A Comparison of the Ventilation Rates Established by Three Common Building Codes in Relationship to Actual Occupancy Levels and the Impact of these Rates on Building Energy Consumption

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Abstract

Ventilation rates for HVAC systems are often selected for the maximum projected occupancy in a given room. These projections are based on code dictated requirements and can be strongly influenced by the furniture lay outs shown for offices and conference rooms and interviews with occupants. Final design ventilation requirements are developed based on the anticipated needs of the space within the context of the governing code and the architectural information. While some consensus has been reached in recent years among various codes and standards, there can still be considerable variation in actual ventilation rates implemented by a given design in a specific building depending on which code is in force, the designer's interpretation of the projected use of the areas served, and the difference between the projected peak design occupancy and the actual average occupancy seen in day to day operation of the building.

Indoor air quality and energy efficiency are growing concerns requiring better design and maintenance. This paper explores the differences and similarities between several common codes and standards with regard to ventilation requirements and how these differences can impact the energy consumption of a building. The energy implications of a design based on the maximum projected occupancy level for a space compared to the average occupancy level are also explored.

Introduction

The topic of this paper has the potential to be quite controversial. However, that is not the intent of the authors. The concept of the paper evolved out of field and design experience. The authors realized that, despite good intentions on the part of code officials, designers, and operators, ventilation rates in many buildings were higher than seemed necessary to adequately and safely meet the daily needs of the occupants. This appeared to place an unnecessary energy burden on the central heating and cooling equipment. For instance, on one site, the boiler system was firing at 50% of its design-maximum, winter time rate on the warmest day of summer to serve reheat loads that, to a large extent, were related to the minimum flow settings for conference room and office zones. On another site, electric reheat coils were consuming considerable amounts of energy for similar reasons. Thus the following questions arose:

- How were the ventilation rates for these areas selected in the first place?
- Would the current codes in force allow a less energy intensive approach as long as safe and adequate ventilation rates were provided for these areas?

- Since ventilation rates seem to be driven by the projected populations, are there different ways to project occupancy during design and what are the implications?
- How closely do the design projections agree with observed populations?
- What areas should be targeted for additional research to allow future HVAC systems to provide safe levels of ventilation without using excessive energy ?

This paper evolved from our attempts to look at these issues and present our findings to others for review and discussion.

Background

Outdoor air that is introduced into a building for the purpose of ventilation is a key factor in maintaining a healthy building environment and good indoor air quality. Indoor air contaminants are controlled by assuring that a portion of the air inside the building is exhausted and replaced with fresh, uncontaminated air. When done at the proper rates, this process will dilute and control the contaminants in the building to levels that are safe for human exposure. The requirement to supply ventilation air carries with it an energy burden since the air delivered to the space must be moved, heated, cooled, and dehumidified. Thus it is desirable to provide as much ventilation air as is necessary to provide a safe building environment but no more than that. Over ventilation can result in significant first cost burdens in the form of oversized equipment and an ongoing energy burden for the life of the facility. But, under ventilation can expose the building occupants to indoor air contamination that can threaten their health and in the worst case make the building uninhabitable. This can have significant litigation liabilities in addition to obvious health and resource problems.

The primary focus of the ventilation section of building codes is to require ventilation levels that will provide a safe and healthy building environment. Energy use considerations are secondary in these sections, but most current codes contain provisions that provide windows of opportunity allow a knowledgeable and creative designer or operator to achieve the required results with minimal energy consumption. The energy sections of the same codes may also provide additional criteria to assist with this process. But the capacity required at the central heating and cooling plant to meet the ventilation needs of the building is primarily related to the designer's interpretation and application of the code criteria. The on going energy use of this equipment is related to both the initial rates set by the designer and how these rates are controlled, maintained and adjusted over the life of the building by the facility engineers and operators. The most successful designs will provide sufficient capacity to meet any foreseeable ventilation need but at the same time will provide the operators and engineers with the flexibility to tailor the systems to the current building requirements.

Most codes address ventilation issues by prescribing criteria that must be met by building designers in order to assure suitable indoor air quality. Historically, this information has been in tables that specify ventilation rates per person or ventilation rates per square foot. Design maximum occupancy levels area also specified. This rate-based procedure is an indirect solution to the problem of indoor air contaminant control; it assumes that if the prescribed rates are supplied, then the required level of indoor air quality will be maintained.

