Energy Cost and IAQ Performance of Ventilation Systems and Controls

Project Report # 3 **Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings**

Zonal Distribution of Outdoor Air and Thermal Comfort Control

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INTRODUCTION

Purpose and Scope of this Report

A companion to this report (see Project Report #2) found that the VAV systems with fixed outdoor air fraction controls set to deliver 20 cfm of outdoor air per occupant, actually delivered significantly less during part load conditions. These systems provided no energy advantage over alternative controls which maintain a minimum of 20 cfm per occupant over the full operating cycle.

This report, a sequel to Project Report #2, examines the performance of the CV and VAV systems in their delivery of outdoor air to individual zones, and also assesses their control of indoor climate in those zones. It is designed to assess the extent to which unequal zonal distributions of supply air affect the outdoor air delivery to occupied spaces. The examination of indoor climate is performed to see whether, in combination with outdoor air flow characteristics, the inherent design of these systems is likely to generate situations conducive to sick building syndrome complaints in situations where air mixing is not significant.

Background

This report is part of a larger modeling project to assess the compatibilities and trade-offs between energy, indoor air, and thermal comfort objectives in the design and operation of HVAC systems in commercial buildings, and to shed light on potential strategies which can simultaneously achieve superior performance on each objective.

This is a modeling study, subject to all the limitations and inadequacies inherent in using models to reflect real world conditions that are complex and considerably more varied than can be fully represented in a single study. Nevertheless, it is hoped that this project will make a useful contribution to understanding the relationships studied, so that together with other information, including field research results, professionals and practitioners who design and operate ventilation systems will be better able to save energy without sacrificing thermal comfort or outdoor air flow performance.

The methodology used in this project has been to refine and adapt the DOE-2.1E building energy analysis computer program for the specific needs of this study, and to generate a detailed database on the energy use, indoor climate, and outdoor air flow rates resulting from various ventilation systems and control strategies. Constant volume (CV) and variable air volume (VAV) systems in different buildings, with different outdoor air control strategies, under alternative climates, provided the basis for parametric variations in the database.

Seven reports, covering the following topics, describe the findings of this project:

- ! Project Report #1: Project objective and detailed description of the modeling methodology and database development
- ! Project Report #2: Assessment of energy and outdoor air flow rates in CV and VAV ventilation systems for large office buildings:
- ! Project Report #3: Assessment of the distribution of outdoor air and the control of thermal comfort in CV and VAV systems for large office buildings
- ! Project Report #4: Energy impacts of increasing outdoor air flow rates from 5 to 20 cfm per occupant in large office buildings
- ! Project Report #5: Peak load impacts of increasing outdoor air flow rates from 5 to 20 cfm per occupant in large office buildings
- ! Project Report #6: Potential problems in IAQ and energy performance of HVAC systems when outdoor air flow rates are increased from 5 to 15 cfm per occupant in auditoriums, education, and other buildings with very high occupant density
- ! Project Report #7: The energy cost of protecting indoor environmental quality during energy efficiency projects for office and education buildings

DESCRIPTION OF THE BUILDING AND VENTILATION SYSTEMS MODELED

A large 12 story office building was modeled in three different climates representing cold (Minneapolis), temperate (Washington, D.C.), and hot/humid (Miami) climate zones. The building has an air handler on each floor servicing four perimeter zones corresponding to the four compass orientations, and a core zone. A dual duct constant volume (CV) system with temperature reset, and a single duct variable volume (VAV) system with reheat were modeled. Constant volume systems control the thermal conditions in the space by altering the temperature of a constant volume of supply air. VAV systems provide control by altering the supply air volume while maintaining a constant supply air temperature.

Three basic outdoor air control strategies were modeled: fixed outdoor air fraction (FOAF), constant outdoor air (COA), and air-side economizer (ECON). The FOAF strategy maintained a constant outdoor air fraction (percent outdoor air) irrespective of the supply air volume. The FOAF strategy maintained a constant outdoor air fraction (percent outdoor air) irrespective of the supply air volume. For VAV systems, the FOAF may be approximated in field applications by an outdoor damper in a fixed position (Cohen 1994; Janu 1995; and Solberg 1990), but specific field applications are not addressed in this study. The FOAF strategy was modeled so that the design outdoor air flow rate is met at the design cooling load, and diminishes in proportion to the supply flow during part-load. The COA strategy maintains a constant volume of outdoor air irrespective of the supply air volume. In a CV system, the FOAF and the COA strategies are equivalent, and are referred to in this report as CV (FOAF). In a VAV system, the COA strategy might be represented in field applications by a modulating outdoor air damper which opens wider as the supply air volume is decreased in response to reduced thermal demands. Specific control mechanics which would achieve a VAV (COA) have been addressed by other authors, (Haines 1986, Levenhagen 1992, Solberg 1990) but are not addressed in this modeling project.

Two air-side economizer strategies are used, one based on temperature ($ECON_t$) and one on enthalpy ($ECON_e$). The economizer strategies override the outdoor air flow called for by the prevailing strategy (FOAF or the COA) by bringing in additional quantities of outdoor air to provide “free cooling” when the outdoor air temperature (or enthalpy) is lower than the return air temperature (or enthalpy). The quantity of outdoor air is adjusted so that the desired supply air discharge temperature (or enthalpy) can be achieved with minimum mechanical cooling. Because outdoor air humidity levels are sometimes high during warm weather, the temperature economizer in this project is shut off at outdoor temperatures above 65^o F.

A more detailed description of the building and ventilation system is provided in Report #1.

APPROACH

For this analysis, zone level outdoor air flow and indoor temperature are determined for each hour of the year and were organized in graphic or tabular formats. Zone level data for relative humidity was not available, but the relative humidity in the return air duct was organized in the same fashion. This was done for each HVAC system and OA control strategy. The systems design setting is 20 cfm of outdoor air per occupant, which is the level prescribed by ASHRAE Standard 62-1999[1].

RESULTS

The presentation of results is designed to shed light on the following questions:

a. How well do alternative outdoor air control strategies for CV and VAV systems deliver requisite quantities of outdoor air to individual zones?

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[1] This project was initiated while ASHRAE Standard 1989 was in effect. However, since the outdoor air flow rates for both the 1989 and 1999 versions are the same, all references to ASHRAE Standard 62 in this report are stated as ASHRAE Standard 62-1999.

b. How well do alternative outdoor air control strategies for CV and VAV systems maintain indoor climate control?

c. Where potential shortfalls in outdoor air or indoor climate control occur in individual zones, what solutions are appropriate, and what are the energy implications of those solutions?

Delivery of Outdoor Air to Individual Zones

The quantity of outdoor air delivered to an individual zone in both CV and VAV systems depends on the supply air flow, the proportion of the supply air which is outdoor air (outdoor air fraction), and the proportion of the supply air delivered to the zone in question. The interplay of these three variables is different for CV and VAV systems because of the way in which each system controls indoor climate.

CV Systems

In CV systems, the supply air quantity is determined by the peak thermal loads of the building, and each zone, and remains fixed throughout the year. For CV(FOAF) systems, the outdoor air fraction is determined by the outdoor air requirements of the building (e.g., 20 cfm per occupant) and is fixed. With CV(ECON) systems, the economizer increases the outdoor air fraction above the minimum requirement during much of the year. Each zone receives a proportion of the supply air depending on the peak thermal load of that zone. Thus, perimeter spaces get a larger quantity of supply air than the core, and the south zone receives a larger quantity of supply air than the north zone, etc. Since the outdoor air fraction is the same for all zones, the zones with the larger quantity of supply air will receive a larger quantity of outdoor air and vice versa. This suggests that the core zone in CV systems may receive an inadequate quantity of outdoor air, even when a sufficient quantity of outdoor air enters the air handler.

This *deficiency* of outdoor air in the core zone is shown clearly for the CV(FOAF) system in Exhibit 1, which presents outdoor air flow rates achieved for each zone in this system in the temperate climate of Washington, D.C. over all outdoor temperature conditions. The core zone was consistently under-supplied while the perimeter zones were consistently oversupplied with outdoor air. The results for all climate zones are similar.

Similar plots for the CV(FOAF) system with temperature and enthalpy economizers are presented in Exhibits 2 and 3. The deficiency of outdoor air flow for systems with economizers only occurred in the summer season (when the economizer is not operational). The economizer increased the delivery of outdoor air to all zones, and insured that even the core zone had sufficient outdoor air during much of the year, depending on the climate.

The results for all three systems in a cold climate (Minneapolis), temperate climate (Washington, D.C.), and a hot/humid climate (Miami) are summarized in Exhibit 4. This Exhibit shows clearly that the CV(FOAF) system under-supplied the core zone, providing 11-15 cfm of outdoor air per occupant rather than 20 cfm/occupant, during all occupied hours in all climates. This resulted solely from the unequal distribution of supply air to individual zones, based on peak thermal requirements.

The extent to which the economizers make up for the inherent deficiency of outdoor air to the core zone is dependent on the proportion of the year the temperatures are cool enough for the economizer to be operational. Economizers are operational approximately 70% of the time in Minneapolis, 60% of the time in Washington, D.C., and 10% of the time in Miami. Thus, economizers make up for the core zone deficiency most in cold climates and least in hot/humid climates. In addition, since the temperature economizer was set to shut off when the temperature exceed 65^{o}F to avoid potential humidity problems, the enthalpy economizer operates over a slightly larger portion of the year and therefore had a greater effect on zonal outdoor air flow rates.

VAV Systems

Like the CV(FOAF) system, the VAV(COA) system provide for a minimum outdoor air flow to the building of 20 cfm per occupant during all operating conditions. VAV systems also distribute the supply air to individual zones based on their relative thermal loads. However, while the distribution of air to individual zones in CV systems is based on peak cooling needs and is fixed throughout the year, VAV systems respond to daily and seasonal changes in thermal loads. Because of this, the zonal distribution pattern for outdoor air in the VAV(COA) system will be similar, but not identical, to that of the CV(FOAF) system.

Exhibit 5 shows the flow of outdoor air for the VAV(COA) for each zone over the full range of outdoor temperatures, where minimum VAV box settings were at 30% of peak supply air flow. The core zone consistently received less than the perimeter zones at between 15 and 20 cfm per occupant, except that as the outdoor temperature rose above 65^{o}F, the perimeter zones drew slightly more air at the expense of the core zone. However, the core zone maintained at least 10 cfm per occupant at all times.

