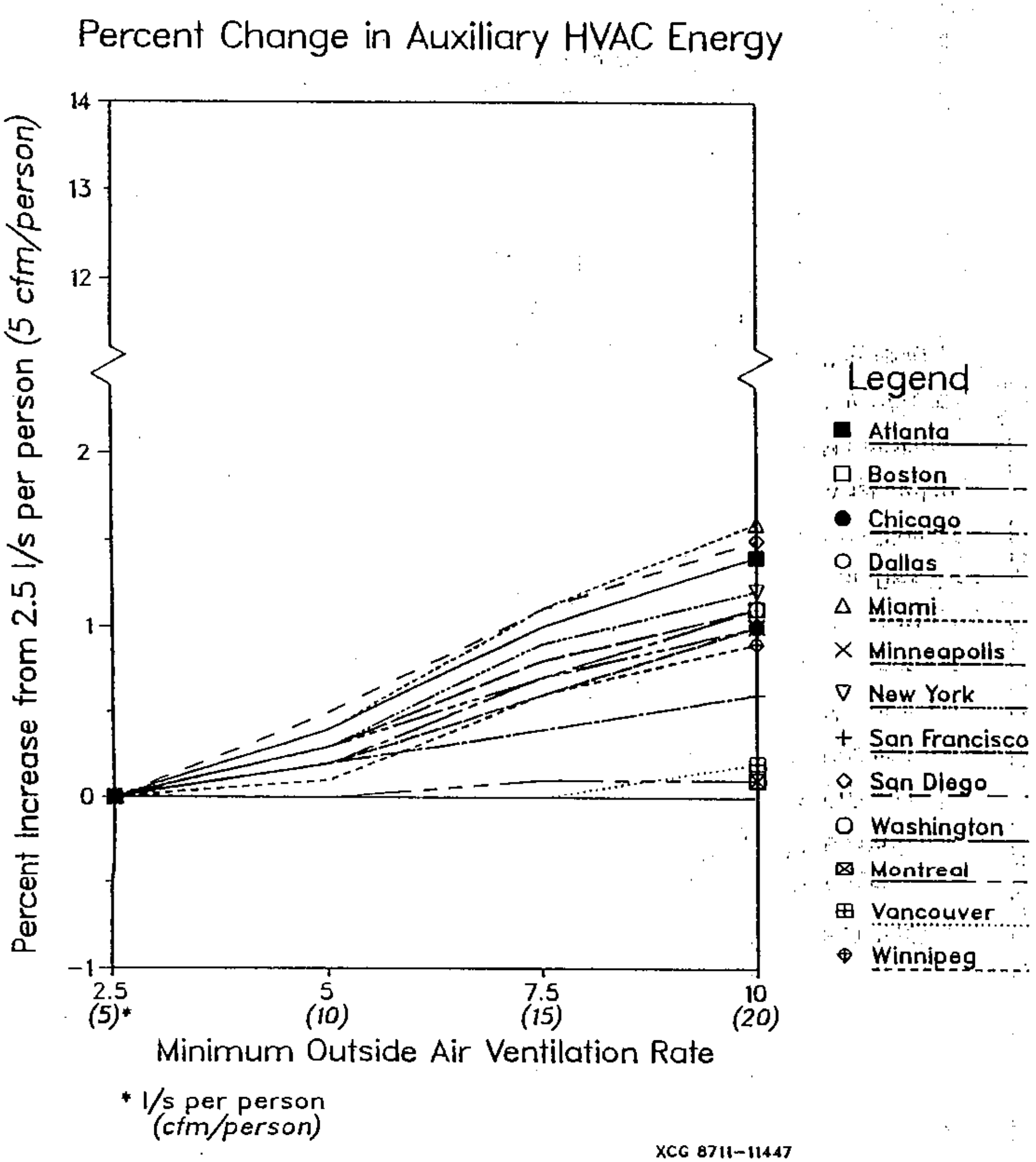

Figure 5 *Percent change in auxiliary HVAC energy as a function of increases in minimum outside air ventilation rates*