Recent research and advances in technology have opened the door to more direct solutions for indoor air contaminant control. Typically, these solutions consist of a combination of an engineered ventilation solution that quantitatively addresses the anticipated sources of indoor contamination coupled with sensing and control systems that measure selected representative contaminants and then adjust the ventilation rate in real time in order to adequately control the contaminates. Many, but not all building codes, have adopted language that allows this type of approach to be taken. The approach potentially reduces the energy requirements associated with the ventilation process, but requires complicated and costly engineering and a more complex and sophisticated control system.

Litigation concerns, conflicting or difficult to interpret code and standard requirements, and public perceptions tying high outdoor air ventilation rates to good indoor air quality seem to be leading system designers toward air handling system designs that incorporate increasingly higher ventilation rates. There have been instances where 100% outdoor air Heating, Ventilating, and Air Conditioning (HVAC) systems have been proposed as design solutions for the sole purpose of assuring high indoor air quality. The design proposal addressed the significant energy penalty associated with this decision by incorporating heat and cooling recovery systems, but these systems added another level of complexity and first costs to the project, which in turn raise resource utilization, operation, and maintainability concerns.

While there is a distinct relationship between outdoor air ventilation rates and indoor air quality, we feel there are limits to this relationship. In other words, beyond a certain point, more is not necessarily better. In fact, if ventilation air is not properly handled and/or conditioning equipment is not properly selected, adjusted, installed, or maintained, then more can actually be worse and/or counter-productive to the over all goal of efficiently maintaining a healthy indoor air environment. Potential problems include:

- Design ventilation rates significantly higher than those required by the actual use and occupancy of the building.
- Ventilation rates not meeting design or operating requirements due to calibration problems and/or the failure of sophisticated but delicate control equipment and sensing systems
- Ventilation HVAC parameters not being maintained due to lack of understanding, lack of familiarity, or lack of necessary resources to allow the equipment and system to be properly maintained and operated.
- Building envelope and system degradation due to condensation and related problems (corrosion, mold growth, insulation failures, etc.) associated with HVAC and building envelope designs that do not adequately address or anticipate the requirements associated with high ventilation rates.

These problems could be addressed or mitigated by adequately addressing the initial problem. By carefully considering the design ventilation requirements for the building and assuring that they are adequate but not excessive, the resulting systems will be less complex, more reliable, and will pose less of a first cost and ongoing resource burden to the building over its life. The remainder of this paper will focus on how current codes and standards are used to develop these design requirements and discuss the related energy and resource issues.

Discussion

For the purposes of this paper, the ventilation requirements from the following codes and standards were reviewed.

- 1997 Uniform Mechanical Code/1997 Uniform Building Code (UBC)

- 1993 BOCA National Mechanical Code (BOCA)
- 1998 International Mechanical Code (IMC)
- ANSI/ASHRAE 62-1989 - Ventilation for Acceptable Indoor Air Quality

All of these codes are currently in use in various sections of the country. The ANSI/ASHRAE standard is a current standard developed by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE, a national professional organization) in conjunction with the American National Standards Institute (ANSI).

It should be noted that there has been a recent revision to the ASHRAE standard which is called ASHRAE 62-1999. The standard is nearly identical to the ANSI/ASHRAE 62-1989 standard with the following exceptions:

- Miscellaneous footnotes and references are eliminated and modified.
- Consideration of thermal comfort is removed.
- Disclaimers are added that state that compliance with the standard will not necessarily result in acceptable indoor air quality for a variety of reasons.
- References ventilation rates that will accommodate a moderate amount of smoking are eliminated.
- Clarifications are added regarding CO_2.

Table 1 compares the various codes and the ASHRAE standard as they relate to ventilation requirements for an office building type occupancy.

Discussion of Ventilation Rates and Occupant Loads

All of the codes and standards that were reviewed for this paper contained a prescriptive-rate-based technique for determining the minimum required outdoor air flow rate for a building. The most basic was a simple statement in UBC of 15 cfm per person for all portions of the building that were occupied. The code also provides more occupancy-specific criteria in an optional appendix in terms of cfm per square foot of occupiable area. Adoption of the appendix is at the discretion of the code authority that is enforcing the code. Both the primary code as well as the optional appendix reference ASHRAE 62-1989 with language indicating that compliance with the ASHRAE "shall be prima facie evidence of compliance" with the requirements of the UBC.

The other codes and standards all contain a table with occupancy specific criteria in terms of design cfm per person and a design occupant load number in terms of people per square foot of heated or cooled space. Areas that tend not to be continuously occupied (corridors, utility areas, duplicating areas) had design flow rates specified in terms of cfm per square foot of area. The criteria for office type occupancies (offices, conference rooms, reception) was fairly uniform across BOCA, IMC, and ASHRAE with the one exception being that BOCA required 20 cfm per person in the reception areas while IMC and ASHRAE required only 15.