Exhibit 6 summarizes the outdoor air delivery rates for the VAV(COA) system, with and without economizers, for all climates. For all practical purposes, the VAV(COA) system performed just as well or slightly better than the CV(FOAF) system in its delivery of outdoor air to individual zones, though the core zone was consistently under ventilated in both types of systems.

The VAV(FOAF) system provided significantly less outdoor air to all zones than the previous cases. For VAV(FOAF), the outdoor air fraction at the air handler was established to satisfy the outdoor air needs of all the zones serviced (20 cfm per occupant) at peak cooling loads, when supply air quantities are at their maximum. Thus, at part load conditions, the VAV(FOAF) system reduced the overall quantity of outside air and hence diminished the quantity of outside air to each zone.

Exhibit 7 shows the zonal distribution pattern for a VAV(FOAF) system without economizer with all VAV boxes set at a minimum of 30%. This shows that the core zone was consistently provided with less than 8 cfm per occupant.

Exhibit 8 summarizes the outdoor air flow rates for the VAV(FOAF) systems in all climates with and without economizers. The core zone received less than 10 cfm/occupant during all occupied hours for Minneapolis and Washington, D.C. climates and for 73% of the occupied hours in Miami, even though the system design setting was 20 cfm per occupant. Other zones were also under supplied, but less frequently. The economizers improved the outdoor air performance considerably, but only when the economizer is operating. The problem of under-supplying individual zones because of the unequal distribution of air that was experienced with the VAV(COA) and CV(FOAF) system was thus magnified with VAV(FOAF) system which also under- supplied the building with outdoor air during part load conditions.

This pattern of unequal zonal distribution need not be a problem where there is significant mixing between zones, such as in open plan offices that span both the perimeter and the core zones. However, where air mixing is interrupted, as may be the case with closed offices, this deficiency in air delivery to the core zones could be a problem. The problem would be partially mitigated by the fact that both the perimeter and core zones share the same return air stream, but this would is not likely to be significant especially if the outdoor air delivery to the air handler is also inadequate.

Climate Control with CV and VAV systems

Space Temperatures

The thermostat settings of both the CV and VAV systems were the same, and were designed to maintain temperature between 70^o F and 79^o F. Exhibit 9 presents the temperature control performance of each system in each zone. All systems in all climates in all zones maintained indoor temperatures within this range. However, the CV system modeled tended to maintain a lower average temperature than the VAV system. The north and west zones of the CV(FOAF) system maintained temperatures right at the lower temperature limit of 70^o F 2% - 12% of the time in Minneapolis and Washington, D.C., while these zones in the CV system with economizers did so more often, 12 - 22% of the time. Conversely, the core zone of the VAV(FOAF) remained at 79^{o}F almost the entire year in Miami and for over half the time in Washington, D.C. The addition of the economizer made no real difference in this performance for Miami and lowered average temperatures only slightly in Washington, D.C. In addition, the VAV(COA) system with and without economizers, almost never achieved the high limit temperature in any zone.

If the modeling results are correct, these results suggest that the introduction of outdoor air may tend, in general, to lower temperatures for both the CV and VAV systems modeled. For the CV system, adding an economizer tended to exacerbate problems of temperature control in the north and west zones which may occur in cold and temperate climates. For the VAV systems, economizers tended to improve temperature control where problems may occur in hot and temperate climates, but the improvement occurred only when the economizer was operating. The more consistent gain in temperature control was the VAV(COA) system (compared to the VAV(FOAF) system) which maintained 20 cfm of outdoor air per occupant during all occupied hours.

Relative Humidity

The HVAC systems modeled were not equipped with specific humidification or dehumidification equipment. All dehumidification took place through the normal cooling process. Exhibit 10 shows data on the relative humidity in the return air stream during the year. This data suggests that, for properly sized systems, interior spaces in office buildings are not likely to experience relative humidity which is too high. The highest relative humidity were experienced in Miami, but even in this climate all HVAC systems maintained the relative humidity between 30 - 50%.[2]

Low relative humidity problems are not simply a function of equipment sizing. The simulations show that relative humidity below 20% occurred frequently, often over half the time, in the temperate and cold climate. Because of the low humidity content of cold outside air, as more outdoor air is drawn into the ventilation system, temperate and cold climates will experience dryer indoor climate conditions during cold weather. As expected, this occurred more often in cold climates than in temperate climates, and more often for systems with economizers. Also, while not shown in the data presented, when these buildings were modeled at 5 cfm rather than 20 cfm of outdoor air per occupant, the proportion of time that relative humidity dropped below 20% decreased in all but the economizer systems. No attempt was made to model the energy implications of humidification.

PROBLEMS AND POTENTIAL SOLUTIONS WITH VAV(FOAF)

VAV controls which approximate the VAV(FOAF) system appear to have a number of inherent features that argue against their use. First, the VAV(FOAF) almost always provided below design quantities of outdoor air from the air handler. Second, it provided little if any energy savings over the VAV(COA) system which provided design quantities all year round[3]. This problem of VAV(FOAF) was exacerbated by the tendency of all these systems to under-supply the core zone and to a lesser extent, the north zone, with outdoor air.

All VAV systems modeled tended to maintain space temperatures at the higher end of the temperature control deadband. In the core zone, the combination of higher temperatures and lower quantities of outdoor air could create conditions conducive to sick building complaints in some buildings. While economizers tend to improve the overall performance of VAV(FOAF) systems in

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[2] While not presented in this report, none of the other office buildings examined in this project presented relative humidity which ever exceeded 60%, including buildings with low shell efficiencies or high occupant densities in the hot/humid climate of Miami. This is interpreted to be the result of properly sized equipment. However, relative humidity in excess of 60% or even 70% can be a problem in very high occupant density buildings (e.g., schools, auditoriums) without proper controls (see Project Report # 6). Humidity could also potentially be a problem with temperature controlled economizers (see Project Report # 2). Finally, while DOE-2 calculates a moisture balance, it has very limited capabilities in tracking relative humidity, so modeling results must be interpreted with caution.

[3] See Project Report #2

the delivery of outdoor air, they do not improve the performance during the summer season, when temperature conditions may be the warmest.

In Project Report # 2, it was suggested that problems with the VAV(FOAF) type systems may be worth avoiding. This report reinforces that suggestion. In Project Report #2, operational modifications to improve the outdoor air performance of FAV(FOAF) systems at the air handler were explored. These options appeared to offer reasonable improvements in outdoor air flow at only marginal changes in energy cost.
In this report, potential methods of providing a more even distribution of outdoor air to each zone are explored, first by operationally altering the VAV box minimum flow settings, then by a system redesign.

VAV Box Minimum Flow Settings

In previous runs, all the VAV boxes employed a minimum setting of 30%. Altering VAV box minimum settings can alter both the total supply air delivered from the air handler, and the distribution of that air to each zone. To better understand this process, the VAV box settings were systematically changed.

In the VAV(FOAF) system, the VAV box minimum setting for the core zone was changed from 30% to 75% in an effort to increase the flow of outdoor air to that zone. All other zone VAV boxes remained set at 30%. The results are shown in Exhibit 11. No change was observed in the outdoor air flow rates to any zone based on this change. Apparently, the relative constant thermal demands of the core zone make it insensitive to changes in its VAV box minimum flow setting.

Modeling runs were also made for the VAV(FOAF) system in which all VAV box minimum settings were changed. In addition to the 30% flow setting, settings of 0%, 45%, and 75% were modeled. The results of these runs are shown in Exhibits 12 and 13.

From these exhibits two things become apparent. First, lowering or raising all VAV box minimums settings lowers or increases outdoor air flow from the air handler to all zones. Thus, the deficiency of the VAV(FOAF) system observed previously in total flow and zonal flow are magnified with settings below the original 30% minimum flow. Second, as the minimum flow settings are increased, the VAV system begins to approach the flow behaviors of the CV system. For example, the zone level flow rates of the VAV(FOAF) system with minimum flow settings of 75% in Exhibit 13 are very similar to those of the CV(FOAF) system in Exhibit 1.

From these exercises, there does not appear to be a reasonable way to alter the VAV box minimum settings in the VAV(FOAF) system in order to accommodate the outdoor air needs of the occupants while still maintaining the energy advantages of a VAV system. Even for the VAV(COA) system, however, the unequal distribution of outdoor air among zones left the core, and sometimes the north zone under-supplied. This may or may not be a problem depending on the degree of internal mixing among zones. However, for HVAC engineers who choose to avoid this problem, a redesign alternative was examined.

Dual System Design

It is not uncommon for design engineers to service the core zone of a building with a CV system, and provide a VAV system for the perimeter zones. This makes sense because the thermal conditions of the core zone remain relatively constant, while the perimeter zones experience daily and seasonal swings. This option was modeled using a CV for the core zone and alternately combined with a VAV(FOAF) system and a VAV(COA) system for the perimeter. The outdoor air flows achieved are compared to the original single system VAV(FOAF) and VAV (COA) respectively. The outdoor air flow rates for both perimeter and core zones are summarized in Exhibit 14. The HVAC annual energy costs of these systems is also compared in Exhibit 15.

The dual system design using a CV system for the core zone and a VAV(FOAF) system for the perimeter zones insures that the core zone always achieves 20 cfm of outdoor air per occupant. However, in general, the perimeter zones tended to receive less outdoor air than the single VAV(FOAF) system design, with the north and west zones being particularly under-supplied. For example, in this dual system, the north zone received less than 10 cfm of outdoor air per occupant between 38% and 96% of the time, depending on climate.

The dual system design using a VAV(COA) system for the perimeter zones improved the perimeter outdoor air performance considerably, and appears to be preferable. However, even this dual system still leaves shortfalls which may be unacceptable in the north and west zones.

Exhibit 15 suggests that the dual system would compare favorably to the single systems in energy cost (plus or minus $0.01per square foot) in the cold and temperate climates of Minneapolis and Washington, D.C., but would add about $.04 per square foot (approximately 5%) to the HVAC energy costs in Miami.

SUMMARY

Whenever an air handler services more than one zone, differences in the thermal requirements among zones will cause an unequal distribution of supply air, and therefore outdoor air, to individual zones. The core zone, and to a lesser extent, the north zone, appear to be the most significantly under-supplied with outdoor air.

