Energy Cost and IAQ Performance of Ventilation Systems and Controls

Project Report # 5: **Peak Load Impacts of increasing Outdoor Air Flows from 5 to 20 cfm per Occupant in Large Office Buildings**

Indoor Environments Division
Office of Radiation and Indoor Air
Office of Air and Radiation
United States Environmental Protection Agency
Washington, D.C. 20460

January 2000

Energy Cost and IAQ Performance of Ventilation Systems and Controls

Project Report #5: Peak Load Impacts of increasing Outdoor Air Flows from 5 to 20 cfm per Occupant in Large Office Buildings

INTRODUCTION

Purpose and Scope of this Report

In order to achieve acceptable indoor air quality in office environments, ASHRAE Standard 62-1989 (and subsequently ASHRAE Standard 1999[1]) raised the recommended outdoor air ventilation rates from 5 cfm/occupant to 20 cfm/occupant. This four-fold increase has raised a number of questions concerning the feasibility and cost of implementing this standard.

A companion paper (Project Report # 4) quantifies the energy and energy cost impact of raising outdoor air ventilation rates in office buildings. That report suggests that raising outdoor air flow rates from 5 to 20 cfm/occupant only modestly changes energy costs by $0.02 - $0.06 per square foot in most cases. However, in extreme cases, energy costs were reduced as much as $0.02 per square foot, and increased by as much as $0.19 per square foot. High occupant density and extended operating hours had the most profound effects on the energy cost impact.

The purpose of this report is to examine the peak load impacts which occur when outdoor air flow rates are raised. This issue is important for both new and existing buildings. First, downsizing is an important feature of many energy conscious designs and retrofit strategies. This report sheds light on the extent to which downsizing is possible when buildings operate at elevated outdoor air flow rates. Second, owners of existing buildings which may have been designed to operate at relatively low outdoor air flow rates are being asked to raise these rates in order to improve indoor air quality. This report also addresses the extent to which such increases are feasible for these buildings, and identifies situations in which serious problems may occur if capacity issues are not properly addressed.

---

[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.

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. It is hoped that this project will contribute to the body of new data needed by professionals and practitioners who design and operate ventilation systems as they attempt to reduce costs and 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 of various ventilation systems and control strategies. Constant volume (CV) and variable air volume (VAV) systems in different buildings and 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:

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 BUILDINGS AND VENTILATION SYSTEMS MODELED

A large 12 story office building (Building A), along with 13 additional parametric variations (Buildings B-N) were modeled in three different climates representing cold (Minneapolis), temperate (Washington D.C., and hot/humid (Miami) climate zones. All buildings have 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, and a single duct variable volume (VAV) system with reheat were modeled using alternative outdoor air control strategies. Constant volume systems control the thermal conditions in the space by altering the temperature of a constant volume of supply air, while VAV systems alter the supply air volume while maintaining a constant supply air temperature. The building and HVAC parameters used in this analysis are described in Exhibit 1.

The basic outdoor air control strategy which was modeled for both CV and VAV systems is one that provides the design outdoor air flow during all operating conditions. To this basic strategy, a temperature air-side economizer strategy is also presented. To avoid humidity problems, the economizer is shut off at outdoor temperatures above 65^{o}F. The outdoor air flow rate reverts to its base level (5 or 20 cfm per occupant) when the economizer is in the "off" mode.

A more detailed description of all the buildings and ventilation systems modeled in this project is provided in Report #1.

APPROACH

The CV and VAV systems were each modeled for the entire year for each HVAC system in each of the three climates using 5 cfm and 20 cfm of outdoor air per occupant. From the data, the peak hourly load on the heating coil, cooling coil, and preheat coil were identified. Comparisons were then made between the two runs (5 cfm and 20 cfm per occupant) to determine the impact of an increased outdoor air flow on these peak loads.

RESULTS

Exhibits 2 and 3 presents the peak load impacts of raising outdoor air flow rates in CV systems (with and without economizers) in each of the three climates. Exhibits 4 and 5 presents the same data for VAV systems.