Both IMC and ASHRAE 62-1989 allow alternative ventilation solutions based on a quantitative or statistical approach to controlling indoor contaminants. UBC could also be said to contain this provision due to its reference to the ASHRAE standard. In addition to making provisions to allow for this approach, the ASHRAE standard also provides information to help guide and support the designer through the process. IMC simply states that such an approach would be allowed and leaves it to the discretion of the designer to develop and document the necessary design.

Table 1. Comparison of Design Mechanical Ventilation Requirements for Various Codes for an Office Building Occupancy

Item	1997 Uniform Mechanical and Building Codes	1993 BOCA National Mechanical Code	1998 International Mechanical Code	ANSI/ASHRAE 62-1989
Minimum required outdoor air ventilation rate	Chapter 12 states that 15 cfm per person is required in all portions of the building during such time as the building is occupied. Appendix 12 contains additional, more specific criteria (see below). The mechanical code requires that sufficient ventilation air be provided to make up for any exhaust and that the systems be electrically interlocked with their associated exhaust systems.	Determined in accordance with Table M-1604.3 based on the occupancy of the space and the occupancy load. The amount of supply air is to be approximately equal to the amount of return and exhaust air.	Determined in accordance with Table 403.3 based on the occupancy of the space and the occupant load. The amount of supply air is to be approximately equal to the amount of return and exhaust air. An exception allows reductions if a registered professional can demonstrate that an engineered ventilation system design will prevent the maximum concentration of contaminants from exceeding that obtained by the code specified ventilation rate.	The standard includes both a rate procedure and an indoor air quality procedure. The rate procedure uses estimated occupancy levels and flow rates in terms of cfm per person or cfm per square foot to determine the necessary ventilation rates. The indoor air quality procedure is focused on restricting the concentration of contaminants to specific acceptable levels, which are published in the standard. This information would be one basis that could be used for an engineered ventilation system design as was mentioned by the International Building Code.
Basis for design occupant load	Not specifically stated. The Appendix 12 table references cfm per square foot of area. Both Chapter 12 and Appendix 12 reference standard ANSI/AHRAE 62-1989 which contains occupant based criteria.	Not less than the number determined from the estimated maximum occupant load rate indicated in Table M-1604.3.	Based on the estimated maximum occupant load from Table 403.3 unless approved statistical data can be used to document the accuracy of an alternate anticipated occupant density.	For the rate procedure it is the density listed in Table 2 of the standard (estimated maximum occupancy per 1000 sq.ft.). The standard provides for using the actual anticipated occupancy load if it will be different than what is prescribed in the table.

Item	1997 Uniform Mechanical and Building Codes	1993 BOCA National Mechanical Code	1998 International Mechanical Code	ANSI/ASHRAE 62-1989
Provisions for ventilation reduction below design rate based on actual occupant load?	Yes - Both Chapter 12 and Appendix 12 by reference to ASHRAE Standard 62-1989. In addition, Appendix 12 Table A-12-A note 2 contains additional provisions in which controls are permitted to adjust outdoor air ventilation rates to provide equivalent rates per person under different conditions of occupancy.	Yes - The minimum amount of outdoor air supplied during the period the building is occupied shall be permitted to be based upon the rate per person indicated in table M1604.3 and the actual number of occupants present.	Yes - During actual operation (as compared to design), the minimum outdoor air flow rate can be based on the applicable rate per person from Table 403.3 and the actual number of occupants present.	Yes - see preceding comment. In addition, the standard allows the ventilation rate to be further reduced if the duration of the peak occupant load will be three hours or less with a limit of no less than one half of the maximum.
Requirements for common ventilation systems serving areas with different ventilation requirements	Not specifically stated, but addressed by reference to ANSI/ASHRAE Standard 62-1989 by both Chapter 12 and Appendix 12.	Not specifically addressed.	Specifically addressed using the ANSI/ASHRAE Standard 62-1989 equation.	Yes; the standard provides an equation to calculate the corrected fraction of outdoor air required in a common system serving areas with different ventilation requirements.
Requirements for Variable Air Volume (VAV) system control	Not specifically stated, but addressed by reference to ANSI/ASHRAE Standard 62-1989 by both Chapter 12 and Appendix 12.	Not specifically addressed.	Requires a control system to regulate the outdoor air to meet the requirements of the code.	The standard contains a general requirement that provisions be made to maintain acceptable indoor air quality when the space is occupied and the air volume is reduced.
Specified Outdoor Air Ventilation Rate for Office Spaces	0.14 cfm per square foot of area (Appendix 12).	20 cfm per person with an estimated maximum occupant load of 7 persons per 1,000 square feet.	20 cfm per person with an estimated maximum occupant load of 7 persons per 1,000 square feet.	20 cfm per person with an estimated maximum occupant load of 7 persons per 1,000 square feet.
Specified Outdoor Air Ventilation Rate for Conference Rooms	1.00 cfm per square foot of area (Appendix 12).	20 cfm per person with an estimated maximum occupant load of 50 persons per 1,000 square feet.	20 cfm per person with an estimated maximum occupant load of 50 persons per 1,000 square feet.	20 cfm per person with an estimated maximum occupant load of 50 persons per 1,000 square feet.

