Optimizing Ventilation Design in Commercial Buildings using HAP

Introduction

HVAC system designs for most commercial buildings today must comply with ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality, which is referenced by mechanical codes. Compliance is typically achieved using the Ventilation Rate Procedure in Standard 62.1. The objective of the ventilation rate calculation is to determine how much outdoor air must be introduced at the HVAC system outdoor air intake to ensure every space served by the system receives the required minimum ventilation to the breathing zone. Ventilation air dilutes pollutants generated by occupants, furnishings and building materials in the space.

HVAC systems which serve multiple spaces often require excess airflow at the outdoor air intake to ensure each space receives its required ventilation airflow. Excess outdoor airflow can have significant cooling and heating energy consequences. Therefore, when excess airflow is required, engineers often seek to optimize the system design to minimize the extra airflow required.

This article first describes how Carrier's Hourly Analysis Program (HAP) applies Standard 62.1 Ventilation Rate Procedure calculations to determine outdoor airflow at the intake. With that as background, the article then explains how to use features of HAP to optimize the design to minimize ventilation airflow. This article uses ASHRAE Standard 62.1-2007 as the basis for discussion and examples, but principles described here also apply equally to Standard 62.1-2010.

Setting HAP Project Preferences

The first step in using HAP to calculate Standard 62.1 ventilation requirements is to set the ventilation standard for your project. Choose the Preferences option on the View Menu to display current preferences (Figure 1). For the examples that follow we'll use ASHRAE Standard 62.1-2007 as the project preference. This will enable options for defaulting space ventilation requirements and calculation procedures per Standard 62.1-2007.

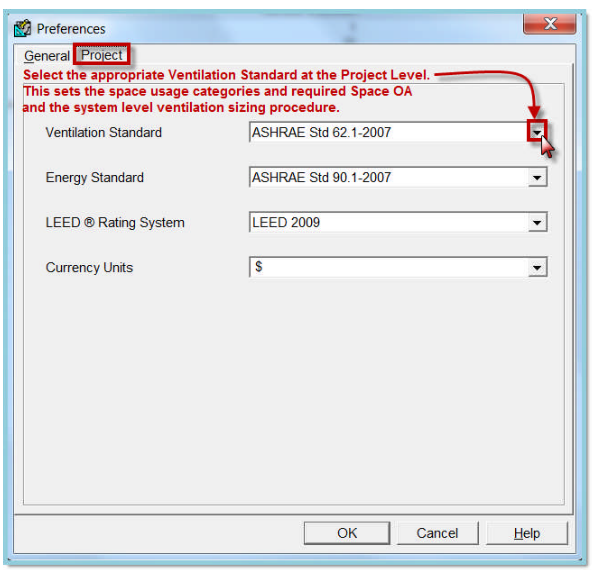

Figure 1. HAP Project Level Preferences

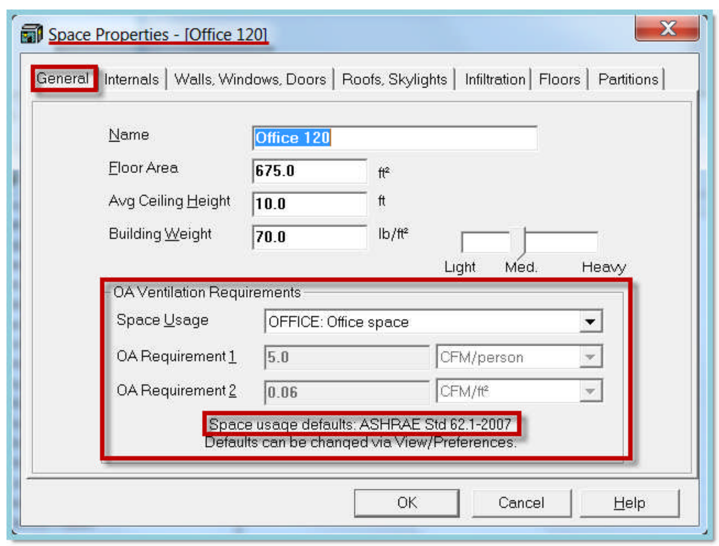

Figure 2. Space OA Requirements

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Space Level Ventilation in ASHRAE 62.1-2007

The next step in the ventilation analysis is to define ventilation requirements while entering space data. HAP offers an option to select a "space usage" type, based on the list of space usage types found in Table 6-1 in the standard (Figure 2). When you choose a space usage HAP will automatically default the CFM/sqft and CFM/person (L/s/sqm and L/s/person) ventilation requirements from the Standard. A note at the bottom of the input screen in Figure 2 indicates which edition of Standard 62.1 is used for defaulting.

Figure 3 shows an excerpt from Table 6-1 in the Standard listing the minimum ventilation rates at the breathing zone for different occupancy categories.

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s • person	cfm/ft²	L/s • m²		#1000 ft² Or #100 m²	cfm/person	L/s • person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Day room	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	[illegible]	0.06	0.3		15	9	[illegible]	

Figure 3. ASHRAE 62.1-2007 – Table 6-1 (Minimum Ventilation Rates in Breathing Zone, V_{bz})

Space Usage Comparisons and Two-Part OA Requirement

ASHRAE 62.1-2007 determines the total outdoor airflow rate for the system using the Ventilation Rate Procedure from Section 6.2 and Appendix A. This procedure involves a two-part outdoor air (OA) requirement. The first part addresses dilution required for pollutants and odors generated by occupants in the space. The second part addresses pollutants and odors generated by furnishings and building materials in the space.

The procedure for calculating space and system level ventilation airflow in Standard 62.1-2007 involves two steps.

1. Calculating the required ventilation airflow to the space. This requires three separate calculations:
   a. Summing the occupant dependent and floor area dependent portions of the space requirements.
   b. Applying time averaging to modify the occupant dependent portion of the space requirement, if applicable.
   c. Considering the space air distribution effectiveness.

2. Calculating the airflow required at the central system outdoor air intake to ensure each space receives its required ventilation. As we will see, the ventilation airflow required at the system intake can be larger than the sum of space requirements because of "critical space" issues.

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NOTE: Before continuing, we should clarify some terminology between HAP and ASHRAE. ASHRAE Standard 62.1-2007 uses the term ventilation "zone" to refer to one occupied space. In HAP this unit of a building is referred to as a "space". To avoid confusion, the following discussions will use HAP terminology. Therefore Standard 62.1 terms like "zone ventilation efficiency" will be referred to as "space ventilation efficiency."