The CV systems modeled tended to provide indoor space temperatures close to the lower end of the temperature deadband, particularly in the north and west zones, while the VAV systems modeled provided space temperatures close to the high end, particularly in the core zone. Since the core and north zones were also zones that had the lowest supply of outdoor air, the combination of extreme temperature and poor outdoor air performance may be conducive to sick building syndrome complaints, especially where air mixing is limited.

The VAV(FOAF) system experienced the lowest zonal outdoor air flow rates. Attempts to remedy the problem by raising VAV box minimum settings were unsuccessful. Raising VAV box minimum setting in the core zone only, showed no change in outdoor air performance. Raising the VAV box minimum settings in all zones improved the outdoor air performance, but it did so by raising the supply air flow rate in the whole system, making the VAV system behave like a CV system, and removing the inherent energy advantage of the VAV system.

Building professionals might consider providing separate HVAC systems for the perimeter and the core zones in new building designs. Such a system was modeled using a CV system to service the core zone, and a VAV(FOAF) or a VAV(COA) system to service the perimeter zones. For these dual systems, the outdoor air flow rate performance for the core zone was greatly improved, but the performance of the perimeter zones showed significant shortfalls for the north and west zones. Dual systems using VAV(COA) provided greater quantities of outdoor air to these zones than VAV(FOAF), and would appear to be preferable. The energy cost of the dual system was similar to the single system in the cold and temperate climates, but was about 5% higher in the hot and humid climate.

The results of this report may be of interest to interior design professionals, and suggests that whatever the HVAC system design, good air flow communication between zones could be an important concern. Attention directed to communication from the zones with ample outdoor air supply to the under-supplied zones might forestall sick building complaints in the under-supplied zones.

BIBLIOGRAPHY

Bearg, D, W. 1995. Demand-controlled ventilation. *Engineered Systems* April 1995: 28-32.

Filardo, M. J. 1993. Outdoor air - how much is enough? *ASHRAE Journal* 35(1): 34-38.

Ke, Y., Mumma, S. A. 1996. A generalized multiple-space equation to accommodate any mix of close off and fan powered VAV boxes. *ASHRAE Transactions* 102(1): 3950.

Ke, Y. P., Mumma, S. A., Stanke, D., 1997. Simulation results and analysis of eight ventilation control strategies in VAV systems. *ASHRAE Transactions* 103(2): 381-392.

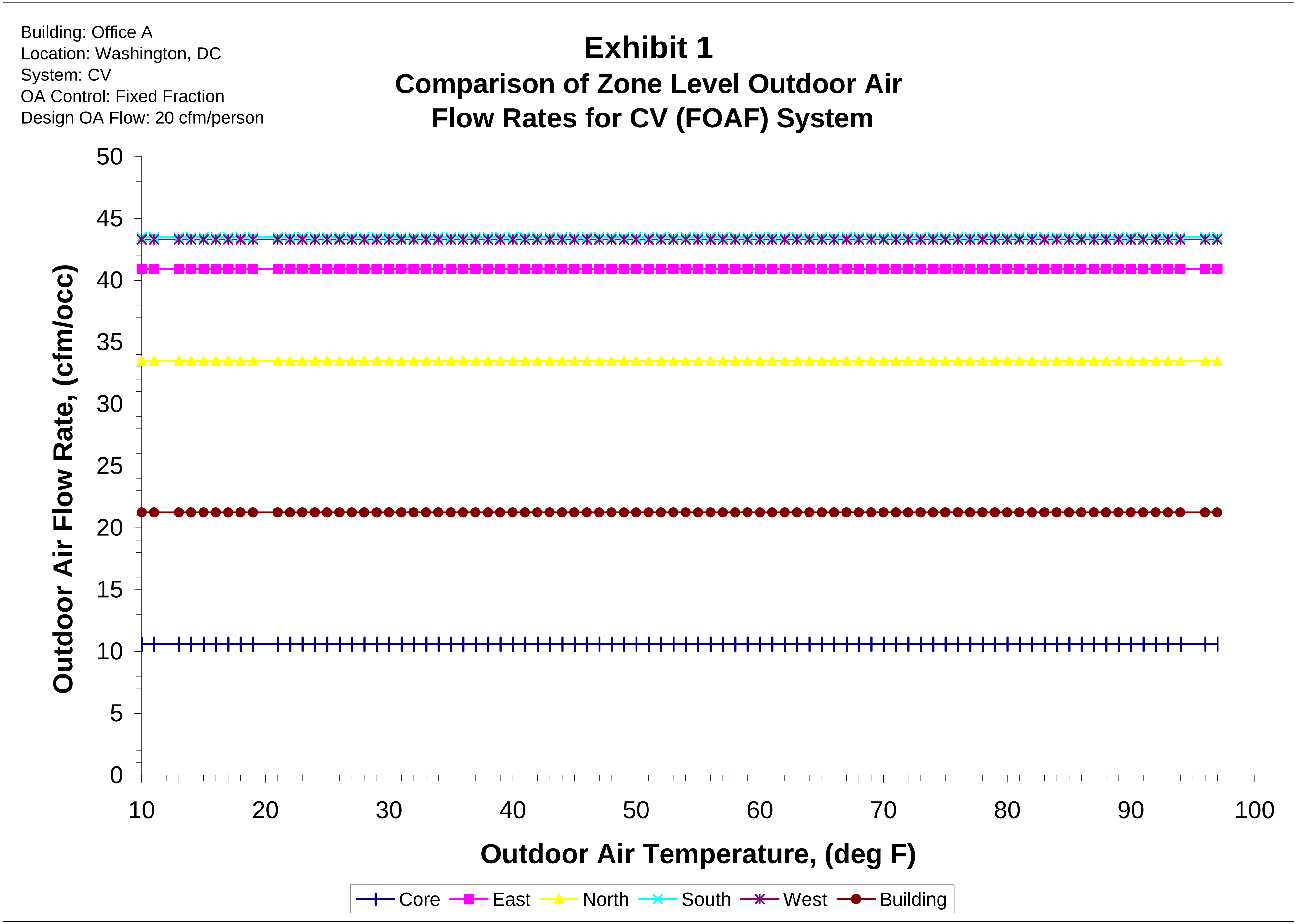
Levenhagen, J. I. 1992. Control systems to comply with ASHRAE Standard 62-1989. *ASHRAE Journal* 34(9):40-44

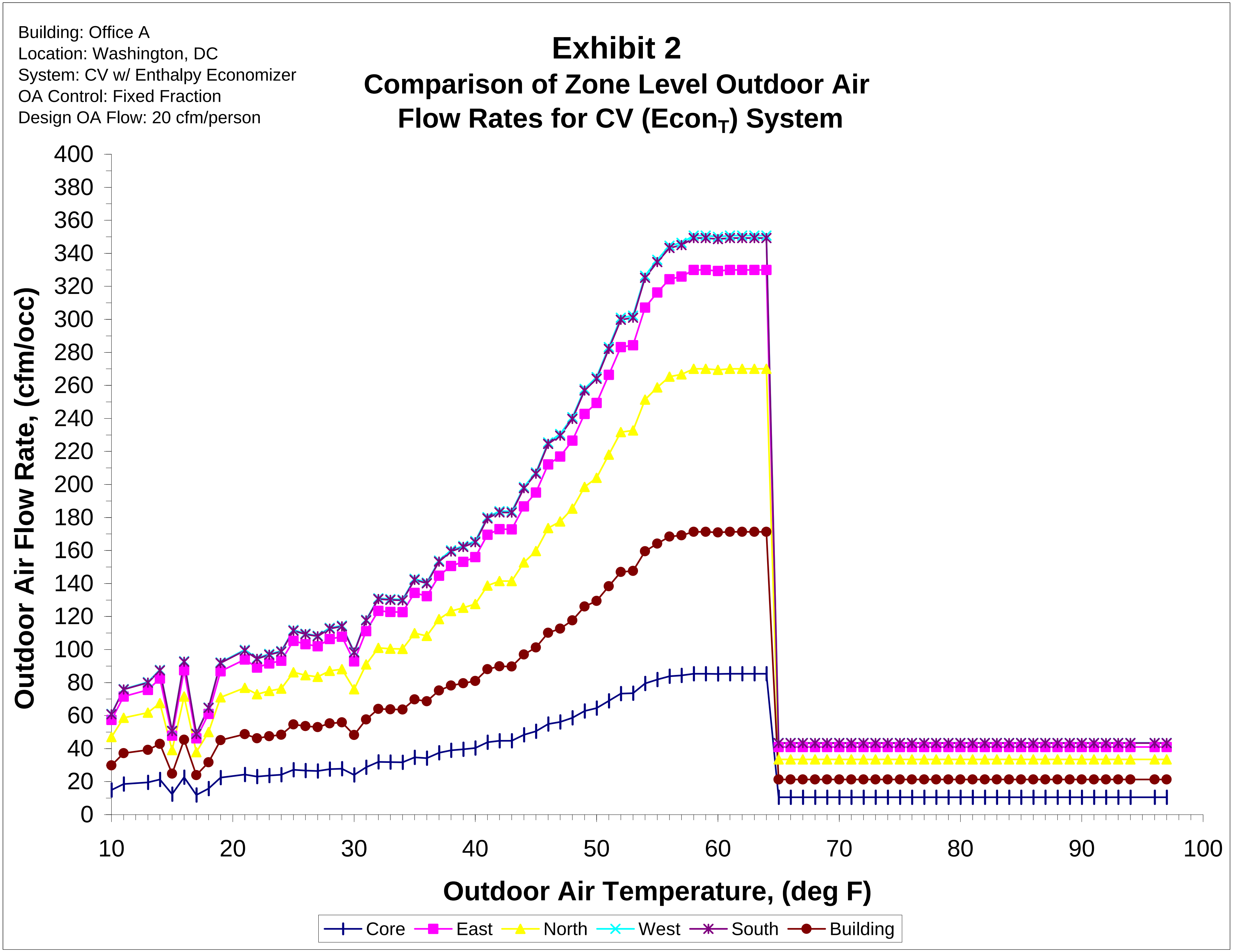
Mumma, S. A., Bolin, R. J. 1995. Real-time, on-line optimization of VAV system control to minimize the energy consumption rate and to satisfy ASHRAE Standard 62-1989 for all occupied zones. *ASHRAE Transactions* 101(1): 3753.

Mutammara, A.W., and Hittle, D.C. 1990. Energy effects of various control strategies for variable air volume systems. *ASHRAE Transactions* 96(1): 98-102.

Warden, D. 1996. Outdoor air: calculation and delivery. ASHRAE Journal 37(6): 54-61.