Item	1997 Uniform Mechanical and Building Codes	1993 BOCA National Mechanical Code	1998 International Mechanical Code	ANSI/ASHRAE 62-1989
Specified Outdoor Air Ventilation Rate for Reception Areas	0.90 cfm per square foot of area (Appendix 12).	20 cfm per person with an estimated maximum occupant load of 60 persons per 1,000 square feet.	15 cfm per person with an estimated maximum occupant load of 60 persons per 1,000 square feet.	15 cfm per person with an estimated maximum occupant load of 60 persons per 1,000 square feet.
Specified Outdoor Air Ventilation Rate for Corridors and Utility Areas	0.05 cfm per square foot of area (Appendix 12).	0.05 cfm per square foot called out under Public Spaces with no estimated maximum occupant load specified.	0.05 cfm per square foot called out under Public Spaces with no estimated maximum occupant load specified.	0.05 cfm per square foot called out under Public Spaces with no estimated maximum occupant load specified.
Specified Outdoor Air Ventilation Rate for Duplicating Areas	0.50 cfm per square foot of area (Appendix 12).	0.50 cfm per square foot called out under Workrooms with no estimated maximum occupant load specified.	0.50 cfm per square foot called out under Workrooms with no estimated maximum occupant load specified.	0.50 cfm per square foot called out under Workrooms with no estimated maximum occupant load specified.
Square footage basis	Net occupiable square footage.	Net occupied heated or cooled space.	Net occupied heated or cooled space.	Net occupiable square footage.
Temperature requirement specified?	The mechanical code contains some references to maximum temperatures in different duct classes, but no specific references to ventilation air temperatures were found. Additional requirements are implied by the reference to the ASHRAE standard.	The temperature difference between the ventilation air and the conditions space shall not exceed 10°F except for ventilation air that is part of the air conditioning system.	Not specifically stated.	Reference is made to ASHRAE Standard 55-1981 - Thermal Environmental Conditions for Human Occupancy.
Outdoor air quality statement?	The mechanical code Chapter 4 contains some general criteria for outdoor air quality and source requirements. More stringent criteria are implied by reference to the ASHRAE standard.	Outdoor air quality is specified by very specific criteria contained in Table M-1604.6.	General requirements regarding distances from sources of contamination, etc. are given.	Outdoor air quality is specified by very specific criteria set by EPA. In addition, the standard gives a procedure by which outdoor air can be evaluated for acceptability.

Item	1997 Uniform Mechanical and Building Codes	1993 BOCA National Mechanical Code	1998 International Mechanical Code	ANSI/ASHRAE 62-1989
Filtration Requirements	Filters are required as a general statement in the mechanical code with no efficiencies specified other than for Group I (Hospitals and Correction Facilities). Location is to be upstream of the equipment except for Group I, in which case they are to be downstream of the equipment. Filters are to be Class I or Class II.	A general statement is made indicating that air filtration, or some other means or a combination of air filters and some other means shall be provided to bring outdoor air quality into compliance with the code.	Not specifically stated.	The standard contains general guidelines and tables covering particle sizes and also references other ASHRAE standards and publications regarding filter testing and filtration and dust control and collection equipment.
Alternative technique for determining acceptable ventilation rates?	Yes - cfm per person in accordance with nationally recognized standards. Chapter2 12 and 35 recognize ANSI/ASHRAE 62-1989 with addendum 62a-1990.	None listed.	Yes - Engineered and/or statistical solutions for both ventilation rates and occupant load are allowed. See preceding comments.	Yes - See previous comments.
Exhaust Requirements - Toilet rooms	Chapter 12 requires a mechanical exhaust system capable of providing one air change every 15 minutes. Appendix 12 requires 50 cfm per water closet or urinal. Reference to the ASHRAE standard by both sections implies the use of similar criteria from ASHRAE as being acceptable.	Mechanical exhaust required. The outdoor air requirement is 75 cfm per water closet or urinal.	Mechanical exhaust required. The outdoor air requirement is 75 cfm per water closet or urinal.	50 cfm per water closet or urinal. Direct exhaust is not required and the standard contains provisions and requirements to define air cleaning requirements which will allow air to be recirculated in many applications. In some applications, recirculation is specifically prohibited.