Step 1: Determining the Space Level Minimum Ventilation Requirements

1. Summing the OA Requirements

During sizing calculations for Standard 62.1-2007, HAP first sums the two outdoor air requirements for the space..

Example: Consider the "D 101 Classroom" space shown in Figure 6. This classroom space has 840ft² (78.0 m²) of floor area and 25 occupants. Calculation of the uncorrected ventilation air requirement is shown in the tables below.

Space Usage Category	Calculation	Uncorrected Ventilation Air
Classroom (Ages 9+)	25 x 10 CFM/person =	250 CFM
	840 sqft x 0.12 CFM/sqft =	101 CFM
	Sum:	351 CFM

Space Usage Category	Calculation	Uncorrected Ventilation Air
Classroom (Ages 9+)	25 x 4.7 L/s/person =	118 L/s
	78.0 sqm x 0.61 CFM/sqft =	48 L/s
	Sum:	166 L/s

The uncorrected ventilation air is 351 CFM (166 L/s), where uncorrected means we must still apply additional considerations or "adjustments" as required by the Standard.

2. Calculating the Time Averaging Factor

If the number of people in the space fluctuates over time, Standard 62.1-2007 allows estimating the space population by applying a time averaging procedure. HAP applies the occupant schedule along with the equations in paragraph 6.2.6.2 of ASHRAE Standard 62.1-2007 to produce a "time averaging interval". The interval length is a function of the ventilation air change for the space. HAP uses the calculated average occupant values for this interval and uses the largest average value in determining the time averaging factor. HAP uses this factor to correct the OA per person ventilation amount.

For example, suppose a 2000ft² (185.8m²) space with floor to ceiling height of 9 ft (2.74 m) has 10 occupants. The requirements for this space are 5 CFM/person (2.36 L/s/p) and 0.06 CFM/ft² (0.028 L/s/m²). The uncorrected outdoor air requirement for the space is (10 people x 5 CFM/person) + (0.06 CFM/sqft x 2000 sqft) = 170 CFM (80.2 L/s). The time averaging interval is calculated as (3 x Space Volume) / (Uncorrected Outdoor Airflow), or (3 x 2000 sqft x 9 ft) / 170 CFM which equals 318 minutes or 5.3 hours. HAP rounds this to 5 hours.

Next, HAP calculates an average schedule factor for each group of five consecutive hours in the occupant design day schedule. First HAP uses hours 0000 thru 0400, then 0100 thru 0500, then 0200 thru 0600, etc. If the schedule values for five consecutive hours are 60%, 80%, 100%, 100% and 100%, for example, the average for this block of time is 88%. Once HAP calculates these averages for each 5-hour block in the day, HAP identifies the largest average as the Time

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Averaging Factor. If the largest was 88% the people count would be 0.88 X 10 = 8.8 occupants. Then the new uncorrected outdoor airflow requirement is (8.8 people x 5 CFM/person) + (0.06 CFM/sqft x 2000 sqft) = 164 CFM (77.4 L/s).

Note that the time averaging procedure does not always result in a downward correction to the occupant count and an associated decrease in ventilation. If the people schedule uses 100% for all hours, for example, the Time Averaging Factor is 100% because the average schedule factor for any time interval is 100%.

3. Assigning Space Air Distribution Effectiveness

It is not enough to simply deliver the proper quantity of ventilation air to a space. That air must effectively reach the breathing zone of its occupants. The Standard defines the breathing as the space between 3" and 72" (7.6cm to 1.8m) above the floor as shown in Figure 4. The "air distribution effectiveness" factor describes the fraction of ventilation air supplied to a space which reaches this breathing zone. Examples:

1. A ceiling diffuser delivering cold air to a space has an air distribution effectiveness of 1.0, meaning 100% of outdoor air in the supply air reaches the breathing zone. This is because the cold supply air is more dense than room air and therefore falls through the space, reaching the breathing zone.
2. A ceiling diffuser delivering warm air to the space, where the difference between supply air temperature and room temperature is 15 F (8.3 K) or more, and where a ceiling return exists, will have an air distribution effectiveness of 0.8. This means 80% of outdoor air mixed in the supply air will reach the breathing zone. Because warm air is less dense than room air, some portion of the supply air will remain near the ceiling and will be drawn into the return before reaching the breathing zone.

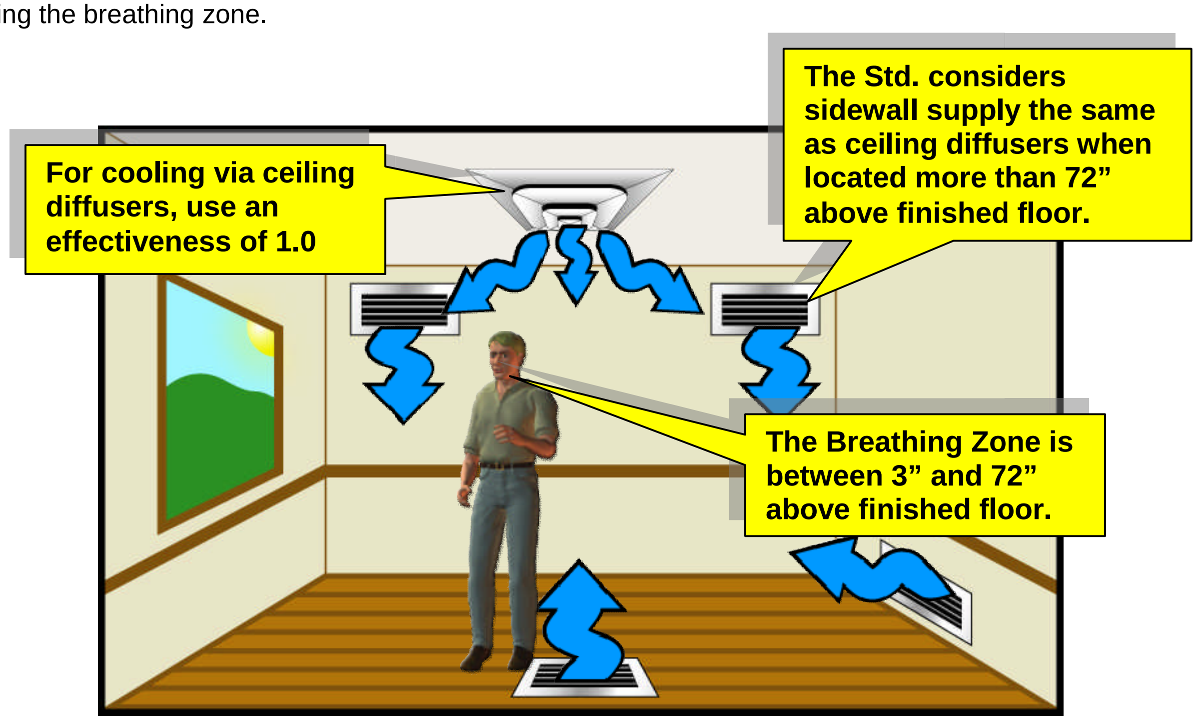

Figure 1 – Space Air Distribution Effectiveness

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The outdoor ventilation air requirement for a space is the uncorrected airflow divided by the air distribution effectiveness.

