Update, Analysis and Recommendations -

ANSI/ASHRAE STANDARD 62.1 – 2004, *Ventilation for Acceptable Indoor Air Quality*

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BACKGROUND

This paper is an updated version of a similar one published for Standard 62-2001. Please study the complete documents discussed in this paper and review the bibliography. This short paper should not be considered a substitute for the complete document, nor is it a shortcut to compliance with the standard. There are many other issues to consider that are not discussed here.

ANSI/ASHRAE Standard 62.1-2004 is an often misunderstood document outlining ventilation requirements intended to provide acceptable indoor air quality for new buildings or those with major renovations. Because of the rate-based nature of both procedures allowed for compliance, this analysis focuses on the needs for reliable intake rate control and the risks of some popular indirect controls. Design recommendations offered are intended to increase the potential for both predictable compliance and for the flexibility to accommodate future changes, while providing the greatest control reliability with the most energy efficient methods.

INTRODUCTION

This is a brief summary of ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality (IAQ) in Commercial, Institutional, Industrial and High Rise Residential Buildings* [1]*,* as it impacts and is influenced by ventilation control requirements, methods and equipment. Operational implementation of these requirements can have a sizeable influence on energy usage, when applied improperly or incompletely. Operational precision and design reliability are essential to minimize energy usage, when compliance with 62.1 and energy codes are simultaneous goals.

This ANSI-approved standard has been developed by a Standing Standards Project Committee (SSPC) of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE), under a ‘continuous maintenance’ protocol. At any point in time, the ’official’ Standard is comprised of both the most recently published parent document and all current addenda. The latest parent document was republished earlier this year to combine 17 addenda that had been approved subsequent to the original release of the 62-2001 parent document in January 2002. The result is a final version that is substantially different from the basic ventilation standard we have used since 1989.

In 2003, the scope of the Standard officially changed and a separate ASHRAE committee was formed to address the specific needs of Low-Rise Residential Buildings. The existing Standard became known as 62.1 and the new residential standard became 62.2.

The long promised *62.1 User’s Manual* was recently published and is now available at www.ASHRAE.org. Work continues on *Guideline 19P*, which is intended to provide design guidance for methods of compliance that exceed the minimum requirements of the Standard.

Both of these supplemental documents should assist the designer and facility operator in the understanding of and compliance with the Standard.

ANALYSIS AND RECOMMENDATIONS

Our discussion of Standard 62.1 will mimic most of its structure, provide recommendations for compliance and highlight methods and assumptions to avoid. Our objectives have determined the content.

The Standard's "Purpose" and "Scope" are covered in Sections 1 and 2. To comply with the Standard, designers of mechanical ventilation systems are tasked to provide specific minimum rates of acceptable outdoor air to the breathing level of the occupied structures. In doing so, an acceptable indoor environment may be achieved providing improved occupant comfort, productivity and health. The procedures allowed for compliance with our national standard on ventilation are prescriptive or performance-based. Your selection should be evaluated for IAQ risk by the design practitioner.

DEFINITIONS

Section 3 addresses the definition of terms used within the Standard. Noteworthy is the Standard's definition of "acceptable indoor air quality" which is provided as

> "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction [1]."

This means that 62.1, like all ASHRAE Standards, assumes one out of five occupants (20%) may not be satisfied with the results of compliance and may express dissatisfaction with the indoor air quality, even if the Standard is followed perfectly. Many sources have concluded that the majority of HVAC systems designed in the U.S. do not meet the minimum ventilation rates prescribed during operation. In which case, the actual occupant dissatisfaction level is exponentially greater in practice [2]. It is not uncommon for rates to fall below levels that result in occupant dissatisfaction significantly greater than 50%. Many systems cannot meet the minimum airflow requirements at the occupied space during operation because of design choices and equipment limitations, or due to the dynamic nature of mechanical ventilation systems and the constant external forces acting on the building envelope.

The impacts from these continuously changing external conditions are not limited to Variable Air Volume (VAV) systems [2]. Outdoor airflow rates will also vary for systems that provide a Constant Volume of supply air (CAV) to the conditioned space, as a result of:

a) changes in wind and/or stack conditions on the intake system [3],
b) changes in filter loading,
c) changes in airflow requirements during an economizer cycle.

The lack of specific guidelines to overcome the effect of changing system dynamics on ventilation rates and air distribution for today's HVAC systems is partially to blame for many design deficiencies observed.

Unlike thermal comfort, the effect of indoor air quality is difficult to measure.[1] Many believe that the outdoor air levels specified by ASHRAE are too low and should actually be increased, as indicated by published research and reflected in European standards from CEN Technical Committee 156 and their publication CR1752 [4].

OUTDOOR AIR QUALITY

Section 4 of the Standard describes a three-step process to evaluate outdoor air for acceptability. One of those steps requires examination of both the regional and local air quality by the building owner. The section also specifies the documentation required to support the conclusions of this preliminary review.

If the outdoor air quality is found to be unsuitable per Section 4, then treatment may be required as indicated in §6.2.1. Outdoor air treatment involves removal of the particulates and/or gases encountered that are in excess of the minimum standards cited by cognizant authorities in §4.1.