Peak Cooling Loads

Peak Coiling Loads at 5cfm Per Occupant

Peak cooling loads for CV and VAV systems were similar, except that CV systems experienced peak cooling loads which were generally 5-10% higher in all climates compared to VAV systems.

A low efficiency shell and a high perimeter to core ratio raised the peak cooling load, since these buildings are most affected by outdoor climate conditions. Buildings with a high exhaust rate experienced a higher peak cooling load because they have a higher flow of replacement air which, during the heat of the summer, will raise the peak cooling load. Similarly, buildings which operate over 24 hours tend to had higher peak cooling loads because there are a larger number of hours where the peak may occur. The highest peak cooling loads were experience by the high occupant density building. Occupants generate heat which increases the demand for cooling, so that the peak cooling load rises as occupant density rises. Economizers do not affect peak cooling loads because when the peak occurs, the economizer is shut off. In addition, the peak cooling load is not predictably affected by climate. The peak cooling load in Minneapolis, for example, was not much different than the peak cooling load in Miami or Washington, D.C. even though the overall weather patterns are substantially different.

Impact of Higher Outdoor Air Flow Rates on Peak Cooling Load

Raising outdoor air flow rates from 5 cfm to 20 cfm per occupant typically increased peak cooling loads by 15%-25% with the highest increases in the Miami climate. CV and VAV systems had comparable increases in peak cooling load. Economizers made no difference, since the economizer was not operating when the peak cooling load occurs.

The one notable exception is that occupant density had a dramatic influence, increasing the peak cooling load impact to 41% for both CV and VAV systems in Miami, and approximately 30% in Washington, D.C. and Minneapolis. The dramatic effect that occupant density had on the impact on peak cooling loads from increased outdoor air flow rates raises potentially serious issues concerning the viability of raising outdoor air flow in very high density buildings such as education buildings, auditoriums, and theaters. These issues are explored in detail in a companion report (Project Report # 6).

Peak Heating Loads

Peak Heating Loads at 5 cfm Per Occupant

Unlike peak cooling loads that were not significantly affected by outdoor climate, peak heating loads were significantly affected by outdoor climate, especially for CV systems. For example, the peak heating load for the CV system of the base building in Miami was only 191 kBTU/h while it was 6,649 kBTU/h for the same building in Minneapolis. The effect of climate on peak heating loads for VAV systems was much less dramatic than for CV systems because the VAV system modeled here uses a zone reheat system, which heats the supply air at the VAV box after it has been cooled. The heatng coil load is therefore less dependent on outdoor weather conditions. Thus, for the VAV system, the same building experienced peak heating loads of 1,940 kBTU/h in Miami and 6,131 kBTU/h in Minneapolis.

In contrast to the cooling coil, economizers significantly increased the peak load on the heating coil, though this is true only for the CV systems. For example, the peak heating coil load for the CV system in the base building in Washington, D.C. without economizer was 2,572 kBTU/h. Adding an economizer increased this to 3936 k BTU/h. This is because the economizer increases the flow of outdoor air in the winter to take advantage of free cooling. This increased the heating requirement in zones requiring heat. In VAV systems, the economizer did not affect the peak heating load because heating needs are accommodated by reheating 55^{o}F air at the VAV box, and this is not affected by an economizer.

As expected, buildings with low shell efficiency and high perimeter to core ratios experienced higher peak heating loads than buildings with high shell efficiency and low perimeter to core ratios.

Impact of Higher Outdoor Air Flow Rates on Peak Heating Coil Loads

Raising the outdoor air flow rate from 5 cfm to 20 cfm per occupant typically raised the peak heating coil load by 5% - 20%**,** but sometimes this increase was as high as 40-45%. The most important feature which can drive the heating coil impact up appears to be high occupant density. However, low perimeter to core ratios and high efficiency shell resulted in high heating coil impacts. The absolute impact of higher outdoor flow rates in Miami was small, but it was sometimes proportionally high because the base peak heating coil loads were generally low.