Example: The uncorrected outdoor airflow for a space is 350 CFM. For a heating condition, the air distribution effectiveness is 0.8. Therefore, 350/0.8 or 437.5 CFM of outdoor air must be supplied to the space to ensure that 350 CFM reaches the breathing zone.

Note: HAP performs the entire Standard 62.1-2007 calculation twice for each system if the system provides cooling and heating. It performs it once assuming cooling operation and then for heating operation. HAP uses the larger result for outdoor air intake airflow. Because the air distribution effectiveness for overhead supply of air is 0.8 for many heating scenarios, heating is frequently the condition that generates the worst case ventilation requirement.

Step 2: Determining the System Level Minimum Ventilation Requirements

Step 2 determines how much outdoor ventilation air is required at the common outdoor air (OA) intake to ensure that each space receives its required ventilation. As we will see, the ventilation airflow required at the intake can be larger than the sum of the space airflows calculated in Step 1 due to issues related to the "critical space". Determination of the OA amount at the unit intake also involves calculation of a space and system "ventilation efficiency" using equations in ASHRAE 62.1-2007. This section develops the procedures for system level ventilation calculations.

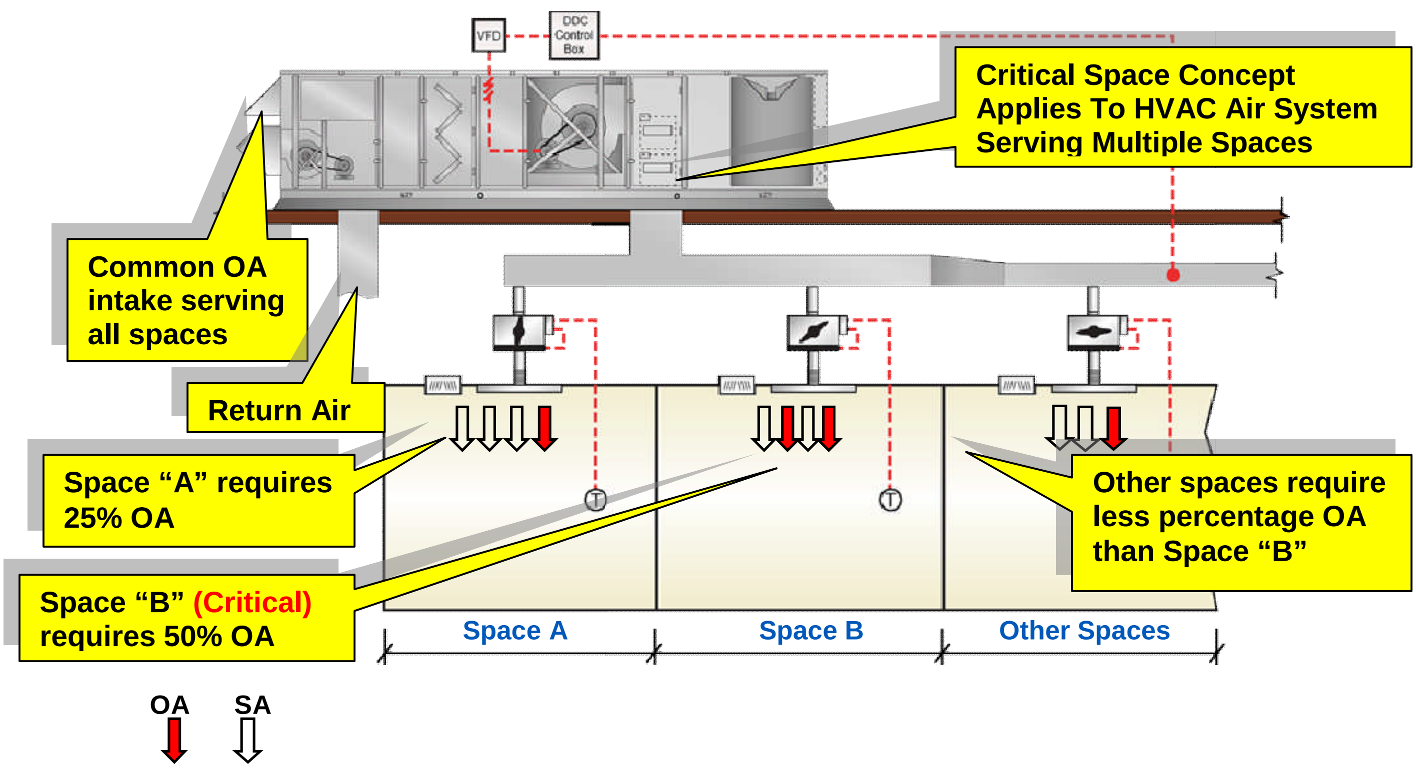

Figure 2 – Typical VAV System Critical Space

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"Critical Space" involves a concept that meeting the ventilation requirements of one space may require over ventilating other spaces. The example in Figure 5 supposes Space “A” requires a total of 800 CFM (377.6 L/s) supply air, which includes 200 CFM (94.4 L/s) of outdoor air. The ratio of outdoor air to supply air is the "outdoor air fraction" and is 25% for space "A". Space "B" requires a total of 600 CFM 283.2 L/s) supply air, which includes 300 CFM (141.6 L/s) of outside air, or an outdoor air fraction of 50%. Both spaces receive supply air from the same rooftop unit (RTU). If that RTU total supply air contains 25% ventilation air, the ventilation requirement of Space “A” is met, but the ventilation requirement of Space “B” is not met. The higher the outdoor air fraction, the more critical the space tends to be.

The common supply air must have an outdoor air fraction of more than 25% outdoor air in order to meet Space “B” requirements. This results in Space "A" being over ventilated. However, once Space “A” is over ventilated, there is unused or "unvitiated" ventilation air that re-circulates from Space “A” which moderates the need to increase the system-wide outdoor air fraction to 50% of supply air. In this example, Space “B” is the critical space, as it requires a greater outdoor air fraction than any other space.

