Technical University of Denmark

Thermal and Air Quality Acceptability in Buildings that Reduce Energy by Reducing Minimum Airflow from Overhead Diffusers

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Abstract:

There is great energy-saving potential in reducing variable air volume (VAV) box minimum airflow setpoints.

In the past, setpoints have been maintained at high levels because of three concerns: 1) low flows might cause the occupants draft discomfort from insufficient mixing of diffuser discharge air, 2) inability of VAV boxes to control at low flows, and 3) poor air quality resulting from a combination of poor control and insufficient diffuser mixing. It is worth examining these concerns to see whether they are justified. The controller accuracy and stability have recently been addressed by RP 1353, in which VAV boxes were found to control well at very low flow levels. The diffuser mixing issue and impact on comfort are addressed in this research project, RP 1515.

RP 1515 is a combined field and laboratory study, in which occupants' thermal comfort and air quality satisfaction is evaluated in the field under reduced minimum VAV flow rate setpoints, and the mixing performance of diffusers is measured in the laboratory. The laboratory portion was

performed with co-funding from Price Industries. Additional co-funding from the California Energy Commission's PIER program allowed us to quantify the HVAC energy savings resulting from the reduced flows in the field study buildings.

Thermal and Air Quality Acceptability in Buildings that Reduce Energy by Reducing Minimum Airflow from Overhead Diffusers

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ASHRAE RP-1515
November 2012

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EXECUTIVE SUMMARY

There is great energy-saving potential in reducing variable air volume (VAV) box minimum airflow setpoints. In the past, setpoints have been maintained at high levels because of three concerns: 1) low flows might cause the occupants draft discomfort from insufficient mixing of diffuser discharge air, 2) inability of VAV boxes to control at low flows, and 3) poor air quality resulting from a combination of poor control and insufficient diffuser mixing. It is worth examining these concerns to see whether they are justified. The controller accuracy and stability have recently been addressed by RP 1353, in which VAV boxes were found to control well at very low flow levels. The diffuser mixing issue and impact on comfort are addressed in this research project, RP 1515.

RP 1515 is a combined field and laboratory study, in which occupants' thermal comfort and air quality satisfaction is evaluated in the field under reduced minimum VAV flow rate setpoints, and the mixing performance of diffusers is measured in the laboratory. The laboratory portion was performed with co-funding from Price Industries. Additional co-funding from the California Energy Commission's PIER program allowed us to quantify the HVAC energy savings resulting from the reduced flows in the field study buildings.

Our hypothesis for the field study was that the low flow operation would not degrade comfort significantly. We modified controls setpoints for VAV box minimum flow in four large buildings in the Yahoo! campus in Sunnyvale, CA, and in a county government building in Martinez, CA, entitled the 800 Ferry Building. Toggles were installed in software to allow us to globally switch the controls between high to low minimums.

Occupants were given repeated 'right-now' surveys over the period of testing, to obtain their perception of thermal comfort, perceived air quality, and perceived air movement. In roughly the middle of each of three survey periods, the VAV minimum flow rate setpoint was switched between high (~30% of the unit's maximum flow rate) and low (~10%-15% of the unit's maximum flow rate). The switching allowed us to compare the occupants' satisfaction levels under high- and low-minimum operation modes. Surveys at the Yahoo! buildings yielded a total of 9500 responses from 450 occupants. At 800 Ferry, there were about 1000 responses from 65 occupants.

The Yahoo! buildings are unusual in that they are normally operated under low minimum flow rate setpoints. The occupants' response to this form of operation could be tested against the large CBE database of occupant satisfaction, which forms a de facto benchmark of building performance. The CBE survey ('background survey') was conducted in all six Yahoo! office buildings and in one small office building at UC Merced that is also normally operated under low minimum flows. 1279 people at Yahoo! (33% of the total Yahoo! population) and 44 out of 85 in the UC Merced building (52% response rate) participated in the background survey. The Ferry Building, which normally operated at high minimum, was also given the background survey.

We installed energy measurement meters in all air conditioning units of four Yahoo! buildings and 800 Ferry. These meters provide continuous sub-metering of cooling and fan energy. We also metered gas use. The minimum flow rates of VAV terminal units were switched between high and low a few times during the monitoring period of November 2010 – May 2012. Regression analysis and monte carlo simulations were used to predict the annual energy savings of this intervention. HVAC system operations were also monitored for the entire research period by the Building Management System (BMS), including terminal unit flow rates, zone temperatures, and discharge air temperatures.

The mixing performance of a range of diffuser types was determined in one of the test chambers at Price Industries. Temperature and velocity profiles were measured and ventilation effectiveness quantified for various flow rates representing high and low minimum operation.

This report presents the comparisons between the two operation modes (~30% and ~10%-15% minimum flow rates) for occupants' responses, energy measurements, and diffuser mixing performance.

Occupant surveys in the Yahoo! buildings and 800 Ferry supported the hypothesis that there would be no degradation in occupant comfort. In winter, there was no appreciable difference between the two modes of operation. In summer, however, we were surprised to find significantly improved thermal comfort ($p<0.001$) under low minimum operation. The dissatisfaction rate found under high minimum operation was reduced by 47% in both summer studies in Yahoo! buildings and in 800 Ferry. The comfort improvements appear to be due to a reduction in summer over-cooling, as the zones have more capability to turn down at low load conditions. We encountered no evidence of draft sensation at low flow rates. In fact, upending the hypothesis, occupants perceived the most air movement when the flow rate was high, not low. The perceived air quality was also improved in the summer when the high minimum operation was switched to low operation. The proportion of respondents dissatisfied with the air quality dropped by 32% in the Yahoo! buildings and 62% in 800 Ferry.

The background surveys from the buildings that are normally operated under low minimum setpoints (six Yahoo! buildings and one at the University of Merced) show that occupant satisfaction for temperature and perceived air quality ranked high when compared to overall building satisfaction, and when benchmarked against the comfort and air quality categories in the entire CBE database. The six Yahoo! buildings rank in the 89th percentile for temperature satisfaction, the 76th percentile for perceived air quality, and the 60th percentile for general building satisfaction. The UC Merced building ranks in the 75th percentile for temperature satisfaction, the 75th percentile for perceived air quality, and the 40th percentile for general building satisfaction.

On the Yahoo! campus, using the low VAV minimum setpoints reduced gas use by an average of 12.2% (0.0225 therms/sf-year), and AC unit energy including fan and cooling consumption by an average of 13.5% (0.45 kWh/sf-year). In 800 Ferry, the low VAV minimum setpoints reduced gas use by 6.1% (0.011 therms/sf-year), cooling energy by 28.8% (0.34 kWh/sf-year), and supply fan energy by 42.6% (0.86 kWh/sf-year). Annual trends show that zone loads are generally very low which results in most zones spending most of the time at their minimum airflow setpoint.

The temperature and velocity profiles measured in the Price Industries chamber show that diffusers mounted flush with the ceiling have high ADPI down to 10% flow fractions and average air speeds that decrease with lower flow fractions. These results explain why occupants in the field study did not experience draft discomfort. Diffusers mounted on a sidewall or without a ceiling, thus absent the Coanda effect, resulted in significant reductions in ADPI at low flow fractions suggesting that the Coanda effect may be important for maintaining comfort at low flow. None of the buildings in this study had these diffuser configurations.

Cooling mode air change effectiveness (ACE) measurements in the Price Industries chamber showed consistent full mixing with ACE greater than 0.96 down to 10% flow for two types of ceiling diffusers. These results corroborate past research and extend the result down to 10% flow. One test was done in heating mode that showed the potential for reduced ACE in certain situations, but further study is needed. Heating mode experiments were not in the scope of this study.

Reducing the minimum flow rate setpoints can be done simply by modifying parameters in the building control system that are often readily accessible. It is a very low-cost retrofit option that can be carried out with no modification to the building.

Moderately low minimum flow rate operations (to 20% of maximum) are now required by California's Title-24 energy code (and are proposed for ASHRAE 90.1). These findings support those of RP 1353 to suggest that that the VAV minimum can be lower than this (to the vicinity of 10% or to the minimum ventilation requirement). The findings also show effects we have not seen discussed before, but which in retrospect might have been obvious: that the lower minimums have the effect of improving comfort in summer, and reducing or eliminating over-cooling in buildings.

STATEMENT

This project is funded by ASHRAE (award number 030341-003) and is co-funded by the California Energy Commission (CEC/CIEE, contract number: 500-99-013, work Authorization Number: BOA-POB-244-B65). The ASHRAE project started in November 2010 and finished in November 2012. The focus of the ASHRAE project is to characterize in detail the comfort effects of the different levels of VAV minimums, and to do controlled temperature and velocity profile measurements for various types of diffusers and minimum flow rates in an environmental chamber at Price Industries in Winnipeg. The focus of the CEC/PIER project is on the installation of energy meters, control re-programming, energy measurements, and saving analysis. This report includes results covered by both funding sources.

1 Introduction and Background

1.1 *Problem Statement*

Variable Air Volume (VAV) box minimum airflow setpoints have tremendous energy implications. By lowering the minimum airflow setpoint, it is possible to reduce HVAC energy on the order of 10-30%. This is a remarkable saving for a very low-cost retrofit option that can be carried out with no modification to the building. There are, however, two concerns about low setpoints: the stability and accuracy of VAV controls under low flows, and the room air distribution resulting from diffuser discharge, which might affect occupants' thermal comfort and air quality exposure.

Recent research has been addressing the stability and accuracy issue. Pacific Gas and Electric, Taylor Engineering, and Darryl Dickerhoff Consulting recently completed a study of VAV box controls at low flows (http://www.taylor-engineering.com/downloads/reports/Final%20Report%20with%20Appendices.pdf). They found that current VAV box control technology can control stably at much lower than 30% of design flow. As a result of this research, SSPC 90.1 now has an addendum out for public review with a requirement for 20% minimums (when heating maximums are above 30%) so we will most likely see many more buildings with low VAV minimums in the future. ASHRAE Research Project RP-1353, which was completed in February 2012 (Liu et al. 2012), is a follow-up study to the Taylor/Dickerhoff research. This research is expected to validate the Taylor/Dickerhoff conclusions over a wider range of technologies and field conditions. Given that VAV box controls appear to be stable at very low flows, the outstanding question then becomes: can comfort and IEQ be maintained at low flows?

Overhead diffusers are typically selected for optimum performance at maximum airflow and should provide good room air mixing if selected properly. Room air distribution changes significantly when zone airflow is decreased at lower cooling loads, and also during heating, so there is concern that improper air mixing will produce uncomfortable conditions or poor ventilation. Primary comfort concerns are draft sensations from "dumping" diffusers, vertical air stratification, and poor temperature distribution across the space. Existing guidance from diffuser manufactures suggest minimum airflows from 30%-50% of design airflow but there is little or no published research validating these limits.

A number of research projects have looked at comfort and ventilation effectiveness at low flow conditions. Bauman (1995) used a test chamber with a thermal manikin and found that acceptable comfort conditions could be maintained at 25% flow. Fisk (1997) obtained similar results. This is in contrast to ADPI information in the ASHRAE Handbook and in diffuser manufacturers' literature which suggest that comfort cannot be maintained below 30%-50% flow. Anecdotal data from the large stock of existing buildings with low minimum flow setpoints also suggest that ADPI predictions do not apply to actual occupied buildings. Research has also shown that ventilation effectiveness may be maintained at low flow from overhead diffusers in cooling and in low temperature heating (Persily and Dols 1991, Persily 1992, Offerman and Int-Hout, 1989, Bauman 1993, Fisk 1995). Some of the results from these studies showed that ventilation effectiveness was maintained outside of the diffuser manufacturer's recommended ranges.

There are, however, significant gaps in the research base on comfort and ventilation effectiveness at low flows, especially performance below 25% flow and performance in low-flow heating applications.

While most engineers are still using single maximum zone control sequences with VAV box minimum flows in the range of 30%-50%, some designers are claiming successful comfort performance while employing a dual maximum strategy with minimums in the range of 10% to 20% of the cooling maximum airflow.

Simulations done by Taylor Engineering show that reducing zone minimum flows in a typical office building from 30% to 20% can save \$0.10/ft^2-yr in fan, cooling, and reheat energy (approximately a 10% reduction in total energy use). Multiplied across the millions of square feet of commercial space served by VAV boxes, the potential economic and environmental benefits are tremendous. Savings can be achieved in new construction and in existing buildings through low cost control system re-programming.

Research on minimum flows could have far-reaching implications in support of changes, ranging from the ASHRAE Handbook to manufacturers' literature and to the way engineers calculate minimum flow rates. It will also support proposed changes in Standards 90.1, 62.1 and 55.

There is a need for generalizable guidance to designers and standards developers who are currently considering the use of low minimum airflows.

Throughout this report, we shall refer to "high minimum" and "low minimum" VAV control sequences. Let "high minimum" represent standard engineering practice, in which VAV minimums are in the range of 30-50% of maximum flow. In the field studies conducted, we fixed VAV minimums to 30% to represent high minimum control. Further, let "low minimum" represent the proposed retrofit, in which the VAV minimum setpoints are generally in the range of 10-20%. The minimum setpoint for each VAV unit is taken to be the larger of (1) 0.15 cfm/sf, or the minimum outside air rate, and (2) the minimum controllable setpoint. This insures that the minimum setpoint both satisfies the ventilation requirement and can be achieved by the VAV unit. Thus, the results can be interpreted as the savings between a benchmark case with 30% VAV minimums, and the retrofit case in which the generic strategy described above was applied.

1.2 *Objectives*

The hypothesis is that low zone airflow minimums provide acceptable thermal and air quality conditions in occupied buildings during normal operation. Expressed another way: zones operating under low minimums do not perform worse than when operated under conventional high minimums.

The project characterizes the indoor environment quality (IEQ) when overhead diffuser flow is reduced, including:

- Thermal comfort and acceptability
- Sense of air movement (or "dumping")
- Ventilation and air quality acceptability

In addition, the project intervenes in existing occupied buildings and alternates high and low minimum flow rate sequences in order to compare the energy consumption resulting from the two system operation modes.

Finally, the project quantifies the air distribution characteristics of diffusers at low flows, and suggests system control strategies that maintain comfort and acceptability at low minimum flows.

2 Methods

This study was carried out in three ways:

1. Occupant satisfaction surveys to evaluate indoor environments.
    - Select buildings and re-program building control systems to allow minimum VAV flow rates to be switched between high and low.
    - Real-time occupant satisfaction surveys during high minimum and low minimum operation modes.
    - Background occupant satisfaction survey for buildings operated with low minimum flow rates.
2. Energy monitoring and analysis to evaluate savings when the minimum flow rate is switched from high to low.
3. Physical measurements in occupied buildings and a laboratory to describe space temperatures and velocity profiles under the two operation modes.

2.1 *Literature review*

The literature study summarizes thermal comfort with local air movement, and HVAC system operation pertaining to VAV and ADPI.

2.1.1 *Literature review of dual maximum and low minimums*

Dual Maximum

Perhaps the first instance of dual maximum zone controls in the literature is the 2003 Advanced VAV Design Guide authored by Taylor Engineering (energy design resources 2003). This was followed by a new version of the Advanced VAV Design Guide by Taylor Engineering in 2007 and 2010 (energy design resources 2007, 2010): http://www.energydesignresources.com/resources/publications/design-guidelines/design-guidelines-advanced-variable-air-volume-(vav)-systems.aspx

Two excellent articles on dual maximum by Steve Taylor and Gwelen Paliaga and Jeff Stein and Steve Taylor were published in the December 2012 and 2013 issues of the AHSRAE Journal (Steve et al. 2012, Stein and Steve 2013).

Dual maximum was first mentioned in the ASHRAE Handbooks in the 2007 version of the Applications Handbook of (see excerpt below). Prior to 2007 the Handbooks only described single maximum controls.

As part of this research project we surveyed over a dozen VAV box and controls manufacturers asking if they could point us to literature on their websites describing dual maximum sequences as a standard or optional sequence with their equipment. 10 Manufacturers responded. All said that dual maximum was an available option but amazingly not one could point us to literature describing it. In our own review of the manufacturers literature we saw many examples of single maximum and dual maximum with constant volume heating (neither of which are allowed by Title 24-2008 or 90.1-2013), but no examples of dual maximum with discharge air temperature control (as required in Title 24 and 90.1).

Figure 2.1.1 shows the single control sequence.

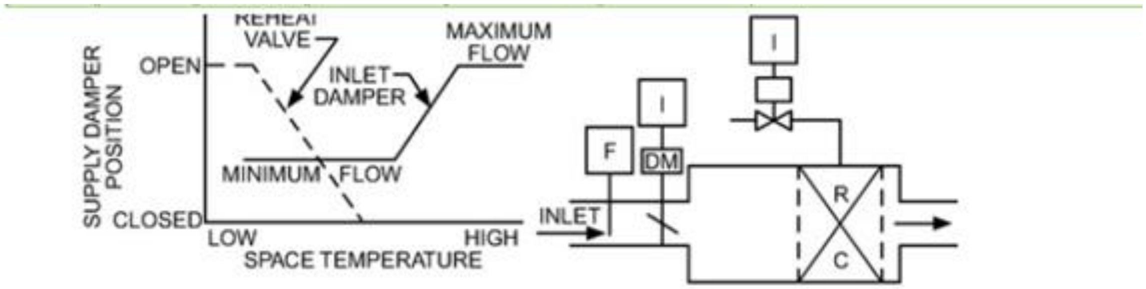


Figure 2.1.1 Throttling VAV terminal unit: single minimum control sequence (excerpt from 2011 ASHRAE Applications Handbook)

One disadvantage of this sequence is that the minimum flow set point must be high enough to meet the design heating load at a supply air temperature that is low enough to prevent stratification (e.g., less than 90°F). Therefore, the minimum flow set point typically must be 30 to 50% of the maximum flow set point, as limited by energy standards such as ASHRAE Standard 90.1. This wastes a great deal of reheat and fan energy, particularly for zones that are very conservatively sized.

A more energy-efficient sequence is the dual maximum sequence in Figure 2.1.2. As the space goes from design cooling load to design heating load, the airflow set point is first reset from the cooling maximum to the minimum. Then the supply air temperature is reset from minimum (e.g., 55°F) to maximum (e.g., 90°F), and the reheat coil is modulated to maintain the supply air temperature at set point. Lastly, the airflow set point is reset from the minimum up to the heating maximum. One of the advantages of the dual maximum sequence is that the minimum flow set point is not limited by stratification (as described for the single maximum) and can be set as low as 10 to 20% of the maximum flow, depending on ventilation requirements and the lowest nonzero controllable flow. Thus, the dual maximum sequence can greatly reduce wasted reheat and fan energy. This logic is mandated by some energy standards wherever DDC zone controls are used.

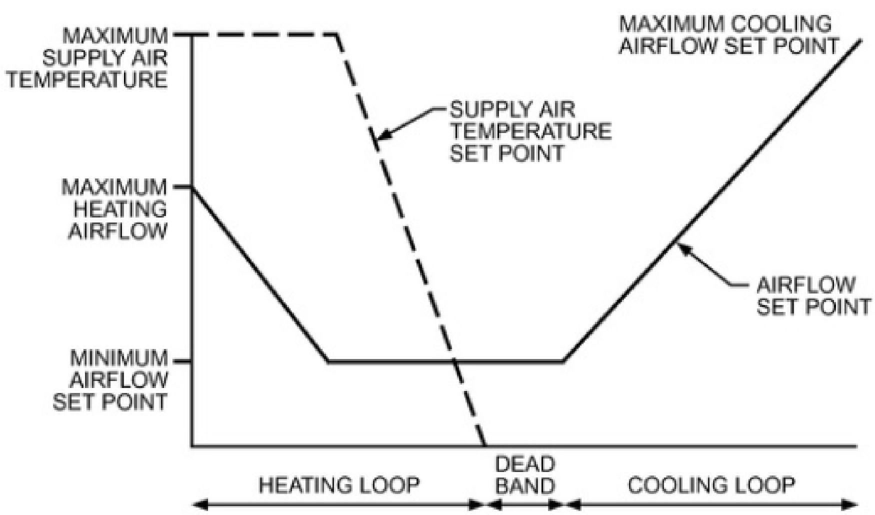


Figure 32. Throttling VAV Terminal Unit: Dual Minimum Control Sequence

Figure 2.1.2. Throttling VAV terminal unit: dual minimum control sequence (excerpt from 2011 ASHRAE Applications Handbook)

Low Minimums

One of the main problems hindering the expanded use of low minimums is the fact that most VAV box manufacturers list minimum flow rates in their literature that are actually quite high. The 2012 Titus catalog, for example, lists minimums for digital controls that are about 30% of the design CFM for typical VAV box selections. While it is not stated in the catalog, it is pretty clear that the Titus minimums are based on a velocity pressure signal of 0.03". However, Dickerhoff and Stein (2007) and ASHRAE RP-1353 both found that VAV boxes can be stable and accurate at velocity pressure signals as low as 0.004". Figure 2.1.3 listed CFM ranges of minimum and maximum settings.

Inlet Size	Total CFM Range	CFM Ranges of Minimum and Maximum Settings							
		PESV - Pneumatic TITUS II Controller		PESV - Pneumatic TITUS I Controller		AESV - Analog Electronic TA1 Controller		DESV - Digital Electronic TD1 Controller	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
4	0-225	45*-170	80-225	55*-170	80-225	45*-225	45-225	45*-225	45-225
5	0-350	65*-270	120-350	85*-270	120-350	65*-350	65-350	65*-350	65-350
6	0-500	80*-330	150-500	105*-330	150-500	80*-500	80-500	80*-500	80-500
7	0-650	105*-425	190-650	135*-425	190-650	105*-650	105-650	105*-650	105-650
8	0-900	145*-590	265-900	190*-590	265-900	145*-900	145-900	145*-900	145-900
9	0-1050	175*-700	315-1050	225*-700	315-1050	175*-1050	175-1050	175*-1050	175-1050
10	0-1400	230*-925	415-1400	300*-925	415-1400	230*-1400	230-1400	230*-1400	230-1400
12	0-2000	325*-1330	600-2000	425*-1330	600-2000	325*-2000	325-2000	325*-2000	325-2000
14	0-3000	450*-1800	810-3000	575*-1800	810-3000	450*-3000	450-3000	450*-3000	450-3000
16	0-4000	580*-2350	1100-4000	750*-2350	1100-4000	580*-4000	580-4000	580*-4000	580-4000
24x16	0-8000	1400*-5200	2600-8000	1800*-5200	2600-8000	1400*-7500	1400-7500	1400*-7500	1400-7500

* Factory CFM settings (except zero) will not be made below this range because control accuracy is reduced.
On pressure dependent units, minimum CFM is always zero and there is no maximum.

Figure 2.1.3. CFM ranges of minimum and maximum settings (excerpt from Titus VAV Box Catalog)

The Envirotech VAV box catalog is a little better than the Titus catalog because it clearer states the velocity pressure signal at which the minimum flow rates are calculated and gives different minimum flow rates for different possible velocity pressure signals. See Figure 2.1.4 for details.

UNIT SIZE	400 SERIES (PNEUMATIC) STANDARD CONTROLLER		7000 SERIES ANALOG ELECTRONIC		DDC CONSIGNMENT CONTROLS (See Notes Below)				
					MIN.			MAX.	
					Min. transducer differential pressure (in. w.g.)			Max. transducer differential pressure (in. w.g.)	
	MIN.	MAX.	MIN.	MAX.	0.015	0.03	0.05	1.0	≥1.5
4	43	250	35	250	30	43	55	250	250
5	68	350	50	350	48	65	88	350	350
6	75	490	60	550	53	75	97	435	530
8	145	960	115	1000	105	145	190	840	1000
10	235	1545	185	1600	165	235	305	1355	1600
12	340	2250	285	2300	240	340	440	1975	2300
14	475	3100	390	3100	335	475	615	2750	3100
16	625	4100	520	4100	440	625	805	3595	4100
19	1180	6500	1025	6500	845	1180	1510	6375	6500
22	1730	8000	1450	8000	1260	1730	2200	8000	8000

NOTES:
1. Minimum and maximum airflow limits are dependent on the specific DDC controller supplied. Contact the control vendor to obtain the minimum and maximum differential pressure limits (inches W.G.) of the transducer utilized with the DDC controller.
2. Maximum CFM is limited to value shown in General Selection Data.

Figure 2.1.4. CFM ranges of minimum and maximum settings (excerpt from Titus VAV Box Catalog)

2.1.2 *Thermal comfort, air movement, and draft*

As Toftum pointed out in “air movement – good or bad” (2004), air movement can be perceived as pleasurable in warm environments or draft (unwanted air movement) in cool environments.

Since the turn of the century, ASHRAE and thermal comfort researchers have worked to define levels of air movement appropriate for different levels of temperatures, and examined sensitivities of various body parts to air movement and its direction. Houghten (1924, 1938) specifically tested air movement sensation at the back of the neck and ankle and found that back of the neck is about 2.5 more sensitive to the air movement than the ankle with sock and shoe. Later in 1950s, Rohles (1974) exposed subjects to nine experimental combinations of air temperature and air movement within the ranges of 72ºF to 85.2ºF (22.2ºC to 29.5ºC) and 0.2 to 0.8 m/s. Draft was not found at warm temperature so an extended summer comfort zone was incorporated into ASHRAE Standard 55-1981 with air movement up to 0.8 m/s.

Researchers in Denmark Technical University did several lab studies to examine people “draft sensations” with air movement and turbulence intensities, by providing air flow behind the subjects, directed toward the back of the neck because this direction was judged to be the most sensitive direction (Fanger and Pederson 1977, Fanger and Christiansen 1986, and Fanger et al. 1988). Air movement limits were determined by predictions of draft discomfort (DR), based on these laboratory studies and embodied in both the ASHRAE (1992) and ISO 7730.

The draft limit was developed based on the lab studies when subjects’ thermal sensation was slightly cool. In warmer environments, many studies show that higher velocities (up to 0.8 m/s by Roles et al. 1974, 1983, 1.0 m/s by Scheatzle et al. 1989, Busch 1990, and Tanabe and Kimura 1987, 1.2 m/s by Kontz et al. 1983, 1.6 m/s by Tanabe et al.) were preferable or perceived as pleasant and no unpleasant draft was perceived. A literature review examining air motion, comfort, and standard was provided by Fountain and Arens (1993), also in Fountain et al. (1991, 1994).

Toftum (2004), Zhang et al. (2007), and Arens et al. (2009) examined air movement preference using ASHRAE database and a study in a naturally ventilated building, and found that far more people prefer more air movement than less that in slightly coo to warm environments. Based on these studies, ASHRAE Standard 2010 includes new provisions for using air movement to offset warm air temperatures (Arens et al. 2009)

2.1.3 *Air diffusion performance index (ADPI)*

The air diffusion performance index (ADPI) is a single-number rating of the air diffusion performance of a mixing system, as installed in a defined space, for specified supply air conditions and space cooling load. The ADPI is based only on air speed and effective draft temperature and is not directly related to the wet-bulb temperature or relative humidity. Wet-bulb temperature, humidity, and similar effects (such as mean radiant temperature) can be accounted for according to ASHRAE Standard 55. The ADPI method for mixing systems should be applied to traditional overhead air distribution systems under cooling operation only.

The ASHRAE-specified method of testing for room air diffusion is described in ASHRAE Standard 113-2009. Standard 113 defines a repeatable method of test in which detailed air velocity and air temperature measurements are made at multiple locations and heights within the occupied zone (up to 6 ft (1.8 m) height) of the space. Often these tests consist of moving a tripod supporting at least four pairs of velocity and temperature sensors from position to position throughout the test space. Typically the test positions are distributed uniformly in the test area with a spacing between 2–6 ft (0.6–1.8 m) with four measurement heights of 4, 24, 43, and 67 in. (0.1, 0.6, 1.1, and 1.7 m) above the floor. It is important to remember that this method of test is for purposes of assessing the performance of a system (or collection) of diffusers and should not be used to measure individual air outlets (see ASHRAE Standard 70-2006).

In the early years of VAV air distribution systems, a considerable amount of research was conducted investigating space air diffusion to maintain thermal comfort and provide acceptable indoor air quality. These studies led to the development of the ADPI test method as a practical means of assessing the quality of performance of mixing (typically overhead) air distribution systems. It was found that a high percentage of people will be comfortable under sedentary conditions where the effective draft temperature is between –3°F and +2°F with an air speed of less than or equal to 70 fpm (–1.7°C and +1.1°C with an air speed less than or equal to 0.35 m/s). Please refer to Standard 113-2009 for more details. If several measurements of air velocity and air temperature are made throughout the occupied zone of an office, the ADPI is the percentage of measurement locations where these criteria for effective draft temperature and air velocity were met.

$$\text{ADPI} = \frac{\text{Number of test points that meet criteria}}{\text{Total number of test points}}\ \%$$

An ADPI approaching 100% indicates the most desirable conditions (Miller 1971; Miller and Nash 1971; Miller and Nevins 1969, 1970, 1972; Nevins and Miller 1972; Nevins and Ward 1968). The ADPI rating is designed to reward system configurations and operating conditions that provide uniform air temperatures at relatively low velocities throughout the occupied zone.

It is common practice within the HVAC industry to focus attention on design load conditions, and because of this, most previous experience with ADPI testing tended to look at air diffusion performance under higher airflow rates. Until recent years with the trend of reducing interior loads, most interior systems were designed for 1 cfm/ft^2 (5 L/s-m^2), representing a fairly high airflow rate for today's load levels. There has existed among many practitioners a resistance to reducing or turning down the airflow volumes in a VAV system out of concern for diffuser "dumping" at low airflows. As discussed by Int-Hout (2004), diffuser velocities at low airflows may not be high enough to create the Coanda effect necessary to overcome negative buoyancy of the cold air being discharged, thereby causing cold air to drop into the space. However, despite this cautionary guideline about possible discomfort occurring at low airflow rates, there is little evidence in the literature documenting such events. Further discussion of designing effective air distribution systems, including the use of ADPI are presented in several recent ASHRAE Journal articles by John 2012 and Int-Hout (2012a, 2012b).

2.2 *Building selection, instrumentation, and controls reprogramming*

2.2.1 *Intervention study building selection criteria and repetitive right-now surveys*

In order to complete the research goals, we searched for buildings that would allow us to apply three primary research methods: (1) programming a toggle function to switch between a conventional high minimum sequence to a low minimum sequence in all zones, (2) installing energy meters that allow us to monitor the energy consumption of various HVAC equipment operating under high and low minimum operation modes, and (3) conducting occupant satisfaction surveys during both high and low minimum operation modes.

We selected six buildings on the Yahoo! campus, Sunnyvale, California and “800 Ferry,” a county government building in Martinez, in which to conduct the study.

2.2.2 *General description of Yahoo! buildings*

The Yahoo Campus was built in 2001 and is located in Sunnyvale, California. It consists of seven buildings, totaling 980,000 ft^2. An overview of the campus including buildings A – G and a view of Building D from outside are shown in Figure 2.2.1.

Site view　　　　Façade of Building D

Figure 2.2.1 Yahoo Campus

In total, there are 3850 employees. The sizes of each building and the number of HVAC units are summarized in Table 2.2.1.

Building	Area[1] (ft^2)	Stories	No. of packaged AC units	No. of chillers	Air terminal units
Building A (w. data center)	180,700	4	2	3	186
Building B	180,700	4	2	2	188
Building C (Dining)	52,700	2	2		56
Building D	180,400	5	2	1	225
Building E	212,600	5	3	3	243
Building F	91,000	3	2	1	92
Building G	79,700	3	2	1	83
Totals	977,800		15	11	1073

Table 2.2.1 Summary of Campus Buildings and HVAC units

Interior partitions and diffuser type. The offices in Yahoo! are mostly cubicles in an open interior plan. There are two types of partitions, high and low (see Figure 2.2.2). For a typical layout, about six cubicles share two plaque face diffusers.

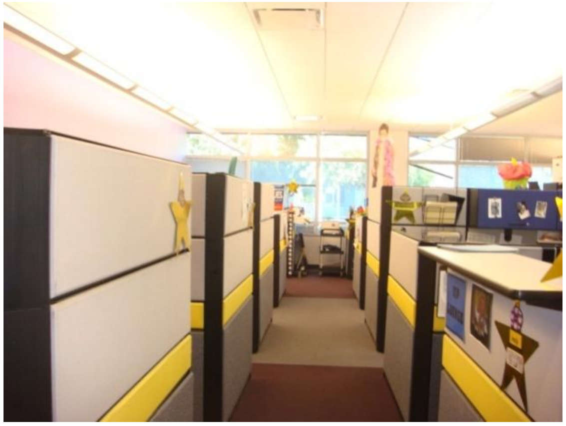


Figure 2.2.2 Office layout and high/low partitions of Yahoo! buildings (Building A, 3rd floor shown)

VAV box types. There are 1073 VAV zones on the campus, of which 254 are cooling only, 246 are fan powered, and 573 have reheat coils. Table 2.2.2 (below) summarizes the VAV units on each floor of each building across the campus.

	VAV Box Types			Grand Total
	Cooling Only	Fan Powered	Reheat	
Building A Totals	**45**	**51**	**90**	**186**
Bldg A - Floor 1	18	6	16	40
Bldg A - Floor 2	14	14	19	47
Bldg A - Floor 3	13	16	21	50
Bldg A - Floor 4	0	15	34	49
Building B Totals	**53**	**46**	**89**	**188**
Bldg B - Floor 1	26	3	16	45
Bldg B - Floor 2	13	16	20	49
Bldg B - Floor 3	14	12	20	46
Bldg B - Floor 4	0	15	33	48
Building C Totals	**16**	**0**	**40**	**56**
Bldg C - Floor 1	16	0	21	37
Bldg C - Floor 2	0	0	19	19
Building D Totals	**52**	**62**	**111**	**225**
Bldg D - Floor 1	15	6	21	42
Bldg D - Floor 2	13	15	21	49
Bldg D - Floor 3	12	17	17	46
Bldg D - Floor 4	12	12	22	46
Bldg D - Floor 5	0	12	30	42
Building E Totals	**52**	**69**	**122**	**243**
Bldg E - Floor 1	15	8	20	43
Bldg E - Floor 2	13	15	21	49
Bldg E - Floor 3	12	16	21	49
Bldg E - Floor 4	12	15	23	50
Bldg E - Floor 5	0	15	37	52
Building F Totals	**21**	**9**	**62**	**92**
Bldg F - Floor 1	9	7	14	30
Bldg F - Floor 2	12	1	18	31
Bldg F - Floor 3	0	1	30	31
Building G Totals	**15**	**9**	**59**	**83**
Bldg G - Floor 1	5	5	14	24
Bldg G - Floor 2	10	1	18	29
Bldg G - Floor 3	0	3	27	30
Grand Total	**254**	**246**	**573**	**1073**

Table 2.2.2 Box types and counts by building

Most of the VAV units are reheat units. Fan-powered VAV units typically serve enclosed spaces such as conference rooms. Cooling-only VAV units typically serve interior zones.

2.2.2.1 Description of Site Control System and Trending Capability

The site controls system is an Automated Logic Controls system. This provides zone-level control throughout the campus. Two years of trend data archives, including detailed measurements of VAV operation, were obtained and analyzed. Table 2.2.3 shows typical trend information available for different types of equipment in the historical database currently available for Yahoo!.

This research project upgraded the trending functions of the system as follows:

- All available I/O points and setpoints are trended, not a select subset.
- All VAV zone control points are trended on one-minute time intervals.
- The control system's database is used for trend storage as opposed to the previous trend storage method. This was to export a custom Excel sheet of trend data every two weeks for each building. The result is a large collection of spreadsheets that cannot be easily queried.

Controls re-programming. We hired a controls contractor to reprogram all 1,017 VAV units in six Yahoo! buildings so that the buildings can be operated at different minimum flow rates (building C, the dining facility, was excluded due to its unique controls). A diagram of the new control sequences is shown below.

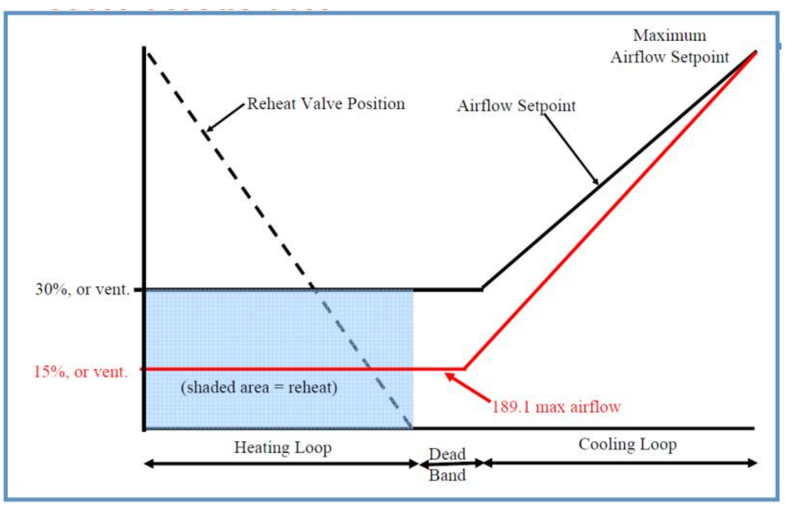


Figure 2.2.3 Control diagram for single maximum VAV logic (black line)

Our specification asked for the zones to have a program with both the existing minimum flow setpoints and the new minimum flow setpoints, but it turned out that the existing Automated Logic U-line controllers did not have the memory capability to perform this extra functionality. The controls contractor proposed an alternative that used a SOAP/XML

Table 2.2.3 Trended information

Building
Outside Air Temperature
KW Demand
AC unit
Supply Fan VFD Speed (%)
Return Fan VFD Speed (%)
Cooling Stages On
Condenser Fan Stages
Economizer Position (%)
Outside Air Flow (KCFM)
Duct Static Pressure (in. w.c.)
Duct Static Pressure SP (in. w.c.)
Return Air Temperature (deg. F)
Supply Air Temperature (deg. F)
Supply Air Temperature SP (deg. F)
RA-CO2 (ppm)
VAV Terminal (Reheat)
Discharge Air Temperature (deg F)
Zone Temperature (deg F)
Cooling Setpoint (deg F)
Heating Setpoint (deg F)
Zone Cooling (%)
Zone Heating (%)
Air Flow Actual (CFM)
Heating Valve Position (%)
VAV Terminal (Fan Powered)
Discharge Air Temperature (deg F)
Zone Temperature (deg F)
Cooling Setpoint (deg F)
Heating Setpoint (deg F)
Zone Cooling (%)
Zone Heating (%)
Air Flow Actual (CFM)
Heating Valve Position (%)
Chiller (trends for building E only)
Chiller-1 Current (amps)
Chiller-2 Current (amps)
Chiller-3 Current (amps)
Chiller-1 CHWS (deg F)
Chiller-2 CHWS (deg F)
Chiller-3 CHWS (deg F)
Chiller-1 CHWR (deg F)
Chiller-2 CHWR (deg F)
Chiller-3 CHWR (deg F)
SCHWS Temperature (deg F)
SCHWRTemperature (deg F)
CHW System Pressure (PSI)
CHWP-1 Status
CHWP-2 Status
CHWP-3 Status
Cooling Requests

connection to the building management system that would read or write the minimum flow rate parameter from an external spreadsheet. An example of the SOAP/XML worksheet is shown in Figure 2.2.4. This interface provided more control over the system than we expected because it allowed the research team to change the minimum flow setpoints to any value in a matter of minutes.

Yahoo Sunyvale Campus Building A

Total Number of VAVs:		187														
		Current Parameters					Write Parameter Set 1					Write Parameter Set 2				
		Read					Write 1					Write 2				
		Airflow Parameters														
Airflow Microblock Reference Names: Bold Parameter Reference Names to Include in Read/Write Parameters)		/legacy_fb/parameters/cd/cma	/legacy_fb/parameters/cd/hma	/legacy_fb/parameters/cd/oma	/legacy_fb/parameters/cd/uma	/legacy_fb/parameters/cd/ahmf	/legacy_fb/parameters/cd/cma	/legacy_fb/parameters/cd/hma	/legacy_fb/parameters/cd/oma	/legacy_fb/parameters/cd/uma	/legacy_fb/parameters/cd/ahmf	/legacy_fb/parameters/cd/cma	/legacy_fb/parameters/cd/hma	/legacy_fb/parameters/cd/oma	/legacy_fb/parameters/cd/uma	/legacy_fb/parameters/cd/ahmf
Equipment	GQL Reference Name Bold GQL Reference to Include in Read/Write Parameters)	Cool Max	Heat Max	Occupied Min	Unoccupied Min	Aux Heat Flow	Cool Max	Heat Max	Occupied Min	Unoccupied Min	Aux Heat Flow	Cool Max	Heat Max	Occupied Min	Unoccupied Min	Aux Heat Flow
VAVRH-A-1-1	**#rha11**	1835	20	100	0	160			0		0					
VAVRH-A-1-2	**#rha12**	1635	200	100	0	160			0		0					
VAVRH-A-1-3	**#rha13**	1925	450	190	0	190			300		300					
VAVRH-A-1-4	**#rha14**	1400	140	500	0	140			300		300					
VAVRH-A-1-5	**#rha15**	2100	700	300	0	210			385		385					
VAVRH-A-1-6	**#rha16**	1635	490	165	0	165			300		300					
VAVRH-A-1-7	**#rha17**	450	400	150	0	100			90		90					
VAVRH-A-1-8	**#rha18**	450	200	150	0	50			90		90					
VAVRH-A-1-9	**#rha19**	810	300	200	0	85			145		145					
VAVRH-A-1-10	**#rha110**	2015	425	500	0	200			385		385					
VAVRH-A-1-11	**#rha111**	1600	605	300	0	200			385		385					
VAVRH-A-1-12	**#rha112**	1340	450	200	0	130			300		300					
VAVRH-A-1-13	**#rha113**	450	180	45	0	45			190		190					
VAVRH-A-1-14	**#rha114**	1500	450	200	0	150			300		300					
VAVRH-A-1-15	**#rha115**	1250	600	200	0	205			385		385					
VAVRH-A-1-16	**#rha116**	1560	510	300	0	150			300		300					

Figure 2.2.4 SOAP/XML interface for uploading new flow setpoints

The controls contractor was also tasked to set up all of the trends required to gather data for our research analysis. The scope of trending reconfiguration included:

- Add new trends to include key parameters for every zone: flow rate, discharge air temperature, reheat valve position, cooling loop output, and heating loop output.
- Add new trends to monitor new power meters: amps, volts, cumulative energy use, and instantaneous power draw.
- Add new trends to monitor VFD drives on supply and exhaust fans: volts, amps, and power.
- Change trend storage to be in an SQL database native to the Automated Logic control system and configure trends to store for 3 months.
- Add new, larger hard drive to store trends.

Installation of power meters and gas metering. The controls contractor also installed energy meters in four of the 6 Yahoo! Buildings (Buildings A, B, E, and G). We measured energy use between November 2010 and May 2012.

- A total of nine power meters were added for each AC unit, and connected to the control systems with a BACnet interface so that power could be trended continuously and stored with other trend data.
- Twelve existing VFD drives on the supply and exhaust fans were connected to the BACnet system so that power input could be trended.
- The controls specification included BTU metering of boilers, but the price was much higher than the project budgeted for. Further conversation with the facilities managers revealed that the only gas appliance in these buildings was the boiler (domestic hot water is provided by electricity) so monitoring of the PG&E gas meters would measure boiler energy input. The existing gas meters did not have pulsed output so we decided to monitor the analog meter dials with digital time lapse photography, using a wildlife observation camera. The method proved to be very cost effective with the only drawback being that the photographs needed to be transcribed. Figure 2.2.5 (below) shows one of the gas metering setups.

Figure 2.2.5 Gas Meter digital photography

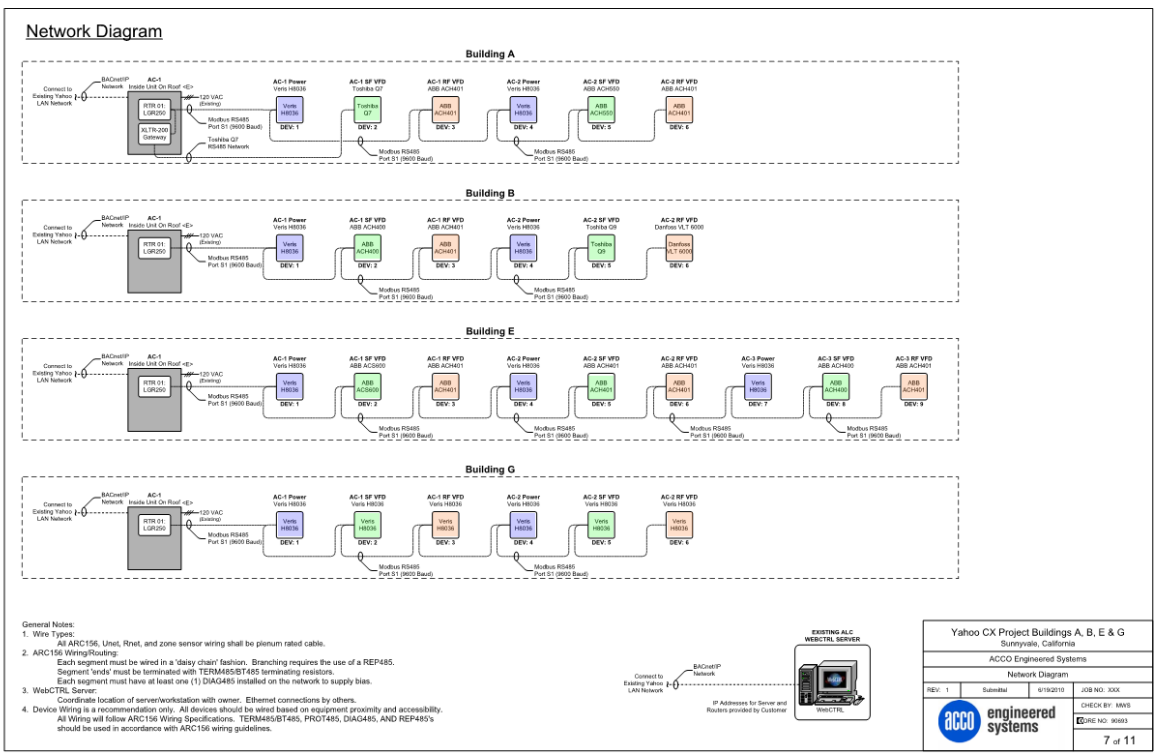


Figure 2.2.6 Control diagram for new power metering

Control diagram for new power metering is shown in Figure 2.2.6. In the figure, blue indicates new power meters, green indicates supply fan power from VFD, and orange indicates return fan power from VFD. See appendix for detailed controls drawings.

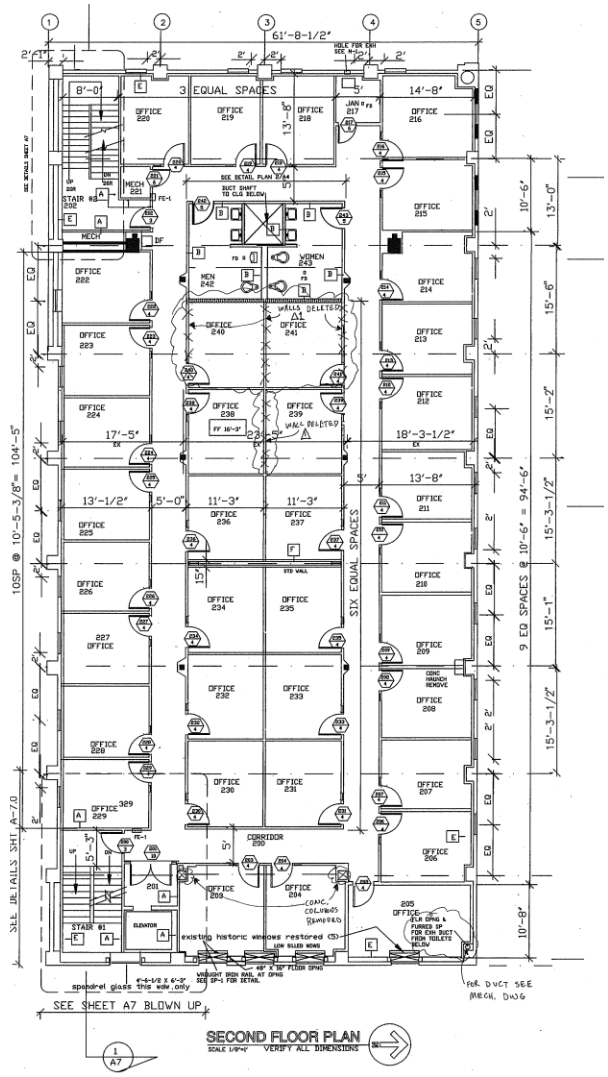
All the new metering provided separate sub-metering of heating (and reheat), cooling, and fan energy. Each of these is impacted by changing VAV minimums, and the metering gave us the capability to measure the magnitude of savings for each end-use.

2.2.3 *A county government office building in Martinez, California*

2.2.3.1 General description

The Contra Costa County legal office is located at 800 Ferry Street, and we refer to it in this report mostly as "800 Ferry." It is a 20,000 ft^2 historical theater building that was renovated into an office building in 1997. Private offices comprise 60% of the floor space with the remaining space consisting of conference rooms, open plan offices, and other support spaces. Perforated diffuser with blades in face are used.

Picture 2.2.1 Contra Costa County legal office



Picture 2.2.2 Contra Costa County legal office 2nd floor plan

2.2.3.2 VAV box types

The building has 22 VAV zones. 4 zones are cooling only VAV and the rest are VAV with hot water reheat.

2.2.3.3 Description of Site Control System and Trending Capability

The site controls system is Alerton BacTalk.

2.2.3.4 Controls re-programming

We hired a controls contractor to install energy meters connected to the control system for trending. The original minimum flow rates were high, in the range of 30 – 50%. The building engineer made the changes to the VAV minimums when the research team requested a change. The small number of zones made manual changes feasible, unlike the huge Yahoo! study site where automated switch-over was required.

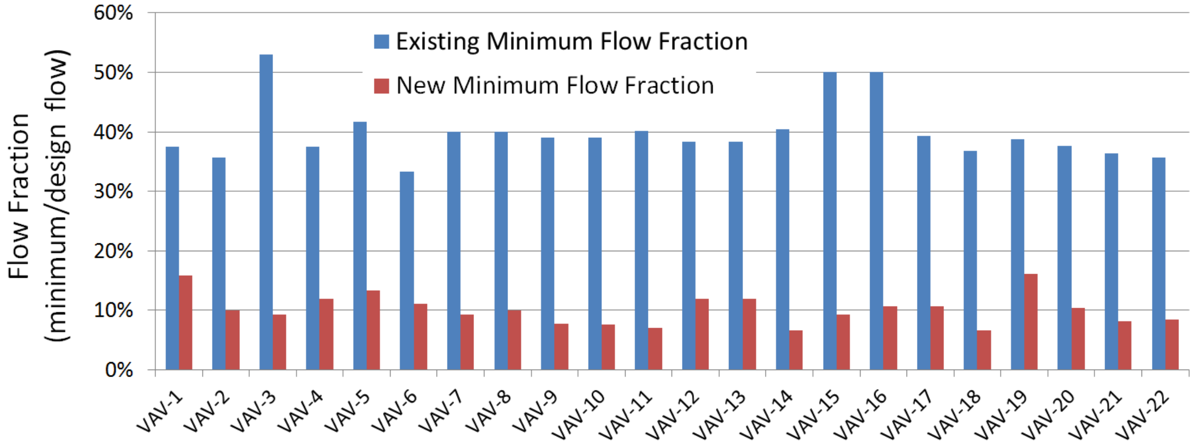


Figure 2.2.7 800 Ferry comparison of minimum airflow setpoint before and after intervention

800 Ferry VAV Box Minimum Flow Setpoints

		Current Setpoints			New Setpoints		
VAV Number	Device ID	Maximum CFM	Minimum CFM	Reheat CFM	Maximum CFM	Minimum CFM	Reheat CFM
VAV-1	1065	1200	450	650	1200	190	650
VAV-2	1066	1400	500	700	1400	140	700
VAV-3	1067	1980	1050	1200	1980	185	1200
VAV-4	1068	1600	600	600	1600	190	600
VAV-5	1069	600	250	300	600	80	300
VAV-6	1070	900	300	450	900	100	450
VAV-7	1071	1500	600	795	1500	140	795
VAV-8	1072	1000	400	500	1000	100	500
VAV-9	1073	1280	500	640	1280	100	640
VAV-10	1074	2560	1000	1280	2560	195	1280
VAV-11	1075	1990	800	995	1990	140	995
VAV-12	1076	2215	850	1110	2215	265	1110
VAV-13	1077	2215	850	1110	2215	265	1110
VAV-14	1078	2840	1150	1320	2840	190	1320
VAV-15	1079	700	350	350	700	65	350
VAV-16	1080	700	350	400	700	75	400
VAV-17	1081	1400	550	700	1400	150	700
VAV-18	1082	2850	1050	1425	2850	190	1425
VAV-19	1083	840	325	420	840	135	420
VAV-20	1084	1730	650	865	1730	180	865
VAV-21	1085	2340	850	1170	2340	190	1170
VAV-22	1086	2240	800	1120	2240	190	1120

Figure 2.2.8 800 Ferry VAV airflow setpoints before and after intervention

2.2.3.5 *Installation of power meters and gas metering.*

We installed separate meters for the supply fan, return fan, and AC units, a total of 4 in 800 Ferry.

2.3 *Occupant survey*

We conducted two types of occupant satisfaction surveys. The *right-now* survey asks people's subjective perceptions right at the moment of answering the questions. The survey measures occupants' responses to thermal comfort, local body part discomfort, air movement perception, perceived indoor air quality, acoustical quality, and other indoor environment related questions. The right-now survey was administered under both high- and low-minimum operation, allowing us to compare occupant perceptions between the two operation modes. The *background* survey measures occupants' long-term satisfaction with their work environments in terms of thermal comfort and other indoor environment related questions. For this we used the CBE web-based occupant satisfaction survey, so that its results could be compared to a large database of previous results (65,000 respondents in 600 buildings) for benchmarking. The purpose of the background survey was to compare the occupants' satisfaction with buildings that have been operated under low minimum flows against the entire CBE benchmarking database of buildings.

2.3.1 *Repetitive occupant satisfaction right-now surveys*

Yahoo! buildings. We conducted the right-now survey in the six office buildings on the Yahoo! Campus (the other building is a cafeteria) during the cool season from Dec. 2 – Dec. 23, 2010, and during the warm season from Sept. 29 – Oct. 26, 2011. We received about 7330 individual responses from 432 occupants during the cool season, and 2100 responses from 83 occupants during the warm season.

We surveyed occupants' satisfaction during three 3 – 4 week periods in the warm and cool seasons (about three months in total). The survey questionnaire was conducted three times per day, normally around 10 AM, 2 PM, and 4 PM. About the middle of each survey period, we switched the low minimum flow rate between high and low minimum operation, using the toggle function described above. The schedules of the high/low minimum flow rate during the occupant survey period, together with the number of participants and number of responses, are shown in Table 2.3.1.

	Low minimum flow rate	High minimum flow rate	Number of responses	Number of participants
Yahoo! cool season	Dec. 2 – 13, 2010, 2 PM	Dec. 13 2 PM – Dec 23, 2011	7330	432
Yahoo! warm season	Oct. 10 5 PM – Oct. 26, 2011	Sep. 29 - Oct. 10, 2011, 5 PM	2100	83
800 Ferry warm season	Oct. 6, 6 AM – Oct. 21, 2011	Sept. 22 – Oct. 5, 2011, 6 AM	996	61

Table 2.3.1 Survey periods under high/low minimum flow rates

800 Ferry building. We conducted surveys only during the warm season (Sept. 22 – Oct. 21 2011), since we were unable to start before March 2011. After installing the control toggles and power meters, only the warm season was available for the occupants' satisfaction survey. In this survey, we received 996 individual votes from 61 occupants.

To invite people to participate in the survey, CBE first asked the building managers to send an invitation letter to employees inviting them to participate. The letter contained a web link allowing those who agreed to participate to register their email address. These occupants were later sent reminders to complete the surveys. Survey questionnaire reminders were sent out three times per day by a CBE researcher during the survey periods, normally around 10 AM, 2 PM, and 4 PM. The survey reminders each provided a link for people to take the survey. The first page is the consent form, approved by the UC Berkeley committee for protection of human subject test (CPHS committee). The questionnaire measured occupants' satisfactions in terms of thermal comfort, local body part discomfort, air movement perception, perceived indoor air quality, acoustical quality, and other questions related to the indoor environment. The survey also included branching questions that appear whenever occupants express dissatisfaction in response to a survey question, to help identify the source of the dissatisfaction. The branching questions asked about diffuser dumping, drafts, cold feet, and other issues that might pertain to low VAV airflows. The complete survey questions are included in A.

2.3.2 *Background survey*

We conducted the CBE background survey in the six Yahoo buildings and one building at UC Merced. These buildings had been already been operating under low minimum flow rate setpoint for over a year. The CBE survey questionnaire (http://www.cbe.berkeley.edu/research/survey.htm) and the unique size of its database (about 65,000 responses to the same question set in 600 buildings) provides a stable benchmark for evaluating the indoor environmental qualities of study buildings and comparing them with a large set of conventional buildings. So the Yahoo! and Merced surveys measure the long-term satisfaction possible for buildings operated under low minimums. A background survey was also carried out at 800 Ferry, but because this this building had been operated more conventionally using high minimums it does not provide a comparison.

The Background Survey took approximately 10-15 minutes to complete. It began with basic demographic questions about age, gender, then the amount time working in the building and at their workstation, and experience with air-conditioning in previous buildings, at their home, and in their car. The background survey measures occupants' satisfaction with, and assessment of, their work environments in terms of thermal comfort, perceived indoor air quality, and other indoor environment related questions. The background survey includes branching questions that appear whenever occupants express dissatisfaction in response to a survey question, to help identify the source of dissatisfaction. The branching questions included questions about diffuser dumping, drafts, cold feet, and other issues that might pertain to low VAV airflows. The entire right-now survey questionnaire is included in A .

The background survey was conducted February 26 – March 12, 2011 in the 6 Yahoo! buildings, November 28 – December 17, 2011 in a small office building at UC Merced. 1279 people at Yahoo! participated in the background survey (33% of the Yahoo! population, and 44 out of 85 in the office building at UC Merced (52% response rate).

Before conducting the right-now survey in the 800 Ferry building, we also conducted CBE background survey in the 800 Ferry building in July 28 – August 15.

3 RESULTS

The results will be placed into four categories: (1) HVAC system control analysis comparing the diffuser flow rates under high and low minimum operation, (2) occupants' satisfaction survey based on both the repeated right-now survey and the background survey, (3) energy savings analysis based on measured data, and (4) chamber tests to determine temperature and velocity profiles for various diffuser types and additional flow rates.

3.1 *Observed flow rates under high and low minimum VAV flow rate operations*

Yahoo buildings. Trends for the new power meters, VFD power input, and all VAV zones were collected from October 2010 – May 2012. The database grew by about 10 GB per week. During the study, the VAV minimum flow setpoints were alternated several times between the new calculated low minimums, and 30% minimums representing standard commercial building practice.

