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ASHRAE Standard 62-1989
Energy, Cost, and Program Implications

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SYNOPSIS

ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality", increases ventilation rates from 5 to 15 CFM. This study evaluated implications for commercial buildings conservation and demand side management programs adopting Standard 62-89, including potential increases in energy use and cost, and problems with interpretation and verification.

Commercial buildings prototypical of construction in the Pacific Northwest were analyzed by modeling energy use on the DOE-2.1D energy simulation computer program. Standard 62-89 specifies ventilation rates per person with estimated occupancy densities. Use of its occupancy density is at the user's option. This study analyzed the new ventilation rates, by (1) Standard 62-89 occupancy densities, and (2) alternative occupancy densities. For Standard 62-89 densities, energy use and cost increases varied less than 1% up to 43% depending on building type. For densities based on assumed actual occupancies, increases varied less than 1% to 15%. Standard 62-89's occupancy densities created ventilation requirements exceeding system capacity in high density building types.

The study recommends adoption of the new higher ventilation rates, but with the use of alternative occupancy densities. To verify compliance with Standard 62-89, the study recommends the method of taking a ratio of temperatures to determine percent outdoor air with a total supply air measurement to determine supplied outside air for each air handler serving the building.

1.0 BACKGROUND

ASHRAE Standard 62-1989 (Standard 62-89) "Ventilation for Acceptable Indoor Air Quality" is the new heating, ventilating, and air-conditioning (HVAC) industry consensus for ventilation air in commercial buildings. Bonneville Power Administration (Bonneville) references ASHRAE Standard 62-81 (the predecessor to Standard 62-89) in their current environmental documents for required ventilation rates. In terms of Bonneville-sponsored commercial building energy conservation programs, the two most important revisions for the new Standard are (1) the deletion of the distinction between smoking-permitted and non-smoking spaces and (2) an increase in the minimum outside air requirement for most spaces from 5 cfm/person to 15 cfm/person.[1]

Before incorporating Standard 62-89 into Bonneville's energy conservation programs for both new and existing commercial buildings, it was important to review the revised standard to determine the need for interpretation and evaluate its enforceability. Minimum ventilation rates have been tripled by Standard 62-89 (for non-smoking spaces). With almost all buildings, increasing the amount of outdoor ventilation air will increase energy consumption. Therefore, it is important to understand the significance of outdoor ventilation air in terms of energy and cost. Bonneville also experienced problems in interpretation and compliance when Standard 62-81 was simply referenced as the ventilation requirement in commercial building energy conservation programs.

This study was performed with the specific objectives of evaluating the energy and cost implications of Standard 62-89 and providing an interpretation and a verification procedure for use in Bonneville's commercial building programs. To evaluate the energy and cost impacts of Standard 62-89, we performed hourly energy simulations on ten building types in two climates using the DOE-2.1D energy simulation program. Results from these simulations estimate the energy and cost impacts associated with Standard 62-89. To interpret Standard 62-89 we considered only one path of compliance: The Ventilation Rate Procedure. Within that procedure are several provisions, each of which is discussed and interpreted. The costs of verifying compliance with Standard 62-89 are outlined and a verification procedure is given.

2.0 ENERGY USE AND COST IMPLICATIONS

A paper published in the ASHRAE Journal investigated the issue of increased ventilation air on building energy use.[2] The authors performed a study which found annual energy operating costs increase by less than 5 percent as a result of Standard 62-89. Bonneville supported further similar study for the following reasons:

1. No Pacific Northwest climates were considered.
2. Only one building, a large office, was included in the paper.
3. The building had a gas heating system, which would underestimate any impacts on electric demand.

2.1 STUDY OVERVIEW

Bonneville's study estimated the energy and cost implications of ASHRAE Standard 62-89 using simulations based on DOE-2.1D, a computer simulation program which estimates building use hourly as a function of building characteristics and climactic location. Ten types of prototypical commercial buildings used by Bonneville for load forecasting purposes were examined: Large and Small Office, Large and Small Retail, Restaurant, Warehouse, Hospital, Hotel, School, and Grocery. These building characterizations are based on survey and energy metering data and represent average or typical construction and operation practices and mechanical system types.

For each building type, there is an existing building model and a new building model, totaling 20 building models. Each of the prototypes are all-electric, and exist as files on the DOE-2.1D simulation program.

Prototypical building ventilation rates were varied in five steps to estimate the impacts of outside air on building energy use. Input to DOE-2.1D for ventilation air is accomplished in the SYSTEMS portion of the program. Ventilation air can be specified as either a fraction of total supply air, outside air per person, or cfm. For this study, ventilation air was specified as outside air per person. The calculated rate is the minimum outside air rate when the HVAC system supply fans are on and with no economizer control.

2.1.1 Occupancy

Occupancy levels appeared significant when Standard 62-89 Estimated Maximum Occupancy values were compared to the assumed values used in the prototypes. Table 2.1 shows the result of this comparison. For all building prototypes, the Standard 62-89 values for suggested occupancy were significantly higher than those assumed in the prototypes. To interpret the relevancy of these higher occupancy values, we compared Standard 62-89 to two other industry standards: 1988 Uniform Building Code (UBC) occupant load factors for building egress and ASHRAE Standard 90.1P Occupancy Density for use in energy calculations.

Standard 62-89 Estimated Maximum Occupancy values were comparable to UBC occupant load factors. The prototype-assumed levels of occupancy were comparable to ASHRAE Standard 90.1P Occupancy Density. Thus, we concluded that Standard 62-89 Estimated Maximum Occupancy values are specified for sizing the ventilation system and the heating and cooling equipment, since the UBC occupant load factors are meant to represent maximum (not average) peak occupancies while the Standard 90.1P Occupancy Density values represent average conditions.

Although an interpretation of Standard 62-89 was not available at the time of this writing, assuming that occupancy values specified by Standard 62-89 are for sizing building ventilation systems implies that Standard 62-89 requires building ventilation systems to be capable of providing outside air at a rate equivalent to the Estimated Maximum Occupancy values. However, the actual operating outside air rate would be equivalent to the operating maximum number of people. To assess the significance of this assumption, we evaluated both of these occupancy levels (Standard 62-89 Estimated Maximum Occupancy values and assumed prototype values) in estimates of energy use and cost.