The data present some odd results which are not easily predicted or explained. For example, in some buildings with CV systems, the peak heating load impact was reduced. An examination of the data reveals that the peak typically occurred at start-up. Since the system only occasionally cycles on at night, the indoor climate conditions at start up are highly dependent on when the system was last on before start-up. Raising the outdoor air flow rate from 5 to 20 cfm per occupant could affect the on/off cycle at night and therefore the indoor climate conditions at start-up, and this could present counterintuitive results on the peak heating coil. For example, some CV systems without economizers in Miami experienced a decrease in peak heating coil load when outdoor air flow rates were increased.

Peak Preheat Coil Loads

Peak Preheat Coil Loads at 5 cfm Per Occupant

The preheat coil for both CV and VAV systems in all buildings in all climates experienced no load when outdoor flow rates were at 5 cfm per occupant.

Impact of Higher Outdoor Air Flow Rates on the Preheat Coil Load

Even when the outdoor air flow rates are raised from 5 cfm to 20 cfm per occupants, none of the CV systems experienced a preheat coil load in any climate. This is because the preheat coil loads only occur when the mixed air temperature is below 45^{o}F. Since return air is at or above room air temperature, the mixed air temperature can only fall below 45°F if the outdoor air temperature is cold ***and*** the outdoor air fraction is high. Since CV systems have high winter supply air flow rates relative to VAV systems, the outdoor air fraction of the CV systems was evidently not high enough to trigger the need for preheat coils, even in the cold climate of Minneapolis.

However, VAV systems have much lower outdoor air fractions, so that in almost every VAV building in the Minneapolis climate, the system experienced a preheat coil load when the outdoor air flow rate was raised to 20 cfm per occupant. The loads which typically appeared at 20 cfm per occupant ranged from 700 to 1500 kBTU/h. However, both the medium and high occupant density building were above this range, resulting in loads of 2700 and 5800 kBTU/h respectively. Economizers made no meaningful difference in peak preheat coil load impact.

In general, the preheat peak loads experienced are moderate and may well fall within the excess capacity range of existing systems or within the safety factor of most new system designs. However, many existing buildings do not have preheat coils. Raising the outdoor air flow rate to 20 cfm in these building, even in temperate climates, runs the risk of damaging the coil, particularly for medium or high occupant density buildings, or buildings that operate with extended operating hours. This is an especially high risk for cold climates, though buildings in cold climates are more likely to have some preheat coil capacity.

SUMMARY AND CONCLUSIONS

With the exception of very low occupant density buildings, every HVAC system in every building in every climate experienced a large peak load increase in one of the three coil systems.

Because many buildings have excess capacity precisely in order to avoid unexpected problems, this analysis may overstate the potential problem in many buildings. However, in individual cases, this analysis suggests that it would be extremely unwise for owners of existing buildings to raise outdoor air flow rates without first carefully performing a load analysis.

Occupant density was the single most important factor in determining the increase in peak coil loads when outdoor air flow rates are increased. This suggests that buildings with exceptionally high occupant densities, such as education buildings, auditoriums, or theaters may have significant capacity issues associated with high outdoor air flow rates. These issues are examined in detail in a companion report (Project Report #6).

Buildings that were built with energy efficiency in mind may have the least excess capacity and therefore may have the greatest difficulty in raising outdoor air flow rates to meet current ASHRAE standards. In addition, this report suggests that downsizing as an energy conservation strategy ought to be judiciously applied, taking into account the increased capacity needed to accommodate outdoor air flow rates consistent with indoor air quality.

BIBLIOGRAPHY

Harriman, L. G., Plager, D., Kosar, D. 1997. Dehumidification and cooling loads from ventilation air. *ASHRAE Journal* 39(11): 37-45

Hathaway, A. 1995. The link between lighting and cooling. *Engineered Systems Maintenance* July 1995: 18-19.