Item	1997 Uniform Mechanical and Building Codes	1993 BOCA National Mechanical Code	1998 International Mechanical Code	ANSI/ASHRAE 62-1989
Exhaust Requirements - Spaces with Class I, II, or III liquids	Both Chapter 12 and Appendix 12 specify 6 air changes per hour taken from a point near floor level.	Requires 1 cfm per square foot of floor area and not less than 150 cfm total for hazardous material storage locations if required by the Fire Code. Consideration is to be given to the nature of the fumes released (heavier or lighter than air). Emergency shut off may be required.	Covered in a separate chapter.	Specific requirements deal with specific occupancies and hazards in Table 2. In addition, the narrative sections of the standard discuss the need and requirements for local exhaust and contaminant control. The book "Industrial Ventilation - Manual of Recommended Practice" is referenced.
Transfer of air from surrounding spaces permitted?	Yes - Appendix 12 Table A-12-A allows transfer air for certain applications including public restrooms in office buildings.	Yes - Allowed unless specifically prohibited by Table M-1604.3.	Yes - Allowed unless specifically prohibited by Table 403.3.	Yes - Unless specifically prohibited in Table 2.
General comments	Chapter 12 of the Building Code and Chapter 4 of the Mechanical Code deal with ventilation. Chapter 12 also contains an appendix. The information in Appendix 12 does not apply unless it is specifically adopted.	None.	None.	Some of the information is contained in Appendices, which are not a part of the standard but are included for information purposes and to support the information in the standard.

It is quite common for air handling systems to serve areas with different ventilation requirements. Lacking a better technique, designers are forced to deliver the highest percentage of outdoor air required by the critical zone to all zones in order to assure that the critical zone is satisfied. As an example, consider a system serving one zone that requires 50% outdoor air to satisfy its ventilation needs while the remaining zones only required 20% outdoor air. With out a code provision that would allow a designer to use an alternative technique, the designer may conclude that he must supply 50% outdoor air to all zones in order to assure that adequate ventilation is supplied to the zone requiring 50% outdoor air. This will result in over ventilation of the zones with a 20% outdoor air requirement and can place a significant burden on the central heating and cooling plant. Both IMC and ASHRAE 62-1989 make provisions for calculating a reduced ventilation fraction for systems that serve areas with different ventilation requirements. BOCA contains no direct provisions that allow a designer to take this step. So, even if the designer was aware of the potential to reduce the ventilation load while still providing suitable indoor air quality based on procedures covered by ASHRAE 62-

1989, he or she would be powerless to do so in a locality where the BOCA code was enforced. In such a situation it is always possible that a variance could be negotiated with the local code authority, but this process can be lengthily and a successful outcome is not always guaranteed. Given the low fee structures associated with typical office building projects and the compressed, (often frantic) design and construction schedules that are often associated with them, the engineering team may have little choice other than to simply design a system that meets the local code requirements. Thus, the opportunity to provide a less energy intensive solution is lost.

Variable Air Volume (VAV) air handling systems are a very common approach to office area HVAC. The design of these systems allows the flow rate to the zones to be varied as a function of the load, thereby saving considerable fan energy as well as heating and cooling energy. However, this approach presents a significant problem to the system designer because the system must vary the primary air flow in response to the load while maintaining the required outdoor air ventilation rate as required by the current occupancy level. The occupant level may or may not be directly related to the current load on the system. If the occupant load is insignificant relative to the over all load on the system (a computer room or a building with a lot of clear glass and significant solar gains), then a system without active minimum outdoor air control will quite likely over-ventilate the space. The minimum outdoor air flow rate will follow the system flow rate up and down as the total system load varies due to physical relationships that exist in the system even though the occupant count does not vary significantly over the course of the load change. This would place unnecessary loads on the central plant. On the other hand, a system that has a load that is highly occupant dependent may under ventilate at low load conditions if an active minimum outdoor airflow control system is not provided. This would in fact reduce the plant energy burden but at the expense of indoor air quality. The IMC and ASHRAE 62-1989 contain language that covers this contingency. UBC also covers it via it reference to ASHRAE. BOCA does not address the issue, but it also does not prevent the designer from taking steps to address the issue; the designer would simply be going above and beyond the requirements of the code.