3.1.1 *Low minimum flow setpoint distribution in existing Yahoo! buildings*

The original HVAC engineering and controls drawings for the Yahoo campus stipulated 30% minimum flow rates for all VAV boxes. The Yahoo facility managers believed that the campus was still operating at the original 30% minimum. Analysis of the controls programming revealed that the Yahoo buildings were in fact operating with low minimum flow rate setpoints before the intervention. Figure 3.1.1 shows the existing minimum flow setpoints for the entire campus.

We analyzed roughly one year's worth of trend data (before Oct 2010 when the study started) for zones on campus. Roughly 870 zones had been trended, and provided usable data.

Actual behavior was categorized in terms of the airflow that occurred during heating and cooling, and broken out by type of air terminal: cooling-only, reheat, and fan-powered terminals were reviewed separately.

Table 3.1.1 shows that the minimum airflow rate varies quite widely: some zones already have a 10% minimum airflow (about 180 total). 35% of Yahoo! zones had minimum flow rate below 10%. 68% of zones had minimum flow rates below 20%, lower than the conventional minimum of 30%. Therefore, the Yahoo buildings had been operating under low minimum flow rate.

Table 3.1.1 Zone airflow analysis

Min. airflow as % of max airflow	# of zones	% of total zone count	
0%	85	9.7%	
5%	42	4.8%	
10%	180	20.6%	35%
15%	138	15.8%	
20%	150	17.2%	33%
25%	78	8.9%	
30%	88	10.1%	19%
35%	42	4.8%	
40%	28	3.2%	8%
45%	12	1.4%	
50%	10	1.1%	3%
55%	8	0.9%	
60%	4	0.5%	
65%	3	0.3%	
70%			
75%	4	0.5%	2%
	872		100%

While it is not clear why the VAV box minimum flow fractions were reset to values less than 30%, it was probably done over time by facilities staff. Facilities staff typically operate in a reactive mode, responding to occupant complaints as they occur. Various hot, cold, draft, or ventilation complaints were probably dealt with by adjusting zone parameters. The zone maximum flow setpoints also varied from the original design drawings, indicating that most setpoints have been adjusted at some point in time.

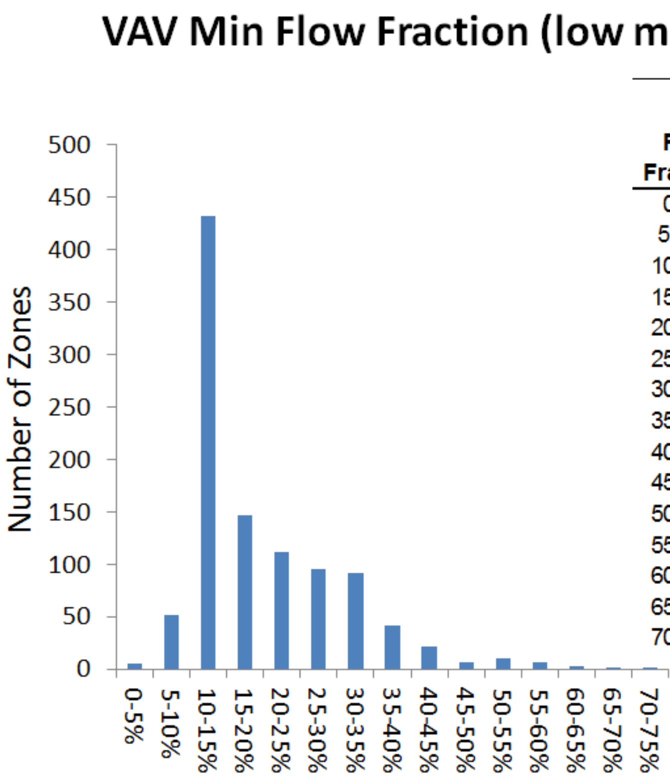
3.1.2 ***Calculation of new setpoints for experimental intervention***

Calculation of new zone minimums. Minimum flow setpoints were calculated according to the procedures recommended in in the Energy Design Resources Advanced VAV Design Guide (EDR 2010) and (Taylor & Stein 2004, Taylor et. Al 2012) and an abbreviated description follows: The minimum flow rate that a VAV box can operate is limited by the code-required minimum ventilation rate and by the limitations of the controllers that become unstable or inaccurate at very low flow. Ventilation rates are prescribed in the California Title 24 Building Code and for office buildings are determined by the maximum of 15 CFM/person or 0.15 CFM/ft^2. VAV controllers are limited by the pressure transducer that reads the velocity pressure at the VAV flow cross sensor. VAV pressure transducers can read down to 0.004" H_2O column.

For each zone on campus we gathered the following information:

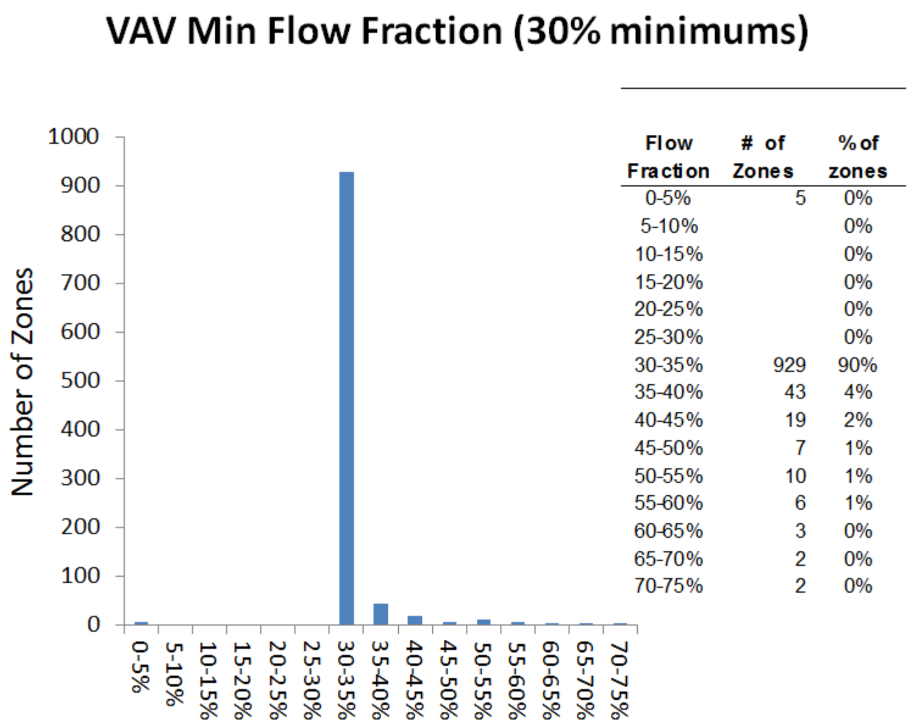
- Zone area (ft^2) – Derived from mechanical CAD drawings
- Number of people in each zone
- VAV box size (to determine the controllable minimum)

A new minimum flow was calculated for every zone from these data. Experiments were carried out in two operating modes that we call 'high' and 'low'. The high mode set every zone to a 30% minimum, unless the ventilation rate was higher, to reflect standard practice and the original design for the Yahoo campus. Five zones had zero minimums in both modes because they served unoccupied spaces such as data closets. Low minimum mode setpoint calculation was described previously. Setpoints are summarized in the following figures.



Flow Fraction	# of Zones	% of zones
0-5%	5	0%
5-10%	51	5%
10-15%	432	42%
15-20%	146	14%
20-25%	112	11%
25-30%	95	9%
30-35%	92	9%
35-40%	42	4%
40-45%	21	2%
45-50%	7	1%
50-55%	10	1%
55-60%	6	1%
60-65%	3	0%
65-70%	2	0%
70-75%	2	0%

Figure 3.1.1 Distribution of zone minimum setpoints (flow fraction) for new low minimum setpoints



Flow Fraction	# of Zones	% of zones
0-5%	5	0%
5-10%		0%
10-15%		0%
15-20%		0%
20-25%		0%
25-30%		0%
30-35%	929	90%
35-40%	43	4%
40-45%	19	2%
45-50%	7	1%
50-55%	10	1%
55-60%	6	1%
60-65%	3	0%
65-70%	2	0%
70-75%	2	0%

Figure 3.1.2 Distribution of zone minimum setpoints (flow fraction) for 30% minimum

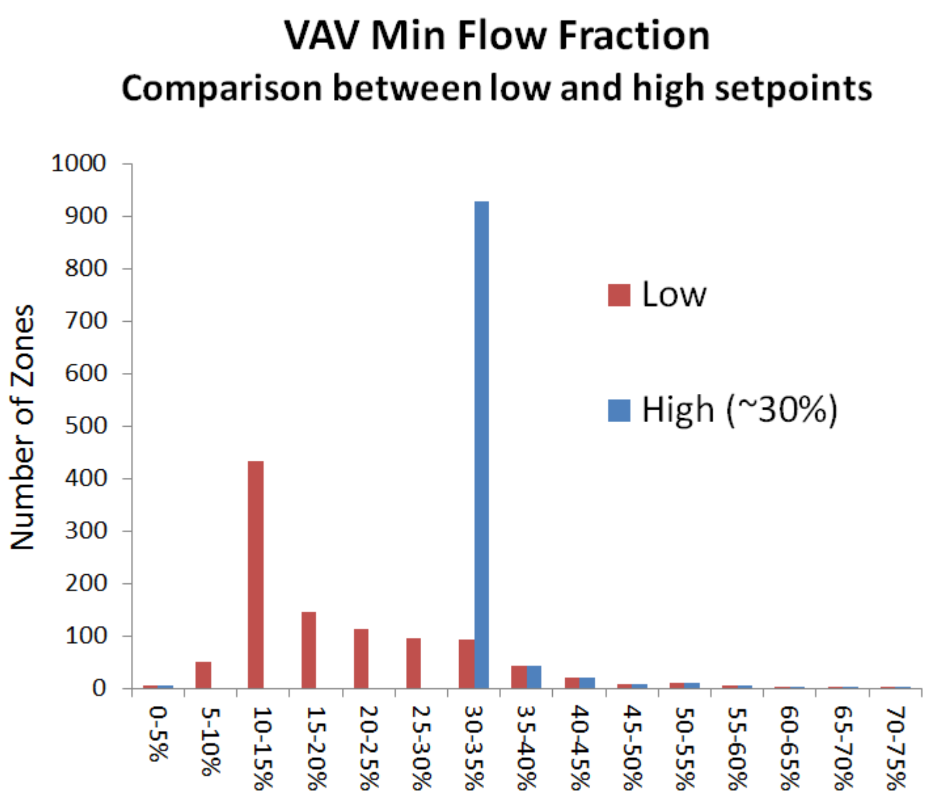


Figure 3.1.3 Distribution of zone minimum setpoints (flow fraction) comparing high (~30%) minimums to low minimums

Above 30% the zone counts are identical because the minimum is set by the ventilation rate.

3.1.3 *An example of actual flow rate distribution in an existing Yahoo! building*

In the previous section, Figure 3.1.1 to Figure 3.1.3 show the setpoints of the minimum flow rates for zones and different types of terminals in the Yahoo! buildings before intervention. In this section, we will show the actual flow rate distribution in existing Yahoo! buildings by showing one example.

The area that we will show is in Building A, 3rd floor, facade facing WSW (corresponding to Area D in Figure 3.1.4)

Figure 3.1.4 Building A, 3rd floor, plan view

The actual flow rate summary for an entire year (July 2009 – July 2010) is displayed in Figure 3.1.5. These VAV units serve adjacent zones, with preheats daily. From the actual flow rate distribution, we see that high percentage of time the VAV units were operated under low minimum flow rate. That indicates the potential to save energy when the minimum flow rate setpoint is lowered.

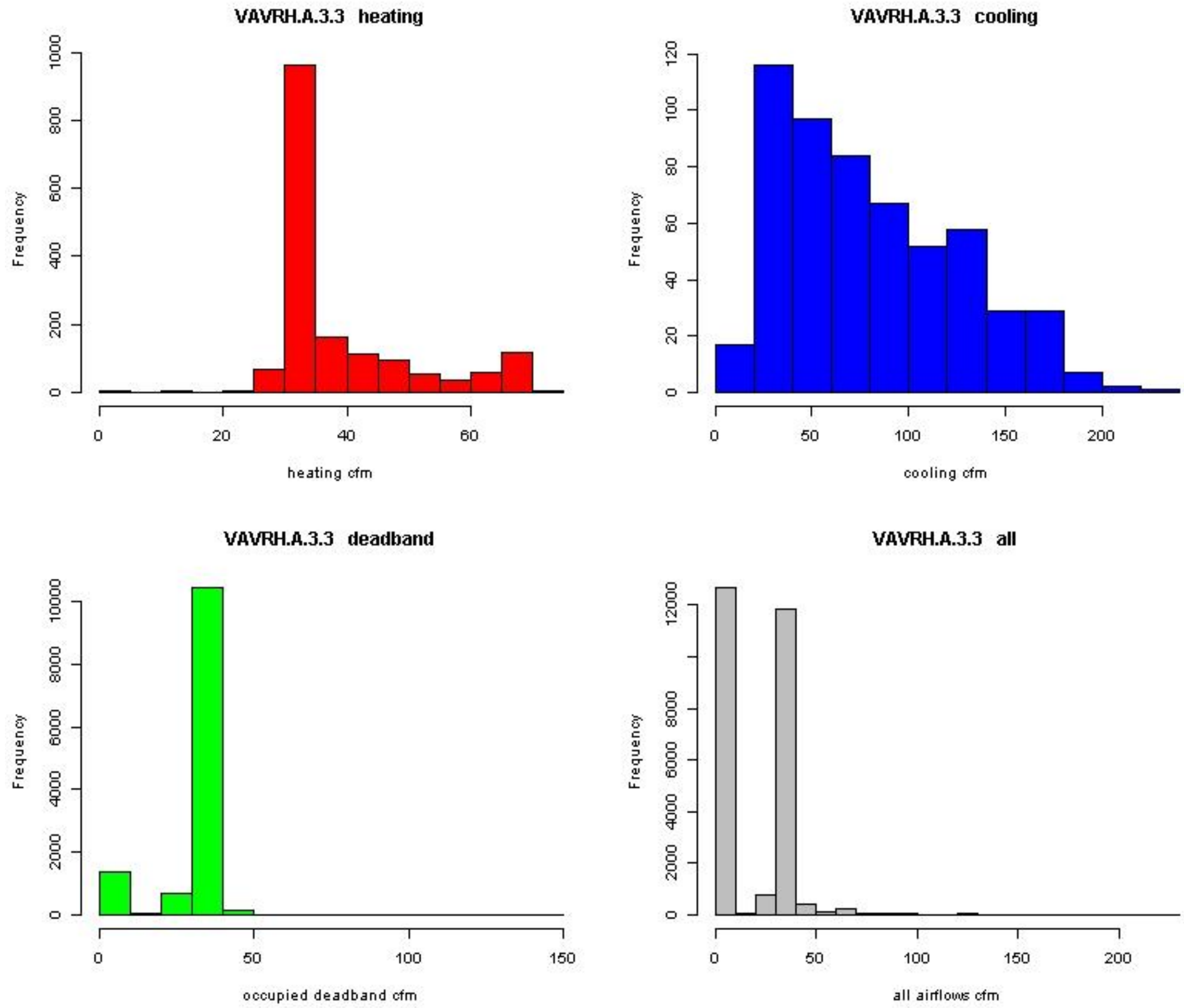
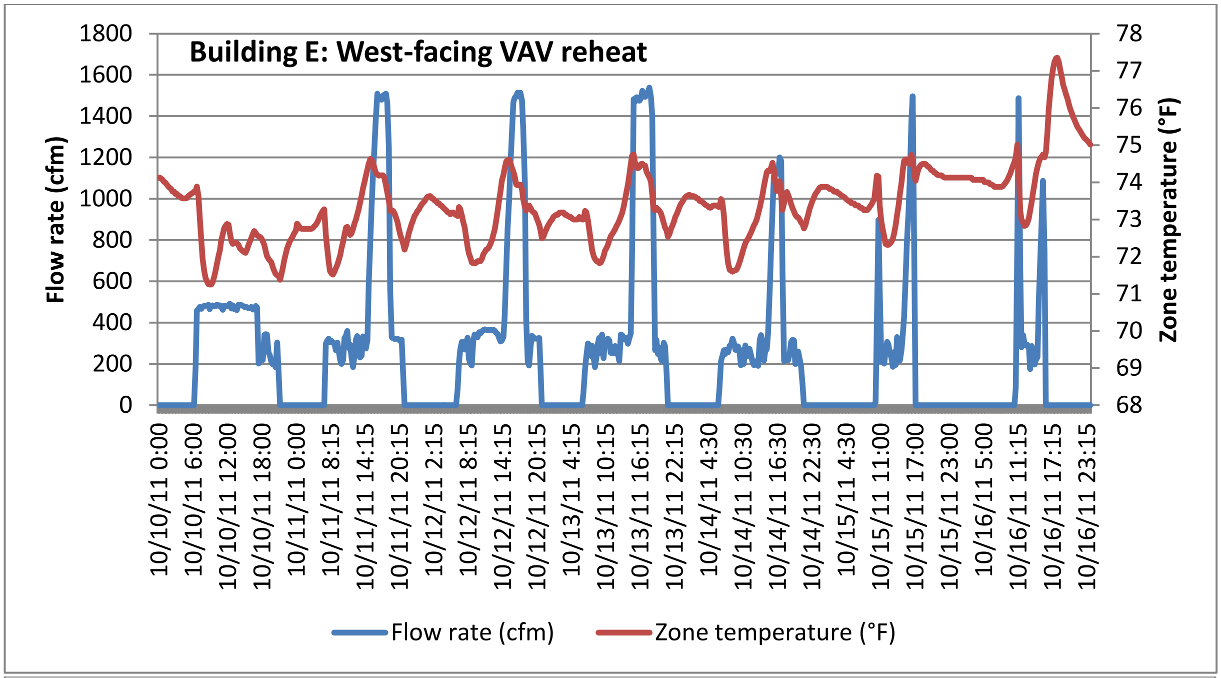
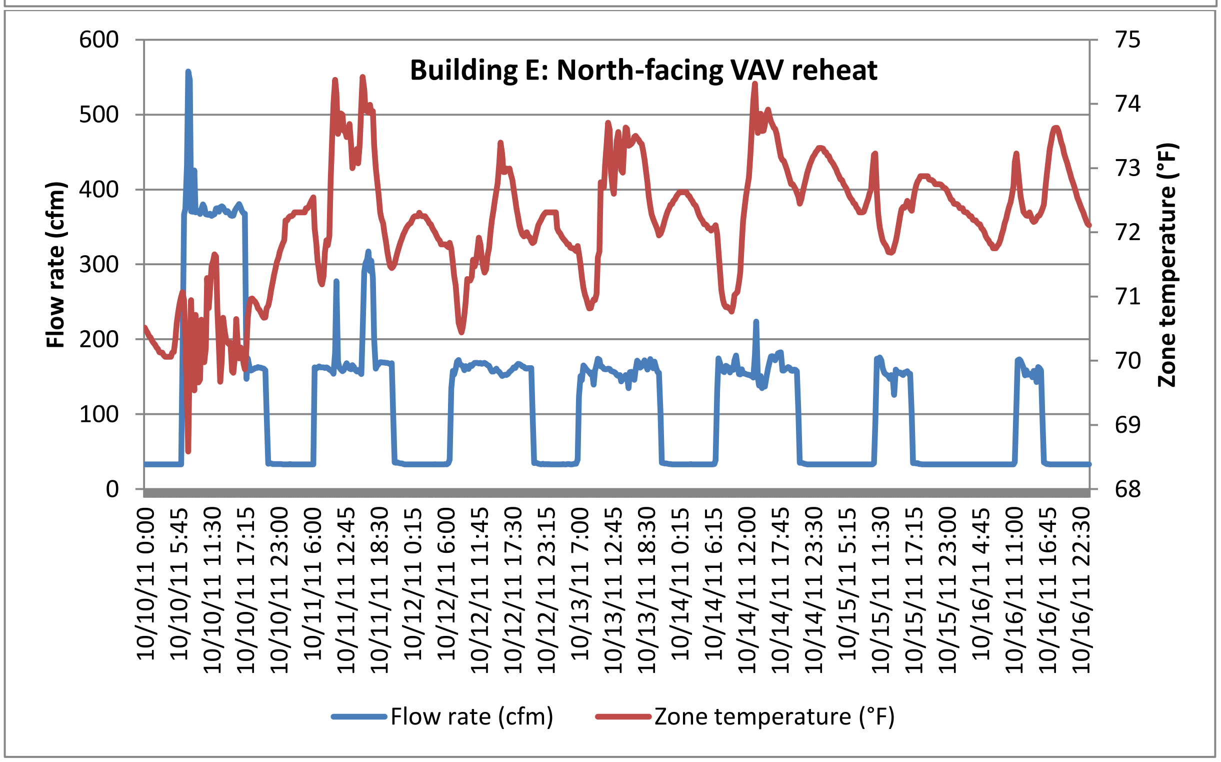


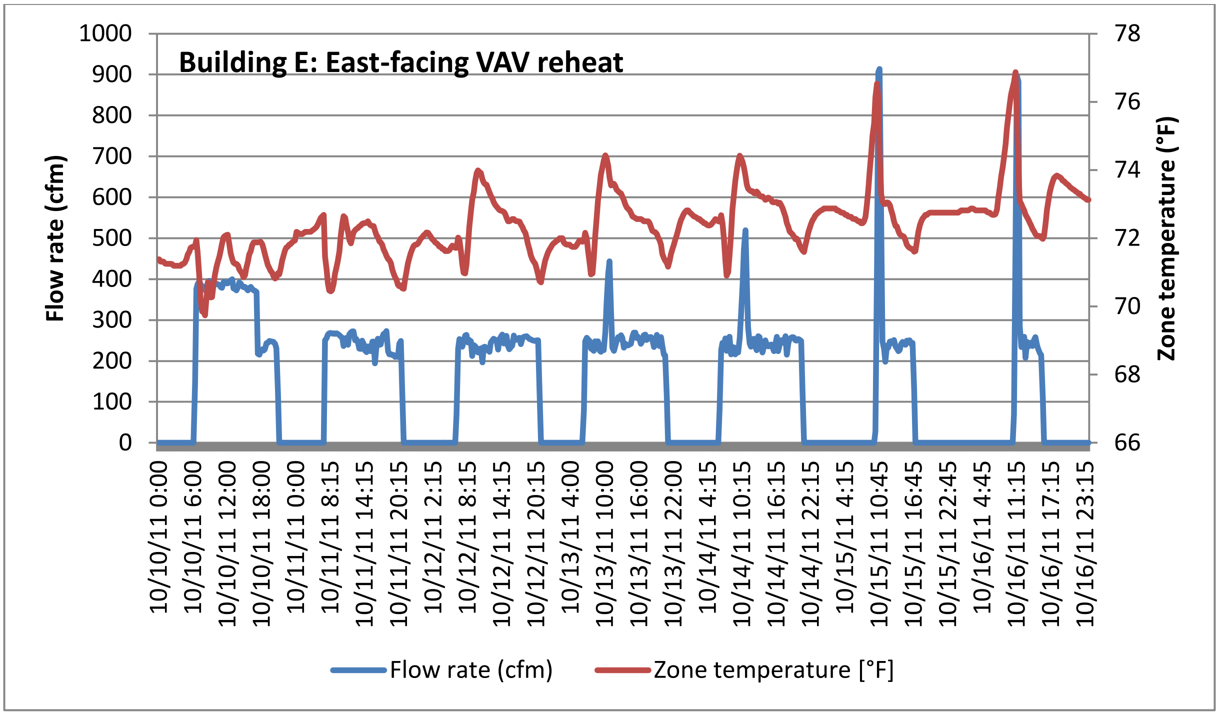
Figure 3.1.5 Actual flow rate distribution for Building A 3rd floor area D

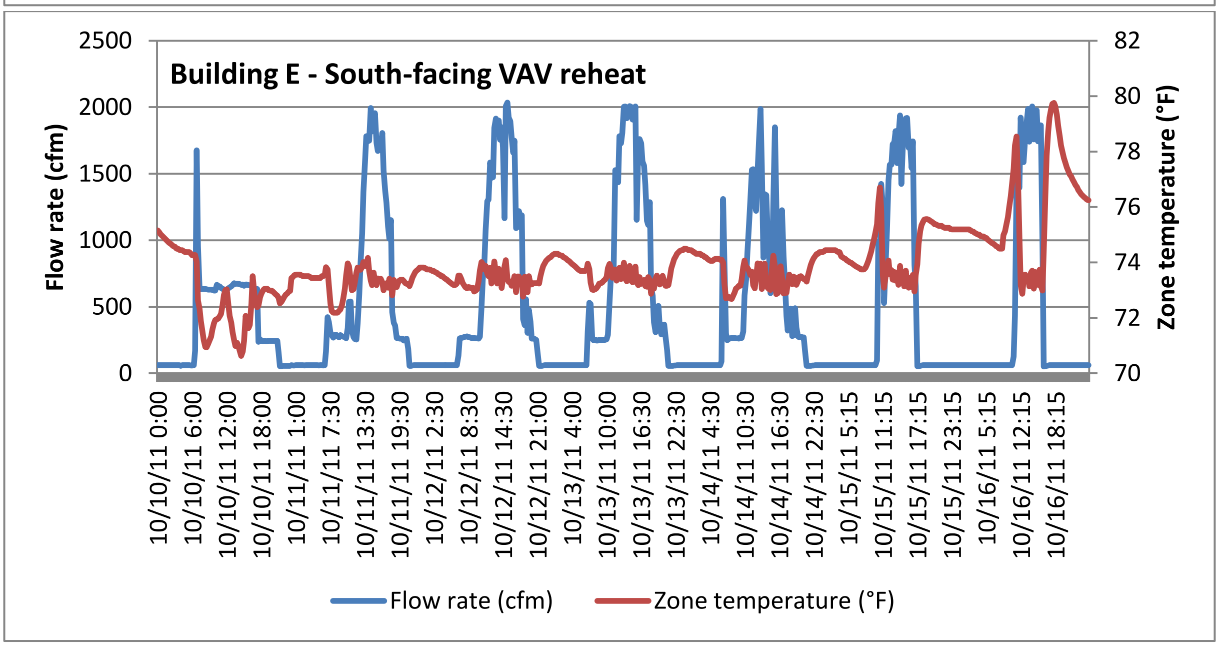
VAV units operate at low minimum often, as the following figures demonstrate. With the exception of VAV units serving south-facing zones, units tend to operate at minimum for the majority of the day. During the warm season, a west-facing zone operates at minimum for most of the day, and cools during the late afternoon. On occasion, there will be a brief period of precooling in the morning. For north-facing zones, cooling is occasional, and it is not atypical for the unit to be at minimum all day. East-facing zones often have a brief period of cooling in the morning and operate at minimum for the rest of the day. A typical south-facing zone actively cools throughout warm days. During the cool season, west-facing zones will have a morning warm-up, and maintain setpoint operating mostly at minimum flow. East-facing zones behave similarly. North-facing zones, despite usually being the coolest zones, will operate at minimum for most of the day, typically heating in the morning and late afternoon. In this particular climate, south-facing zones tend to cool throughout the year, as conditions are mild. Core zones operate mostly at minimum regardless of the season. Overall, the time that zones spend at minimum is quite significant, and thus has a large impact on energy consumption.

The following several charts illustrate the descriptions of the behavior of zones facing each exposure, in this case for Building E. They show flow rates and corresponding zone temperatures throughout a typical week in each of the warm and cool seasons (10 – 16 Oct 2011 for the warm season, and 12 – 18 Feb 2012 for the cool season). These figures illustrate how frequently the zones operate at minimum volume.


Building E: West-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
1800
1600
1400
1200
1000
800
600
400
200
0
78
77
76
75
74
73
72
71
70
69
68
10/10/11 0:00
10/10/11 6:00
10/10/11 12:00
10/10/11 18:00
10/11/11 0:00
10/11/11 8:15
10/11/11 14:15
10/11/11 20:15
10/12/11 2:15
10/12/11 8:15
10/12/11 14:15
10/12/11 20:15
10/13/11 4:15
10/13/11 10:15
10/13/11 16:15
10/13/11 22:15
10/14/11 4:30
10/14/11 10:30
10/14/11 16:30
10/14/11 22:30
10/15/11 4:30
10/15/11 11:00
10/15/11 17:00
10/15/11 23:00
10/16/11 5:00
10/16/11 11:15
10/16/11 17:15
10/16/11 23:15
Flow rate (cfm)
Zone temperature (°F)


Building E: North-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
600
500
400
300
200
100
0
75
74
73
72
71
70
69
68
10/10/11 0:00
10/10/11 5:45
10/10/11 11:30
10/10/11 17:15
10/10/11 23:00
10/11/11 6:00
10/11/11 12:45
10/11/11 18:30
10/12/11 0:15
10/12/11 6:00
10/12/11 11:45
10/12/11 17:30
10/12/11 23:15
10/13/11 7:00
10/13/11 12:45
10/13/11 18:30
10/14/11 0:15
10/14/11 6:15
10/14/11 12:00
10/14/11 17:45
10/14/11 23:30
10/15/11 5:15
10/15/11 11:30
10/15/11 17:15
10/15/11 23:00
10/16/11 4:45
10/16/11 11:00
10/16/11 16:45
10/16/11 22:30
Flow rate (cfm)
Zone temperature (°F)


Building E: East-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
Flow rate (cfm)
Zone temperature [°F]


Building E - South-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
Flow rate (cfm)
Zone temperature (°F)

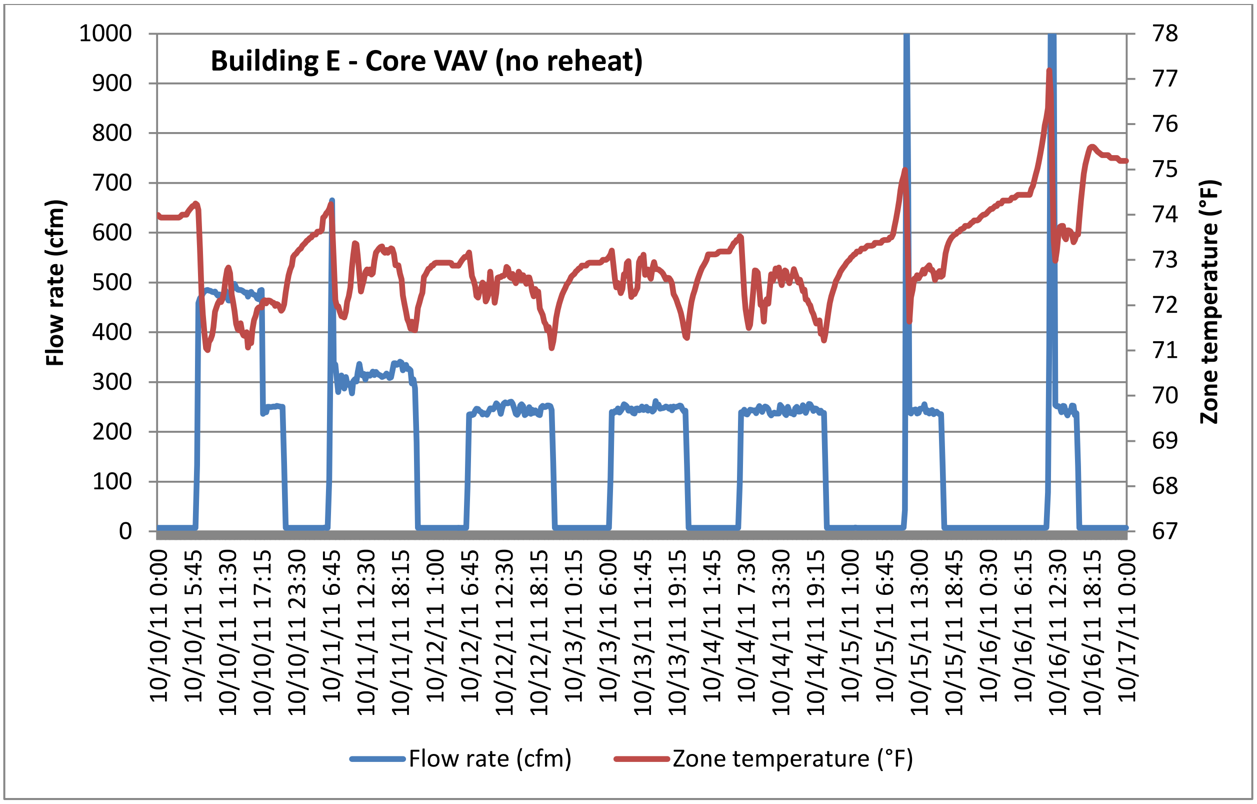
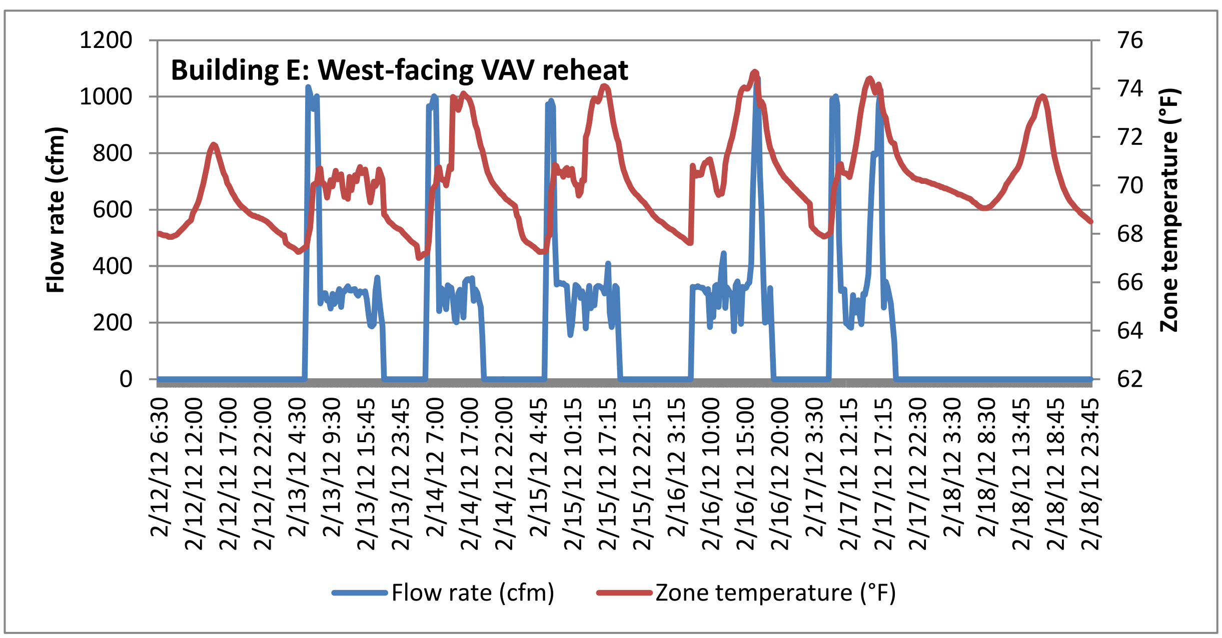
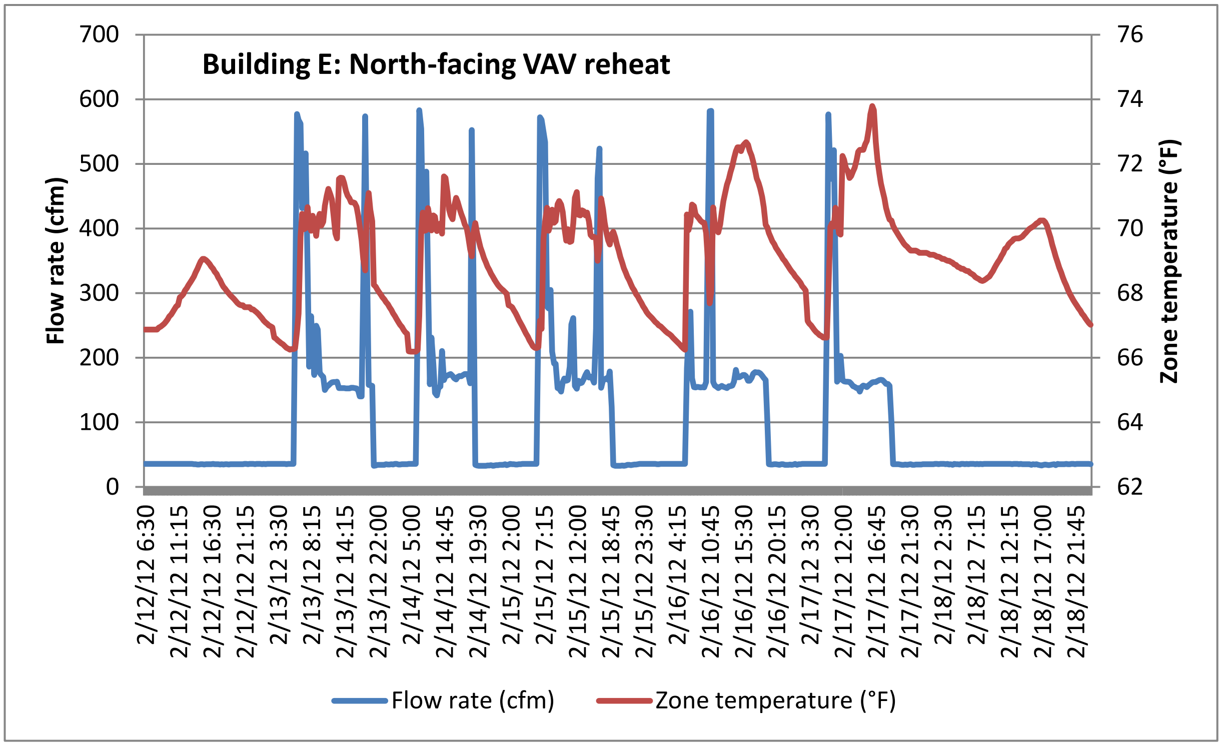
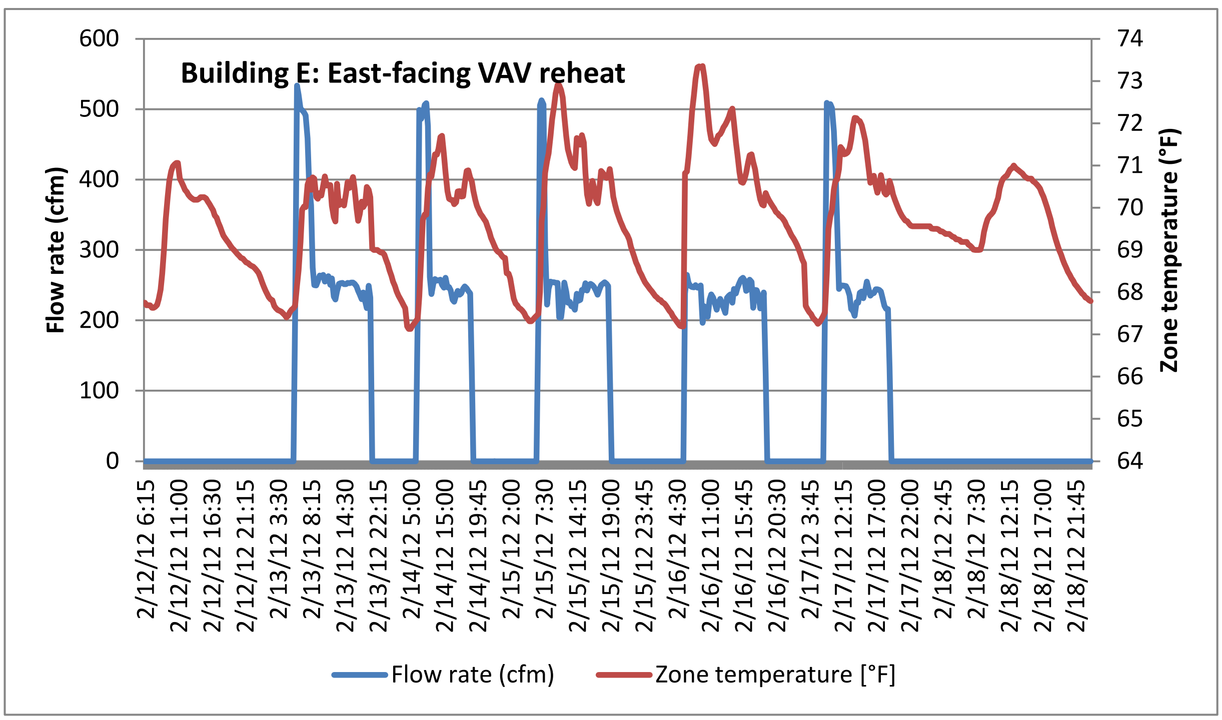


Figure 3.1.6 Warm season: October 10-17

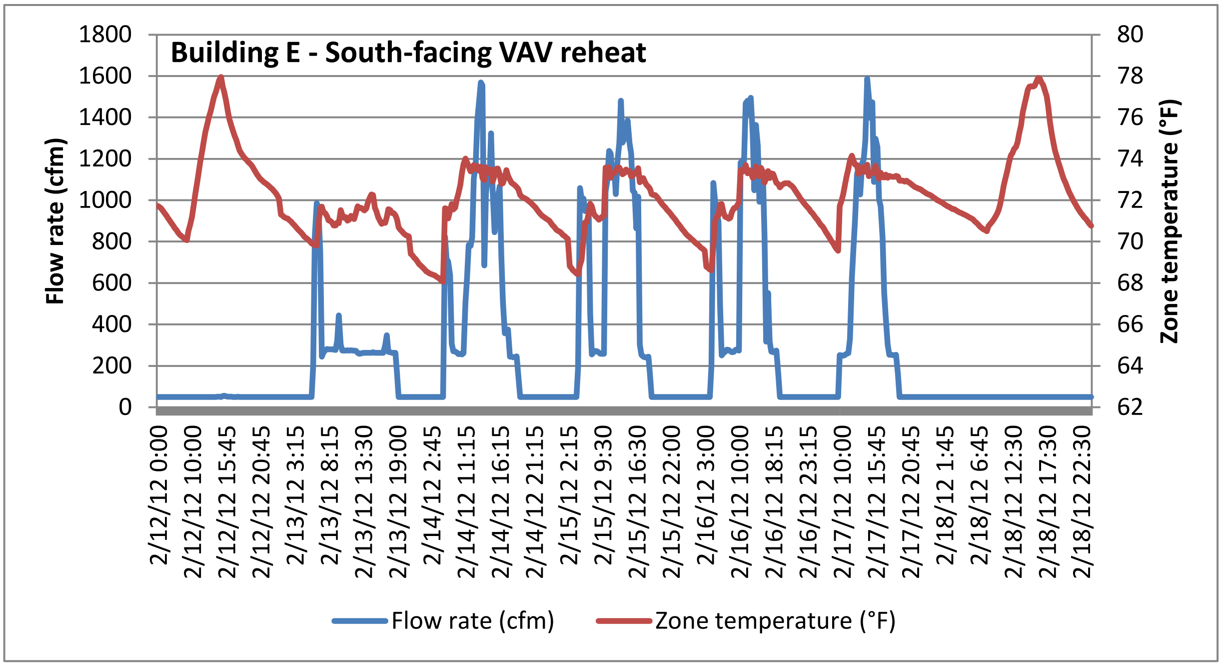




Building E: North-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
700
600
500
400
300
200
100
0
76
74
72
70
68
66
64
62
2/12/12 6:30
2/12/12 11:15
2/12/12 16:30
2/12/12 21:15
2/13/12 3:30
2/13/12 8:15
2/13/12 14:15
2/13/12 22:00
2/14/12 5:00
2/14/12 14:45
2/14/12 19:30
2/15/12 2:00
2/15/12 7:15
2/15/12 12:00
2/15/12 18:45
2/15/12 23:30
2/16/12 4:15
2/16/12 10:45
2/16/12 15:30
2/16/12 20:15
2/17/12 3:30
2/17/12 12:00
2/17/12 16:45
2/17/12 21:30
2/18/12 2:30
2/18/12 7:15
2/18/12 12:15
2/18/12 17:00
2/18/12 21:45
Flow rate (cfm)
Zone temperature (°F)



Building E: East-facing VAV reheat
Flow rate (cfm)
Zone temperature (°F)
600
500
400
300
200
100
0
74
73
72
71
70
69
68
67
66
65
64
2/12/12 6:15
2/12/12 11:00
2/12/12 16:30
2/12/12 21:15
2/13/12 3:30
2/13/12 8:15
2/13/12 14:30
2/13/12 22:15
2/14/12 5:00
2/14/12 15:00
2/14/12 19:45
2/15/12 2:00
2/15/12 7:30
2/15/12 14:15
2/15/12 19:00
2/15/12 23:45
2/16/12 4:30
2/16/12 11:00
2/16/12 15:45
2/16/12 20:30
2/17/12 3:45
2/17/12 12:15
2/17/12 17:00
2/17/12 22:00
2/18/12 2:45
2/18/12 7:30
2/18/12 12:15
2/18/12 17:00
2/18/12 21:45
Flow rate (cfm)
Zone temperature [°F]



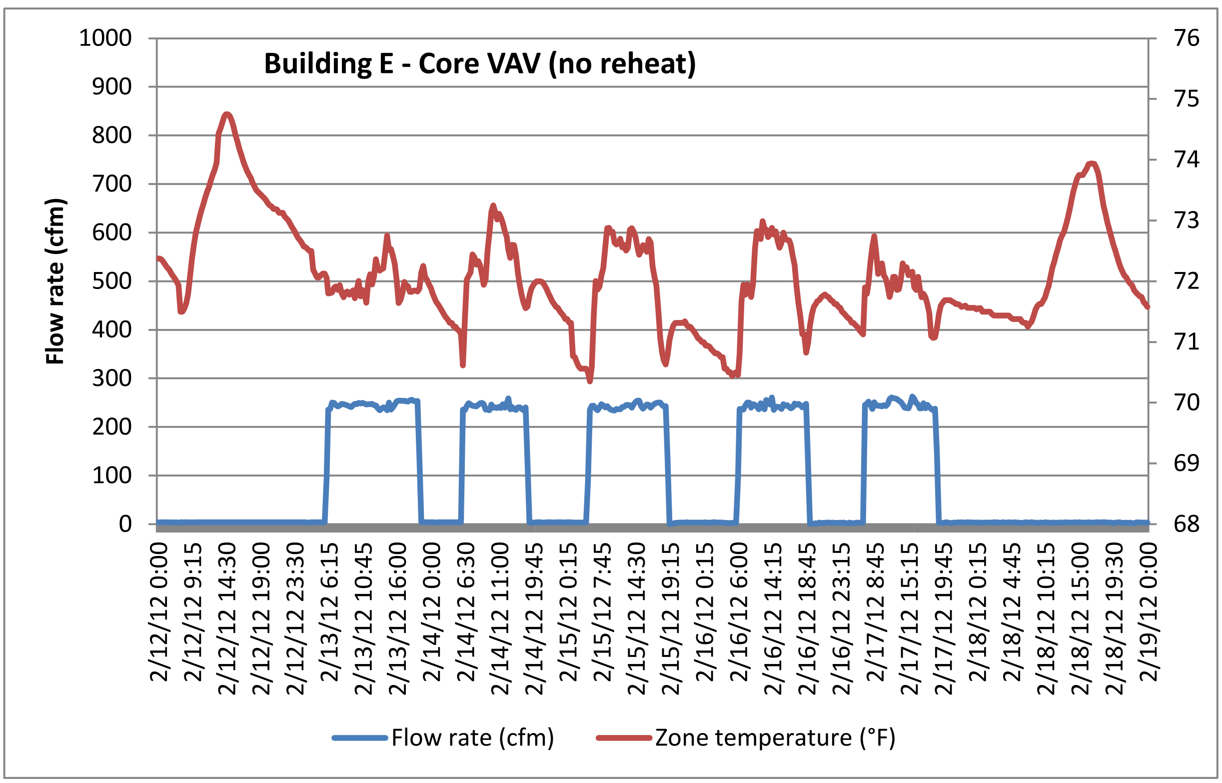


Figure 3.1.7 Cool season: February 12 – 18

The temperature setpoints in the Yahoo! buildings vary between zones significantly. The setpoint differences are likely the result of both varying design specifications between zones and facilities technicians responding to complaints. The typical heating setpoint is 70°F, and the typical cooling setpoint is 74°F, but it is not uncommon for a zone to deviate from the typical setpoints by 2°F or more. Figure 3.1.8 provides a histogram of the distribution of heating and cooling setpoints.

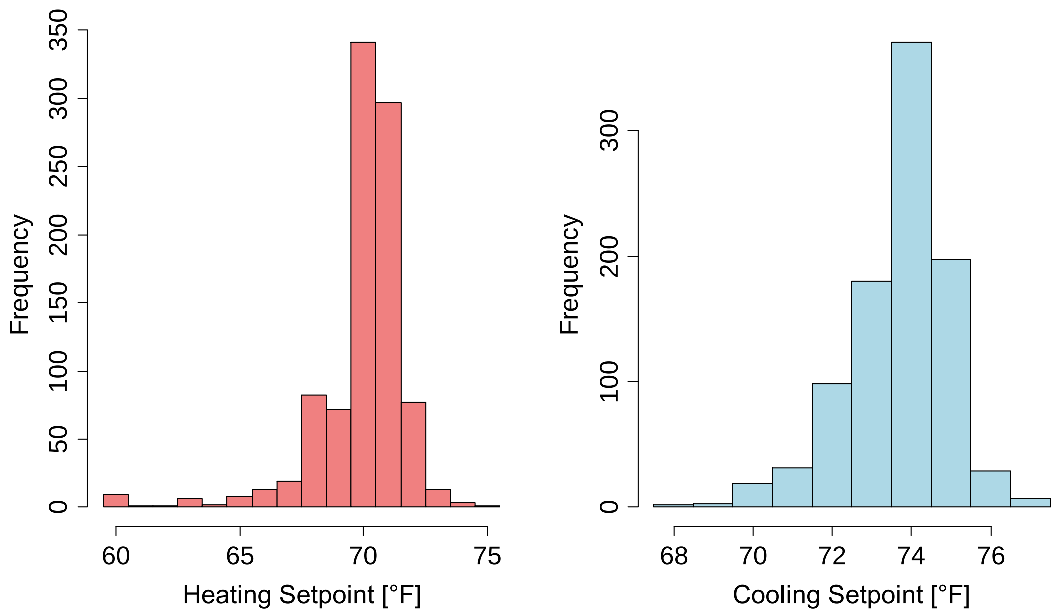


Figure 3.1.8 Yahoo! campus VAV heating and cooling setpoint distributions

Another important aspect of system control that can impact energy consumption is supply air temperature reset. The reset strategy is visualized in Figure 3.1.9, which shows how the supply air temperature decreases as the outside air temperature increases.

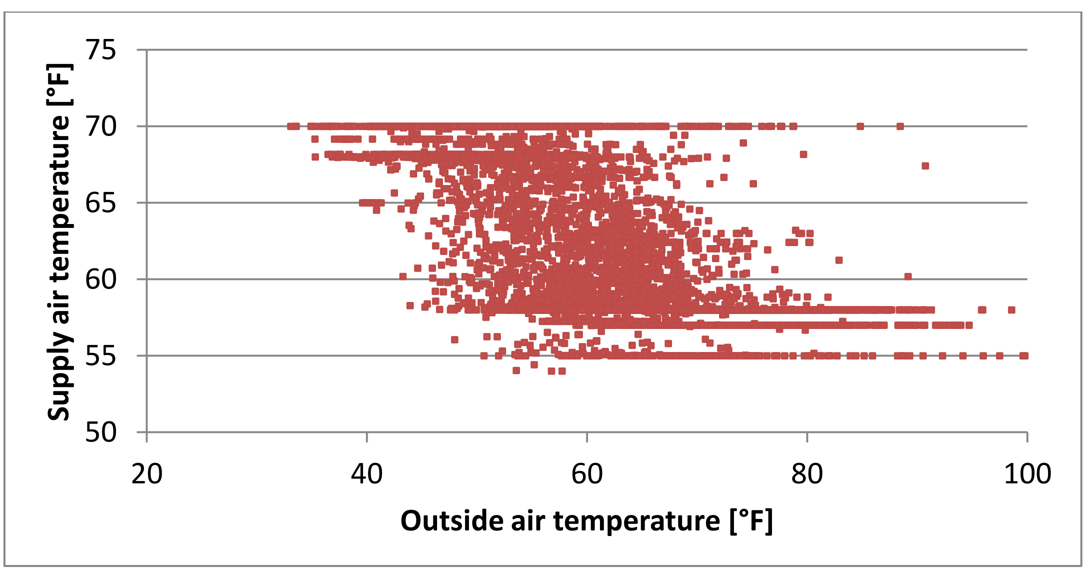


Figure 3.1.9 AC E1 supply air temperature reset

3.1.4 *Observed flow rates before and after intervention, for all buildings*

Distributions of flow fraction (flow rate as a fraction of the maximum flow rate) show how often the terminal units operate at each flow fraction.

3.1.4.1 Distribution of flow rates occurring at the actual time the surveys were taken

We first matched occupant satisfaction responses to the instantaneous VAV box flow rate in the respondent's zone. Flow rates that correspond to survey responses are labeled as "time-of-survey." Surveys were conducted 3 times per day, most often around 10am, 2pm and 4pm.

Figure 3.1.10 shows the time-of-survey flow rate distribution for all the Yahoo! buildings in the warm season (the blue line is for surveys that took place under low minimum flow rate setpoints, and the red line is for those under high minimum flow rate setpoints). Figure 3.1.11 is for all the Yahoo! buildings in the cool season, and Figure 3.1.12 shows the results from 800 Ferry in the warm season.

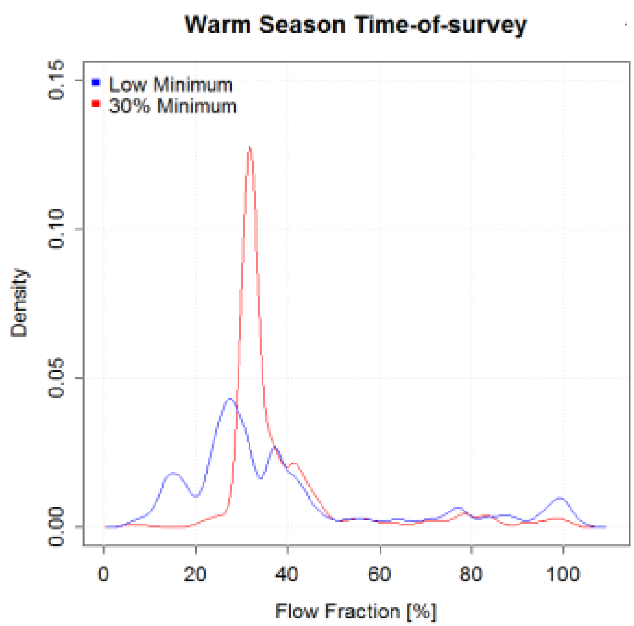


Figure 3.1.10 Yahoo! warm season time-of-survey

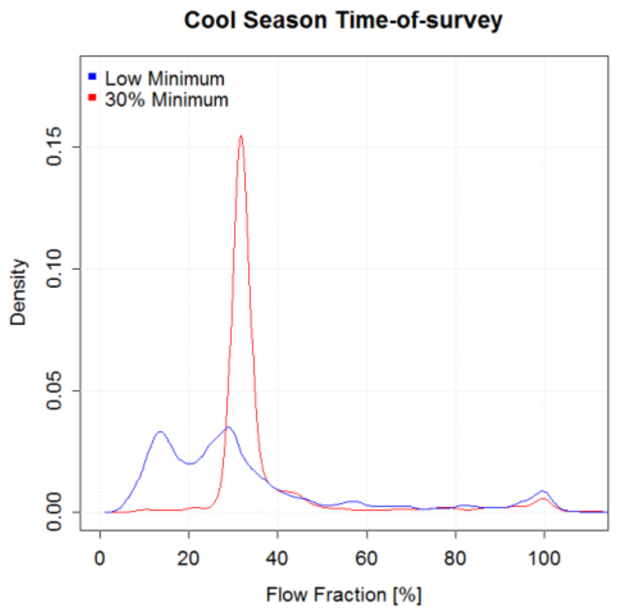


Figure 3.1.11 Yahoo! cool season time-of-survey

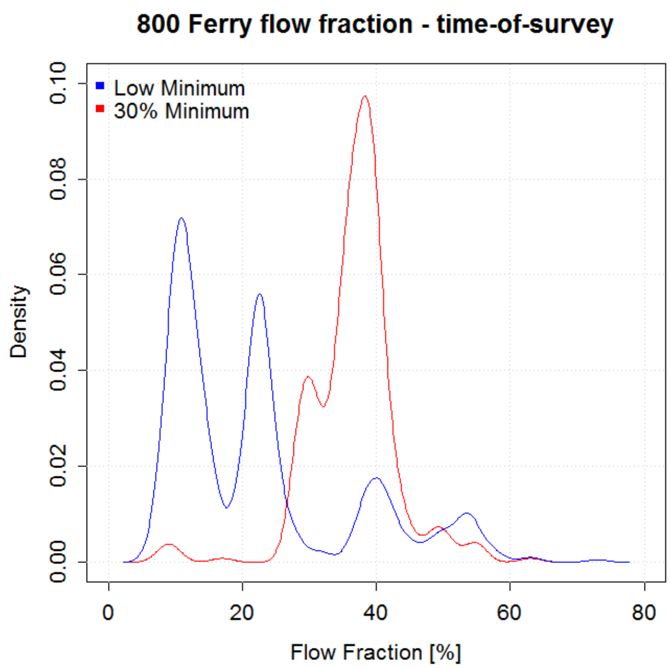


Figure 3.1.12 800 Ferry building warm season time-of-survey

The average values for the three survey periods are presented in the Table 3.1.2.

	Low minimum flow rate	High minimum flow rate
Yahoo! warm season	37.7%	36.9%
Yahoo! cool season	24.8%	32.3%
800 Ferry building	22.4%	36%

Table 3.1.2 Average flow rates based on the trend data corresponding to the survey times

The VAV discharge flow rate depends on the internal load. When the load is high, the VAV flow rate is normally higher than the minimum flow rate setpoint. Thus, for high load conditions, no difference between low and high minimum operation mode is expected. Minimum flow rate setpoints only affect diffuser flow rates when the load is low and the VAV unit is being operated at its minimum flow rate.

During the Yahoo! warm season, high loads and flow rates skewed the average flow rate. While the flow rate averages in Table 3.1.2 are roughly equal, density plots in Figure 3.1.13 below) show a clear difference in behavior of VAV units, with a significant decrease in flow fraction at low minimum operation. In the Yahoo! cool season, we saw a 7.5% difference in the average flow rates (24.8% vs. 32.3%). In the 800 Ferry building, internal loads are low. Even in the peak periods, the system often is operated at the minimum flow rate. Therefore, we see a 13.6% difference in the average flow rates.

3.1.4.2 Distribution of flow rates during all occupied hours within the survey periods

The VAV units typically operate at minimum when the load is low in the space. Mornings and early evenings are periods of low cooling load, while the surveys regularly occur in afternoons when the cooling load is high. Here we characterize the flow rates during high and low operations with density charts, comparing the flow rate profiles for all occupied hours against the instantaneous flow rates that occurred at the time-of-survey.