SYSTEMS AND EQUIPMENT

Section 5 specifies the minimum systems and equipment required under Standard 62.1. §5.4 states,

> "Mechanical ventilation systems shall include controls, manual or automatic, that enable the fan system to operate whenever the spaces served are occupied. The system shall be designed to maintain the minimum outdoor airflow as required by Section 6 under any load condition. Note: VAV systems with fixed outdoor air damper positions must comply with this requirement at minimum supply airflow [1]."

Because the requirements in the Standard for compliance are set forth "under any load condition," we are being asked to maintain a constant rate of outdoor airflow in dynamic systems. Logically, there should also be a requirement for continuous airflow measurement at the intake of all air-handling units with automatic controls providing a space with a constant rate of outdoor air, regardless of the system size, type or point of operation. Doing so would alleviate several issues, clarifying application and compliance questions in §6.2.7 Dynamic Reset; §7.2.2 Air Balancing; and §8.4.1.8 Outdoor Airflow Verification. A continuous outdoor air measurement requirement was included in the draft Standard 62-89R before becoming politicized, much more complicated and vague to the point of confusion.

The Standard encourages us to use direct measurement feedback for continuous control on all VAV designs, even those using a powered outdoor air system (i.e. injection fan, HRV/ERV, smaller DOAS, etc.). Although not contained in the Society's 'minimum' standard, ASHRAE is highlighting the potential source of problems and a few of the more obvious means to avoid them.

We believe and recommend that Section 5 of the Standard encourages the use of airflow measuring devices at the intake of all systems and in the supply air to critical zones of VAV systems. This allows for not only improved operating savings, continuous verification of

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[1] "The work item that caused most controversy was an attempt to standardise [sic] design criteria for the indoor environment. The criteria developed in the process have been published as a CEN Technical Report CR 1752. It specifies the levels of temperature, air velocity, noise, and ventilation for occupied spaces. Values are given for three categories of environmental quality: A - a high level of expectation, B - a medium level and C - a moderate level. Supporting information is given on the derivations of the specified values of the parameters as well as to enable alternatives, such as different clothing levels, to be accommodated in the design assumptions. The most debatable section is on indoor air quality. Here, prominence is given to the evaluation of the required ventilation rate for comfort based on perceived air quality, the method developed by Professor Fanger and his colleagues in Denmark. While some data is presented, it is acknowledged that more research is needed to provide reliable information on pollution loads from materials and on the additive effects of emissions from multiple sources." Source: http://www.aivc.org/frameset/frameset.html?../Air/20_3/jackman.html~mainFrame accessed June 2005.

compliance and use as a diagnostic tool, but also may be used to reset intake rates based on changes in occupancy. Polularly known as "Demand Controlled Ventilation," the technology is available to count or estimate zone populations in real time and are surprisingly cost effective. When compared to the potential energy savings without negatively impacting occupant productivity and health, there is no reason to avoid it.

PRESSURIZATION & MOLD

Problems identified immediately after publication of Addendum 62x (62-2001) generated Addendum 62ai (renamed 62.1a for the 2004 version and quoted below). The Public Review[2] for this addendum is underway at this writing (August 2005) and is expected to be approved by the Board of Directors.

The addendum only addresses positive pressure during periods of dehumidification. However, it clarifies several issues, including exceptions to the 65% RH requirement and for labs and industrial spaces.

> "5.10 **Dehumidification Systems.** Mechanical air-conditioning systems with dehumidification capability shall be designed to comply with the following:
>
> 5.10.1 **Relative Humidity.** Occupied zone relative humidity shall be designed to be limited to 65% or less at either of the two following design conditions: 1) at the peak outdoor dew point design conditions and at the peak indoor design latent load, or 2) at the lowest space sensible heat ratio expected to occur and the concurrent (simultaneous) outdoor condition when system performance is analyzed with outdoor air at the dehumidification design condition (that is, design dew point and mean coincident dry bulb temperature), and with the space interior loads (both sensible and latent) at cooling design values and space solar loads at zero.
>
> **Note:** System configuration and/or climatic conditions may adequately limit space relative humidity at these conditions without additional humidity-control devices. The specified conditions challenge the system dehumidification performance with high outdoor latent-load and low space sensible heat ratio. (cont'd)
>
> **Exception**: Spaces where process or occupancy requirements dictate higher humidity conditions, such as kitchens, hot tub rooms that contain heated standing water, refrigerated or frozen storage rooms and ice rinks, and/or spaces designed and constructed to manage moisture, such as shower rooms, pools and spas.
>
> 5.10.2 **Exfiltration.** For a building, the design minimum outdoor air intake shall be greater than the design maximum exhaust airflow when the mechanical air conditioning systems are dehumidifying.
>
> **Exception**: Where excess exhaust is required by process considerations and approved by the authority having jurisdiction, such as in certain industrial facilities. **Note:** Although individual zones within a building may be neutral or negative with respect to outdoors or to other zones, net positive mechanical intake airflow for the building as a whole reduces infiltration of untreated outdoor air."

