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Service Center and Computer Server Facility Indoor Air Quality and Comfort Report

Location: Champaign, Illinois

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Executive Summary for the Facility

This document is an example assessment report of indoor environmental quality (air quality and comfort conditions) for an actual service center and computer server facility located in central Illinois. The building is occupied during normal working hours with an average of 130 employees. The building is 25,000sqft and is all-electric powered.

Current efforts to conserve energy and lower utility bills without regard to employee productivity are shifting cost burdens from the bottom line of the maintenance department's budget to others as more employees must be hired to make up for lowered productivity and increased employee absenteeism. Maintaining comfortable and healthy indoor environments are not only nice, but provide a dollar benefit that is much greater than utility costs savings. As businesses seek to improve utility costs, it is very important that utility savings are not gained at the expense of employee well-being and productivity.

Carbon dioxide (CO2) levels, temperature, relative humidity, and total volatile organic compounds (VOCs) levels were measured throughout the facility for one week. CO2 levels were high throughout the workdays and are indicative of levels that impact employee productivity. Some elevated temperature levels were detected resulting in potential productivity loss due to non-optimal comfort conditions. Total VOC levels were normal indicating no abnormal generation of VOCs.

CO2 (Carbon Dioxide) Levels:

Exposure to high CO2 concentrations produce a variety of adverse health effects. These include headaches, dizziness, tiredness, and restlessness. In extremely high concentration environments, effects can lead to difficulty breathing, sweating, increased heart rate, elevated blood pressure, coma, asphyxia, and convulsions. Indirectly, high CO2 levels are indicative of higher concentrations of other pollutants and contagions that may increase employee absenteeism.

The example facility's air exceeds 1,000 ppm of CO2 from 9 am until 8 pm on weekdays resulting in reduced worker productivity (RWP). At current conditions, the RWP cost is estimated to be $25,060 per week (assumes 130 employees, $25/hour wage, 8 hour work day). A change in fresh air ventilation flow rates can reduce the workday CO2 average from 1,323 ppm to 891 ppm with *no increase in utility cost*. Improved fresh air ventilation scheduling can reduce RWP to an estimated $9,000 per week. RWP can be further reduced with DCV (Demand Control Ventilation) that actively monitors and adjusts fresh air flow as needed.

Comfort Conditions (temperature and relative humidity)

Indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance at work. The ideal temperature range to maximize worker productivity is from 71 to 75 deg F. Relative humidity can affect the incidence of respiratory infections and allergies. Relative humidity ranges of 30% to 60% are acceptable and minimize adverse health effects.

During workday measurement periods, the facility temperature and humidity were mostly comfortable. Two locations exhibited brief periods in which the ambient temperature exceeded 80 deg F. Improved temperature control in these locations can improve employee productivity due to comfort without significant impact on building utility cost. At current conditions, the estimated loss in worker productivity due to elevated temperature is estimated to be $370 per weekday (assumed 130 employees, $25/hour wage, 8 hour work day).

Total VOCs (Total Volatile Organic Compounds) Levels:

VOCs include both human-made and naturally occurring chemical compounds. Most scents or odors are VOCs, however, many VOCs at harmful concentrations are not detectable by humans. Some VOCs are dangerous to human health or cause harm to the environment. Harmful VOCs are typically not acutely toxic, but instead have compounding long-term health effects.

Total VOCs were found to be at reasonable levels throughout the facility at all times. No concentrated sources of VOC emission were found and average VOCs indicate a level expected relative to the human activity.

Recommendations

A ventilation schedule with elevated fresh air flow rates during workday hours (9 hours per day) of 2,200 cfm and a reduced fresh air flow rate as low as 220 cfm during non-working hours will keep CO2 concentrations below 1, 000 ppm throughout the day.

Utility Bill Impact to Improve Employee Productivity and Comfort

Power for the facility's computer servers dominate the building's utility usage. Current annual utility usage at the facility is 850 MWh per year. Improvements to the facility's fresh air ventilation flow rates will not increase the annual utility usage. Changes to fresh air ventilation flow rate do require a site survey and assessment of current ventilation and building conditioning system capabilities.

Background and Setup

Indoor environment quality impacts employee productivity with costs that are much greater than a building's utility cost. Appendix A, "Value of Comfort and Indoor Air Quality" provides background information and compares the value of employee productivity and utility costs relative to indoor temperatures and fresh air ventilation rates.

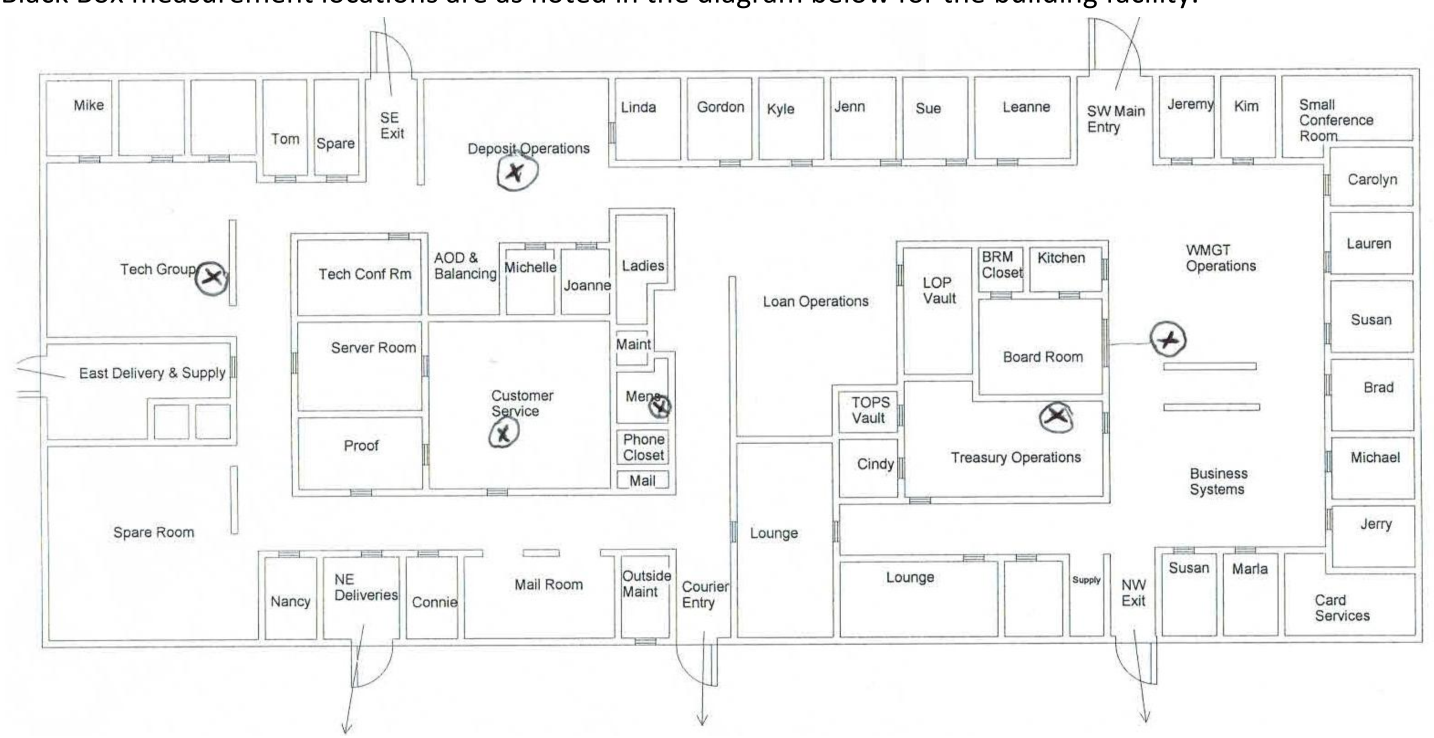
The service center and computer server building is a 25,000 square foot, single story building with 130 employees and a computer server facility. Building energy is dominated by server power and associated air conditioning requirements. Fresh air ventilation is based on a conventional fixed ventilation system without active control.