The results are presented in Figure 3.1.13 for the Yahoo! buildings and the 800 Ferry building, and the average flow rates are presented in Table 3.1.3. As expected, unlike the values shown in Table 3.1.2, here (Table 3.1.3), we do see a difference (9.9%, 25.9% vs. 35.8%) in the average flow rate for the Yahoo! warm season. Since the loads were low in the Yahoo cool season and the 800 Ferry building during the survey times, therefore, we see similar results for these two periods, 7.9% difference in the average flow rates (25.7% vs. 35.4%) for the Yahoo! cool season and 13.6% for the 800 Ferry building warm season.

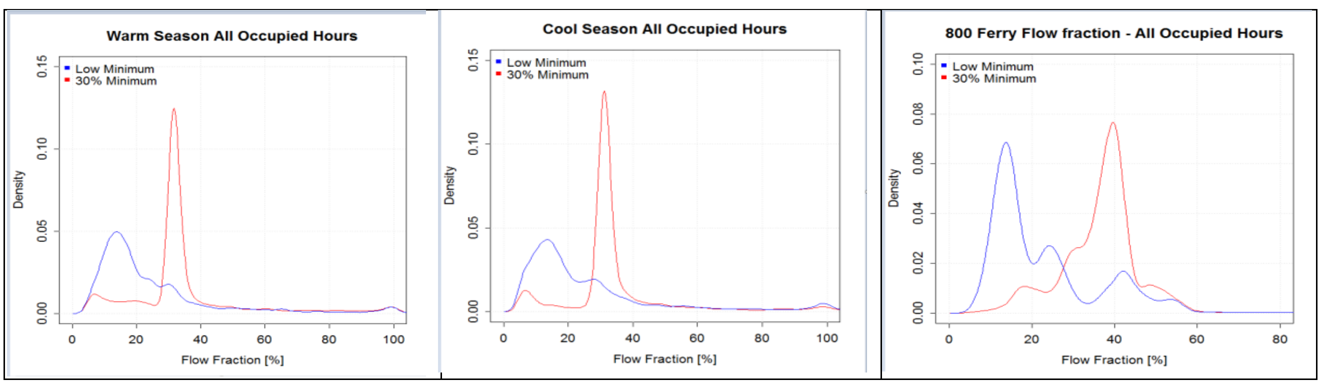


Figure 3.1.13 Flow rate distributions during occupied hours - Yahoo! warm season, Yahoo! cool season, 800 Ferry warm season

	Low minimum flow fraction (%)	High minimum flow fraction (%)
Yahoo! warm season	25.9	35.8
Yahoo! cool season	27.5	35.4
800 Ferry	23.1	36.7

Table 3.1.3 Average flow fractions based on the trend data during occupied hours during survey periods

3.1.4.3 Flow rates for the entire study period (November 4. 2010 – May 2012)

We switched between high and low minimum operation several times during the one-and-a-half-year study. Although the survey periods were took place during short intervals within this period, the whole period was used for measuring energy consumption. The following timelines show when these changes occurred for the Yahoo! buildings and 800 Ferry building.

Yahoo! Building

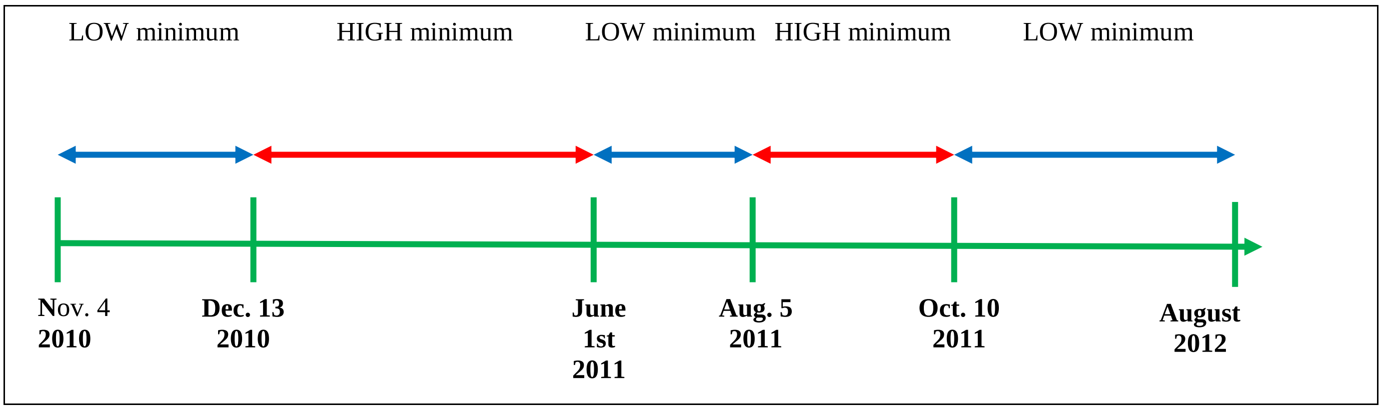


Figure 3.1.14 Yahoo! entire study period

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800 Ferry building

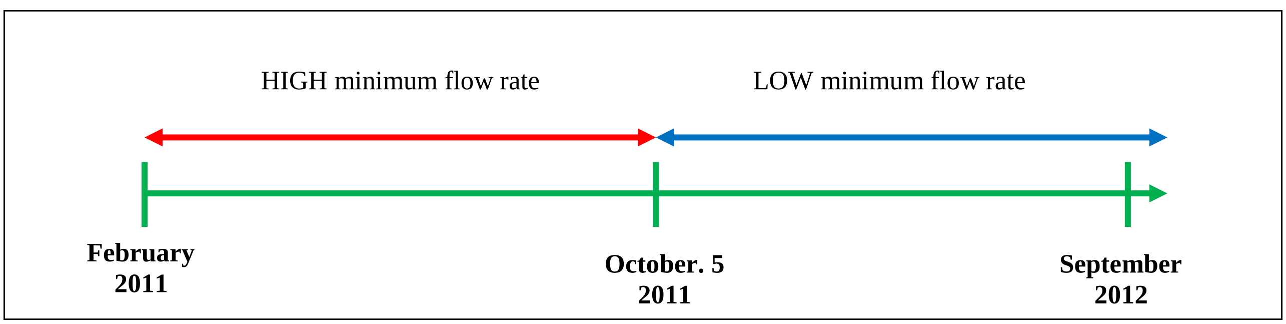
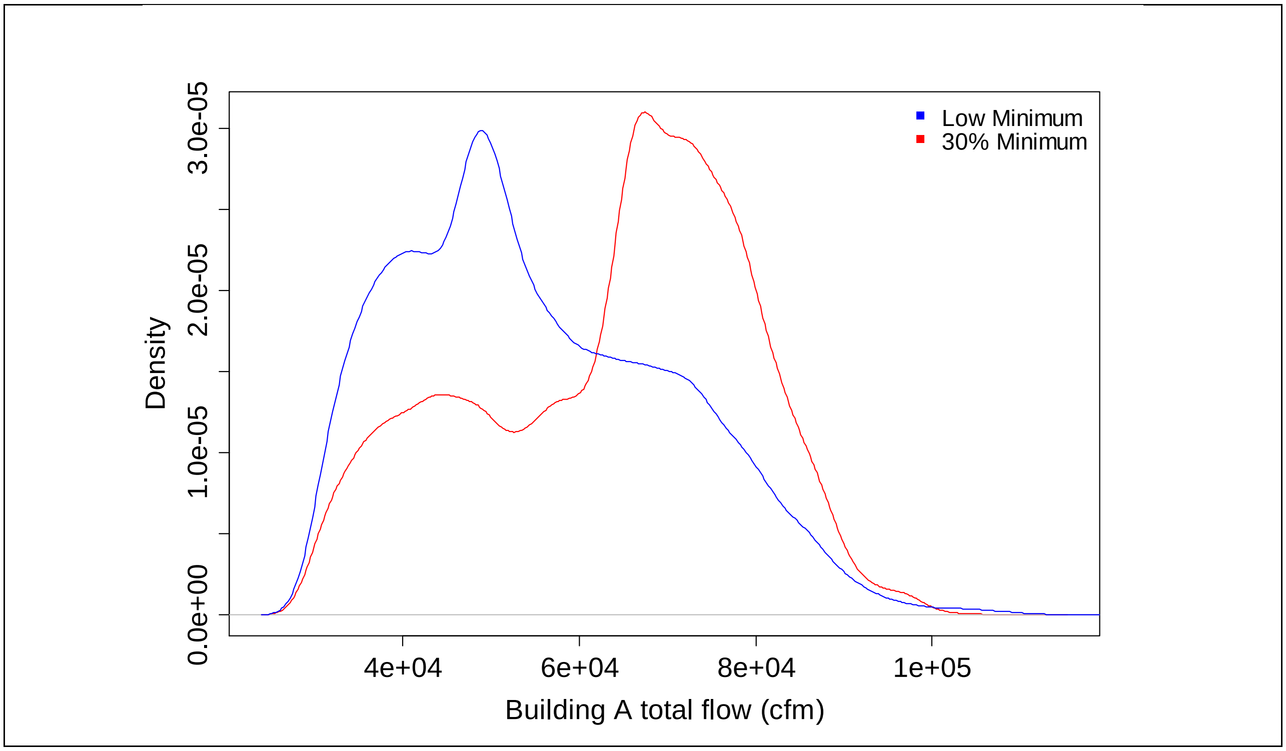


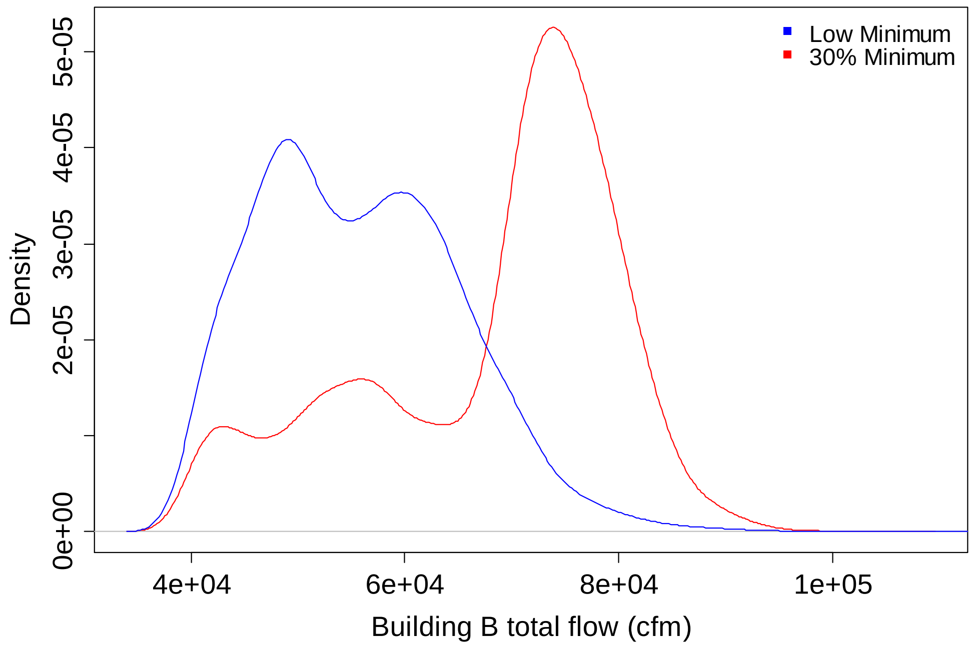
Figure 3.1.15 800 Ferry building entire study period

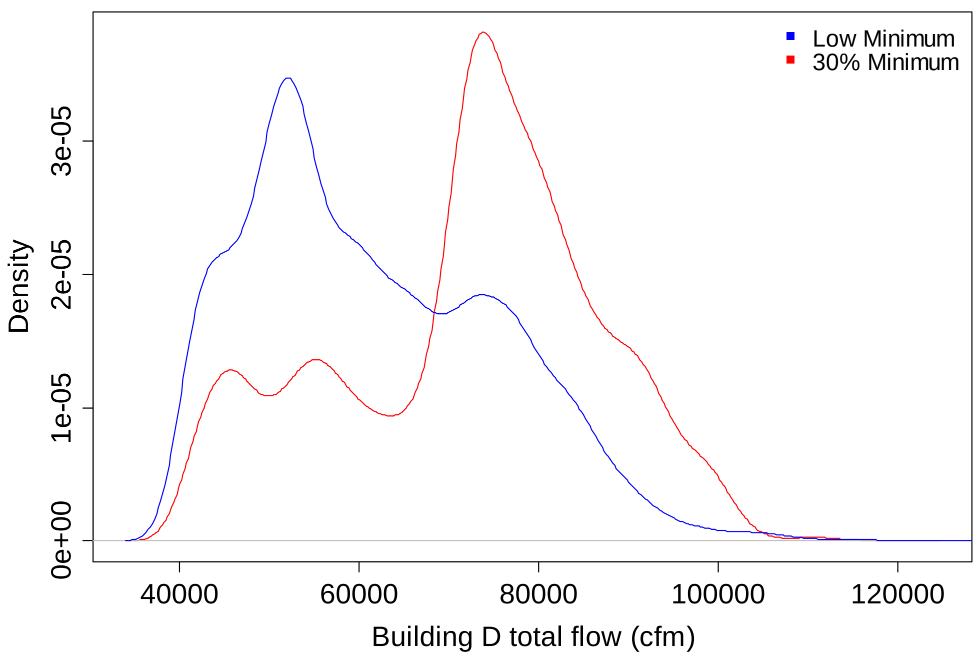
	Low minimum setpoint	High minimum setpoint
Yahoo!	4 November 2010 – 13 December 2010, 2 PM	13 December 2010, 2 PM – 1 June 2011, 8 AM
	1 June 2011, 8 AM – 5 August 2011, 1 PM	5 August 2011, 1 PM – 10 October 2011, 5:20 PM
	10 October 2011 5:20 PM– August 2012	
800 Ferry building	5 October 2011, 6 AM – September 2012	February 2011 – 5 October 2011, 6 AM

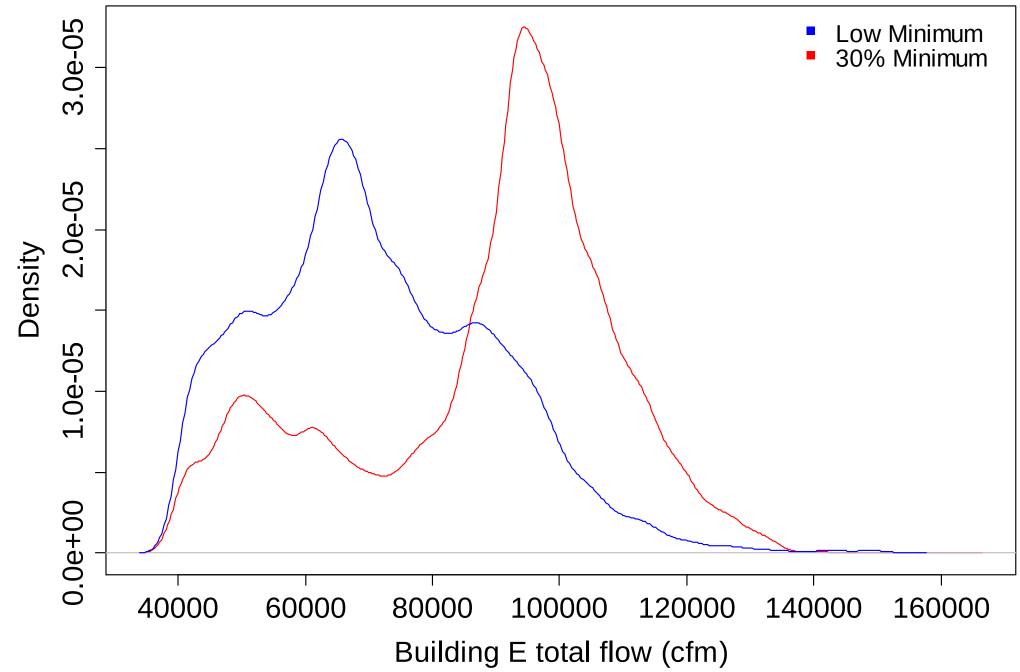
Table 3.1.4 Schedule of minimum flowrate setpoints

Figure 3.1.16 summarizes actual flow rates for the six Yahoo! Buildings, A, B, D, E, F, and G under the low and high minimum operation periods, drawn from data from April 2011 through March 2012. The figure represents the distribution of total airflow in each building during occupied hours, which was obtained by summing all VAV terminal airflow rates. We see in every building a significant shift to airflow rates under low minimum operation, which contributes to the energy savings described in section 2.1. In Figure 3.1.17, we see a comparable summing of all VAV airflows in the 800 Ferry building, and an even stronger shift in the airflow distribution.

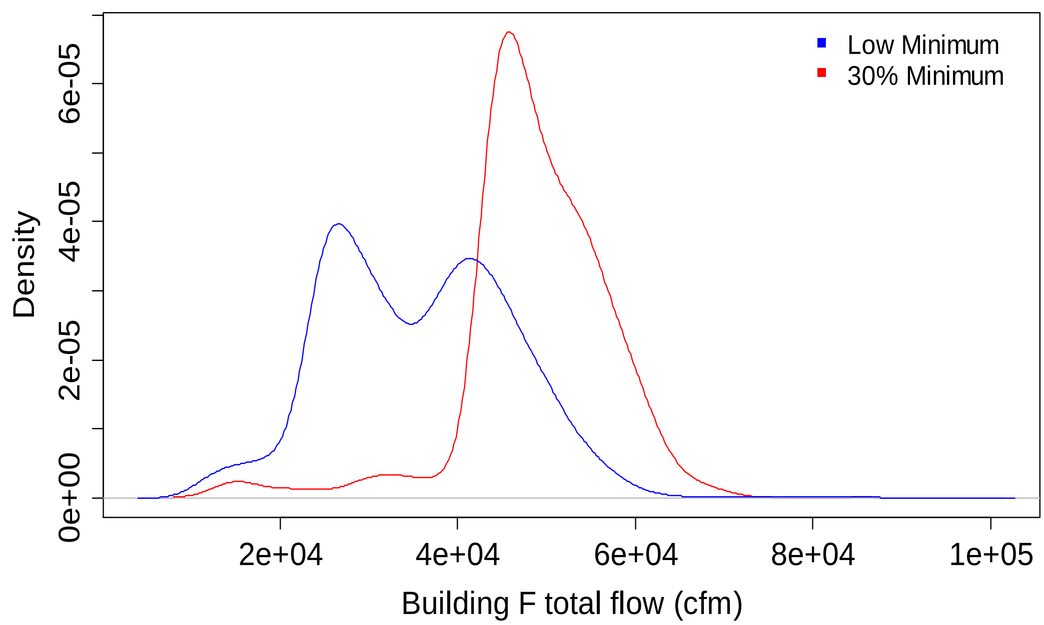



Low Minimum
30% Minimum
Density
0e+00
2e-05
3e-05
4e-05
5e-05
4e+04
6e+04
8e+04
1e+05
Building B total flow (cfm)


Low Minimum
30% Minimum
Density
0e+00
1e-05
2e-05
3e-05
40000
60000
80000
100000
120000
Building D total flow (cfm)



Low Minimum
30% Minimum
Density
0.0e+00
1.0e-05
2.0e-05
3.0e-05
40000
60000
80000
100000
120000
140000
160000
Building E total flow (cfm)



Low Minimum
30% Minimum
Density
0e+00
2e-05
4e-05
6e-05
2e+04
4e+04
6e+04
8e+04
1e+05
Building F total flow (cfm)

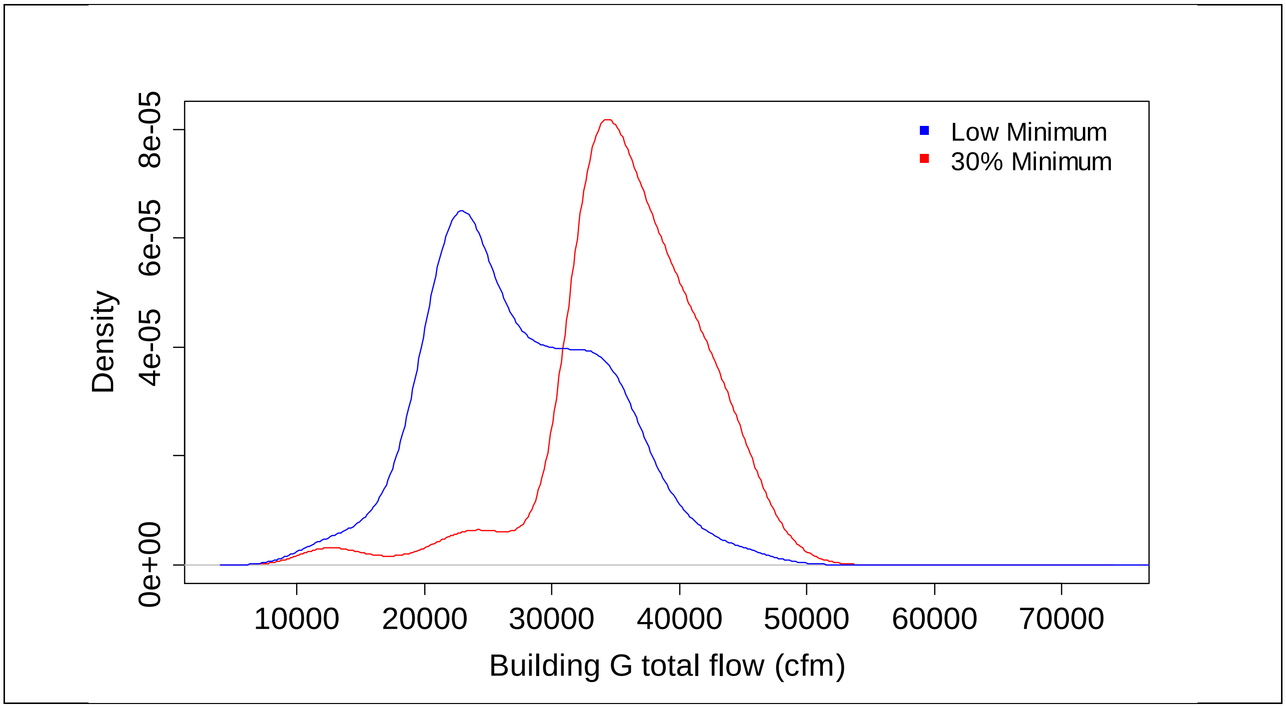


Figure 3.1.16 Yahoo! Buildings A,B,D,E,F,G total flow rate distribution

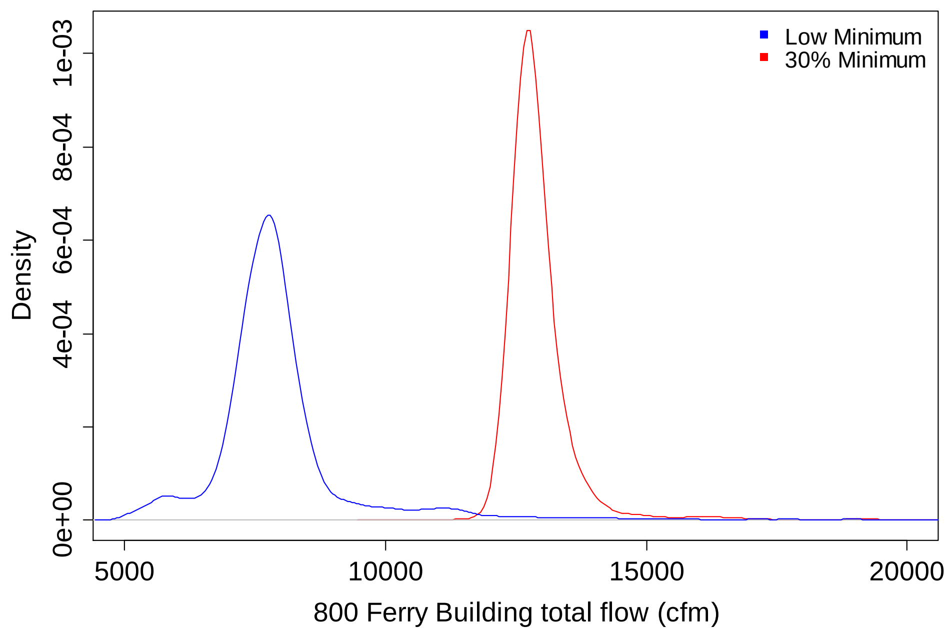


Figure 3.1.17 800 Ferry Building total flow rate distribution

3.2 *Repetitive 'right-now' surveys, administered before and after the intervention*

3.2.1 Daily average temperature satisfaction

Yahoo! warm season. The survey for the Yahoo! warm season started September 29, 2011. The high minimum operation period was September 29th – October 5th 5PM, when we toggled to low minimum. The low minimum period is October 5th 5PM to October 26th. The survey (see A), used a 7-point satisfaction scale, with -3 representing 'very dissatisfied' and 3 representing 'very satisfied'. In the following sections, satisfaction analysis is presented in terms of 'dissatisfied' votes. Any of the negative values (-3 to -1) count as 'dissatisfied'. The daily temperature dissatisfaction rates are presented in Figure 3.2.1.The numbers on top of the bars represent the total number of votes for each day. A total of 1851 votes were received.

The figure shows that the temperature dissatisfaction reduced significantly (statistical significance, p<0.001) when the minimum flow rate setpoint was changed from high to low. In surveys, it normally takes a few days after the survey is first initiated for the occupants' responses to reach a stable state. In the analysis that we did in following sections, we only used responses when a stable state had been reached, shown by two green boxes in each figure. For the survey in this period (September 29 – October 26, Figure 3.2.1), the responses from the first day were excluded in the analysis because occupants' responses had not reached to stable state.

The average dissatisfaction rate was reduced from 19.8% to 10.5% when the minimum VAV flow rate setpoint was changed from high to low, a 47% reduction (Table 3.2.1).

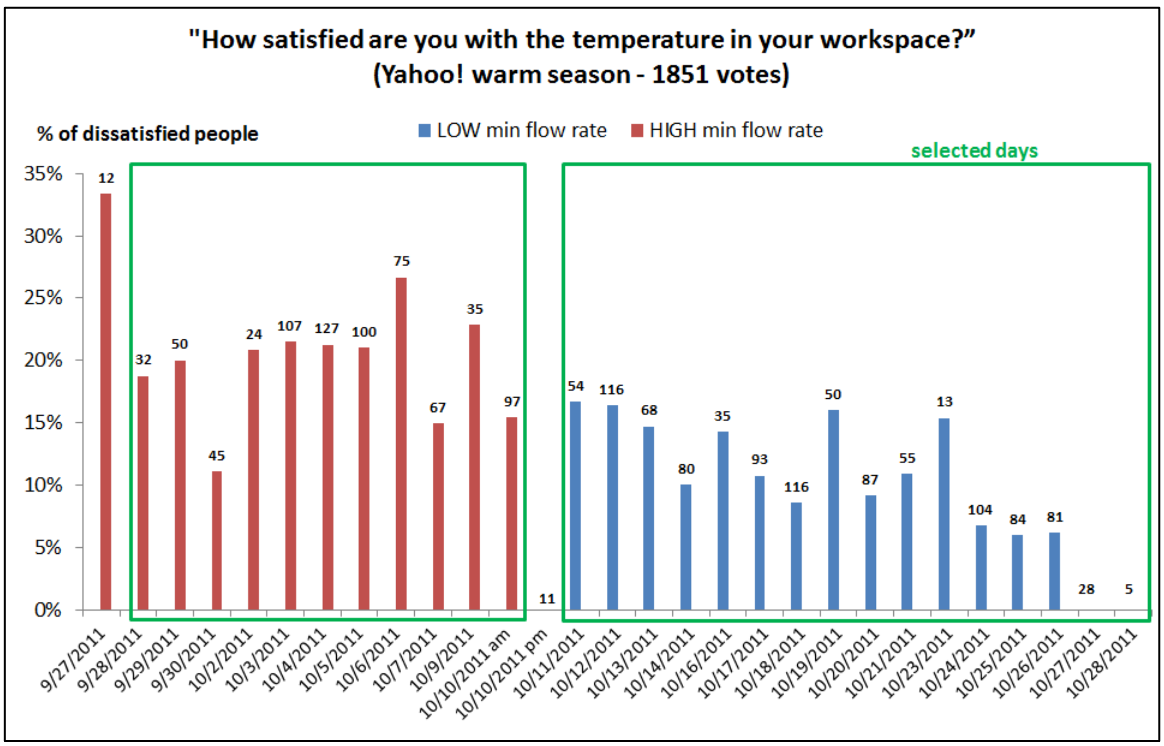


Figure 3.2.1 Dissatisfaction rate from the Yahoo! warm season survey

	Number of dissatisfied votes	% dissatisfied votes	Total votes
HIGH min flow rate	150	**19.8%**	759
LOW min flow rate	112	**10.5%**	1064

Table 3.2.1 Dissatisfaction rates with the high and low minimum flow rate setpoints for Yahoo! warm season survey

Yahoo! cool season. The survey for the Yahoo! cool season started December 2, 2010. The low minimum operation period was December 2 – December 13, 2010, 2 PM, and the high minimum operation period was 13 December 2010 2pm – 23 December 2010. A total of 6667 responses were received.

The cool season survey was the first time the Yahoo! building occupants had seen the survey. In repetitive surveys, occupants are known to unload pent-up complaints on the first or second time that they log on. After that they give more focused responses that remain stable over time. In this survey the responses didn't reach a stable condition (dissatisfaction rate consistently dropping) until about 5 days into the survey (December 10), even though the conditions during that time were constant and the preceding building operation had also been mostly low-minimum. We made a logistical error not to extend the first condition for an extra week, so that we could have eliminated this warm-up effect and have several days of good data. But we were pressed by the upcoming Christmas holiday which presented a firm end to the session.

So we can look at the results in a couple ways, with similar results. First, the descending votes were filtered out, along with the votes in the afternoon on the day of the switch (after December 13 at 2 PM,) not used because the occupants were then experiencing the change in environmental conditions. Using the responses in the two green boxes as representing the stable periods, the daily dissatisfaction rates in Figure 3.2.2 are seen to be similar for the high and low minimum flow rate operations, 8.3% and 8.8% respectively (see also Table 3.2.2).

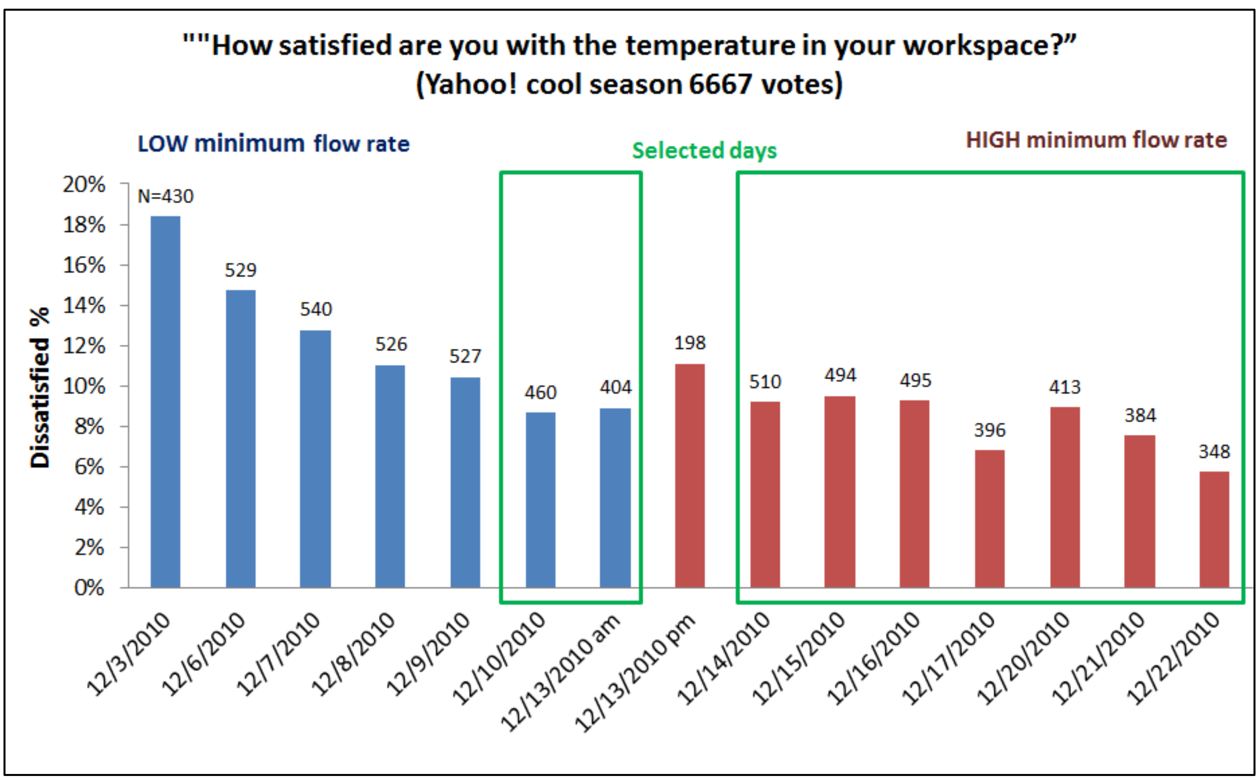


Figure 3.2.2 Dissatisfaction rate from the Yahoo! cool season survey

	Number of dissatisfied votes	% dissatisfied votes	Total votes
HIGH min flow rate	253	**8.3%**	3040
LOW min flow rate	76	**8.8%**	864

Table 3.2.2 Dissatisfaction rates with the high and low minimum flow rate setpoints for Yahoo! cool season survey

Second, one might also select and compare equal periods three days directly before and after the switch of minimum flow rate (December 13 at 2 PM), as indicated by the two green boxes in Figure 3.2.3. The total number of responses included in these two three-day periods are 1391 (low minimum) and 1499 (high minimum), with equal dissatisfaction rates of 9.3% and 9.3% respectively (Table 3.2.3).

The conclusion for either of these analyses is that there is little or no difference in dissatisfaction between high and low-minimum operation in the cool season.

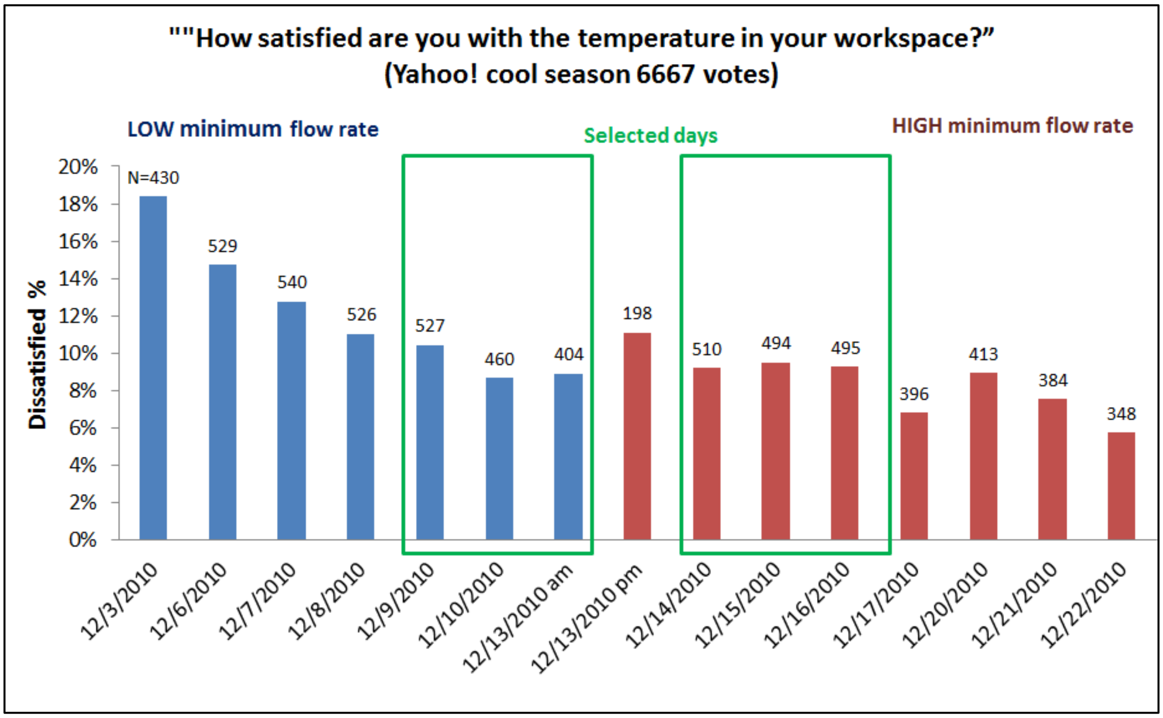


Figure 3.2.3 Dissatisfaction rate from the Yahoo! cool season survey

	Number of dissatisfied votes	% dissatisfied votes	Total votes
HIGH min flow rate	140	**9.3%**	1499
LOW min flow rate	131	**9.4%**	1391

Table 3.2.3 Dissatisfaction rates three days before and after the minimum flow rate setpoint change for Yahoo! cool season survey

800 Ferry building warm season. Before we started the right-now survey in 800 Ferry, we did a CBE background survey (July 28 – August 15 2011). The results show that the comfort satisfaction is low, and the major source of discomfort is overcooling. The building is normally operated under high minimum operation. It was during the first intervention period that we switched the flow rate to minimum operation. The right-now survey for the 800 Ferry building in the warm season started September 22, 2011. High minimum operation (30% of the maximum) period is September 22 – October 5, 2011, 6 AM, and low minimum operation period is October 5, 6 AM - October 22, 2011. The daily 'dissatisfaction' rates are presented in Figure 3.2.4. Similar to the Yahoo! warm season survey in Figure 3.2.1, the dissatisfaction rate was significantly reduced after the minimum VAV setpoints were reduced from high to low.

This was also the first time we did the repeated occupants' survey in this building, therefore, the votes in the first two days (September 22-23) were not stable, and are excluded from the comparison analysis. There was a system problem during the first day of the switch (October 5). The CBE researcher contacted the operator of the building and the problem was fixed in the following day. Therefore, the votes on October 5 also are excluded from the analysis.

The average dissatisfaction rate was reduced 47% (from 21.7% to 11.5%, statistically significant, $p<0.001$) when the minimum flow rate setpoints were reduced from high to low (Table 3.2.4).

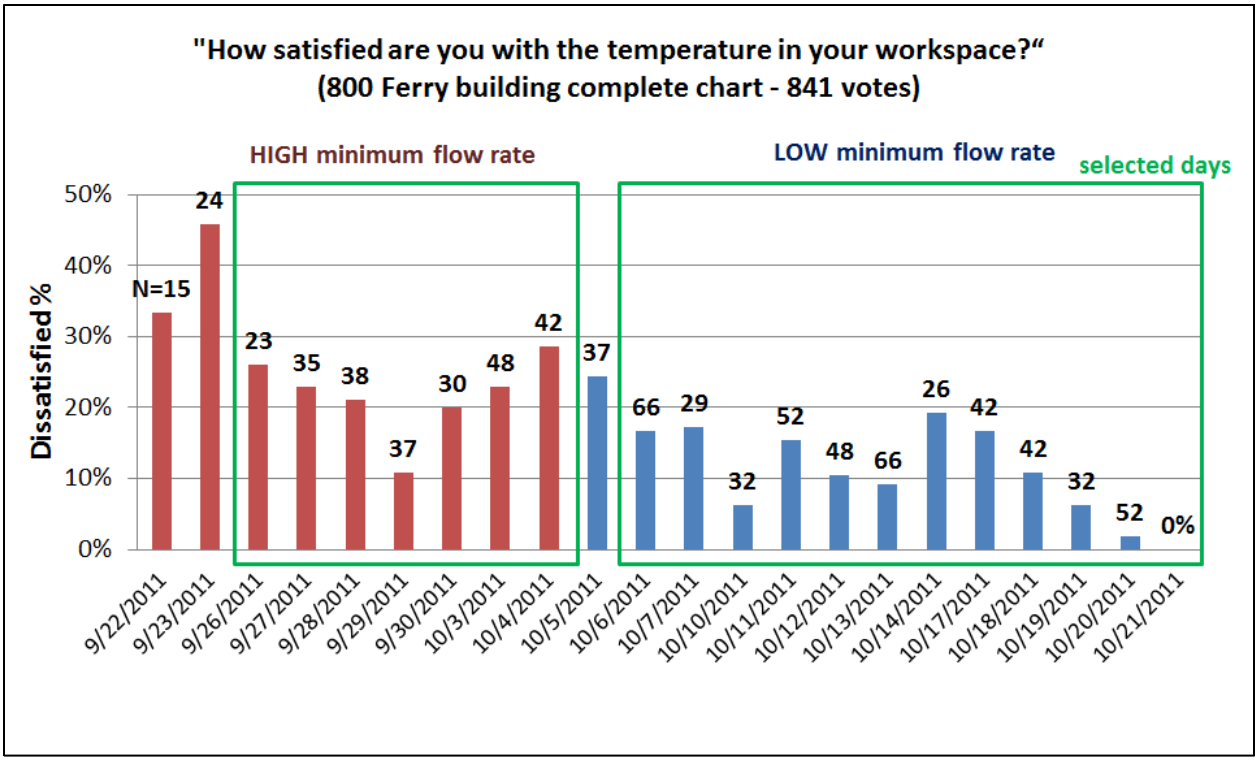


Figure 3.2.4 Dissatisfaction rate from the 800 Ferry building warm season survey

	Number of dissatisfied votes	% dissatisfied votes	Total votes
HIGH min flow rate	55	**21.7%**	253
LOW min flow rate	59	**11.5%**	512

Table 3.2.4 Dissatisfaction rates with the high and low minimum flow rate setpoints for the 800 Ferry building warm season survey

Summary of satisfaction during high and low minimum operation. The comparison of the temperature satisfaction between high and low minimum operation using the data in the selected green boxes for the three surveys (Yahoo! warm season, Yahoo! cool season, and the 800 Ferry warm season) are presented in Figure 3.2.5. The values of the dissatisfaction are summarized in Table 3.2.5.

As described earlier, when the VAV minimum setpoint was reduced from high to low, the warm-season dissatisfaction rates were reduced by 47%, both in the six Yahoo! buildings and in the 800 Ferry building,. Among the three surveys, the dissatisfaction rate was highest in the 800 Ferry building. During the cool season, the six Yahoo! buildings all show similar dissatisfaction rates between the two minimum flow rate operation modes.

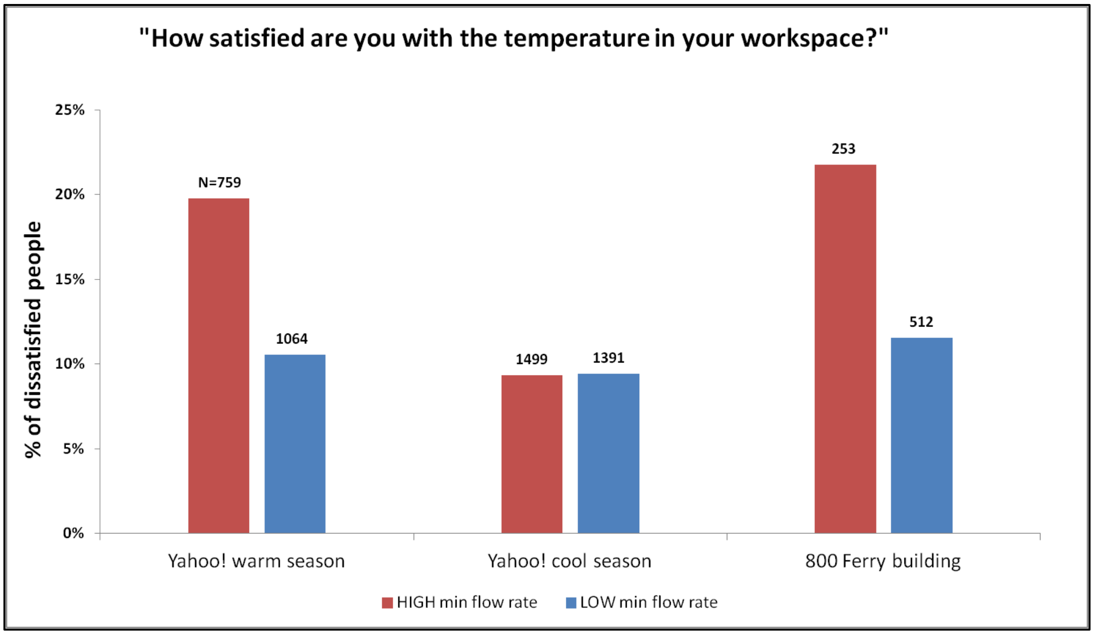


Figure 3.2.5 Comparison of temperature dissatisfaction rates under high and low minimum operation modes for the three surveys

% Dissatisfied people	HIGH min flow rate	LOW min flow rate
Yahoo! warm season	**19.8%**	**10.5%**
Yahoo! cool season	**9.3%**	**9.4%**
800 Ferry Building	**21.7%**	**11.5%**

Table 3.2.5 Summary of dissatisfaction rates for temperature satisfaction under high and low minimum flow rate setpoints for the three surveys

3.2.2 *Thermal sensation distribution*

The higher rate of dissatisfaction under high minimum flow rate operation during the warm season may be a result of summer over-cooling of the buildings. Figure 3.2.6 shows thermal sensation distributions in the three surveys (Yahoo! warm and cool seasons and 800 Ferry warm season).

The sensation ranges within the data are defined as follows: ‘cold’ (sensation scale less than -2.5), ‘cool’ (sensation scale -2.5 to – 1.5), ‘slightly cool’ (sensation scale -1.5 to -0.5), ‘neutral’ (sensation scale -0.5 to 0.5), ‘slightly warm’ (sensation scale 0.1 to 1.5), ‘warm’ (sensation scale 1.5 to 2.5), and ‘hot’ (sensation scale above 2.5).

In the Yahoo! warm season survey, 21.5% felt slightly cool under high minimum flow operation, 10.4% felt ‘cool’, and 5.5% felt ‘cold’, a total of 37.4% of the population feeling ‘slightly cool’ to ‘cold’. In comparison, only 16.7% felt ‘slightly warm’, 4.3% ‘warm’, and no one felt ‘hot’, a total of 21.1% of the population feeling ‘slightly warm’ to ‘warm’. When the VAV operation was changed from high to low minimum, summer over-cooling was reduced because less cool air was sent to the space. In the results, 13.2% of the population switched from the ‘cool’ and ‘cold’ categories to the ‘neutral’ category. As described in section 3.2.1, that corresponds to a 47% reduction in the dissatisfied population.

In the Yahoo! cool season survey, the thermal sensation distributions between high and low minimum operation are very similar (Figure 3.2.7).

It appears that with high minimum operation, summer over-cooling in the 800 Ferry building is stronger than in the Yahoo! buildings. Although the portion of the population feeling 'slightly cool' to 'cold' (37.6%) is similar to the Yahoo! buildings (37.4%), 10.6% feel 'cold' in the 800 Ferry building, almost twice the 'cold' population in the Yahoo! buildings (5.5%, Figure 3.2.8). 20.7% feel 'slightly cool', and 6.4% feel 'cool'. When the VAV operation was switched from high to low minimum, the population feeling 'cool' and 'cold' reduced from 37.4% to 15.8%, 8.5% moved to the 'neutral' category, and 13.3% moved to the 'slightly warm' and 'hot' category. Again, the shift on sensation towards warmth reduced the size of the dissatisfied population by 47% (described in section 3.2.1).

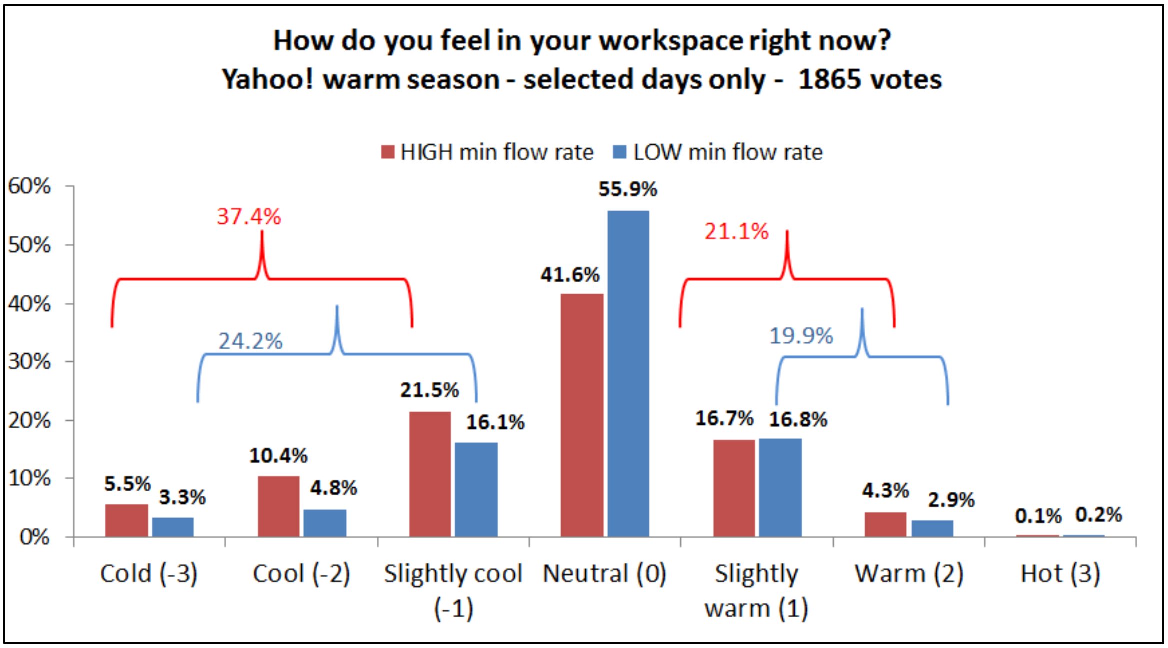


Figure 3.2.6 Thermal sensation distribution (Yahoo! warm season survey)

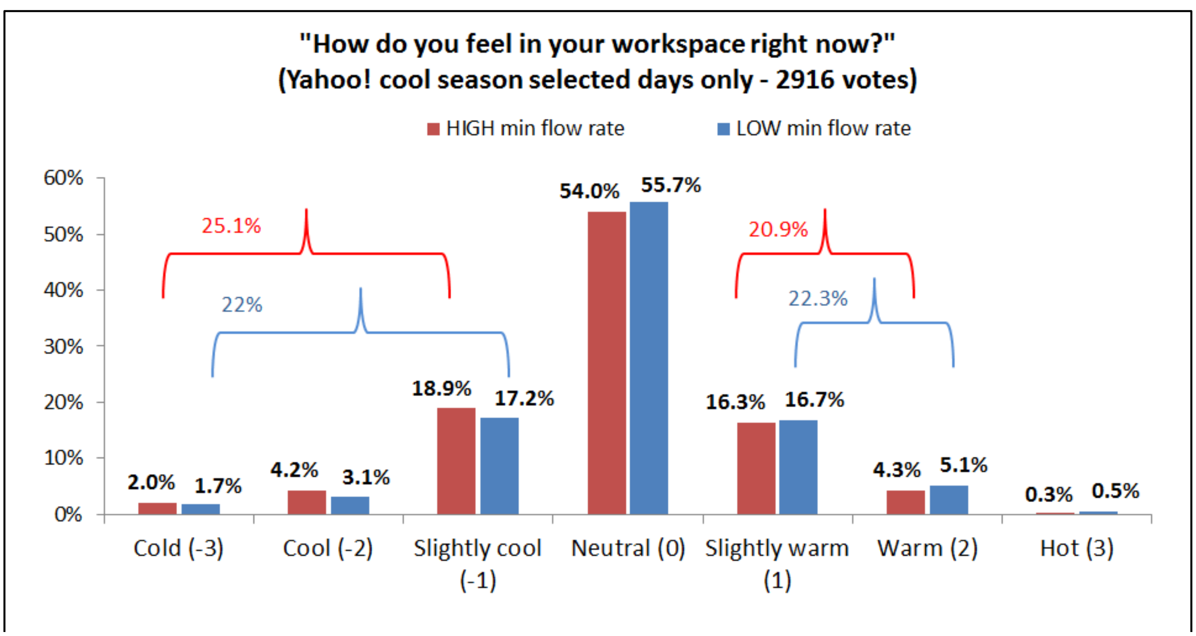


Figure 3.2.7 Thermal sensation distribution (Yahoo! cool season survey)

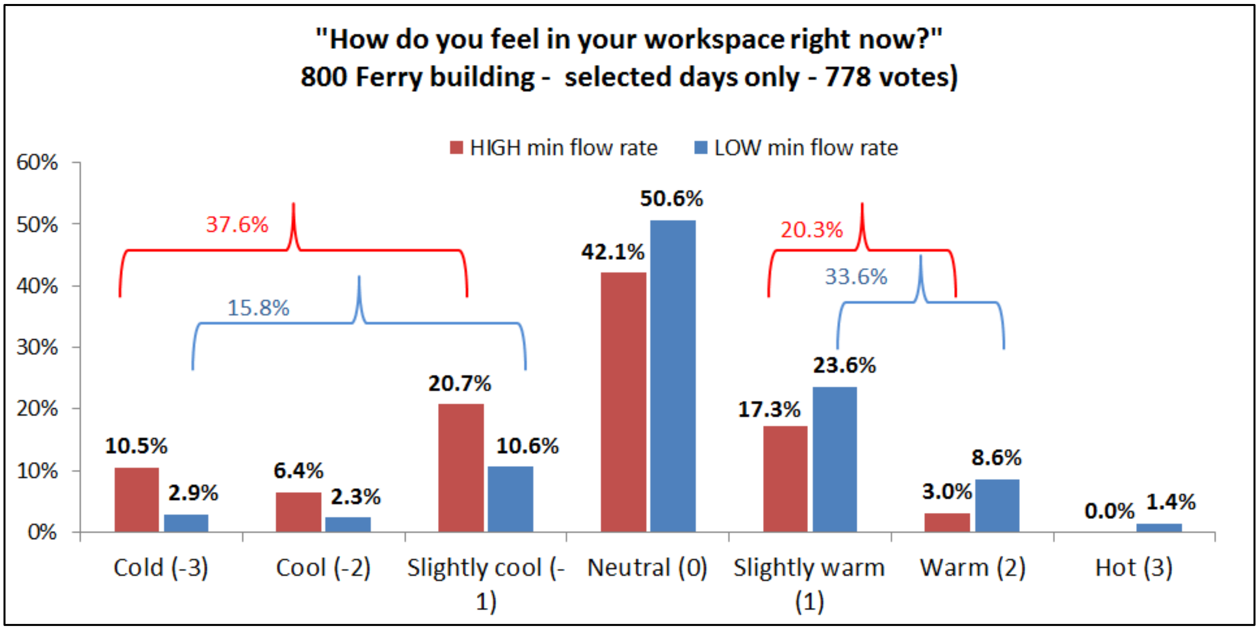


Figure 3.2.8 Thermal sensation distribution (800 Ferry building warm season survey)

3.2.3 *Survey comments regarding summer overcooling*

In order to better understand the occupants' perception regarding their cool feeling in summer, we copied all comments related with over-cooling from the two summer surveys (Yahoo! warm season and 800 Ferry building warm season) in the following tables.

Yahoo! warm season (2011). Under high minimum operation (Sept. 28 – Oct. 10 5 PM), there were 27 summer over-cooling complaints vs. 29 non-summer over-cooling complaints/comments. Almost half (48%) of the complaints are summer over-cooling related. (See Table 3.2.6). The remainder of the complaints are mostly non-thermal in nature (8 about noise, 13 about general issues like lighting or smell, 2 about air movement), and only 4 are warm-related.

Under low minimum (Oct. 11 – Oct. 27 2011), there were 18 summer over-cooling related complaints vs. 25 non-summer over-cooling complaints/comments. (See Table 3.2.7).

Sept. 27 5 PM	"The warmer it gets outside, the more the air conditioner makes it cold over me, and blows cold air at me. Sometimes it freezes my hands. I have brought a big wool sweater for those days."
Sept. 28 2:40 PM	"When the air kicks it at certain times of the day and especially in the afternoon, I get very cold even with a light sweater or jacket on."
Sept. 28 2:40 PM	"like the air movement, but wish it were warmer."
Sept. 28 5 PM	"Feel cool air blowing from vent above me."
Sept. 28 6 PM	"Im always cold in my cube. I have a sweatshirt, jacket, and a space heater to warm me as needed during the day."
Sept. 29 11:30 AM	"Too cold & too noisy. Too many co-workers in a small work space. Too much traffic in & out of small space. Air conditioner - too much cold air."
Sept. 29 11:30 AM	"It generally gets cold later in the afternoon. The meeting rooms are also often too cold…".
Sept. 29 12:22 PM	"Typically, I am comfortable in the morning and very cold in the afternoon. I have a vent above my cube and it blows cold air in the afternoon."
Sept. 30 10:30 AM	"I also keep a blanket at my cube due to the AC being on so often."
Oct. 3 3 PM	"First day of cooler temperatures and I do not notice the cold air blowing strongly like I have

	in the afternoons all summer long. Yet, its still cool in the office."
Oct. 3 10:50 AM	"It is warming up a little. It was much cooler about an hour ago. When my hands get too cold I have to stop typing and fetch something warm to drink."
Oct. 3 11:45 AM	"The air flow is fine, just a little cool."
Oct. 3, 11:50 AM	*"the work place is very very cold in summer. all my team members have the same complains. The A/C temperature is set too low in summer. We feel the more hot outside, the indoor gets colder."*
Oct. 3, 2:30 PM	"My hands are really cold now. Its starting to make my finger joints hurt when I type."
Oct. 3, 2:30 PM	"When I say head, its really my nose." (sensation was -2, cool)
Oct. 4 11:50 AM	"Building E is always too cold. Conference rooms included."
Oct. 4 11:50 AM	"Building E is always cold."
Oct. 4 12:50 PM	"I actually added a light coat on top of my sweater and blouse so Im not as cold."
Oct. 4 1:30 PM	"Still have coat on as well."
Oct. 4 3:30 PM	"I also have a light coat on in addition to the sweater."
Oct. 5 10:40 AM	"I would definitely be more productive in the office if the office space for our group wasnt so cold."
Oct. 5 4 PM	"Grabbing my jacket to put on!"
Oct. 5 4 PM	"its raining so would prefer less air movement if that means it will be less cold in the office. It's not cold in the office currently, but just saying."
Oct. 7 11 AM	"It's cooling down right now. It was warm earlier. The drop has been fairly rapid." (sensation, -1, slightly cool)
Oct. 10 12 noon	"Too cold now. Fingers are freezing. Will need to take a hot beverage break."
Oct. 10 12 noon	"I was feeling cold earlier but just had a hot cup of soup and I feel comfortable."
Oct. 10 12:20 PM	*"The only time my workspace is comfortable is when they turn off AC and blowers to reduce electricity demand."*

Table 3.2.6 Under high minimum operation (Sept. 28 – Oct. 10 5 PM), 27 summer over-cooling complaints vs. 29 non-summer over-cooling related complaints/comments

Oct. 11,13:45 PM	*"For head, specifically my nose."(sensation -2, cool)*
Oct. 11,13:45 PM	*"For head, specifically my nose."(sensation -2, cool)*
Oct. 12 10:30 AM	"On head, nose is cold."
Oct. 12 11:50 AM	"Its blowing cold air. Im not freezing yet, but I have a lot of clothes on."
Oct. 12 10:20 AM	"Putting on my jacket!"
Oct. 13 3:40 PM	"It is really cold in here. Ive just got myself a hot drink to warm up!"
Oct. 17 3:15 PM	" starting to get cooler. My hands will start getting cold pretty soon. This usually means its warming up outside."
Oct. 18 11:10 AM	"I also keep a blanket in my cube due to the constant air movement, the air is very annoying and loud as well. I feel like I am on an airplane when they turn the air up this much."
Oct. 19 10:20 AM	"I am FREEZING. They are air conditioning me. I am going to have to leave my desk to get a hot drink."
Oct. 19 10:25 AM	"I also have a blanket on."
Oct. 19 2:26 PM	"My hands are having a hard time warming up since they froze me with a/c earlier today."
Oct. 19 3 PM	"cold air blowing on my head. Hands are cold. I am very dressed today, and cant keep myself warm."
Oct. 20 10:15 AM	"Hands are cold. I will fetch something hot to drink."
Oct. 20 10:30 AM	"Because the office is usually too cold I have to wear warm, unattractive clothes to work instead of the comfortable, appropriate clothing I wear elsewhere."
Oct. 21 11:40 AM	"On face, my nose is cold."
Oct. 25 11:25 AM	"On my head, my nose is cold along with my arms, hands and torso."
Oct. 26 10:20 AM	"A little better today because we complained to REW yesterday but still slightly cool on my hands."
Oct. 26 11 AM	"It started out warm and stuffy in here early this morning. Now the cold air is blowing on my pretty hard and my fingers are freezing. I can feel the cold air on my shoulders."