Noting the proliferation of mold in buildings, the ASHRAE Board stated that sound moisture management should take precedence over energy cost savings when it issued *Minimizing Indoor Mold Through Management of Moisture in Building Systems* in June 2005 [5]. This Position Paper outlines recommendations by describing issues related to the topic and

[2] 30 and 45-day Public Review drafts of ASHRAE Standard 62.1-2004 with comment instructions are posted periodically at http://www.ashrae.org/template/TechnologyLinkLanding/category/1634

highlighting resources available through the Society. This policy will eventually trickle-down through the society's organization and eventually impact technical programs, research and standards.

Included in their recommendations for proper moisture management are:

- Building and system design, operation and maintenance provide for drying of surfaces and materials prone to moisture accumulation under normal operating conditions.
- Mechanical system design should properly address ventilation air.
- The sequence of operation for the HVAC system should contain appropriate provisions to manage humidity, control pressurization and monitor critical conditions [5].

The flaw of ASHRAE's position is in not recognizing the potential for high humidity alone to provide sufficient moisture content for mold growth. Studies have shown that a temperature between 30°F – 86°F [-17°C - 30°C] and humidity of only 70% RH (non-condensing infiltration), mold growth has appeared on plasterboard, brick and concrete within 3 days. At 65.3°F [18.5°C] (with adequate RH and "inadequate" substrate) mold grows on building materials after 6 hours. It was shown to take only 1 hour with "adequate" substrate [2, 6].

Part of the solution to preventing infiltration of unfiltered and unconditioned humid air appears to be simple. In 1996 the Florida Solar Energy Center first published a case study which identified that an extremely small negative pressure differential created conditions that lead to mold problems in a small commercial building. This was later supported by a 2002 Journal article whose recommendations indicated that differential pressures as low as +0.004 to +0.008 in. WG [1 to 2 Pa] will prevent moisture infiltration problems [7]. This counter-flow overcomes most of the natural pressures that power moisture migration, namely: vapor, temperature (stack), and wind pressures. Those periods when pressurization flow is insufficient to counter infiltration are generally limited in duration. Thereafter, the flow of air to the direction of higher dew point temperature can remove any residual moisture in the wall cavity.

Control precision and stability must be key objectives when energy usage is to be minimized and dynamic control of space pressurization is used.

The Standard should address wind and stack effect, and provide guidelines that reflect conditions that influence buildings in their normal environment. In addition, increased humidity combined with wind and stack driven infiltration during periods when the ventilation system is not operating, may be a significant factor influencing mold and fungal growth, e.g. offices and schools during closures. Designers and building operators should consider a limited night setback mode with provision for humidity and pressurization flow controls. Such a provision would also tend to compensate for the building-generated contaminants by supplying a base ventilation rate, sufficient for minimal pressurization flow.

PROCEDURES

Section 6, Procedures, is the heart of the Standard. For compliance, designers must claim using one or the other, not both. You may choose between the Ventilation Rate Procedure (VRP) and the Indoor Air Quality Procedure (IAQP) to determine the minimum dilution ventilation rate required for design. Designers and operators cannot selectively ignore the parts they do not like. One entire procedure must apply. Parts from each procedure cannot be combined to achieve ventilation rates lower than those determined by the VRP alone. Great care should be given to the selection between these procedures.

The VRP as defined in 6.1.1: "…is a prescriptive procedure in which outdoor air intake rates are determined based on space type/application, occupancy level and floor area [1]." The key phrase is "prescriptive procedure in which outdoor air intake rates are determined." Very simply, this implies the need for some form of airflow measurement.

The alternative IAQP in 6.1.2: "…is a design procedure in which outdoor air intake rates and other system design parameters are based on an analysis of contaminant sources, contaminant concentration targets and perceived acceptability targets [1]." Any analysis of this procedure quickly reveals the clear discussion of airflow rate requirements based on varying contaminant levels.

VENTILATION RATE PROCEDURE

The VRP detailed in §6.2 is rate based. No question. In fact, the entire Standard is rate-based, including the IAQP, which only provides the means to calculate allowable reductions in the design ventilation rate from those in Table 6-1 (see also Appendix D for alternate methods of calculation). The explicit statement to this effect was removed last year in an effort to render the language in the Standard more 'code enforceable.'

Designers claiming compliance with the VRP must be able to document and substantiate that minimum intake rates can be maintained during operation "under all load conditions," at not less than the higher of either code-required levels or those indicated by table 6-1 and the calculations in §6.2.

Once the outdoor air is determined to be acceptable or has been treated for use indoors, we can begin to determine how much is needed under our specific design situation.

First, we must calculate outdoor airflow requirements for the **zone** (V_{oz}), as detailed in §6.2.2.1 through §6.2.2.3 which can be summarized below with their corresponding equations and reference numbers:

- Calculate breathing-zone outdoor airflow - $V_{bz} = R_pP_z + R_aA_z$ (6-1)
- Determine zone air distribution effectiveness - E_z = Table 6-2
- Calculate zone outdoor airflow at diffusers - $V_{oz} = V_{bz}/E_z$ (6-2)

Then, determine the outdoor airflow requirements for the **system** (V_{ot}) and calculate minimum outdoor air intake flow. We are given 3 general system types to choose from:

- Single-zone systems: $V_{ot} = V_{oz}$ (6-3)
- 100% OA systems: $V_{ot} = \sum_{\text{all zones}} V_{oz}$ (6-4)
  and
- Multiple-zone recirculating systems
  Outside Air Intake: $V_{ot} = V_{ou}/E_v$ (6-8)

In Multi-zone recirculating systems, the variables needed to solve for V_{ot} (V_{ou} and E_v), are determined in §6.2.5.1 – §6.2.5.4 summarized below, and will be examined in more detail later.