Warden, D. 1996. Dual fan, dual duct systems. *ASHRAE Journal* 38(1): 36-41.


Building: Office A
Location: Washington, DC
System: CV
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 1
Comparison of Zone Level Outdoor Air
Flow Rates for CV (FOAF) System
Outdoor Air Flow Rate, (cfm/occ)
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Building


Building: Office A
Location: Washington, DC
System: CV w/ Enthalpy Economizer
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 2
Comparison of Zone Level Outdoor Air Flow Rates for CV (Econ$_T$) System
Outdoor Air Flow Rate, (cfm/occ)
Outdoor Air Temperature, (deg F)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
10
20
30
40
50
60
70
80
90
100
Core
East
North
West
South
Building

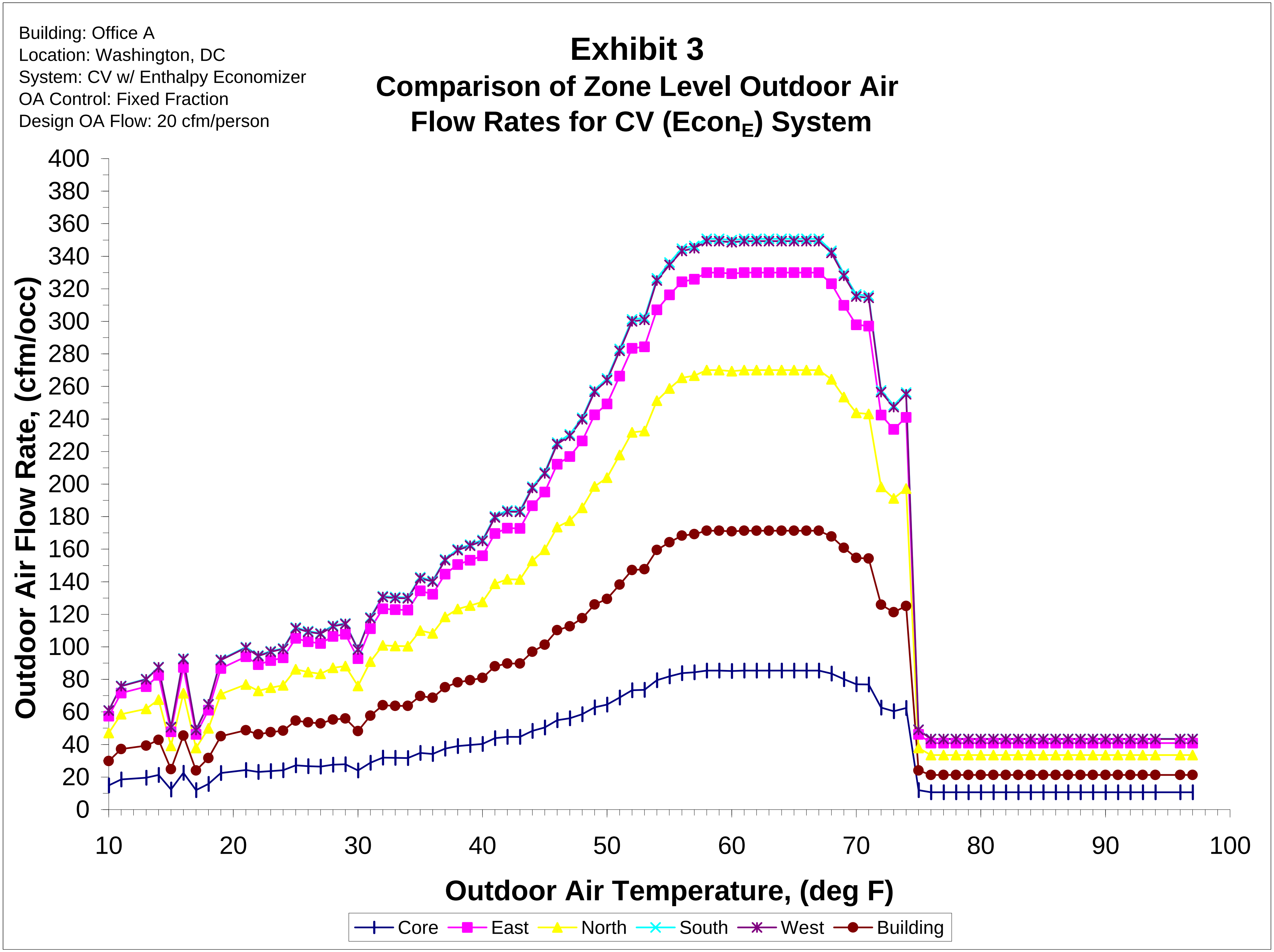

Building: Office A
Location: Washington, DC
System: CV w/ Enthalpy Economizer
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 3
Comparison of Zone Level Outdoor Air Flow Rates for CV (Econ$_E$) System
Outdoor Air Flow Rate, (cfm/occ)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Building

Exhibit 4
Occurance of Zone OA Flow Rates for CV Systems
(% of Occupied Hours)

Climate and Zone	CV(FOAF)					CV(FOAF) $Econ_T$					CV(FOAF) $Econ_E$				
	OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)				
	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20
Minnea., MN															
Core			100.0					40.2	4.6	55.2			29.0	4.6	66.4
East					100.0					100.0					100.0
North					100.0					100.0					100.0
West					100.0					100.0					100.0
South					100.0					100.0					100.0
Wash., DC															
Core			100.0					49.9	0.6	49.5			34.5	0.6	64.9
East					100.0					100.0					100.0
North					100.0					100.0					100.0
West					100.0					100.0					100.0
South					100.0					100.0					100.0
Miami, FL															
Core			100.0					94.2		5.8			82.2		17.8
East					100.0					100.0					100.0
North					100.0					100.0					100.0
West					100.0					100.0					100.0
South					100.0					100.0					100.0

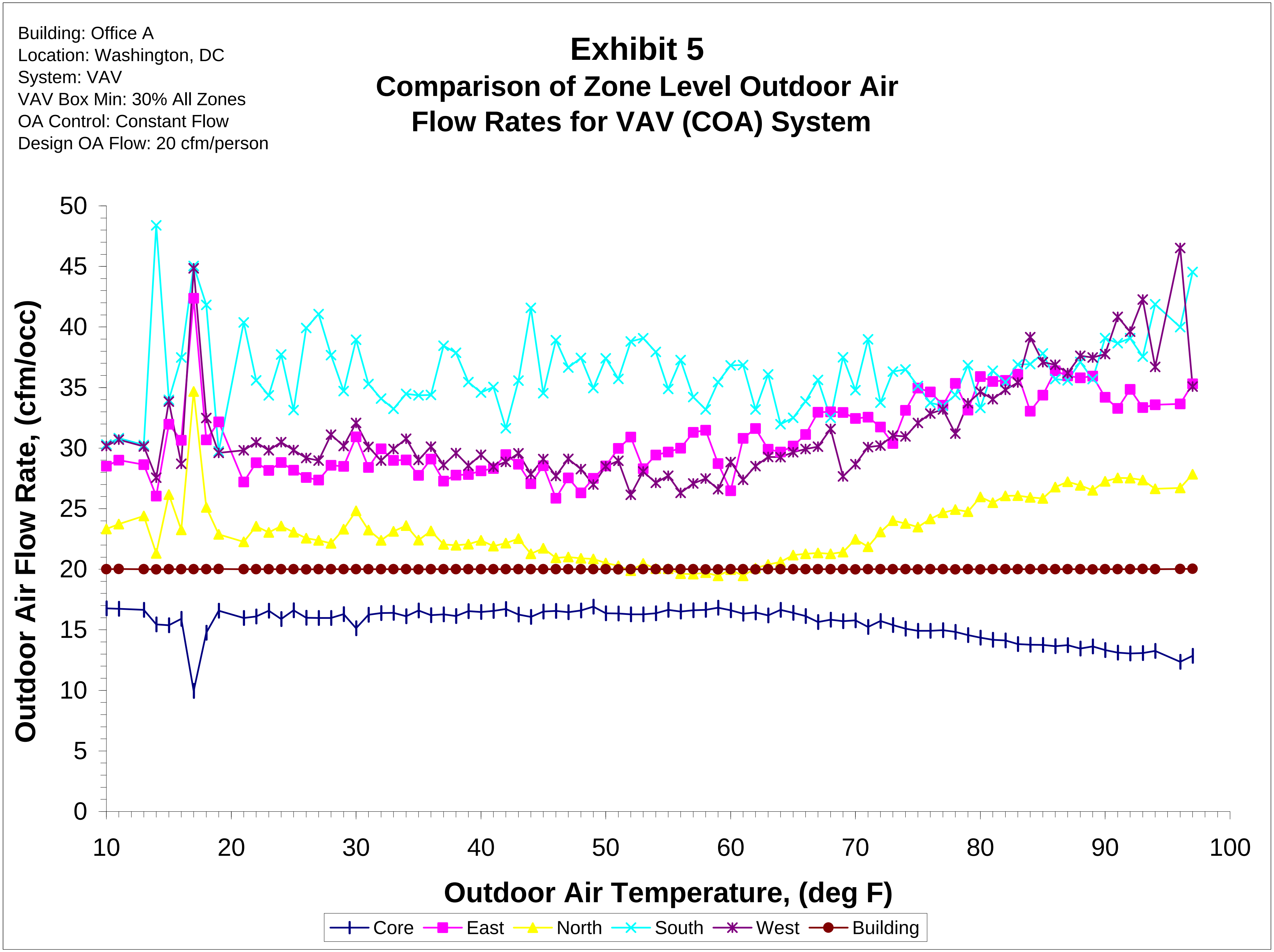

Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 30% All Zones
OA Control: Constant Flow
Design OA Flow: 20 cfm/person
Exhibit 5
Comparison of Zone Level Outdoor Air Flow Rates for VAV (COA) System
Outdoor Air Flow Rate, (cfm/occ)
Outdoor Air Temperature, (deg F)
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
Core
East
North
South
West
Building

Exhibit 6
Occurance of Zone OA Flow Rates for VAV(COA) Systems
(% of Occupied Hours)