Build Equinox placed Black Box IAQ™s in six different locations within the building (see location diagram in Measurement Locations section). The Black Box IAQ contains temperature, humidity, CO_2 and VOC sensors and a micro-computer for continuously collecting data. The data is used to estimate employee productivity levels during the workday relative to utility cost.

Utility data supplied by building owner has been compared to a building energy simulation model. The simulation model allows energy impact due to variations in the building's ventilation schedule to be investigated. A transient indoor air quality model that predicts CO_2 concentration levels has been compared to the measured CO_2 data. The CO_2 model is then used to investigate variations in ventilation scheduling in order to determine methods for reducing CO_2 levels and increasing worker productivity capabilities.

Measurement Locations

Black Box measurement locations are as noted in the diagram below for the building facility.

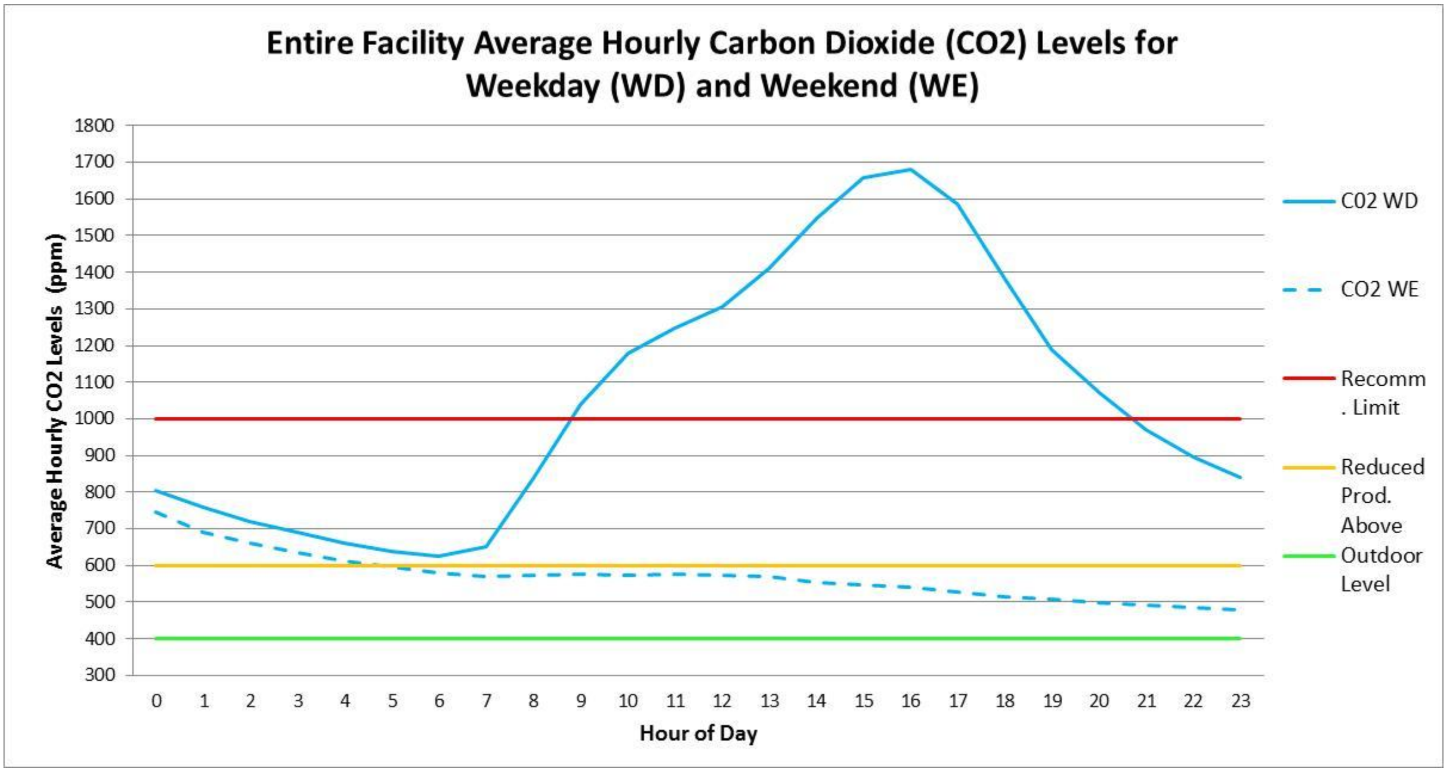


Carbon Dioxide Levels

Exposure to high CO2 concentrations can produce a variety of known health effects. These may include headaches, dizziness, tiredness, and restlessness. In extremely high concentration environments effects can lead to difficulty breathing, sweating, increased heart rate, elevated blood pressure, coma, asphyxia, and convulsions. At more moderate conditions, CO2 impacts cognition processes that direct affects creativity, productivity, and decision making abilities.