- Calculate the Zone primary outdoor air fraction: $Z_p = V_{oz}/V_{pz}$ (6-5)
- Determine the Uncorrected outdoor air intake: $V_{ou} = D \sum_{\text{all zones}} R_pP_z + \sum_{\text{all zones}} R_aA_z$ (6-6) and
  Accounting for Occupant Diversity: $D = P_s/\sum_{\text{all zones}} P_z$ (6-7)

One subtle change in the updated Standard includes the usage and definition of "breathing zone." In addition, rates will no be longer determined solely on occupancy "per person." Separate component rate requirements are included to address both occupant and building-generated contaminants.

> "6.2.2.1 **Breathing Zone Outdoor Airflow.** The design outdoor airflow required in the *breathing zone* of the occupiable space or spaces in a *zone*, *i.e., the breathing zone outdoor airflow* (V_{bz}), shall be determined in accordance with Equation 6-1.
>
> $$V_{bz} = R_p P_z + R_a A_z \qquad (6\text{-}1)$$
>
> where*:*
>
> A_z = *zone floor area*: the net occupiable floor area of the *zone* m^2, (ft^2).
>
> P_z = *zone population*: the largest number of people expected to occupy the zone during typical usage. If the number of people expected to occupy the zone fluctuates, P_z may be estimated based on averaging approaches described in Section 6.2.6.2.
> **Note**: If P_z cannot be accurately predicted during design, it shall be an estimated value based on the zone floor area and the default occupant density listed in Table 6-1.
>
> R_p = outdoor airflow rate required per person as determined from Table 6-1.
> **Note**: These values are based on adapted occupants.
>
> R_a = outdoor airflow rate required per unit area as determined from Table 6-1.
> **Note**: Equation 6-1 is the means of accounting for people-related sources and area-related sources for determining the outdoor air required at the *breathing zone.* The use of Equation 6-1 in the context of this standard does not necessarily imply that simple addition of sources can be applied to any other aspect of indoor air quality [1]."

Total intake rates at the air handler can be directly determined with hand-held instruments used in accordance with prescribed standards, or by using an appropriate and permanently installed airflow measuring device. Total intake rates may be indirectly estimated by several other means (i.e. Supply/Return differential calculation, temperature balance, mass balance, steady-state CO_2 concentration, etc.). However, the uncertainty of indirect techniques introduces a significant level of risk [2,7]. The designer, facility owner and occupants should carefully consider the method employed prior to implementing any CO_2-based Demand Controlled Ventilation scheme as the sole method of intake rate control.

The new VRP in §6.2 recognizes the magnitude of building generated pollutants, therefore added the "building component" in the zone ventilation equation. Table 6-1 and the accompanying notes specify outdoor air requirements for specific applications. Equation 6-1 (§6.2.2.1 above) is now based on the combination of ventilation rates per person (as CFM/p) PLUS ventilation rates per floor area (as CFM/ft^2). Therefore, systems that meet these requirements:

(a) the minimum requirements of Table 6-1, combined with
(b) the calculated volume of outdoor air required by 6.2 and
(c) the outdoor air quality requirements set forth in Section 4
(d) while "under any load condition,"

can claim that their ventilation system complies with the Standard through the VRP.

Under ideal and very specific conditions, CO_2 levels can only reflect the rate that outdoor air enters the building on a per person basis – through any and all openings. Therefore, CO_2-based DCV with single 'ppm' set point control cannot be implemented under the new requirements of

Standard 62.1 unless applied with excessive conservatism and the accompanying increase in energy usage. Otherwise, CO_2-based DCV will invariably under ventilate spaces, over ventilate spaces or require that the Standard be interpreted in such a way to allow the potentially large airflow errors that will result from using multiple commercial CO_2 sensor inputs.

Table 1: Steady-state CO_2 Differentials

(Area = 1,000 ft^2)

# People	Required Total OA	CFM/Person	CO_2 Rise [C_i-C_o]	Comments
7 (+17%)	95 CFM	13.5	807 ppm	} **Under ventilated**
6 **(base)**	90 CFM	15	700 ppm	using a 700 ppm differential set point
5 (-17%)	85 CFM	17	644 ppm	} **Over ventilated**
3 (-50%)	75 CFM	26	438 ppm	

Total OA CFM Required = 0.06 CFM/ft^2 + 5 CFM/person (Source: ASHRAE 62.1-2004, Table 6-1, offices)

Calculated using the concentration balance formula in ASHRAE 62.1 Appendix C,
at Various Population Densities in an Office Space [2]

Indirect measurements for control typically carry such a large degree of uncertainty, one can never be secure that the controlled variable (ventilation rates) will not drop below or substantially exceed the mandated minimums under operating conditions.