The Standard defines a complex calculation procedure that HAP follows to determine the ventilation efficiency for each space. This calculation procedure is different depending on the system type. A dual duct or recirculation system like fan powered VAV boxes requires a more involved calculation than a single-duct system. This calculation determines the "ventilation efficiency" for each space in the system. Ventilation efficiency describes the efficiency with which an HVAC system distributes outdoor air from the intake to the breathing zone of the space. An efficiency of less than 1.0 means additional outdoor air at the intake is required to satisfy the space requirement. A value greater than 1.0 means the space receives excess outdoor air from the system supply.

Example: A space requires 200 CFM (94.4 L/s) of uncorrected outdoor air and has a space ventilation efficiency of 0.75. This means 200/0.75 or 267 CFM (126 L/s) must be introduced at the system intake to ensure that 200 CFM reaches the breathing zone of the space.

The space having the smallest space ventilation efficiency dictates the overall outdoor airflow for the system. The smallest space ventilation efficiency becomes the "system ventilation efficiency". The total outdoor intake airflow is calculated as the sum of uncorrected space outdoor airflows divided by the system ventilation efficiency.

Example: In Figure 6 the total uncorrected outdoor airflow is 1470 CFM (693.8 L/s). The system ventilation efficiency is 0.673. The outdoor air intake airflow required is 1470 / 0.673 or 2183 CFM (1030.3 L/s).

Note 1: The previous discussion applies to HVAC systems which serve multiple spaces. For an HVAC system serving only one space, the critical space concept does not apply as all outdoor air introduced at the intake is supplied to the single space.

Note 2: For Direct Outside Air Systems (DOAS) serving terminal fan coil units (FCUs) or water source heat pumps (WSHPs), each FCU or WSHP represents an "HVAC System". If the FCU or WSHP serves multiple spaces, then a separate critical space analysis is performed for each FCU or WSHP zone. If the FCU or WSHP serves only a single space, then there is no critical space analysis as all outdoor air supplied through the FCU or WSHP reaches the space it serves.

HAP Ventilation Sizing Summary Report

When HAP completes its Standard 62.1-2007 ventilation calculations, results are provided on the Ventilation Sizing Summary report (Figure 6). The example system in Figure 6 is a 7-zone variable air volume (VAV) system supplying multiple classroom spaces, a corridor and a vestibule.

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This example has an outdoor air intake airflow of 2183 CFM (1030.3 L/s), shown as the "Design Ventilation Airflow Rate" on the report. Notice the Design Condition for the calculation is “minimum flow (heating)”. As discussed previously, because this is a cooling and heating system, HAP performs the Standard 62.1-2007 ventilation air calculation once for cooling and once for heating and uses the higher of the two outdoor air intake values. In this example, heating duty was higher because the heating duty air distribution effectiveness was lower (0.80) than cooling duty (1.0) which results in 25% more ventilation air required to each space

1. Summary

Ventilation Sizing Method	ASHRAE Std 62.1-2007	
Design Condition	Minimum flow (heating)	
Occupant Diversity	1.000	
Uncorrected Ventilation Airflow Rate	1470	CFM
System Ventilation Efficiency	0.673	
Design Ventilation Airflow Rate	2183	CFM

Design Ventilation Airflow Rate = Uncorrected CFM / Ventilation Efficiency = 1470/.673 = 2183 CFM

2. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Minimum Supply Air (CFM)	Floor Area (ft²)	Required Outdoor Air (CFM/ft²)	Time Averaged Occupancy	Required Outdoor Air (CFM/person)	Air Distribution Effectiveness	Required Outdoor Air (CFM)	Uncorrected Outdoor Air (CFM)	Space Ventilation Efficiency
D100 IT Room										
D 100 IT Server Room	1	14	35.0	0.06	0.6	5.00	0.80	6	5	1.240
D 101 Classroom										
D 101 Classroom	1	439	840.0	0.12	25.0	10.00	0.80	**439**	351	0.673
D 102 Classroom										
D 102 Classroom	1	439	840.0	0.12	25.0	10.00	0.80	**439**	351	0.673
D 103 Classroom										
D 103 Classroom	1	439	840.0	0.12	25.0	10.00	0.80	**439**	351	0.673
D 104 Classroom										
D 104 Classroom	1	439	840.0	0.12	25.0	10.00	[illegible]	**439**	351	0.673
D 105 South Vestibule										
D 105 South Vestibule	1	35	88.0	[illegible]	[illegible]	[illegible]	[illegible]	**7**	5	1.486
D 114 Corridor										
D 114 Corridor	1	380	950.0	[illegible]	[illegible]	[illegible]	[illegible]	**71**	57	1.486
Totals (incl. Space Multipliers)		**2183**							**1470**	**0.673**

Critical Space Ventilation Efficiency = .673

Figure 3 – Ventilation Sizing Summary Report for VAV System

The following discussion explains the column headings of the Ventilation Sizing Summary Report for our VAV system.

Minimum Supply Air (CFM)

This value represents the minimum supply airflow for the VAV terminal for each space. In the HAP Air System Properties under the Zone Components tab/ Supply Terminals/ Minimum Airflow, we defined the minimum supply airflow as 50% of the supply terminal airflow.

This column heading only appears for VAV systems where minimum airflow will be a worst case condition for ventilation. For a constant air volume (CAV) system, the column heading would be “Maximum Supply Air (CFM) (L/s)” because a CAV system diffuser has no minimum airflow setpoint like a VAV terminal.

Floor Area (ft²) (m²)

This is the space floor area used in the uncorrected ventilation airflow calculation based on CFM/ft² (L/s/m²).

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Required Outdoor Air (CFM/ft²) (L/s/m²)

This represents the required ventilation airflow per unit floor area required.

Time Averaged Occupancy

This value represents the number of occupants used in the final calculations for ventilation air. HAP accounts for any headcount reductions based on the time averaging factor calculations discussed earlier.

Required Outdoor Air (CFM/Person) (L/s/p)

This represents the ventilation airflow per person required.

Air Distribution Effectiveness

This value takes into consideration the ability of the supply air from the diffusers or registers to reach the breathing zone.

Required Outdoor Air (CFM) (L/s)

This column contains the calculated outdoor air quantities after taking into account the air distribution effectiveness. The uncorrected outdoor air CFM (L/s) divided by the air distribution effectiveness is the required outdoor air CFM (L/s) for each space. This is not the final airflow for the common OA intake for the system.

Uncorrected Outdoor Air (CFM) (L/s)

This column contains the required airflow for the space before taking into account air distribution effectiveness. It is the sum of the area-based and people-based ventilation requirements for the space.