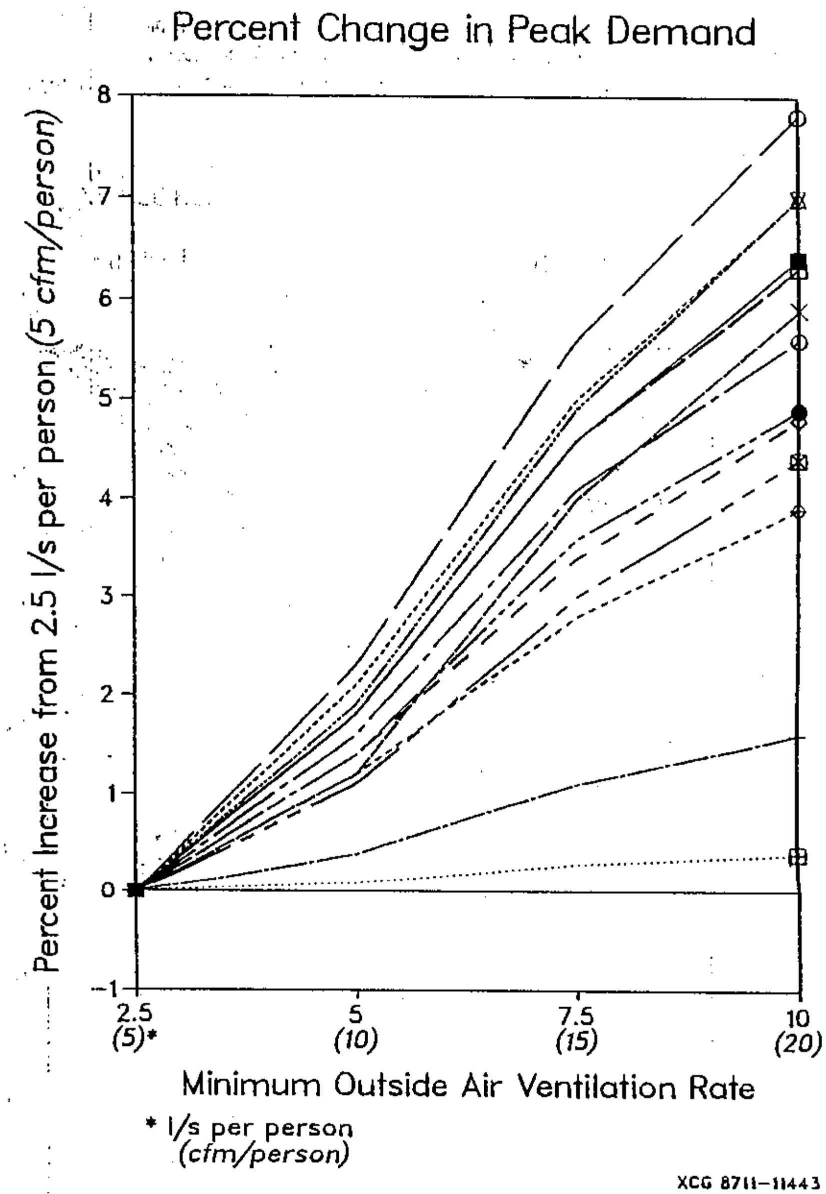

Figure 6 *Percent change in peak electrical demand as a function of increases in minimum outside air ventilation rates*