Climate and Zone	**VAV(COA)**					**VAV(COA) Econ$_T$**					**VAV(COA) Econ$_E$**				
	OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)				
	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20
Minnea., MN															
Core		0.1	48.7	51.2			0.1	29.0	9.5	61.4		0.1	18.5	8.1	73.3
East					100.0					100.0					100.0
North			0.7	22.5	76.8			0.1	2.3	97.7				0.4	99.6
West				0.5	99.5				0.4	99.6				0.1	99.9
South					100.0					100.0					100.0
Wash., DC															
Core		0.2	51.5	48.3				39.0	10.4	50.6			27.1	5.0	67.9
East					100.0					100.0					100.0
North				14.4	85.6				4.1	95.9				0.4	99.6
West					100.0					100.0					100.0
South					100.0					100.0					100.0
Miami, FL															
Core			80.7	19.3				78.8	15.4	5.8			70.8	12.3	16.9
East					100.0					100.0					100.0
North			5.5	7.5	86.9			1.5	6.2	92.3			1.1	2.9	96.1
West				2.1	97.9				1.2	98.8				0.7	99.3
South					100.0					100.0					100.0

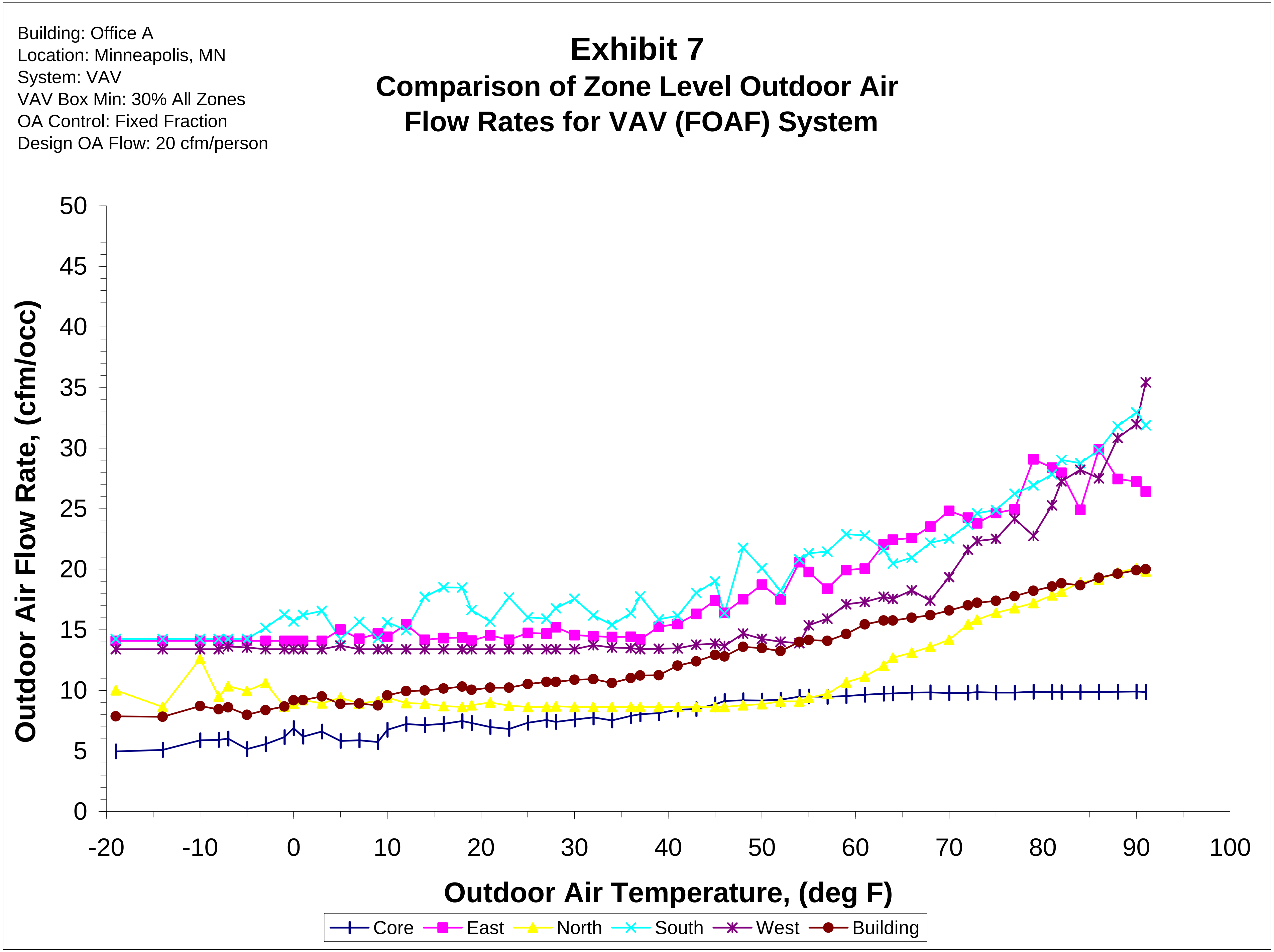

Building: Office A
Location: Minneapolis, MN
System: VAV
VAV Box Min: 30% All Zones
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 7
Comparison of Zone Level Outdoor Air Flow Rates for VAV (FOAF) System
Outdoor Air Flow Rate, (cfm/occ)
Outdoor Air Temperature, (deg F)
0
5
10
15
20
25
30
35
40
45
50
-20
-10
0
10
20
30
40
50
60
70
80
90
100
Core
East
North
South
West
Building

Exhibit 8
Occurance of Zone OA Flow Rates for VAV(FOAF) Systems
(% of Occupied Hours)

Climate and Zone	VAV(FOAF)					VAV(FOAF) $Econ_T$					VAV(FOAF) $Econ_E$				
	OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)				
	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20
Minnea., MN															
Core	3.2	96.8					32.8	1.7	4.0	61.4		19.2	1.7	4.0	75.1
East				68.3	31.7			3.1	8.0	88.9			2.2	3.9	93.9
North		61.8	20.5	16.7	1.0		0.8	18.1	13.7	67.4		0.2	7.0	11.7	81.1
West			68.2	13.1	18.6			6.9	11.2	81.8			2.7	6.8	90.6
South			49.9	9.9	40.2			4.2	5.9	89.9			2.5	3.1	94.4
Wash., DC															
Core	0.7	99.3					49.3	0.1	0.1	50.6		28.6	0.1	0.1	71.2
East			46.4	15.3	38.3			6.3	13.5	80.2			1.6	6.2	92.2
North			69.4	24.4	6.2		3.5	19.4	23.8	53.2			6.3	19.6	73.9
West			54.2	15.0	30.8			9.7	14.5	75.7			2.4	8.7	88.9
South			35.2	10.7	54.1			6.1	8.8	85.1			2.3	5.2	92.5
Miami, FL															
Core		73.3	26.7				94.2			5.8		77.9			22.1
East			3.2	9.4	87.4			2.2	10.3	87.5			1.2	6.5	92.3
North		5.8	24.1	43.3	26.7		2.0	28.7	46.0	23.2		0.6	17.2	42.7	39.5
West			11.6	23.3	65.1			8.9	27.1	64.0			4.6	20.9	74.4
South				13.5	86.5			5.4	9.2	85.4			3.4	8.0	88.6

Exhibit 9
Percent of Occupied Hours with Specified Indoor Air Temperatures by Zone

System and Temperature	Minneapolis, MN					Washington, DC					Miami, FL				
	Core	E	N	W	S	Core	E	N	W	S	Core	E	N	W	S
CV(FOAF)															
<=70	0.0	2.2	11.7	3.4	1.7	0.0	0.4	8.9	1.7	0.5	0.0	0.0	0.3	0.0	0.0
71-72	1.6	91.0	88.3	91.0	79.8	0.3	90.0	91.0	93.4	82.5	0.0	72.9	29.3	91.3	88.8
73-74	1.9	4.7	0.0	2.9	9.0	0.7	4.7	0.0	3.0	6.8	0.0	12.0	22.0	4.3	6.6
75-76	9.5	1.8	0.0	1.9	7.1	3.7	3.8	0.0	1.3	7.1	0.0	9.1	28.2	3.2	3.6
77-78	85.9	0.3	0.0	0.8	2.4	90.8	1.1	0.0	0.6	3.1	99.9	5.7	20.1	1.1	1.0
>=79	1.1	0.0	0.0	0.0	0.0	4.5	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0
CV(FOAF)Econ$_T$															
<=70	0.0	9.7	19.5	12.1	5.8	0.0	4.1	21.7	15.7	6.3	0.0	0.2	0.7	2.4	0.5
71-72	1.6	84.0	80.5	82.4	75.9	0.3	86.4	78.2	79.5	77.1	0.0	72.7	28.9	89.0	88.3
73-74	1.9	4.4	0.0	2.9	9.1	0.7	4.9	0.0	2.9	7.0	0.0	12.0	22.0	4.3	6.6
75-76	9.9	1.6	0.0	1.8	7.1	4.0	3.5	0.0	1.3	6.9	0.0	9.3	28.2	3.2	3.5
77-78	85.6	0.3	0.0	0.8	2.2	90.7	1.0	0.0	0.6	2.7	99.9	5.7	20.1	1.1	1.0
>=79	1.0	0.0	0.0	0.0	0.0	4.4	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0
CV(FOAF)Econ$_E$															
<=70	0.0	9.7	19.5	12.2	5.8	0.0	4.1	21.7	15.7	6.3	0.0	0.2	0.8	2.4	0.4
71-72	1.6	84.0	80.5	82.4	76.0	0.3	86.6	78.3	79.5	77.2	0.0	72.8	28.9	89.0	88.4
73-74	1.9	4.5	0.0	2.8	9.1	0.7	4.8	0.0	2.9	6.9	0.0	12.0	21.9	4.3	6.6
75-76	9.9	1.5	0.0	1.7	7.0	4.0	3.2	0.0	1.3	7.0	0.0	9.2	28.2	3.2	3.5
77-78	85.6	0.3	0.0	0.8	2.2	91.0	1.1	0.0	0.6	2.7	99.9	5.6	20.1	1.1	1.1
>=79	1.0	0.0	0.0	0.0	0.0	4.0	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0

Exhibit 9 (Cont'd)
Percent of Occupied Hours with Specified Indoor Air Temperatures by Zone