Space Ventilation Efficiency

HAP uses space ventilation efficiency in identifying the critical space in the system. The space with the lowest ventilation efficiency is the most critical therefore it dictates the outdoor airflow for the system to ensure it receives its required airflow. The Uncorrected Outdoor Air (1470 CFM) (693.8 L/s) divided by the lowest Space Ventilation Efficiency (.673) value is the final answer called Design Ventilation Airflow Rate (2183 CFM or 1030.3 L/s).The Space Ventilation Efficiency is calculated by HAP using the procedures in Appendix A of the Standard, as opposed to using the more simplified method in table 6-2 of the Standard. This results in the highest level of accuracy.

Why Optimize the Ventilation Design?

The ASHRAE Standard 62.1 Ventilation Rate Procedure for multiple-space systems ensures adequate ventilation for all spaces served by the HVAC system, but does not automatically yield the most efficient ventilation design. It can often result in systems with excess ventilation, possibly higher operating costs and higher installed cost due to the need for larger capacity HVAC equipment. The reason for this is the *critical space* which requires excess outdoor airflow at the system intake to ensure the critical space receives its required breathing zone ventilation airflow. HVAC systems serving multiple spaces with spaces having ventilation efficiency value significantly less than the other spaces can benefit from ventilation design optimization.

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Optimizing Ventilation Design

The process of ventilation optimization is an iterative design process involving the following steps:

1. Energy use is typically a concern, so we first simulate the original "non-optimized" system design to determine annual energy cost for indoor fans, cooling and heating. This simulation serves as a benchmark for comparing our optimized alternatives.
2. Generate the **Ventilation Sizing Summary** report in HAP and identify the design condition (cooling or heating), System Ventilation Efficiency and critical space(s). The critical space is the space with the lowest space ventilation efficiency.
3. Compare critical space ventilation efficiency to other space ventilation efficiencies. If critical space has a significantly lower space ventilation efficiency than other spaces, increase supply airflow to critical space to increase its space ventilation efficiency. For VAV systems this involves incrementally increasing the minimum airflow setting on the VAV box serving the critical space. Use small increments of change such as 5-10% of flow to avoid drastic changes. The downside to increasing the minimum VAV box flow (with reheat coil) is an increase in reheat loads. The upside is the design ventilation air quantity decreases as the system-level ventilation efficiency increases, saving cooling and/or heating energy in the central HVAC unit which helps to offset the additional reheat energy.
4. Re-run calculations and generate the Ventilation Sizing Summary report. Note any changes to the space ventilation efficiency for the critical space. Repeat Step 3 until the critical space ventilation efficiency increases to that of other spaces, or a different space becomes the critical space.
5. Repeat steps 3 and 4 to increase the airflow to the new critical space until all spaces have about the same space ventilation efficiency. Simulate the building during the optimization process to quantify the energy saving strategies. At some point, you will discover that further optimization is not possible as further increases in critical space ventilation efficiencies results in increased overall energy use. When this occurs, you have optimized the design and balanced performance with operating cost.

Notes:

a. This is a generalized procedure, not specific to a climate zone or building design. In some cases, you may discover that increasing outdoor ventilation actually saves operating cost due to additional "free" cooling (economizer effect), while in other designs, reducing ventilation air saves energy. This suggested optimization procedure requires iterative analysis in determining best practices for your climate and design.

b. It may also be useful to set a "target" upper limit on the system-level ventilation percentage, i.e. 20 or 25% of ventilation air, which becomes the maximum system level ventilation setting. Most direct expansion (DX) systems cannot handle more than 30-40% ventilation air so there is a practical upper limit to the design parameters based on equipment selection. It may be useful to decide in advance the maximum VAV box minimum position. Going above 50% minimum position limits the allowable turndown and defeats the advantage of a VAV system.

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Ventilation Design Optimization Example

A 10-zone VAV system using fan powered mixing boxes (FPMXB) is designed for a building in Dallas, TX using the ASHRAE 62.1-2007 Ventilation Rate Procedure. The air system sizing results appear in Figure 7 below. Notice the required ventilation rate of 1966 CFM (927.9 L/s) listed near the bottom of the report. The calculated supply air is 3710 CFM (1750.9 L/s) meaning the outdoor air fraction is 53%.

Air System Information

Air System Name	AHU-1		Number of zones	10	
Equipment Class	PKG ROOF		Floor Area	6587.0	ft²
Air System Type	VAV		Location	Dallas, Texas	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM	Peak zone sensible load		Calculation Months	Jan to Dec
Space CFM	Individual peak space loads		Sizing Data	Calculated

Central Cooling Coil Sizing Data

Total coil load	15.7	Tons	Load occurs at	Jul 1500	
Total coil load	188.3	MBH	OA DB / WB	100.0 / 74.0	°F
Sensible coil load	139.6	MBH	Entering DB / WB	89.1 / 68.8	°F
Coil CFM at Jul 1500	3662	CFM	Leaving DB / WB	53.1 / 51.4	°F
Max block CFM at Jul 1500	3710	CFM	Coil ADP	49.1	°F
Sum of peak zone CFM	3747	CFM	Bypass Factor	0.100	
Sensible heat ratio	0.741		Resulting RH	44	%
ft²/Ton	419.8		Design supply temp.	55.0	°F
BTU/(hr-ft²)	28.6		Zone T-stat Check	5 of 10	OK
Water flow @ 16.0 °F rise	N/A		Max zone temperature deviation	1.1	°F

Preheat Coil Sizing Data

Max coil load	45.2	MBH	Load occurs at	Des Htg	
Coil CFM at Des Htg	1156	CFM	Ent. DB / Lvg DB	17.0 / 54.0	°F
Max coil CFM	1966	CFM			
Water flow @ 20.0 °F drop	N/A				

Supply Fan Sizing Data

Actual max CFM at Jul 1500	3710	CFM	Fan motor BHP	3.04	BHP
Standard CFM	3630	CFM	Fan motor kW	2.27	kW
Actual max CFM/ft²	0.56	CFM/ft²	Fan static	2.50	in wg

Outdoor Ventilation Air Data

Design airflow CFM	1966	CFM	CFM/person	30.72	CFM/person
CFM/ft²	0.30	CFM/ft²			

Figure 4 - Air System Sizing Summary Report

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Next, review the Ventilation Sizing Summary in Figure 8 to see how the 1966 CFM (927.9 L/s) ventilation requirement was derived. In the “Summary” section of Figure 8, note the design condition occurs during the heating mode for minimum flow.