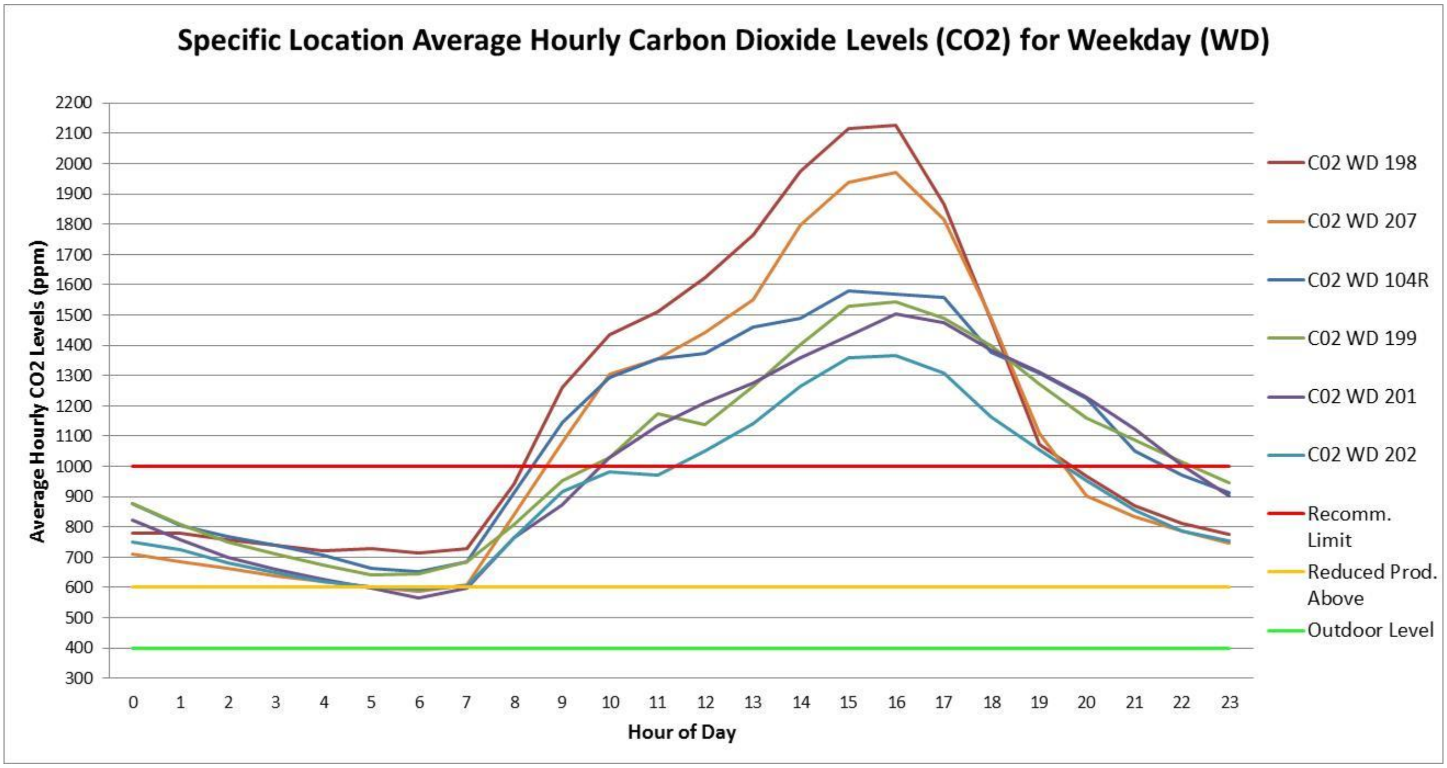
Hourly Building Average CO2 Levels

Average CO2 levels exceed 1,000 ppm starting at 9am during normal weekday working hours. Weekday CO2 concentrations fall back below 1,000 ppm at 8pm.



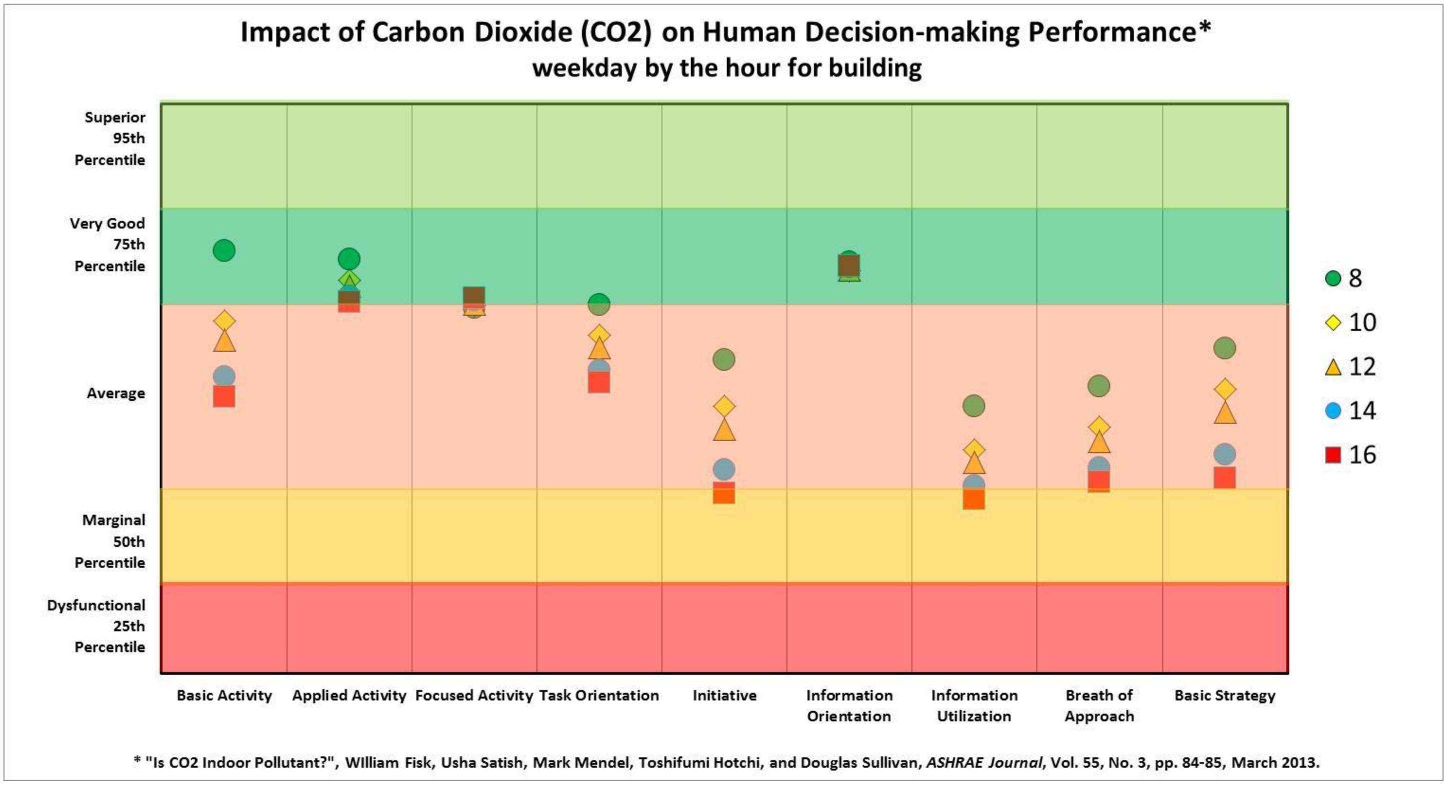
Hourly Weekday CO2 Concentration Levels by Location

Readings taken at the west end of the building, where the greatest number of employees reside, show the highest CO2 concentrations. Box 198 was located in the west end of the building (most populated) and Box 201 was located in the east end of the building (least populated). Box 202 was located in the men's room and shows low CO2 concentration due to the continuous ventilation.



CO2 Concentration Impact on Cognitive Performance for the Building Facility

The cognitive performance impact of CO2 concentration in the facility during the week at 8am, 10am, noon, 2pm and 4pm are shown in the chart below. Noticeable performance declines can be seen in the cognitive areas of *Basic Activity*, *Task Orientation* , *Initiative*, *Information Utilization*, *Breadth of Approach*, and *Basic Strategy*.



Nine areas of cognitive performance affected by CO2 have been investigated by Satish et al [3] and are described in the table below. Appendix A further describes worker productivity effects and presents a chart with cognitive performance relative to CO2 concentration.

Area	Description
Basic Activity	number of actions taken
Applied Activity	opportunistic actions
Focused Activity	strategic actions in a narrow endeavor
Task Orientation	focus on concurrent task demands
Initiative	development of new/creative activities
Information Search (or Orientation)	openness to and search for information
Information Usage (or Utilization)	ability to use information effectively
Breadth of Approach	flexibility in approach to the task
Basic Strategy	number of strategic actions

Satish used 600 ppm of CO2 as the baseline for his study. We assume this to be the best score for each category. Based on the average hourly CO2 levels for the entire building, we were able to calculate the average percent decline over all nine cognitive areas for each weekday hour (8am to noon and 1pm to 5pm).

Assuming 130 employees at an average wage of $25/hour for an eight hour work day, we can calculate loss productivity in dollars caused by CO_2 levels in excess of 600 ppm. *For example:*

At 2pm, the average hourly CO_2 concentration for the entire building is 1,548 ppm. At this CO_2 concentration level, the average decline in cognitive performance of the 9 cognitive areas is 25.3%. Assuming 130 employees at an average wage of $25/hour, the loss productivity is $822/hour (= $25/hour x 130 employees x 25.3% decline in cognitive performance).