2.1.2 Utility Rate Structures

In order to estimate the cost to building owners of meeting Standard 62-89, utility rates were applied to estimated energy use. Two utility rate structures were chosen as representative of the climate zones east and west of the Cascades: City of Richland General Service Electric Rate and Seattle City Light Schedule 34 . The weather files used in conjunction with these utility rate structures were Typical Meteorological Year (TMY) hourly weather files for Sea-Tac and Yakima, which are the closest available hourly weather sites.

2.1.3 Energy Simulation Method

DOE-2.1D accounts for occupant density in building areas with two inputs: (1) occupancy schedules and (2) peak occupancy value or Number Of People (NOP). Occupancy schedules are hourly ratios of the specified NOP, as in the following example of the large office prototype:

DAYS	HOURS	HOURLY FRACTION
(WEEKDAYS)	(1-6)	(0.0)
	(7)	(0.1)
	(8-17)	(1.0)
	(18)	(0.1)
	(19-24)	(0.02)
(SATURDAY)	(1-8)	(0.0)
	(9-12)	(1.0)
	(13-24)	(0.0)
(SUNDAYS, HOLIDAYS)	(1-24)	(0.0)

Most of the prototype buildings have more than one occupancy schedule to account for different areas. NOP is input as a single number; for example, "58" in the Lobby Zone of the Large Office. The hourly occupant density is then this peak occupancy value times the hourly fraction. The SYSTEMS portion of DOE-2.1D, with outside air specified as OA-CFM/PER (cfm/person), sets the minimum outside air rate equal to the NOP multiplied by the OA-CFM/PER. For prototype buildings with economizer control, the minimum outside air rate is exceeded during pre-specified outside air temperature conditions.

We considered peak occupancy a variable since it isn't clear whether Standard 62-89 is specifying a value or not. This led to two sets of DOE-2.1D simulation runs.

For the first set of simulation runs, we modeled each prototype building, both new and existing, utilizing the assumed prototype peak occupancy densities for sizing the equipment. DOE-2.1D has an autosizing feature which sizes equipment to accommodate the building load. By removing the hard inputs for system equipment in the prototype input files, we enabled DOE-2.1D to size the equipment for the prototype occupancy densities using the Standard 62-89 ventilation rates per person.

Then we varied the specified cfm/person from 5 to 25 in steps of 5. Next, the files were simulated using the two utility rate structures for the corresponding weather files for a total of 20 files/building.

For the second set of simulation runs, we modeled each prototype building, both new and existing, by first creating an "ASHRAE occupancy" equivalent. This was accomplished by increasing the peak occupancy value NOP to the Standard 62-89 specified value and decreasing the hourly fractions so that the hourly number of people would correspond to the prototype assumed values. We used the DOE-2.1D equipment autosizing feature to simultaneously accomplish two effects: (1) keeping the building's heating and cooling loads constant while (2) simultaneously increasing the minimum outside air rates.

We again varied the specified cfm/person from 5 to 25 in steps of 5, and simulated these using the two utility rate structures for the corresponding weather files for an additional 20 files/building.

Within building types, occupancies are further delineated in Standard 62-89 (see Table 2.2). This delineation was included in the simulations by adjusting the specified cfm/person within different occupancies so that both the entire building and each of the different occupancies met Standard 62-89 at the same time. For instance, in the Large Retail building the basement and street level retail areas were specified as respectively having outside air rates at a ratio of .30/.20 times higher than the upper retail areas.

Since Standard 62-89 gives the Estimated Maximum Occupancy in sq. ft./person for retail areas, we assumed that an equivalent cfm/person could be derived by multiplying the Standard 62-89 specified values for cfm/sq. ft. and sq. ft./person. This resulted in an equivalent ventilation rate in retail areas of 10 cfm/person.

From each of the 40 energy simulations per building, five numbers were extracted: annual electric energy consumption, peak demand, annual energy cost, total cfm, and outside air cfm. Based on these numbers, we estimate regional energy impacts of Standard 62-89 and assess the expected costs to individual building owners of implementing Standard 62-89.

Table 2.1

Comparison of Occupant Densities

Number of People/1000 ft.^{2}

Occupancy	Prototype	Standard 62-89	UBC	Standard 90.1P
Grocery	4.3	8.0	10.0	3.3
Large Office	4.5	7.0	33.3	3.6
Small Office	4.1	7.0	33.3	3.6
Large Retail				
Sales, Lower	2.9	30.0	33.3	3.3
Sales, Upper	2.8	20.0	16.7	3.3
Storage	0.6	15.0	10.0	3.3
Small Retail				
Sales	3.9	30.0	33.3	3.3
Storage	3.0	15.0	10.0	3.3
Restaurant				
Fast Food	30.5	100.0	66.7	10.0
Kitchen	7.6	20.0	5.0	10.0
Warehouse				
Office	2.6	7.0	33.3	3.6
Warehouse	0.5	5.0	2.0	0.07
Hospital				
Rooms	5.9	10.0	n/a	n/a
Surgery	7.1	20.0	n/a	n/a
Admin.	4.4	7.0	33.3	5.0
Other	4.2	20.0	12.5	5.0
Hotel				
Rooms	5.1	20.0	n/a	n/a
Lobby	2.0	30.0	5.0	4.0
Conf. Rooms	13.5	50.0	66.7	n/a
School				
Classroom	19.8	50.0	50.0	13.3
Auditorium	7.2	150.0	142.9	20.0
Office	4.3	7.0	33.3	3.6
Cafeteria	32.4	100.0	142.9	10.0

Table 2.2

ASHRAE STANDARD 62 VENTILATION AIR REQUIREMENTS

BUILDING TYPE		VENTILATION AIR REQUIREMENTS	UNITS
Grocery/Supermarket		15	CFM/PERSON
Hospital			
	Patient Rooms	25	CFM/PERSON
	Med. Procedures	30	CFM/PERSON
	Other	15	CFM/PERSON
Hotel			
	Rooms	30	CFM/ROOM
	Lobby	15	CFM/PERSON
	Conf. Rms	20	CFM/PERSON
Office		20	CFM/PERSON
Restaurant			
	Dining Rooms	20	CFM/PERSON
	Kitchens	15	CFM/PERSON
Retail			
	Basement & Street	0.30	CFM/FT^2
	Upper	0.20	CFM/FT^2
	Storage	0.15	CFM/FT^2
School			
	Classroom	15	CFM/PERSON
	Library	15	CFM/PERSON
	Auditorium	15	CFM/PERSON
Warehouse		0.05	CFM/FT^2

2.2 Simulation Test Results

Simulation test results, shown in Tables 2.3 through 2.10, are as labeled. The following sections, which discuss the test results, are divided into categories for Prototype number of people and Standard 62-89 number of people because of the significance of this parameter to the results.