Often the design occupant load in a building is significantly larger than the actual occupant load. There are many reasons for this including:

- Code dictated occupant levels that must be used as the design criteria by the system designer.
- Changes in the use of the building or future provisions made at the time of design that are not realized during the actual occupancy of the building.
- Interpretation of the information presented on the architectural furniture plans or other architectural drawings.

Often times, these differences can amount to a significant ventilation burden that is not really justified or necessary when the day to day operation of the facility is reviewed. This can have several significant impacts on the over-all load for the facility including:

- Minimum flow rates to zones will exceed the zone cooling requirement resulting in nearly continuous reheat and no flow variation. This effect can become especially pronounced in conference rooms.
- The outdoor air fraction for the space with the highest percentage of outdoor air will become the outdoor air fraction for the entire system unless the code permits adjustment of the minimum flow rate for combined occupancies based on some sort

of integrated average. If the code does allow some sort of integrated adjustment, then the effect will not be as severe (unless the fraction is 100%).

- System fan energy will increase at low load conditions due to the higher minimum flow rates on the zones with higher outdoor air fractions.

The IMC and ASHRAE62-1989 contain a formula that allows the over-all air handling system outdoor air fraction for systems serving occupancies with different outdoor air fractions to be adjusted to take the combined effects into account. Without this provision, the designer would either have to set the entire system outdoor air fraction at the level associated with the zone with the highest outdoor air fraction requirement or provide separate systems for occupancies with significantly different requirements. Both options have obvious first cost and on-going operation and maintenance cost implications.

All of the codes and standards reviewed contained provisions that allow the ventilation rate to be adjusted to match the actual number of occupants present. Unfortunately, there are many instances where the design occupancy rate is never compared to the actual occupancy rate in the building after it has been occupied and in use. We have observed several instances where the documented day-to-day census of the building would result in ventilation rates that were 40-50% of that provided by the original design. Adjusting the rates to match the actual building census resulted in a significant reduction in the peak cooling load, a significant reduction in the summer time reheat load, and virtual elimination of the need to preheat. The preheat load was eliminated because the mixing of warm return air with the lower minimum outdoor air flow rates provided by the air handling system's economizer cycles was able to provide the necessary supply temperature without additional heating. On one recently encountered site, these adjustments were worth tens of thousands of dollars per year in operating costs in electricity and gas.

In addition to allowing the ventilation rate to be adjusted to match the actual occupant load, ASHRAE 62-1989 also allow the designer to base outdoor air flow rates on the average occupancy rather than the peak occupancy if the period of peak occupancy is relatively short. This can be helpful because many times, the average occupancy of a building is fairly constant and simply shifts around in the building over the course of the day. Office workers may leave their offices and meet together in a conference room or a manager's office for an hour or two. During this period, the occupancy level of the conference room or manager's office might rise, but the over all occupancy level of the building has not changed.

Example

The following tabulations illustrate the differences between the ventilation rates established by the various codes and/or their interpretations when they are applied to a typical office environment. They also look at the impact of design vs. actual occupant counts. The calculations are based on an nominal 100 foot by 100 foot office floor with the following characteristics:

- Open office area with cubicles for the major portion of the space.
- Two 15 foot by 25 foot conference rooms.
- Three management level private offices with conference tables.
- Conditioned space above and below the floor in consideration.
- 15% - 20% glass area on the perimeter walls with high performance glass and well insulated wall construction

- One common VAV air handling system serving all of the spaces on the floor from a central location.

These assumptions, while somewhat simplified, closely match conditions that have been observed in numerous office building occupancies through-out the country. Each individual space was analyzed to show the impact of using various basis of occupancy to determine the ventilation outdoor air requirements for each zone. Then, the multiple space equation contained in the IMC and ASHRAE 62-1989 was used to demonstrate the combined effect of the various minimum outdoor air fractions on a common central system serving the entire area. Cooling flows were calculated based on a 57°F supply temperature and a 72°F space. The outdoor air fraction indicated is as a percentage of the required cooling supply flow.