Table 3.2.7 Low minimum (Oct. 11 – Oct. 27 2011). 18 summer over-cooling related complaints vs. 25 non-summer over-cooling complaints/comments

800 Ferry building(2011). Because 800 Ferry building is significantly over-cooled in summer, the complaints were reduced dramatically when the high minimum operation was switched to low minimum operation. During high minimum operation, 25 complaints were about over-cooling (see Table 3.2.8, which is 53% of all complaints/comments (there were 22 other complaints, 12 about noise and 10 about general).

When the high minimum (Sept. 28 – Oct. 4) was switched to low minimum (Oct. 6 – Oct. 21), the number of over-cooling complaints were reduced to 10 (see Table 3.2.9, which is 23% of the total complaints/comments), and there were 14 good comments about the thermal environments (see Table 3.2.10). In these good comments, several people pointed that they noticed the change in the thermal environments and felt much more comfortable than before. There were 20 non-over-cooling related complaints/comments. Among them, 2 could almost be considered as positive comments about the thermal environments, the remaining 18 comments are 8 noise related, 8 general issue related, and two related with warm feeling. (Note: the building operator switched the low minimum setpoint from high to low on Oct. 5 at 6 AM, but the HVAC system had a problem that day, so October 5 data is not included.)

Sept. 24 4 PM	"Just cold! I have to out on a heater."
Sept. 24 2 PM	"I often come into my office and immediately put on a sweater because it is too cold for me. I dont have the sweater right now which is why I feel cold."
Sept. 24 2 PM	"I find that as the day progresses, my floor (the third of three floors) gets colder due to the air conditioner."
Sept. 24 2 PM	"I noticed right after lunch, I was extremely cold, but maybe because I had just eaten."
Sept. 27 11 AM	"Its cold! Ill turn on my heater..."
Sept. 27 1:30 PM	"Its cold! Ill turn on my heater..."
Sept. 27 3 PM	"In the morning the office temp is good, but by 2:30 it starts to cool down when the sun moves away from the window."
Sept. 28 7:30 AM	"I don't feel the direct air flow but it is for sure cold in here always."
Sept. 28 10 AM	"Now that this survey requires me to focus attention on my work environment several times a day, it is clear to me that my environment starts out in the morning just right. It gets progressively colder and less comfortable during the course of the day."
Sept. 28 10:10 AM	"Very Cold Im moving around the Office more and I feel more air movement then I felt just sitting down."
Sept. 28 11:40 AM	"Very cold!"
Sept. 28 3 PM	"LITTLE MORE AIR CONDITIONED."
Sept. 29 11:30 AM	"Its just cold all the time!"
Sept. 29 12:45 PM	"You should send this survey on Monday when its going to be freezing in this building."
Oct. 3 10 AM	"Please help my office because it is always cold...."
Oct. 3 12:15 PM	"Cold in here."
Oct. 3 1:30 PM	"Cold, Cold, Cold!!!!!"
Oct. 4 8:40 AM	"its cold in here. They need to turn on the heat."
Oct. 4 10 AM	"cold in here. Turn on some heat."
Oct. 4 11:50 AM	"cold."
Oct. 4 11:54 AM	"cold. Need heat."
Oct. 4, 12:10 PM	"warmer on cold days, cooler on hot days."
Oct. 4 3:30 PM	"my arms are cold too, but there wasnt a check for that."
Oct. 4 3:35 PM	"cold."
Oct. 4 4:40 PM	"I have on a sweater and coat..."

Table 3.2.8 High minimum operation (Sept. 28 – Oct. 4): 25 summer over-cooling complaints

Oct. 4 3:35 PM	"cold."
Oct. 4 4:40 PM	"I have on a sweater and coat..."
Oct. 6 10:30 AM	"I have my protable heater on and its still cold in here...."
Oct. 6 4 PM	"cold"
Oct. 6 4 PM	"Very cold today!"
Oct. 10 1:10 PM	"Its freezing!!!"
Oct. 12 11:40 AM	"It got cool in here!"
Oct. 14 2:45 PM	"The a/c is blasting in my office right now. I am cold and it is noisy."
Oct. 17 3:12 PM	"I have my space heater on and its still cold in my office."
Oct. 17 3:30 PM	"My office just went from uncomfortably warm to uncomfortably cool when the air conditioning turned on in the span of 20 mins."
Oct 18 8:32 AM	"I had to turn my heater on!!!!!"
Oct 18 9:04 AM	"Its cold in here!"

Table 3.2.9 During low minimum operation (Oct. 6 – Oc. 21): 10 summer over-cooling complaints

Oct 7 3 PM	"There is less background noise in my office this afternoon. It is great!" (noise complaints were referred to often referred to the noise from AC systems)
Oct. 10 11:32 AM	"feels good today. They County must have turned on the heat."
Oct. 10 3:30 PM	"I definitely notice a difference in the noise level in my office. I hardly hear it all. Thank you if you have had anything changed!!"
Oct. 11 2:30 PM	"Office is just right today!"
Oct. 12 10:20AM	"the temperature and noise control is perfect."
Oct. 12 11:55 PM	"I am still enjoying the climate in the office. A couple of days ago, the office was unusually cold. I am not experiencing the cold air at this time..".
Oct. 12 5:20 PM	"I love the air temp. It is warm and not cold (AC on in the winter) like it normally is.".
Oct. 13, 11 AM	"Warm in here today. its nice outside so it is nice inside."
Oct. 13 2:26 PM	"nice day. wish they were all like this."
Oct. 14 2:44 PM	"The temp is perfect!"
Oct 19 4:40 PM	"Just right!"
Oct. 19 4:50 PM	"Great!"
Oct. 20 12:33 PM	"nice day today, which makes it warm in the building."
Oct. 20, 2:30 PM	"Kinda cool outside now, but the office feels really good. Thank you!"
Oct. 20 2:30 PM	"Thanks for your involvement. I have definitely noticed an improvement in my office environment."

Table 3.2.10 During low minimum operation (Oct. 6 – Oc. 21): 15 good comments

3.2.4 *Zone ambient air temperatures, sensation and satisfaction.*

3.3.4.1. Zone air temperature under high and low minimum operations

To explain the thermal sensation changes towards warmth when lowering the minimum flow rate setpoints, we looked at the corresponding zone ambient temperatures at the time-of-survey under both high and low minimum operation modes (weekend and evening data are therefore not included). Daily average zone temperatures and distributions in the three survey periods are presented in Figure 3.2.9 to Figure 3.2.11. In the figure, red bars and red words at the bottom of each chart represent high minimum operation, and blue bars and blue words at the bottom of each chart represent low minimum operation.

Although in general the zone temperature variations were small in those air-conditioned spaces due to narrow thermostat setpoint ranges, (this is reflected by all the small zone air temperature differences shown in the data analysis described in followings sections), we still see the impact of the two minimum operation modes on zone air temperature. For the Yahoo!

warm season survey, the corresponding average zone air temperature increased 0.5ºF, from 72.6ºF to 73.1ºF, when the minimum flow rate setpoint was reduced. For the Yahoo! cool season survey, the increase is 0.7ºF, from 72.1ºF to 72.8ºF. The biggest increase is shown for the 800 Ferry building. It increased from 71.2ºF (high minimum) to 73.3ºF (low minimum), a 2.1ºF increase.

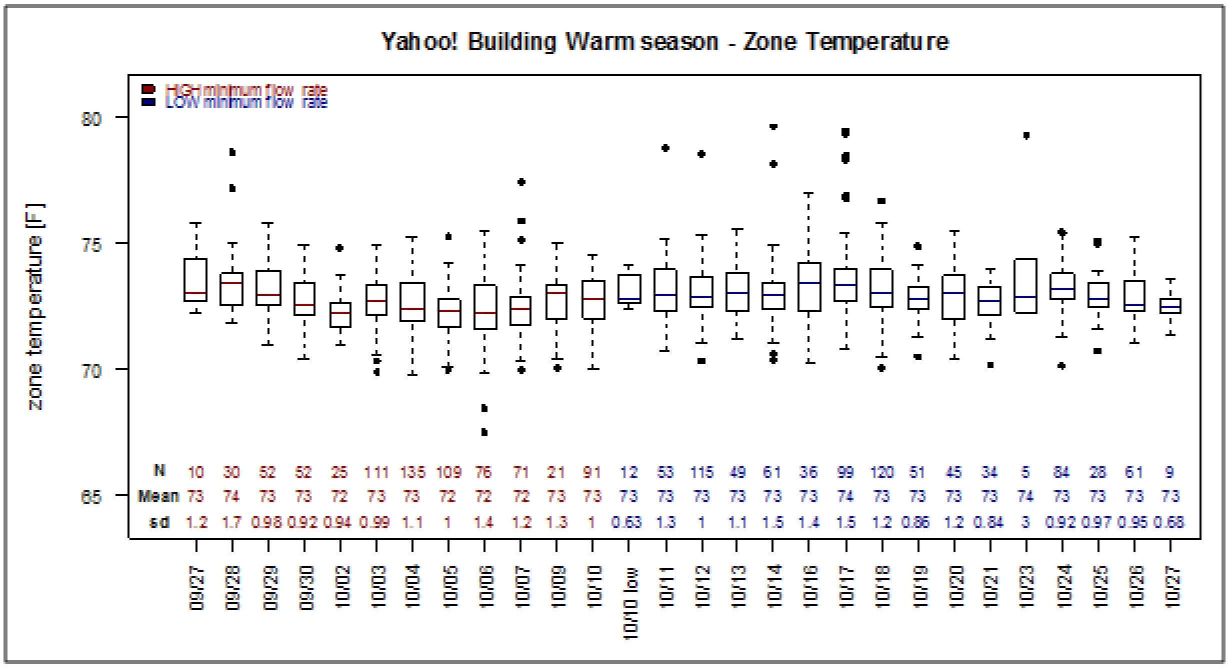


Figure 3.2.9 Zone temperatures under high and low minimum operations (Yahoo! warm season)

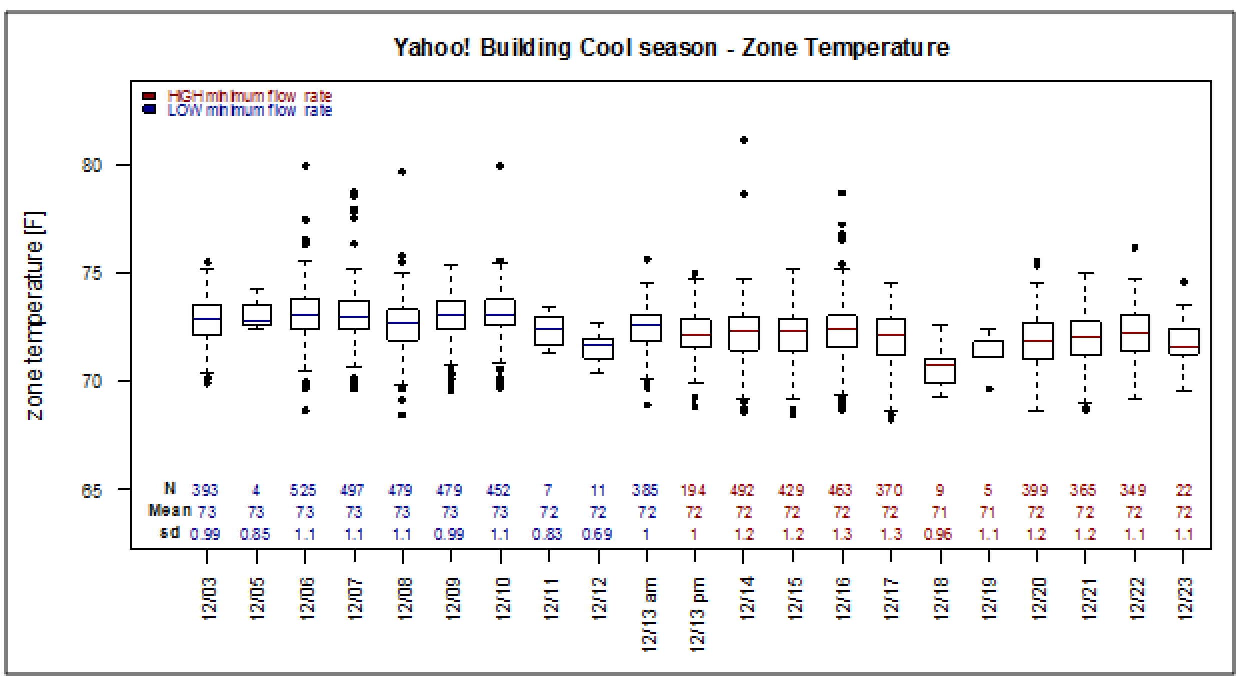


Figure 3.2.10 Zone temperatures under high and low minimum operations (Yahoo! cool season)

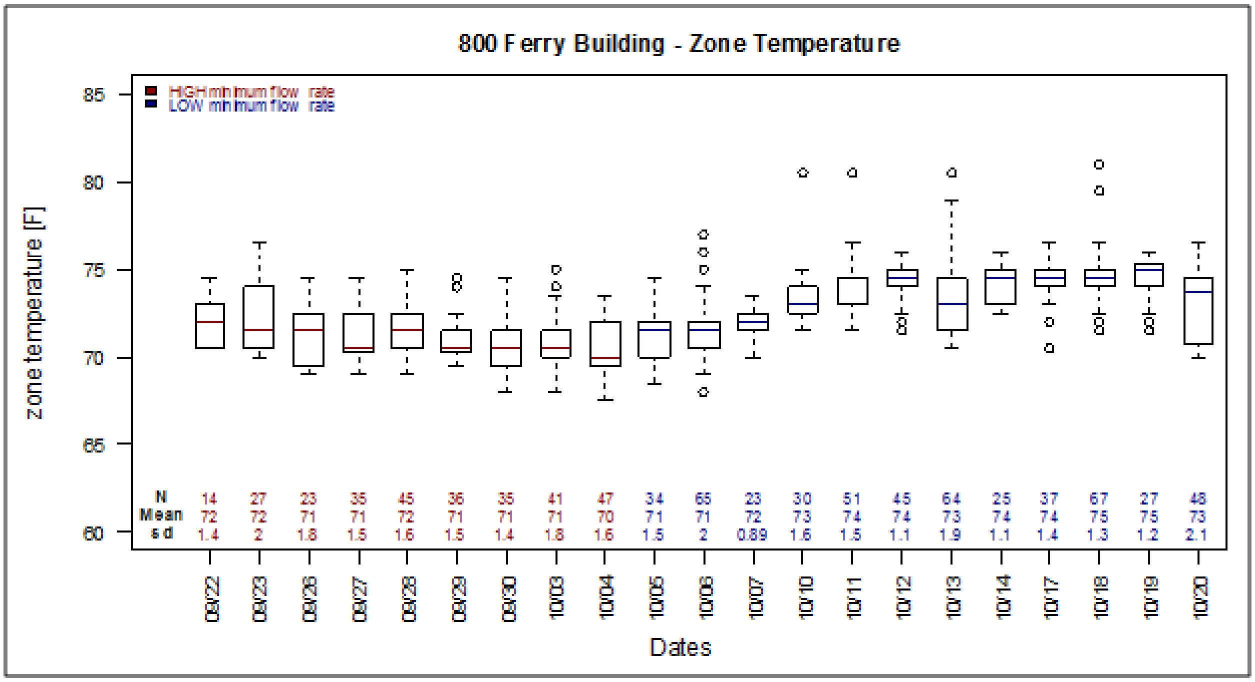


Figure 3.2.11 Zone temperatures under high and low minimum operations (800 Ferry)

Because we saw significant over-cooling complaints in afternoons when the outside air temperatures became warmer, here we further separate zone air temperatures between mornings and afternoons. The following three figures show the results for the three surveys. In the figures, each day is separated by vertical lines, with morning and afternoon data separately presented between the day's lines. The red and blue words below each chart represent morning data for the high and low minimum operations, and the black words represent afternoon data. These charts show that heating happened in both mornings and afternoons for all three survey periods. Heating in afternoons indicates that the buildings were over-cooled in afternoons.

The average zone air temperatures in mornings and afternoons are summarized in Table 3.2.11. Under high minimum operation, the zone air temperatures are same for mornings and afternoons for all three studies. Under low minimum operation, the average zone air temperatures were 0.2F higher in the afternoon than in the morning for the two Yahoo studies, and 1.5F higher for the 800 Ferry building.

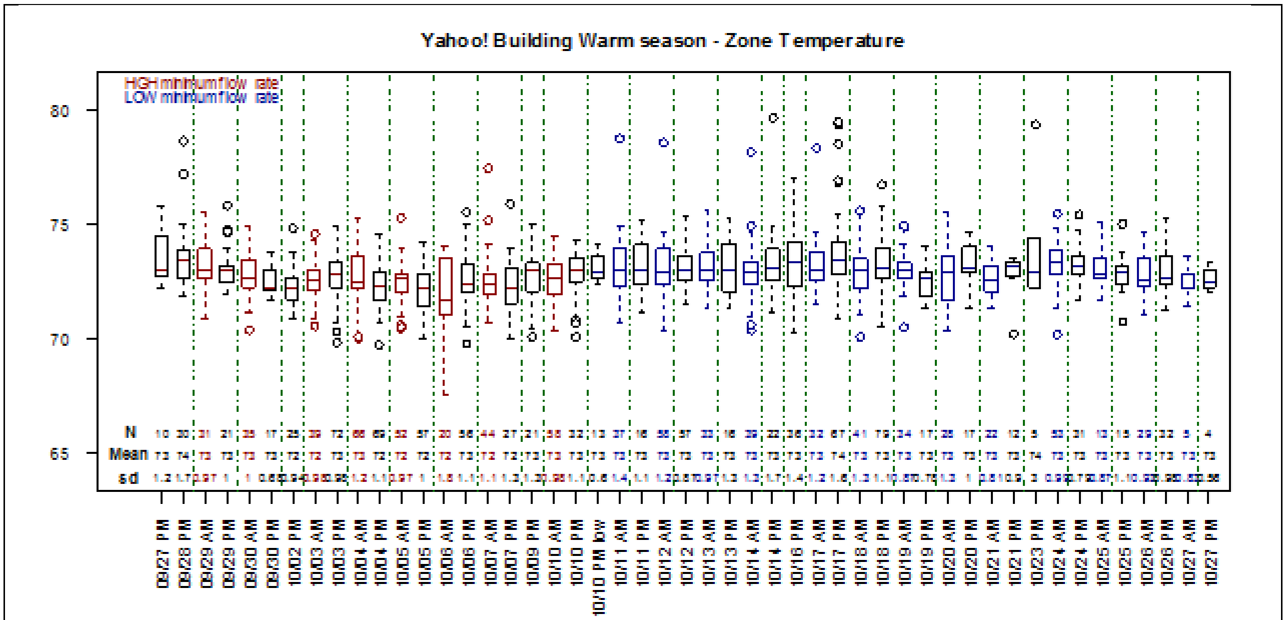


Figure 3.2.12 Morning and afternoon zone air temperatures, Yahoo! warm season

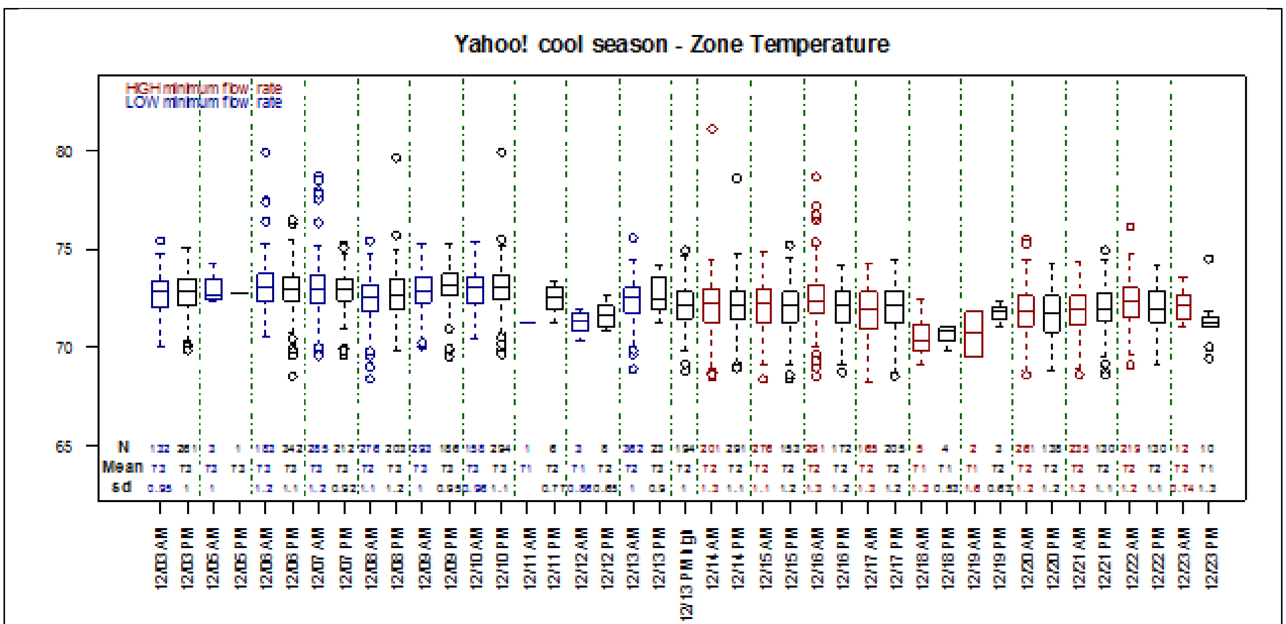


Figure 3.2.13 Morning and afternoon zone air temperatures, Yahoo! cool season

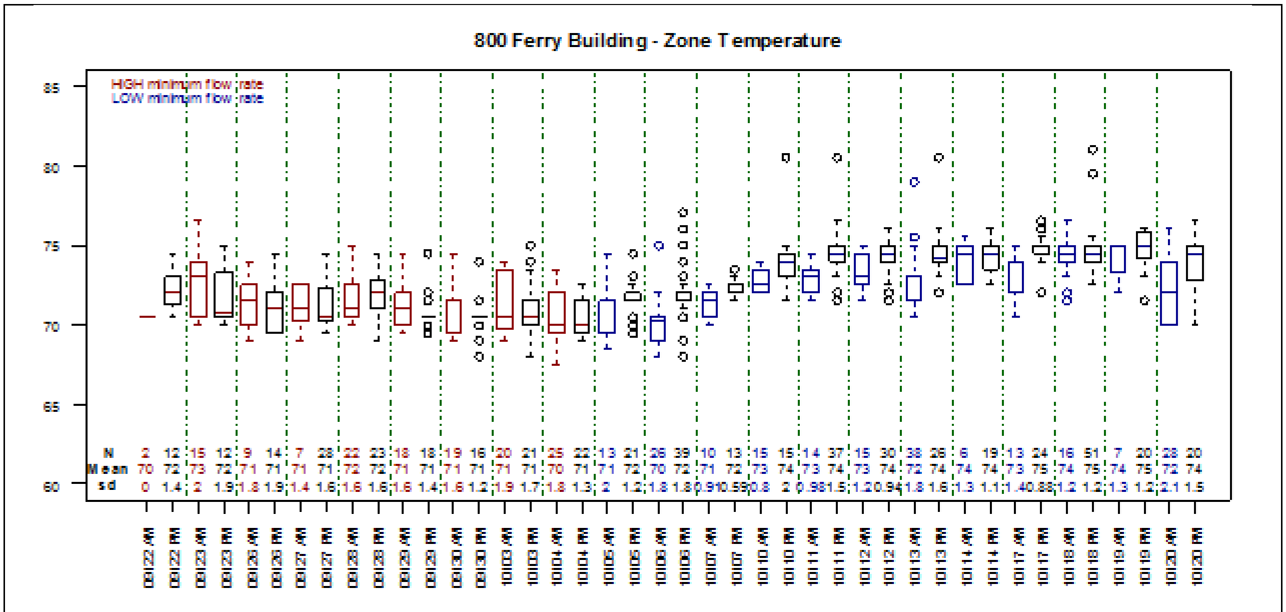


Figure 3.2.14 Morning and afternoon zone air temperatures, 800 Ferry building

Average zone temperature (F)	HIGH min flow rate		LOW min flow rate	
	AM	PM	AM	PM
Yahoo! warm season	72.6	72.6	73.0	73.2
Yahoo! cool season	72.1	72.0	72.7	72.9
800 Ferry building	71.2	71.2	72.4	73.9

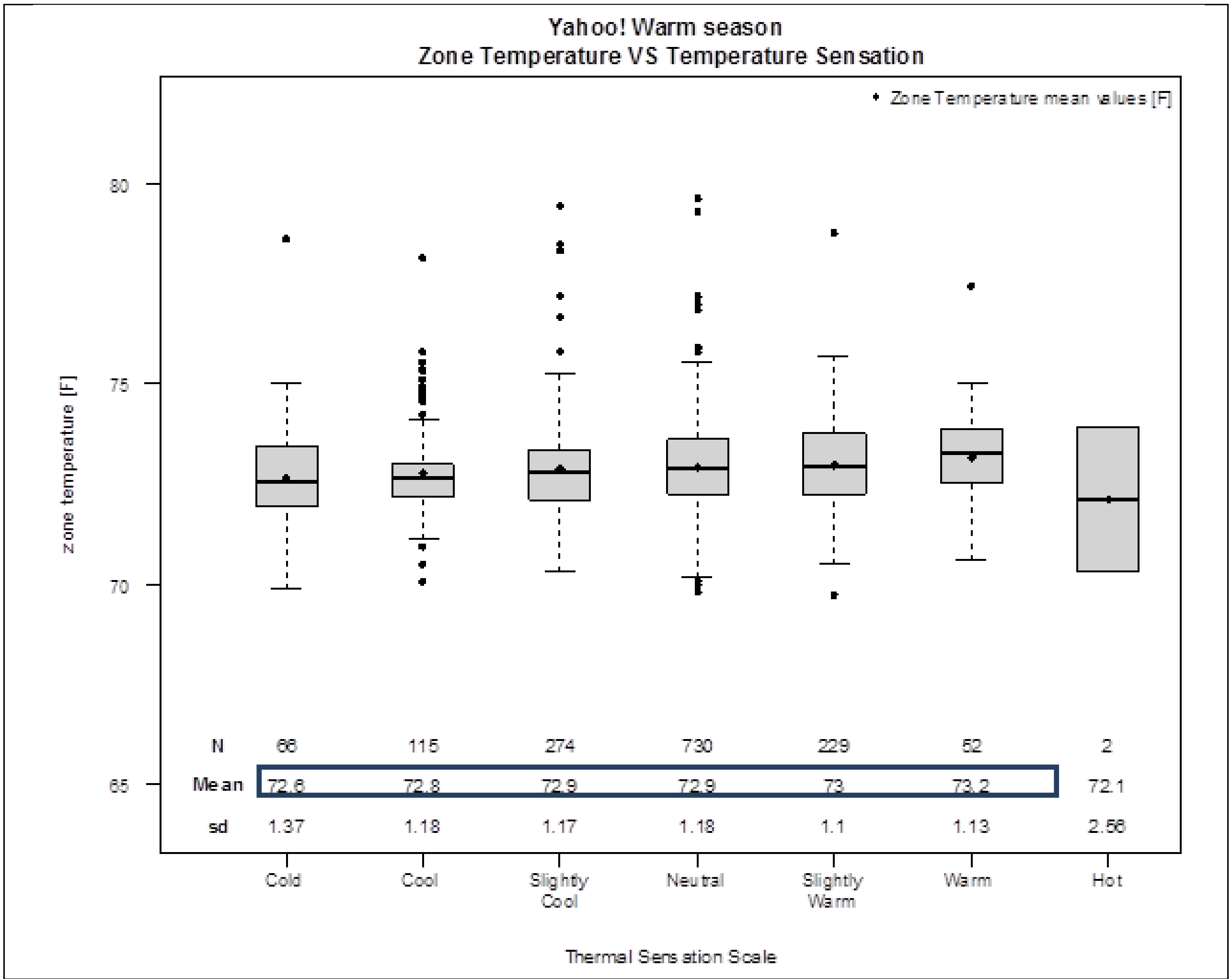
Table 3.2.11 Average zone air temperature in mornings and afternoons

3.3.4.2 Thermal sensation corresponding to zone air temperature

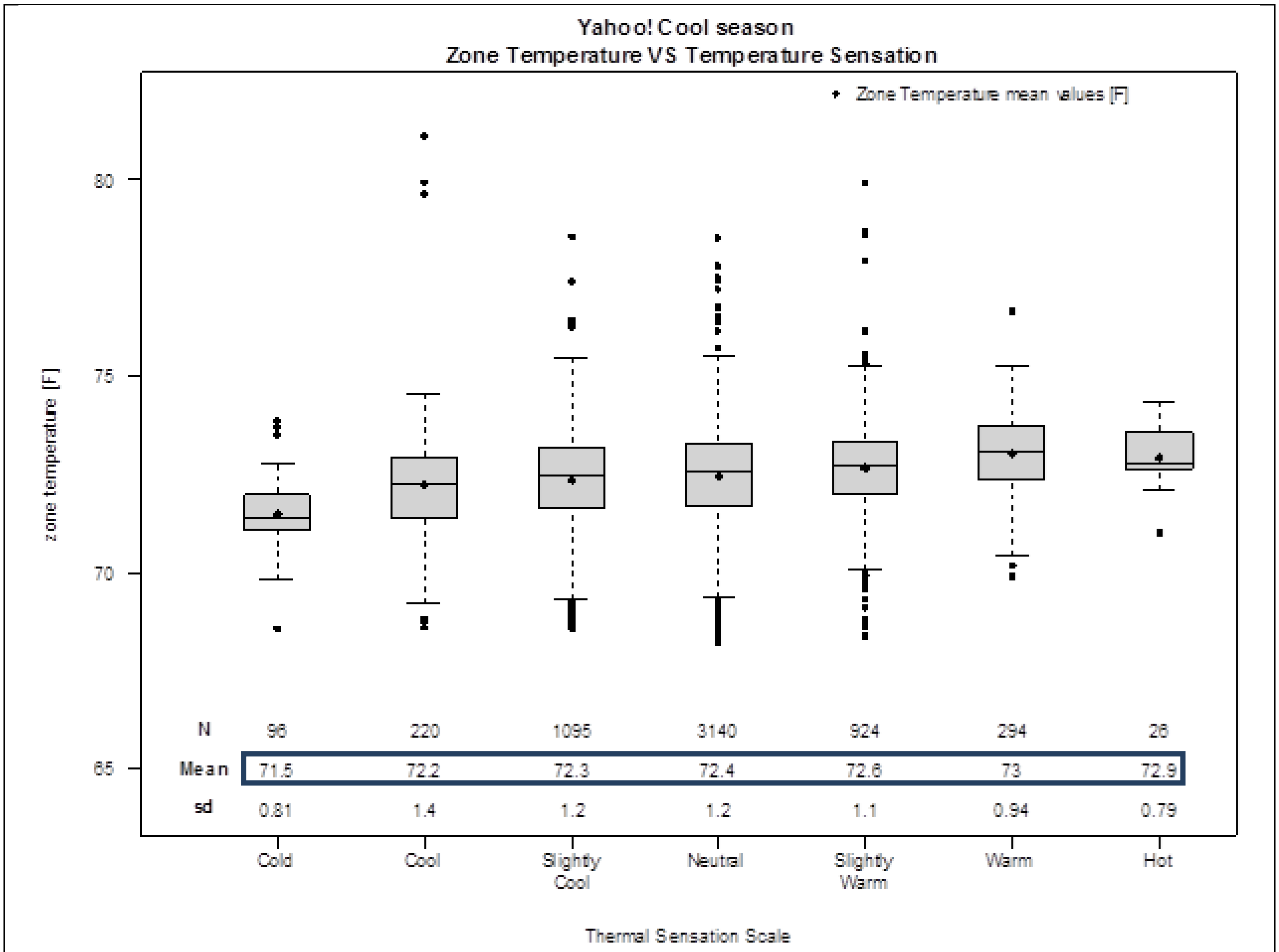
Here we examine the relationship between thermal sensation responses and the corresponding zone air temperatures (Figure 3.2.15; the X axis represents thermal sensation, and the Y axis represents temperature range). The mean zone temperature (in the blue box) and the standard deviations are presented together at the bottom of each chart with the total number of observations under each sensation category.

Although the mean corresponding air temperature increases as sensation changes from cold to warm, the differences are not large overall. During the Yahoo! warm season survey, as sensations changed from cold to warm, the mean corresponding zone temperature only increased 0.6ºF (from 72.6ºF to 73.2ºF). This difference is larger for the Yahoo! cool season survey and the 800 Ferry warm season survey. The difference is 1.5ºF (from 71.5ºF to 73ºF) in the Yahoo! cool season survey and 1.8ºF (from 72ºF to 73.8ºF) in the 800 Ferry building.

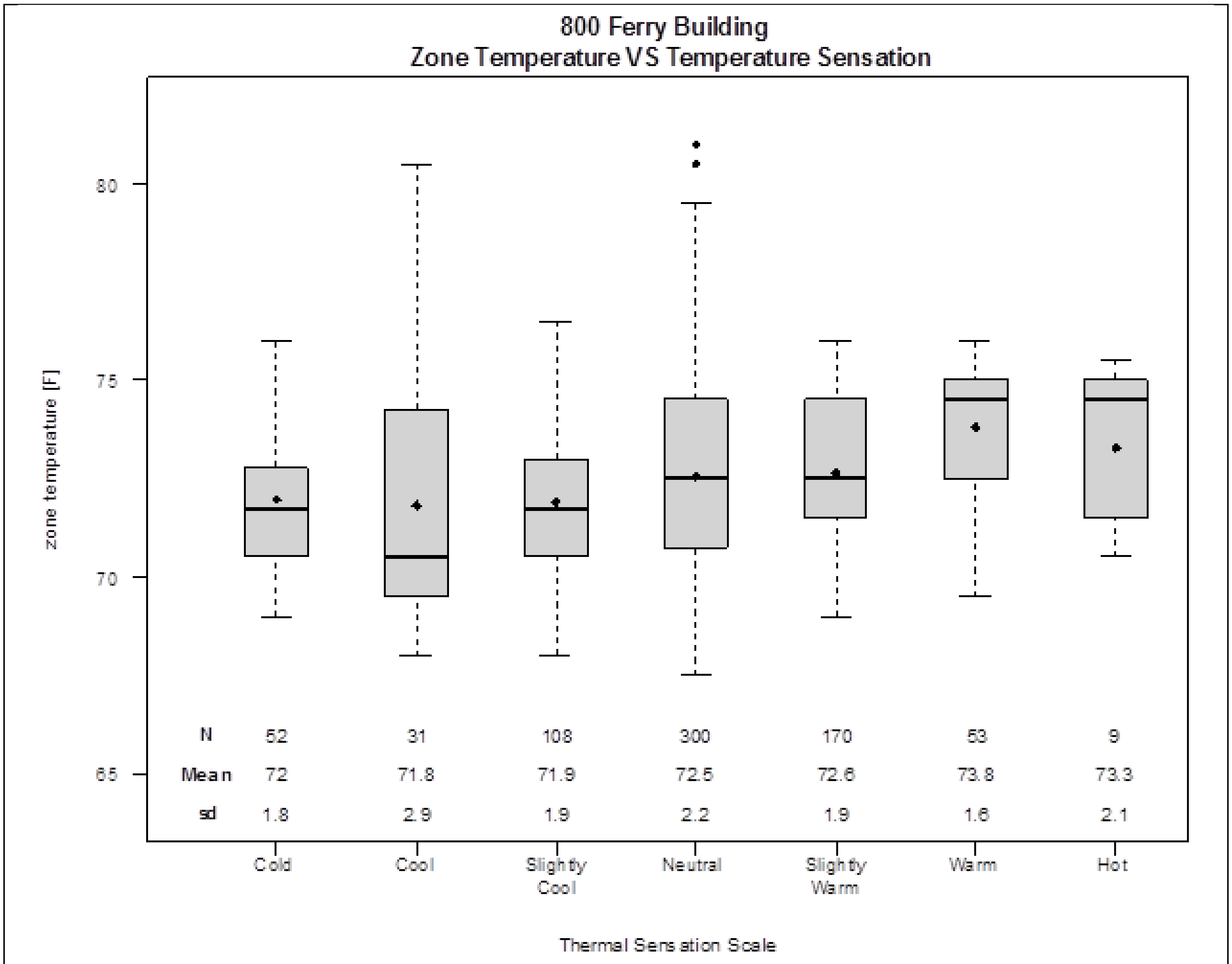
The small difference for the mean air temperature among wide ranges of thermal sensation is an indication of the individual variability among occupants. Within small air temperature differences, occupants' sensations ranged from 'cold' to 'warm'.



Yahoo! warm season (ignore the category "hot" because there are only 2 votes)



Yahoo! cool season



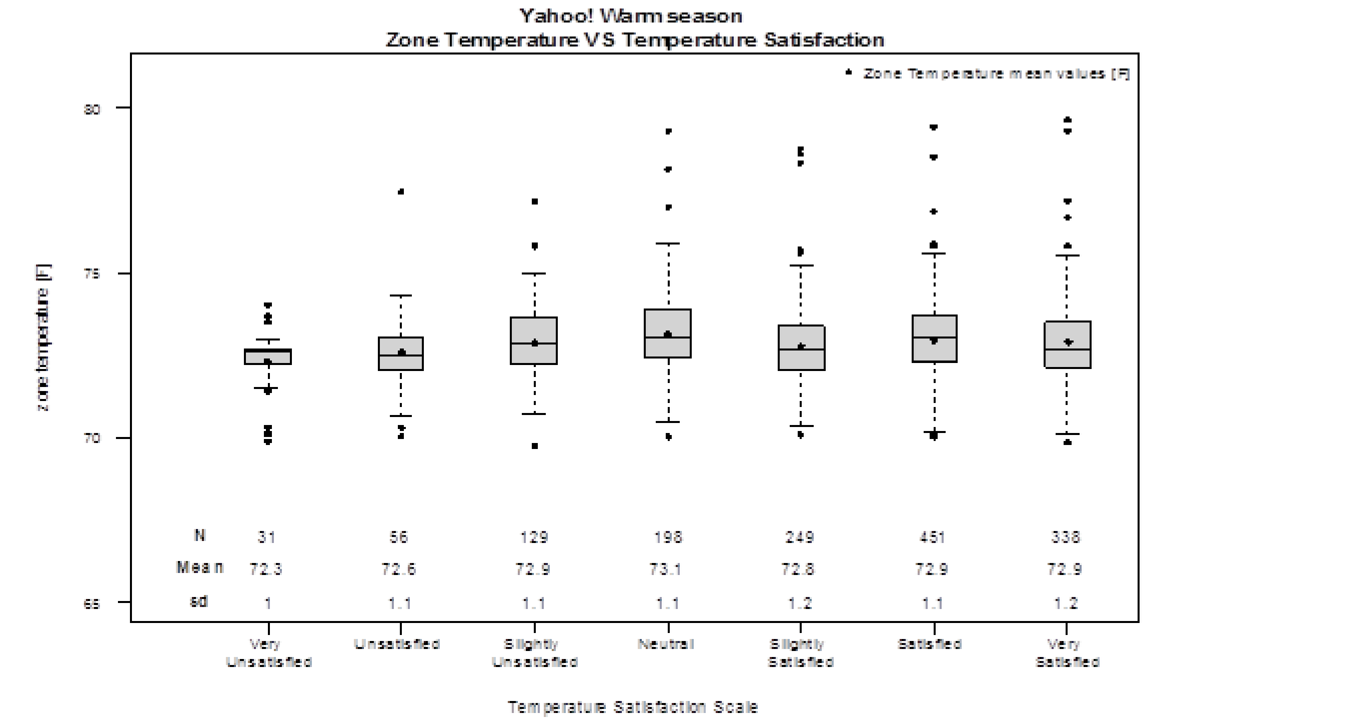
800 Ferry building (ignore the category "hot" because there are only 9 votes)

Figure 3.2.15 Thermal sensation and zone air temperatures

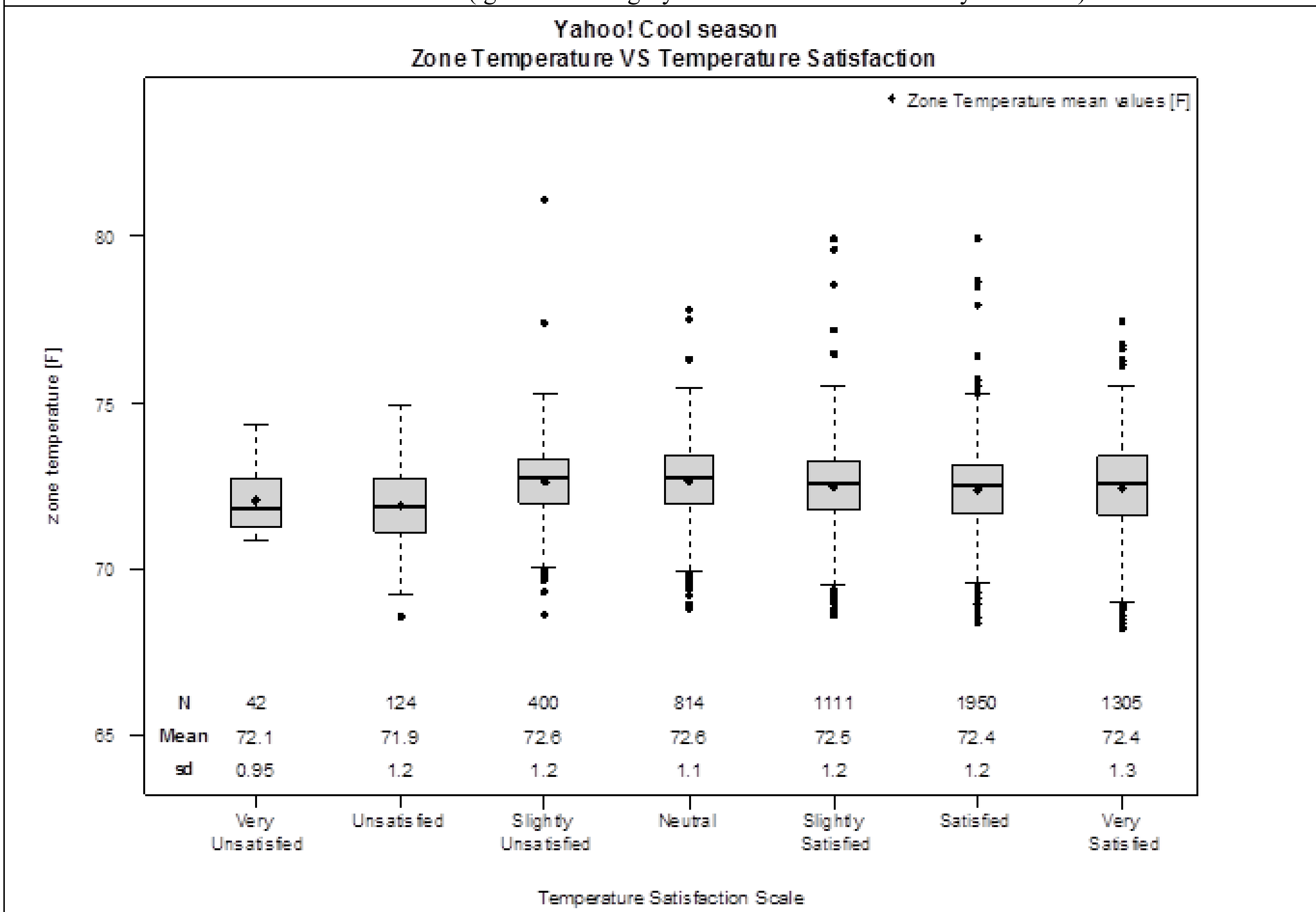
3.3.4.3 Temperature satisfaction corresponding to zone air temperature

This section analyzes the relationship between temperature satisfaction and zone air temperature. Since the dissatisfied percentage was reduced 47% in summer when low minimum was reduced from high to low, and the thermal sensation shows that people felt cooler under high minimum than low minimum setpoint, we expect to see higher temperature satisfaction at higher room air temperature.

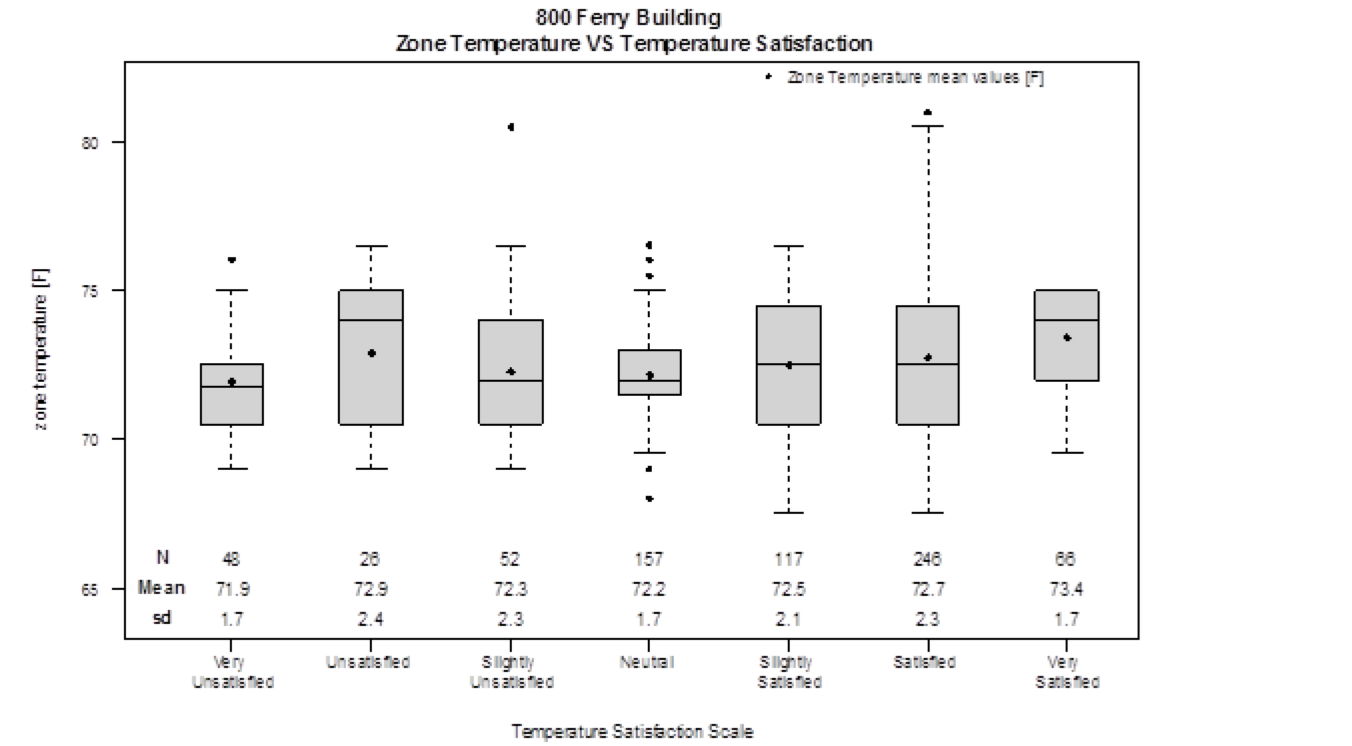
Figure 3.2.16 shows temperature satisfaction vs. zone air temperatures for the three surveys (the two blue boxes in each chart separate the temperatures for the satisfied and dissatisfied group respectively). Again, although we could see a slight trend that at a higher zone temperature the satisfaction is higher, the temperature difference is really small. Again, this indicates large variations among individuals, so that within a small zone temperature differences the satisfaction ranges from 'very dissatisfied' to 'very satisfied'.



Yahoo! warm season (ignore the category "hot" because there are only two votes)



Yahoo! cool season



800 Ferry building

Figure 3.2.16 Temperature satisfaction and zone air temperatures

More detailed analysis showing sensation and temperature satisfaction distributions under each 1F binned zone temperature is presented in Appendix B.

3.2.5 *Discharge air temperature, thermal sensation and satisfaction*

This section focuses on corresponding discharge air temperatures at the time-of-survey under both high and low minimum operation modes (weekend and evening data are therefore not included).

3.2.5.1 Discharge air temperature under high and low minimum operations

Most of the time during the Yahoo! warm season survey, the discharge air served to cool the spaces (Figure 3.2.17). However, there was occasional heating being delivered to the space. The average discharge air temperature and standard deviation are higher under high minimum operation (63.5ºF, 14ºF) than low minimum operation (60.7ºF, 8.7ºF). This might suggest that the spaces were overcooled during high minimum operation, and may have required more reheat to maintain space temperature.

Since the Yahoo! campus is in a mild climate and the buildings are dominated by internal loads, cooling occurs most of the time even during the cool season. However, heating still occurs more frequently in the cool season than in the warm season (Figure 3.2.18). Again, the average discharge air temperature and standard deviation are much higher under high minimums (74.7ºF, 23.6ºF) than under low minimums (65.6ºF, 15.3ºF). This may be due to reheat needed to offset overcooling.

For the 800 Ferry building summer survey period, the discharge air temperature and standard deviation under high minimum operation (64.7ºF, 4.2ºF) were lower than under low minimum operation (66.9ºF, 5.5ºF). (See Figure 3.2.19) This is opposite to what we have seen in the Yahoo! buildings. This means more heating during low minimum operation. When heating, the discharge air temperature was much lower in the 800 Ferry building than the values in the Yahoo! buildings. Therefore we don't see a large standard deviation under low minimum operation.

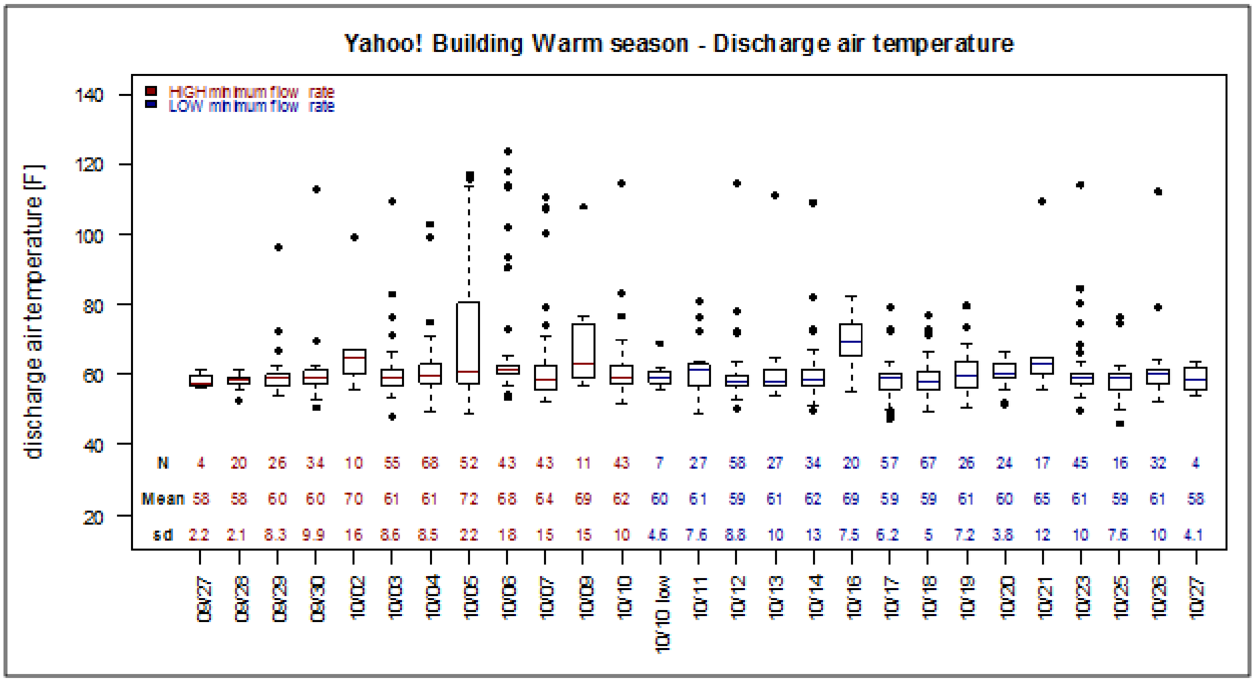


Figure 3.2.17 Average daily discharge air temperature (Yahoo! warm season)

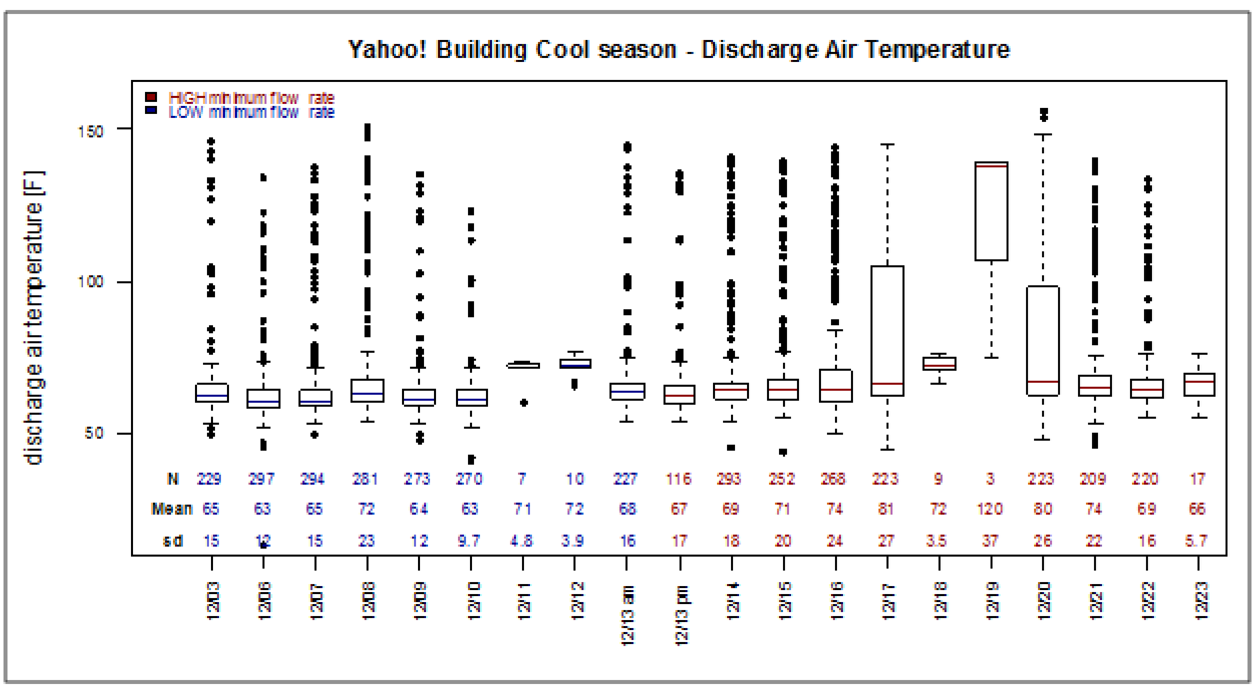


Figure 3.2.18 Average daily discharge air temperature (Yahoo! cool season)

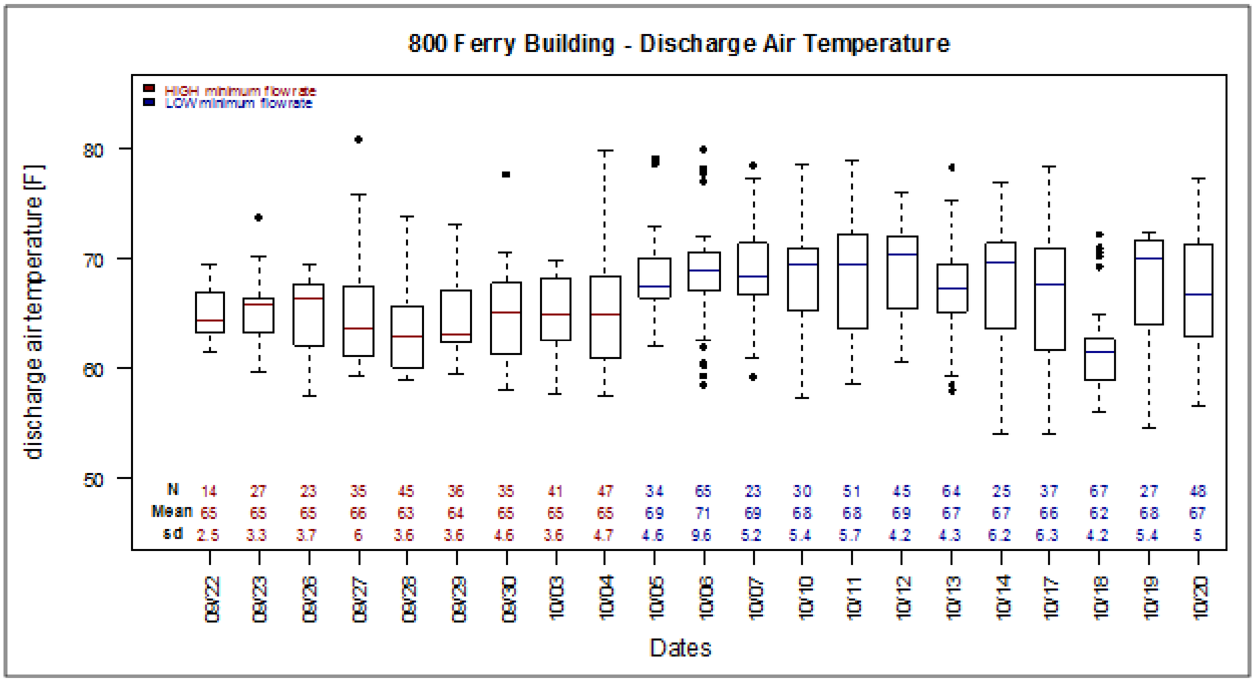


Figure 3.2.19 Average daily discharge air temperature (800 Ferry building)

We further separated the discharge air temperature in mornings and afternoons in order to understand discharge air temperatures changes, (see Figure 3.2.20 to Figure 3.2.22). For the Yahoo! warm survey, we see that more heating was involved in the afternoons (represented by black dots and words) under high minimum (red bars and words) operation than low minimum operation (blue bars and words). The difference is not clear for the Yahoo! cool survey. For the 800 Ferry building, it seems that the heating might happened slightly more in the afternoons under low than high minimum operations.