Too much risk. Compliance with the IMC using CO_2 is entirely at the discretion of the “Authority Having Jurisdiction,” upon application for exemption. Compliance with ASHRAE 62.1 is indicated, but the method is left in doubt. The new *62.1 User’s Manual* does attempt to offer some possible alternatives, but the limitations in use and vagueness leave much to the determination of the individual designer – and entirely at your own risk, without even a nod to compliance with the standard. For example:

Why risk it when there are other more reliable methods available to accomplish the same function without the risk, yet provide similar or superior results?

MULTI-SPACE ‘EQUATIONS’ BECOME A DESIGN ‘PROCEDURE’

Once the breathing zone outdoor air requirement is determined, the Standard requires an adjustment based on the distribution system efficiency and effectiveness. This makes complete sense since the air must reach the breathing zone to be effective.

Multi-zone recirculating systems are not as efficient as 100% OA systems and are therefore required to be factored by their approximate and relative inefficiency. We are given two methods to determine this factor:

1. Table 6-3, “default E_v” method
2. Appendix A, “calculated E_v” method

These methods produce significantly different results. The more precise one is contained in Appendix A and as might be expected, is more involved. The table’s conciseness requires it to be more conservative and therefore not as efficient in many situations.

For each multiple zone recirculating system (VAV or CAV), the primary outdoor airflow fraction must be calculated for all zones that may become ‘critical’ (only one zone can be critical on CAV systems). The “critical zone” is defined as the zone that has the highest percentage of outdoor air required in the primary air stream. When analyzing a VAV system dynamically, treat it as a CAV system.

As an example, if the supply air distribution system is located close to the return air, a short circuit is generally created. The Standard requires designers to use a zone air distribution effectiveness (E_v) of 0.5 which essentially doubles the amount of outdoor air required. In contrast to this example, a system with a ceiling supply and a ceiling return has a zone distribution effectiveness of 1.0 during cooling and 0.8 during heating. Therefore, the outdoor air set point must be reset seasonally or a more conservative and less energy-efficient factor used.

Systems that provide a variable supply of air volume to the conditioned space are influenced by everything previously discussed. In addition, outdoor airflow rates will vary as a result of changes in mixed air plenum pressure. If the design did not assume the worst-case scenario when the outdoor airflow rate for the air handler was determined, outdoor airflow rates on VAV systems may need to be reset based on calculations of the multi-space equations (6-5 through 6-8, defined in §6.2.5 below), in order to avoid potentially excessive over ventilation and the associated energy penalty.

“6.2.5 **Multiple-Zone Recirculating Systems.** When one air handler supplies a mixture of outdoor air and recirculated return air to more than one zone, the *outdoor air intake flow* (V_{ot}) shall be determined in accordance with §s 6.2.5.1 through 6.2.5.4 [Equations 6-5 through 6-8].

6.2.5.1 **Primary Outdoor Air Fraction.** When Table 6-3 is used to determine system ventilation efficiency, the *zone primary outdoor air fraction* (Z_p) shall be determined in accordance with Equation 6-5.

$$Z_p = V_{oz}/V_{pz} \qquad (6\text{-}5)$$

where V_{pz} is the zone primary airflow, i.e., the primary airflow to the zone from the air handler including outdoor air and recirculated return air.
Note: For VAV systems, V_{pz} is the minimum expected primary airflow for design purposes.

6.2.5.2 **System Ventilation Efficiency.** The *system ventilation efficiency* (E_v) shall be determined using Table 6-3 or Appendix A.

6.2.5.3 **Uncorrected Outdoor Air Intake.** The design *uncorrected outdoor air intake* (V_{ou}) shall be determined in accordance with Equation 6-6.

$$V_{ou} = D \sum_{all\ zones} R_p P_z + \sum_{all\ zones} R_a A_z \qquad (6\text{-}6)$$

The *occupant diversity*, D, may be used to account for variations in occupancy within the zones served by the system. The *occupancy diversity* is defined as:

$$D = P_s / \sum_{all\ zones} P_z \qquad (6\text{-}7)$$

where the *system population* (P_s) is the total population in the area served by the system. Alternative methods may be used to account for population diversity when calculating V_{ou}, provided that the resulting value is no less than that determined by Equation 6-6.

Note: The *uncorrected outdoor air intake* (V_{ou}) is adjusted for diversity but uncorrected for ventilation efficiency.

6.2.5.4 **Outdoor Air Intake.** The design *outdoor air intake flow* (V_{ot}) shall be determined in accordance with Equation 6-8.

$V_{ot} = V_{ou} / E_v$ (6-8)" [1]

Advanced VAV control strategies can dynamically satisfy the requirements of §6.2.5.1 – §6.2.5.4 and therefore more efficiently than static strategies. This can be accomplished by automatically determining the critical zone fraction, to continuously calculating the corrected fraction of outdoor air. The calculation requires that the total supply airflow rate be continuously measured and the airflow rate of the critical zones is measured with permanent airflow measuring devices capable of very accurate measurement.