Table 2 – Conference Room Ventilation Rate Comparison for Various Occupancies

Occupancy Basis	People Count	Outdoor Air Required - cfm	Space Cooling Load - btu/hr	Design Cooling Flow - cfm	Outdoor Air Fraction
Code based square feet per person	8	160	3,075	190	84%
Architectural drawing with 25 chairs	25	500	7,325	452	111%
Average observed occupancy	3	60	1,825	113	53%

For the conference rooms, even if the average observed occupancy is used in the calculations, the outdoor air fraction is still over half of the total volume delivered to the space due to the low internal gains. In the case where occupancy is based on the architectural information, the system would need to be set to deliver a minimum flow rate that is above that required to cool the space. This means that the system would always be reheating and that the air flow to the zone would never vary regardless of the level of occupancy, including times when the room was totally unoccupied.

Table 3 – Management Office Ventilation Rate Comparison for Various Occupancies

Occupancy Basis	People Count	Outdoor Air Required - cfm	Space Cooling Load - btu/hr	Design Cooling Flow - cfm	Outdoor Air Fraction
Code based square feet per person	1	20	1,380	85	23%
Architectural drawing showing 5 chairs	5	100	2,380	147	68%
Average observed occupancy	1	20	1,380	85	23%

In this area, the code based analysis and the average observed occupancy produce very similar results. However, as in the conference room example, an analysis based on the architectural drawing information has a significant impact.

Table 4 – Open Office Space Ventilation Rate Comparison for Various Occupancies

Occupancy Basis	People Count	Outdoor Air Required - cfm	Space Cooling Load - btu/hr	Design Cooling Flow - cfm	Outdoor Air Fraction
Code based square feet per person	60	1,200	112,885	6,968	17%
Architectural drawing showing 70 cubes with one person each	70	1,400	115,385	7,123	20%
Average observed occupancy	64	1,280	113,885	7,030	18%

In the case of the open office areas, there is very little difference between the results produced by the various analyses.

Table 5 – Comparison of the Impact of Different Occupancy Basis on the Outdoor Air Fraction for a Common System Serving Multiple Areas

Occupancy Basis	Code based square feet per person	Architectural drawing interpretation	Average observed occupancy
Critical Space	Conference Rooms	Conference Rooms	Conference Rooms
Total People Count	79	135	73
Sum of All Outdoor Air Flow Rates (Von)	1,580	2,700	1,460
Total Flow Rates (Vst)	7,603	8,563	7,511
X = Von/Vst	0.21	0.32	0.19
Critical Space Outdoor Air Requirement (Voc)	160	500	60
Critical Space Supply Flow Rate (Vsc)	190	500	113
Z = Voc/Vsc	0.84	1.00	0.53
Corrected system outdoor air supply fraction (Y)	57%	100%	29%

When the requirements of the various spaces are combined and served by one air handling system, the impact of the basis of occupancy once again becomes very significant. Most significant is that in the case of the architectural basis, the fact that the conference rooms must be served with a 100% outdoor air fraction requires that the combined system use 100% outdoor air, even when the multisystem equation contained in the IMC or ASHRAE 62-1989 is applied. This is the same result as one would obtain from a code such as BOCA, which makes no provision for combining spaces. Additional analysis reveals that if the outdoor air fraction were reduced from 100% to 95% for the conference room, the multisystem equation causes the central air handling system outdoor air fraction to be reduced to 85%. In the case of a system designed under BOCA (no multispace equation) then the central system fraction still needs to be 95% and the designer may find it desirable to consider providing two independent systems, one for the conference areas and one for the remaining office areas.

Even if the architectural based analysis is discarded, using the observed occupancy level instead of the occupancy level dictated by the codes results in a significant reduction in the minimum outdoor air requirement for the central system. In most parts of the country, this is the difference between having to preheat a significant portion of the time during the fall, winter and spring months and not having to preheat due to mixing via the economizer cycle. There would also be an impact on the peak load seen by the cooling system with the impact being most significant in areas with high ambient humidity levels during the summer months.

All of the preceding being said, in the case of new construction, it may be highly desirable to provide a ventilation rate during the first year of occupancy that is significantly higher than that which would be required for ongoing operation after the first year. This is because there can be significant off gassing of contaminants from the new building materials during the first months or year after they are installed in the building. A designer addressing variable occupancy levels either through an engineered ventilation design or via control may want to consider using different criteria or set points for the system during the construction phase and first year of operation. This particular issue does not seem to be well addressed in the rate based codes as an independent issue. The premise appears to be that if the designer provides the specified levels of ventilation, then adequate contamination control will be maintained through all phases of a building's life.

Outdoor Air Quality and Filtration Requirements

All of the codes reviewed had general requirements regarding the minimum distances between the air handling systems outdoor air intakes and sources of contamination such as chimneys, flues, exhaust fan discharges, plumbing stack vents, etc. BOCA and ASHRAE 62-1989 go on to state very specific criteria in terms of long term and short term averages for various contaminates including sulfur dioxide, particles, carbon monoxide, ozone, nitrogen dioxide, and lead.