System and Temperature	Minneapolis, MN					Washington, DC					Miami, FL				
	Core	E	N	W	S	Core	E	N	W	S	Core	E	N	W	S
VAV(FOAF)															
<=70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71-72	0.0	7.7	23.9	20.1	7.2	0.0	1.2	9.7	5.3	0.5	0.0	0.0	0.1	0.0	0.0
73-74	0.1	46.4	33.9	36.3	31.6	0.0	34.8	37.0	39.4	24.0	0.0	0.9	1.7	4.5	0.8
75-76	5.4	35.4	34.5	30.1	35.5	0.9	44.5	47.5	39.6	45.9	0.0	48.9	13.1	62.6	66.7
77-78	94.2	10.5	7.7	12.9	25.3	35.5	18.8	5.8	15.3	29.2	0.0	46.0	80.8	32.2	31.8
>=79	0.3	0.0	0.0	0.6	0.3	63.7	0.6	0.0	0.4	0.4	100.0	4.2	4.3	0.7	0.7
VAV(FOAF)Econ$_T$															
<=70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71-72	0.0	9.4	25.9	22.5	8.3	0.0	1.4	11.6	6.0	0.6	0.0	0.0	0.1	0.0	0.0
73-74	0.2	46.3	33.7	35.7	32.0	0.0	36.9	36.8	40.4	25.4	0.0	1.1	1.9	5.0	1.0
75-76	8.1	34.6	32.7	29.0	37.5	1.2	43.1	45.8	38.1	47.6	0.0	49.1	13.1	62.2	66.9
77-78	91.5	9.7	7.7	12.3	21.9	47.3	18.1	5.8	15.1	26.0	1.2	45.6	80.5	32.2	31.4
>=79	0.3	0.0	0.0	0.6	0.4	51.5	0.6	0.0	0.4	0.4	98.8	4.2	4.2	0.7	0.7
VAV(FOAF)Econ$_E$															
<=70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
71-72	0.0	9.4	25.9	22.6	8.3	0.0	1.5	11.6	6.1	0.6	0.0	0.0	0.1	0.0	0.0
73-74	0.2	46.4	33.7	35.5	32.0	0.0	37.1	37.0	40.6	25.5	0.0	1.1	1.9	5.0	1.0
75-76	8.1	34.7	32.7	29.0	37.8	1.2	43.0	45.6	37.9	47.6	0.0	49.1	13.4	62.2	67.3
77-78	91.5	9.5	7.7	12.2	21.6	48.9	17.9	5.8	14.9	25.9	1.2	45.6	80.3	32.0	31.0
>=79	0.3	0.0	0.0	0.6	0.3	49.9	0.6	0.0	0.4	0.4	98.8	4.1	4.2	0.7	0.7

Exhibit 9 (Cont'd)
Percent of Occupied Hours with Specified Indoor Air Temperatures by Zone

System and Temperature	Minneapolis, MN					Washington, DC					Miami, FL				
	Core	E	N	W	S	Core	E	N	W	S	Core	E	N	W	S
VAV(COA)															
<=70	0.0	2.2	11.7	3.4	1.7	0.0	0.4	8.9	1.7	0.5	0.0	0.0	0.3	0.0	0.0
71-72	1.6	91.0	88.3	91.0	79.8	0.3	90.0	91.0	93.4	82.5	0.0	72.9	29.3	91.3	88.8
73-74	1.9	4.7	0.0	2.9	9.0	0.7	4.7	0.0	3.0	6.8	0.0	12.0	22.0	4.3	6.6
75-76	9.5	1.8	0.0	1.9	7.1	3.7	3.8	0.0	1.3	7.1	0.0	9.1	28.2	3.2	3.6
77-78	85.9	0.3	0.0	0.8	2.4	90.8	1.1	0.0	0.6	3.1	99.9	5.7	20.1	1.1	1.0
>=79	1.1	0.0	0.0	0.0	0.0	4.5	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0
VAV(COA)Econ$_T$															
<=70	0.0	9.7	19.5	12.1	5.8	0.0	4.1	21.7	15.7	6.3	0.0	0.2	0.7	2.4	0.5
71-72	1.6	84.0	80.5	82.4	75.9	0.3	86.4	78.2	79.5	77.1	0.0	72.7	28.9	89.0	88.3
73-74	1.9	4.4	0.0	2.9	9.1	0.7	4.9	0.0	2.9	7.0	0.0	12.0	22.0	4.3	6.6
75-76	9.9	1.6	0.0	1.8	7.1	4.0	3.5	0.0	1.3	6.9	0.0	9.3	28.2	3.2	3.5
77-78	85.6	0.3	0.0	0.8	2.2	90.7	1.0	0.0	0.6	2.7	99.9	5.7	20.1	1.1	1.0
>=79	1.0	0.0	0.0	0.0	0.0	4.4	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0
VAV(COA)Econ$_E$															
<=70	0.0	9.7	19.5	12.2	5.8	0.0	4.1	21.7	15.7	6.3	0.0	0.2	0.8	2.4	0.4
71-72	1.6	84.0	80.5	82.4	76.0	0.3	86.6	78.3	79.5	77.2	0.0	72.8	28.9	89.0	88.4
73-74	1.9	4.5	0.0	2.8	9.1	0.7	4.8	0.0	2.9	6.9	0.0	12.0	21.9	4.3	6.6
75-76	9.9	1.5	0.0	1.7	7.0	4.0	3.2	0.0	1.3	7.0	0.0	9.2	28.2	3.2	3.5
77-78	85.6	0.3	0.0	0.8	2.2	91.0	1.1	0.0	0.6	2.7	99.9	5.6	20.1	1.1	1.1
>=79	1.0	0.0	0.0	0.0	0.0	4.0	0.1	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0

Exhibit 10
Percent of Occupied Hours with Specified Return Air Relative Humidity

System and Climate	Relative Humidity					
	<20%	21-29%	30-50%	51-60%	61-70%	>70%
CV(FOAF)						
Minneapolis, MN	41.3	16.8	41.9			
Washington, DC	26.0	15.4	58.5	0.1		
Miami, FL	1.0	1.8	96.2	1.1		
CV(FOAF) $Econ_T$						
Minneapolis, MN	50.4	10.5	38.6	0.5		
Washington, DC	31.5	11.9	54.8	1.6	0.1	
Miami, FL	1.6	1.4	95.5	1.4	0.1	
CV(FOAF) $Econ_E$						
Minneapolis, MN	48.6	11.4	37.5	2.4		
Washington, DC	31.8	12.3	51.3	4.2	0.4	
Miami, FL	1.6	1.4	93.0	3.9	0.1	

Exhibit 10 (Cont'd)
Percent of Occupied Hours with Specified Return Air Relative Humidity

System and Climate	Relative Humidity					
	<20%	21-29%	30-50%	51-60%	61-70%	>70%
VAV(FOAF)						
Minneapolis, MN	37.6	21.6	40.8			
Washington, DC	26.1	17.5	56.4			
Miami, FL	1.3	2.0	96.7			
VAV(FOAF) $Econ_T$						
Minneapolis, MN	54.3	12.7	33.0			
Washington, DC	36.1	11.9	52.0			
Miami, FL	2.1	2.1	95.8			
VAV(FOAF) $Econ_E$						
Minneapolis, MN	52.5	15.1	32.3			
Washington, DC	37.0	13.8	49.3			
Miami, FL	2.3	3.3	94.5			
VAV(COA)						
Minneapolis, MN	50.8	14.0	35.1			
Washington, DC	32.1	14.6	53.3			
Miami, FL	1.7	2.0	96.2			
VAV(COA) $Econ_T$						
Minneapolis, MN	54.6	13.3	32.1			
Washington, DC	36.3	12.8	50.9			
Miami, FL	2.2	2.4	95.4			
VAV(COA) $Econ_E$						
Minneapolis, MN	52.5	15.2	32.2			
Washington, DC	37.0	13.9	49.2			
Miami, FL	2.3	3.2	94.5			