Meckler, M. 1994. Desiccant-assisted air conditioner improves IAQ and comfort. *Heating/Piping/Air Conditioning* October 1994: 75-84.

Rengarajan, K., Shirey, D. B., Raustad, R. A. 1996. Cost-effective HVAC technologies to meet ASHRAE Standard 62-1989 in hot and humid climates. *ASHRAE Transactions* 102(1): 3949.

Shirey, D. B., Rengarajan, K. 1996. Impacts of ASHRAE 62-1989 on small Florida offices. *ASHRAE Transactions* 102(1): 3948

Exhibit 1
Building and HVAC Characteristics

Building Configuration	Window R-Value	Window Shading Coeffic.	Roof Insulation	Infiltration Rate	Chiller COP	Boiler Effic. (%)	Occup. Density (Occup/ 1000 SF)	P/C Ratio	Exhaust Flow Rate (cfm)	Daily Operating Hours (hrs/day)
A. Base Case	2.0	0.8	10	0.5	3.5	70	7	0.5	750	12
B. High Effic. Shell	3.0	0.6	20	0.75	3.5	70	7	0.5	750	12
C. Low Effic. Shell	1.0	1.0	5	0.25	3.5	70	7	0.5	750	12
D. High Effic. HVAC	2.0	0.8	10	0.5	4.5	80	7	0.5	750	12
E. Low Effic. HVAC	2.0	0.8	10	0.5	2.5	60	7	0.5	750	12
F. High Occup.Density	2.0	0.8	10	0.5	3.5	70	15	0.5	750	12
G. Med Occup. Density	2.0	0.8	10	0.5	3.5	70	10	0.5	750	12
H. High P/C Ratio	2.0	0.8	10	0.5	3.5	70	7	0.8	750	12
I. Low P/C Ratio	2.0	0.8	10	0.5	3.5	70	7	0.3	750	12
J. High Exhaust Rate	2.0	0.8	10	0.5	3.5	70	7	0.5	1500	12
K. Low Occup Density	2.0	0.8	10	0.5	3.5	70	5	0.5	750	12
L. Very Low Occ. Density	2.0	0.8	10	0.5	3.5	70	3	0.5	750	12
M. Extended Oper. Hours	2.0	0.8	10	0.5	3.5	70	7	0.5	750	18
N. 24 Hour Operation	2.0	0.8	10	0.5	3.5	70	7	0.5	750	24

Exhibit 2

Changes in Peak Coil Load Due to Increased Outdoor Air Flow Rates From 5 to 20 cfm per Occupant: CV Systems without Economizers {CV(FOAF)}