Summing up the hourly productivity loss from elevated CO_2 concentrations yields a daily loss productivity of $5,060 or approximately *$1.3 million per year*. <u>Even if the loss productivity were 1/10th of the estimated value it would still represent over $130,000 per year in lost productivity, which is more than the total yearly building utility cost.</u>

Lost Productivity ($)	**Hour**	**Average CO2 concentration (ppm)**
$210	8	838.85
$390	9	1038.69
$510	10	1179.32
$570	11	1248.90
lunch hour	12	1306.32
$710	13	1409.90
$820	14	1547.60
$920	15	1658.24
$930	16	1680.28
$5,060		

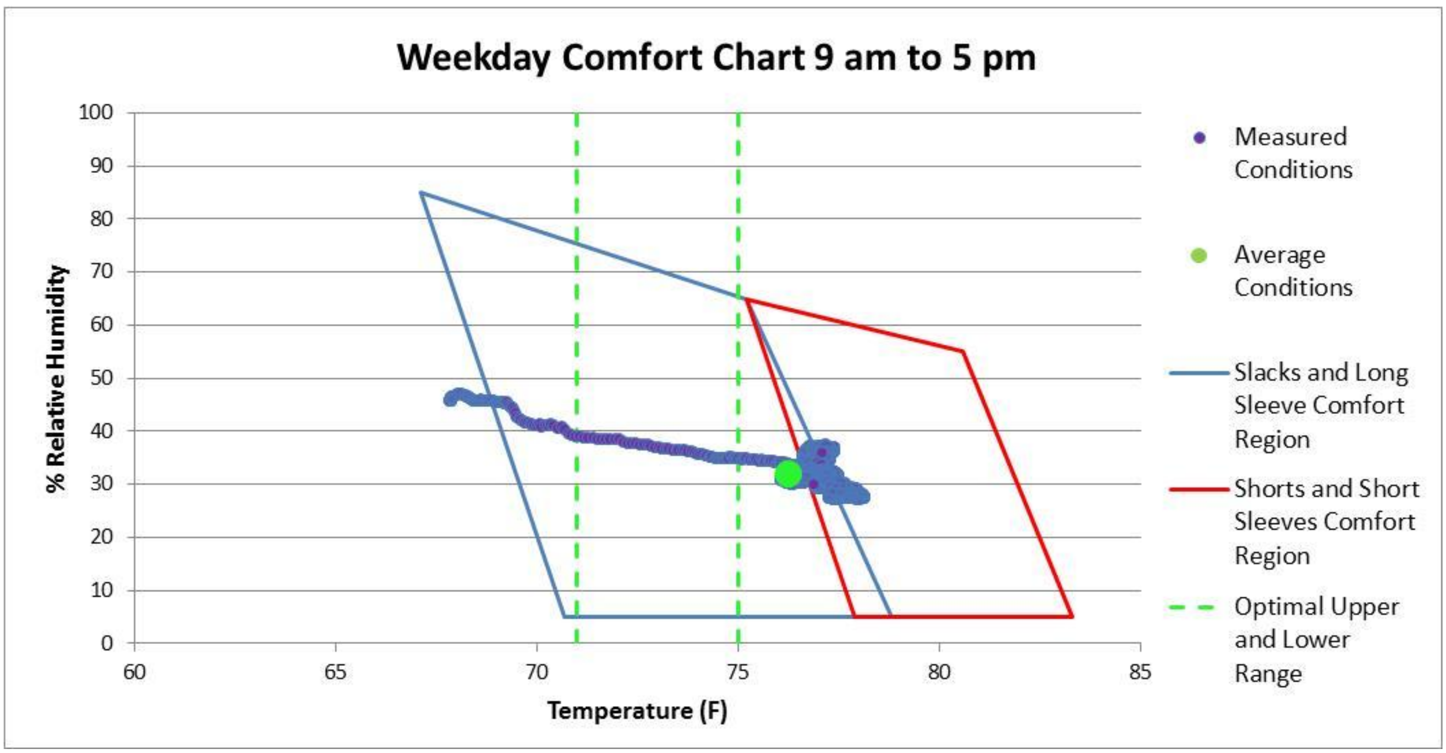
Comfort Conditions and Volatile Organic Compound Levels

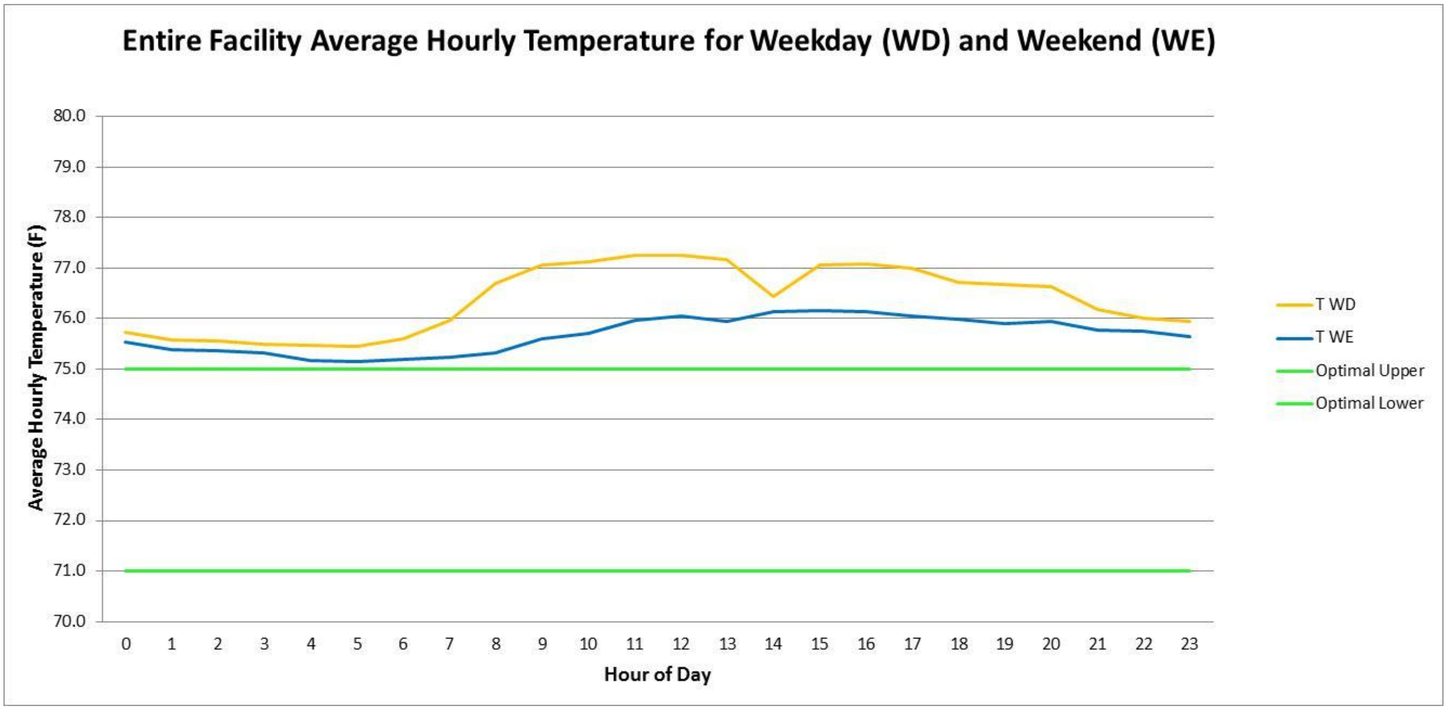
Comfort conditions include temperature and relative humidity levels. Indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance at work. Relative humidity can affect the incidence of respiratory infections and allergies. Relative humidity ranges of 30% to 60% are acceptable and minimize adverse health effects. Workers generally feel more comfortable in the lower end of this range.