Airflow sensors traditionally provided with VAV boxes should not be used for these calculations. Although the OEM devices may be adequate in modulating a terminal box for thermal comfort, the combination of typically poor inlet conditions, low quality airflow pickups and low cost pressure sensors in the DDC controller will not result in the measurement accuracy necessary for proper calculation of Equations 6-1 and 6-5 through 6-8. Conservative mathematical modeling has demonstrated that typical VAV box measurement performance can be statistically exceeded by boxes without a measurement device [2]. Accurate airflow measuring devices having a total installed accuracy better than 5% of Reading at maximum system turndown should be installed in the supply ducts for critical zones.

The result from these multi-space equations can provide wide variations in outdoor airflow requirements in some systems. Increasing the critical zone supply flow while using reheat, can reduce total outdoor airflow rates and overall energy usage. This method has been simulated at Penn State University using the multi-space equation from Standard 62-2001, with published results showing greater energy efficiency than the same system supplying the maximum, worst-case V_{ot} continuously. The basic variables, relationships and the end results should be the same using the VRP of Standard 62.1.

Then, the VRP continues and provides us with additional options to help make the design more specific to the designer's needs and to the demands of the situation. You may…

1. design using the short-term "averaged" population, rather than the peak – 6.2.6 (6-9)
2. operate (and dynamically reset requirements) using "current" population data – 6.2.7, "DCV"

6.2.6 **Design for Varying Operating Conditions.**

6.2.6.1 **Variable Load Conditions.** Ventilation systems shall be designed to be capable of providing the required ventilation rates in the breathing zone whenever the zones served by the system are occupied, including all full- and part-load conditions [1].

The peak population value may be used as the design value for P_z. Alternatively, time-averaged population determined as described in §6.2.6.2, may be used to determine P_z.

Outdoor airflow rates can also be reduced if the critical zones have variable occupancy or other unpredictably variable (dynamic) conditions. Changes in occupancy (or ventilation 'demand') can be detected in many ways, as indicated in the 'note' below. Therefore, Demand Controlled Ventilation systems otherwise known as Dynamic Reset should not be limited to CO_2 measurement input alone.

§6.2.7 on Dynamic Reset addresses conditions when the ventilation control system…

> "…may be designed to reset the design *outdoor air intake flow* (V_{ot}) and/or space or zone airflow as operating conditions change. These conditions include but are not limited to:
>
> 1. Variations in occupancy or ventilation airflow in one or more individual zones for which ventilation airflow requirements will be reset.
> **Note**: Examples of measures for estimating such variations include: occupancy scheduled by time-of-day, a direct count of occupants, or an estimate of occupancy or ventilation rate per person using occupancy sensors such as those based on indoor CO_2 concentrations.
>
> 2. Variations in the efficiency with which outdoor air is distributed to the occupants under different ventilation system airflows and temperatures.
>
> 3. A higher fraction of outdoor air in the air supply due to intake of additional outdoor air for free cooling or exhaust air makeup [1]."

There is no direction in the Standard on how to implement Dynamic Reset using CO_2, which was left to be addressed by the *User's Manual*. This section of the Standard, independent of the *User's Manual*, would lead one to believe that CO_2 is a method of 'counting' and not an input to be used for direct ventilation control. Therefore, any counting method could be used to reset a flow rate established and controlled by some other measurement means.

Now that the *62.1 User's Manual* is available, we recommend that you read it, particularly sections 6.2 on the VRP and Appendix A on CO_2-based Demand Controlled Ventilation. It only discusses internal CO_2 measurement (using an assumed average for outside concentrations) as a means of partially satisfying the VRP through Dynamic Reset. It may not provide firm "how-to" guidance and may generate more questions than answers. But, it should help everyone get a better understanding of the committee's intentions. Here are some excepts from Appendix A.

> *"Overview - This appendix describes how CO_2 concentration may be used to control the occupant component of the ventilation rate.*[AUTHORS' NOTE: This avoids discussing how to handle the building component]. *The approaches described may be used to dynamically control ventilation in compliance with § 6.2.7." and "… it is most cost effective in those occupancies that have a high design occupancy density but which are not occupied at that density consistently. Examples include ballrooms, conference/meeting rooms, and lecture halls."* Pg. A-1
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> *"…the steady-state assumption in Equation A-H is made not because the actual system is at steady-state but because the ventilation rate equation, Equation 6-B, is based on steady-state conditions." And "…In practice, acceptable performance will also hinge on the ability of the control system to sense CO_2 concentrations and adjust ventilation rates according to the equation.* Pg. A-3
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> *"…the most accurate approach…results in actual differential CO_2 concentration measurement, this approach can also be the least accurate and reliable due to sensor inaccuracy.…The accuracy of differential CO_2 concentration measurement can be improved by using a single CO_2 sensor with a sampling pump, sequenced valves, and tubes piped to the zone and to the outdoors—but first costs will be higher."* Pg. A-4

The *User's Manual* insinuates that using CO_2-DCV for the direct control of intake rates is problematic, risky, inaccurate, violates the requirements of Chapter 4 - Ventilation in the IMC and may not even lead to compliance with the VRP requirements of Standard 62.1.