2.2.1 Prototype Number of People

2.2.1.1 Required Outside Air

As shown in Table 2.3, assuming daily maximum amounts of people (prototype assumptions), Standard 62-89 resulted in outside air rates of from 0.7% to 41.0% of total building supply air (excluding areas requiring 100% outside air). With the exception of the School, these rates should not be considered excessive. In fact, minimum outside air rates of 10% are equivalent to current practice. The School prototype had exceptionally high occupancy density (second only to Restaurant dining areas) which resulted in relatively high outside air requirements.

2.2.1.2 Energy Use Increase

Increasing the outside air from 5 cfm/person to Standard 62-89-required cfm/person resulted in annual energy increases as shown in Tables 2.4 and 2.5. Whether a building is located in Seattle, Washington, or Richland, Washington, the annual energy increase was less than 13%. For prototype buildings, other than the School, the increase was less than 6%. For the Hospital -- the building with the smallest percent increase -- the increase was less than 0.1% in Seattle.

The increase in energy on a kWh/yr basis (see Table 2.5) showed more variability between prototype buildings than when taken as a percent increase. The Large Office prototype building, because of the dominant cooling load, actually saved energy by increasing the minimum outside air. The other prototype buildings all showed the expected increase in annual energy consumption. The largest increase was the Hotel prototype in Richland, Washington, at 307,950 KWh/yr. (Yakima, Washington, TMY weather).

2.2.1.3 Energy Cost Increase

The equivalent increase in annual energy cost, as a percent of total energy cost, is shown in Table 2.6. As with energy use, the average increase in energy cost was less than 5%. The largest increase was the School prototype annual energy cost in Richland, Washington, at 14.6%. The Hospital and Large Office prototypes showed the smallest increases, less than 0.1%.

2.2.1.4 Regional Impacts

The regional increase in energy use (aMW, where aMW is equivalent to the annual energy savings (kWh/yr) divided by 8,760 hrs/yr) is shown in Table 2.7. For all buildings the estimated increase was 115.2 aMW .

The building types and floor area estimates were derived from the Bonneville Load Forecast for new commercial buildings built between 1992 and 2010.

2.2.2 Standard 62-89 Number of People

2.2.2.1 Required Outside Air

Assuming the Standard 62-89 occupancy density resulted in outside air rates from 6.0% to 94.2% of total building supply air (excluding areas requiring 100% outside air). Considering any outside air rate in excess of 20% to be excessive, 6 of the 10 prototypes exhibited excessive outside air rates.

2.2.2.2 Energy Use Increase

Increasing the outside air from 5 cfm/person to the Standard 62-89 required cfm/person resulted in prototype building annual energy increases as shown in Tables 2.7 and 2.8. The increases in energy use assuming the Standard 62-89 number of people were substantially more significant for some of the prototype buildings. For prototype buildings like Grocery and Hospital, the impact of ventilation air was masked on a percentage basis due to high energy use in areas other than HVAC . The Large Office had such a small heating energy use that the increase in ventilation air did not cause a significant increase in total energy use.

The increase in energy on a kWh/yr basis (see Table 2.5) showed more variability between prototype buildings then when taken as a percent increase. The Large Office prototype building, because of the dominant cooling load, showed only a small increase in energy use. The other prototype buildings all showed the expected increase in annual energy consumption. The Hospital prototype building showed an increase of 497,200 kWh/yr in Richland, Washington. The largest increase was 2,416,600 kWh/yr for the Hotel prototype building in Richland, Washington (Yakima, Washington, TMY weather).

2.2.2.3 Energy Cost Increase

The equivalent increase in annual energy cost, as a percent of total energy cost, is shown in Table 2.6. As with energy use, the average increase in energy cost was significant with some of the prototype buildings. The School showed the largest increase in energy cost with an increase of 42.2% in Seattle. The Hotel was close behind with an increase of 39.6% in Richland, Washington.

2.2.2.4 Regional Impacts

The regional increase in energy use (aMW) is shown on Table 2.8. The estimated increase in annual energy use is 687.1 aMW. The regional increase in energy use is 3 times greater for Standard 62-89 than when prototype number of people was assumed.

2.2.3 Adequacy of Ventilation Systems Design

Design of new buildings tends to include less oversizing of equipment than existing construction. The prototype building constructions reflect current design practice. Tables 2.9 and 2.10 show the outside air as per cent of supply air for the most extreme case: new construction with the higher Standard 62-89 occupancy densities. Where outside air reached 100% the building required higher total supply air rates than the system would provide to accommodate the quantity of outside air necessary. The results show that for the ASHRAE occupancy densities, ventilation at the higher rates, although excessive for more than half the buildings, was within the normal system capacity for all buildings except the Restaurant. Here again, the Restaurant and School were at or exceeding the system capacity because of their exceptionally high occupancy densities.

For the Prototype occupancy densities, the Standard 62-89 rates never exceeded the normal capacity of the ventilation systems.

Table 2.3

Number of People/Required Outside Air

Building Type	Number of People		Required Outside Air (cfm)		Required Outside Air (% of supply air)	
	Prototype	Std 62	Prototype	Std 62	Prototype	Std 62
Grocery	111	208	1,670	3,130	10.2	17.1
Hospital	1,115	3,685	21,800	65,880	9.8	27.3
Hotel	532	4,845	9,610	58,890	5.5	37.0
Small Office	20	34	400	680	7.7	14.3
Large Office	1,824	2,856	36,480	57,120	0.7	6.0
Restaurant	50	157	800	2,490	30.6	94.2
Small Retail	50	365	500	3,650	4.1	33.9
Large Retail	300	2,730	3,000	27,300	4.3	40.2
School	970	3,603	16,700	34,590	41.0	87.0
Warehouse	14	96	210	1,150	1.7	4.0

Note: Percent outside air column excludes outside air used for process loads, such as kitchen ventilation air, medical procedures ventilation air, etc.