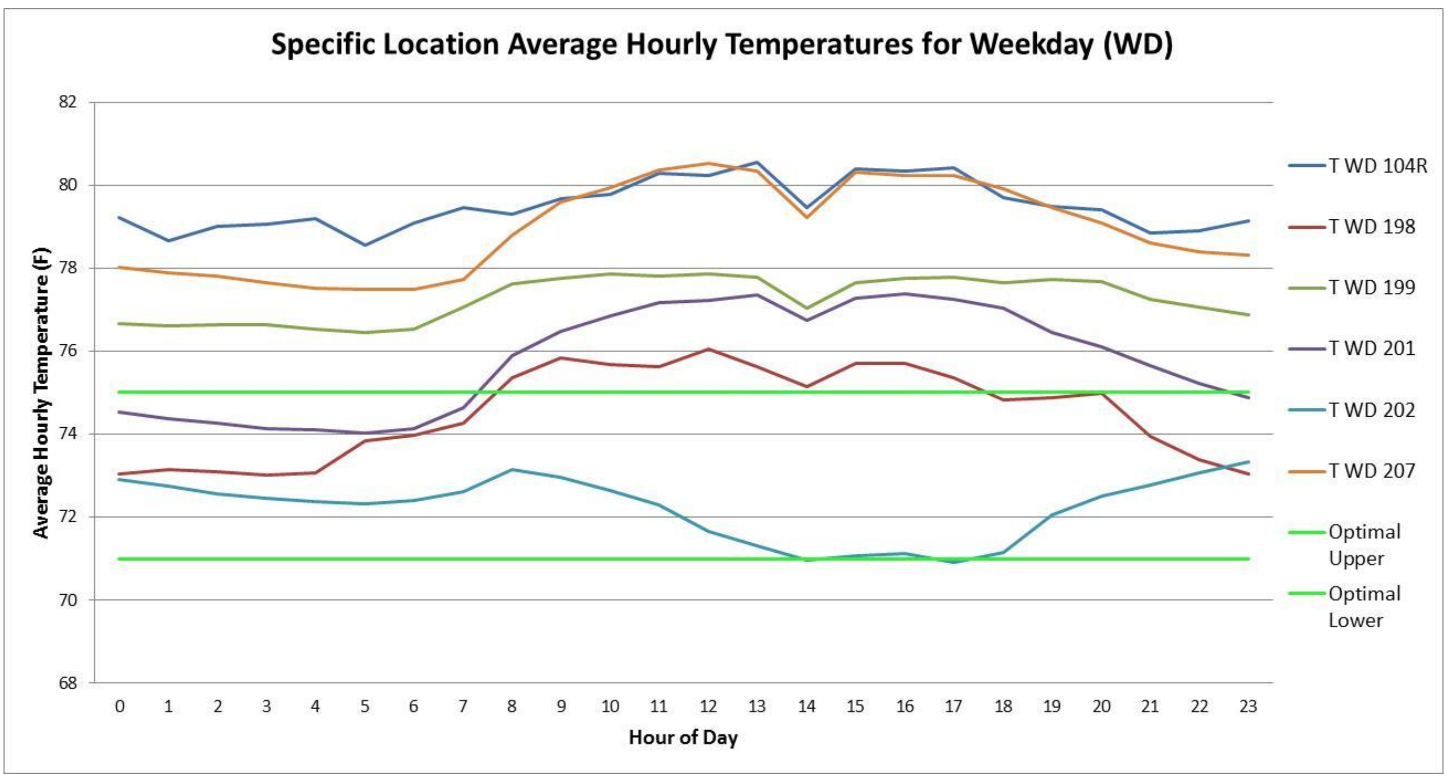
VOCs include both human-made and naturally occurring chemical compounds. Most scents or odors are VOCs. Some VOCs are dangerous to human health or cause harm to the environment. Harmful VOCs are typically not acutely toxic, but instead have compounding long-term health effects.

Weekday Building Comfort Conditions (temperature & relative humidity)

The building facility mostly maintains conditions considered comfortable by most people. Average building temperatures are slightly above the 71 to 75F ideal range. Modestly lower temperature set points will result in more comfortable and productive employees. Average weekday building temperature is approximately 2 deg F over the optimal upper limit of 75 deg F for most of the work day. The warmest locations in the building during the week were office regions 104R and 207. For several hours each day, temperature exceeded 80 deg F. The coolest location was 202, the men's room. For every degree F above 75F, worker productivity declines by 1% (see Appendix A for more discussion).