Also note in Figure 8 the System Ventilation Efficiency is 0.307. The critical space is the "Break Room" in zone "FPT 1-1". Such a low ventilation efficiency means the outdoor air intake airflow is more than three times the sum of uncorrected outdoor airflows for the system since:

Design Ventilation Airflow Rate = Uncorrected Ventilation Airflow Rate / System Ventilation Efficiency

Our optimization goal is to make this system ventilation efficiency as large as feasible to minimize the required ventilation without increasing the operating cost of the system.

1. Summary

Ventilation Sizing Method .... ASHRAE Std 62.1-2007
Design Condition .... Minimum flow (heating)
Occupant Diversity 1.000
Uncorrected Ventilation Airflow Rate .... 604 CFM
System Ventilation Efficiency 0.307
Design Ventilation Airflow Rate .... 1966 CFM

2. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Minimum Supply Air (CFM)	Floor Area (ft²)	Required Outdoor Air (CFM/ft²)	Time Averaged Occupancy	Required Outdoor Air (CFM/person)	Air Distribution Effectiveness	Required Outdoor Air (CFM)	Uncorrected Outdoor Air (CFM)	Space Ventilation Efficiency
FPT 1-1										
Break Room	1	35	134.0	0.06	4.0	5.00	0.80	35	28	0.307
FPT 1-2										
Corridor 100	1	19	249.0	0.06	1.0	0.00	0.80	19	15	0.763
Corridor 102	1	34	455.0	0.06	1.0	0.00	0.80	34	27	0.673
FPT 1-3										
Elec Room	1	13	84.0	0.06	1.0	0.00	0.80	6	5	1.028
FPT 1-4										
File Storage Rm	1	22	149.0	0.12	0.0	0.00	0.80	22	18	0.672
Janitor's Storage	1	7	49.0	0.12	0.0	0.00	0.80	7	6	0.672
FPT 1-5										
Lobby	1	26	186.0	0.06	2.0	5.00	0.80	26	21	0.536
FPT 1-6										
Main Conference	1	180	326.0	0.06	22.0	5.00	0.80	162	130	0.833
FPT 1-7										
Men's RR	1	71	567.0	0.00	4.0	0.00	0.80	0	0	1.259
Women's RR	1	71	567.0	0.00	4.0	0.00	0.80	0	0	1.259
FPT 1-8										
Office 120	1	93	675.0	0.06	4.0	5.00	0.80	76	61	0.817
Office 124	1	82	540.0	0.06	4.0	5.00	0.80	65	52	0.826
FPT 1-9										
Office 126	1	117	810.0	0.06	6.0	5.00	0.80	98	79	0.673
Office 135	1	21	148.0	0.06	1.0	5.00	0.80	17	14	0.670
FPT 1-10										
Open Office Area	1	364	1648.0	0.06	10.0	5.00	0.80	186	149	1.067
Totals (incl. Space Multipliers)		1156							604	0.307

Figure 5 - Ventilation Sizing Summary Report (Non-Optimized)

In Figure 5 the space ventilation efficiency values for other spaces reports the second worst space is the "Lobby" in zone "FPT 1-5" with an efficiency of 0.536. Therefore, if we could optimize the ventilation efficiency for the Break Room zone to greater than 0.536, the "Lobby" would become the new critical space

Looking at the "Break Room", we see the minimum supply airflow is 35 CFM (16.5 L/s) and this is also the required outdoor air. This means the space is receiving supply air that is 100% outdoor air an unvitiated air in order to satisfy its ventilation requirement. From Figure 9 the design airflow for zone FPT 1-1 is 95 CFM (44.8 L/s) Originally minimum airflow was set to 30% of design supply airflow. For FPT 1-1 this would be 95 CFM x 0.30 = 29 CFM (13.7 L/s). Standard

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62.1 is requiring more than 30% for this zone to meet minimum ventilation requirements. Therefore, we need to increase the minimum VAV box position to a level greater than 30% to over-air the zone and drive up the space ventilation efficiency.

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (MBH)	Design Air Flow (CFM)	Minimum Air Flow (CFM)	Time of Peak Load	Maximum Heating Load (MBH)	Zone Floor Area (ft²)	Zone CFM/ft²
FPT 1-1	2.0	95	35	Jul 1500	0.4	134.0	0.71
FPT 1-2	3.2	150	53	Jul 1400	2.4	704.0	0.21
FPT 1-3	0.9	43	13	Jul 1500	0.7	84.0	0.51
FPT 1-4	0.9	44	30	Jul 1400	1.3	198.0	0.22
FPT 1-5	1.8	83	26	Jul 1500	0.6	186.0	0.45
FPT 1-6	12.7	600	180	Jul 1700	9.5	326.0	1.84
FPT 1-7	10.1	477	143	Jul 1500	3.4	1134.0	0.42
FPT 1-8	12.4	585	175	Jul 1500	7.0	1215.0	0.48
FPT 1-9	9.7	458	137	Jul 1500	2.8	958.0	0.48
FPT 1-10	25.6	1212	364	Jul 1500	28.9	1648.0	0.74

Figure 6 - Zone Sizing Summary Report

However, before we do this we need to run an energy simulation and generate annual energy costs to serve as a benchmark prior to making any changes. Table 1 of the HAP Annual Cost Summary Report indicates the annual energy cost of the existing design is $3588 (Figure 10). This is our benchmark cost.

Initial Benchmark Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	302
Cooling	1,981
Heating	1,304
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	3,588
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	24,706
Grand Total	28,294

Figure 7 - Annual Cost Summary Report - Benchmark

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Now let us increase the "FPT 1-1" zone minimum airflow to 40%. **Do not forget to uncheck the "All zones are the same" box in Figure 11 or you will be changing the minimum setting for all 10 zones in the system.**