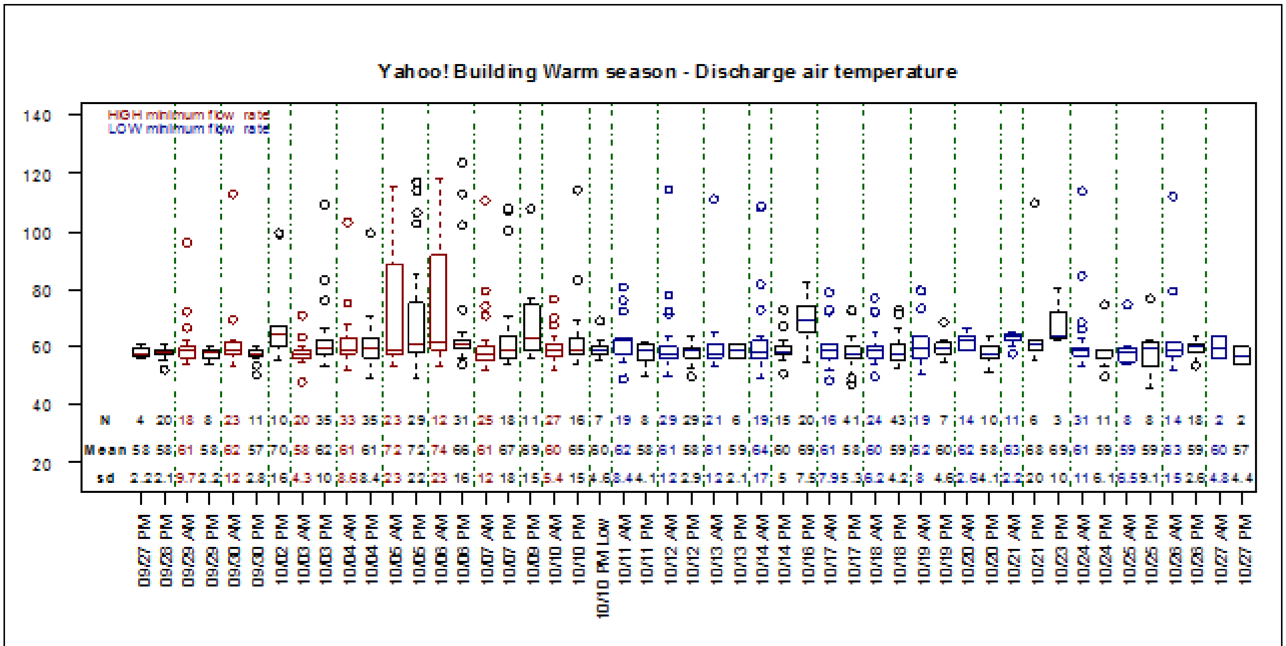


Figure 3.2.20 Discharge air temperature in mornings and afternoons, Yahoo! warm

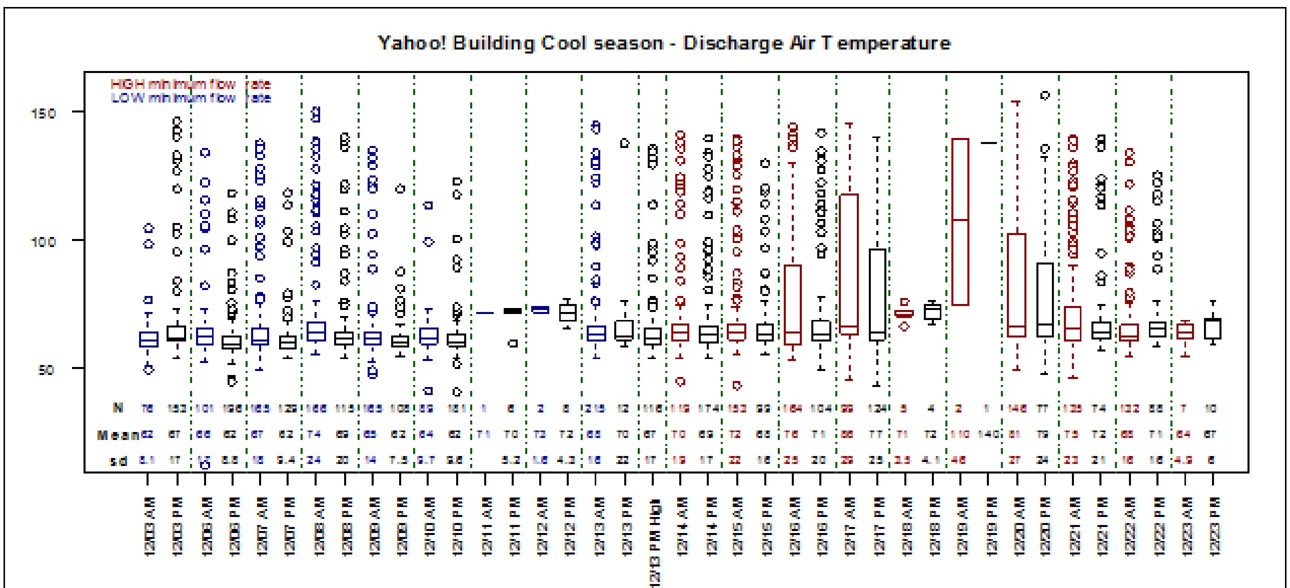


Figure 3.2.21 Discharge air temperature in mornings and afternoons, Yahoo! cool

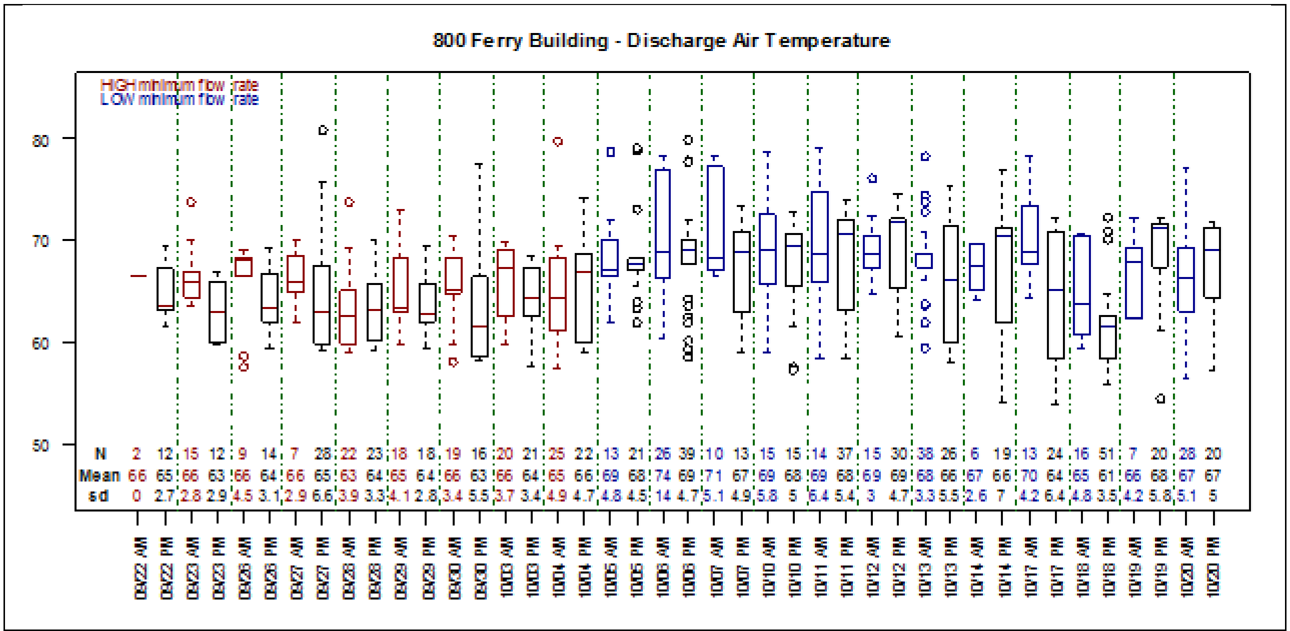


Figure 3.2.22 Discharge air temperature in mornings and afternoons, 800 Ferry building

The summary of the discharge air temperatures for mornings and afternoons is presented in Table 3.2.12. The discharge air temperatures are lower than zone air temperature, indicating that HVAC systems basically provide cooling for all the three studies in both warm and cool seasons. The average discharge air temperatures in the morning were much higher than in the afternoon for the Yahoo! cool study. Looking at Figure 3.2.21, it was caused by morning heating.

For the warm season studies (Yahoo! warm and 800 Ferry building), the discharge air temperatures were also higher (about 1 – 2K) in the morning than in the afternoon (except Yahoo! warm study under high minimum operation). Referring to Figure 3.2.20 and Figure 3.2.22, the higher morning discharge air temperatures were also due to morning heating.

For Yahoo! warm study under high minimum operation, the discharge air temperature is 1.3F higher in the afternoon than in the morning. Refereeing to Figure 3.2.20, the higher discharge air temperature in the afternoon was also caused by heating. This again shows that in summer under high minimum operation, the buildings was overcooled, especially in the afternoon, because heating had to be applied in order to keep the low setpoint of the thermostat.

Average discharge air temperature (F)	HIGH min flow rate		LOW min flow rate	
	AM	PM	AM	PM
Yahoo! warm season	62.8	64.1	61.4	60.2
Yahoo! cool season	75.2	71.5	67.3	64.1
800 Ferry building	65.2	64.3	68.9	66.4

Table 3.2.12 Average discharge air temperatures in the morning and in the afternoon

3.2.5.2. Discharge air temperature vs. thermal sensation and temperature satisfaction.

If "dumpling" does happen under low minimum operation (supply air from diffusers is not mixed well before reaching occupants), then the discharge air temperature might be important affecting occupants' thermal comfort. We grouped discharge temperature into four groups: 55 – 60, 60 – 65, 65 – 70, 70 – 75, and examined differences of thermal sensation and temperature satisfaction, under both high and low minimum operations. There is no clear relationship found between discharge temperature and thermal sensation, or discharge air temperature with temperature satisfaction. The conclusion is that discharge air temperature under currently examines ranges do not seem to have strong influence on sensation and comfort. The detailed results are presented in Appendix C.

3.2.6 *Satisfaction with perceived air quality*

When the minimum flow rate setpoints are reduced from high to low, the volume of outside air entering the air handler unit (AHU) is not changed. Only the volume of recirculated air is decreased. Therefore, indoor air quality should not be changed if the fresh air is delivered appropriately to the occupants.

However, there is still a concern that if mixing is not done well, there might be perceived air quality issues by the occupants. In our occupant survey questionnaire, we asked occupants' perception of perceived air quality. We analyzed the data for selected days (excluding the days when stable state wasn't reached), indicated by the green boxes shown in Figure 3.2.23 and Figure 3.2.24.

Yahoo! warm season. Similar to temperature satisfaction, Figure 3.2.23 shows that, on average, the percentage of people dissatisfied with perceived air quality under high minimum flow operation (9.2%, total N=763) is reduced under low minimum flow operation (6.3%, total N=1072), a 32% reduction (statistically significant, $p<0.001$).

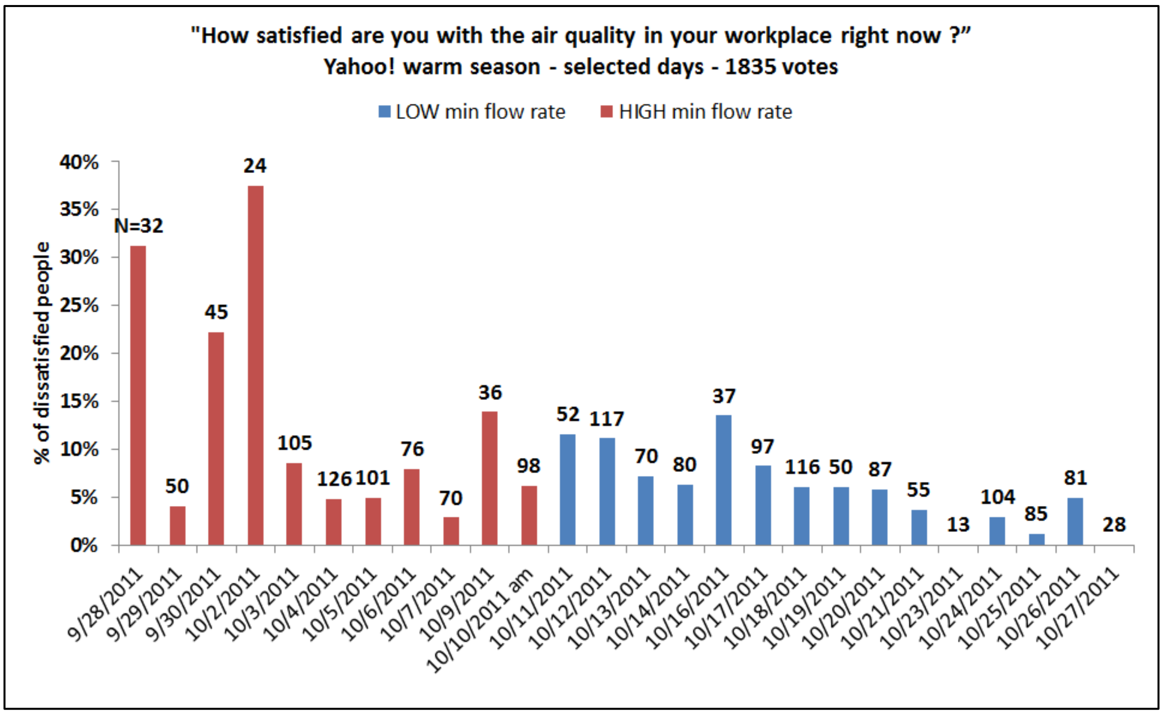


Figure 3.2.23 Perceived air quality under high and low minimum operations (Yahoo! warm season)

Yahoo! cool season. The perceptions of perceived air quality for the three days before and after the change of the low minimum setpoint are similar (see Figure 3.2.24). On average, the percentage of occupants dissatisfied with perceived air quality is 6.3% (total N=1397) at high minimum operation, and 6.6% (total N=1508) at low minimum operation.

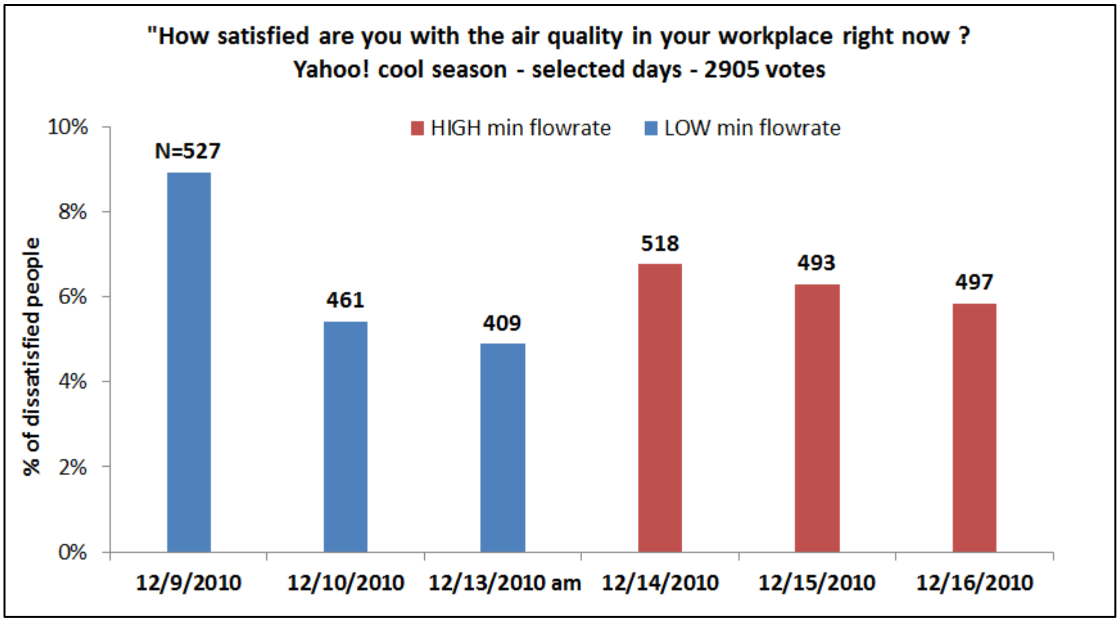


Figure 3.2.24 Perceived air quality under high and low minimum operations (Yahoo! cool season)

The 800 Ferry building. Again, similar to temperature satisfaction, Figure 3.2.25 shows that, on average, the percentage of occupants dissatisfied with perceived air quality under high minimum flow operation (19.6%, total N=263) was significantly reduced under low minimum flow operation (7.4%, total N=512), a 68% reduction (statistically significant, $p<0.001$).

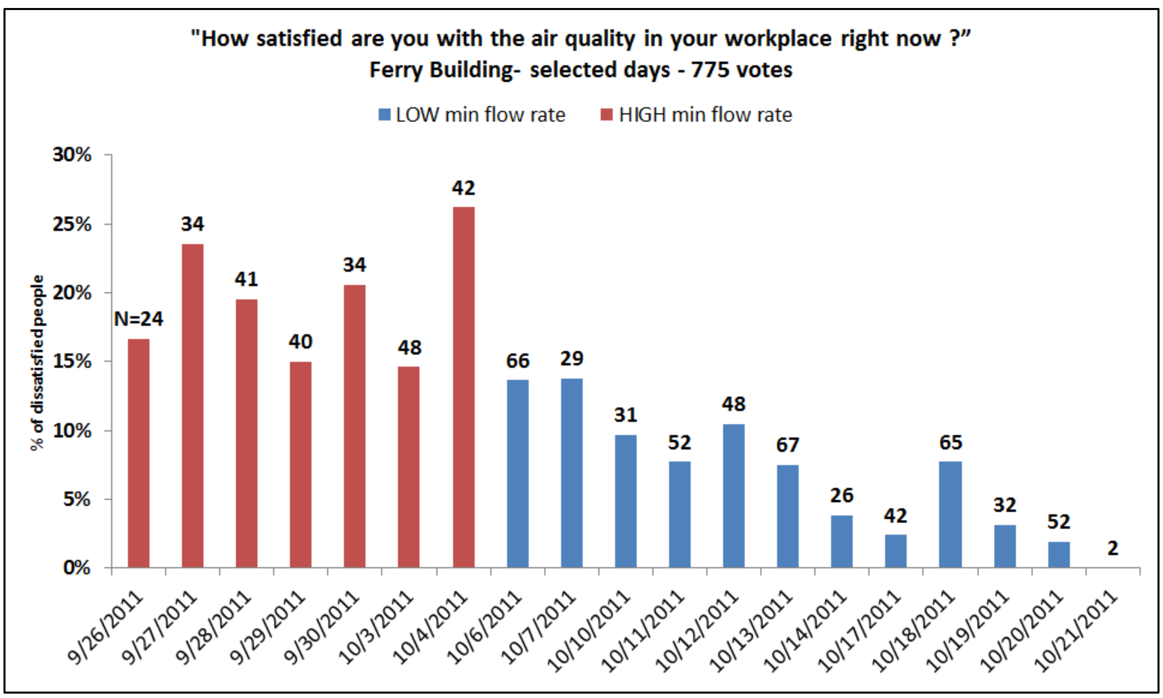


Figure 3.2.25 Perceived air quality under high and low minimum operations

(800 Ferry building, warm season)

Summary. Similar to the temperature satisfaction results summarized in Figure 3.2.5, the perceived air quality was also significantly improved in the warm season surveys (Yahoo! buildings and the 800 Ferry building) when the minimum flow setpoint was reduced. Perceived air quality is similar between the two modes of operations in the Yahoo! cool season survey. The summary chart is presented in Figure 3.2.26, and the values are in Table 3.2.13.

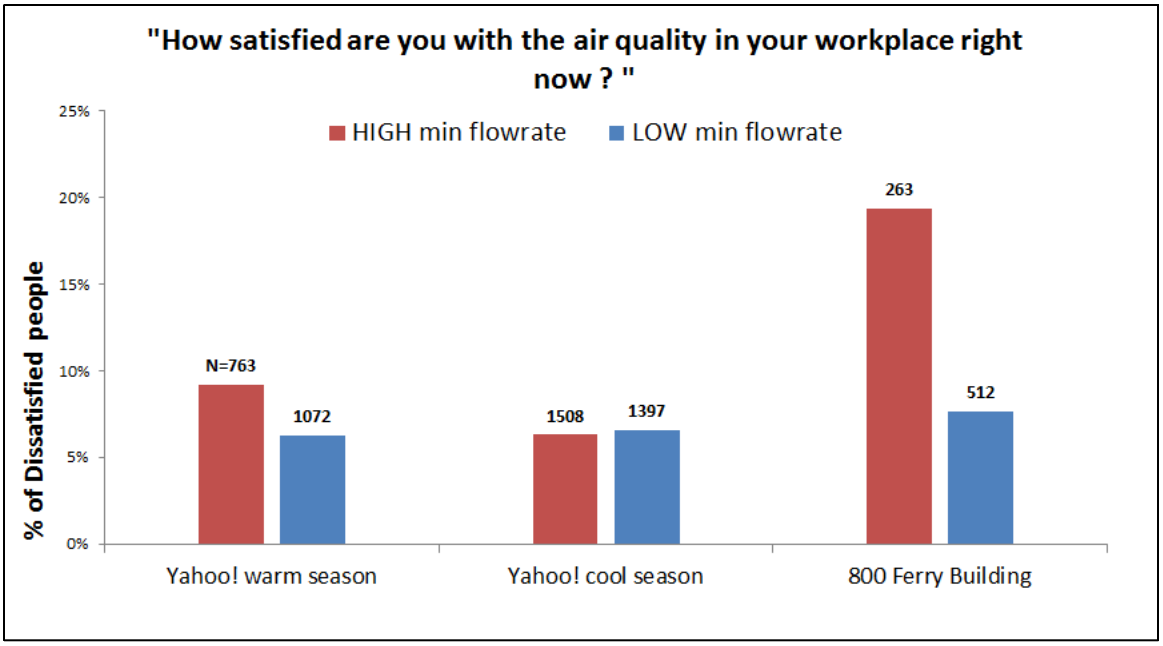


Figure 3.2.26 Comparison of perceived air quality dissatisfaction rates under high and low minimum operations for the three surveys

	Perceived air quality dissatisfaction: High minimum operation	Perceived air quality dissatisfaction: Low minimum operation
Yahoo! warm season	**9.2%**	**6.3%**
Yahoo! cool season	**6.3%**	**6.6%**
800 Ferry Building	**19.6%**	**7.4%**

Table 3.2.13 Summary of dissatisfaction rates for perceived air quality with high and low minimum flow rate setpoints for the three surveys

More detailed information about perceived air quality satisfaction vs. binned zone air temperature and discharge air temperature is presented in Appendices D and E.

3.2.7 *Sense of air movement*

3.2.8.1 Sense of air movement. Another concern about the consequences of low minimum operation is that people near diffusers may sense a “draft of air movement”, by assuming that the discharge air may not mix well. In order to address this concern, we grouped people together based on the flow rate (<30%, 30 - 40%, and >90%) to examine their sense of air movement. Four choices were presented in the survey: (1) no air movement, (2) little air movement, (3) moderate, and (4) strong. Table 3.2.14 shows the percentage of occupants that sensed air movement as moderate or strong. The results from the Yahoo! buildings show that there is little or no difference when the flow rate was at <30% and 30 - 40%. It was when flow rate was high (>90%) that the population feeling the air movement “moderate and strong” is nearly doubled. In the 800 Ferry building, the sense of air movement is higher (16%) when the flow rate is 30 - 40% than when the flow rate is <30%.

There is no data when the flow rate is >90%. These results contradict the original concern - that when the flow rate is as low as 10%, it could cause “draft sensation of the air movement” problems.

Sense of air movement (%)		VAV flow rate		
		< 30%	30% - 40%	>90%
Yahoo! warm season	Total Votes	919	669	88
	moderate and strong (%)	11	11	20
Yahoo! cool season	Total Votes	3180	2452	309
	moderate and strong (%)	7	4	13
800 Ferry building	Total Votes	456	233	0
	moderate and strong (%)	9	16	0

Table 3.2.14 Sense of air movement for the three surveys

3.8.2.2 Impact of distance to diffuser on air movement preference. We also asked about air movement preference in our survey (more, no change, or less). In order to examine whether discharge air was directly “dumped” on the people near diffusers, we grouped people based on their workstation’s distance from diffusers: close (diffuser above workstation), middle (diffuser nearby but not in workstation), or far away (diffuser is at least one workstation away). The following analysis focuses on the distance of the workstation from a diffuser. Table 3.2.15 shows that when comparing the workstations close to diffusers to the workstations far from diffusers, there is a 4% increase in the population who would like to have less air movement, and an 8% decrease in the population who would like to have more air movement.

Air movement preference - Yahoo! Warm + Cool season	Far	Close
N	2014	3660
less (%)	7%	11%
more (%)	29%	21%

Table 3.2.15 Air movement preferences for people whose workstations are close or far away from diffusers

The above analysis indicates that people in workstations which are closer to diffusers are likely to experience high sensations of air movement. Therefore, we will specifically examine air movement preferences for those people according to different flow rates (<30%, 30 - 40%, >90%, Table 3.2.16). Again, the table shows that it is when the flow rate is high that more people from workstations which have a diffuser in the workstation would like to have less air movement, and a reduction in occupants that want more air movement.

Air preference for "close to diffuser" population - Yahoo! Warm + Cool season	< 30%	30% - 40%	>90%
	1746	1300	162
Less	191	122	25
More	371	303	25
Less (%)	11%	9%	15%
More (%)	21%	23%	15%

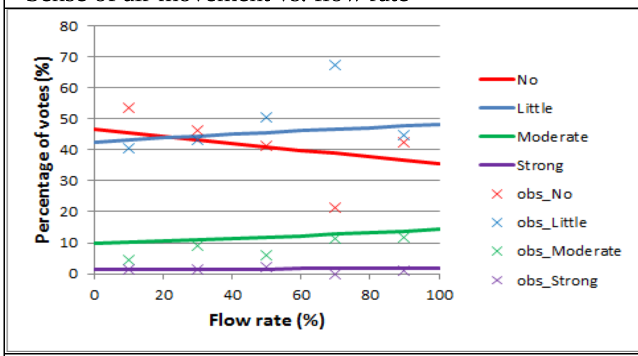
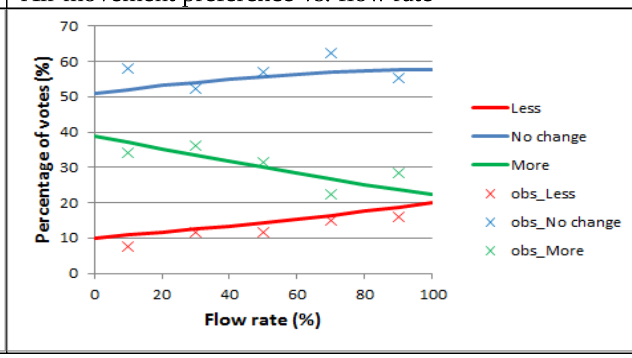
Table 3.2.16 Air movement preference with flow rate for people whose workstation has a diffuser

3.8.2.3 Logistic regressions for the air movement vs. flow rate. Combining all of the data, we did a logistic regression analysis for the “sense of air movement” and “air movement preference” based on flow rates for the three survey results. The original binned data and the fittings are shown in Figure 3.2.27. These fittings are all statistically significant ($p<0.001$).

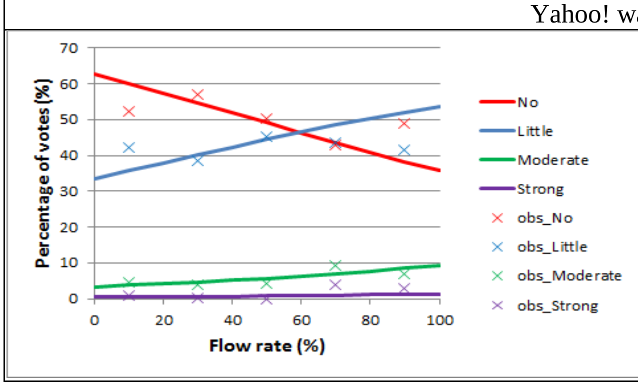
The three figures in the left column show the sense of air movement based on flow rate. Similar to the results shown in Table 3.2.14, as the flow rate increases, the sense of “no air movement” is reduced, and the sense of “little” and “moderate” air movement increases. These changes are more dramatic in the Yahoo! cool season survey and in the 800 Ferry building survey. This indicates that in these two buildings, people were more sensitive to air movement when the flow rate changed. Possible reasons might be that summer over-cooling is stronger in the 800 Ferry building warm season survey than in the Yahoo! warm season survey (explained in sections 3.2.1 and 3.2.2), and that in the cool season, people are more sensitive to air movement. The sense of “strong” air movement is very low in the two Yahoo! surveys across all flow rates (near zero), but it is much stronger in the 800 ferry building survey when the flow rate is high. Again, this could be due to the stronger summer over-cooling in the building.

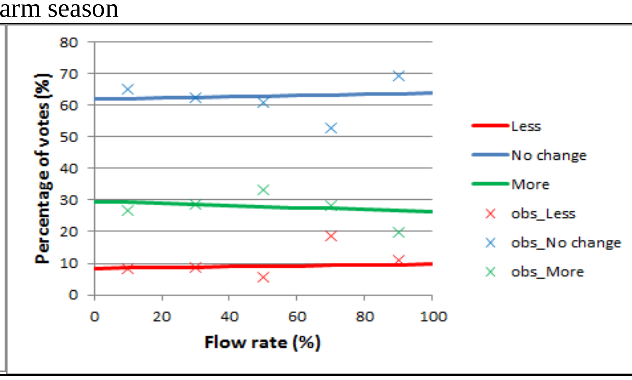
The three figures in the right column show “air movement preference”. The regression lines clearly show that the preference for “less air movement” increases and the preference for “more air movement” decreases as the flow rate increases. The curves for “no change in air movement” do not change much across the entire range of flow rates.

Note that the curves in the logistic regression charts fit the data according to the number of observations at each point. Therefore, if there are few observations in a certain preference category (such as in the 800 Ferry building survey air movement preference categories "no change" and "less"), the resulting model will give more weight to the other preference categories with more responses. This can create the effect of curves not appearing to follow the points on the chart. However, if one considers that all of the lines are modeled simultaneously and sum to 100%, it becomes clear that it may not follow the data precisely.

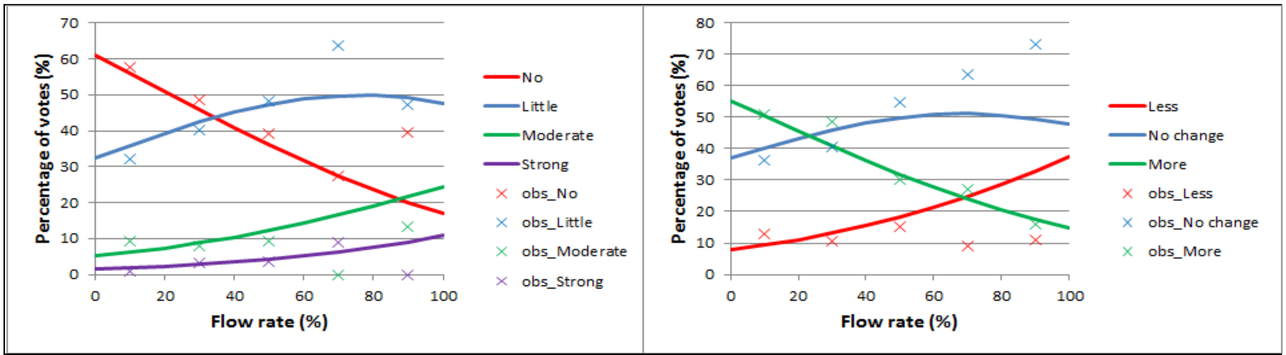
Sense of air movement vs. flow rate	Air movement preference vs. flow rate
	

Yahoo! warm season





Yahoo! cool season



800 Ferry building

Figure 3.2.27 "Sense of air movement" and "air movement preferences" based on flow rate for the three surveys

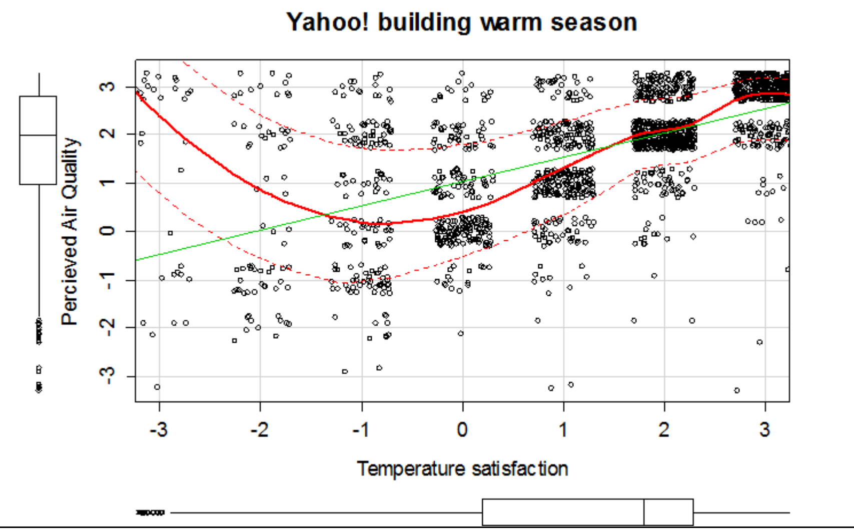
Detailed information for the sense of air movement vs. binned zone air temperature or binned discharge air temperature is presented in Appendix E and F.

3.2.8 *Perceived air quality vs. temperature satisfaction*

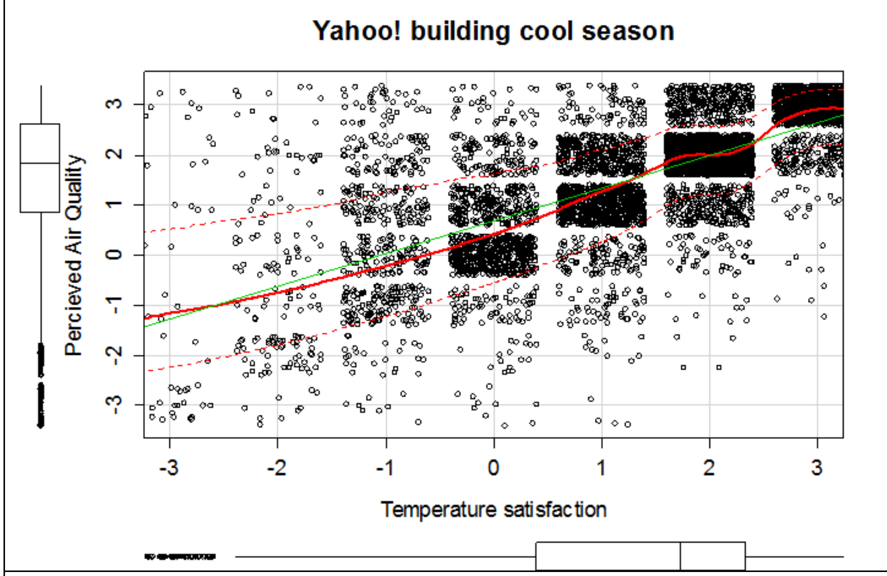
Figure 3.2.23 to Figure 3.2.26 show that the daily dissatisfaction with perceived air quality distribution is similar to the dissatisfaction with temperature satisfaction (Figure 3.2.5 to Figure 3.2.5). Figure 3.2.28 pulls all of the data together to show the relationship between temperature satisfaction and perceived air quality. Because the votes are integers (-3 to 3), in order to show the density of votes across each scale unit, the data is perturbed. That is why the figures show dots grouped together forming rectangular cells.

Interestingly, there is a roughly linear relationship between temperature satisfaction and perceived air quality in the Yahoo! cool season and 800 Ferry warm season surveys (as indicated by the green line – the linear regression line, and the three red lines – a weighted polynomial regression and the upper limit 75 percentile and the lower limit 25 percentile). The relationship is much clearer in the 800 Ferry survey. In the Yahoo! warm season survey, the mean perceived air quality went up when the temperature satisfaction decreased. This means when people are not satisfied with the temperature, their perceived air quality can be good; the lower the temperature satisfaction, the better the perceived air quality.

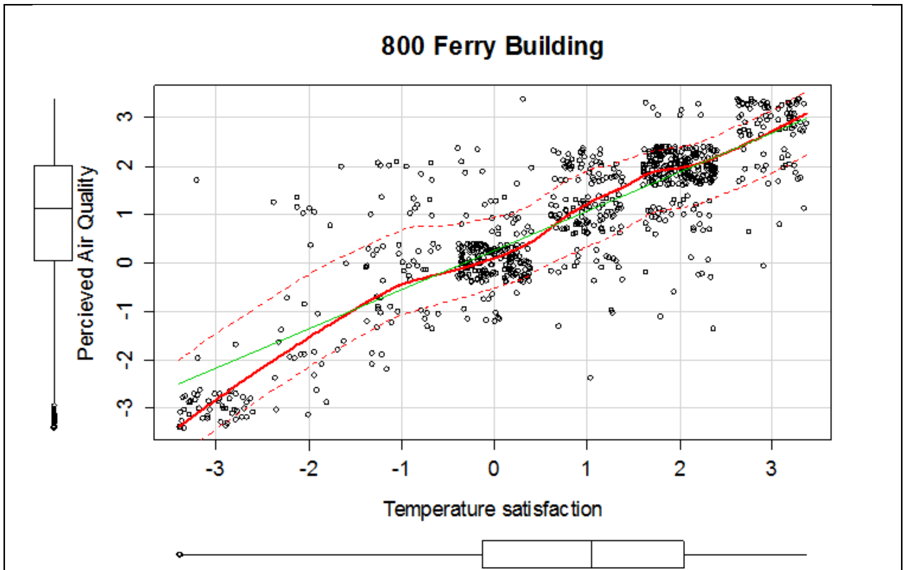
Looking at the three charts, another interesting trend is that people tend to vote similarly on the perceived air quality and temperature satisfaction. We see a heavy group of dots along the voting scale points at (0,0), (1,1), (2,2), and (3,3). In the 800 ferry building survey, most dots are around (0,0) and (2,2). This might be psychologically related – it seems that people like to put their votes in the middle of a scale (middle of the entire scale from -3 to 3, and middle of the satisfied side scale from 0 to 3).



Yahoo! warm season



Yahoo! cool season



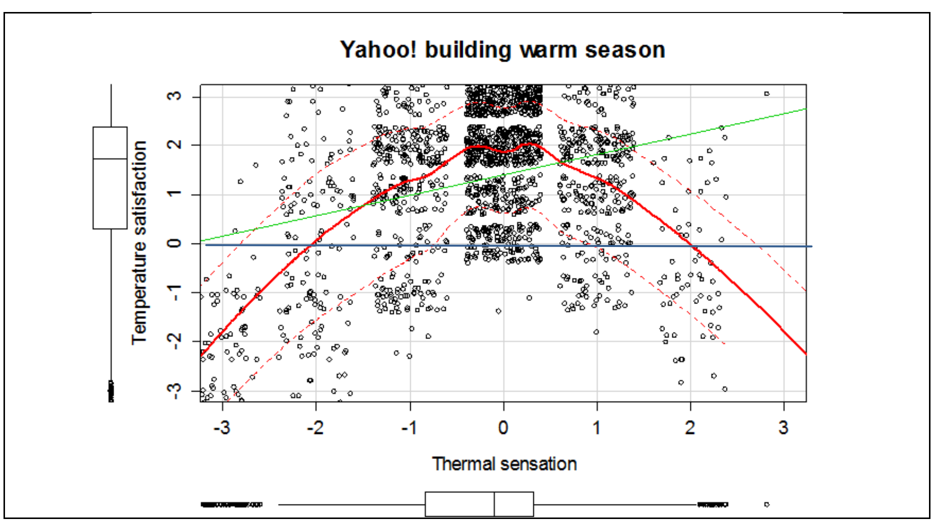
800 Ferry building

Figure 3.2.28 Relationship between perceived air quality and temperature satisfaction for the three surveys

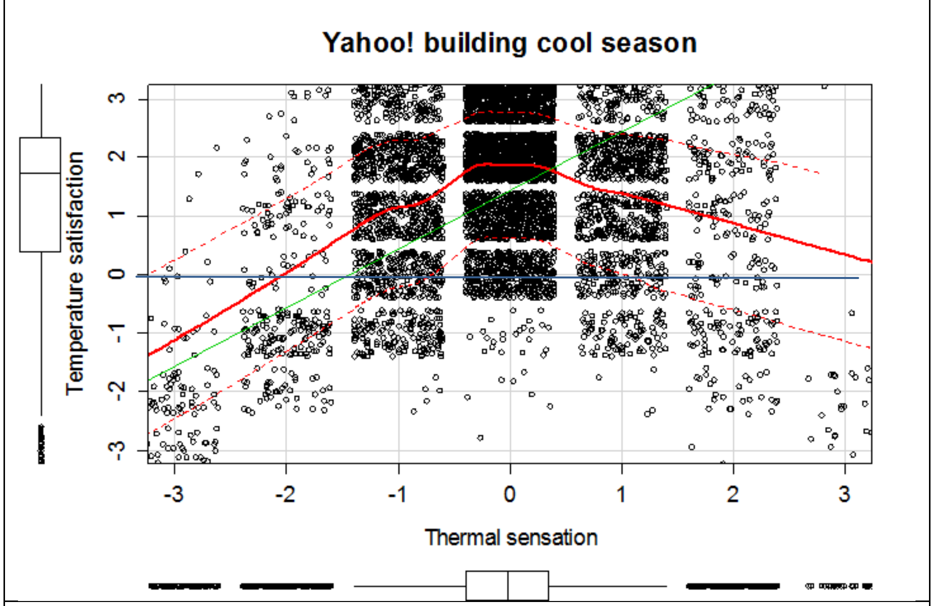
3.2.9 *Temperature satisfaction with thermal sensation*

This section examines the thresholds for thermal sensation when people are considered satisfied. The three charts below (Figure 3.2.29) show the temperature satisfaction (Y axis) vs. thermal sensation (X axis). The three red lines represent the mean temperature satisfaction values and the standard deviation, and the blue horizontal lines emphasize the middle of the satisfaction scale (data above means satisfied, and data below means dissatisfied). Again, the data was perturbed in order to see the number of votes in each scale.

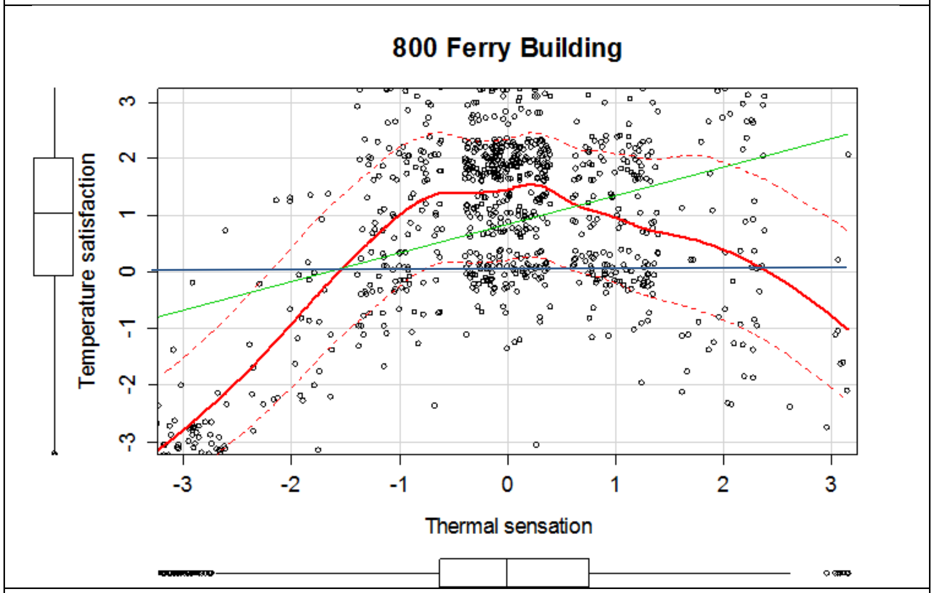
By finding the points where the temperature satisfaction polynomial regression curve (solid red line) crosses the middle of the satisfaction scale (blue line), we found that for the Yahoo! warm season survey, sensations -2 and 2 are thresholds. Sensations between -2 and 2 show that temperature satisfaction can be maintained. In the Yahoo! cool season survey, a sensation of -2 represents the cool side of the threshold, while the warm side of the threshold appears to be 2 or higher. The data suggests that in the cool season, people are satisfied with warm thermal sensation. In the 800 Ferry building, the thresholds seem to move 0.4 scale units towards warmth, with the sensation thresholds around -1.6 and +2.4. The higher levels of satisfaction on the warm side of the sensation scale could be due to the stronger summer over-cooling of the building.



Yahoo! warm season



Yahoo! cool season



800 Ferry building

Figure 3.2.29 Relationship between temperature satisfaction and thermal sensation for the three surveys

3.3 *CBE's Occupant Satisfaction background survey*

Using the CBE web-based occupant satisfaction survey, between February 26 and March 12, 2011 we conducted the background survey in the six Yahoo! buildings, and between November 28 – December 17, 2011 in a small office building at UC Merced. This survey has been used since 2000 (http://www.cbe.berkeley.edu/research/survey.htm) and the unique size of the database (about 60,000 votes in 550 buildings) provides a stable benchmark for evaluating the indoor environmental qualities of the surveyed buildings for this study. The background survey measures occupants' satisfaction with, and assessment of, their work environments in terms of thermal comfort, perceived indoor air quality, and other indoor environment related questions. Whenever occupants express dissatisfaction in response to a background survey question, branching questions appear to help identify the source of dissatisfaction.

The major concerns with the low minimum flow rates are for thermal comfort and perceived air quality due to less mixing of the room air. The purpose of the background survey is to compare them against the entire benchmarking database.

1279 people at Yahoo! (33% of the Yahoo! population) and 44 out of 85 in the small office building at UC Merced (52% response rate) participated in the background survey. The comparison of the mean values of the nine categories from the surveys at the 6 Yahoo! buildings, the small office building in UC Merced, and the 372 office buildings from the entire CBE database is shown in Figure 3.3.1.The blue diamonds represent the CBE benchmark data. Although the results from the 7 buildings are similar to the CBE database in terms of general satisfaction with the building and workspace, the thermal comfort and perceived air quality (highlighted by a blue box) in the Yahoo! buildings and the small office building are exceptionally better than the averages for the CBE database. The comparisons are similar for 4 other categories (office layout, office furnishing, lighting, acoustic quality), and slightly better for the category "cleaning and maintenance".

The results from the Yahoo! buildings and the small office do not show that comfort and perceived air quality are low or poor.

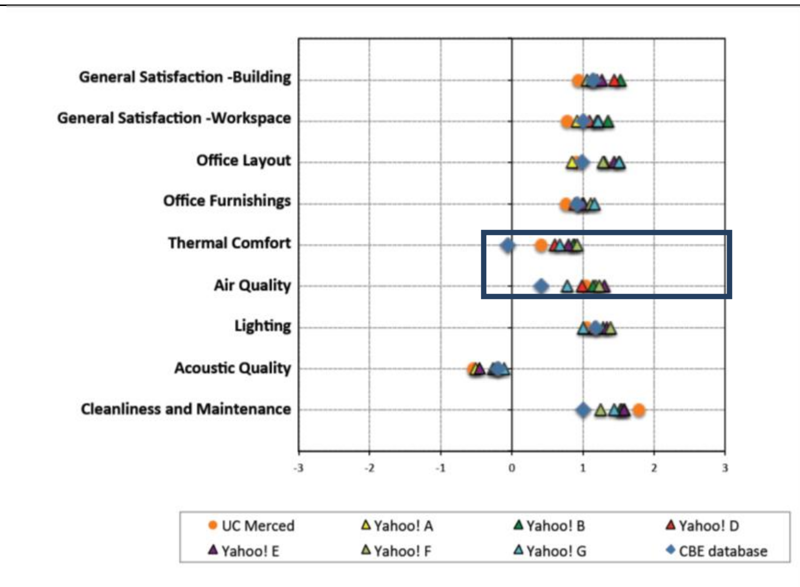


Figure 3.3.1 CBE background survey comparison for the 7 buildings from the current study with the 372 office building from the entire CBE database

To further compare the results from the 7 buildings with the entire CBE database, we show the ranks of each of the 7 building for a few selected categories. Figure 3.3.2 and Figure 3.3.3 show that for general satisfaction with the building and workspace, the Yahoo! buildings are between 45th and 60th percentile. They are slightly lower for the small building at UC Merced, 40th and 32th percentile respectively.

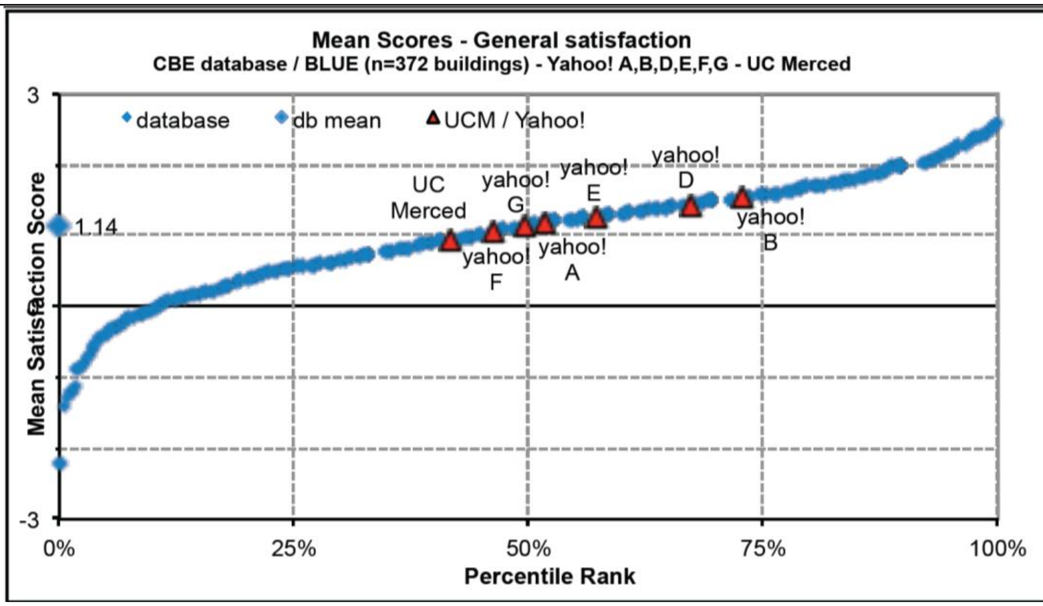


Figure 3.3.2 Ranking of the 7 buildings from the current study with the entire CBE database for category general satisfaction with building

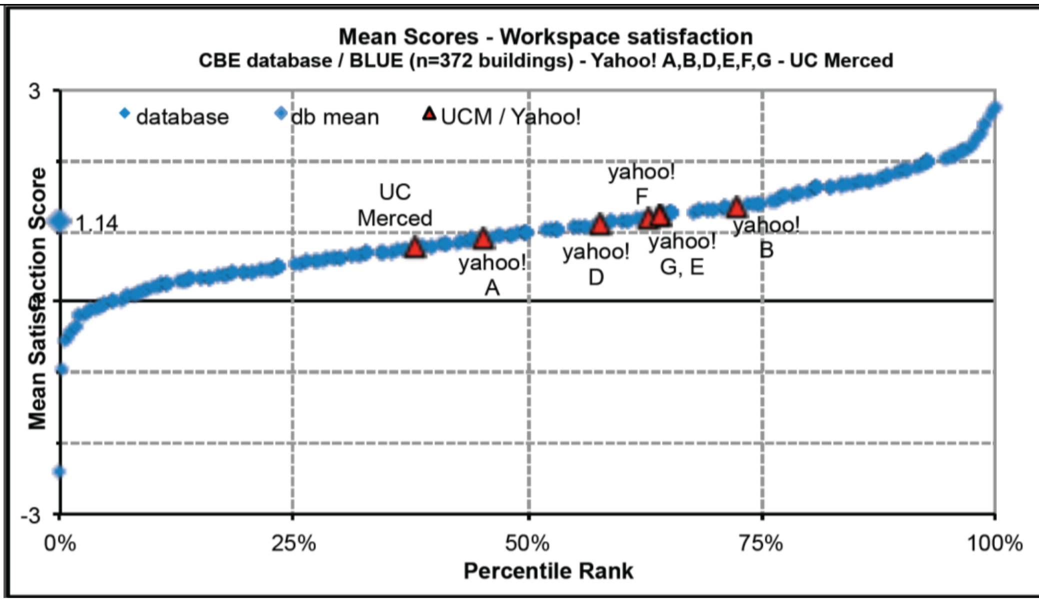


Figure 3.3.3 Ranking of the 7 buildings from the current study with the entire CBE database for category general satisfaction with building

The ranks for temperature satisfaction and perceived air quality are high (Figure 3.3.4 and Figure 3.3.5) compared to other categories. Averaging the results from the 6 Yahoo! buildings, the temperature satisfaction rank is the 89th percentile, and the perceived air quality rank is the 76th. For the small office building at UC Merced, the ranks for both categories are the 75th percentile.

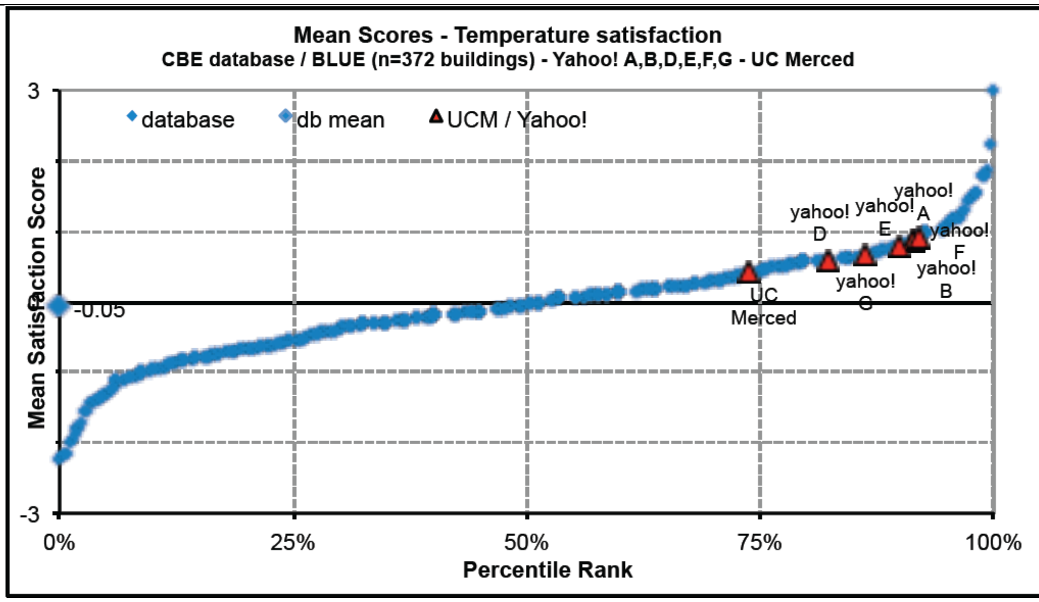


Figure 3.3.4 Ranks of the 7 buildings from the current study with the entire CBE database for temperature satisfaction

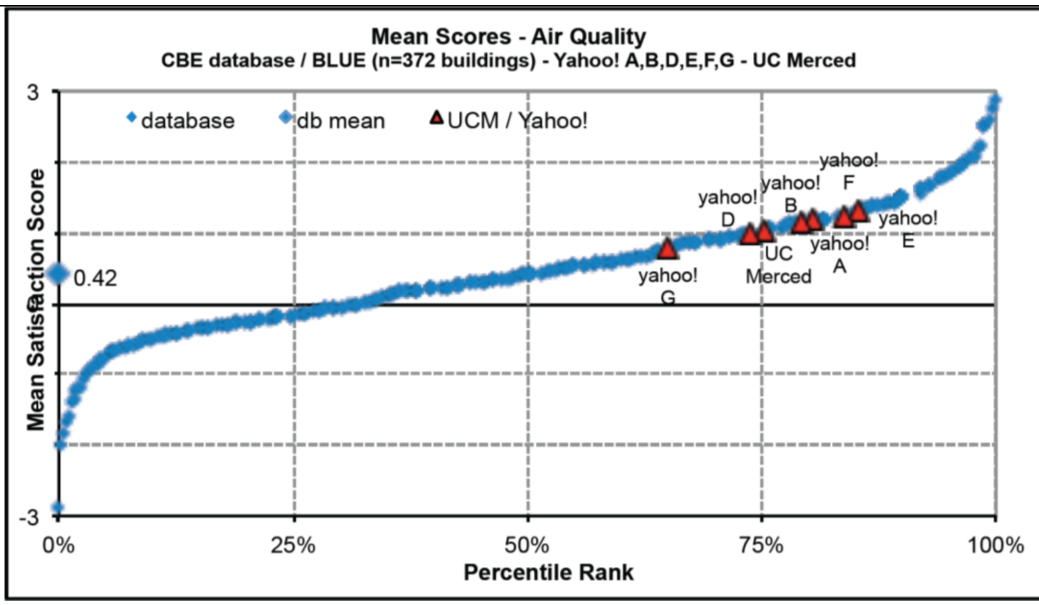


Figure 3.3.5 Ranks of the 7 buildings from the current study with the entire CBE database for perceived air quality

In the survey, we also asked question to the occupants whether the thermal comfort in their workspaces enhancing or interfering with their ability to get the job done. 79% of the surveyed population (including the neutral votes) from the 6 Yahoo! buildings, and 64% of population in the small office building at UC Merced, indicated on average that the thermal comfort in their workspaces enhanced their ability to get their job done (Figure 3.3.6). Considering the fact that the thermal comfort category is normally rated second lowest among the 9 categories surveyed (Figure 3.3.1), for 79% of the population to respond that their thermal comfort is "enhancing" their work performance can be considered as a very high value. In the small office building, 64% responded that their thermal comfort is enhancing their work performance.