Table 2.4

Average Energy Increase
(Percent of Total Energy)

Building Type	Assumed Number of People — Seattle		Richland	
	Proto	Std 62	Proto	Std 62
Grocery	1.5	3.2	1.6	3.5
Hospital	0.0	0.9	0.1	1.4
Hotel	3.9	31.9	4.7	33.6
Small Office	5.5	10.3	5.6	10.5
Large Office	- 0.1	0.0	0.1	0.4
Restaurant	2.5	10.4	2.8	10.7
Small Retail	1.6	11.8	1.5	10.9
Large Retail	0.7	16.5	0.9	15.4
School	12.8	42.3	13.0	40.8
Warehouse	0.4	1.1	0.4	1.1

Note: Percent energy increases are averages between new and existing building configurations and are based on the difference between annual energy consumption at Standard 62-cfm/person and the annual energy consumption at 5 cfm/person.

Table 2.5

Average Energy Increase
(kWh/yr)

Building Type	Seattle Proto	Seattle Std 62	Richland Proto	Richland Std 62
	Assumed Number of People			
Grocery	13,700	53,300	14,600	58,800
Hospital	5,000	335,000	10,600	497,200
Hotel	241,500	2,149,000	307,950	2,416,600
Small Office	5,700	11,000	6,600	12,400
Large Office	-3,100	2,000	9,200	38,700
Restaurant	8,500	35,900	9,900	39,200
Small Retail	8,900	28,200	3,900	31,400
Large Retail	14,600	386,700	22,200	399,400
School	127,000	483,900	135,000	489,400
Warehouse	1,000	2,800	1,200	3,300

Note: Average energy increases are averages between new and existing building configurations and are based on the difference between the energy consumption at Standard 62-required cfm/person and the energy consumption at 5 cfm/person.

Table 2.6

Average Energy Cost Increase
(Percent of Total Energy Cost)

Building Type	Seattle Proto	Seattle Std 62	Richland Proto	Richland Std 62
	Assumed Number of People			
Grocery	1.7	3.9	2.2	4.6
Hospital	0.0	2.7	0.1	3.5
Hotel	4.7	35.8	6.1	39.6
Small Office	5.8	10.7	8.0	14.5
Large Office	0.1	0.1	0.1	0.6
Restaurant	3.1	11.8	3.5	12.4
Small Retail	1.8	13.2	1.7	12.2
Large Retail	0.9	19.8	1.2	18.0
School	13.8	42.2	14.6	38.2
Warehouse	0.5	1.3	0.5	1.9

Note: Percent energy cost increases are averages between new and existing building configurations and are based on the difference between the energy cost at Standard 62-required cfm/person and the energy cost at 5 cfm/person.

Table 2.7

Regional Increase in Energy Use
Assuming Prototype Number of People
(MW)

Building Type	Regional Floor Area (Million Sq Ft)	Prototype Floor Area (Sq Ft)	Base Energy Use (kWh/yr)	Base EUI (kWh/Sq Ft-yr)	Percent Increase (%)	Energy Increase (MW)
Large Office	117.7169	408,000	8,115,521	19.9	-0.05	-0.1
Small Office	85.2433	4,880	97,012	19.9	5.4	10.4
Large Retail	85.3179	120,000	2,069,755	17.2	0.65	1.1
Small Retail	116.3793	13,125	221,314	16.9	1.5	3.4
Restaurant	84.6534	2,624	276,161	105.2	2.1	21.4
Grocery	31.7115	26,050	1,696,155	65.1	1.5	3.5
Hotel/Motel	101.1193	198,500	6,445,550	32.5	3.8	14.2
School	138.2092	62,614	768,725	12.3	15.7	30.4
Warehouse	99.3555	18,025	238,754	13.2	0.4	0.6
Hospital	0	236,620	14,351,413	60.7	0.05	0.0
College	57.6664	N/A				15.8
Health	121.1435	N/A				6.0
Miscellaneous	226.7427	N/A				8.5
	TOTAL					115.2

Notes:

1. Regional floor area is for all buildings built between 1992 and 2010 and is derived from the Bonneville load forecast.

2. Base EUI is the New prototype building energy use at 5 cfm/person for Seattle, Washington, divided by the prototype total square footage.

3. Percent increase in energy consumption is the average prototype value using the assumed value for number of people when ventilating at Standard 62-89 for the new prototype in Seattle, Washington.

4. Energy increase = percent increase (%) x energy intensity (kWh/sq. ft./yr) x regional floor area (sq. ft.) / 8760 hrs/yr.

5. College, Health, and Miscellaneous building categories are derived from combinations of the other prototypes.

Table 2.8

Regional Increase in Energy Use
Assuming Standard 62-89 Number of People
(MW)

Building Type	Regional Floor Area (Million Sq Ft)	Prototype Floor Area (Sq Ft)	Base Energy Use (kWh/yr)	Base EUI (kWh/Sq Ft-yr)	Percent Increase (%)	Energy Increase (MW)
Large Office	117.7169	408,000	8,452,790	20.7	0.0	0.0
Small Office	85.2433	4,880	98,461	20.2	10.3	20.2
Large Retail	85.3179	120,000	2,188,533	18.2	39.8	70.7
Small Retail	116.3793	13,125	240,994	18.4	24.2	59.0
Restaurant	84.6534	2,624	346,544	132.1	10.3	131.5
Grocery	31.7115	26,050	1,697,227	65.2	3.1	7.3
Hotel/Motel	101.1193	198,500	6,382,278	32.2	32.9	122.1
School	138.2092	62,614	919,095	14.7	52.0	120.4
Warehouse	99.3555	18,025	239,579	13.3	1.1	1.7
Hospital	0	236,620	13,463,012	56.9	1.6	0.0
College	57.6664	N/A				82.4
Health	121.1435	N/A				27.6
Miscellaneous	226.7427	N/A				44.2
TOTAL						687.1

Notes:

1. Regional floor area is for all buildings built between 1992 and 2010 and is derived from the Bonneville load forecast.

2. Base EUI is the New prototype building energy use at 5 cfm/person for Seattle, Washington, divided by the prototype total square footage.

3. Percent increase in energy consumption is the average prototype value using the Standard 62-89 Estimated Maximum Occupancy value for number of people when ventilating at Standard 62-89 for the new prototype in Seattle, Washington.

4. Energy increase = percent increase (%) x energy intensity (kWh/sq. ft./yr) x regional floor area (Sq. Ft.) / 8760 hrs/yr.