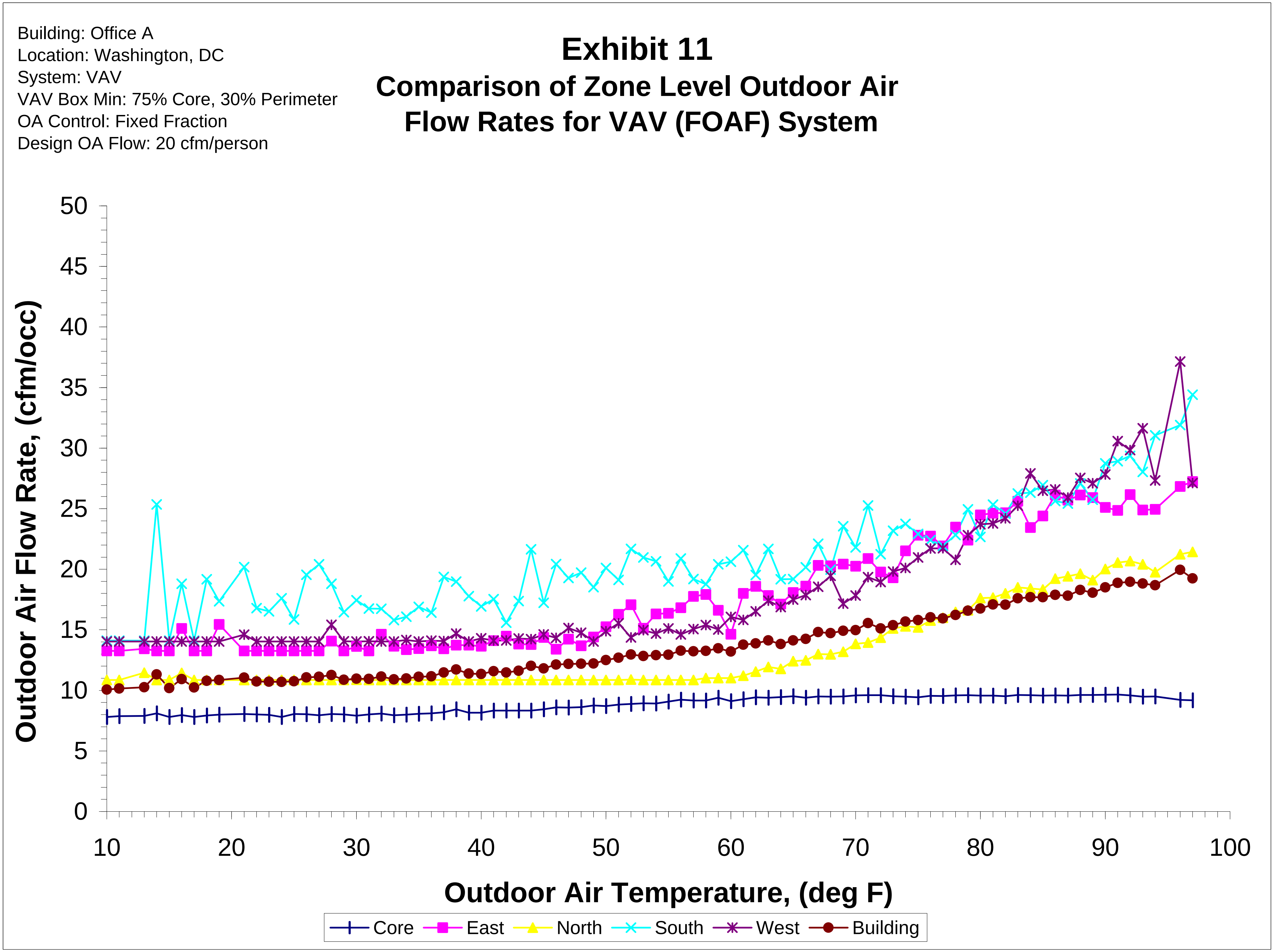
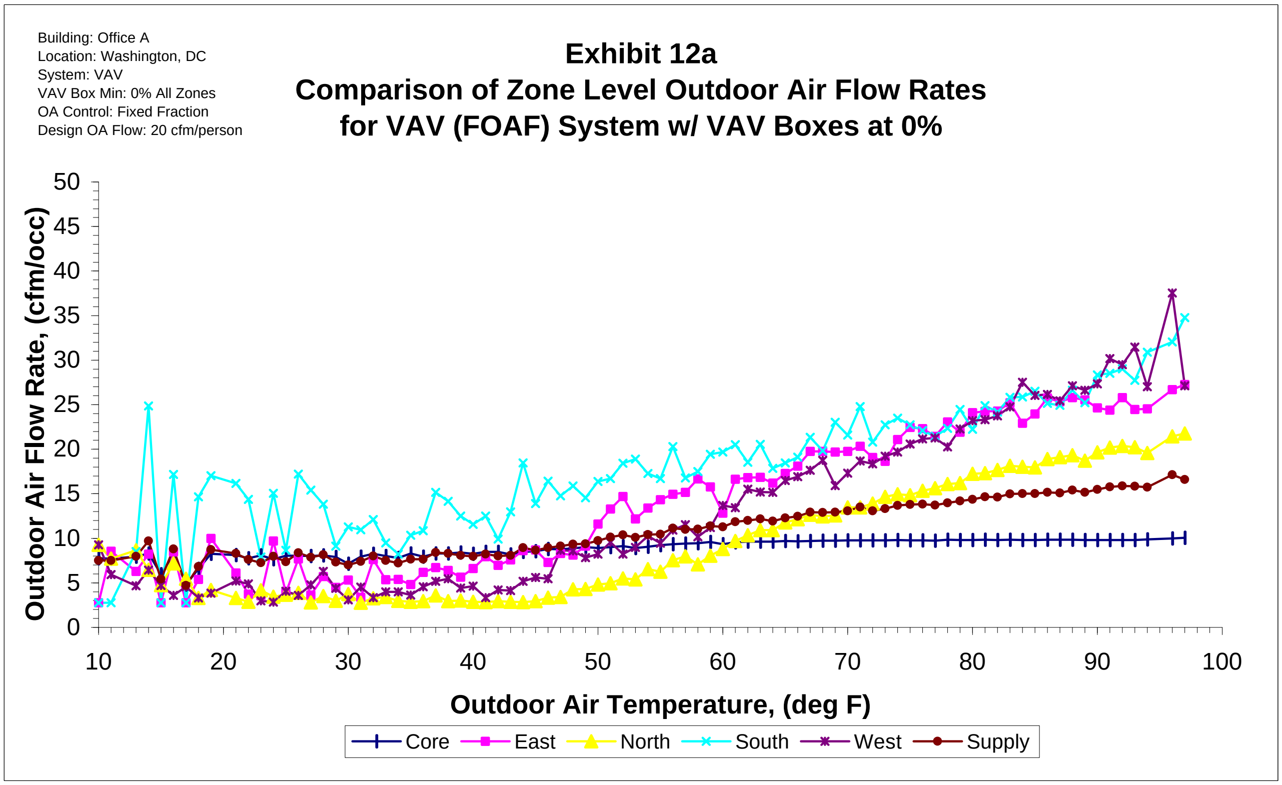

Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 75% Core, 30% Perimeter
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 11
Comparison of Zone Level Outdoor Air Flow Rates for VAV (FOAF) System
Outdoor Air Flow Rate, (cfm/occ)
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Building

Exhibit 12


Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 0% All Zones
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 12a
Comparison of Zone Level Outdoor Air Flow Rates
for VAV (FOAF) System w/ VAV Boxes at 0%
Outdoor Air Flow Rate, (cfm/occ)
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Supply

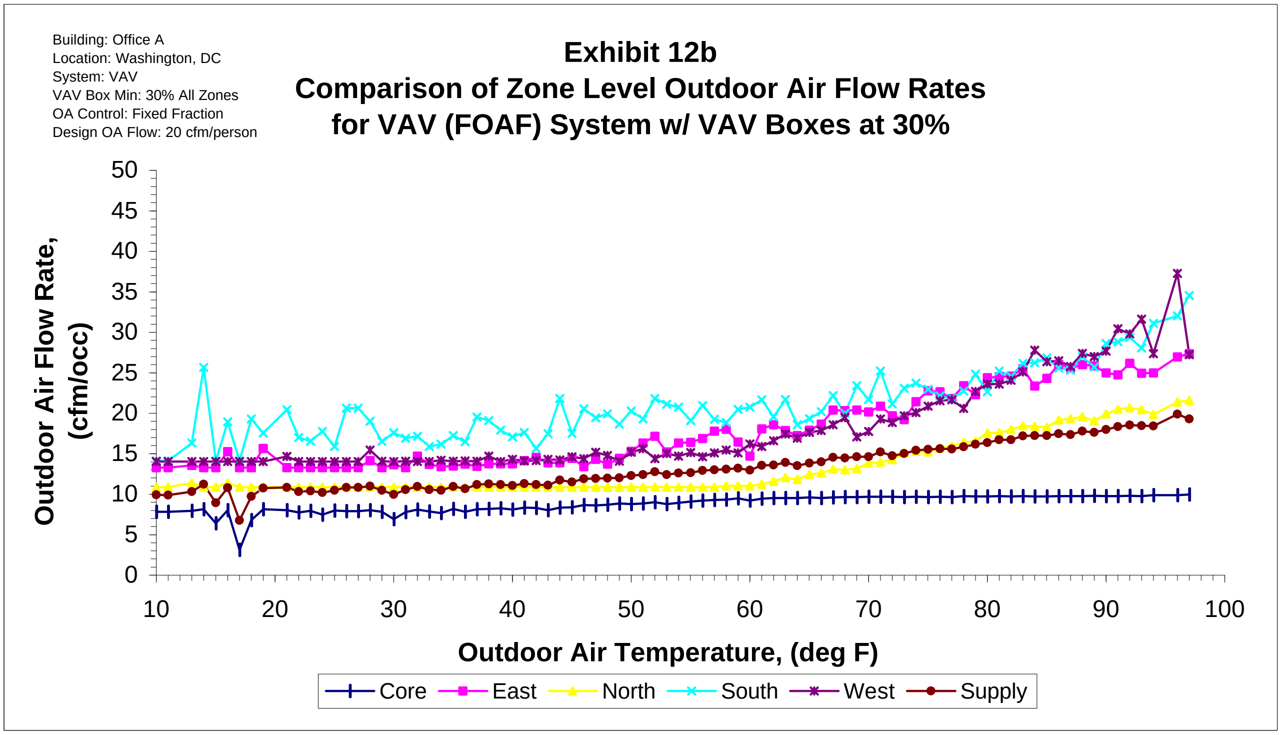
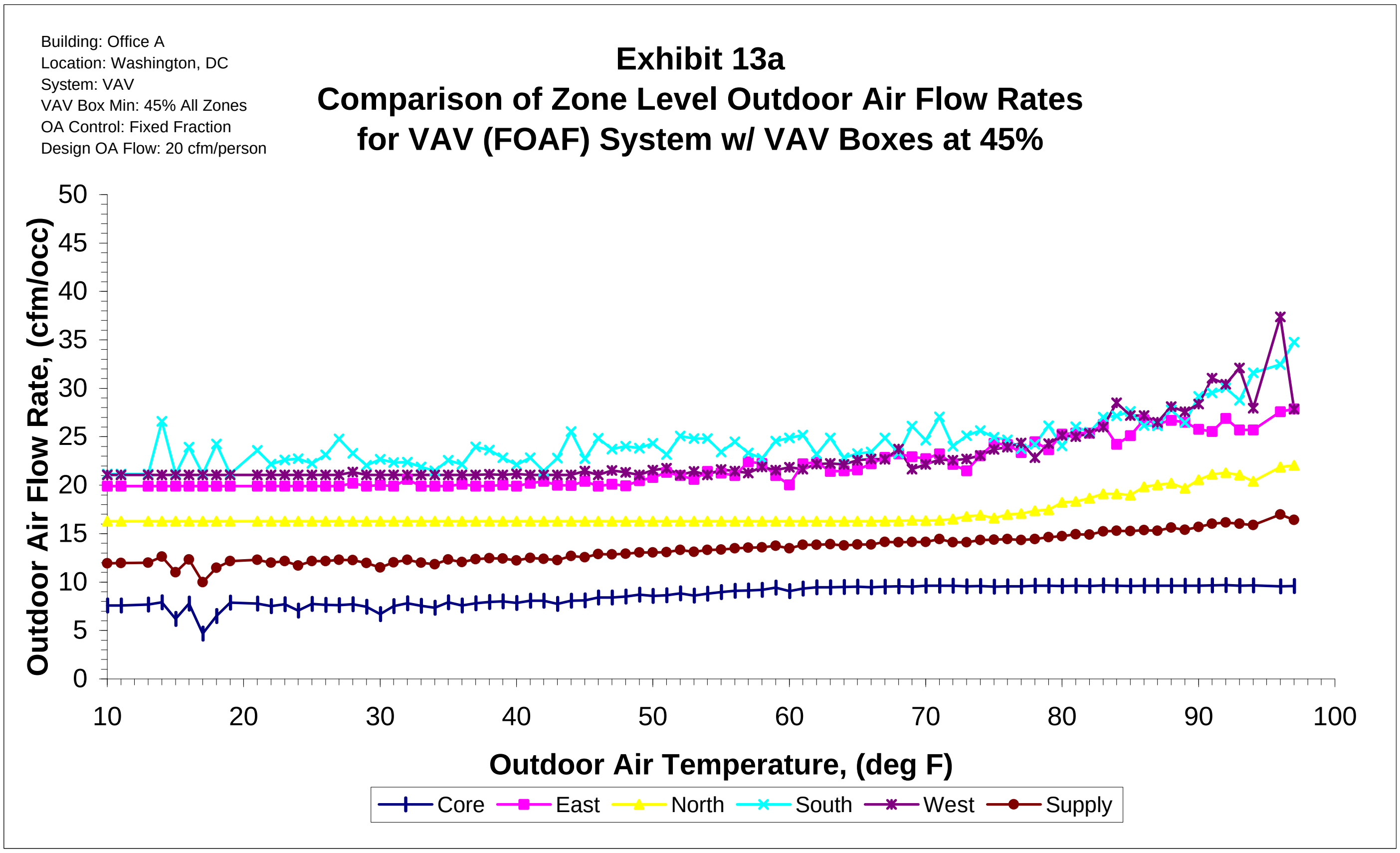
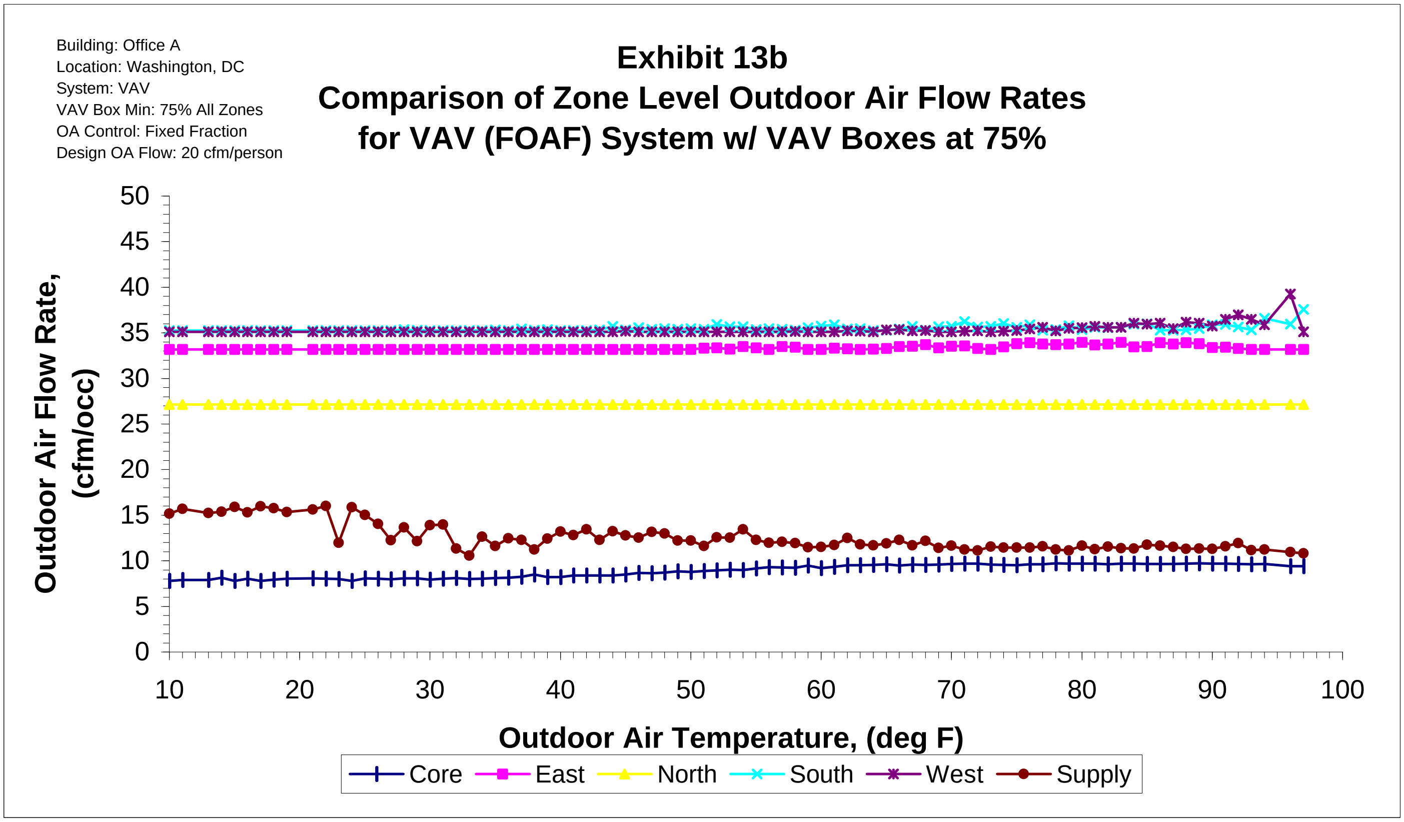

Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 30% All Zones
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 12b
Comparison of Zone Level Outdoor Air Flow Rates
for VAV (FOAF) System w/ VAV Boxes at 30%
Outdoor Air Flow Rate, (cfm/occ)
0
5
10
15
20
25
30
35
40
45
50
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Supply

Exhibit 13



Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 45% All Zones
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 13a
Comparison of Zone Level Outdoor Air Flow Rates
for VAV (FOAF) System w/ VAV Boxes at 45%
Outdoor Air Flow Rate, (cfm/occ)
50
45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Supply



Building: Office A
Location: Washington, DC
System: VAV
VAV Box Min: 75% All Zones
OA Control: Fixed Fraction
Design OA Flow: 20 cfm/person
Exhibit 13b
Comparison of Zone Level Outdoor Air Flow Rates
for VAV (FOAF) System w/ VAV Boxes at 75%
Outdoor Air Flow Rate, (cfm/occ)
50
45
40
35
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
Outdoor Air Temperature, (deg F)
Core
East
North
South
West
Supply

Exhibit 14
Occurance of Zone Ootdoor Air Flow Rates for Single and Dual Air Handler Systems with Fixed Outdoor Air Fraction Control Strategy
(Percent of Occupied Hours)

Climate and Zone	**VAV(FOAF)**					**VAV(FOAF) / Dual AHU**				
	OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)				
	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20
Minneapois, MN										
Core	3.2	96.8				0.1	0.5	5.8	67.0	26.5
East				68.3	31.7		68.1	21.9	6.2	3.7
North		61.8	20.5	16.7	1.0	61.0	37.9	1.1		
West			68.2	13.1	18.6		81.4	12.6	5.7	0.4
South			49.9	9.9	40.2		60.0	29.7	9.7	0.6
Washington, DC										
Core	0.7	99.3						0.3	2.0	97.7
East			46.4	15.3	38.3		64.5	27.4	7.5	0.5
North			69.4	24.4	6.2		96.1	3.9		
West			54.2	15.0	30.8		71.1	19.7	7.7	1.5
South			35.2	10.7	54.1		47.8	37.8	13.1	1.4
Miami, FL										
Core		73.3	26.7							100.0
East			3.2	9.4	87.4		14.2	50.0	22.7	13.1
North		5.8	24.1	43.3	26.7	5.5	73.2	21.3		
West			11.6	23.3	65.1		37.1	51.7	10.5	0.7
South				13.5	86.5		14.3	55.7	22.0	7.9

Exhibit 14 (Cont'd)
Occurance of Zone Ootdoor Air Flow Rates for Single and Dual Air Handler Systems
with Constant Outdoor Air Control Strategies
(Percent of Occupied Hours)

Climate and Zone	**VAV(COA)**					**VAV(COA) / Dual AHU**				
	OA Flow Rate Achieved (cfm/person)					OA Flow Rate Achieved (cfm/person)				
	<=5	6-10	11-15	16-19	>=20	<=5	6-10	11-15	16-19	>=20
Minneapolis, MN										
Core		0.1	48.7	51.2						100.0
East					100.0			0.2	11.4	88.4
North			0.7	22.5	76.8		1.4	42.3	55.8	0.5
West				0.5	99.5			11.0	23.5	65.5
South					100.0			1.6	7.5	90.9
Washington, DC										
Core		0.2	51.5	48.3						100.0
East					100.0			5.1	26.4	68.5
North				14.4	85.6			40.1	58.4	1.4
West					100.0			4.8	29.3	65.9
South					100.0			0.7	10.5	88.8
Miami, FL										
Core			80.7	19.3						100.0
East					100.0				12.2	87.8
North			5.5	7.5	86.9		3.9	49.4	46.7	
West				2.1	97.9			12.4	38.0	49.6
South					100.0			1.1	14.3	84.6

Exhibit 15
Summary of Annual HVAC Energy Use and Costs
for Single and Dual Air Handler Systems

Location / HVAC System	**Annual Energy Use**			**Annual HVAC Energy Costs**		
	Cooling (kBTU/sf)	Heating (kBTU/sf)	Total HVAC (kBTU/sf)	Cooling ($/sf)	Heating ($/sf)	Total HVAC ($/sf)
Minneapolis, MN						
VAV(FOAF)	20.0	20.9	50.6	0.49	0.10	0.79
VAV(FOAF) / Dual AHU	19.8	20.1	49.4	0.50	0.10	0.79
VAV(COA)	18.7	21.2	49.7	0.49	0.10	0.78
VAV(COA) / Dual AHU	19.1	20.3	48.9	0.50	0.10	0.79
Washington, DC						
VAV(FOAF)	21.0	9.8	39.5	0.52	0.05	0.74
VAV(FOAF) / Dual AHU	21.1	9.1	39.1	0.53	0.04	0.76
VAV(COA)	20.3	9.9	38.9	0.52	0.05	0.74
VAV(COA) / Dual AHU	20.8	9.2	38.9	0.53	0.05	0.76
Miami, FL						
VAV(FOAF)	28.5	0.5	38.3	0.62	0.00	0.81
VAV(FOAF) / Dual AHU	30.1	0.4	40.2	0.66	0.00	0.85
VAV(COA)	29.0	0.5	38.9	0.65	0.00	0.83
VAV(COA) / Dual AHU	30.2	0.4	40.3	0.66	0.00	0.86

Note 1: Total HVAC includes fan, heating, and cooling energy use.