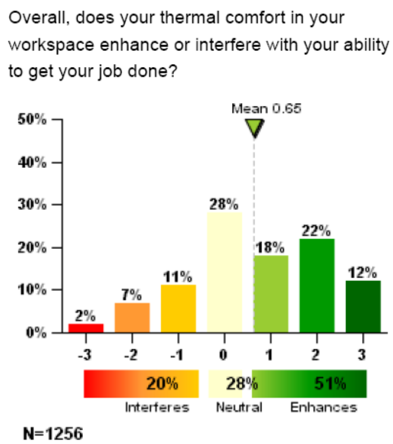
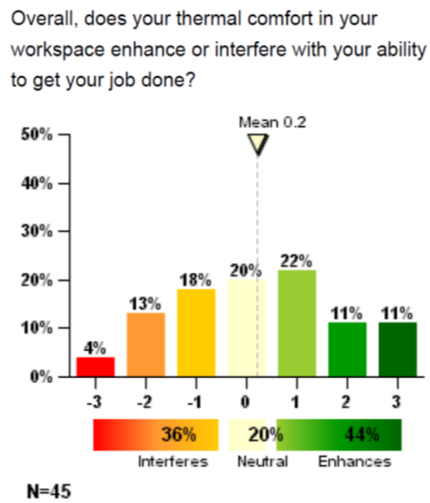
	
6 Yahoo! buildings	A small office building is UC Merced

Figure 3.3.6 Workplace thermal comfort response distributions

3.3.1 *Internal load analysis*

Low An example of sub-set of the data (140 zones) low loads we see are surprising, are a key reason that low minimums save energy, and are also a key explanation for over-cooling.

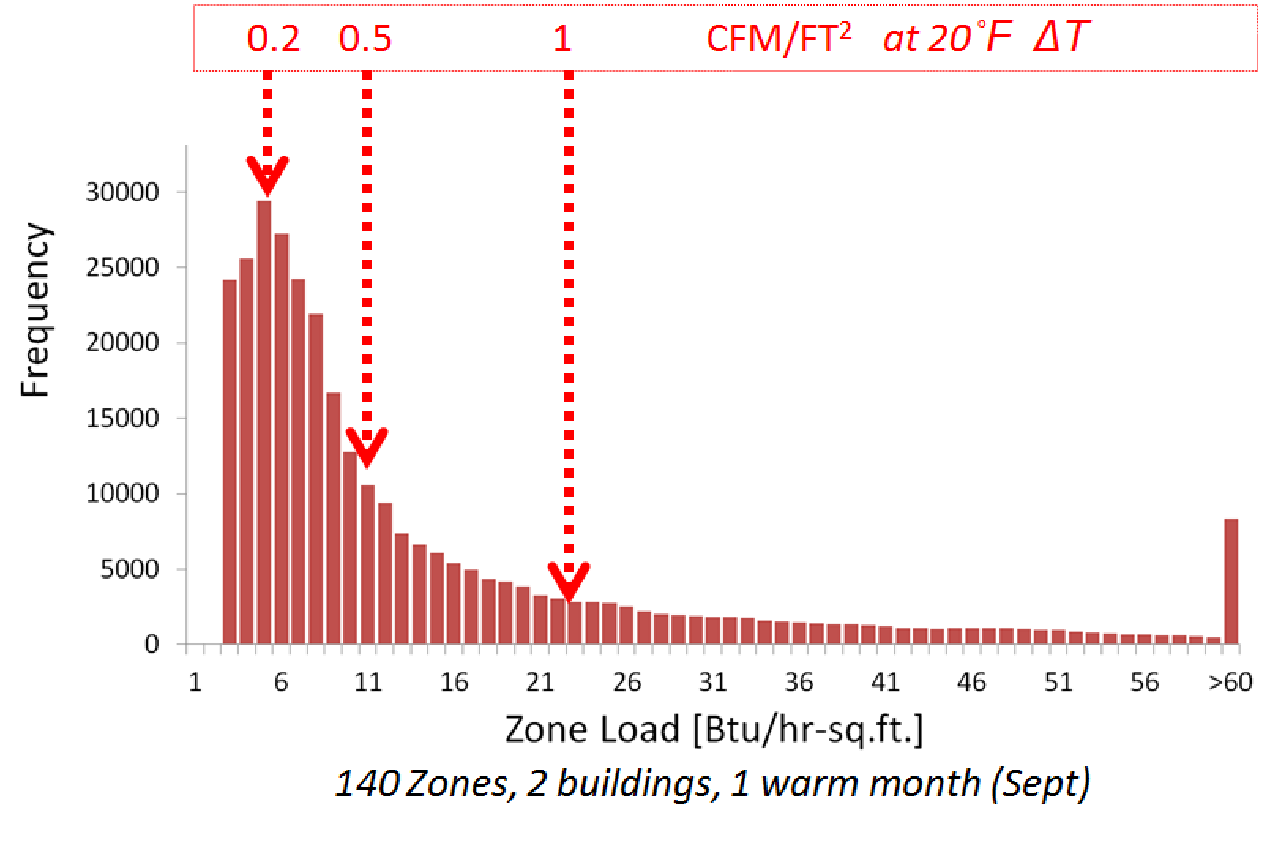


Figure 3.3.7 Load distribution in Yahoo building

3.4 *Field measurement*

On Saturday September 5, 2012, we visited Yahoo! building D and did field measurements in two workstations to examine velocity profiles with high and low VAV flow rates.

One of the workstations is located in a perimeter zone and one in a core zone. Each has tall partitions. The VAV capacity is high for the perimeter zone and low for the core zone. Each VAV box supplies three diffusers. Two pictures showing the two workspaces are displayed in Table 3.4.1, with information about VAV discharge air volumes at different flow rates.

Test conditions: the VAVflow rates from the two diffusers were fixed at 10%, 30%, and 90% of the maximum.

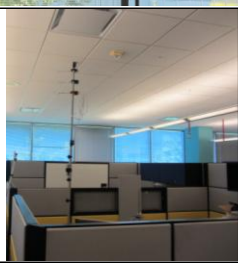
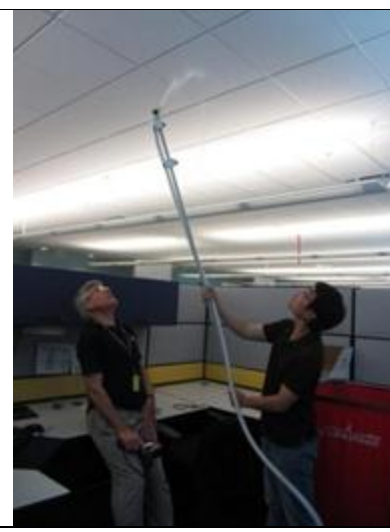
	zone	VAV capacity (cfm)	cfm/each diffuser at flow rate		
			10%	30%	90%
	Perimeter	2200	73	220	660
	core	400	13	40	120

Table 3.4.1 Two workstations and diffuser airflow volumes

The measurements include: 1) velocities and temperatures at 4 heights (0.1m, 0.6m, 1.1m, 1.7m) and near the two diffusers; 2) flow rates from the two diffusers in the two workstations measured by a flowhood, 3) visualizing air flow speed and direction using a fog machine, 4) IR pictures by an IR camera to examine weather "dumping" of cold air exists. The measurement setup and some results are displayed in Figure 3.4.1 .

		
Flowhood to measure diffuser flow rate	Temperature and velocity sensors to measure temperature and velocity profiles near diffusers; a fog machine to visulize air flow direction near diffusers	

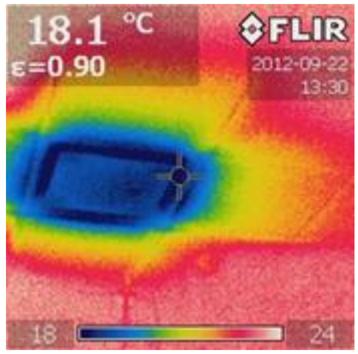
		
Diffuser type	Ceiling temperature at 30% flow rate in the perimeter zone workstation	Screens for taking IR pictures to visualize the vertical air flow profile

Figure 3.4.1 Field study in Yahoo! building D

The velocity and temperature profiles confirmed the occupants responses described in section 0 regarding the sense of air movement. At low flow rates of 10% (13, 73 cmf) and 30% (40, 120 cfm), no air movement in the two workstations were measured or sensed. The IR images show that the discharge air quickly mixed with the nearby air after leaving the diffuser.

It was only at high flow rates at the perimeter zone workstation (660 cfm) that strong air movement was detected. Within the workstation, there were spots where the velocity reached about 0.4 m/s, and up to 0.7 m/s was observed near the window when diffuser discharge air reached to the wall.

3.5 *Energy Savings Analysis*

3.5.1 *Method*

In HVAC and building engineering practice it is often useful to predict the annual energy consumption of a piece or set of equipment. This allows for the effects of retrofit measures such as this one to be quantified with a limited set of measurements. Standard practice suggests the use of piecewise linear models. Model normalization of weather conditions is achieved with the inclusion of outside air temperature as an independent variable. For most types of HVAC equipment, the assumptions of linear regression models will not be satisfied and can produce inaccurate results. A probabilistic alternative to this approach is outlined, in which empirical probability densities of energy consumption respective to a range of outside air temperatures are formed. Sampling of these densities and a full Monte Carlo simulation yields an expected annual energy consumption of the equipment for each of a discrete set of conditions. The practical applications of this method for Yahoo! and the 800 Ferry building are detailed.

In order to accurately estimate the amount of energy savings that the retrofit effects, we normalize the energy consumption according to a typical meteorological year (TMY). In the case of the Yahoo! campus, we are able to use TMY data assembled from the NOAA weather station at Moffett Federal Airfield in Mountain View (KNUQ), located 2 miles from the site. For the 800 Ferry building in Martinez, in the absence of appropriate weather station data, we used one year of climate data collected on site as a representative meteorological year. These TMY data are used as the input to a probabilistic model of energy consumption for each AC Unit and supply fan. In a similar manner, gas consumption is modeled as a function of heating degree days (HDD).

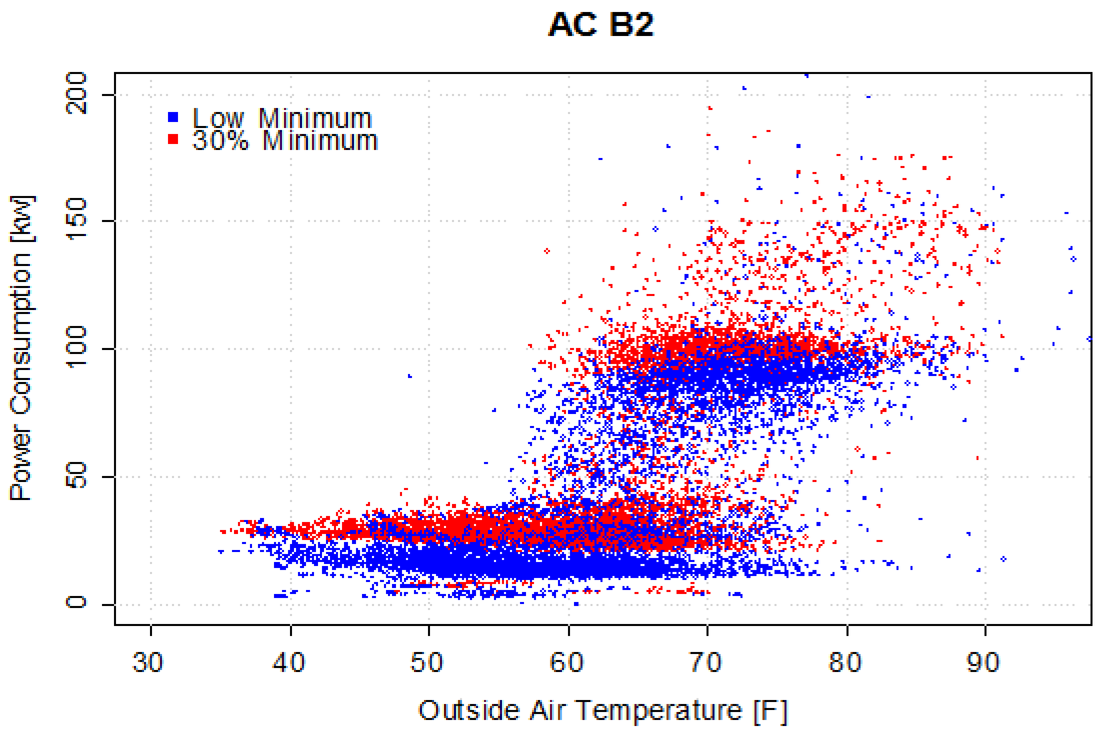


Figure 3.5.1 AC B2 power consumption: Neither linear nor homoscedastic

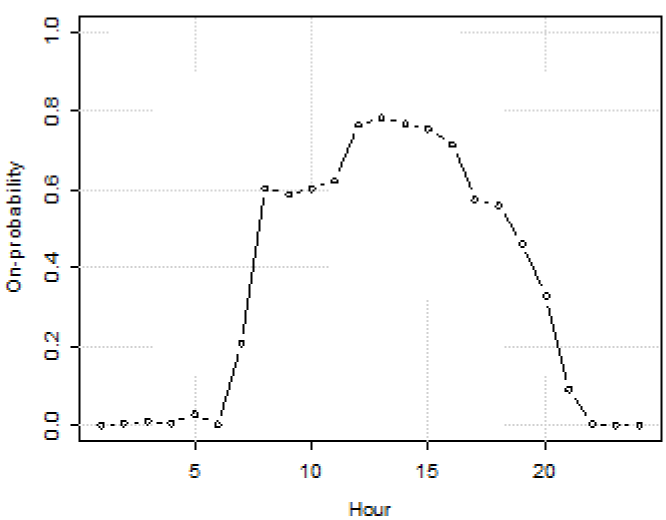


Figure 3.5.2 Typical on/off model: AC E1

These issues are typically addressed with regression modeling. In some cases, regression modeling of power consumption as a function of outside air temperature (OAT) provides adequate estimates for annual energy consumption. However, the assumptions justifying the use of linear regression are almost always not satisfied. In particular, most types of energy data will violate the assumptions of (i) linearity and (ii) homoscedasticity. Refer to Figure 3.5.4 for an example. The AC unit consists of a supply fan and compressor cooling. The compressors are clearly staged, causing the data to have two distinct groupings. Data of this nature is certainly not linear. As a corrective measure, similar data has been modeled as a piecewise linear regression. This will violate the assumption of linearity, since not all segments of the data are linear. Further, the data is not homoscedastic. It suffices to observe that as the outside air temperature increases, the range of power consumption widens. At low temperatures, there is a narrow range of power consumption, since the compressor is off and the supply fan is likely running at minimum volume. For these reasons we have developed a probabilistic method for estimating energy consumption.

AC Units and supply fans are modeled in two steps. The first model determines the on/off state of the equipment. The most rudimentary way to predict whether a unit will be on or off is to simply use the hour of the day as a predictor. For each hour of the day, the total number empirical data points in which the unit is observed on, divided by the total number of data points. In other words, the observed ratio of on-hours represents the probability that the unit is modeled as "on". This will form a function that resembles a daily HVAC or occupancy schedule. Note however, that the probability takes into account weekends, holidays, and other minor anomalies in the schedule. These empirical models for each unit are formed with the data from both pre and post-retrofit periods. An example is shown in **Error! Reference source not found.**.

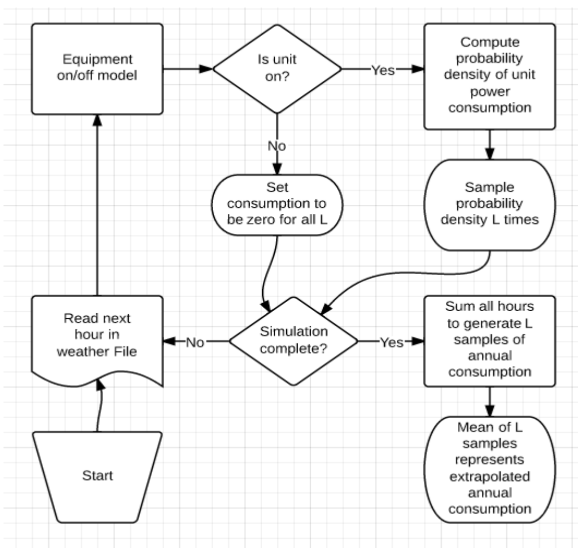


Figure 3.5.3 Flow control of the Monte Carlo simulation

In order to add further accuracy to the on/off model, we also consider outside air temperature as a predictor, making the model bivariate. This measure is taken because AC units are more likely to be on as the outside air temperature increases.

The ability to use these two notions to form a full empirical model is limited by the amount of data available. In this case, one can expect to have little or no data for high temperatures at night, since high temperatures will tend not to occur. The resolution must be carefully selected in order to categorize each state well. In the case of Yahoo! HVAC equipment, there are hourly models in the same form as **Error! Reference source not found.** for each of high (>70°F), mid, nd low temperatures (<60°F).

The second step of the modeling process aims to estimate the distribution of possible power consumption levels of the equipment, given an outside air temperature (T_{oa}) taken from the weather file, and a constant bandwidth (b).

A subset of the empirical data respective to the mode of operation is formed based on these criteria, such that the measured outside air temperature is in the interval (T_{oa} – b, T_{oa} + b). With this subset of the data, the model is formed with a method called Kernel Density Estimation (KDE). KDE is a way to estimate the underlying probability density function of a set of empirical data. Essentially, it is the result of a smoothed histogram with extremely small bins. This process is illustrated in Figure 3.5.4 and Figure 3.5.5. In R, the result of KDE is an object that can be easily sampled, which drives the Monte Carlo simulation.

To begin the Monte Carlo simulation, we first fix the sample size or length (L). This the number of samples generated each hour, as well as the number of estimates of annual energy consumption that the simulation will generate, after summing the 8760 hourly samples. For each entry in the hourly weather file, we repeat the process illustrated in Figure 3.5.3, utilizing the on/off and power consumption models described above. If the unit is determined to be off in the first step, the consumption is set to zero for all L samples. If the unit is on, the power consumption model will produce a probability density for each mode, which are then sampled L times, each sample representing the energy consumption of the unit given

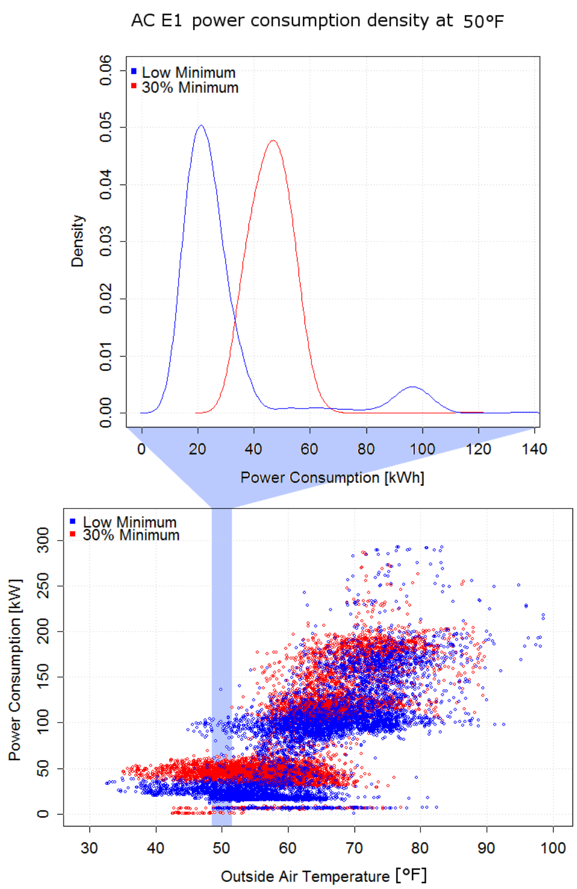


Figure 3.5.4 AC E1 power consumption probability density corresponding to vertical segment of scatter chart

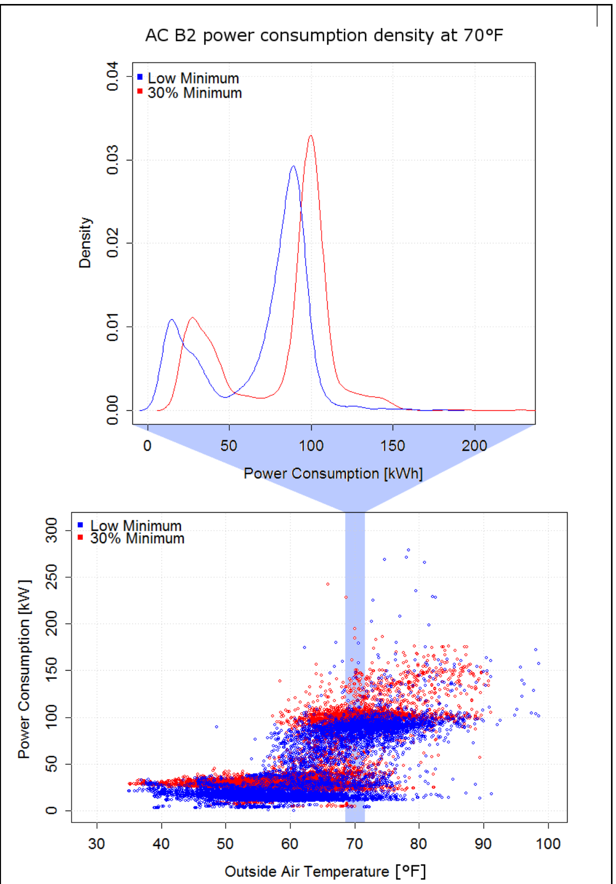


Figure 3.5.5 AC B2: Bi- or multimodal behavior of equipment such as staging is captured in the probability densities

the outside air temperature during that hour. The resultant distribution of annual energy consumption samples is normally distributed as required by the central limit theorem. An example for one unit (AC A1 supply fan) is shown in Figure 3.5.6. The mean of this large sample is the estimate for expected energy consumption of an AC Unit or supply fan. The process is carried out for both high minimum and low minimum operation, allowing us to quantify the savings effected by the VAV minimum flowretrofit.

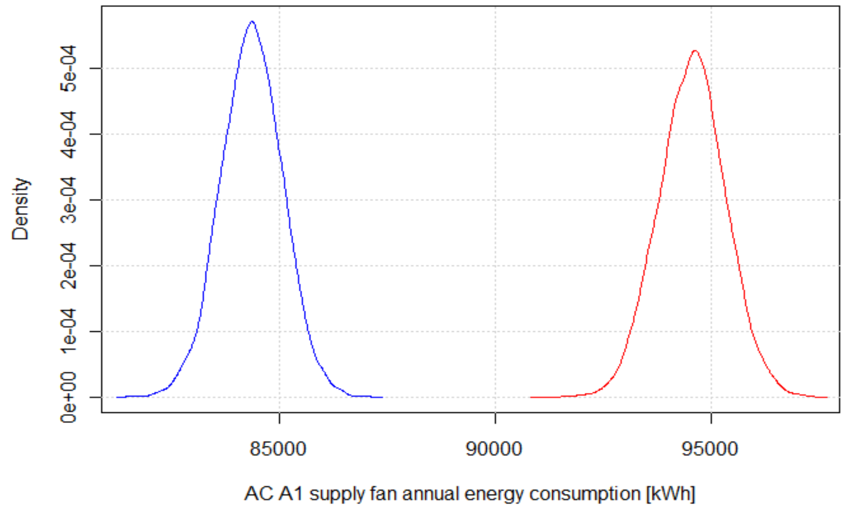


Figure 3.5.6 Distribution of simulated annual energy consumption: AC A1 Supply Fan

The hourly samples from the simulation may also be visualized. In Figure 3.5.7, simulated hourly data are plotted on top of the empirical data used to generate the models. This visually demonstrates the accuracy of the power consumption models generated in the second step.

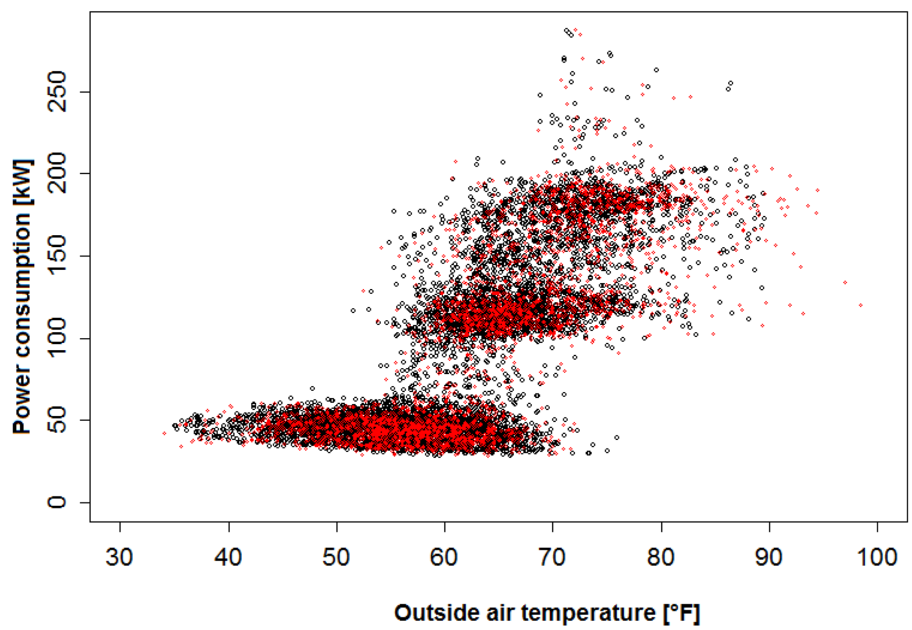


Figure 3.5.7 Yahoo! AC E1 - High minimum simulated data (red) overlaid on empirical (black) data

This specific method was applied to the compressor units and supply fan in the 800 Ferry building, to the packaged AC Units in the Yahoo! buildings (composed of compressors, supply and return fans), and to the supply and return fans in the Yahoo! buildings specifically. In order to extrapolate the gas consumption for Yahoo! and the 800 Ferry building, a similar method was used. Instead of using the hourly outside air temperature as a predictor of gas consumption, daily average outside air temperature was used. The simulation is carried out analogously, iterating over typical daily average outside air temperatures instead of hourly outside temperatures.

3.5.2 *Extrapolated gas energy savings*

The following tables detail the results of the energy analysis. All extrapolated consumption values for the Yahoo! study are normalized to Typical Meteorological Year (TMY3) data (derived from data collected at KNUQ – Moffett Federal Airfield in Mountain View, CA). For the 800 Ferry building, the data was normalized to empirically measured weather data on site. This was used in lieu of high quality weather station data or TMY3 data. For comparison, the actual consumption value for the year in which the study was done is reported as well. During these periods, the system operated in both high and low minimum modes.

Extrapolated annual savings represent the savings realized by switching the minimum flow control sequence from high (30%) to low (10%) as computed in the Monte Carlo simulations.

Yahoo! annual gas consumption	Actual consumption 2011 [th]	High minimum extrapolated annual consumption [th]	Low minimum extrapolated annual consumption [th]	Extrapolated annual savings (%)	Extrapolated annual savings [th/sf-year]
Bldg A	29246	34060	28450	**16.5**	**0.035**
Bldg B	17044	19310	15580	**19.3**	**0.025**
Bldg E	35050	36950	33590	**9.1**	**0.019**
Bldg G	16926	18000	17300	**3.9**	**0.01**
Total Gas	98266	108320	94920	**12.2**	**0.0225**

Table 3.5.1 Extrapolated gas energy savings - Yahoo!

800 Ferry building annual gas consumption	Actual consumption March 2011 - February 2012 [th]	High minimum extrapolated annual consumption [th]	Low minimum extrapolated annual consumption [th]	Extrapolated annual savings (%)	Extrapolated annual savings [th/sf-year]
	3665	3711	3486	**6.1**	**0.011**

Table 3.5.2 Extrapolated gas energy savings - 800 Ferry building

3.5.3 *Extrapolated annual AC unit electricity (fan & cooling) savings in Yahoo! buildings*

AC unit	Actual consumption 2011 [kWh]	High minimum extrapolated annual consumption [kWh]	Low minimum extrapolated annual consumption [kWh]	Extrapolated annual savings (%)	Extrapolated annual savings [kWh/sf-year]
A1	309401	269800	268200	**0.6**	**0.02**
A2	280415	264700	221900	**16.2**	**0.56**
B1	266996	234700	195000	**16.9**	**0.46**

B2	194738	188200	144300	**23.3**	**0.69**
E1	269962	332300	275700	**17.0**	**0.61**
E2	54444	64160	56780	**11.5**	**0.35**
E3	256436	329800	268500	**18.6**	**0.97**
G1	81931	74840	65070	**13.1**	**0.29**
G2	86924	70200	67200	**4.3**	**0.09**
Total	1801248	1828700	1562650	**14.55**	**0.482**

Table 3.5.3 Extrapolated annual AC savings in Yahoo! buildings

3.5.4 *Extrapolated annual AC savings in the 800 Ferry building*

Chilled water units and supply fan at the 800 Ferry building. The cells in blue at the bottom are the total savings for the chilled water units and supply fan combined.

800 Ferry building cooling and fan consumption	**May 2011 - June 2012 [kWh]**	**High minimum extrapolated annual consumption [kWh]**	**Low minimum extrapolated annual consumption [kWh]**	**Extrapolated annual savings (%)**	**Extrapolated annual savings [kWh/sf-year]**
Condensing unit 1	4771	5313	3818	**28.1**	**0.23**
Condensing unit 2	7096	7458	6366	**14.6**	**0.18**
Condensing unit 3	9694	10730	6538	**39.1**	**0.65**
Supply Fan	30419	40520	23270	**42.6**	**0.86**
Total cooling	21561	23501	16722	**28.8**	**0.34**
Total	51980	64021	39992	**37.5**	**1.2**

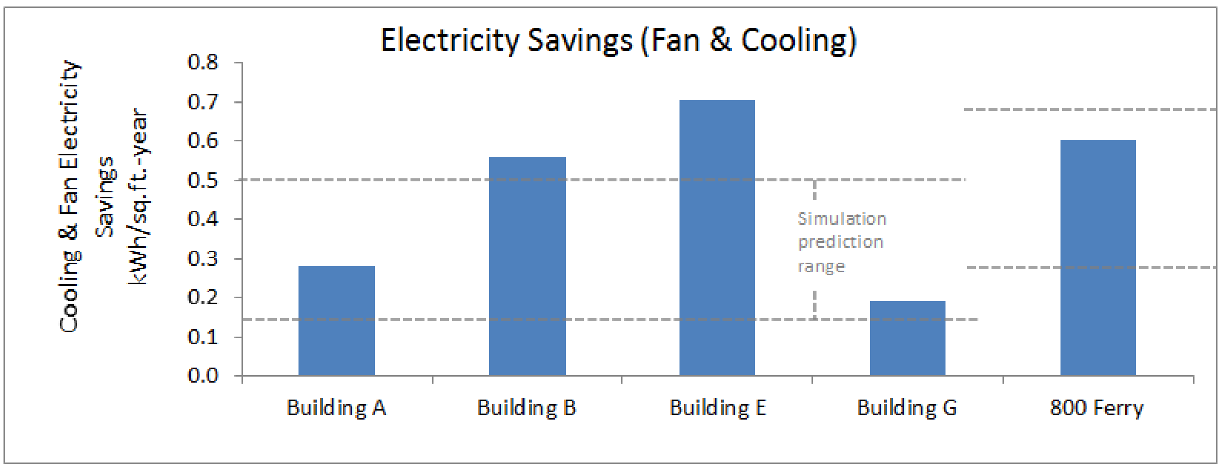
Table 3.5.4 Extrapolated annual AC savings in the 800 Ferry building

3.5.5 *Discussion and summary of overall energy savings*

- All buildings
  - Annual energy use data was compared to typical building use in the CEUS benchmark database and all metered data was within typical ranges.
  - Energy savings is less than the maximum potential and higher savings could be achieved on similar projects. Reasons that savings are less than full potential.
    - Zone sequences do not control discharge air temperature which results in more reheat than the traditional dual-maximum sequences that control discharge air temperature. Explanation: The existing zones controllers had limited memory and the facilities staff and controls contractor were hesitant to add extra programming to the zones.

	Annual Electricity Use				Annual Gas Use			
	Traditional Logic *kWh/sf*	Dual Maximum Logic *kWh/sf*	Savings *kWh/sf*	Savings *%*	Traditional Logic *therms/sf*	Dual Maximum Logic *thems/sf*	Savings *thems/sf*	Savings *%*
Building A	3.4	3.1	0.3	8%	0.22	0.18	0.04	16%
Building B	2.8	2.3	0.6	20%	0.13	0.10	0.03	19%
Building E	4.1	3.4	0.7	17%	0.21	0.19	0.02	9%
Building G	2.2	2.0	0.2	9%	0.27	0.26	0.01	4%
800 Ferry	2.7	2.1	0.6	22%	0.19	0.17	0.01	6%

Figure 3.5.8 Summary of savings by building



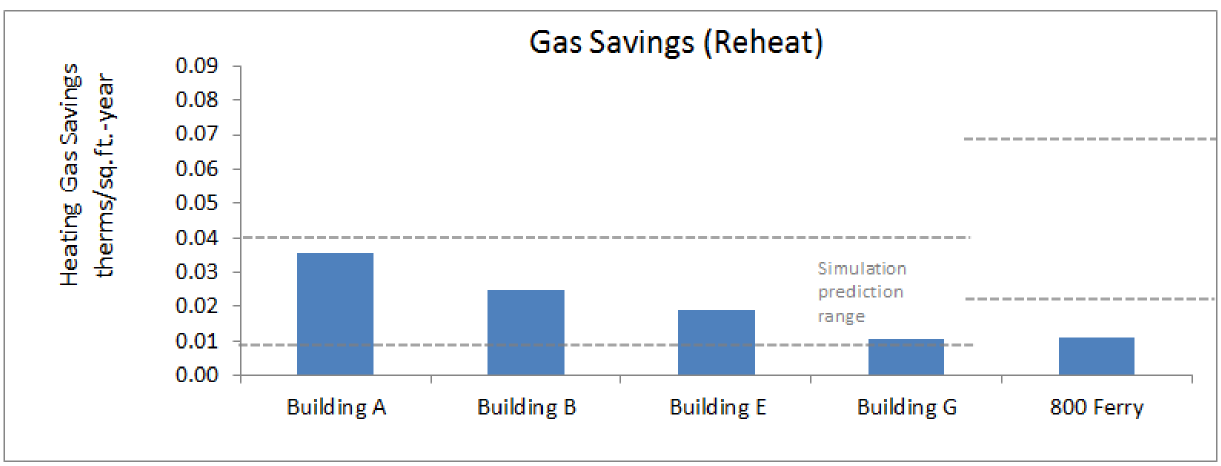


Figure 3.5.9 Annual energy savings compared to past research that predicted savings with simulations

(Pacific Gas and Electric Company 2009)

3.6 *Diffuser testing at Price Industries Laboratory*

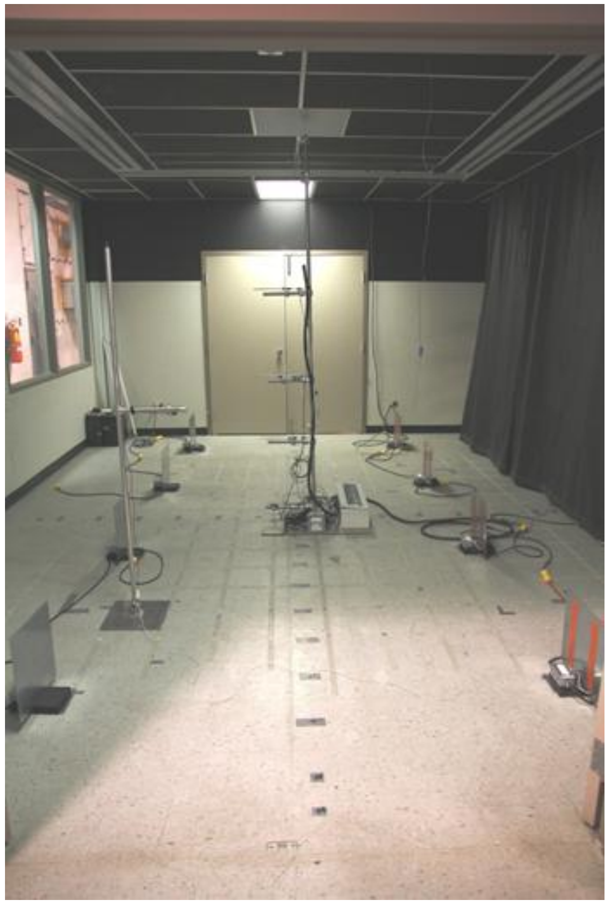
3.6.1 *Air Distribution Test Setup*

In this research, we analyzed in detail the Air Diffusion Performance Index (ADPI) values for 6 different diffusers. They are: Square Plaque Diffuser (SPD), Perforated Face Ceiling Diffuser with the pattern controller inside the face (PDF), Perforated Face Ceiling Diffuser With pattern controller inside the neck (PDN), Linear Slot Diffuser with plenum (SDB), High Side Wall Grille (520 Grille), Round Cone Diffuser (RCD)

In order to perform this analysis, we employed load simulators in strategic positions to achieve the loads required to represent the work space. The Air flows for each diffuser were strictly dependent on the loads and vice versa, and were modified as necessary (i.e. load simulators were added or removed to meet the load required for a specific air flow). We performed our experiment by using load capacities of 80%, 30%, and 13%. Furthermore, with the purpose of attaining accurate readings; we created a coordinate system that covered all cardinal points. Essentially, two planes were created to represent the directions described in Figure 3.6.1. Moreover, our controllers were set so that we could analyze five different airflows at 2 different supplied temperatures 55°F and 65°F. We placed all equipment on each coordinate manually and run our software to obtain data. Once this was done for each flow rate on all diffusers, we proceeded to take measurements at four different heights; 4in, 24in, 42in and 66in. The ranges and accuracy of sensors are described in Table 3.6.1. As a result of correlating all our data, we were able to obtain velocity and temperature stratification profiles. Temperature and velocity readings were averaged over 3 minutes to provide accurate values for comfort measurements. Finally, we made use of smoke testing with the purpose of ensuring that the diffusers' air pattern was within agreement standards.

Room size	20' x 15' x 9' height
Measurement tree heights	4", 24", 42", 66"
Air speed probe model & error	TSI Model 8475, $\pm 3\%$ Reading + $\pm 1\%$ Full Scale
Air temperature	RTD probe ± 0.7 °F (± 0.4°C)
Measurement frequency	30 sec.
Averaging interval	3 min.
Total load from measurement equipement	10 Watts

Table 3.6.1. Sensor measurement ranges and accuracies



Picture 3.6.1 Price Industries testing chamber

3.6.2 ***Ventilation Effectiveness Test Setup***

The air change effectiveness testing was conducted to measure age of air and air change effectiveness. Once the test space had achieved a thermal equilibrium for a minimum of 30 minutes, the gas label, CO_2, was introduced to the air supply stream at a concentration of 4000ppm. The concentration data collected during the step up and decay procedure was analyzed in accordance with ASHRAE Standard 129 to evaluate the age of air at all measurement locations.

Room size	20’ x 16’ x 9’ height
Measurement tree heights	4”, 24”, 42”, 66”
Carbon dioxide concentration	Vaisala GMT220 Series Carbon dioxide transmitter Accuracy (including repeatability, non-linearity and calibration uncertainty) at 25 °C and 101.3 kPa GMT222 ±(1.5 % of range + 2 % of reading) Temperature dependence, typical -0.3 % of reading / °C Pressure dependence, typical +0.15 % of reading/KPa Response time (63 %) - GMT222 30 seconds

Table 3.6.2 Carbon dioxide transmitter accuracy

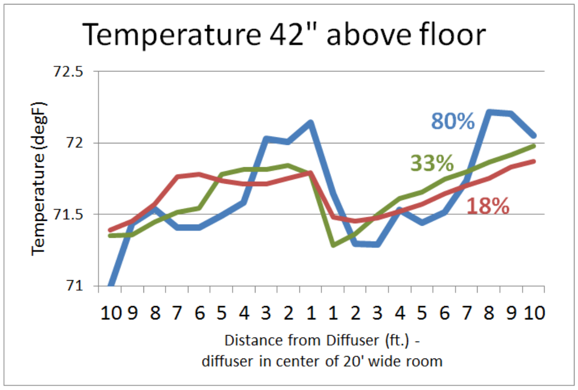
3.6.3 *Air Distribution Test results*

Detailed test results are included in appendices 1H.1 and 1H.2. A summary is described in Table 3.6.3
.

Diffuser type	Result
Square Plaque (SPD)	• ADPI is 98-100% for all tests at both discharge temperatures. • Average air speeds decrease at lower flow and air speeds are slightly lower with 65˚F discharge temperature compared to 55˚F discharge temperature.
Perforated Face Ceiling Diffuser with the pattern controller inside the face (PDF)	• ADPI is almost 100% for all conditions at both discharge temperatures. Minor decrease in ADPI with 55˚F discharge temperature. Flow fraction does not change ADPI. • Average air speeds decrease at lower flow and air speeds are slightly lower with 65˚F discharge temperature compared to 55˚F discharge temperature.
Perforated Face Ceiling Diffuser With pattern controller inside the neck (PDN)	• ADPI is 99-100% for all tests at both discharge temperatures. • Average air speeds decrease at lower flow and air speeds are slightly lower with 65˚F discharge temperature compared to 55˚F discharge temperature.
High Side Wall Grille (520 Grille)	• ADPI decreases at lower flow with 55˚F discharge temperature. Flow fraction does not affect ADPI with 65˚F discharge temperature. • Average air speeds decrease at lower flow and air speeds are lower with 65˚F discharge temperature compared to 55˚F discharge temperature.
Linear Slot Diffuser with plenum (SDB)	• ADPI is 98-100% for all tests and improves at lower flow • Average air speeds decrease at lower flow • Discharge air temperature does not change ADPI or air speed results
Round Cone Diffuser (RCD) * installed 19" below ceiling	• ADPI decreases at lower flow with 55˚F discharge temperature. Flow fraction does not affect ADPI with 65˚F discharge temperature. • Average air speeds decrease at lower flow and air speeds are lower with 65˚F discharge temperature compared to 55˚F discharge temperature.

Table 3.6.3 Summary of diffuser testing in Price Industries laboratory tests

Tests of perforated diffusers with Perforated Face Ceiling Diffuser With pattern controller inside the neck (PDN) show more uniform temperature at lower flow, and lower air speeds in the occupied region at lower flow. See figure 3.6.2)



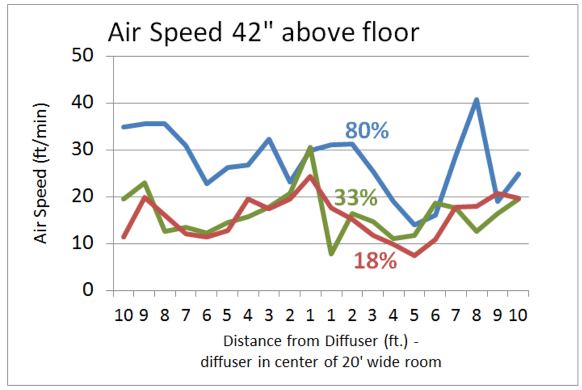


Figure 3.6.2 Air speed and temperature variations in a room transect 42" above the floor with PDN type diffusers at flow fractions of 18%, 33%, and 80%. These results are typical of ceiling diffusers.

3.6.4 *Ventilation Effectiveness Test results*

Cooling mode air change effectiveness (ACE) measurements for slot diffusers and perforated diffusers with blades in the neck are shown below (Figure 3.6.3). The minimum measured ACE is 0.96 for slot diffusers and 0.99 for perforated diffusers.

SDB 100 48" 2 slot 7Ø

		ACE			
		N-43" Height	N-67" Height	S-43" Height	S-67" Height
77 cfm@55F (26%)	Step Up	1.06	1.10	1.00	1.00
	Decay	0.97	1.10	0.96	0.98
55 cfm@55F (18%)	Step Up	1.05	1.11	0.99	0.98
	Decay	0.99	1.16	0.98	0.98
30 cfm@55F (10%)	Step Up	1.01	1.09	0.99	0.99
	Decay	0.99	1.12	0.97	0.99

PDN 24X24 8Ø

		ACE			
		N-43" Height	N-67" Height	S-43" Height	S-67" Height
77 cfm@55F (26%)	Step Up	1.07	1.07	1.10	1.13
	Decay	1.00	1.04	1.05	1.08
55 cfm@55F (18%)	Step Up	1.06	1.03	1.03	1.10
	Decay	1.02	1.02	1.01	1.03
30 cfm@55F (10%)	Step Up	1.04	1.03	1.04	1.04
	Decay	0.99	1.01	1.03	1.03

Figure 3.6.3. Cooling mode air change effectiveness measurements for two types of diffusers

Testing ACE in heating mode was not part of the scope of this project so only one isolated test was performed with the results shown in Figure 3.6.4.

PDN 24X24 8Ø

		ACE			
		N-43" Height	N-67" Height	S-43" Height	S-67" Height
90 cfm@87F (30%)	Step Up	0.56	0.50	0.48	0.51
	Decay	0.67	0.62	0.60	0.61

Figure 3.6.4. Cooling mode air change effectiveness measurements for two types of diffusers

3.6.5 ***Results discussion***

ADPI and air speed results show that diffusers mounted flush with the ceiling (PDF, PDN, SDB, SPD) have excellent air distribution performance down to 10% flow fraction. Discharge air temperature appears to have very little effect on ADPI or average air speeds when diffusers are mounted close to the ceiling and average air speeds decrease at lower flow fractions. ADPI and average air speed results are similar for the following diffusers types that were mounted flush with the ceiling: perforated face diffusers with blades in the neck, perforated face diffusers with blades in the face, plaque face diffusers, and slot diffusers. We presume that Coanda effect has a significant influence over the room air distribution because results varied significantly for the two diffusers not mounted close to the ceiling.

Diffusers mounted below the ceiling (RCD, 520 Grille) showed a significant decrease in ADPI at lower flow fractions. This results are in clear contrast to the results for diffusers mounted flush with the ceiling and suggests that Coanda effect is an important factor at low flow. In addition, average air speeds are higher with lower discharge temperature (55˚F vs. 65 ˚F) suggesting that discharge temperature affects dumping only when diffusers are not mounted flush with a ceiling.

ACE results were similar to ADPI results where ceiling mounted diffusers maintained consistent ventilation performance down to 10% flow. ACE is always greater than 0.96 for all tests of PDN and SDB diffusers. These results confirm past research that showed no degradation in ACE during cooling down to 20% flow and extends the result to 10% flow. No ACE tests were performed on diffusers without ceilings.

One test was done in heating mode. The result was significantly degraded ACE down to 0.48 which suggests a need for further study. Only one test was completed because heating mode ventilation experiments were beyond the scope of this project. One explanation for the degraded performance is that the room setup did not meet the ASHRAE 62.1 criteria that the 150 ft/min. jet reaches to within 4.5 ft. of the floor lever (per table 6-2 of ASHRAE 62.1-2010). Further research should be done on ventilation effectiveness in heating mode at low flow, both to validate ASHRAE Standard 62.1 table 6-2 and provide design guidance for low minimum control sequences in perimeter zones.

4 Implications in Codes and standards

Title 24 now requires VAV zone minimums to be no higher than 20% or the ventilation rate. A similar limitation has been proposed for ASHRAE 90.1 and is expected to be issued for public review shortly. This research shows that much lower minimums, as low as the minimum ventilation rate (often 5-15%), do not have negative impacts on occupants. These results, along with results from research into VAV box controllability and stability at low flow suggests that energy codes and standards could adopt more stringent VAV minimums criteria.

5 DISCUSSION

1) This report focuses on the comfort and energy effects of reducing VAV minimum setpoints. The significant findings are that reduced flow minima not only save energy (as expected), but significantly reduce occupant discomfort from summer over-cooling (this was unexpected, though it might seem obvious in retrospect).

   The low loads we see are significant. They are the reason that low minimums are necessary and save energy. They may also explain the summer over-cooling that is now endemic in the US (Mendell and Mirer 2009). From the load analysis in the studied buildings, one can see that low minimums based on minimum ventilation rates are still higher than the loads for significant parts of the time.

2) We did not focus on comfort under high internal loads and high flow rates. From the occupants' comments, we see that summer over-cooling frequently happens in the afternoons. One example of the comment is this, "..starting to get cooler. My hands will start getting cold pretty soon. This usually means it's warming up outside." This might indicate that draft sensation is occurring at maximum flows.

3) The field study survey results show large personal preference differences for thermal comfort at any temperature. Within each 1F binned ambient air temperature, people's thermal sensation consistently covered the spectrum from 'cold' to 'warm' in the range from 70 to 75ºF. This finding supports previous research by Arens et al. (2009) showing that it is inefficient to provide comfort by narrowing the thermostat deadband.

4) The thermal sensation thresholds at which people found their environments acceptable were -2 to 2 in the Yahoo! buildings and -1.6 to 2.4 in the Ferry building. These results are similar to the results by Zhang et al. (2009) in a laboratory study that showed the sensation range in acceptable thermal environments to be -1.5 to 2.

5) This study shows that perceived air quality correlates well with thermal comfort: the better the temperature satisfaction, the better the perceived air quality. This relationship has also been found in other studies. Humphreys et al. (2002) found that perceived air quality is mostly a function of thermal comfort, not of temperature. Arens et al. (2008) showed a strong correlation between perceived air quality and thermal comfort when the comfort was provided by air movement.

   Because the baseline ambient condition during the two summer surveys was a state of uncomfortable overcooling, the perceived air quality satisfaction improved as the zone air temperature became warmer with the low VAV minimum. This indicates that, under the temperature ranges occurring in this project, it is thermal satisfaction, not the air temperature, that is most important for perceived air quality satisfaction. This contradicts the assertion of Fang (date) that cooler temperatures improve perceived air quality.

6) The temperature and velocity profiles measured in the Price Industries test chamber show that diffusers mounted flush with the ceiling have high ADPI down to 10% flow fractions and average air speeds that decrease with lower flow fractions. These results explain why occupants in the field study did not experience draft discomfort. Diffusers mounted on a sidewall or without a ceiling, thus absent the Coanda effect, resulted in significant reductions in ADPI at low flow fractions in the chamber. This suggests that the Coanda effect may be important for maintaining comfort at low flow.

   Plaque face diffusers were seen in the chamber tests to have worse performance at low flow than perforated face diffusers, presumably due to the low design throw for selections with small neck sizes. Plaque diffusers with larger neck sizes are likely to have better performance because they have higher design throw.

   The diffusers in Yahoo! buildings are plaque face diffusers with varying neck sizes, and the diffusers in 800 Ferry building are perforated with blades in face. The biggest comfort improvement that we saw from the three surveys is in the 800 Ferry building when the minimum flow rate was lowered from high to low. The reduction this caused in summer over-cooling was the major factor in improving comfort. The impact of diffuser type on performance was secondary.

6 CONCLUSIONS

In the field study, we selected six Yahoo! buildings and the 800 Ferry building to evaluate comfort and energy savings when the minimum flow rate setpoints were reduced from high (conventional level: 30-50%) to low (minimum ventilation rate or controllable minimum: ~10-20%).

We first installed system control programs (toggles) in all of the studied buildings, so that we could intervene in the building operation to switch the minimum VAV flow rate setpoints between high and low. In each of the buildings, we surveyed the occupants' thermal comfort during warm and cool seasons in high and low minimum operation modes. We installed energy meters in all air conditioning units of four Yahoo! buildings and the 800 Ferry building, and collected energy use over a period of about one and a half years. These results allowed us to compare thermal comfort and energy savings between the two operation modes. The BMS monitoring report enabled us to see how the control systems changed according to the low minimum setpoints, and to explain from where and how the energy savings resulted.

In a separate set of laboratory studies, we tested velocity and temperature profiles in a chamber for a combination of diffuser types, flow rates, and internal loads. The major conclusions are summarized below:

1) Contrary to the original concern that discomfort ("dumping") may happen due to less mixing of the air, when the VAV flow rate setpoints were changed from high to low, thermal comfort was in fact not reduced. Instead, comfort was significantly improved. Dissatisfaction rates were reduced by 47% in both summer studies in the Yahoo! buildings and the 800 Ferry building.

2) The comfort improvements appear to be due to a reduction in summer over-cooling as the zones have more capability to turn down at low load conditions. Under high minimum operations, about 38% of the population felt "slightly cool" to "cold" in the summer in the Yahoo! buildings and 800 Ferry building. For the 800 Ferry building, 10.5% of population felt "cold". The cool discomfort in the summer was reduced to 24% in the Yahoo! buildings and 16% in the 800 Ferry building when the minimum flow rate was reduced to low minimums, and the population feeling "cold" was reduced to 3%.

3) In the cool season survey in the Yahoo! buildings comfort was unchanged during both high and low minimum operations.

4) Although in general the zone temperature variations were small in those air-conditioned spaces due to narrow thermostat setpoint ranges, we still see the impact of the two minimum operation modes on zone air temperature. For the Yahoo! warm season survey, the corresponding average ambient air temperature increased 0.5ºF, from 72.6ºF to 73.1ºF, when the minimum flow rate setpoint was reduced. For the Yahoo! cool season survey, the increase is 0.7ºF, from 72.1ºF to 72.8ºF. The biggest increase is shown for the 800 Ferry building. It increased from 71.2ºF (high minimum) to 73.3ºF (low minimum), a 2.1ºF increase.

5) Under high minimum operation, a substantial amount of cool air is supplied to occupied spaces when the internal load is low, which not only results in a cooler room air temperatures, but in the case of reheat zones also requires more heating energy as the reheat system tries to keep the room air temperature above the lower setpoint. We saw this from the higher discharge air temperatures during high minimum operation. This is true for all three surveys we conducted. As a result of this high minimum operation, systems cool spaces more, and heat spaces more as well in order to reach the low setpoint. In the absence of reheat, high minimum operation produces overcooled spaces and higher levels of dissatisfaction.

6) Again, contrary to common wisdom, we encountered no evidence of draft discomfort when the flow rate was low (either at high or low minimums) based on the survey results. Occupants perceived most air movement when the flow rate was high, not low. This was confirmed during a field measurement, which shows no air movement differences when the control systems were operated at high or low minimum. The significant sense of air movement happened only for VAV units operating above minimum flow rates.

7) The perceived air quality was also improved in both summer studies when the high minimum operation was switched to low operation. The dissatisfaction was reduced 32% in Yahoo! buildings and 62% in the 800 Ferry building. The perceived air quality satisfaction correlates well with temperature satisfaction.

8) Using the temperature satisfaction scale, the acceptable thermal sensation range for Yahoo! is -2 (cool) to 2 (warm); (2 is a conservative estimate for the upper range for the Yahoo! cool season survey). For the 800 Ferry building warm season survey, the range is -1.6 (between cool and slightly cool) to 2.4 (between warm and hot), a 0.4K shift of the Yahoo! satisfaction range towards warmth.

9) The background surveys from seven buildings which are normally operated under low minimum setpoints (six Yahoo! buildings and an office at the University of California, Merced) show that satisfaction with temperature and perceived air quality are the highest of all of the nine survey categories, and their rankings are high when benchmarked against the entire CBE survey database. The six Yahoo! buildings rank in the 89th percentile for temperature satisfaction, the 76th percentile for perceived air quality, and the 60th percentile for general building satisfaction. The UC Merced building ranks in the 75th percentile for temperature satisfaction, the 75th percentile for perceived air quality, and 40th percentile for general building satisfaction. The low rankings for satisfaction with the building itself exclude the possibility that the high rankings for temperature satisfaction and perceived air quality might be caused by occupants' general building satisfaction.

10) On the Yahoo! campus, the new VAV minimum setpoints reduced gas use by an average of 12.2% (0.0225 therms/sf-year), and AC Unit energy (including fan and cooling consumption) by an average of 13.5% (0.45 kWh/sf-year). In the 800 Ferry building, the new VAV minimum setpoints reduced gas use by 6.1% (0.011 therms/sf-year), cooling energy by 28.8% (0.34 kWh/sf-year), and supply fan energy by 42.6% (0.86 kWh/sf-year). Annual trends show that zone loads are generally very low which results in most zones spending most of the time at their minimum airflow setpoint.

11) The temperature and velocity profiles measured in the Price Industries chamber show that diffusers mounted flush with the ceiling have high ADPI down to 10% flow fractions and average air speeds that decrease with lower flow fractions. These results explain why occupants in the field study did not experience draft discomfort. Diffusers mounted on a sidewall or without a ceiling, thus absent the Coanda effect, resulted in significant reductions in ADPI at low flow fractions suggesting that Coanda effect is important for maintaining comfort at low flow.

    The lab testing also shows that discharge air temperature does not affect zone temperature and velocity profiles when diffusers are mounted flush with a ceiling. This supports the results from subjective responses, which also didn't show an clear impact of discharge air temperature on thermal sensation and temperature satisfaction.

Reducing the minimum flow rate setpoints can be done simply by modifying parameters in the building control system that are often readily accessible. It is a very low-cost retrofit option that can often be carried out with no modification to the building hardware.

7 ACKNOWLEDGEMENTS

We are grateful to Engilina for her assistance with web-based background survey, Caroline Karmann for helping creating charts based on the CBE background survey, Wilmer Pasut, Mallory Taub for their help in the field measurement at Yahoo! campus, and Jessica Uhl for proofread of the report. We also thank Danielle Bricker and Rick Cuevo from Yahoo!, Donna and Dave from the 800 Ferry building, Ashley Chang and John Elliot from UC Merced for their assistant to organize background and repeated right-now surveys.