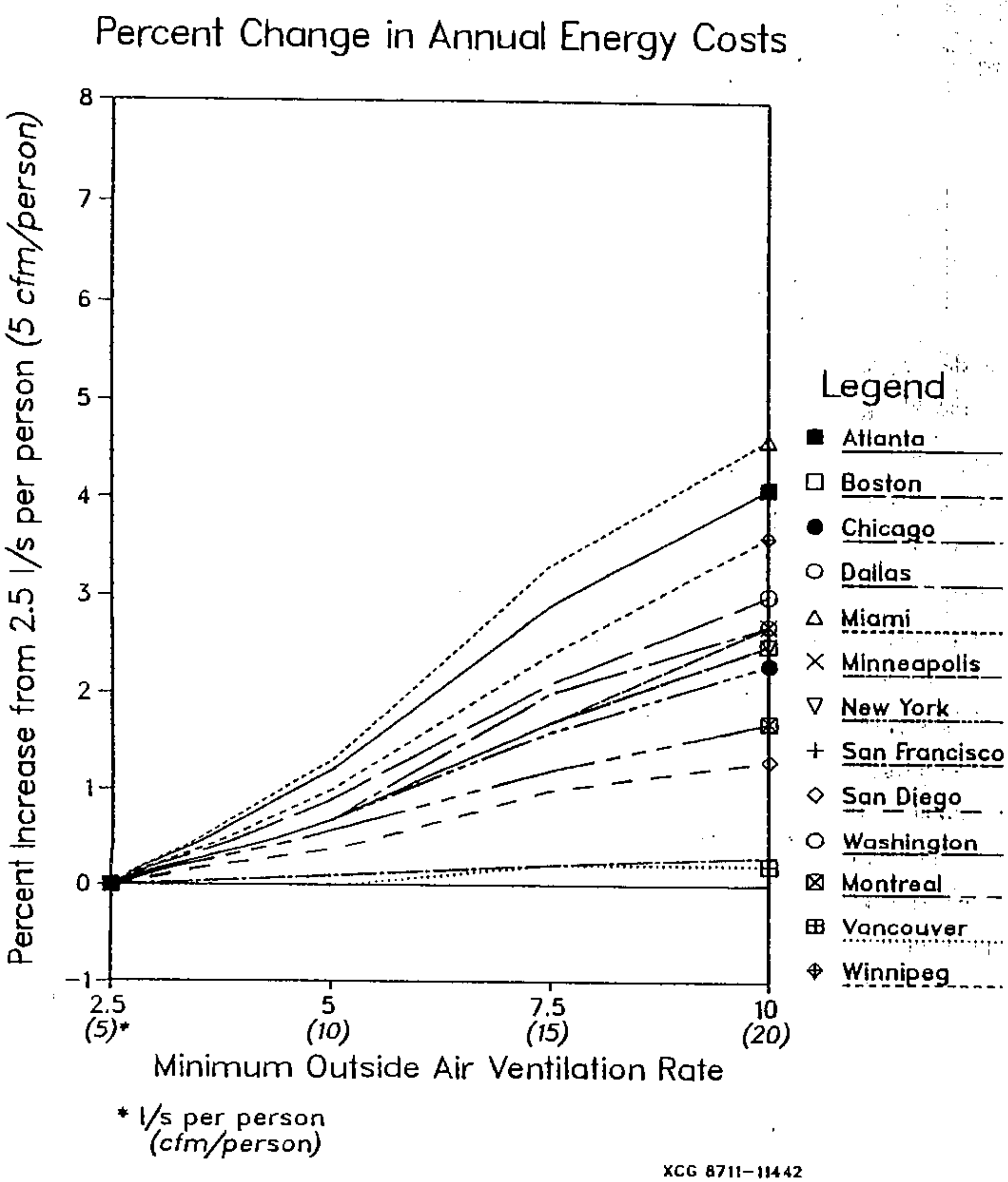

Figure 7 *Percent change in total annual energy costs as a function of increases in minimum outside air ventilation rates*