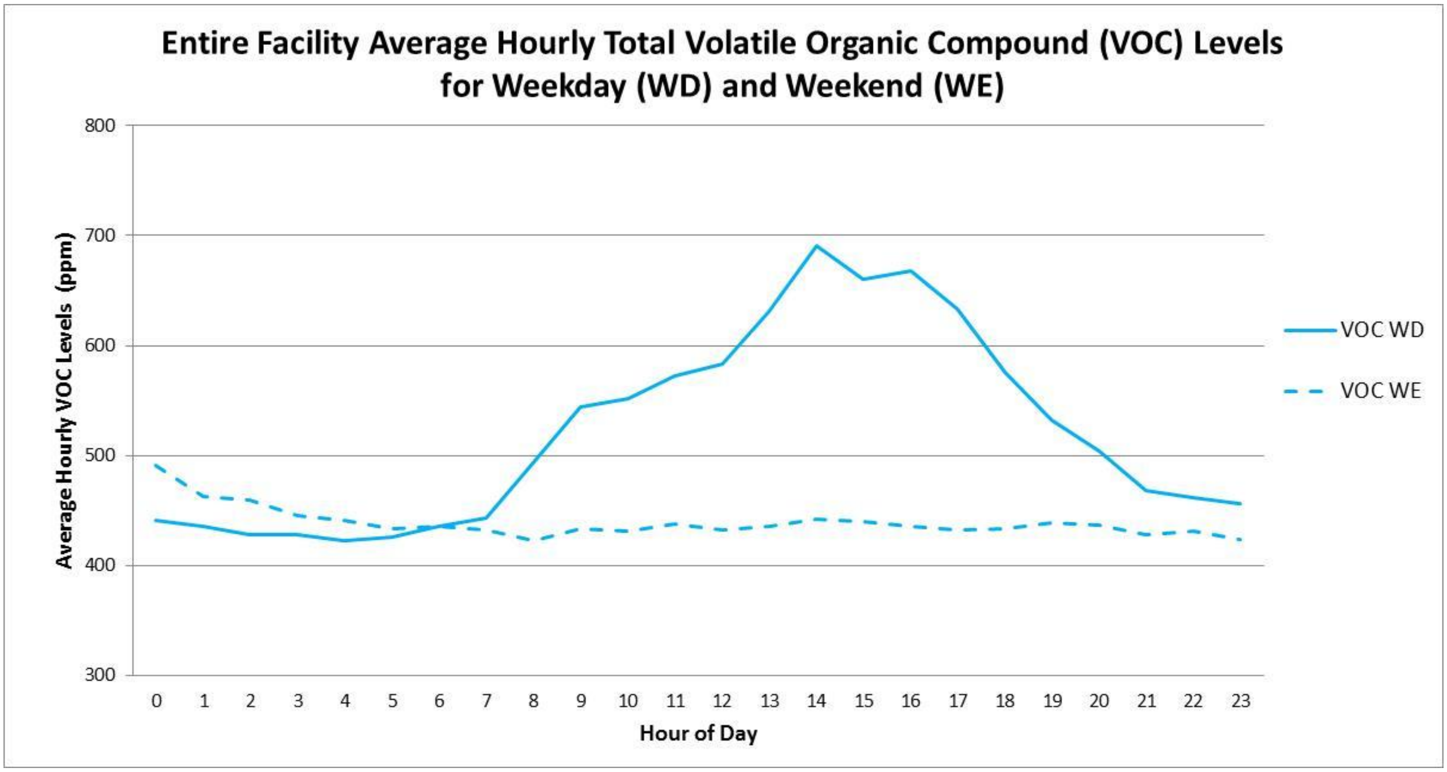


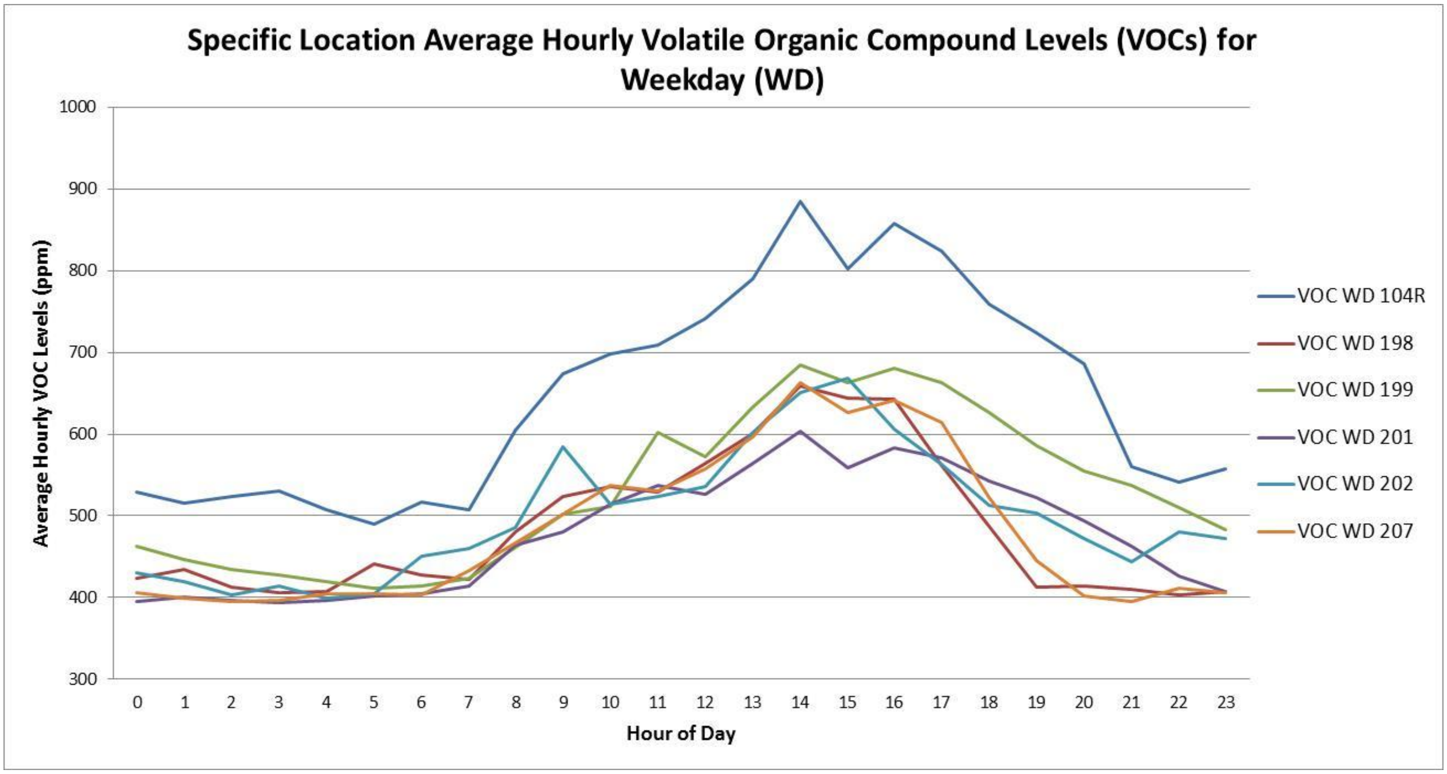

Entire Facility Average Hourly Temperature for Weekday (WD) and Weekend (WE)
Average Hourly Temperature (F)
80.0
79.0
78.0
77.0
76.0
75.0
74.0
73.0
72.0
71.0
70.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of Day
T WD
T WE
Optimal Upper
Optimal Lower


Specific Location Average Hourly Temperatures for Weekday (WD)
Average Hourly Temperature (F)
82
80
78
76
74
72
70
68
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of Day
T WD 104R
T WD 198
T WD 199
T WD 201
T WD 202
T WD 207
Optimal Upper
Optimal Lower

Hourly Building Average VOC Levels

The highest VOC level location was office region 104R. This was one of the warmest locations in the building and higher VOC levels may be attributed to employee perspiration and respiration effects. Higher temperatures also increase the volatility of many substances. Many other factors also increase VOCs such as perfumes and cosmetics, microwave popcorn, pesticides, etc. Note that ventilation improvements for reducing CO2 will also reduce VOC levels.





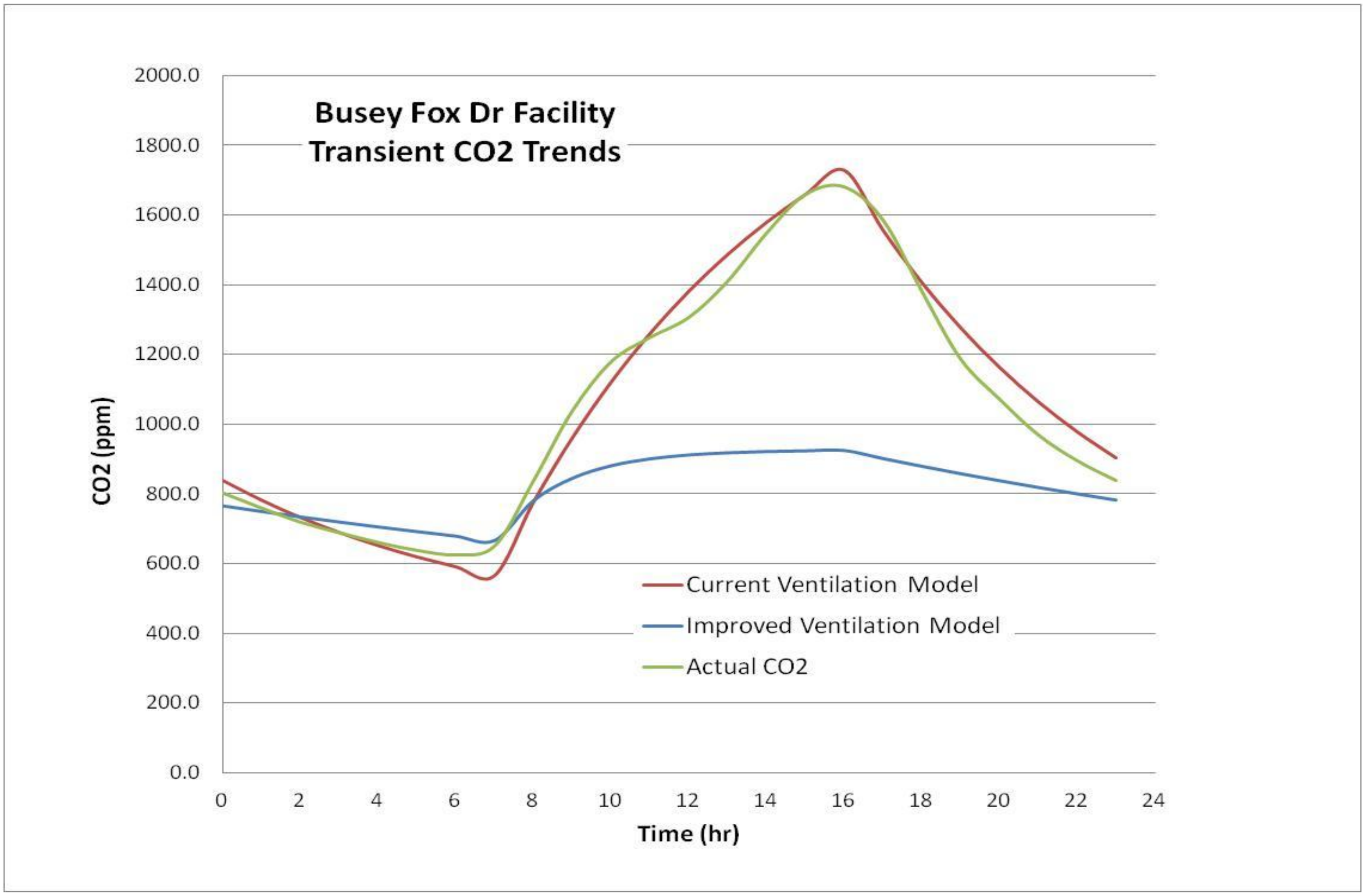
Potential Impact of Fresh Air Flow Changes