What else does the *User's Manual* say that is not in the *Standard*? Quite a bit. The document is actually very well done and should provide significant help to many in the understanding and application of the Standard. Some of the more significant issues that are clarified include the following:

> *"Ventilation System Controls (§ 5.4)…The system must be designed to maintain the minimum outdoor airflow as required by § 6 under any load condition. …In order to comply, most VAV systems will need to be designed with outdoor airflow sensors and modulating dampers or injection fans." Pg. 5-11*
>
> *"In the past, the part-load ventilation requirement has been neglected in many VAV systems. In most cases, an active control system must be provided at the air intake and sometimes at the zone level to ensure minimum rates are maintained."*
>
> *"Variable Air Volume System …Note that a fixed-speed, outdoor-air fan without control devices will not maintain rates within the required accuracy …Using return air, outdoor air, and mixed air temperatures or* CO_2 *concentrations to measure* [AUTHORS' NOTE: indirectly estimated – not measured] *air intake percentage is usually inaccurate when the outdoor and indoor values are close together and thus should only be used with caution. Similarly, measuring outdoor air by taking the difference between supply- and return-airflow measurements will also seldom meet reasonable accuracy requirements due to cumulative errors in airflow measurement and the generally small outdoor airflow rate relative to supply and return-airflow rates." Pg. 5-12*

Because of the high risk of noncompliance and potential excess energy costs (or insufficient dilution air), intake rates should not to be determined indirectly by the 'counting' device alone. So, how do you comply with Standard 62.1? For CONSTANT OCCUPANCY use design conditions to set a fixed outside air rate at the AHU in accordance with the Ventilation Rate Procedure and use an outside airflow station to maintain that level.

- Unless occupancy is extremely variable, there is little to gain by using DCV with the requirements of ASHRAE 62.1-2004. In the example used in our IAQ Seminars, changing a space population -10% would result in a reduction of the outside air by only 3.2%. Is that much savings worth the risk?

- Consider using occupied/unoccupied switches to reset outside air based on design occupancy of variable occupancy zones.

For unpredictably variable and densely occupied spaces, other digital occupancy counting technologies are becoming available that will help users to comply with this standard, most codes and avoid all of the risk and uncertainty of using CO_2.

INDOOR AIR QUALITY PROCEDURE

Section 6.3 INDOOR AIR QUALITY PROCEDURE begins…

> "The Indoor Air Quality (IAQ) Procedure is a performance-based design approach in which the building and its ventilation system are designed to maintain the concentrations of specific contaminants at or below certain limits identified during the building design and to achieve the design target level of perceived indoor air quality acceptability by building occupants and/or visitors…[1]"

The concept of providing "performance-based" solutions is desirable in principle. However, there are numerous risks associated with both the quantitative and subjective evaluations provided within the IAQ procedure that every designer should understand.

Since there are numerous contaminants that either will not be detected or for which "definite limits have not been set," this portion of the procedure has significant risk associated with it. It is unlikely that all contaminants of concern will be evaluated or reduced to acceptable levels. It is also not practical to measure all potential contaminants and in some cases, such as with fungus or mold, measurement may not be possible.

> "6.3.1.3 **Perceived Indoor Air Quality.** The criteria to achieve the design level of acceptability shall be specified in terms of the percentage of building occupants and/or visitors expressing satisfaction with perceived indoor air quality."

> "6.3.1.4 **Design Approaches.** Select one or a combination of the following design approaches to determine minimum space and system outdoor airflow rates and all other design parameters deemed relevant (e.g., air cleaning efficiencies and supply airflow rates).
> (a) Mass balance analysis. The steady-state equations in Appendix D, which describe the impact of air cleaning on outdoor air and recirculation rates, may be used as part of a mass balance analysis for ventilation systems serving a single space.
> (b) Design approaches that have proved successful in similar buildings...
> (c) Approaches validated by contaminant monitoring and subjective occupant evaluations in the completed building. An acceptable approach to subjective evaluation is presented in Appendix B, which may be used to validate the acceptability of perceived air quality in the completed building [1]."

§6.3.1.3 combined with §6.3.1.4 (b) and (c) emphasize the risk associated with the Indoor Air Quality procedure. The uncertainty of using "subjective occupant evaluations" together with the admittedly limited listings in Appendix B - SUMMARY OF SELECTED AIR QUALITY GUIDELINES, may be too great for many designers to 'claim' this procedure for compliance.

However, the concept of controlling the source of the contaminants makes perfect sense and is, in our opinion, more properly utilized under design approach §6.3.1.4 (d).

> "(d) Application of one of the preceding design approaches (a, b, or c) to specific contaminants and the Ventilation Rate Procedure would be used to determine the design ventilation rate of the space and the IAQ Procedure would be used to address the control of the specific contaminants through air cleaning or some other means [1]."

Since airflow rates are typically reduced in the IAQP, the measurement and control of intake rates are even more critical, especially on systems where the thermal load change is independent of the occupants and their activities. In addition, caution should be exercised when reducing outdoor airflow rates since it is also required to maintain proper building pressure, helping to minimize energy use, improve comfort control and prevent mold growth within wall cavities.