5. College, Health, and Miscellaneous building categories are derived from combinations of the other prototypes.

Table 2.9

Adequacy of Ventilation System
(outside air as per cent of supply air)

Building Type	Seattle New Construction (outside air cfm/person)				
	5	10	15	20	25
Restaurant	37.7	74.9	100.0	100.0	100.0
School	53.5	87.2	92.4	94.9	96.4
Large Retail	28.7	57.4	86.2	100.0	100.0
Small Retail	22.6	45.0	67.6	90.1	100.0
Hotel	12.4	24.8	37.3	49.7	62.3
Hospital	11.0	17.7	24.4	31.0	37.7
Grocery	8.1	16.3	24.4	32.6	40.7
Large Office	5.0	9.6	14.4	19.1	23.8
Small Office	4.2	7.7	11.1	15.0	18.4
Warehouse	1.7	3.2	4.8	6.4	8.0

Note: Outside air is based on Standard 62-89 occupancy densities and cfm/person. At 100%, outside air requirements forced increase in total supply air.

Table 2.10

Adequacy of Ventilation System
(outside air as per cent of supply air)

Building Type	Richland New Construction (outside air cfm/person)				
	5	10	15	20	25
Restaurant	32.0	63.6	95.6	100.0	100.0
School	53.5	83.8	91.0	93.8	95.5
Large Retail	24.9	49.7	74.6	99.4	100.0
Small Retail	18.5	36.8	55.3	73.6	92.1
Hotel	11.5	23.0	34.5	46.0	57.6
Hospital	10.6	17.0	23.4	29.9	36.3
Grocery	6.8	13.7	20.5	27.3	34.2
Large Office	4.5	8.8	13.1	17.3	21.6
Small Office	3.5	6.4	9.2	12.5	15.3
Warehouse	1.0	2.0	3.0	4.0	5.0

Note: Outside air is based on Standard 62-89 occupancy densities and cfm/person. At 100%, outside air requirements forced increase in total supply air.

2.3 Conclusions

From the results presented in this chapter we conclude the following:

1. Standard 62-89 has a minimum impact on energy use and energy cost, regardless of building type or location when assuming prototype number of people.

2. Interpreting Standard 62-89 as specifying the occupancy density results in significant energy use and energy cost impacts.

3. Two high density occupancy types, Restaurant and School, account for 45% of the expected regional increase in energy use, though these two types total less than 20% of the regional floor area.

4. No prototype building ventilation system was undersized at Standard 62-89 required ventilation rates; all prototype ventilation systems were able to meet Standard 62-89 ventilation requirements easily at the prototype occupancy densities.

2.4 Recommendations

Based on our investigation, we recommend that Bonneville incorporate Standard 62-89 into its programs as follows:

1. Adopt the new ASHRAE Standard 62-89 Outdoor Air Requirements for cfm per person rates.

2. Continue to design equipment based on assumed occupancy or ASHRAE Standard 90.1 Occupancy Density.

In program design or evaluation, the estimated potential energy savings should be adjusted to account for the slight increase in energy use.

Further study should look at ways to minimize impacts of Standard 62-89 on high density building types, e.g., schools and restaurants.

3.0 ASHRAE STANDARD 62-1989 PROBLEMS

Standard 62-89 allows two paths for compliance: Indoor Air Quality (IAQ) Procedure and Ventilation Rate Procedure. In the first path, compliance is reached when 80 percent of a building's occupants don't complain about air quality. Therefore, no designed ventilation system can completely assure compliance simply based on its design. The second path prescribes ventilation rates, which should assure adequate indoor air quality.

It is assumed that only the Ventilation Rate Procedure will apply to Bonneville's commercial sector energy conservation programs. The remainder of this section discusses problems and confusion with the Ventilation Rate Procedure.

3.1 Number of People

Using the Ventilation Rate Procedure of Standard 62-89 requires that the minimum outside air rate be established. As defined by Standard 62-89, this requires the use of Table 2, contained in the Standard. For most occupancies, Table 2 lists required outdoor air in cfm/person and "where appropriate, the table lists the estimated density of people for design purposes."[1] Further, Standard 62-89 states: "Where occupant density differs from that in Table 2, use the per occupant ventilation rate for the anticipated occupancy load." These two statements appear to be in conflict with one another. On the one hand, it says the Table 2 values for occupant density should be used for design purposes; and on the other hand, it says, better estimates of occupant density should be used (although it isn't specified what they should be used for).

As noted earlier, Standard 62-89 Estimated Maximum Occupancy values are excessive when compared to building average peak occupancy. It would therefore seem logical that they are meant exclusively for design purposes. However, Standard 62-89 does not explicitly state what "design purposes" means.

Our interpretation is that the ventilation system has to be capable of providing the design amount of outside air (cfm/person x Estimated Maximum Occupancy); the building supply air (outside air + return air) should be equal to or greater than cfm/person x Estimated Maximum Occupancy. In operation, however, the ventilation system only need provide outside air at the specified rate to the actual number of people.

3.2 Occupancy Categories

Standard 62-89 provides ventilation air requirements which vary by occupancy category. Within buildings it can be difficult to distinguish between different occupancy categories or where one category begins and another ends. It therefore becomes difficult to meet and consequently to enforce Standard 62-89 in practice.

3.3 Infiltration

Standard 62-89 requires ventilation systems to be either mechanical or natural. With natural ventilation systems the ventilation rates must be demonstrable. Infiltration of outside air into commercial buildings is considered to be natural ventilation. Mechanical ventilation is fan-forced air supplied into a building.

Commercial buildings with mechanical ventilation systems still experience infiltration. It has been found that envelope infiltration rates are often the same order of magnitude as the rates of intentional outdoor air intake.[8,11] One study[8] also found that building ventilation rates (including infiltration) are variable depending on outdoor air intake controls, envelope air tightness, and HVAC system operation schedules. Not recognizing infiltration as a source of outside air for mechanically ventilated buildings results in Standard 62 over-specifying required ventilation rates. Combining this with the

Number of People specified by Standard 62 results in over-designing the system by several factors of safety in the required mechanical ventilation rates.

3.4 Energy Code vs Building Code Requirements

The 1989 Model Conservation Standards Code (MCS) is the basis for most energy codes in the Pacific Northwest. The MCS is based on ASHRAE Standard 90.1. As jurisdictions adopt the new MCS, they will likely incorporate it as amendments to the Uniform Building Code (UBC). UBC provides "minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy,..."[6]

The 1989 MCS references ASHRAE Standard 62-89 for ventilation rates and occupancy densities, in lieu of Standard 90.1. The 1988 Uniform Building Code specifies mechanical ventilation rates for health and safety based on ASHRAE Standard 62-73. Therefore, within one jurisdiction's code, two ventilation rates could be specified. UBC ventilation rates are typically specified as a total circulated air flow of 15 cfm/person of which at least 5 cfm/person is outdoor air. Standard 62-89 ventilation rates are higher than UBC's rates. Because of this, one might assume that a ventilation rate falling between the two rates "met code".