	Miami, FL			Washington, DC			Minneapolis, MN		
Building Configuration	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)
A. Base Case @5	9258	191	0	9017	2572	0	9288	6649	0
Increase	1876	443		1752	1047		1421	649	
Percent Increase	20%	232%	None	19%	41%	None	15%	10%	None
B. High Eff. Shell @5	8662	37	0	8110	1023	0	8307	4298	0
Increase	1851	-12		1856	2000		1398	1864	
Percent Increase	21%	-31%	None	23%	196%	None	17%	43%	None
C. Low Eff. Shell @5	10482	1267	0	10368	5160	0	10361	8818	0
Increase	1845	133		1553	445		1442	71	
Percent Increase	18%	10%	None	15%	9%	None	14%	1%	None
D. High Eff. HVAC @5	9258	191	0	9017	2572	0	9296	6649	0
Increase	1876	443		1752	1047		1423	649	
Percent Increase	20%	232%	None	19%	41%	None	15%	10%	None
E. Low Eff. HVAC @5	9258	191	0	9017	2572	0	9296	6649	0
Increase	1876	443		1752	1047		1423	649	
Percent Increase	20%	232%	None	19%	41%	None	15%	10%	None
F. High P/C Ratio @5	10301	919	0	10277	4007	0	10414	8349	0
Increase	1812	-339		1521	763		1401	380	
Percent Increase	18%	-37%	None	15%	19%	None	13%	5%	None
G. Low P/C Ratio @5	8056	55	0	7940	1452	0	7899	4427	0
Increase	1995	206		1668	1305		1439	1217	
Percent Increase	25%	377%	None	21%	90%	None	18%	28%	None
H. High Exhaust @5	9817	305	0	9465	2886	0	9727	6917	0
Increase	1317	330		1314	733		993	382	
Percent Increase	13%	108%	None	14%	25%	None	10%	6%	None
I. High Occ. Dens. @5	10775	129	0	10927	2923	0	10509	7059	0
Increase	4384	547		3522	1532		3206	1158	
Percent Increase	41%	424%	None	32%	52%	None	31%	16%	None
J. Medium Occ. Dens. @5	9741	168	0	9665	2803	0	9644	6777	0
Increase	2929	472		2465	1099		2192	666	
Percent Increase	30%	281%	None	26%	39%	None	23%	10%	None
K. Low Occ. Dens. @5	9034	221	0	8949	2704	0	9041	6643	0
Increase	1192	421		953	594		960	909	
Percent Increase	13%	190%	None	11%	22%	None	11%	14%	None
L. Very Low Occ. Dens. @5	8811	222	0	8893	2661	0	8786	6566	0
Increase	494	93		247	279		400	406	
Percent Increase	6%	42%	None	3%	10%	None	5%	6%	None
M. Extended Op. Hours @5	9066	810	0	9003	2679	0	8986	5975	0
Increase	1975	316		1572	1482		1490	588	
Percent Increase	22%	39%	None	17%	55%	None	17%	10%	None
N. 24 Hour Operation @5	9621	759	0	8903	3106	0	8896	6657	0
Increase	1331	353		1569	2186		1453	1992	
Percent Increase	14%	47%	None	18%	70%	None	16%	30%	None

Exhibit 3
Changes in Peak Coil Load Due to Increased Outdoor Air Flow Rates From 5 to 20 cfm per Occupant: VAV Systems without Economizers {VAV(COA)}

Building Configuration	Miami, FL			Washington, DC			Minneapolis, MN		
	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)
A. Base Case @5	8670	1940	0	8517	4638	0	8688	6131	0
Increase	1862			1659			1320	456	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
B. High Eff. Shell @5	8010	967	0	7855	3552	0	7966	4868	0
Increase	1881			1695	101		1303	479	745
Percent Increase	23%	None	None	22%	3%	None	16%	10%	Increase
C. Low Eff. Shell @5	9591	3066	0	9360	6168	0	9580	8795	0
Increase	1697			1621	345		1332	50	514
Percent Increase	18%	None	None	17%	6%	None	14%	1%	Increase
D. High Eff. HVAC @5	8670	1940	0	8517	4638	0	8688	6131	0
Increase	1862			1659			1320	456	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
E. Low Eff. HVAC @5	8670	1940	0	8517	4638	0	8688	6131	0
Increase	1862			1659			1320	456	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
F. High P/C Ratio @5	9567	2680	0	9672	5641	0	9666	7862	0
Increase	1759			1425			1298	613	382
Percent Increase	18%	None	None	15%	None	None	13%	8%	Increase
G. Low P/C Ratio @5	7551	1158	0	7476	3490	0	7427	4834	0
Increase	2029			1597	153		1390	515	864
Percent Increase	27%	None	None	21%	4%	None	19%	11%	Increase
H. High Exhaust @5	9238	1940	0	8971	4637	0	9106	6127	0
Increase	1293			1196			934	457	896
Percent Increase	14%	None	None	13%	None	None	10%	7%	Increase
I. High Occ. Dens. @5	10119	1981	0	10128	5598	0	9944	6314	0
Increase	4190	262		3290	979	1539	2899	899	5801
Percent Increase	41%	13%	None	32%	17%	Increase	29%	14%	Increase
J. Medium Occ. Dens. @5	9151	1981	0	9110	4876	0	9098	6203	0
Increase	2782	13		2081	423	451	1993	783	2743
Percent Increase	30%	1%	None	23%	9%	Increase	22%	13%	Increase
K. Low Occ. Dens. @5	8407	1938	0	8496	4576	0	8436	5900	0
Increase	1198			972			878	493	
Percent Increase	14%	None	None	11%	None	None	10%	8%	None
L. Very Low Occ. Dens. @5	8168	1936	0	8282	4550	0	8262	5859	0
Increase	503			407			368		
Percent Increase	6%	None	None	5%	None	None	4%	None	None
M. Extended Op. Hours @5	8363	2321	0	8433	4498	0	8389	6337	0
Increase	1772			1474	114	15	1273	547	1386
Percent Increase	21%	None	None	17%	3%	Increase	15%	9%	Increase
N. 24 Hour Operation @5	8249	2214	0	8336	4827	0	8228	6659	0
Increase	1725	64		1471	24	36	1265	618	1494
Percent Increase	21%	3%	None	18%	1%	Increase	15%	9%	Increase