DESIGN DOCUMENTATION PROCEDURES

Section 6.4, Design Documentation Procedures, states:

> "Design criteria and assumptions shall be documented and should be made available for operation of the system within a reasonable time after installation. See Sections 4.3, **5.2.3,** 5.17.4 and 6.3.2 regarding <u>assumptions that should be detailed</u> in the documentation [1]."

Within which §5.2.3, Ventilation Air Distribution requires us to:

> "…specify minimum requirements for air balance testing or reference applicable national standards for measurement and balancing airflow [1]".

Providing permanently installed instruments and controls that result in, and verify, compliance with ASHRAE Standard 62.1 is perhaps one of the best reasons to provide such devices as part of any HVAC system design. Continuous data inputs may also be used to aid start-up Test and Balance, Commissioning, Measurement and Verification (M&V) for energy usage calculations and ongoing diagnostics. More precise and more reliable control could be viewed as a bonus.

CONSTRUCTION AND SYSTEM START-UP

Section 7 addresses the construction and start-up phases of the project and has been included because a significant number of documented IAQ cases were a result of activities which took place during these phases of the project. The construction phase, addressed in Section 7.1 of the Standard, applies to "ventilation systems and the spaces they serve in new buildings and additions to or alterations in existing buildings [1]." The Standard addresses both the protection of materials and protection of occupied areas.

Mechanical barriers are specified to protect occupied areas from construction-generated contaminants. In addition, the HVAC system must be able to maintain occupied spaces at positive pressures with respect to the construction areas. In many cases, the HVAC system does not have adequate capacity and/or controls to provide a barrier to the migration of contaminants using positive pressurization flow. Designers must consider the condition of the existing ventilation system and its ability to maintain a pressurized environment for spaces expected to continue occupancy, prior to initiating physical construction activities at the site.

The start-up phase, covered in Section 7.2 provides guidelines for air balancing, testing of drain pans, ventilation system start-up, testing of damper controls, and documentation requirements.

§7.2.2, Air Balancing, requires that systems be balanced "at least to the extent necessary to verify conformance with the total outdoor air flow and space supply air flow requirements of this standard [1]." Unfortunately, the airflow rates of the system will vary after this activity has occurred, in most systems, for reasons discussed in the analysis of Section 5, Systems and Equipment. When applied in accordance with the manufacturer's recommendations, some airflow measuring devices only require the verification of operation by Test and Balance professionals. This TAB "snap-shot" of airflow rates is analogous to providing a one-time setup for temperature control, which obviously would not be very effective. Providing permanently mounted airflow measuring stations would also support compliance with and reduce the time required to supply the ventilation documentary requirements set forth in §7.2.6 (c).

OPERATIONS AND MAINTENANCE

It is important to recognize that if the building is altered or its use is changed, the ventilation system must be reevaluated. Buildings that are likely to be changed or altered during their life span, should consider including a robust HVAC system design that takes into account changes in airflow rate requirements imposed by this Standard. Of course, provisions for permanently mounted airflow measurement devices and controls would significantly reduce both the cost and time associated with such changes as long as the HVAC load capacity could accommodate future requirements.

§8.4.1.7 addresses sensors. "Sensors whose primary function is dynamic minimum outdoor air control, such as flow stations…" is discussed in this section even though they were not mentioned under Section 5, Systems and Equipment. Section 8.4.1.7 requires that sensors have their accuracy verified "once every six months or periodically in accordance with the Operations and Maintenance Manual [1]." The Operations and Maintenance Manual for some airflow measuring devices does not recommend periodic recalibration. Permanently calibrated airflow instrumentation has a significant advantage over other airflow measuring technologies and CO_2 sensors, whose transmitters are subject to frequent adjustments, zeroing or regular calibrations to correct for analog electronic circuitry and sensor drift.

However, §8.4.1.8, Outdoor Air Flow Verification, only requires the verification of airflow rates "once every five years [1]." Since external and system factors change continuously, clearly influencing outdoor airflow rates, this requirement does little to assure that proper ventilation rates are maintained under normal operation at different times of the day and the year. It effectively places the burden of verification of new building/system performance on the building operator, who is often not in a position to make such a determination.

This apparent contradiction with §8.4.1.7 will likely be examined by the ASHRAE SSPC-62.1 committee in the near future. Permanent outdoor airflow measuring stations would provide continuous verification and provide necessary control inputs to maintain ventilation requirements, automatically minimizing intake rates for energy usage and preventing other control inputs from causing a maximum intake limit from being exceeded.

CONCLUSIONS

ASHRAE Standard 62.1 prescribes ventilation rates for acceptable indoor air quality. It should be clear to the building operator and the design professional that the dynamic nature of mechanical ventilation requires dynamic control to insure the continuous maintenance of specific predetermined conditions. As a rate-based standard, continuous airflow measurement should logically be a central component of any effective control strategy to assure acceptable indoor air quality, as recently implemented in the latest LEED Rating Systems v2.2 credit requirement EQc1 – "Outdoor Air Delivery Monitoring" for New Construction, Existing Buildings and Core and Scheel Construction. [9]

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