Having the energy code specify higher ventilation rates than the building code causes confusion. Higher ventilation rates usually relate to higher energy usage. Therefore, one could assume that the lower UBC ventilation rates meet the MCS's limits to energy use. However, the MCS specifies ventilation rates as a minimum to assure adequate indoor air quality, since higher ventilation rates are usually associated with better air quality. Therefore, the building which falls between the two rates actually does not meet code.

3.5 Indoor Air Quality Procedure

Compliance with Standard 62 can be shown by using the Indoor Air Quality Procedure. In addition to specifying acceptable contaminant levels and exposure times, this procedure requires that at least 80 percent of a panel of at least 20 untrained observers find the indoor air to be not objectionable under representative conditions of use and occupancy. The procedure does not provide a method of measuring specified indoor contaminants.

For existing buildings, using this procedure would require that pollutants be measured and that occupant exposure times be established. It is referenced in the Ventilation Rate Procedure as the means for providing cleaned, recirculated air in lieu of outside air. This procedure would be both more difficult and more costly to enforce than the Ventilation Rate Procedure.

For new construction, compliance would require obtaining detailed information on finshes, floor and wall coverings, partitions and other materials to be installed. Using manufacturer's data on contaminant outgassing rates, the designer could calculate necessary rates to meet

IAQ limits. In practice, many of these materials are selected long after mechanical design is complete. This is especially true for speculative construction, where the building shell is completed, but the interior is built to suit a tenant at a later date. Therefore, this procedure is unworkable for new construction.

3.6 Outdoor Air Quality

Standard 62 requires outdoor air to be treated or reduced when certain contaminants exceed air quality standards. Reducing outdoor air requires compliance with the Indoor Air Quality procedure. This requirement for using only clean outdoor air was in ASHRAE Standard 62-81, but compliance was rare.[9]. We doubt if this requirement will be enforceable or met with compliance in Standard 62-89 either.

3.7 Ventilation Effectiveness

Standard 62 states that a ventilation effectiveness approaching 100 percent is assumed for the required rates. The Standard defines ventilation effectiveness as the fraction of outdoor air delivered to the space that reaches the occupied zone. Therefore, if only 50 percent of the outdoor air mechanically introduced into a building reaches the occupied zone the ventilation effectiveness would be 0.5 and the required ventilation rates would be doubled. Given that a method to measure effectiveness does not exist, 100 percent will be the value assumed in the field.

3.8 Multiple Spaces

Standard 62 adjusts ventilation air requirements for multiple spaces with the following provision: "Where more than one space is served by a common supply system, the ratio of outdoor to supply air required to satisfy the ventilation and thermal control requirements may differ from space to space. The system outdoor air quantity shall then be determined using $y = x/(1+x-z)$, where y is the corrected fraction of outdoor air in the supply system, x is the uncorrected fraction of outdoor air in the supply system, and z is the fraction of outdoor air in the space with the greatest required fraction of outdoor air in its supply."[4] With this provision, compliance with Standard 62-89 should be easier to verify. For each set of multiple spaces served by a common supply fan, the percentage of outdoor air need only be established once.

This provision "makes sense for applications where supply air for bathrooms or kitchens might come from adjacent spaces. However, many other situations exist where applications of the reduction allowance results in some unreasonable results."[1]

Percent outdoor air is a design value which is fixed for all occupancies served by a given air supply system. It is reasonable to adjust percent outdoor air so that occupancies requiring more or less outdoor air are not penalized by other occupancies.

4.0 ASHRAE STANDARD 62-89 VERIFICATION METHODS

4.1 New Buildings

4.1.1 Plan Review

Building code enforcement officials review design documents for new buildings at the time of code review. Within the design documents, designers specify the amount of outside air to be delivered at each outside air intake. Actual measurements of outside air are not performed.

4.1.2 Test and Balance Report

A qualified company tests the building HVAC system and equipment, usually linked to a system start-up procedure. The company then develops a report which documents measured airflow, pump and fan performance data, and temperature. On smaller buildings, testing and balancing is usually not performed because of cost. Testing and balancing to determine the amount of outside air could conceivably be done by either zonal air flows or whole building outside air flows.

4.1.2.1 Zonal Air Flow Measurementss

For each independent fan system which supplies outside air, the amount of outside air (on a percentage basis) is determined by the following formula: $\% \ OA = (T_S - T_R) / (T_O - T_R)$, where T_S = supply air temperature, T_R = return air temperature, and T_O = outside air temperature. The system has to be set to deliver minimum air (e.g., for a VAV system to deliver minimum air the thermostat has to call for full heating).

4.1.2.2 Whole Building Outside Air Flow Measurements

To reduce time, effort, and costs, another less conclusive method would be to measure the total outside air being introduced at the fan system inlet. This could be done by the following procedures: (1) measuring total supply air and total return air (outside air equals supply air minus return air); (2) measuring percent outside air as above assuming supply air is equivalent to manufacturer's data; or (3) measuring the outside air at the intake. Each of these procedures assumes that the outside air ultimately reaches the building occupants.

4.1.2.3 Tracer Gas Measurements

This procedure is not commonly performed in commercial buildings, due to high cost. "In this procedure, a harmless and non-reactive tracer gas is released into the building and mixed thoroughly with the interior air. Once the tracer gas concentration within the building is uniform, one monitors the decay in tracer gas concentration over time. The rate of decay of the logarithm of concentration is equal to the air exchange rate of the building during the time of the test."[8] This procedure includes the measurement of infiltration air which makes it somewhat incomparable with the previously described methods. It results, however, in time-averaged overall building air-exchange rates. Using this procedure, it has been demonstrated that natural ventilation is an important component in overall building ventilation.