None of the codes contained anything but general requirements with regard to filtration. The ASHRAE standard refers to other ASHRAE documents and standards regarding filters, filter testing, filter efficiencies, dust control, and equipment. Since the UBC references this standard, it can be construed that it also references these other ASHRAE documents. While filtration is not the topic of this paper, it should be noted that proper selection application, installation and maintenance of filters can have significant impacts on the indoor air quality of a building. In addition, the type of filter selected and its associated pressure drop can have a measurable impact on the building's energy use and waste stream.

Exhaust Requirements

All of the codes and standards that were reviewed required that exhaust be taken from the toilet rooms in office buildings. The requirements varied from a simple statement of one air change every 15 minutes in the UBC to a more common statement of cfm exhausted per plumbing fixture in the other standards with the requirements varying from 50 to 75 cfm per water closet or urinal. All of the codes required that the outdoor air flow rate closely match the exhaust flow rate but generally allow the designer to establish the pressure relationships between the various spaces in the building.

The reviewed codes and standards also contained fairly specific requirements regarding exhaust from spaces with Class I, II, and III liquids. The requirements included rates as well as special requirements that considered the nature of the liquids and the fumes they produced.

All of the codes allowed the use of air transferred from adjacent spaces to provide make-up for exhaust air in any given location unless specifically prohibited in the tables included with the code. This provision can be used by designers to minimize reheat requirements by transferring thermally neutral air from an adjacent space into the area where exhaust is required. For instance, if a restroom required 300 cfm of exhaust to meet the exhaust provisions of the code, but could be comfortably maintained by a supply from of 100 cfm from the central air handling system due to low internal gains in the space, then the duct systems could be arranged to transfer 200 cfm of return air from the adjacent spaces into the rest room to provide the necessary make-up flow rate. With out this provision, the designer would have needed to supply 300 cfm from the central system and then reheat it to prevent it from overcooling the space. This would have added significant first costs and ongoing operation and maintenance costs to the project.

Conclusions

The design problems associated with developing the proper and required minimum outdoor air flow rates are complex and confusing. The design engineer finds him or herself confronted with a often bewildering array of codes and standards which often conflict and are very open to different interpretations by the governing code officials. Building ventilation rates that are deemed totally satisfactory under the standards set by one code may be totally unacceptable when applied to identical systems and occupancies under another code. The less complex, more easily applied rate solutions used to establish acceptable ventilation levels will often result in systems that have a higher first cost and significant ongoing operation and maintenance costs when compared to systems that use engineered approaches to quantitatively control contamination. The more sophisticated rate based solutions that use a multi-space equation to minimize the impact of zones with high outdoor air fractions on the central system can become complex to calculate if the zone counts are large and the procedure can be somewhat intimidating for the inexperienced user. The engineering required to develop a quantitative approach for ventilating a building is often beyond the engineering time line or budget available for a project and requires considerable expertise to accomplish successfully. It could also be argued that this approach also has a higher level of liability risk for the design professional.

Adapting the design flow rates to meet the actual conditions encountered in a building (or even simply maintaining the design flow rates) requires a fairly sophisticated level of understanding on the part of the facilities engineering and operations staff. The control systems associated with minimum outdoor airflow can be complex and are often prone to failure. The design assumptions are often not well documented or understood. At best this results in poor maintenance of the original criteria. At worst, this can mean that the original intent is never realized or implemented.

Considerable progress has been made by national and international code and standards organizations toward providing documents that give designers, owners, and operators the framework they need to provide HVAC systems that efficiently and effectively meet the ventilation needs of buildings they serve. Some of the outstanding problems and questions may benefit from additional research and development work in the following areas:

- Continued efforts by codes and standards writers to develop a uniform and consistent strategy for safely and efficiently meeting building ventilation needs.

- Continued efforts to educate design professionals, owners, installers, and facilities engineering professionals in proper ventilation practice from design through operation and maintenance of the HVAC systems.
- Develop HVAC systems and approaches to ventilation that allow designers to provide equipment sized to meet the foreseeable ventilation needs of the building that can also efficiently turn down to meet the variations from this peak requirement.
- Develop control strategies that take advantage of current technology DDC systems to allow owners and operators to adjust the ventilation rates on their systems to match the current occupancy levels.
- Develop additional criteria to allow design professionals, owners, installers, and facilities engineering professionals to assess and accommodate the off-gassing and other indoor contamination issues raised by new construction.

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