Exhibit 4
Changes in Peak Coil Load Due to Increased Outdoor Air Flow Rates From 5 to 20 cfm per Occupant: CV Systems with Economizers {CV(FOAF)Econ}

Building Configuration	Miami, FL			Washington, DC			Minneapolis, MN		
	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)
A. Base Case @5	9258	3446	0	9017	3936	0	9288	6707	0
Increase	1876			1755	35		1421	623	
Percent Increase	20%	None	None	19%	1%	None	15%	9%	None
B. High Eff. Shell @5	8406	2715	0	8110	2786	0	8307	4326	0
Increase	2010			1855	246		1398	1839	
Percent Increase	24%	None	None	23%	9%	None	17%	43%	None
C. Low Eff. Shell @5	10482	3817	0	10368	5532	0	10361	8901	0
Increase	1845	30		1553	135		1442		
Percent Increase	18%	1%	None	15%	2%	None	14%	None	None
D. High Eff. HVAC @5	9258	3446	0	9017	3936	0	9296	6707	0
Increase	1876			1755	35		1423	623	
Percent Increase	20%	None	None	19%	1%	None	15%	9%	None
E. Low Eff. HVAC @5	9258	3446	0	9017	3936	0	9296	6707	0
Increase	1876			1755	35		1423	623	
Percent Increase	20%	None	None	19%	1%	None	15%	9%	None
F. High P/C Ratio @5	10301	4546	0	10277	5451	0	10414	8476	0
Increase	1812			1536	-61		1401	299	
Percent Increase	18%	None	None	15%	-1%	None	13%	4%	None
G. Low P/C Ratio @5	8056	1950	0	7940	2360	0	7899	4461	0
Increase	1995	22		1668	412		1439	1190	
Percent Increase	25%	1%	None	21%	17%	None	18%	27%	None
H. High Exhaust @5	9817	3446	0	9465	3949	0	9727	6967	0
Increase	1317			1317	32		993	364	
Percent Increase	13%	None	None	14%	1%	None	10%	5%	None
I. High Occ. Dens. @5	10775	3238	0	10927	3067	0	10509	7110	0
Increase	4384			3522	1407		3206	1261	
Percent Increase	41%	None	None	32%	46%	None	31%	18%	None
J. Medium Occ. Dens. @5	9741	3371	0	9665	3974	0	9644	6834	0
Increase	2929	-58		2445			2192	626	
Percent Increase	30%	-2%	None	25%	None	None	23%	9%	None
K. Low Occ. Dens. @5	9034	3580	0	8949	3996	0	9041	7006	0
Increase	1192			953			960	588	
Percent Increase	13%	None	None	11%	None	None	11%	8%	None
L. Very Low Occ. Dens. @5	8811	3155	0	8893	3940	0	8786	6952	0
Increase	494			248			400	276	
Percent Increase	6%	None	None	3%	None	None	5%	4%	None
M. Extended Op. Hours @5	9067	3232	0	9003	3575	0	8986	6031	0
Increase	1975			1572	591		1490	562	
Percent Increase	22%	None	None	17%	17%	None	17%	9%	None
N. 24 Hour Operation @5	9621	3056	0	8903	4528	0	8896	9783	0
Increase	1331			1569	2062		1453	1748	
Percent Increase	14%	None	None	18%	46%	None	16%	18%	None