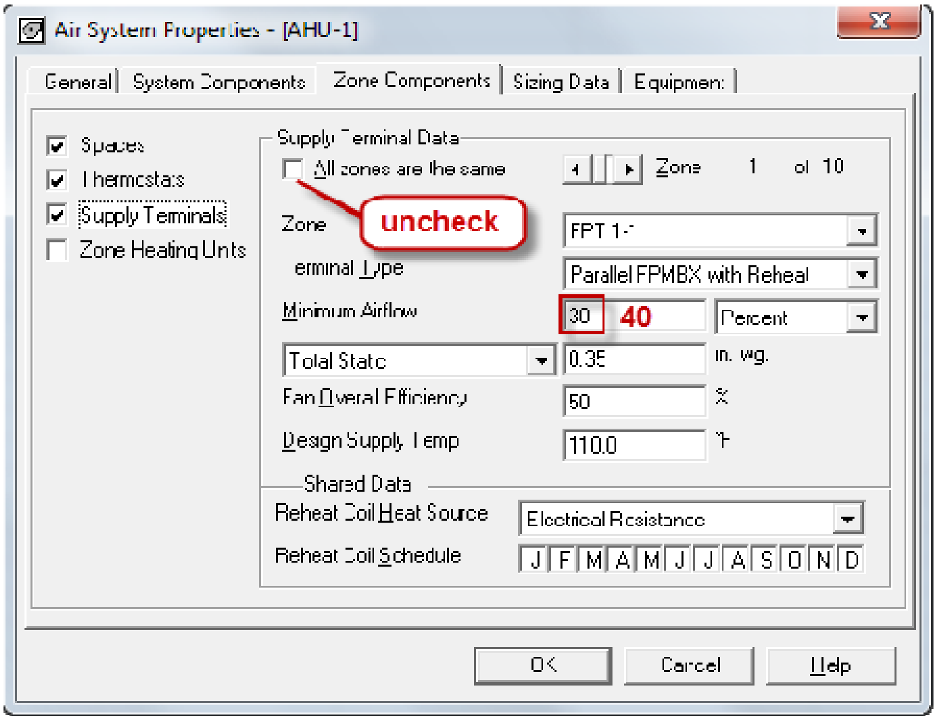

Figure 8 - HAP Air System Properties-Zone Components-Supply Terminals

Next, run system design calculations and generate the Ventilation Sizing Summary Report to see the effects on the critical space ventilation efficiency (Figure 12). The system ventilation efficiency increased from 0.307 to 0.501. The corresponding system ventilation requirement dropped significantly from 1966 (927.8 L/s) to 1205 CFM (568.7 L/s).

The critical space is still "Breakroom" in FPT 1-1, but the "Lobby" space in FPT 1-5 is a close second with a ventilation efficiency of 0.535. We will turn our attention to these spaces next.

Before we do that, however, let's look at how the change affected energy cost. Running the energy simulation after the first set of changes produces the Annual Cost Summary report in Figure 13. The good news is the energy cost dropped by $366 or 10% of HVAC energy cost. This indicates we are going in the right direction.

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Optimizing Ventilation Design in Commercial Buildings using HAP

1. Summary

Ventilation Sizing Method	ASHRAE Std 62.1-2007
Design Condition	Minimum flow (heating)
Occupant Diversity	1.000
Uncorrected Ventilation Airflow Rate	604 CFM
System Ventilation Efficiency	0.501
Design Ventilation Airflow Rate	1205 CFM

2. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Minimum Supply Air (CFM)	Floor Area (ft^2)	Required Outdoor Air (CFM/ft^2)	Time Averaged Occupancy	Required Outdoor Air (CFM/person)	Air Distribution Effectiveness	Required Outdoor Air (CFM)	Uncorrected Outdoor Air (CFM)	Space Ventilation Efficiency
FPT 1-1										
Break Room	1	38	134.0	0.06	4.0	5.00	0.80	35	28	0.501
FPT 1-2										
Corridor 100	1	19	249.0	0.06	1.0	0.00	0.80	19	15	0.762
Corridor 102	1	34	455.0	0.06	1.0	0.00	0.80	34	27	0.672
FPT 1-3										
Elec Room	1	13	84.0	0.06	1.0	0.00	0.80	6	5	1.027
FPT 1-4										
File Storage Rm	1	22	149.0	0.12	0.0	0.00	0.80	22	18	0.671
Janitor's Storage	1	7	49.0	0.12	0.0	0.00	0.80	7	6	0.671
FPT 1-5										
Lobby	1	26	186.0	0.06	2.0	5.00	0.80	26	21	0.535
FPT 1-6										
Main Conference	1	180	326.0	0.06	22.0	5.00	0.80	162	130	0.832
FPT 1-7										
Men's RR	1	71	567.0	0.00	4.0	0.00	0.80	0	0	1.258
Women's RR	1	71	567.0	0.00	4.0	0.00	0.80	0	0	1.258
FPT 1-8										
Office 120	1	93	675.0	0.06	4.0	5.00	0.80	76	61	0.816
Office 124	1	82	540.0	0.06	4.0	5.00	0.80	65	52	0.825
FPT 1-9										
Office 126	1	117	810.0	0.06	6.0	5.00	0.80	98	79	0.672
Office 135	1	21	148.0	0.06	1.0	5.00	0.80	17	14	0.669
FPT 1-10										
Open Office Area	1	364	1648.0	0.06	10.0	5.00	0.80	186	149	1.066
Totals (incl. Space Multipliers)		1159							604	0.501

Figure 9 - Ventilation Sizing Summary Report (Optimized-Iteration #1)

Initial Benchmark Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	302
Cooling	1,981
Heating	1,304
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	3,588
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	24,706
Grand Total	28,294

Iteration #1 Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	302
Cooling	1,616
Heating	1,304
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	3,222
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	24,706
Grand Total	27,928

Figure 10 - Annual Cost Summary Reports (Initial & Iteration #1)

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As our next iteration increase the FPT 1-1 minimum VAV box position from 40% to 50% and increase the FPT 1-5 minimum position from 30% to 40%. Then run calculations and generate the Ventilation Sizing Summary Report (Figure 14). Outdoor air intake airflow decreased further to 1162 CFM (548.4 L/s). This is down from the original 1966 CFM (927.8 L/s) and the 1205 CFM (568.7 L/s) for the first iteration of optimization.

The report shows us we over-aired the FPT 1-1 and FPT 1-5 zones because their space ventilation effectiveness values are now 0.929 and 0.885, respectively. This is higher than many of the other spaces but we will leave them as they are for now. We now have a new critical zone, FPT 1-4, which serves storage spaces. Notice also Corridor 102 in FPT 1-2 has about the same space ventilation efficiency as zone FPT 1-4. The required ventilation quantity has also decreased because the critical space ventilation efficiency is now 0.520. **Another significant change is the design condition now occurs in the cooling not the heating mode.**

1. Summary

Ventilation Sizing Method	ASHRAE Std 62.1-2007
Design Condition	Minimum flow (cooling)
Occupant Diversity	1.000
Uncorrected Ventilation Airflow Rate	604 CFM
System Ventilation Efficiency	0.520
Design Ventilation Airflow Rate	1162 CFM

2. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Minimum Supply Air (CFM)	Floor Area (ft²)	Required Outdoor Air (CFM/ft²)	Time Averaged Occupancy	Required Outdoor Air (CFM/person)	Air Distribution Effectiveness	Required Outdoor Air (CFM)	Uncorrected Outdoor Air (CFM)	Space Ventilation Efficiency
FPT 1-1										
Break Room	1	47	134.0	0.06	4.0	5.00	1.00	28	28	0.929
FPT 1-2										
Corridor 100	1	18	249.0	0.06	1.0	0.00	1.00	15	15	0.677
Corridor 102	1	27	455.0	0.06	1.0	0.00	1.00	27	27	0.523
FPT 1-3										
Elec Room	1	13	84.0	0.06	1.0	0.00	1.00	5	5	1.128
FPT 1-4										
File Storage Rm	1	18	149.0	0.12	0.0	0.00	1.00	18	18	0.520
Janitor's Storage	1	6	49.0	0.12	0.0	0.00	1.00	6	6	0.520
FPT 1-5										
Lobby	1	33	186.0	0.06	2.0	5.00	1.00	21	21	0.885
FPT 1-6										
Main Conference	1	180	326.0	0.06	22.0	5.00	1.00	130	130	0.800
FPT 1-7										
Men's RR	1	71	567.0	0.00	4.0	0.00	1.00	0	0	1.520
Women's RR	1	71	567.0	0.00	4.0	0.00	1.00	0	0	1.520
FPT 1-8										
Office 120	1	93	675.0	0.06	4.0	5.00	1.00	61	61	0.870
Office 124	1	82	540.0	0.06	4.0	5.00	1.00	52	52	0.883
FPT 1-9										
Office 126	1	117	810.0	0.06	6.0	5.00	1.00	79	79	0.847
Office 135	1	21	148.0	0.06	1.0	5.00	1.00	14	14	0.843
FPT 1-10										
Open Office Area	1	364	1648.0	0.06	10.0	5.00	1.00	149	149	1.110
Totals (incl. Space Multipliers)		1162							604	0.520

New critical zone

Figure 11 - Ventilation Sizing Summary Report (Partially-Optimized Ventilation Design, Iteration #2)

Since FPT 1-2 and FPT 1-4 are the new critical zones, we will increase the minimum damper position for these two zones. However, before we do this we should run the energy simulation and examine the energy cost from the last changes. Figure 15 shows the HVAC energy cost has dropped further to $3186.

Optimizing Ventilation Design in Commercial Buildings using HAP

Initial Benchmark Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	302
Cooling	1,981
Heating	1,304
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	**3,588**
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	**24,706**
Grand Total	**28,294**

Iteration #1 Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	302
Cooling	1,616
Heating	1,304
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	**3,222**
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	**24,706**
Grand Total	**27,928**

Iteration #2 Cost

Table 1. Annual Costs

Component	Proposed ($)
Air System Fans	301
Cooling	1,591
Heating	1,294
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	**3,186**
Lights	1,914
Electric Equipment	1,618
Misc. Electric	21,175
Misc. Fuel Use	0
Non-HVAC Sub-Total	**24,706**
Grand Total	**27,892**

Figure 12 - Annual Cost Summary Reports (Initial & Iterations #1 & #2)

For the third iteration, increase the minimum VAV terminal position for FPT 1-2 and FPT 1-4 to from 30% to 40%. Then run calculations and generate the Ventilation Sizing Summary one more time. Results in Figure 16 show the ventilation efficiency for spaces in FPT 1-2 improved, but those in FPT 1-4 decreased. The outdoor air intake airflow increased slightly to 1177 CFM from 1162 CFM.

Optimizing Ventilation Design in Commercial Buildings using HAP

1. Summary

Ventilation Sizing Method .... ASHRAE Std 62.1-2007
Design Condition .... Minimum flow (cooling)
Occupant Diversity 1.000
Uncorrected Ventilation Airflow Rate .... 604 CFM
System Ventilation Efficiency 0.513
Design Ventilation Airflow Rate .... 1177 CFM

2. Space Ventilation Analysis Table

Zone Name / Space Name	Mult.	Minimum Supply Air (CFM)	Floor Area (ft²)	Required Outdoor Air (CFM/ft²)	Time Averaged Occupancy	Required Outdoor Air (CFM/person)	Air Distribution Effectiveness	Required Outdoor Air (CFM)	Uncorrected Outdoor Air (CFM)	Space Ventilation Efficiency
FPT 1-1										
Break Room	1	47	134.0	0.06	4.0	5.00	1.00	28	28	0.922
FPT 1-2										
Corridor 100	1	24	249.0	0.06	1.0	0.00	1.00	15	15	0.881
Corridor 102	1	37	455.0	0.06	1.0	0.00	1.00	27	27	0.766
FPT 1-3										
Elec Room	1	13	84.0	0.06	1.0	0.00	1.00	5	5	1.121
FPT 1-4										
File Storage Rm	1	18	149.0	0.12	0.0	0.00	1.00	18	18	0.513
Janitor's Storage	1	6	49.0	0.12	0.0	0.00	1.00	6	6	0.513
FPT 1-5										
Lobby	1	33	186.0	0.06	2.0	5.00	1.00	21	21	0.878
FPT 1-6										
Main Conference	1	180	326.0	0.06	22.0	5.00	1.00	130	130	0.794
FPT 1-7										
Men's RR	1	71	567.0	0.00	4.0	0.00	1.00	0	0	1.513
Women's RR	1	71	567.0	0.00	4.0	0.00	1.00	0	0	1.513
FPT 1-8										
Office 120	1	93	675.0	0.06	4.0	5.00	1.00	61	61	0.864
Office 124	1	82	540.0	0.06	4.0	5.00	1.00	52	52	0.877
FPT 1-9										
Office 126	1	117	810.0	0.06	6.0	5.00	1.00	79	79	0.840
Office 135	1	21	148.0	0.06	1.0	5.00	1.00	14	14	0.836
FPT 1-10										
Open Office Area	1	364	1648.0	0.06	10.0	5.00	1.00	149	149	1.104
Totals (incl. Space Multipliers)		1177							604	0.513

Figure 16 Ventilation Sizing Summary Report (Iteration #3)

Since the outdoor air intake airflow increased, we could revert to the iteration #2 minimum flow settings for FPT 1-2 and FPT 1-4 and halt optimization here, or we could use a smaller increment to change the minimum flows, for example increasing to 35% instead of 40% as the minimum setting and continue the optimization iterations to see where it leads.

The point in this procedure is that by successively adjusting the minimum flows for critical spaces, space ventilation efficiency can be increased, reducing the outdoor air intake airflow until airflow reductions become small or cease, and/or until energy simulation results show a net increase in energy cost.

If you have further questions about this subject and you are located in the US or Canada, please contact Carrier software support at **software.systems@carrier.utc.com**. Otherwise, please contact your local Carrier sales office for assistance.

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