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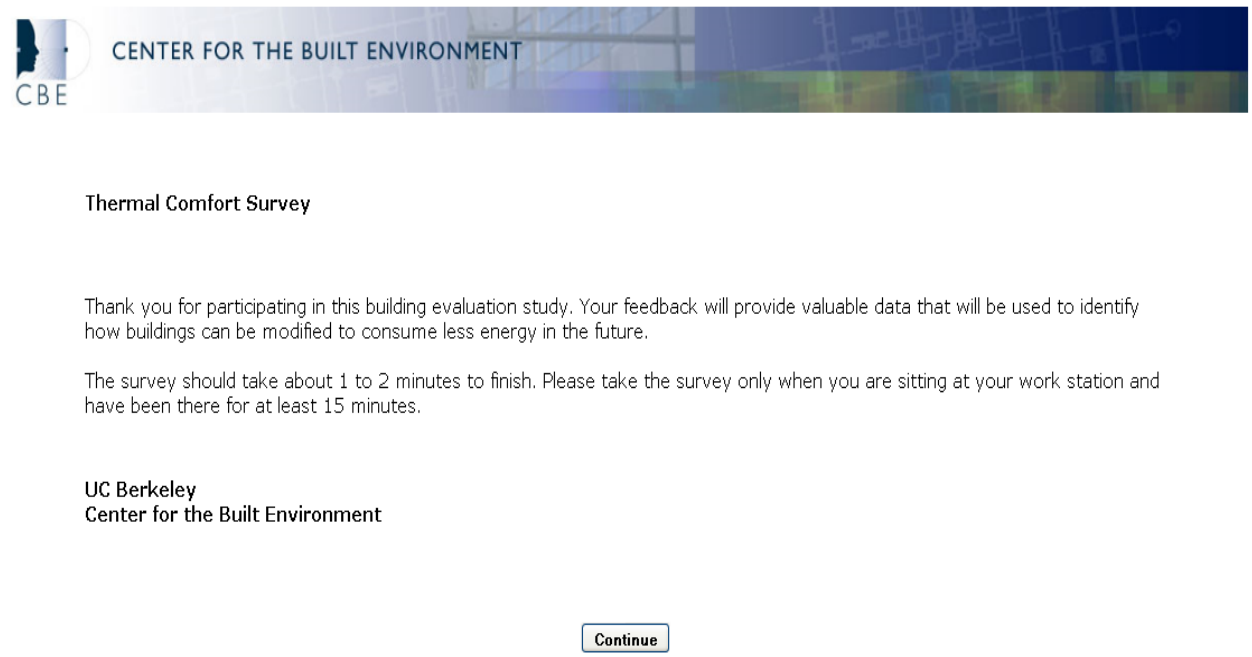
A. *Repetitive survey questionnaire*

The snapshots of the survey questions are presented here. Each picture represents a page in the survey questionnaire.



CBE CENTER FOR THE BUILT ENVIRONMENT

Thermal Comfort Survey

Thank you for participating in this building evaluation study. Your feedback will provide valuable data that will be used to identify how buildings can be modified to consume less energy in the future.

The survey should take about 1 to 2 minutes to finish. Please take the survey only when you are sitting at your work station and have been there for at least 15 minutes.

UC Berkeley
Center for the Built Environment

Continue

Your thermal environment perception

---

1. How satisfied are you with your thermal comfort in your workspace right now?

Very satisfied ○ ○ ○ ○ ○ ○ ○ Very dissatisfied

---

2. Overall, how would you rate your thermal sensation during the last few minutes?

○ Hot
○ Warm
○ Slightly warm
○ Neutral
○ Slightly cool
○ Cool
○ Cold

Continue >>

Your thermal environment perception

---

3. On any part of your body, do you feel uncomfortable?

- (•) Yes
- ( ) No

---

4. Please try to identify the source of the discomfort you feel (check all that apply)

- ☐ Strong solar radiation
- ☐ Cold surface (e.g. window)
- ☐ Too much air movement
- ☐ Too little air movement
- ☐ Space is cool
- ☐ Space is warm

Other, please describe: [ ]

---

5. Please identify the body parts that are uncomfortably warm (check all that apply)

- ☐ Head/Neck
- ☐ Torso
- ☐ Hands
- ☐ Feet
- ☐ None of my body parts feel warm

---

6. Please identify the body parts that are uncomfortably cool (check all that apply)

- ☐ Head/Neck
- ☐ Torso
- ☐ Hands
- ☐ Feet
- ☐ None of my body parts feel cool

[Continue >>]

Your air movement perception

---

7. During the last few minutes have you noticed any air movement in your workspace?

- ○ No air movement (don't notice any)
- ○ A little (slightly perceptible)
- ◉ A moderate amount (clearly noticeable)
- ○ Strong air movement

---

8. On any part of your body, do you feel discomfort due to too much air movement (check all that apply)?

- ☐ Head/Neck
- ☐ Torso
- ☐ Hands
- ☐ Feet

Continue >>

Your air movement perception

9. In your workspace, would you prefer:

- (x) More air movement
- ( ) No change in the air movement
- ( ) Less air movement

10. Why do you prefer more air movement (check all that apply)?

- [ ] Air movement provides relief from feeling too warm
- [ ] I like the feeling of air movement
- [ ] Air movement provides a sense of being outdoors
- [ ] Air movement reduces stuffiness

Other, please describe: ____________________

Continue >>

Other environmental perceptions

---

11. How satisfied are you with the air quality in your workspace right now?

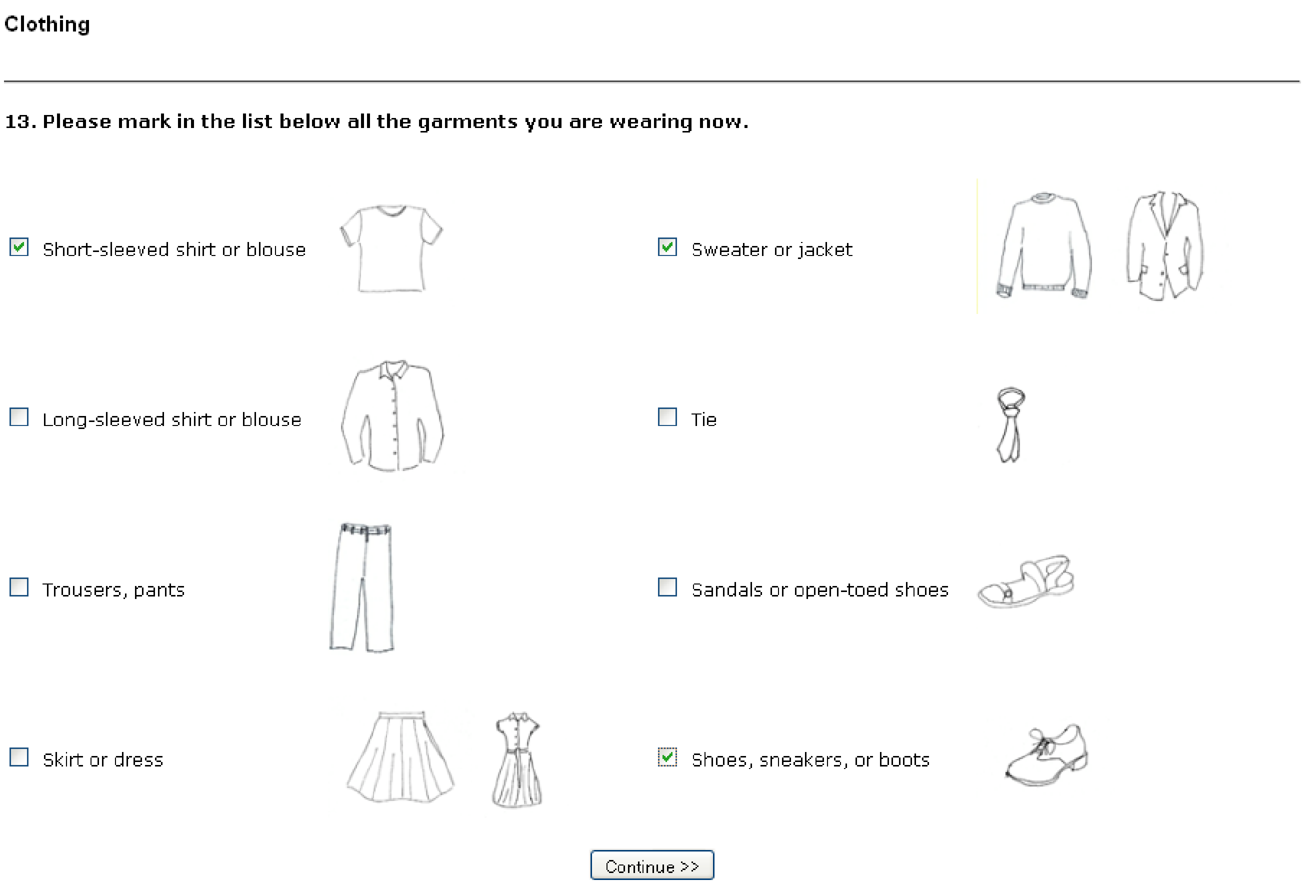
Very satisfied ○ ○ ○ ○ ○ ○ ○ Very dissatisfied

---

12. How satisfied are you with the noise level in your workspace right now?

Very satisfied ○ ○ ○ ○ ○ ○ ○ Very dissatisfied

Continue >>



Clothing

13. Please mark in the list below all the garments you are wearing now.

- [x] Short-sleeved shirt or blouse
- [x] Sweater or jacket
- [ ] Long-sleeved shirt or blouse
- [ ] Tie
- [ ] Trousers, pants
- [ ] Sandals or open-toed shoes
- [ ] Skirt or dress
- [x] Shoes, sneakers, or boots

Continue >>

This page is optionla, appearing only when they changed their clothing.

General comments

---

15. If you have additional comments or recommendations about the environment in your workspace, you may add them in the field below.

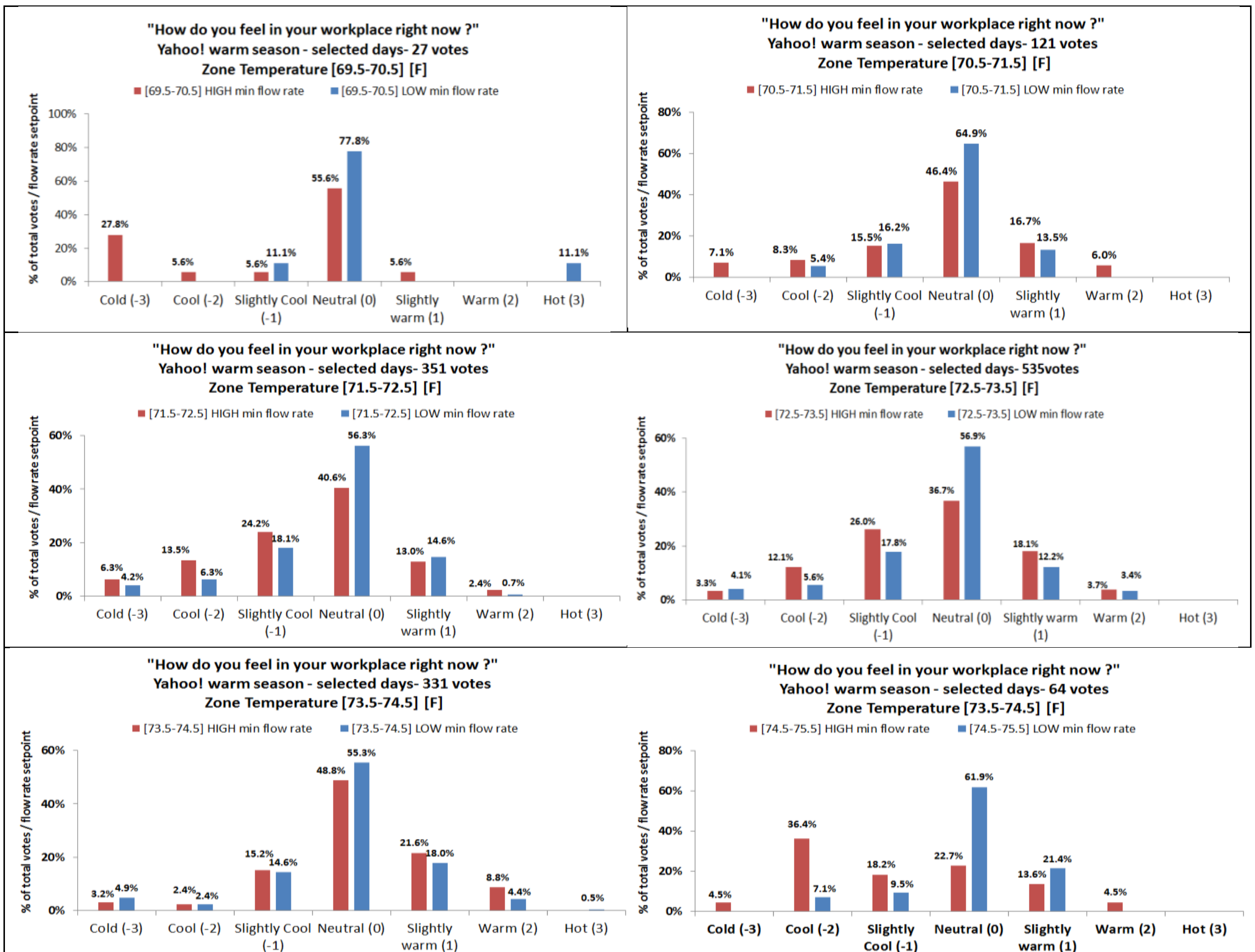
hui zhang test

Continue >>

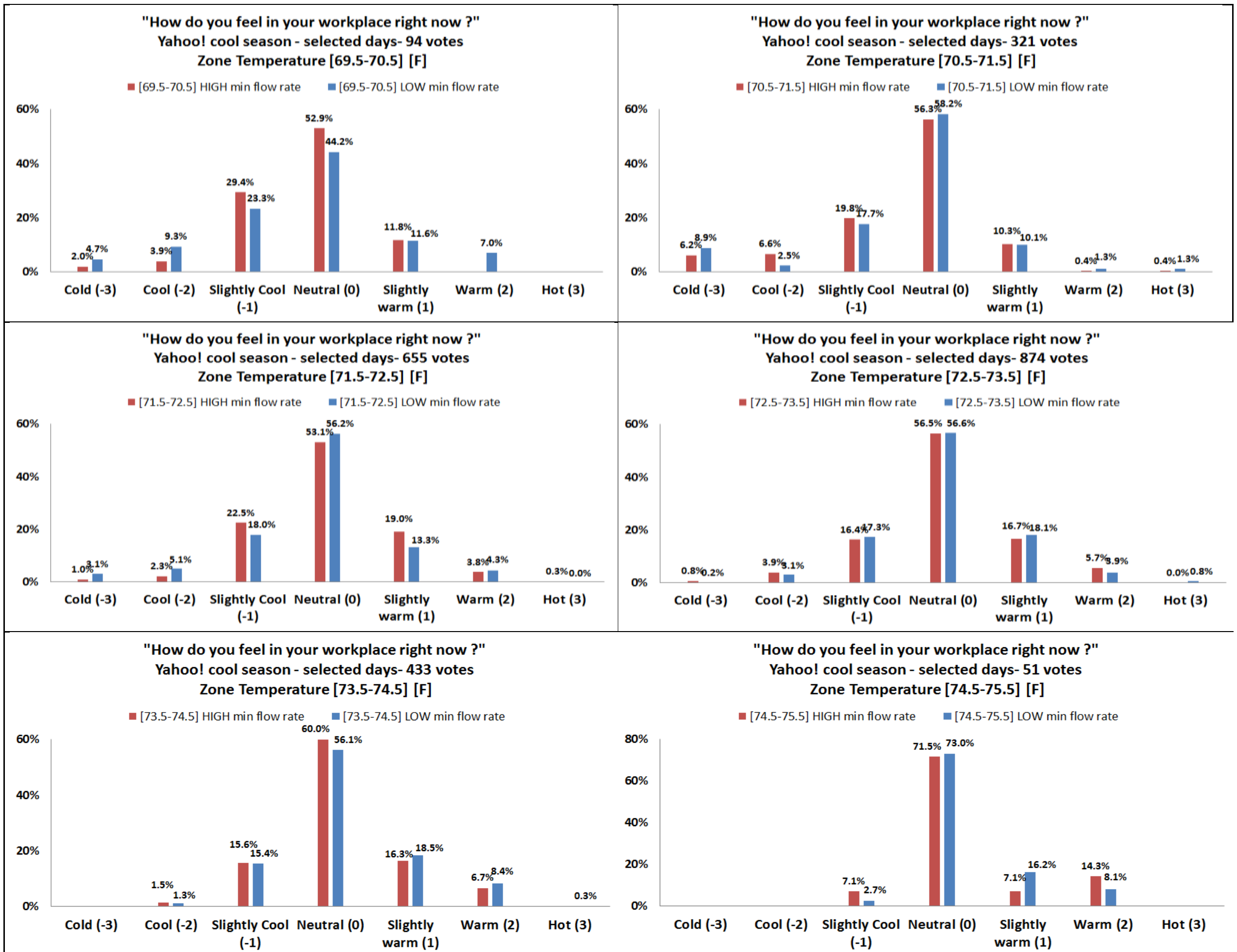
B. Sensation and satisfaction vs. 1F binned zone air temperature

B.1 Thermal sensation distribution under 1F air temperature binned data

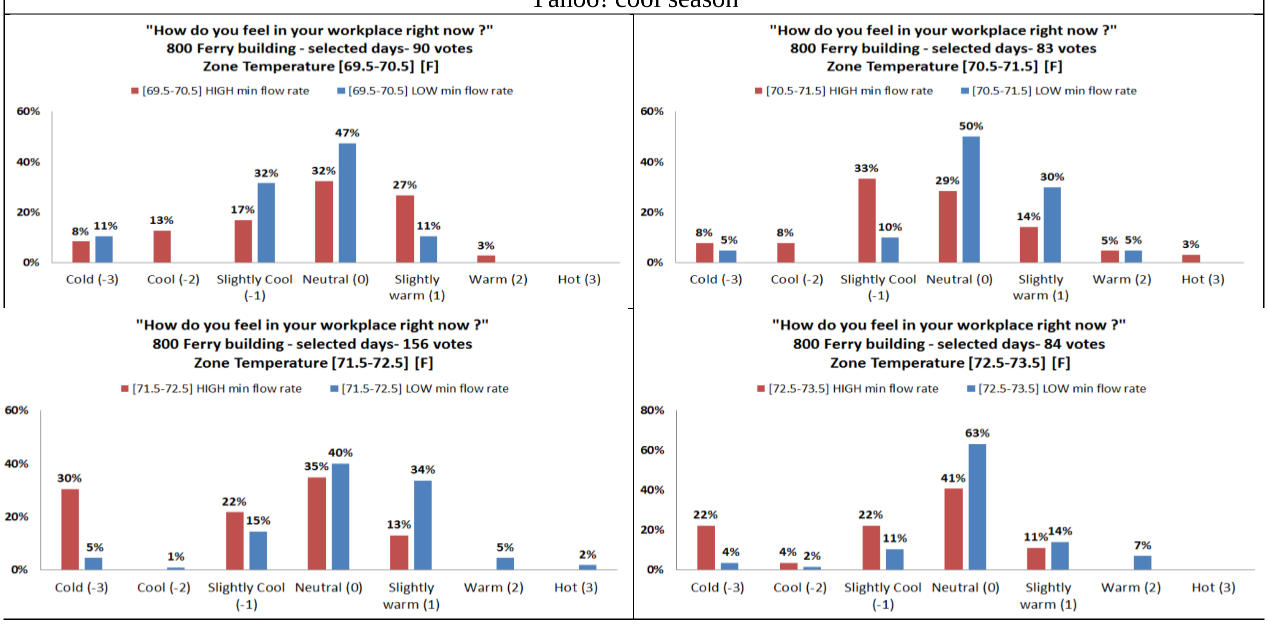
To further examine the relationship between zone air temperature and thermal sensation, we created thermal sensation distribution charts for zone air temperature bins of width 1ºF (Figure B.1). The range of the zone air temperature bins is shown on top of each figure. Six charts for each survey study are included for temperature bins: 69.5ºF – 70.5ºF, 70.5ºF – 71.5ºF, 71.5ºF – 72.5ºF, 72.5ºF – 73.5ºF, 73.5ºF – 74.5ºF, and 74.5ºF – 75.5ºF. The large individual differences among people again are shown in these charts. For example, the sensation distributions for Yahoo! warm season survey responses under ranges 70.5F – 71.5F and 72.5F – 73.5F are similar, even though the air temperature differences are 2ºF. (Note that the scales are different for the two figures. The scale is normally set at 60%, unless there are values that are higher than 60%, such as the case with the binned air temperature range 70.5F – 71.5F, where 80% is used). At both air temperature ranges, the thermal sensation ranges from 'cold' to 'warm'.

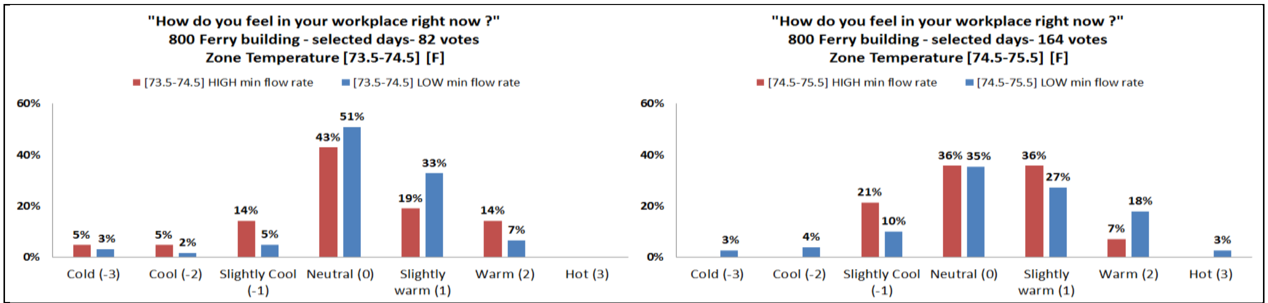


Yahoo! warm season



Yahoo! cool season





800 Ferry building

Figure B.1 Thermal sensation and zone air temperatures

In order to clearly see sensation changes with binned zone air temperature, we summarized sensation votes for each binned zone temperature (see Table B.1). Category "cool" includes sensation votes slightly cool, cool, and cold, and category "warm" includes sensation votes slightly warm, warm, and hot.

For both the Yahoo! warm and the 800 Ferry building surveys, the big jump in reduction in the cool category (and an increase in warm category) happened between zone temperature range 72.5 – 73.5F and 73.5 – 74.5F. Another big jump for the 800 Ferry building survey is between 70.5 – 71.5F and 71.5 – 72.5F. For the Yahoo! cool survey, the changes are more consistent and gradual. With each degree F zone air temperature increase, there is about 5% reduction in cool category, and about 3% in warm category, except between range 70.5 – 71.5F and 71.5 – 72.5F, where a big jump in warm category (8.6%) happened.

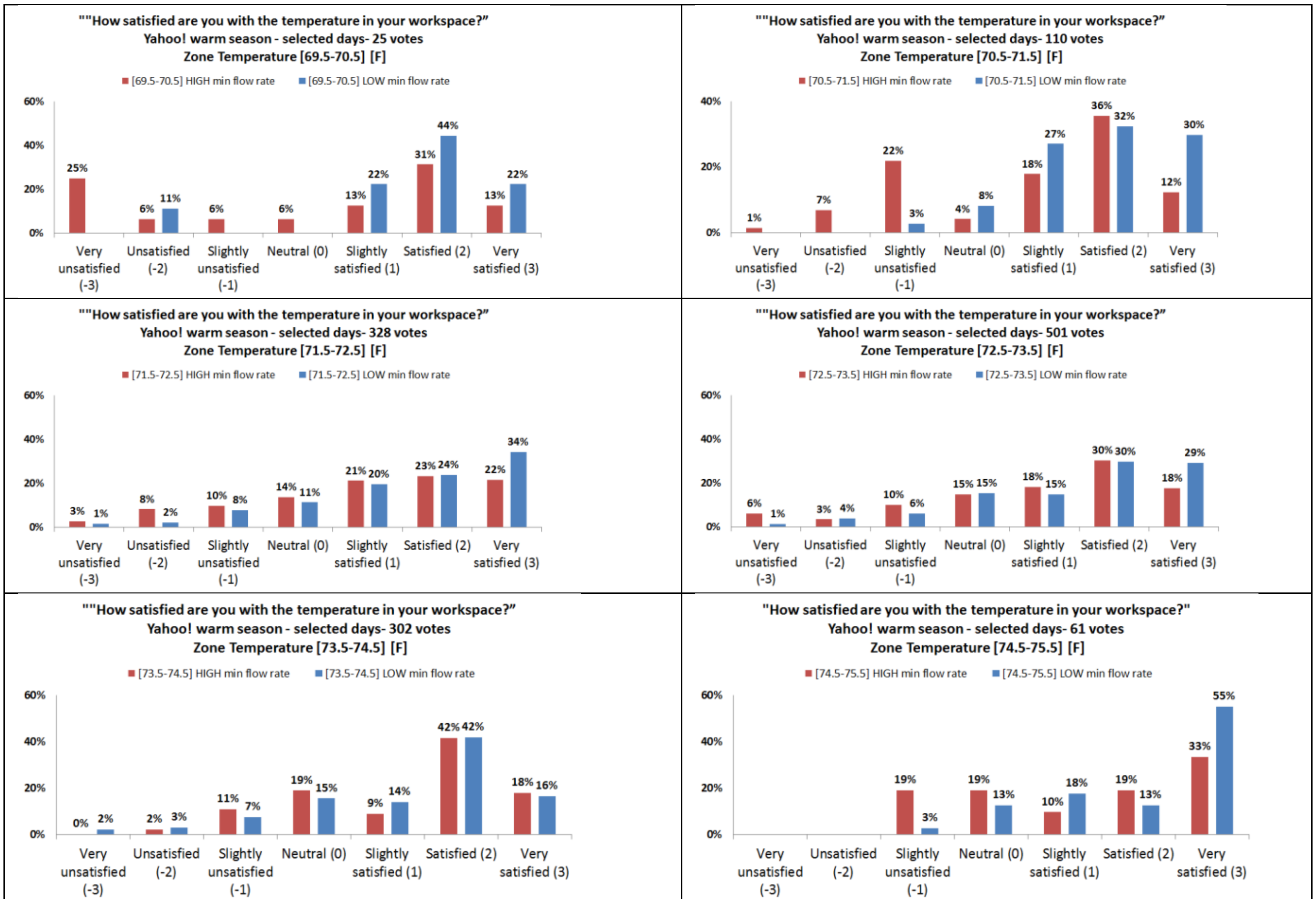
Zone temp. range (F)	Yahoo! warm				Yahoo! cool				800 Ferry building			
	cool	neutral	warm	N	cool	neutral	warm	N	cool	neutral	warm	N
69.5 – 70.5	29.6	63.0	7.4	27	36.2	48.9	14.9	94	38.9	35.5	25.6	90
70.5 – 71.5	28.1	52.1	19.8	121	31.8	56.7	11.5	321	41.0	33.7	25.3	83
71.5 – 72.5	37.6	47.0	15.4	351	26.0	53.1	20.9	655	29.5	38.4	32.1	156
72.5 – 73.5	33.1	48.8	18.1	535	20.8	56.5	22.7	874	26.2	55.9	17.9	84
73.5 – 74.5	21.5	52.9	25.7	331	16.9	57.2	25.9	433	13.4	48.8	37.8	82
74.5 – 75.5	31.3	48.4	20.3	64	3.9	76.6	23.5	51	17.1	35.3	47.6	164

Table B.1 Thermal sensation distributions (%) under each 1ºF binned zone air temperateure

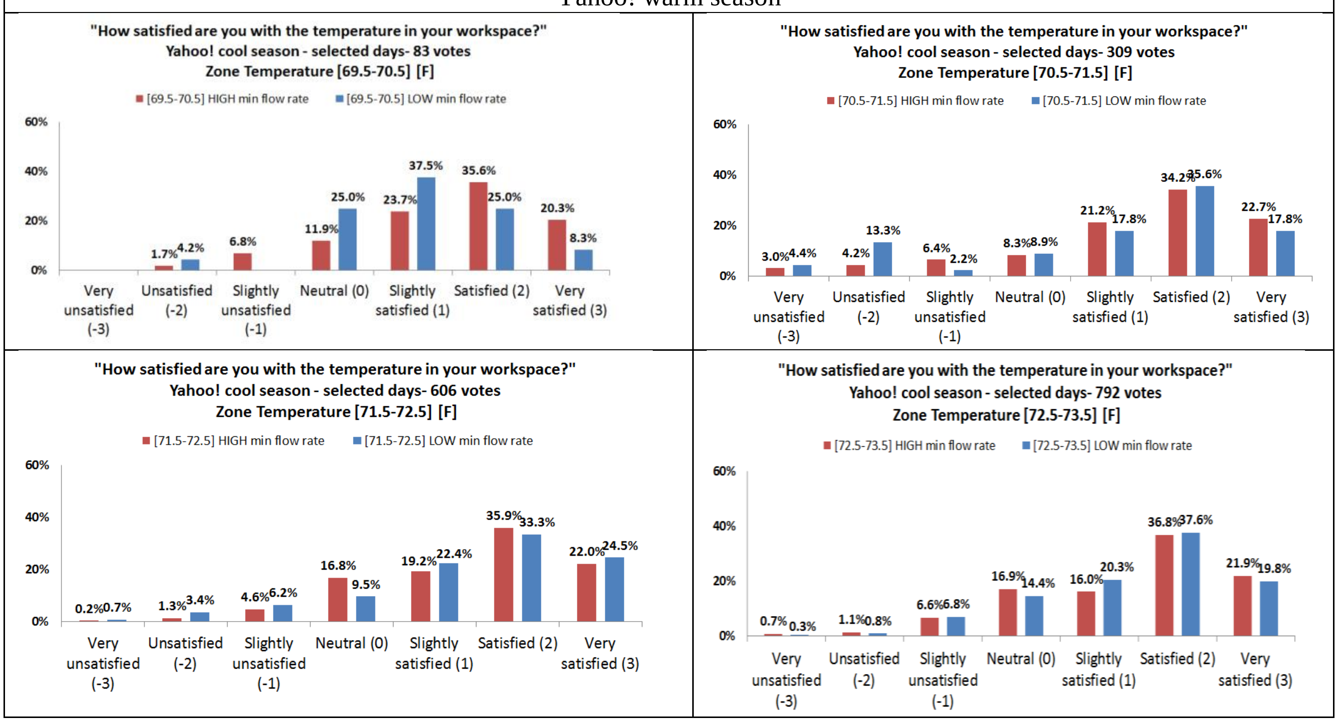
B.2 Temperature satisfaction distribution under 1ºF binned zone air temperature

In order to analyze the relationship between temperature satisfaction and zone air temperature, we created satisfaction distribution charts for each 1ºF binned temperature. The results are shown in Figure B.2.

In general, we see votes from 'very dissatisfied' to 'very satisfied' under each 1ºF binned zone air temperature, from 69.5 - 70.5F to 72.5 – 73.5F. That indicates large individual differences among people. These charts do show a very interesting result: at higher air temperature ranges, 73.5 – 74.5 and 74.5 – 75.5, the numbers of very dis-satisfied votes are very small from all the three surveys. Please also notice that the numbers of votes in 74.5 – 75.5 ranges are also small for the two Yahoo! surveys.



Yahoo! warm season



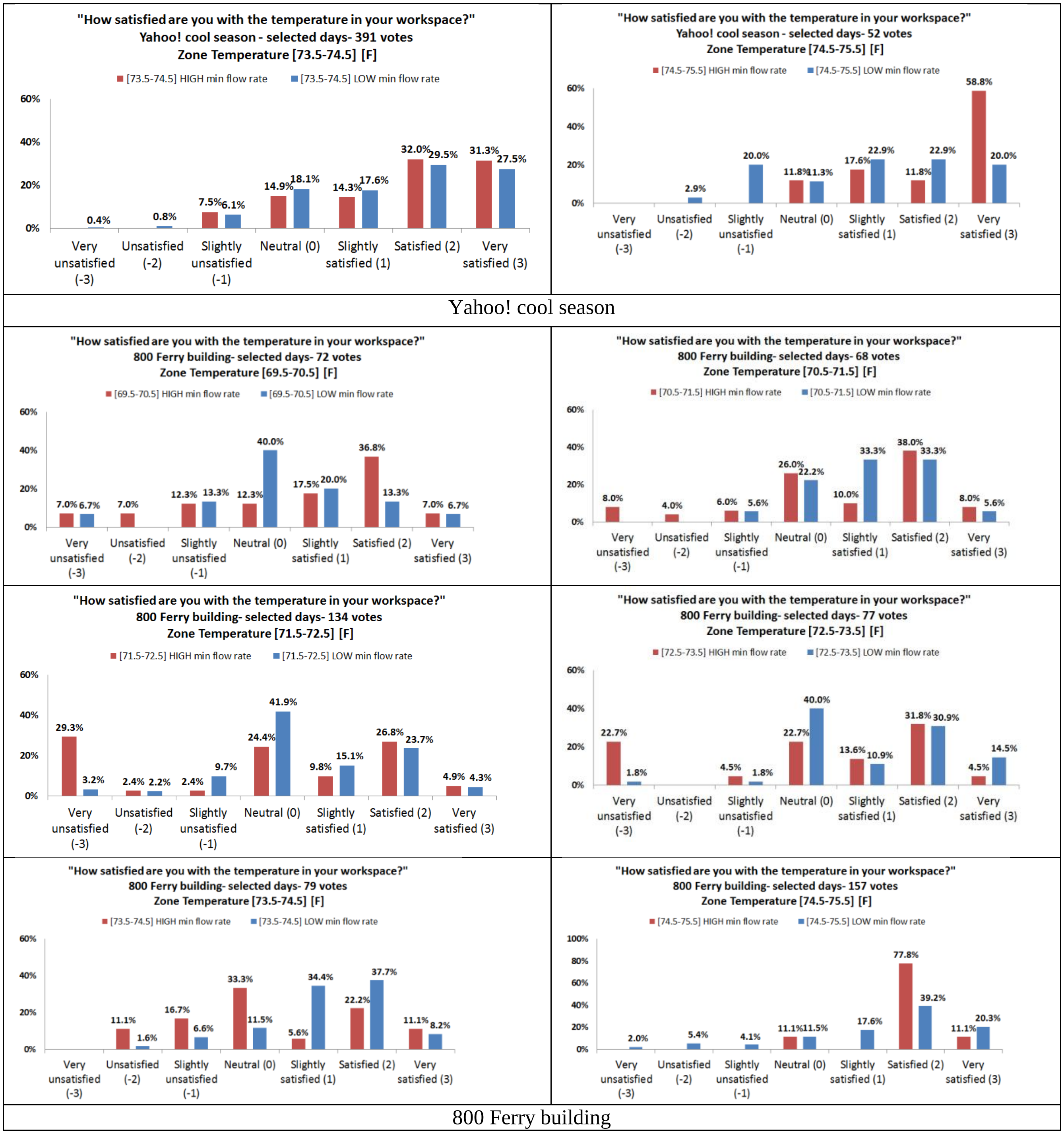


Figure B.2 Thermal sensation and zone air temperatures

Table B.2 summarizes the dissatisfied (satisfaction votes -3, -2, -1) and satisfied (satisfaction votes 0, 1, 2, 3) percentages for each 1F binned air temperature range.

In general, for all three surveys, dis-satisfied rate reduced as each 1F binned zone temperature increased. Following the values when the numbers of votes are large, e.g. Yahoo! warm and Yahoo! cool surveys, we see that there was a bigger comfort improvement (bigger reductions in dissatisfied votes) when the zone air temperature increased from 70.5 – 71.5 to 71.5 – 72.5F (4.4% and 7.5% reductions from the original dissatisfied percentages 20.9% and 14.6%, a 25% to 50%

reduction of these dissatisfied percentages). From zone temperature 71.5 – 72.5 to 73.5 – 74.5F, each 1F increase corresponds to about 2% reduction in dissatisfied percentage in the Yahoo! warm survey (10% reduction of the original dissatisfied rate). For the Yahoo! cool survey, the dissatisfaction percentages are similar in ranges 71.5 – 72.5 to 73.5 – 74.5. For the 800 Ferry building, the biggest dissatisfaction reductions happened in ranges from 69.5 – 70.5F to 70.5 – 71.5F, and 71.5 – 72.5 F to 72.5 – 73.5F. There were times when dissatisfied percentages increased rather than decreased as zone temperature increases, but in general, the dissatisfaction rate was reduced as the zone air temperature increased.

Zone temp. range (F)	Yahoo! warm			Yahoo! cool			800 Ferry building		
	Dissatisfied	satisfied	N	dissatisfied	satisfied	N	dissatisfied	satisfied	N
69.5 – 70.5	28	72	25	7.2	92.8	83	25	75	72
70.5 – 71.5	20.9	71.9	110	14.6	85.4	309	14.7	85.3	68
71.5 – 72.5	16.5	83.5	328	7.1	92.9	606	20.9	79.1	134
72.5 – 73.5	14	86	501	8.2	91.8	792	10.4	89.6	77
73.5 – 74.5	12.6	87.4	302	7.4	92.6	391	12.7	87.3	79
74.5 – 75.5	8.2	91.8	61	15.4	84.6	52	10.8	89.2	157

Table B.2 Temperature dissatisfaction/satisfaction (%) vs. 1F binned zone air temperature

C. Sensation and satisfaction vs. binned discharge air temperature

C.1 Thermal sensation corresponding to discharge temperature

If "dumpling" does happen (supply air from diffusers is not mixed well before reaching occupants), then the discharge air temperature might be important affecting occupants' thermal comfort. In this section, we grouped discharge temperature into four groups: 55 – 60, 60 – 65, 65 – 70, 70 – 75 to examine their impact on thermal comfort. Because often the number of votes in discharge air temperature range 70 – 75F is small, when that happens, the analysis excluded this range. Also, the discharge air temperature in fact affects zone air temperature, so the results presented here might be a combined result together with the zone air temperature.

For the 4 binned discharge air temperature ranges, the sensation distributions for the 3 surveys are presented in Figure C.1 – Figure C.3.

Yahoo! warm. Again, we grouped occupant's thermal sensation results to three categories: cool (sensation slightly cool, cool, and cold), neutral, and warm (sensation slightly warm, warm, and hot), to compare sensation differences with various discharge air temperature ranges (see Table C.1 for Yahoo! warm survey). For the two discharge air temperature ranges 55 – 60F and 60 – 65F, under high minimum operation, the differences are small. When the discharge air temperature range was increased from 55 – 60F to 60 – 65F, there was a 1.7% reduction for "cool" category, and 2.1% increase for "warm" category. Under low minimum operation, the differences are slightly bigger. When the discharge air temperature range was increased from 55 – 60F to 60 – 65F, there was a 3.2% reduction for cool category, and 6.5% increase for warm category. Overall, the changes of thermal sensation with discharge air temperature changes are small.

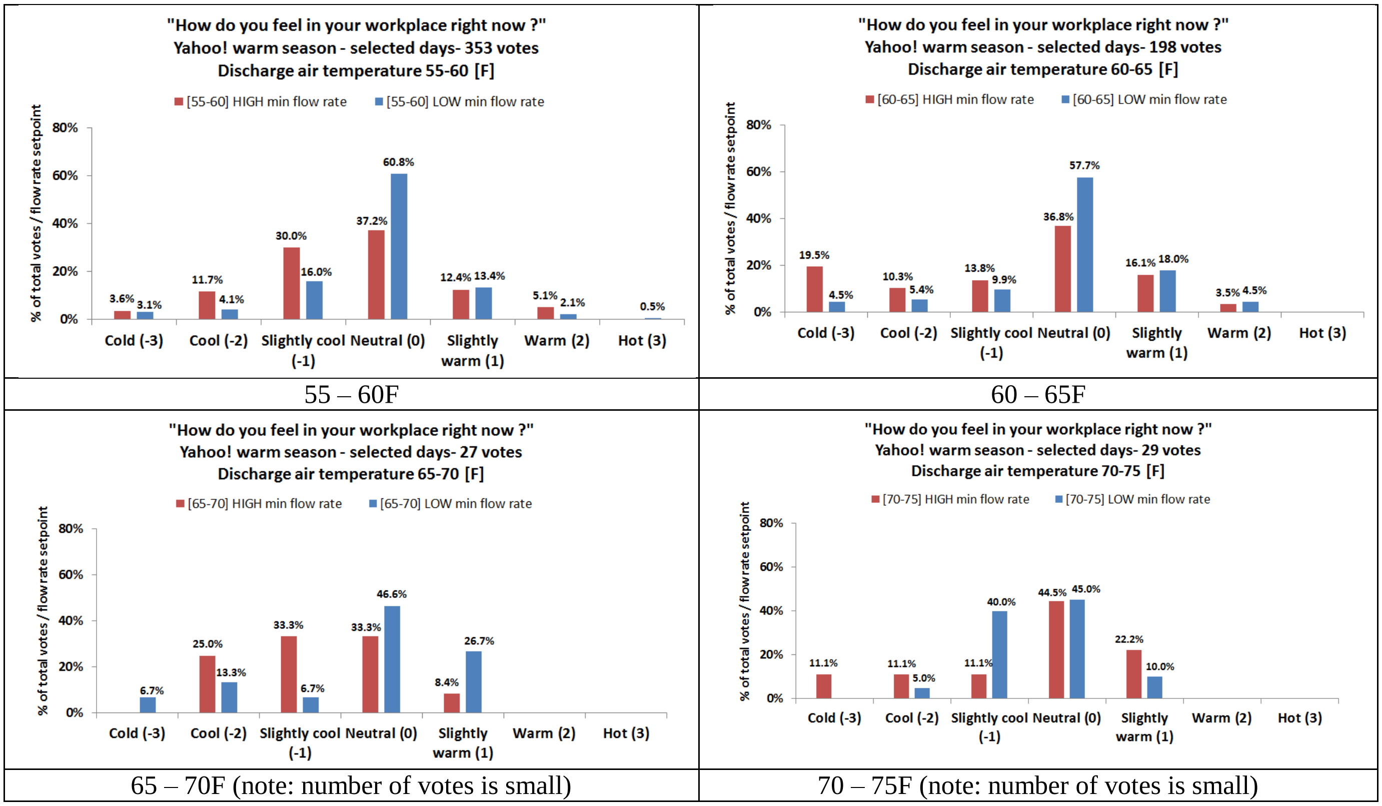


Figure C.1 Thermal sensation vs. discharge air temperature (Yahoo! warm)

Tdis range F	Total N	High (%)			Low (%)		
		cool	neutral	warm	cool	neutral	warm
55 – 60F	353	45.3	37.2	17.5	23.2	60.8	16
60 – 65F	198	43.6	36.8	19.6	19.8	57.7	22.5

Table C.1 Thermal sensation distributions for Yahoo! warm survey

Yahoo! cool. Under high minimum flow operation, there is a 7.3% increase in "warm" category comparing the discharge air temperature range 60 – 65F to 55 – 60F. There is no change in "cool" category. Comparing discharge air temperature ranges 65 – 70F to 55 – 60F, there is a 4.7% reduction in cool category and a 6% increase in warm category. Under low minimum operation, the changes are 3.4% to 5.8% decrease in cool category and 4.5% to 5.8% increase in warm category when the discharge air temperature increased from 55 – 60F, to 60 – 65F, and to 65 – 70F. Again, the changes in thermal sensation corresponding to different discharge air temperature range are not large, within 6%.

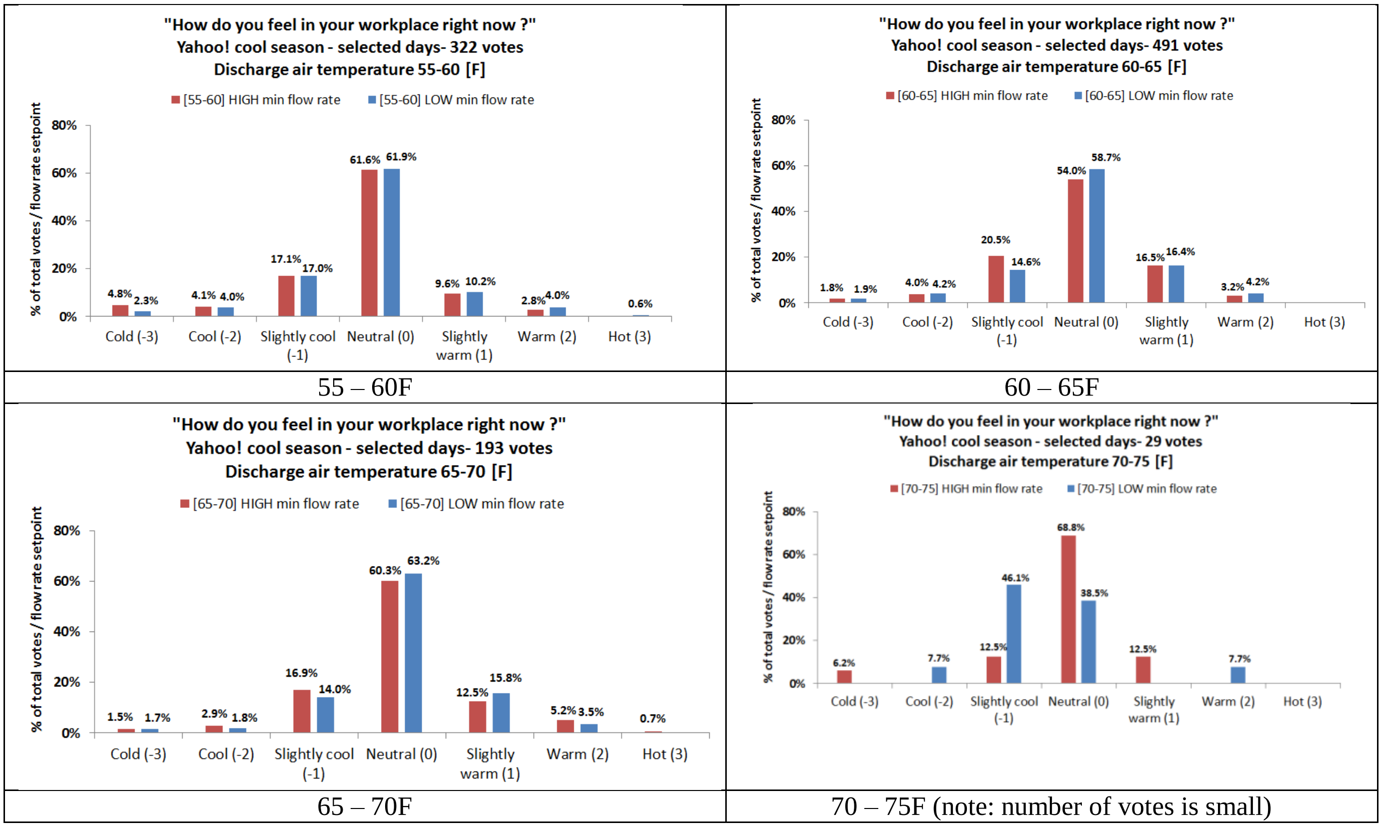


Figure C.2 Thermal sensation vs. discharge air temperature (Yahoo! cool)

Tdis range F	Total N	High (%)			Low (%)		
		cool	neutral	warm	cool	neutral	warm
55 – 60F	322	26	61.6	12.4	23.3	61.9	14.8
60 – 65F	491	26.3	54	19.7	20.7	58.7	20.6
65 – 70F	193	21.3	60.3	18.4	17.5	63.2	19.3

Table C.2 Thermal sensation distributions for Yahoo! cool survey

800 Ferry building. There were unexpected thermal sensation changes comparing discharge air temperature range 55 – 60F to 60 – 65F. Both the "coo" categories and "warm" categories were increased under both high and low operations.

There are about 6% and 10% shifts from cool category to warm category as the discharge air temperature ranges increase from the low group 55 – 60F to high group 70 – 75F under high and low minimum operations.

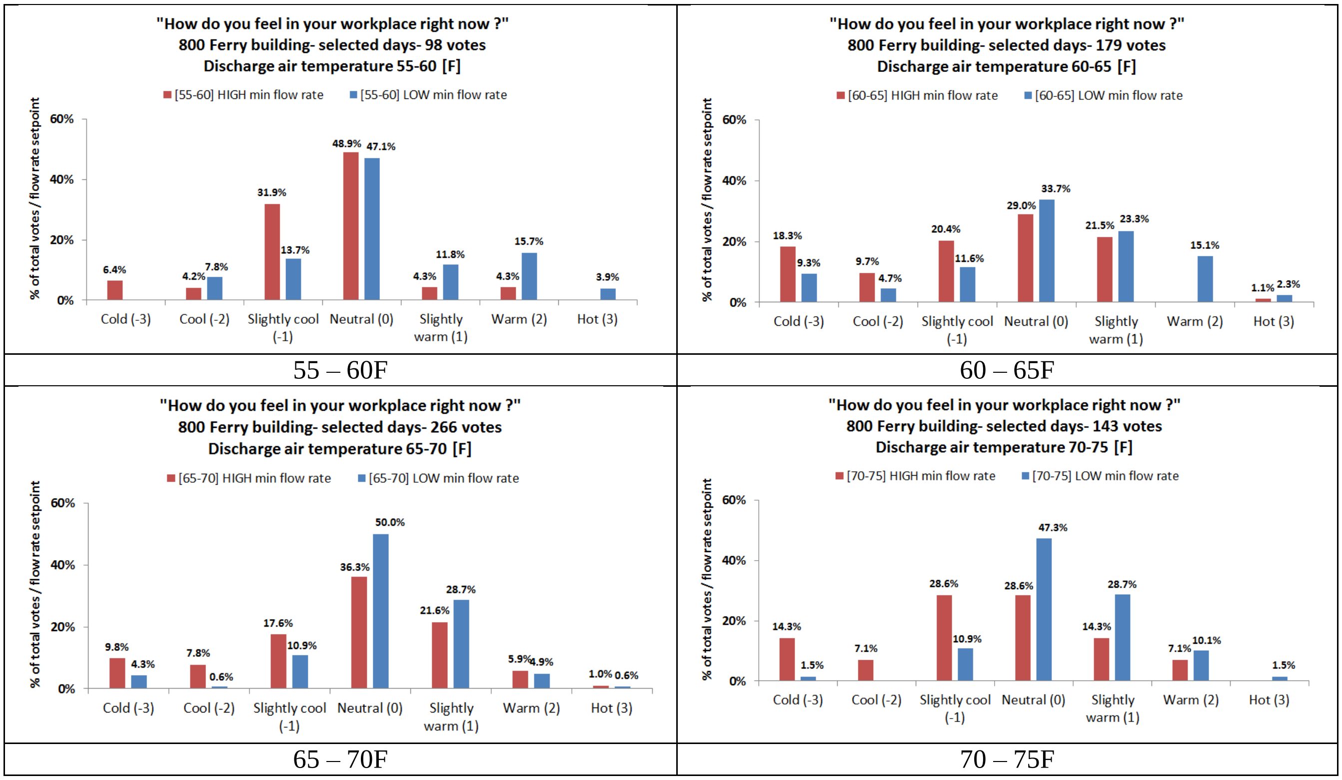


Figure C.3 Thermal sensation vs. discharge air temperature (800 Ferry)

Tdis range F	Total N	High (%)			Low (%)		
		cool	neutral	warm	cool	neutral	warm
55 – 60F	98	42.5	48.9	8.6	21.5	47.1	31.4
60 – 65F	179	48.4	29	22.6	25.6	33.7	40.7
65 – 70F	266	35.2	36.3	28.5	15.8	50	34.2
70 – 75F				21.4	12.4	47.3	40.3

Table C.3 Thermal sensation distributions for 800 Ferry building survey

C.2 Temperature satisfaction corresponding to discharge air temperature

To examine temperature satisfaction with the discharge air temperature, we again grouped the discharge air temperature ranges into the 4 groups as described above, and summarized the satisfaction results.

Yahoo! warm. Figure C.4 and Table C.4 show that satisfaction rates increased 8.6% for high minimum operation when the discharge air temperature was lower (55 – 60F) than higher (60 – 65F). The satisfaction increase rate was less under low minimum operation for the same discharge air temperature change. These changes could not match the sensation changes shown in Table C.1, where when the discharge air temperature was higher, no sensation changes shown under high minimum operation and sensation shifted towards warm side under low minimum operation.

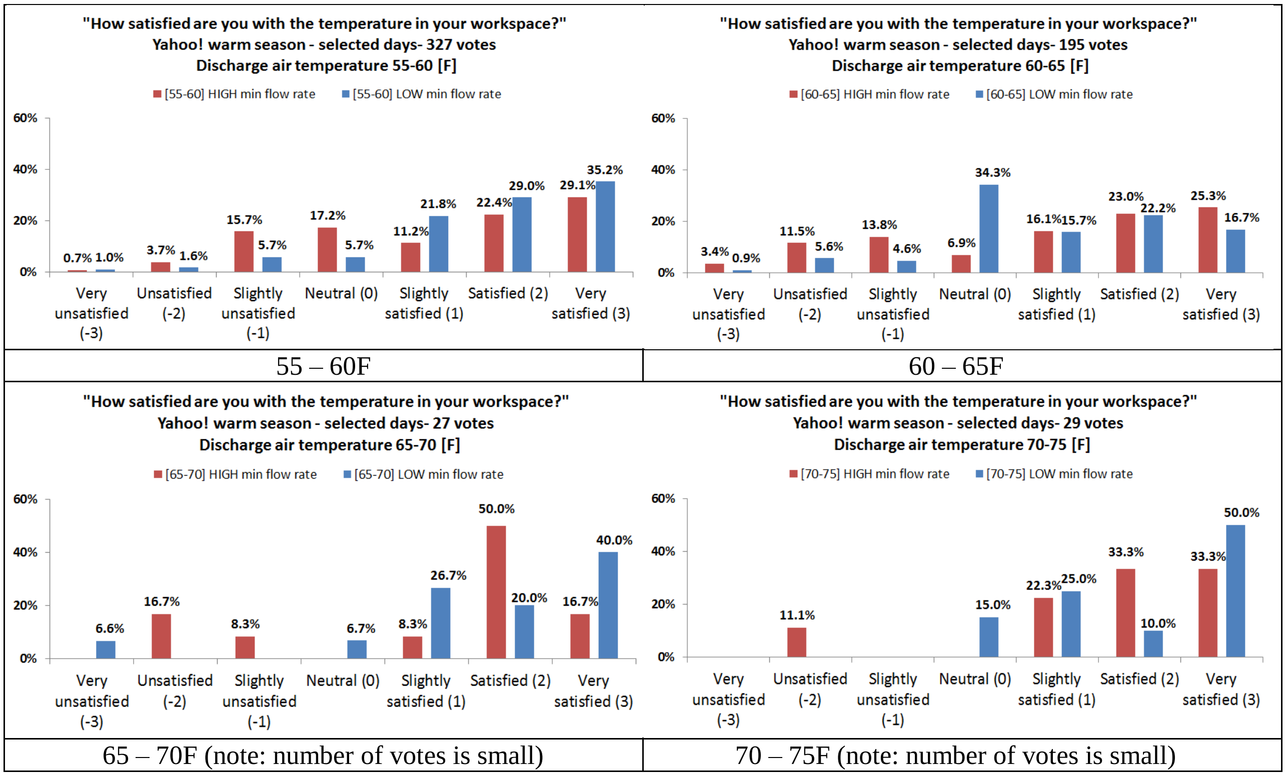


Figure C.4 Temperature satisfaction vs. discharge air temperature (Yahoo! warm)

Tdis range F	Total N	High (%)		Low (%)	
		un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	327	20.1	79.9	8.3	91.7
60 – 65F	195	28.7	71.3	11.1	88.9

Table C.4 Temperature satisfaction change under different discharge air temperature ranges (Yahoo! warm)

Yahoo! cool. The differences are smaller for the Yahoo! cool survey (Figure C.5 and Table C.5). There was no difference when the discharge air temperature was higher (60 – 65) then lower (55 – 60F) for both high and low minimum operations. When the discharge air temperature is at range of (65 – 70F), there was a 3% decrease in satisfaction under high minimum operation and a 3% increase under low minimum operation. Again, these results cannot match the sensation changes shown in Table C.2 where cool sensation group reduced under both high and low minimum operations.

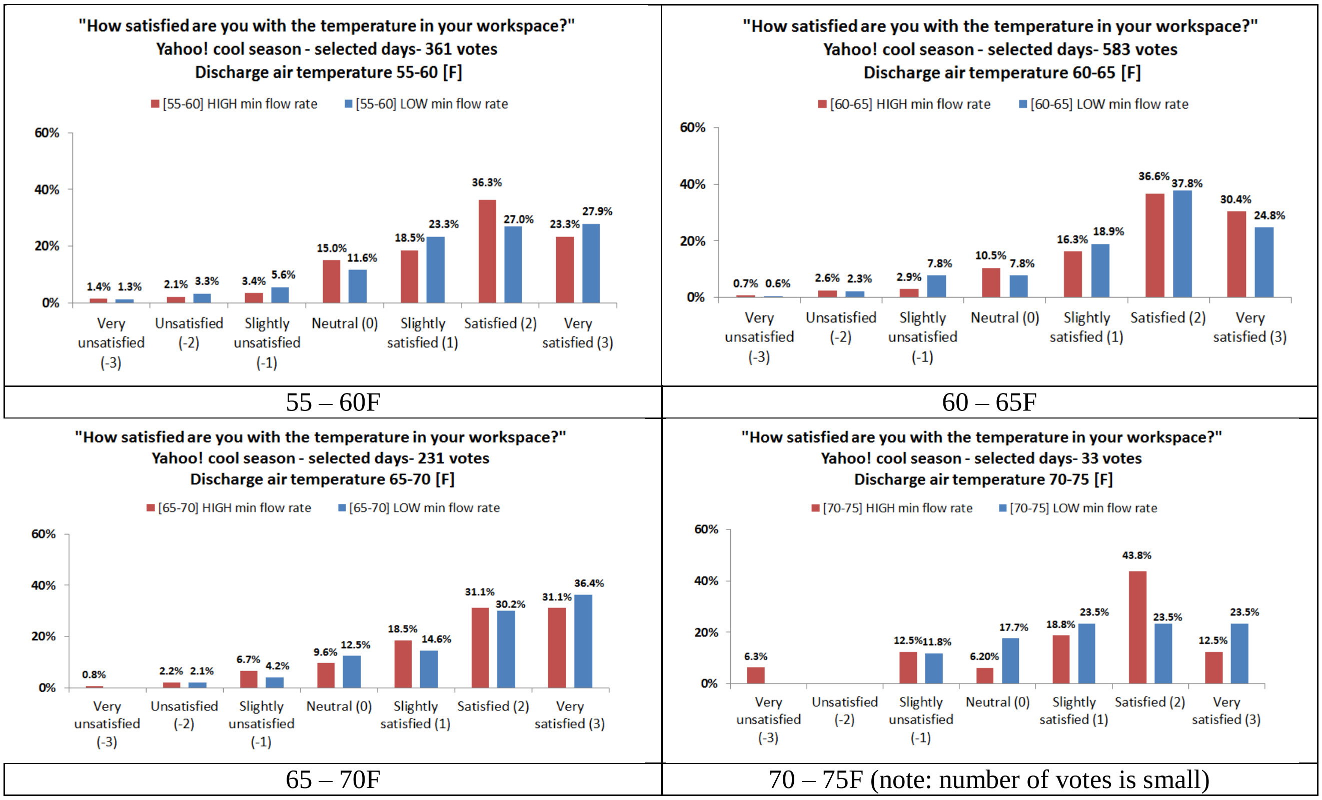


Figure C.5 Temperature satisfaction vs. discharge air temperature (Yahoo! cool)

Tdis range F	Total N	High (%)		Low (%)	
		un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	361	6.9	93.1	10.2	89.8
60 – 65F	583	6.2	93.8	10.7	89.3
65 – 70F	231	9.7	90.3	6.3	93.7

Table C.5 Temperature satisfaction change under different discharge air temperature ranges (Yahoo! cool)

800 Ferry building. In general, the satisfaction in the 800 Ferry building follows thermal sensation shown in Table C.3. When thermal sensation were cooler at 55 – 60F discharge air temperature range, the dissatisfaction rate is increased (see Table C.6 below).