Exhibit 5
Changes in Peak Coil Load Due to Increased Outdoor Air Flow Rates From 5 to 20 cfm per Occupant: VAV Systems with Economizers {VAV(COA)Econ}

	Miami, FL			Washington, DC			Minneapolis, MN		
Building Configuration	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)	Cooling (kBtu/H)	Heating (kBtu/H)	Preheat (kBtu/H)
A. Base Case @5	8670	1949	0	8517	4638	0	8688	6148	0
Increase	1862			1659			1336	444	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
B. High Eff. Shell @5	8010	967	0	7855	3552	0	7962	4868	0
Increase	1881			1694	101		1364	479	745
Percent Increase	23%	None	None	22%	3%	None	17%	10%	Increase
C. Low Eff. Shell @5	9591	3064	0	9360	6168	0	9580	8806	0
Increase	1697			1621	355		1331		514
Percent Increase	18%	None	None	17%	6%	None	14%	None	Increase
D. High Eff. HVAC @5	8670	1949	0	8517	4638	0	8688	6148	0
Increase	1862			1659			1336	444	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
E. Low Eff. HVAC @5	8670	1949	0	8517	4638	0	8688	6148	0
Increase	1862			1659			1336	444	897
Percent Increase	21%	None	None	19%	None	None	15%	7%	Increase
F. High P/C Ratio @5	9567	2691	0	9672	5641	0	9662	7875	0
Increase	1759			1425			1298	602	382
Percent Increase	18%	None	None	15%	None	None	13%	8%	Increase
G. Low P/C Ratio @5	7551	1082	0	7476	3490	0	7427	4834	0
Increase	2029	-17		1596	153		1390	515	864
Percent Increase	27%	-2%	None	21%	4%	None	19%	11%	Increase
H. High Exhaust @5	9238	1949	0	8971	4637	0	9106	6141	0
Increase	1293			1196			947	448	897
Percent Increase	14%	None	None	13%	None	None	10%	7%	Increase
I. High Occ. Dens. @5	10119	1984	0	10128	5598	0	9961	6325	0
Increase	4190	262		3290	979	1539	2903	888	5801
Percent Increase	41%	13%	None	32%	17%	Increase	29%	14%	Increase
J. Medium Occ. Dens. @5	9151	1956	0	9110	4876	0	9114	6218	0
Increase	2782			2082	423	451	1995	767	2743
Percent Increase	30%	None	None	23%	9%	Increase	22%	12%	Increase
K. Low Occ. Dens. @5	8407	1947	0	8496	4576	0	8436	5900	0
Increase	1198			972			878	493	
Percent Increase	14%	None	None	11%	None	None	10%	8%	None
L. Very Low Occ. Dens. @5	8168	1935	0	8282	4550	0	8262	5859	0
Increase	503			407			368		
Percent Increase	6%	None	None	5%	None	None	4%	None	None
M. Extended Op. Hours @5	8363	2331	0	8433	4500	0	8389	6337	0
Increase	1772			1474	121	18	1273	547	1386
Percent Increase	21%	None	None	17%	3%	Increase	15%	9%	Increase
N. 24 Hour Operation @5	8249	2344	0	8335	4921	0	8228	6659	0
Increase	1725			1472		37	1265	618	1494
Percent Increase	21%	None	None	18%	None	Increase	15%	9%	Increase