Building CO2 Variations with Fresh Air Flow

A transient CO_2 concentration simulation model was applied to the facility in order to examine characteristics of CO_2 variations throughout the course of a day. The plot below shows a comparison of the measured hourly workday CO_2 values (average of all Black Box IAQ units) with a computer simulation of the facility. The simulation model assumes a building volume of 25,000 sq ft by 12ft high (the utility space above ceiling is included in the participating volume). 90 people are assumed to be in the building continuously over the course of 9 hours, assuming some fraction of the 120-130 employees are not in the building for the assumed 9 hour workday. The average fresh air ventilation rate is assumed to be 650 cfm based on matching the measured data with simulation model data. Overall, the transient model captures the generation of CO_2 and the decay of CO_2 after work hours quite well.

A potential fresh air schedule that significantly improves air quality with minimal impact on building energy is also shown in the plot. The fresh air ventilation schedule assumes 9 hours of ventilaion at 2,200 cfm during work days, and 220 cfm during non-workday hours. The increased fresh air flow restricts the workday CO_2 to a maximum concentration level below 1,000 ppm, and reduces the loss in worker productivity.

During non-workday hours and weekends, a reduction of fresh air ventilation to 220 cfm is assumed, which may or may not be beneficial from an energy performance perspective. The next section discusses the impact of fresh air ventilation flow on building energy.


Busey Fox Dr Facility
Transient CO2 Trends
CO2 (ppm)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
Time (hr)
Current Ventilation Model
Improved Ventilation Model
Actual CO2

Average Daily Building Energy

Monthly utility bill information for the facility was converted to average daily energy usage and plotted versus the average ambient temperature for each month. The positive slope (increasing daily energy as ambient temperature increases) indicates that the building requires significant air conditioning throughout much of the year. The plot below shows a comparison of actual data versus predictions using ZEROs building modeling software. The building model assumed 80kW average power usage for the servers and 120 people in the building for 9 hours per weekday. The server power is the dominate energy load and causes the building to require cooling into the winter. This characteristic provides the opportunity to increase building fresh air ventilation rates without significant impact on annual building energy because additional fresh air during cooler months can favorably augment the cooling system.

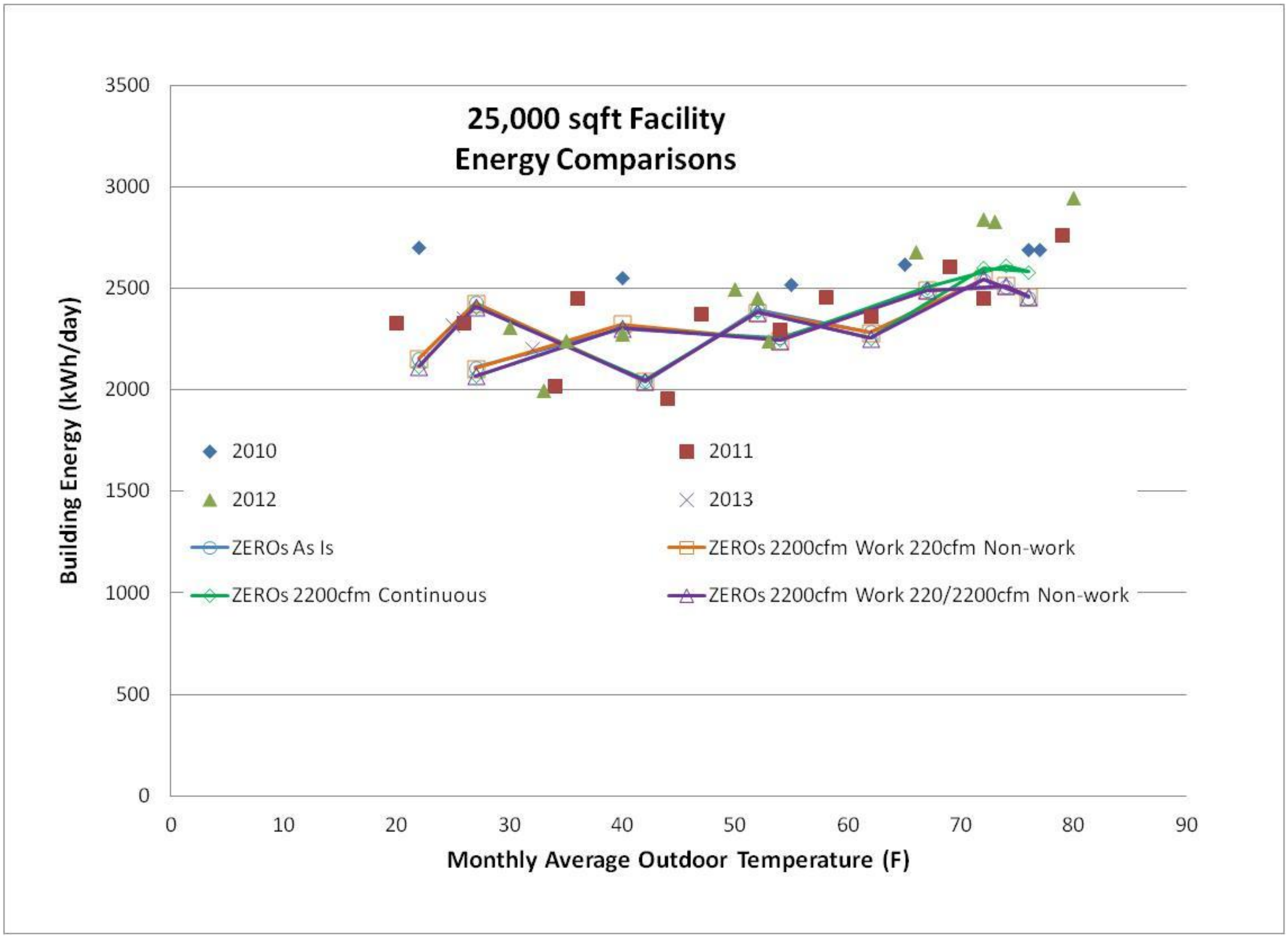
The "As Is" building case model uses the current 650 cfm fresh air ventilation rate discussed in the previous section. The other three models show the impact of increasing the fresh air ventilation rate by a factor of 3 (650 cfm to 2200 cfm). In one case, a fixed schedule of 2200 cfm for 9 hours per day is assumed, with a reduced fresh air ventilation rate of 220 cfm during non-workday periods. A second case assumes a continuous fresh air ventilation air flow of 2200 cfm. Note that during the summer months, a noticeable increase in conditioning energy occurs, however for most of the year, a negligible difference occurs. The third case assumes 2200 cfm during workday periods, and either 220 cfm or 2200 cfm during non-workday periods. Winter months favor higher ventilation rates which help cool the facility for "free" while summer months favor reduced fresh air during non-workday period. The third air flow strategy results in the minimum annual energy with 845,696kWh compared to 849,975kWh for the predicted "As Is" annual energy.