4.1.2.4 Carbon Dioxide Measurement

Standard 62-89 ventilation rates are based on an assumption of 1,000 ppm of Carbon Dioxide (CO_2). The measurement of CO_2 is a relatively easy and simple procedure. It is valuable for buildings which are amenable to a one-time spot measurement of CO_2. The technique requires an assumption of CO_2 generation rates per person and measurements of CO_2 concentration in outside and return air. If the calculated outdoor air flow rate, in cfm per person, is above the required rate the ventilation system meets the Standard. (NOTE: This "method" is contained in Appendix D of the Standard and as such is not a part of the Standard. It was suggested that Bonneville consider this approach due to its low cost and because it seemingly meets the Standard's intent.)

4.2 Existing Buildings

4.2.1 System Test

Outside air in existing buildings is not routinely measured, except at times when the HVAC system undergoes a major renovation or remodel. Then the outside air is measured as a commissioning requirement, in similar fashion to that previously described, using zonal air flows and/or whole building outside air flows.

4.2.2 Tracer Gas Measurements

This procedure is identical to that described above for new buildings. Due to high cost (both equipment and personnel) this procedure is not employed by any firm or individual on a regular basis.

4.3 Standard 62-89 Verification Costs

4.3.1 Costs of Zonal Air Flow Measurements

The cost of performing a total HVAC system test and balance in addition to the cost of establishing design air flows, can include the cost of balancing HVAC water flows and pressures. Considering only the cost of testing and balancing air flows, the costs can vary from as little as \$1,000 for a small single zone HVAC system to over \$25,000 for complex multi-system buildings. These costs are representative of what could be expected when attempting to establish outside air delivered to a particular zone or occupancy category within a building. When delivery of outside air on a percentage basis for each HVAC system is measured, and air delivered from each diffuser is measured, outside air is equal to percent outside air times diffuser cfm. Using the building definitions considered in Chapter 2, the study on energy costs, the costs to perform detailed estimates of outside air following the zonal air flow measurement procedure are summarized in Table 4.1.

Table 4.1: Zonal Outside Air Testing Costs

Building type	Air Testing Cost
Grocery	$ 1,200
Hospital	$27,600
Hotel	$22,600
Large Office	$18,450
Large Retail	$ 7,600
Restaurant	$ 1,280
School	$10,800
Small Office	$ 1,600
Small Retail	$ 2,000
Warehouse	$ 800

These estimates are based on R.S. Means Cost Data.[10] They are specific to the building type considered. The costs are based on $40.00/diffuser and $400.00/system; VAV systems are estimated to cost $800.00. For all buildings except the Grocery, it is assumed that there are 400 cfm/diffuser; for the Grocery, it is assumed that there are 1000 cfm/diffuser. The air flow (cfm) assigned to each building is based on design data.

4.3.2 Costs of Whole Building Outside Air Flow Measurements

If less costly methods were used, such as measuring outside air at the HVAC system inlet and assigning that outside air to the entire building, then air flow would not be measured at diffusers; costs would be a function of number of HVAC systems/outside air inlets and would be approximately that shown in Table 4.2.

Table 4.2: Simplified Outside Air Testing Costs

Building Type	Air Testing Cost
Grocery	$ 500
Hospital	$ 4,500
Hotel	$ 8,000
Large Office	$ 1,000
Large Retail	$ 1,500
Restaurant	$ 1,000
School	$ 4,000
Small Office	$ 1,000
Small Retail	$ 1,000
Warehouse	$ 500

Only the outside air method is referenced in standard testing and balancing manuals.[7] Historically, the determination of outside air has not been a primary purpose of testing and balancing. The absolute accuracy of either the zonal or whole building method has not been established. Companies which specialize in testing and balancing of HVAC systems will quote an accuracy of +/- 10%. This is based on experience rather than empirical data. Fluctuating outside environmental conditions make the measurement of mechanical ventilation difficult.

4.4 Equivalent Energy Savings

For costs of either zonal or whole building verification of Standard 62-89 to be acceptable, the equivalent energy savings of a retrofit conservation measure would have to be on the order of 2.5 times the air testing cost (assuming a program overhead rate of 40%, a fifteen year measure life and a cost-effective limit of 50 mills/kWh). Depending on the method used to establish outside air rates and whether whole building rates are acceptable, the required energy savings would be as shown in Table 4.3. Any increase in energy savings beyond that shown or further decrease in outside air would be cost-effective, in general.

As shown in Table 4.3 at least two of these building types would not likely find a cost-effective retrofit: Hospital and Large Office. The assumptions used for HVAC system(s) are the reason. The Hospital would require a reduction in outside air equivalent to 260 cfm/person if the HVAC systems were tested on a zonal basis; the Large Office would require a reduction of 160 cfm/person. If the whole building approach were used instead, the Hospital would require a reduction of 42 cfm/person the Large Office would require 8.6 cfm/person.

The remainder of the building types could realistically absorb the cost of testing for minimum outside air regardless of the methods considered. Using the whole building approach results in minimal outside air reductions for all other building types.

Table 4.3: Cost-Effective Limits

Building Type	Zonal Testing kWh/yr Savings	Zonal Testing cfm/Person Reduction	Whole Building Testing kWh/yr Savings	Whole Building Testing cfm/Person Reduction
Grocery	3,000	1.2	1,300	0.52
Hospital	69,000	260.	11,300	42.
Hotel	56,500	2.2	20,000	0.77
Large Office	46,100	160.	2,500	8.6
Large Retail	19,000	7.8	3,750	1.5
Restaurant	3,200	3.7	2,500	2.9
School	27,000	2.1	10,000	0.78
Small Office	4,000	11.	2,500	6.6
Small Retail	5,000	7.3	2,500	3.6
Warehouse	2,000	20.	1,300	13.

5.0 RECOMMENDATIONS

5.1 Interpretations of Standard 62-1989

5.1.1 Number of People

Standard 62-89 Estimated Maximum Occupancy values should only be used as a sizing criteria for design of ventilation systems, if at all. In operation, the average peak number of people encountered in the building should be used. When this value is not available or difficult to determine, ASHRAE Standard 90.1 provides a number that should be used.

5.1.2 Indoor Air Quality Procedure

This procedure is valuable when building air quality problems are of concern. It is not viable for use with new buildings not yet occupied or for major retrofit projects where post-conditions have not yet been established. In evaluating air quality problems in operating buildings, this procedure should be used as part of the regulatory functions of OSHA, UBC, or other regulatory agencies that evaluate building air quality problems.

5.1.3 Outdoor Air Quality

This provision is not enforceable because it requires that pollutants be measured at the outdoor air intake for compliance. This provision should not be included in the interpretation.