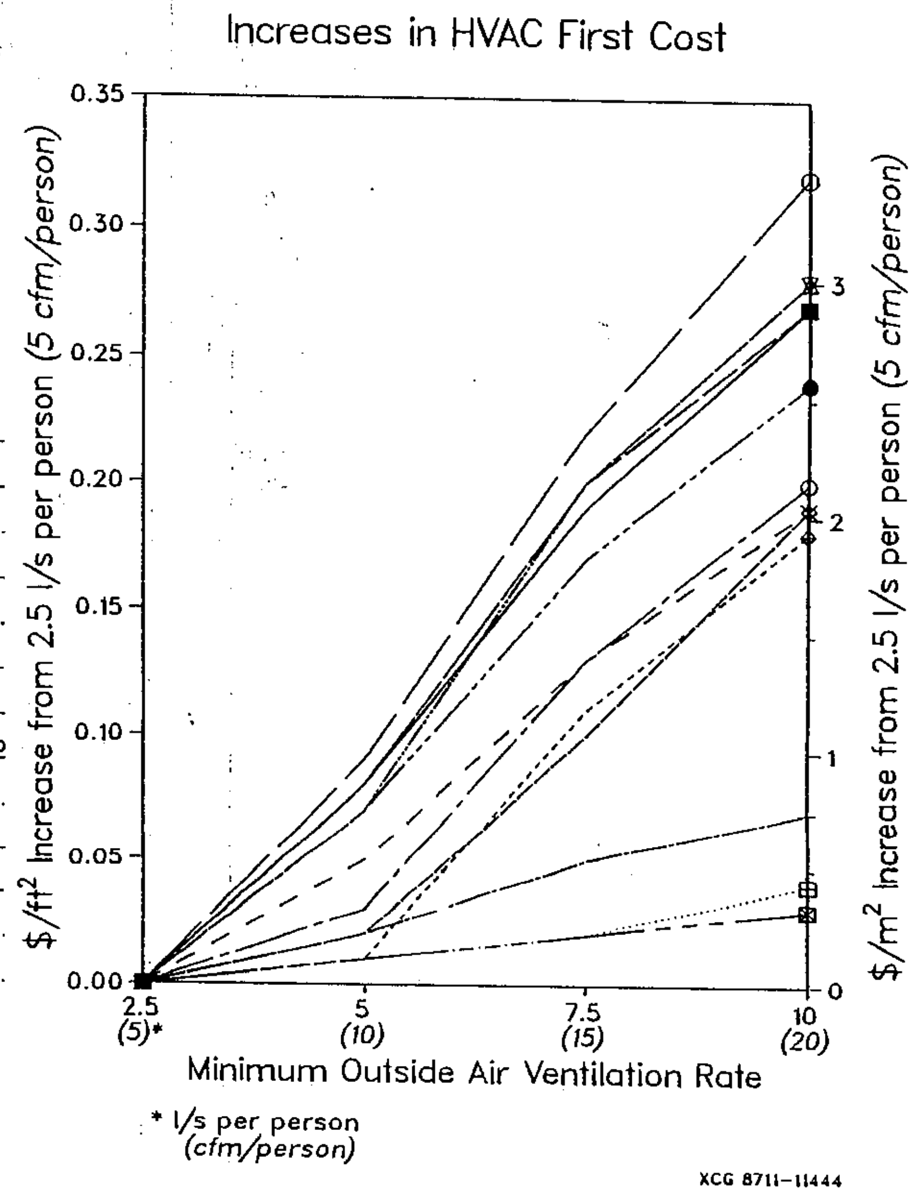

Figure 8 *Changes in the first cost of the HVAC system as a function of increases in minimum outside air ventilation rates*

DISCUSSION

R.A. Macriss, IGT, Chicago, IL: If Standard 62-81 erred on the high side of 5 cfm/person in the past, and we are still plagued with "sick building syndrome" problems, how much more fresh air ventilation can we afford in order to relieve the occupants of any symptoms?

J.H. Eto: The respondent has pointed to an area in which there are many unanswered questions. I refer him to references cited in the paper (Nero and Grimsrud 1984; Leaderer and Cain 1984; and Sterling and Sterling 1984) for detailed discussions of this subject.

R. Anderson, Technology Leader, SERI, Golden, CO: Have you conducted calculations at higher ventilation rates to determine how far the lack of sensitivity found in the present study extends?

Eto: We examined a minimum outside air ventilation rate of 35 cfm/person for selected locations and found that the results were nearly linear extrapolations of our earlier results (i.e., approximately twice the impact found at 20 cfm/person).

J.B. Findlay, Ottawa, Ontario, Canada: The 5 cfm standard was a mistake. Therefore, energy costs to increase ventilation to previous higher standards are not, in fact, true penalties of higher ventilation rates. Compartment systems without economizers conformed to the standard and are now problem buildings.

Eto: I have noted in the paper evidence that suggests that using 5 cfm/person as the starting point for evaluation may be unrealistic for current practice and that perhaps 10 cfm/person would be a more meaningful basis for analysis. Using 10 cfm/person would reduce the impact of increasing the minimum ventilation rate to 20 cfm/person.

D. Grimsrud, Staff Scientist, LBL, Berkeley, CA: How sensitive are your results to your choice of building size? Would you expect similar results in smaller shell-dominated buildings?

Eto: To the extent that internal loads remain fixed, I would expect larger percentage increases for smaller buildings, which tend to have relatively larger shell losses. The reason is that if heat losses/gains are larger, the band width of outside air temperatures during which the economizer cycle operates is narrower. Since the economizer can be thought of as an override to the minimum outside air ventilation rate, fewer hours of economizer operation means more hours that the minimum outside air ventilation constraint will be in effect and, consequently, leads to increased energy use.