	Ave Temp (F)	AveDailyEnergy As Is (kWh)	AveDailyEnergy Case 1 (kWh)	AveDailyEnergy Case 2 (kWh)	AveDailyEnergy Case 3 (kWh)
January	22	2156	2153	2115	2115
February	27	2428	2427	2411	2411
March	42	2042	2042	2050	2042
April	52	2397	2381	2383	2381
May	62	2284	2282	2253	2253
June	72	2543	2546	2600	2546
July	76	2453	2461	2582	2461
August	74	2506	2512	2612	2512
September	67	2489	2490	2503	2490
October	54	2258	2243	2250	2243
November	40	2300	2322	2304	2304
December	27	2111	2105	2068	2068
AnnualEnergy		849975	849907	855100	845696

Case 1 = 2200 cfm fresh air flow during work hours; 220 cfm during non-work hours

Case 2 = 2200 cfm fresh air flow continuously

Case 3 = 2200 cfm fresh air flow during work hours; either 2200 or 220 cfm during non-work hours



Plot of facility energy from 2010-2013 utility bill data and ZEROs building modeling simulations.

APPENDIX A - Value of Comfort and Indoor Air Quality

Human performance is strongly dependent on indoor air quality. The cost of poor indoor air quality is much greater than utility savings associated with reductions in fresh air ventilation rates. Figure A1 shows cognition performance in 9 areas that are typical of activities important to employers [3]. Outdoor air has 400 ppm (parts per million) of CO2. The rule-of-thumb for fresh air ventilation is 20 cfm per person, which is used for most building design (formally, ASHRAE 62.1 Standard is used for building fresh air ventilation design). Within a typical office environment, 20 cfm per person of fresh air ventilation will result in 1,000 ppm CO2 concentration. In addition to CO2 as an indoor air pollutant, elevated CO2 concentrations also correlate with increased levels of other chemicals, allergens, and contagions. These substances further reduce productivity and increase absenteeism.

Increasing fresh air ventilation impacts building utility cost in many climates while increasing worker productivity [4]. For a typical 6,000 square foot office building located in Champaign, Illinois with 20 employees, the annual energy usage would be 55,581 kWh[2] with an indoor temperature of 71F and 20 cfm per employee of fresh air ventilation maintained throughout the year. The annual utility bill would be $5,581 per year with 10 cents per kWh utility cost. An increase of fresh air from 20 cfm/person to 40 cfm/person results in a productivity improvement of 1%, with a value of $10,400 per year based on the Säppenen, et.al. [4] model. Energy for the building, without energy recovery from the ventilation system's exhaust air, would increase by 17,370kWh with an estimated value of $1,740 of increased utility cost. Although this is a substantial utility bill increase, the improvement in employee productivity outweighs the increase in utility cost by a factor of 5. A building energy recovery heat exchanger and DCV (Demand Control Ventilation) system would significantly lower the energy impact while preserving the improvement in air quality.

People must be comfortable in order to be productive, too. Optimal working temperature for most people in an office environment is 71F to 75F. Above 75F, a 1% decrease of work productivity occurs per degree F temperature increase [1]. If thermostats are adjusted to 76F for May through September when cooling is required, the 1% drop in employee productivity has a value of $4,300 based on an average $25 per hour employee cost for the 5 month period with increased temperature. Increasing the building thermostat to 76F during the May through September period reduces the building's annual energy load to 52,211kWh, for an energy savings of 3370kWh per year with an estimated utility savings of $340/year. Productivity related to comfort is more than 10 times the value of energy. Note that a thermostat change to 75F during summer months could have maintained productivity with most of the energy savings. Understanding the balance of building energy requirements with human cognition and productivity impacts is very important.

REFERENCES

1. O. Seppänen, W.J. Fisk, Q.H. Lei, "Effect of temperature on task performance in office environment", LBNL-60946 report, Lawrence Berkeley National Laboratory, July 2006.

2. Build Equinox ZEROs™ building modeling software is used for energy modeling. Each employee is assumed to require 100 Watts of average power for lights, computers, etc. 500cfm of fresh air ventilation with no energy recovery is assumed, resulting in a maximum of 911ppm of carbon dioxide concentration.

3. U. Satish, M. Mendel, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, and W. Fisk, "Is CO2 Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance", *Environmental Health Perspectives*, 120, pp 1671-1677, 2012.

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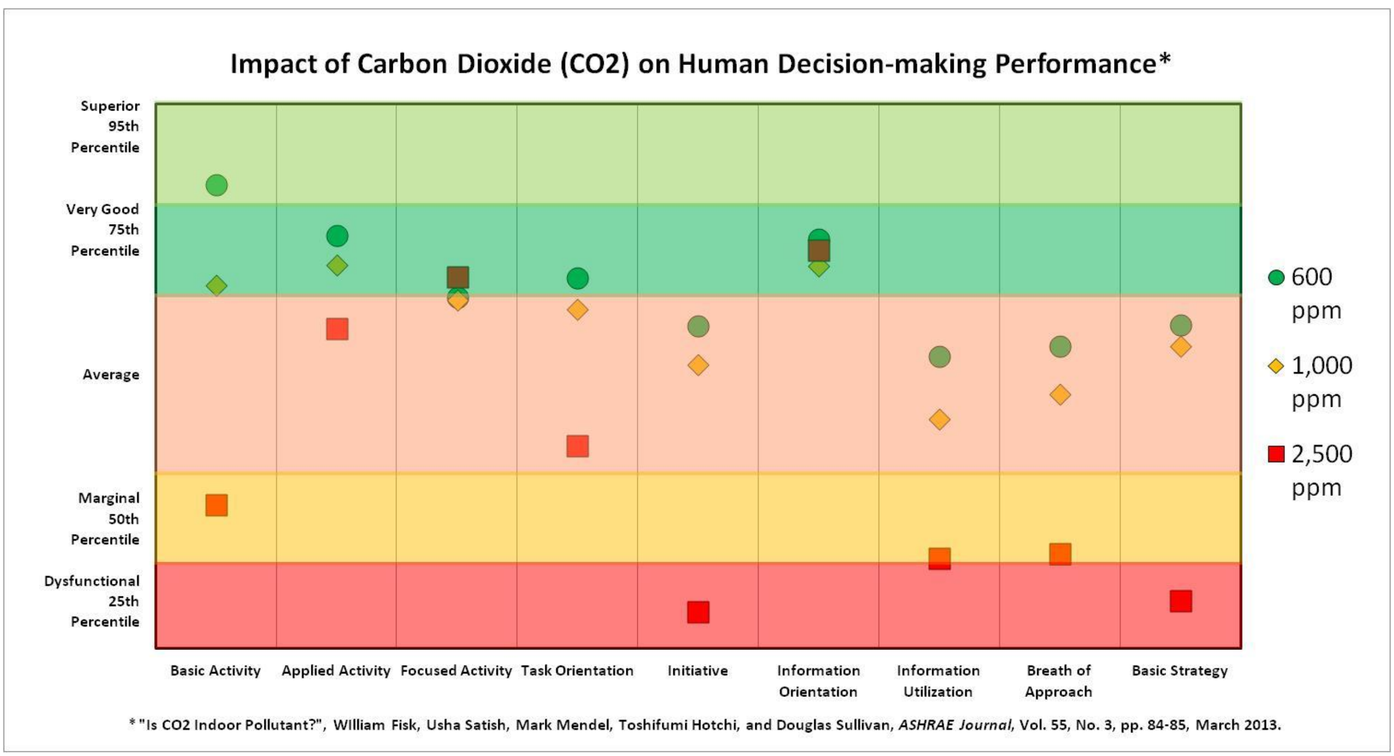

Figure A1 Cognitive performance due to CO2 concentration.