5.1.4 Ventilation Effectiveness

Ventilation effectiveness cannot be measured and therefore should not be a part of our adopted interpretation. Its reference in the Standard should be considered a design constraint: Design the system so that the outdoor air is delivered to occupied zones.

5.1.5 Ventilation Standards

UBC is written for public health and safety. It should be the source for minimum indoor air quality/ventilation standards. The energy code (MCS) should limit maximum ventilation rates for energy reasons but should not take precedence over UBC. The purpose of MCS ventilation requirements should be clarified and the differences between MCS and UBC ventilation rates should be resolved.

5.1.6 Multiple Spaces

The allowance for the adjustment of outside air based on varying occupancies served by the same HVAC system should be adopted. This would allow easy verification of multiple spaces, such as conference rooms and lobbies, for compliance.

5.1.7 Energy Codes and Building Codes

The energy codes should prescribe the maximum ventilation rate. The minimum ventilation rates would be more appropriate in the health and safety codes, because the minimum is for the purpose of ensuring adequate indoor air quality.

5.2 Preferred Method for Determining Outside Air Rates

The following conditions have been shown: (1) Building ventilation systems are affected by ambient temperature and wind conditions and (2) Infiltration is a non-neglible contributor to overall building air-exchange. These facts, coupled with the problem of identifying peak numbers of people, make the usefulness of a detailed measurement of outside air suspect. Therefore, a high value should not be placed on particular mechanical ventilation rate numbers. Instead, the intake and distribution of outside air should be verified, either visually or through measurement techniques. The quantification of air quality in the building should be established through subjective measurements or visually identifiable problems.

Considering the cost and accuracy of the two general methods for determining outside air rates, the preferred method is the "Whole Building" method. This method at least assures that an appropriate amount of outside air is being introduced into the building and is not so difficult that its use would be restricted to testing and balancing companies; utility auditors should be able to use it to adequately determine outside air rates. In summary, this Orocedure requires the following steps:

A. Minimum Outside Air Requirements Calculation

1. Determine peak number of occupants

    i. This should be the highest number of people usually encountered during the average workday. If the peak number of occupants is difficult to determine, use Standard 90.1 occupancy values.

    ii. Where requirements are in cfm/sq ft or cfm/room, calculate the square feet or rooms served by the mechanical ventilation system, as appropriate.

2. Calculate amount of outside air to be provided each occupancy served by each mechanical ventilation system. (Multiply peak number of occupants by the required outside air rate (cfm/person)).

3. Adjust outside air rate to account for different occupancies served by the same ventilation system using equation IAQ-1.

    i. Calculate the uncorrected outdoor air fraction (X) by dividing the sum of all the branch outdoor air requirements (V_{ot}) by the sum of all the branch supply flow rates (V_{on}).

ii. Calculate the critical space outdoor air fraction (Z) by dividing the critical space outdoor air requirement (V_{oc}) by the critical space flow rate (V_{sc}).

iii. Use equation IAQ-1 to find the corrected fraction of outdoor air (Y) to be provided in the system supply.

Equation IAQ-1

$$Y = X / [1 + X - Z]$$

Where,

Y = V_{ot}/V_{st} = corrected fraction of outdoor air in system supply
X = V_{on}/V_{st} = uncorrected fraction of outdoor air in system supply
Z = V_{oc}/V_{sc} = fraction of outdoor air in critical space[1]
V_{ot} = corrected total outdoor air flow rate
V_{st} = the sum of all supply air quantities for all branches of the system
V_{on} = sum of outdoor air flow rates for all branches on system
V_{oc} = outdoor air flow rate required in critical spaces
V_{sc} = supply flow rate in critical space

B. Ventilation System Inspection (not applicable to new buildings)

Prior to ECM installation visually inspect the ventilation system to determine that outside air is reaching building occupants, that harmful or irritating contaminant sources are isolated from the main ventilation system, and that there are no known building ventilation problems which could be compounded or exacerbated by a ventilation reduction. If problems exist they must be corrected prior to ECM installation. A short report documenting the inspection shall be prepared and be available in the Energy Analysis Report or other site visit documentation

C. Ventilation Rate Measurement

Determine outside air rate (cfm) using one of the two following methods. For the measurement, the outside air supply shall be set to the minimum amount for systems which supply varying amounts (e.g. variable air volume, economizer control).

Documentation of ventilation rate measurement results shall be contained in the Energy Analysis Report or other site visit documentation.

1. Percent outside air method

   a. Measure outside, return, and mixed air temperatures. Calculate percent outside air using equation IAQ-2.

   b. Measure total supply air (cfm), either by a pitot tube traverse of main supply duct or by measure of supply air at diffusers.

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1 The critical space is that space with the greatest required fraction of outdoor air in the supply.

Equation IAQ-2

$$\% \, OA = (T_s - T_r) / (T_o - T_r)$$

Where,

T_s = mixed air temperature
T_r = return air temperature
T_o = outdoor air temperature

c. Calculate outside air = (% outside air) x (cfm)

d. Determine total outside air for all mechanical ventilation systems serving building.

e. Determine peak number of occupants

   i. This should be the highest number of people usually encountered during the average workday. If the peak number of occupants is difficult to determine, use Standard 90.1 occupancy values.

   ii. Where requirements are in cfm/sq ft or cfm/room, determine the square feet or number of rooms served by the mechanical ventilation system.

f. Calculate mechanical ventilation rate = outside air (cfm) / peak number of occupants, or cfm/sq ft, or cfm/room as appropriate.

g. Adjust the ventilation rate in accordance with the procedure given for New Buildings.

2. Carbon Dioxide method

Alternatively, where a mechanical ventilation system serves a space(s) where the activities are well known and constant from day-to-day a simplified procedure can be used. This method will show whether indoor carbon dioxide concentrations are below ASHRAE Standard 62-89 recommended levels of 1000 ppm. If the indoor carbon dioxide concentrations are above 1000 ppm, then the building or space does not comply with these requirements.

a. For each mechanical ventilation system measure carbon dioxide concentration in return air and in outside air.

b. Determine if required cfm/person ventilation rate (OA) is being met by solving equation IAQ-3 for indoor carbon dioxide concentration:

Equation IAQ-3

$$OA = Gen.\ Rate / (C_i - C_o)$$

Where,

Gen. Rate = occupant generation rate (cfm/person) of carbon dioxide (refer to Standard 62-89).

C_i = return air (indoor air) carbon dioxide concentration

C_o = outdoor air carbon dioxide concentration

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