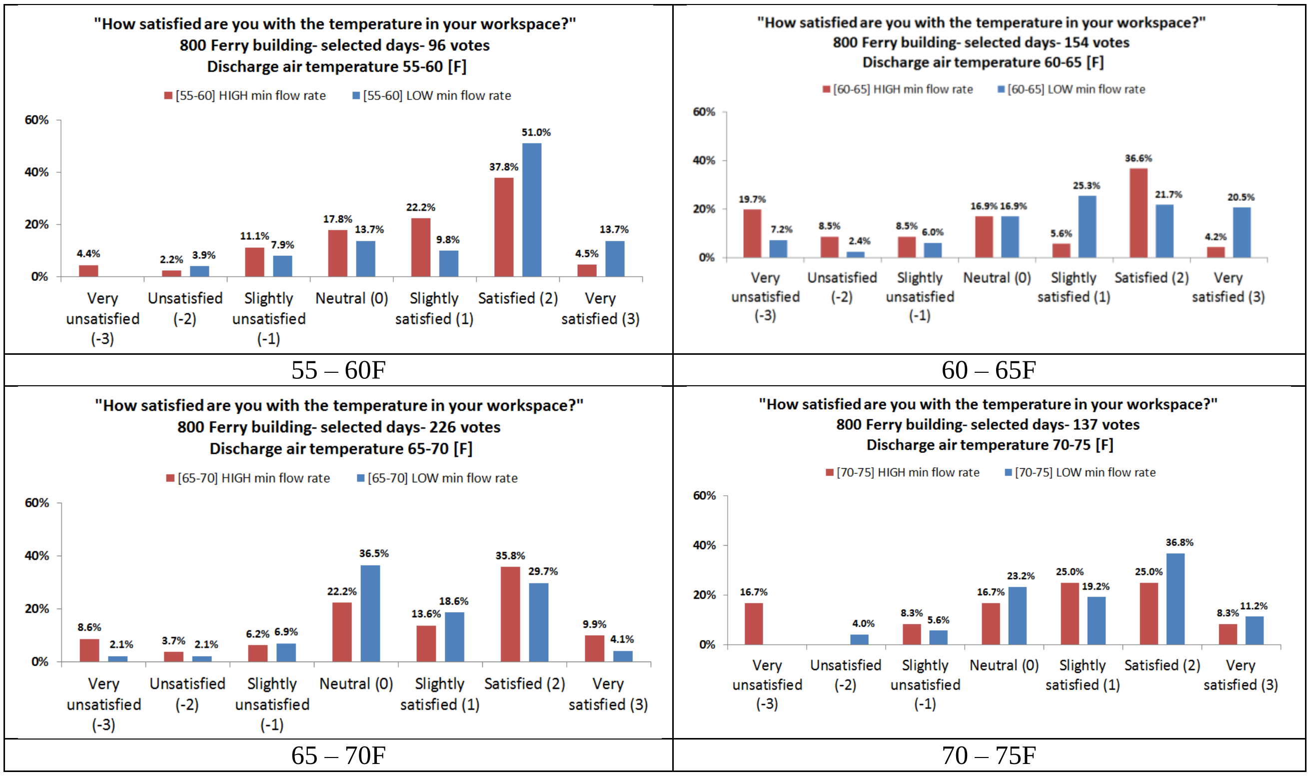


Figure C.6 Temperature satisfaction vs. discharge air temperature (800 Ferry)

Tdis range F	Total N	High (%)		Low (%)	
		un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	96	17.7	82.3	11.8	88.2
60 – 65F	154	36.7	63.3	15.6	84.4
65 – 70F	226	18.5	81.5	11.1	88.9
70 – 75F	137	25	75	9.6	90.4

Table C.6 Temperature satisfaction change under different discharge air temperature ranges (800 Ferry building)

Overall, the relationship of satisfaction with discharge air temperature is weak. Under low minimum operation, the satisfaction increased when the discharge air temperature is higher. Under high minimum operation, the satisfaction seems reduced as the discharge air temperature is higher. It is possible that the influence from the zone temperature is big, and the analysis with discharge air temperature along cannot reach consistent results.

D. *Perceived air quality vs. binned zone air temperature*

Previously we showed that temperature satisfaction was improved under low minimum operation because summer over-cooling was reduced. Here we see perceived air quality was also improved under low minimum operation. Therefore, we try to examine relationship between perceived air quality and zone temperature. Table 3.2.22 presents perceived air quality correlating each 1F binned zone temperature. Similar to the temperature satisfaction, at higher zone air temperature, the satisfaction for perceived air quality is higher for the two summer surveys. For the Yahoo! cool survey, as zone air temperature increased, the there is a slight decrease in perceived air quality satisfaction.

Zone temp. range (F)	Yahoo! warm			Yahoo! cool			800 Ferry building		
	dis-satisfied	satisfied	N	dis-satisfied	satisfied	N	dis-satisfied	satisfied	N
69.5 – 70.5	15.4	84.6	26	5.6	94.4	249	15.6	84.4	90
70.5 – 71.5	15.7	84.3	121	6.6	93.4	791	18.1	81.9	83
71.5 – 72.5	8.2	91.8	352	5.7	94.3	1550	19.2	80.8	156
72.5 – 73.5	4.1	95.9	537	5.5	94.5	1990	11.9	88.1	84
73.5 – 74.5	9.6	90.4	334	8.0	92.0	960	12.3	87.7	81
74.5 – 75.5	9.2	90.8	65	8.0	92.0	113	7.3	92.7	164

Table D.1 Perceived air quality vs. binned zone air temperature

If "dumpling" happens, then cooler supply air temperature might directly reach to occupants. Therefore, we might see differences on perceived air quality with different discharge air temperatures. Figures and tables below examine relationship between PAQ and discharge air temperature.

E. Perceived air quality vs. binned discharge air temperature

In general we see that as discharge air temperature increased, the perceived air quality decreased. This changes is more obvious in Yahoo! warm survey and less obvious in Yahoo! cool survey. It is interesting to see that again, in the 800 Ferry building survey, the least satisfied votes for PAQ is at the discharge temperature range, 60 – 65F, where the sensation was coolest and that the temperature satisfaction the lowest.

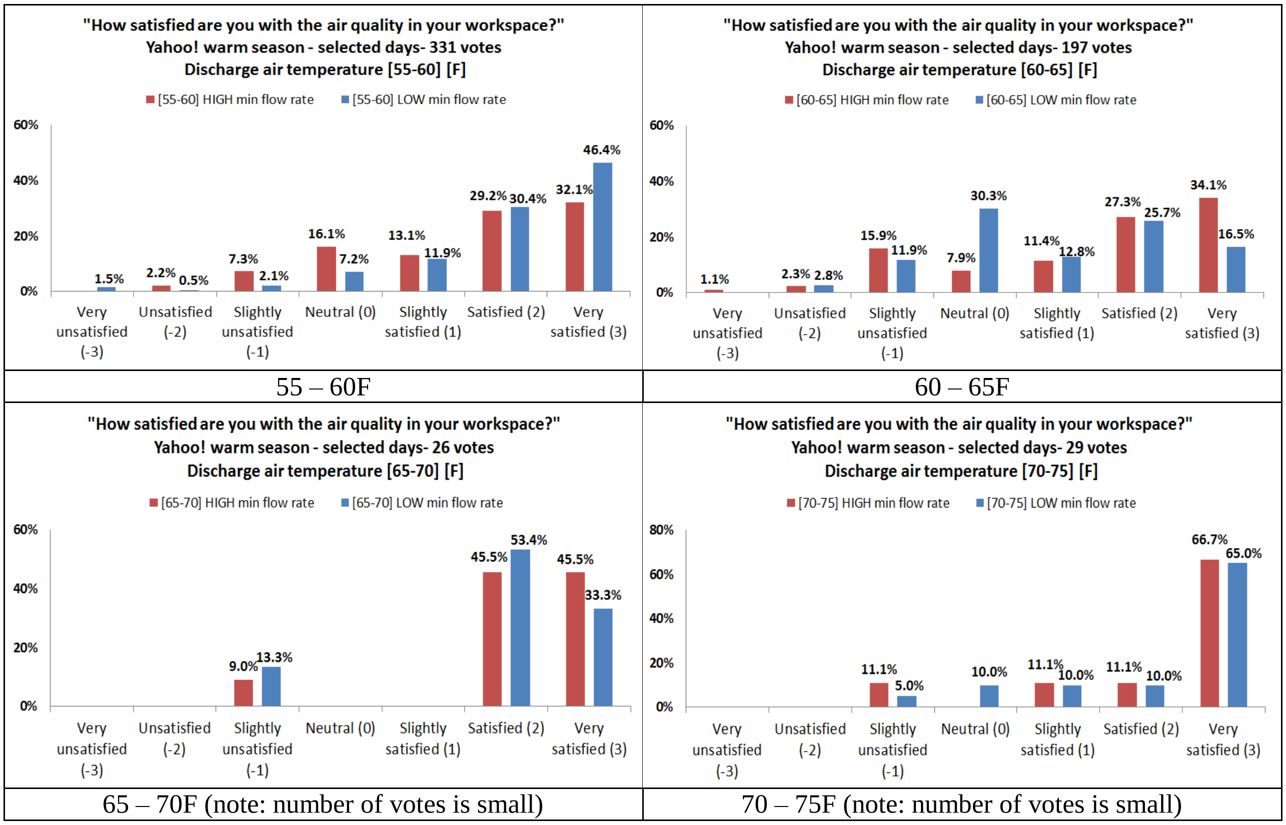


Figure E.1 Perceived air quality vs. discharge air temperature (Yahoo! warm)

Yahoo! Warm season	High (%)		Low (%)	
	un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	9.5	90.5	4.1	95.9
60 – 65F	19.3	80.7	14.7	85.3

Table E.1 Satisfaction with perceived air quality under different supply air temperatures (Yahoo! warm)

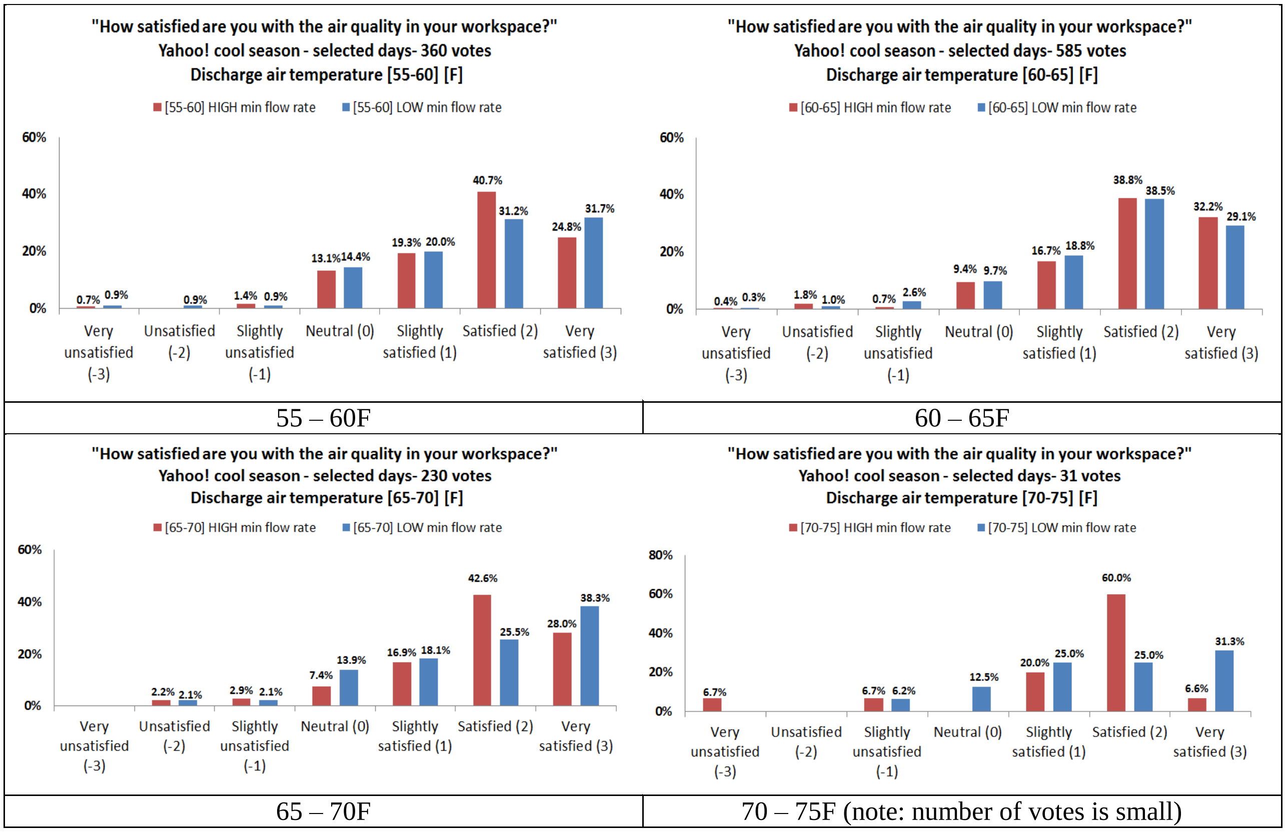
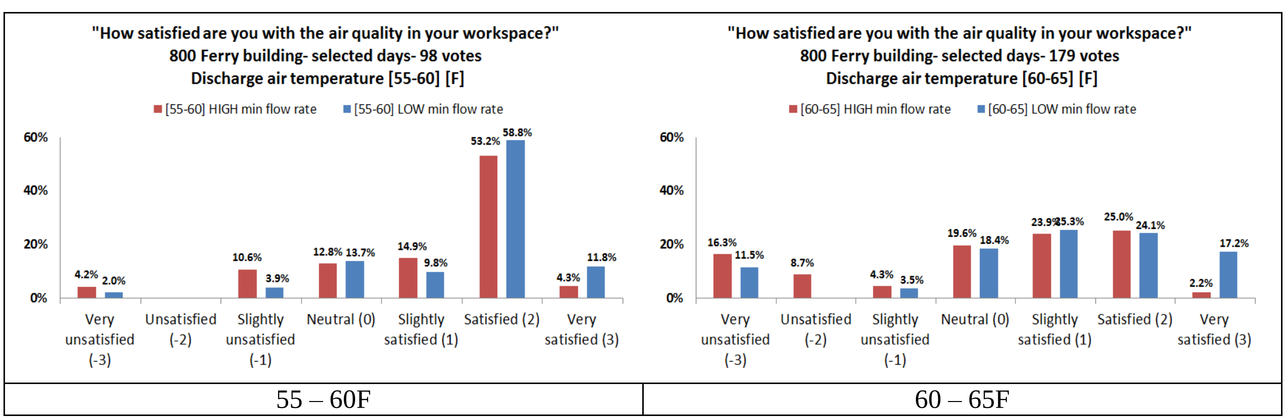
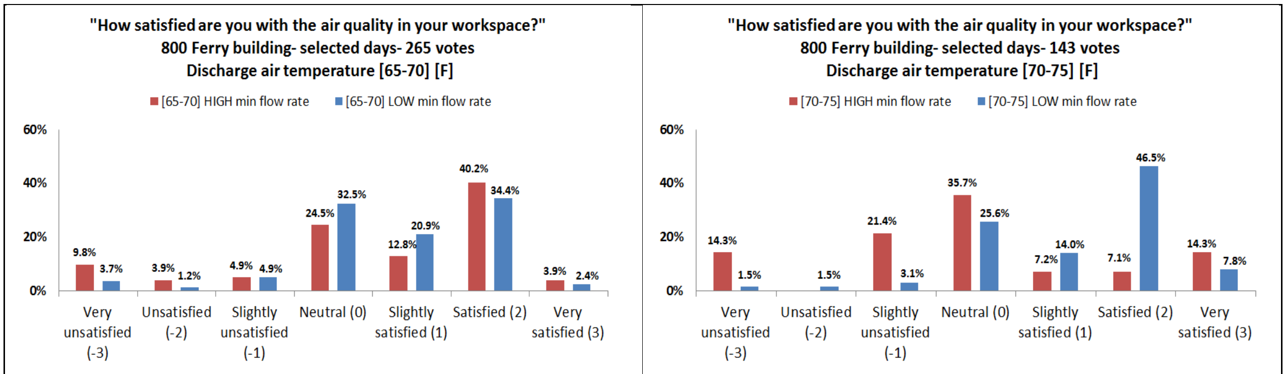


Figure E.2 Perceived air quality vs. discharge air temperature (Yahoo! cool)

Yahoo! Warm season	High (%)		Low (%)	
	un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	2.1	97.9	2.7	97.3
60 – 65F	2.9	97.1	3.9	96.1
65 – 70F	5.1	94.9	4.2	95.8

Table E.2 Satisfaction with perceived air quality under different supply air temperatures (Yahoo! warm)





65 – 70F	70 – 75F (note: number of votes is small)

Figure E.3 Perceived air quality vs. discharge air temperature (800 Ferry building)

Yahoo! Warm season	High (%)		Low (%)	
	un-satisfied	satisfied	un-satisfied	satisfied
55 – 60F	14.8	85.2	5.9	94.1
60 – 65F	29.3	70.7	15	65
65 – 70F	18.6	81.4	9.8	90.2
70 – 75F	35.7	64.3	6.1	93.9

Table E.3 Satisfaction with perceived air quality under different supply air temperatures (Yahoo! warm)

F. Sense of air movement vs. binned zone air temperature

Yahoo! Warm season

Zone temp. range (F)	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	no	little	moderate+strong
69.5 – 70.5	16	75.0	25.0	0.0	25.0	75.0	0.0	18.2	9.1	72.7
70.5 – 71.5	111	42.9	46.4	10.7	41.0	47.0	12.0	4.3	73.9	1.7
71.5 – 72.5	298	29.	43.4	27.0	38.4	41.9	19.7	52.4	33.3	19.7
72.5 – 73.5	437	48.0	40.8	11.2	40.8	49.1	10.1	81.3	6.3	12.5
73.5 – 74.5	206	58.4	36.6	5.0	65.5	27.4	7.1	38.0	36.6	25.4
74.5 – 75.5	51	56.5	39.1	4.4	58.3	25.0	16.7			

Yahoo Cool season

Zone temp. range (F)	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	no	little	moderate+strong
69.5 – 70.5	202	48.6	41.4	10.0	52.9	43.7	3.4	57.8	35.5	6.7
70.5 – 71.5	745	51.0	42.2	6.8	46.9	47.8	5.3	59.1	31.8	9.1
71.5 – 72.5	1456	54.2	41.1	19.7	53.6	42.1	4.3	13.3	56.7	30.0
72.5 – 73.5	1718	57.5	39.2	3.3	61.2	34.5	4.3	20.7	63.4	15.9
73.5 – 74.5	736	65.0	30.6	4.4	64.0	32.2	3.8	37.4	53.8	8.8
74.5 – 75.5	80	0	0	0.0	70.6	29.4	0.0	30.0	50.0	20.0

800 Ferry building

Zone temp. range (F)	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	no	little	moderate+strong
69.5 – 70.5	75	39.3	50.0	10.7	38.3	40.4	21.3			
70.5 – 71.5	81	48.7	43.6	7.7	33.3	50.0	16.7			
71.5 – 72.5	151	62.4	26.5	11.1	14.7	50.0	35.3			
72.5 – 73.5	79	42.1	49.1	8.8	18.2	72.7	9.1			
73.5 – 74.5	54	74.3	23.1	2.6	46.7	53.3	0.0			
74.5 – 75.5	124	54.3	37.9	7.8	54.3	38.1	4.6			

Table F.1 Air movement preference with flow rate for people whose workstation has a diffuser

G. Sense of air movement vs. binned discharge air temperature

For Yahoo! warm survey, when the discharge air temperature increased from 55 – 60F to 60 – 65F, the sense of air movement "moderate and strong" increased significantly at the lower flow rate (<30% and between 30% and 40%). We will not analyze the flow rate when it is >90%. The reason is that the number of votes are small for the flow rate >90% category. When binned the data based on discharge air temperatures, the number of responses are even smaller. For Yahoo! cool study, for three ranges of the discharge air temperatures (55 – 60F, 60 – 65F, 65 – 70F), the differences on the sense of air movement (moderate and strong) are very small. For the 800 Ferry building, as the discharge air temperature ranges increased, the sense of air movement as "moderate and strong) were significantly reduced.

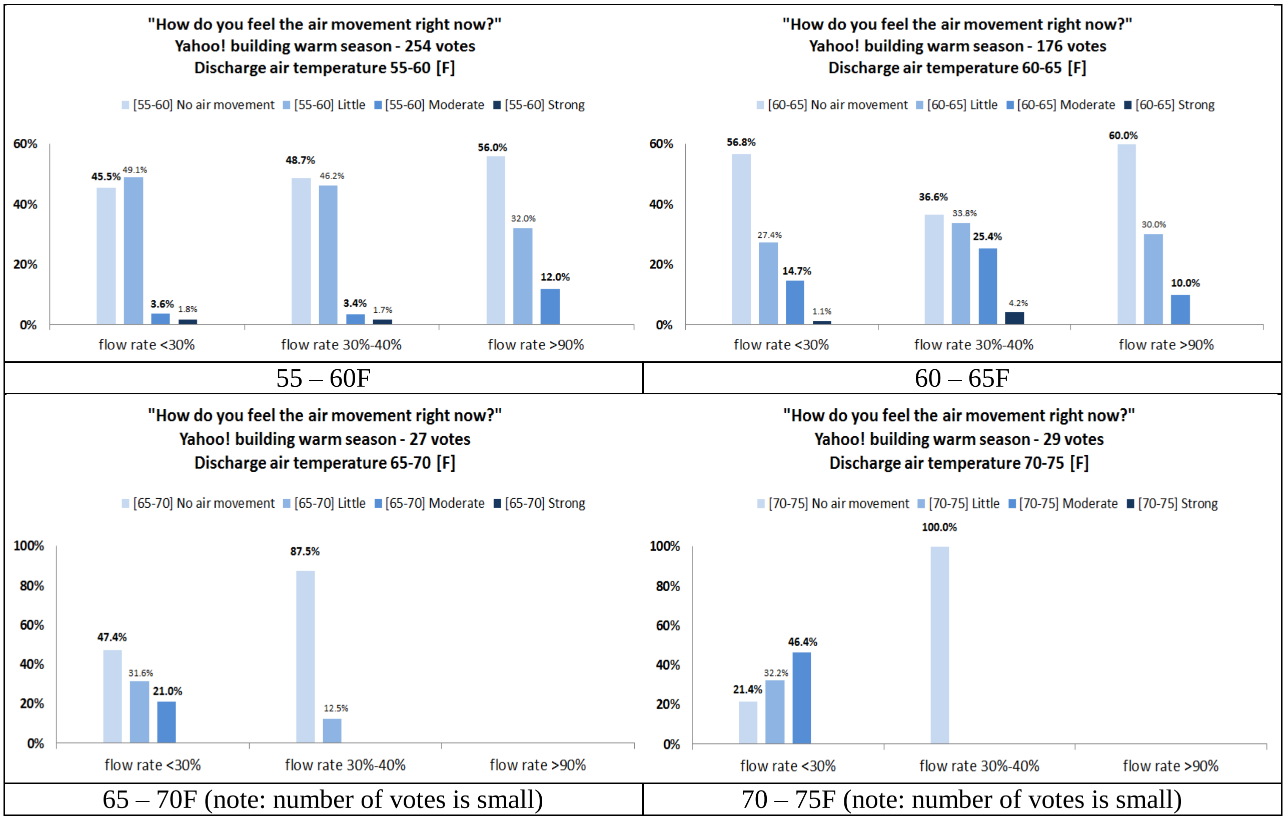


Figure G.1 "Sense of air movement" (Yahoo! warm)

Sense of air movement distribution (%)

Tdis range F	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	no	little	moderate+strong
55 – 60	256	45.5	49.1	5.4	48.7	46.2	5.1	56	32	12
60 – 65	176	56.8	27.4	15.8	36.6	33.8	29.6	60	30	10

Table G.1 Sense of air movement vs. discharge air temperature (Yahoo! warm)

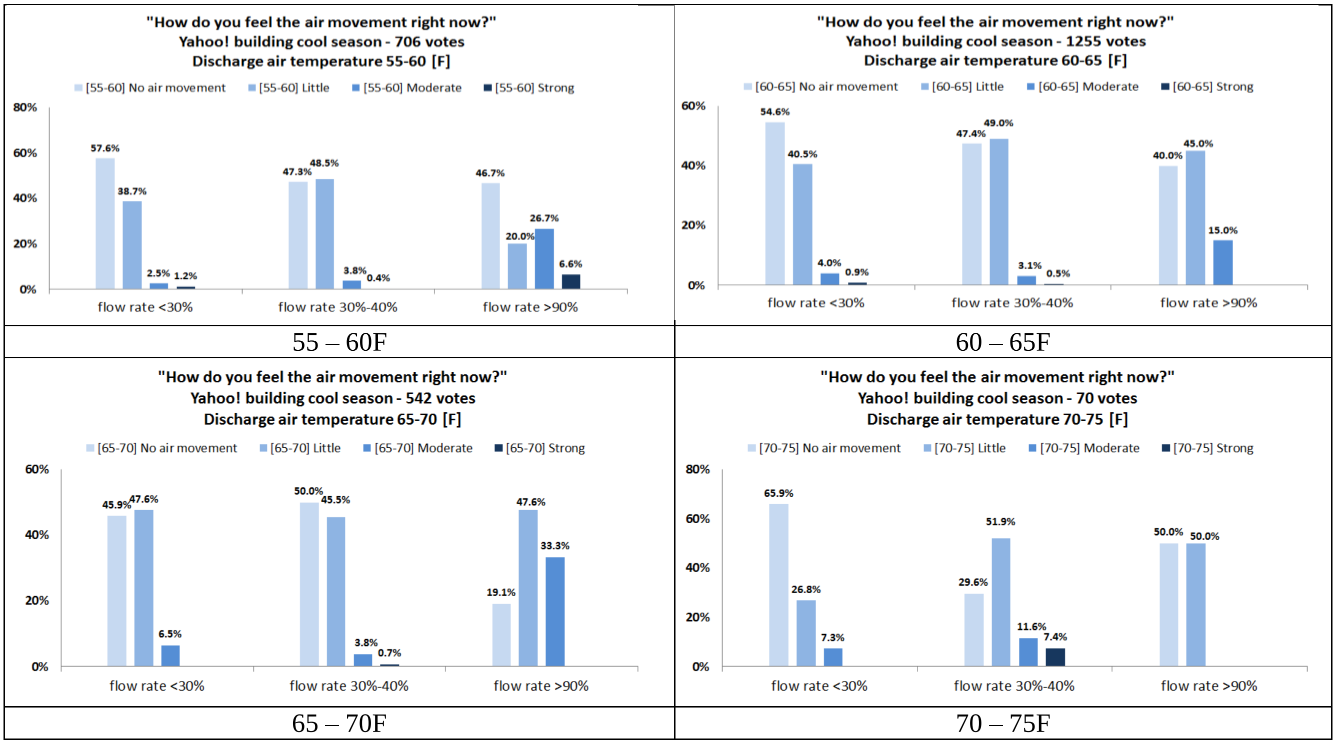
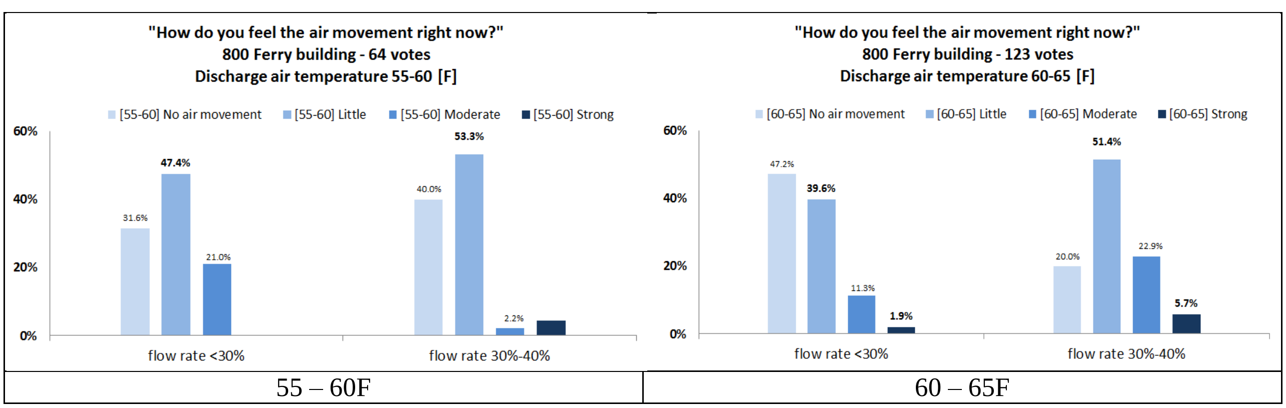
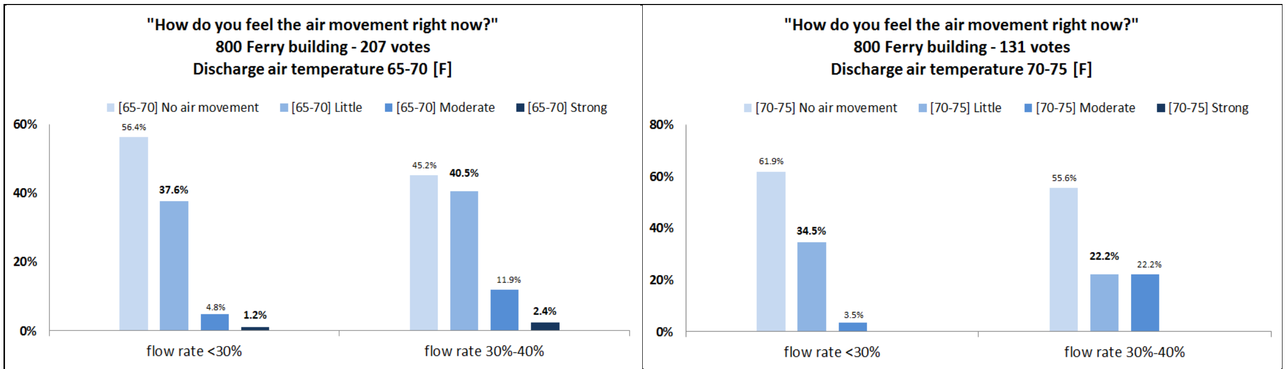


Figure G.2 "Sense of air movement" (Yahoo! cool)

Tdis range F	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	no	little	moderate+strong
55 – 60	706	57.6	38.7	3.7	47.3	48.5	4.2	46.7	20	33.3
60 – 65	1255	54.6	40.5	4.9	47.4	49	3.6	40	45	15
65 – 70	542	45.9	47.6	6.5	50	45.5	4.5	19.1	47.6	33.3

Table G.2 Sense of air movement vs. discharge air temperature (Yahoo! cool)





65 – 70F	70 – 75F

Figure G.3 "Sense of air movement" (800 Ferry)

Tdis range F	Total N	flow rate <30%			flow rate 30% - 40%			flow rate >90%		
		no	little	moderate+strong	no	little	moderate+strong	No	little	moderate+strong
60 – 65	123	47.2	39.6	13.2	20	51.4	28.6	0	0	0
65 – 70	207	56.4	37.6	6	45.2	40.5	14.3	0	0	0
70 – 75	131	61.9	34.5	3.5	55.6	22.2	22.2	0	0	0

Table G.3 Sense of air movement vs. discharge air temperature (800 Ferry building)

H. Price Industries test results

H.1 Air Distribution Summary Report

RESEARCH CENTER NORTH

LABORATORY TEST REPORT

638 Raleigh Street • Winnipeg, Manitoba • R3K 2Z9 • Canada

ASHRAE RP 1515 – (SDS 100 – RCDE – 520 Grille Diffuser – PDF - PDN)

Lab File Number X112

Introduction

In this research, we analyzed in detail the Air Diffusion Performance Index (ADPI) values for 6 different diffusers. Specifically, we studied each of the following Diffusers: Square Plaque Diffuser (SPD), Perforated Face Ceiling Diffuser with the pattern controller inside the face (PDF), Perforated Face Ceiling Diffuser With pattern controller inside the neck (PDN), Linear Slot Diffuser with plenum (SDB), High Side Wall Grille (520 Grille), Round Cone Diffuser (RCD).

In order to perform this analysis, we employed load simulators in strategic positions to achieve the loads required to represent the work space. The Air flows for each diffuser were strictly dependent on the loads and vice versa, and were modified as necessary (i.e. load simulators were added or removed to meet the load required for a specific air flow). We performed our experiment by using load capacities of 80%, 30%, and 13 %, as requested. Furthermore, with the purpose of attaining accurate readings; we created a coordinate system that covered all cardinal points. Essentially, two planes were created to represent the directions described in Figure 1. Moreover, our controllers were set so that we could analyze five different airflows at 2 different supplied temperatures 55°F and 65°F. We placed all equipment on each coordinate manually and run our software to obtain data. Next, we proceeded to take Velocity and Temperature measurements at four different heights; 4in, 24in, 42in and 66in. As a result from correlating all our data, we were able to obtain temperature draft, and velocity plots. Also, all temperature and velocity readings were averaged over 3 minutes to provide accurate measurements. Finally, we made use of smoke testing with the purpose of ensuring that the diffusers' air pattern was within agreement standards.

Test Setup

ROOM DIMENSION 20 X 15 X 9

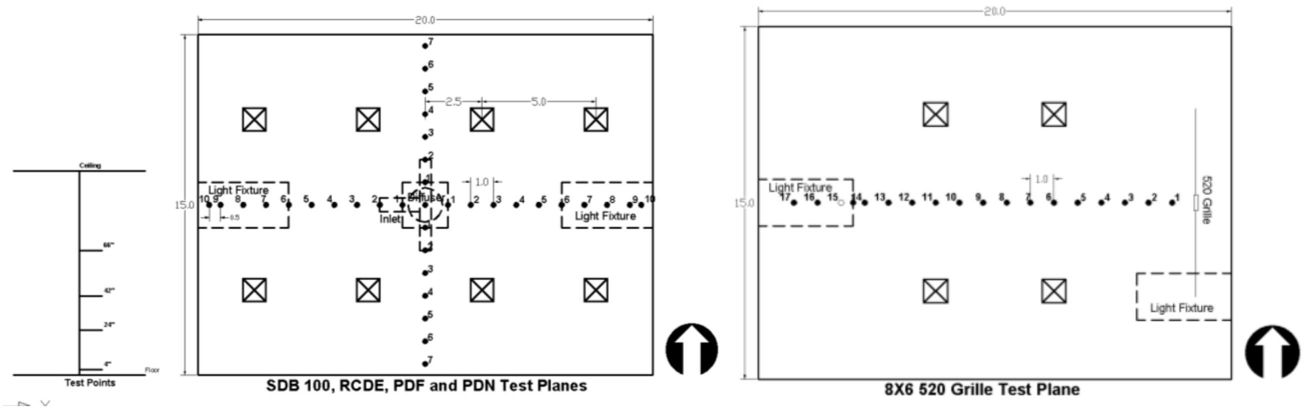
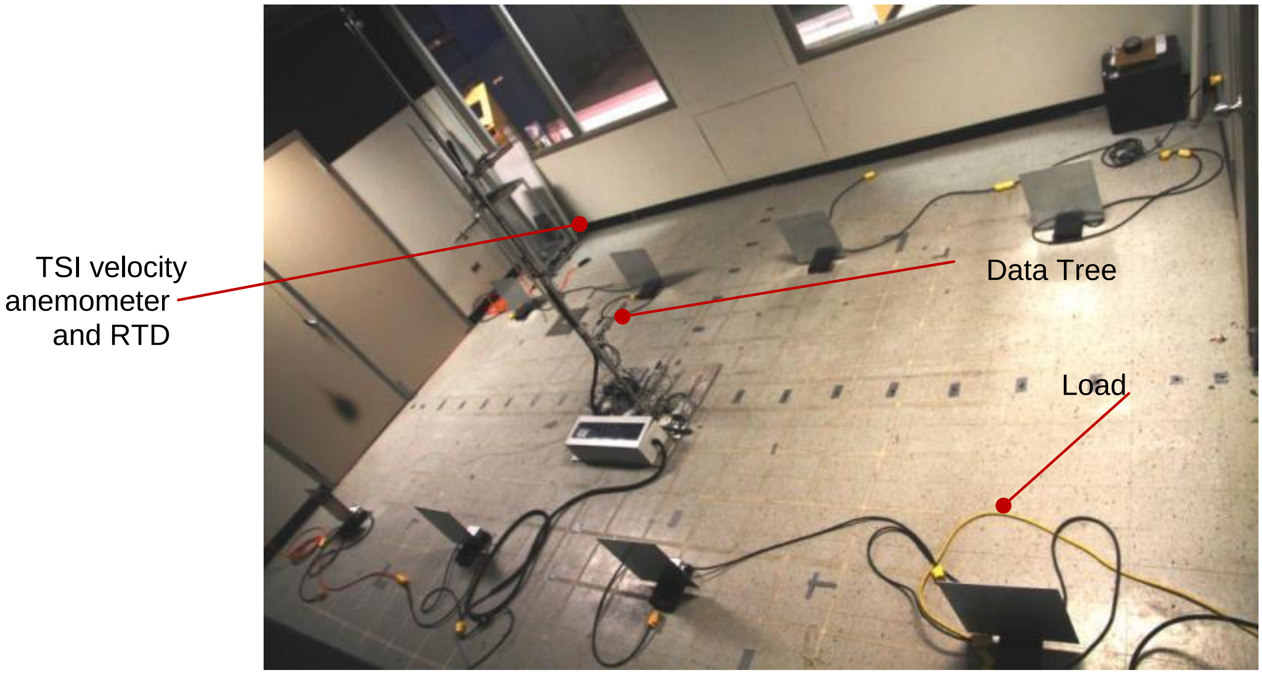
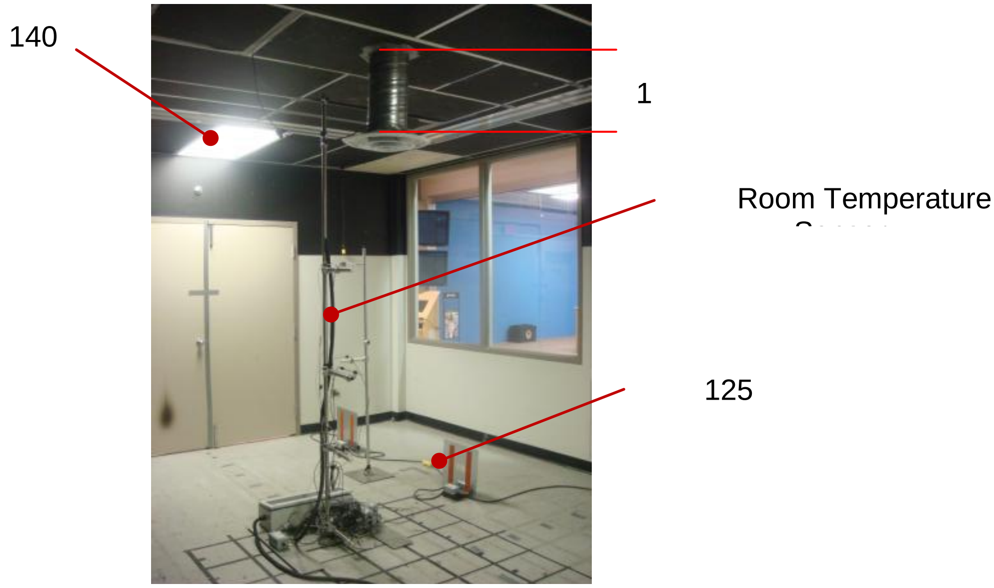


Figure 1: Measurement Points @4", 24", 42" and 66" height





8Ø RCDE Test Setup

8Ø RCDE Smoke pattern

48” SDB100 2 way Smoke pattern

8x6 520 Grille Test Setup

8x6 520 Grille Smoke pattern

Test Equipments

8.1.1

8.1.2 *Measurement Tree*

The measurement tree configuration and sensor heights are shown in Figure 1.

8.1.3 *Measurement Error*

TSI Model 8475 (velocity): $\pm 3\%$ Reading + $\pm 1\%$ Full Scale
RTD Probe: ± 0.7 °F (± 0.4°C)

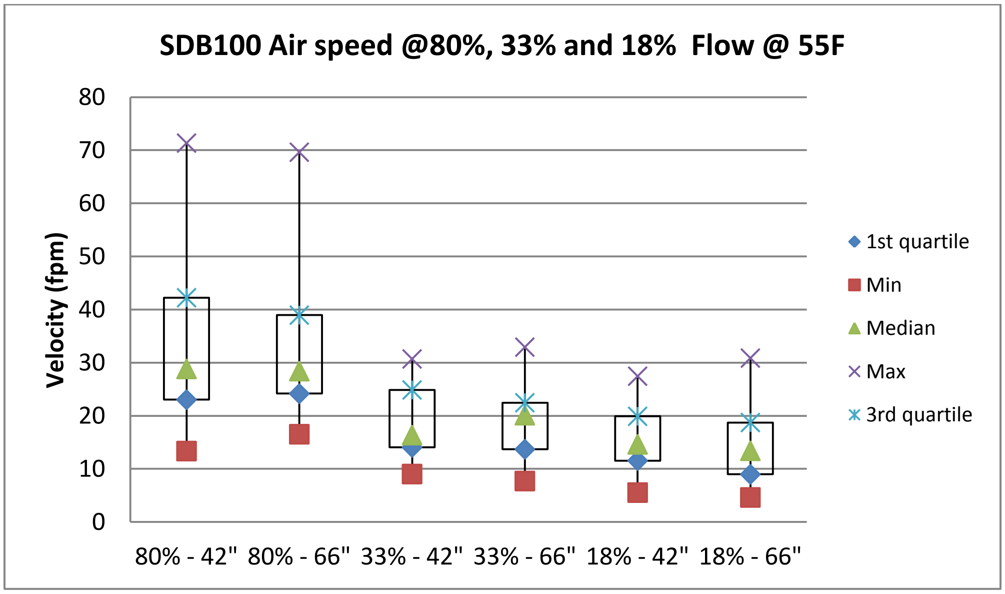
8.1.4 *Data Logging*

All readings were recorded every 30 seconds through the use of a data logger exporting data to an Excel spreadsheet. The measurement equipment added 10 Watts of loading to the room.

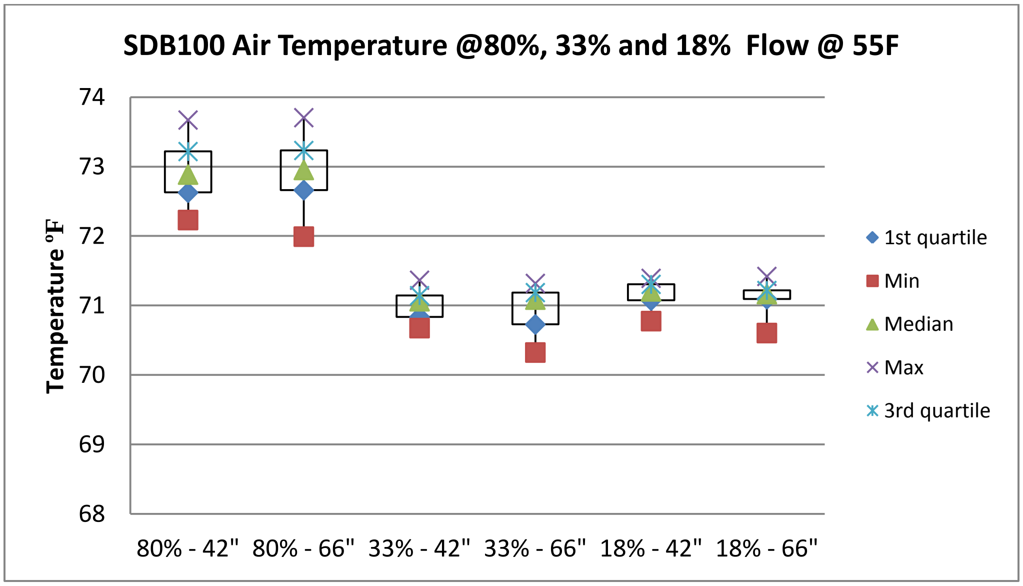
Test Results

SDB100 48" 2 way diffuser

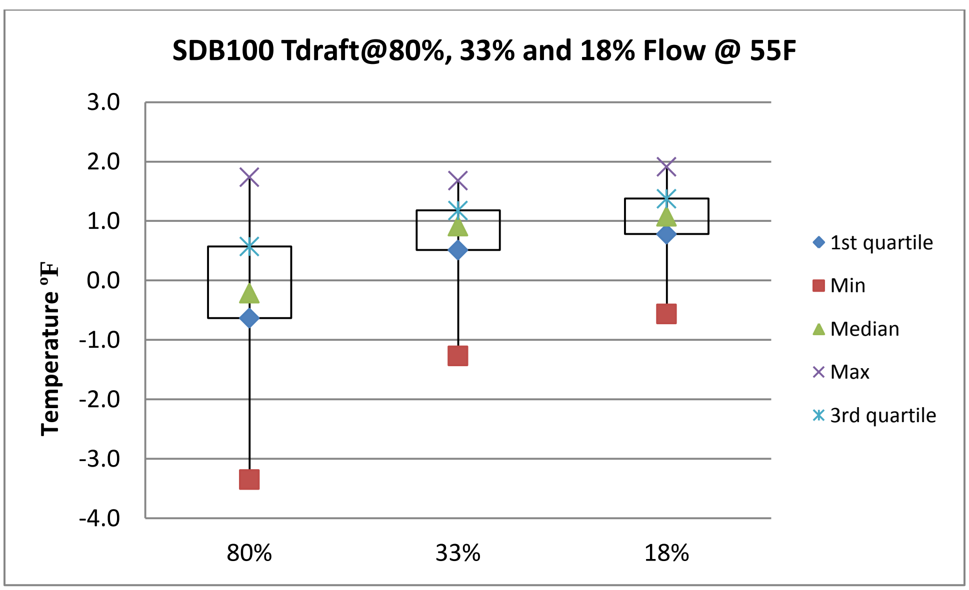
Diff user	Size (in. x in)	Ran ge (cfm)	Supply Air Volume (cfm)	% Design	Suppl y Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
SDB 100	48" 2 SLOT 7"Ø	100 -340	239	80%	55	72	300	1290
			100	33%	55	72	300	540
			55	18%	55	72	300	290
SDB 100	48" 2 SLOT 7"Ø	100 -340	239	80%	65	72	300	540
			100	33%	65	72	300	275
			55	18%	65	72	300	135



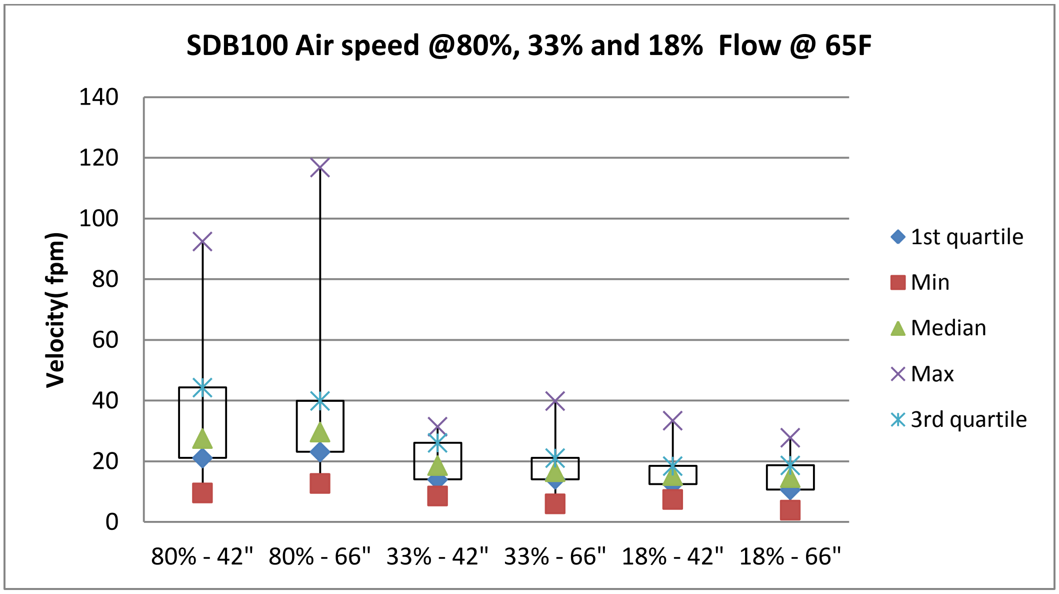
Velocity vs. Flow Rate @ 42" and 66" Height



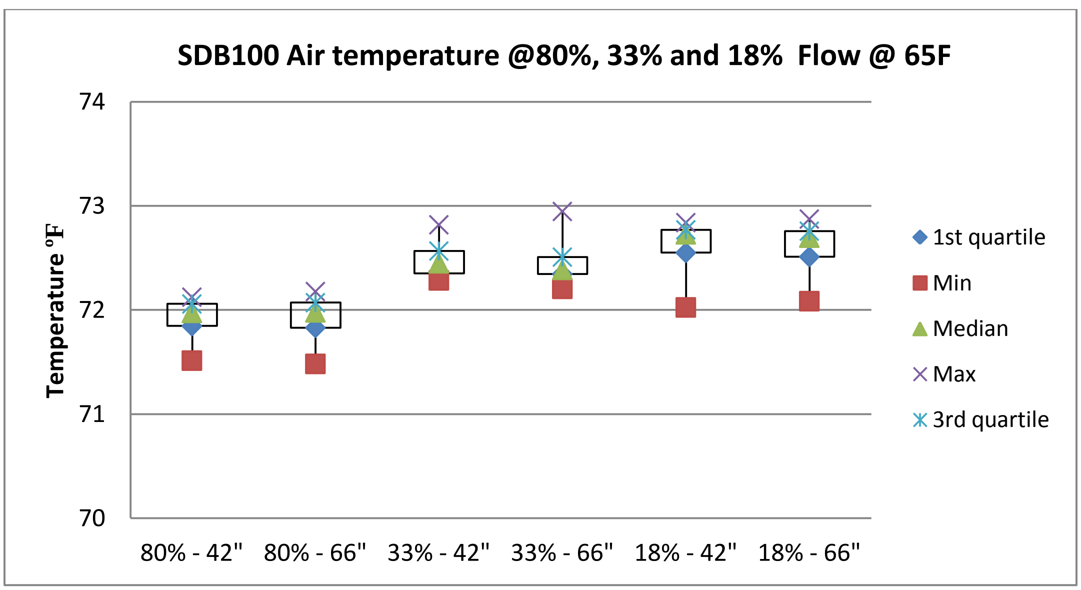
Temperature vs. Flow Rate @ 42" and 66" Height



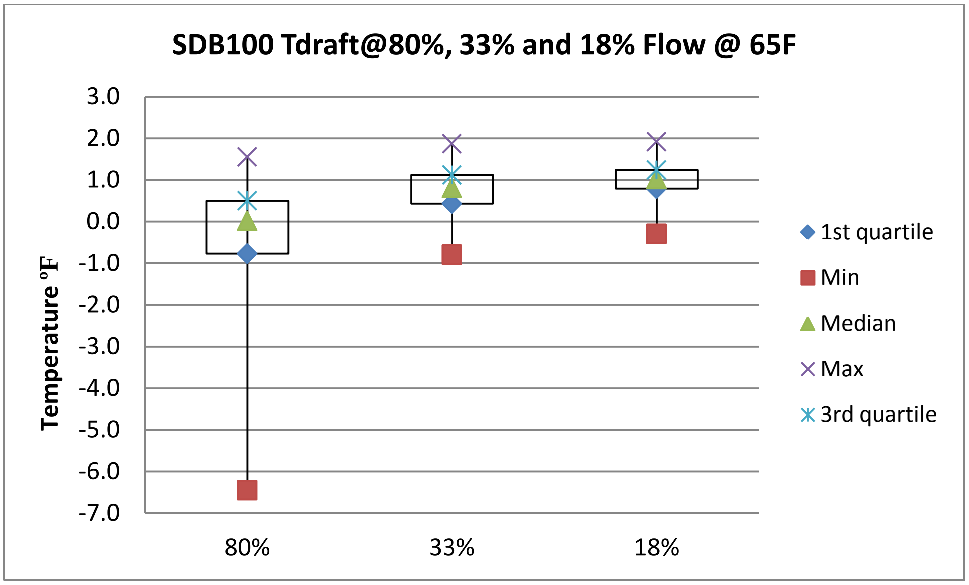
Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

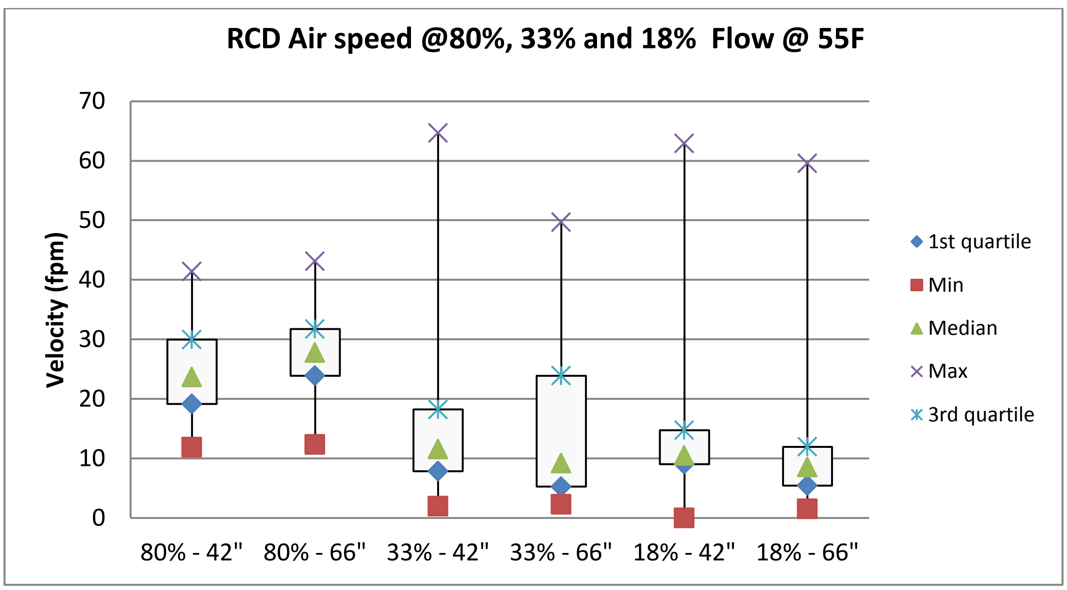
SDB100 48" 2 way diffuser - Air Diffusion Performance Index

	55°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2
Average Room Temp (Tr)	73	73	72	72	71	71	72	72	72	72
Average Test Temp (Tac)	73	73	72	72	71	71	72	71	71	71
Average Velocity	32	33	26	26	16	21	19	19	14	16
ADPI	98		100		100		100		100	

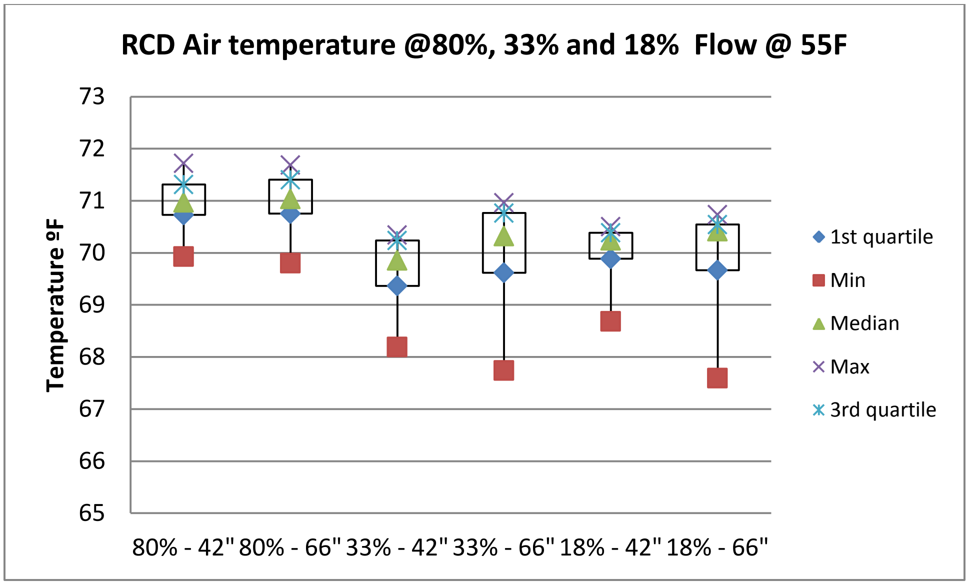
	65°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2
Average Room Temp (Tr)	72	72	72	72	73	73	72	72	72	72
Average Test Temp (Tac)	72	72	72	72	72	72	72	72	71	71
Average Velocity	35	33	22	22	20	19	17	17	14	16
ADPI	98		99		100		100		100	

RCD (Exposed) Diffuser

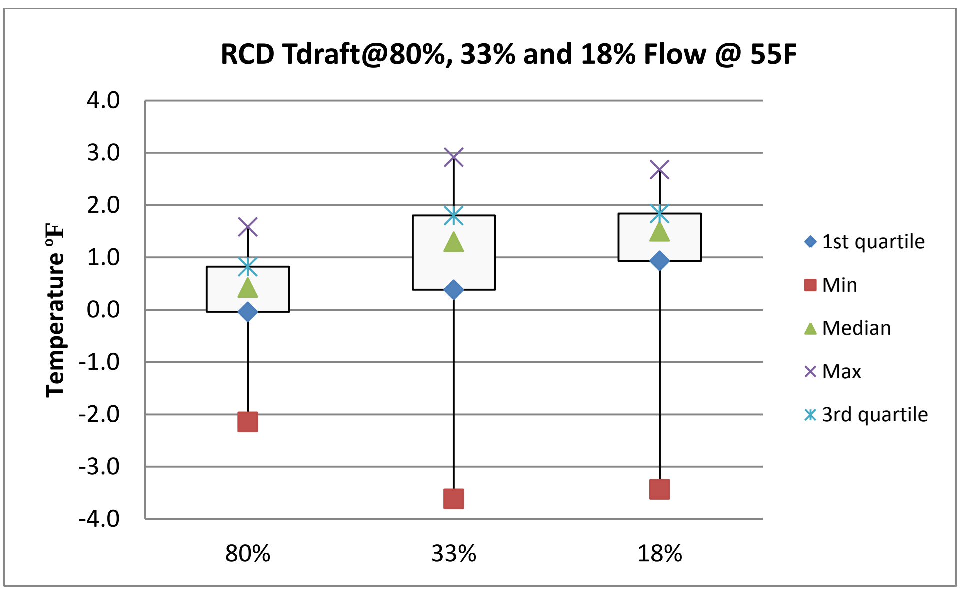
Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
RCD (Exposed)	8"Ø	140 -560	239	80%	55	72	300	1290
			100	33%	55	72	300	540
			55	18%	55	72	300	290
RCD (Exposed)	8"Ø	140 -560	239	80%	65	72	300	540
			100	33%	65	72	300	275
			55	18%	65	72	300	135



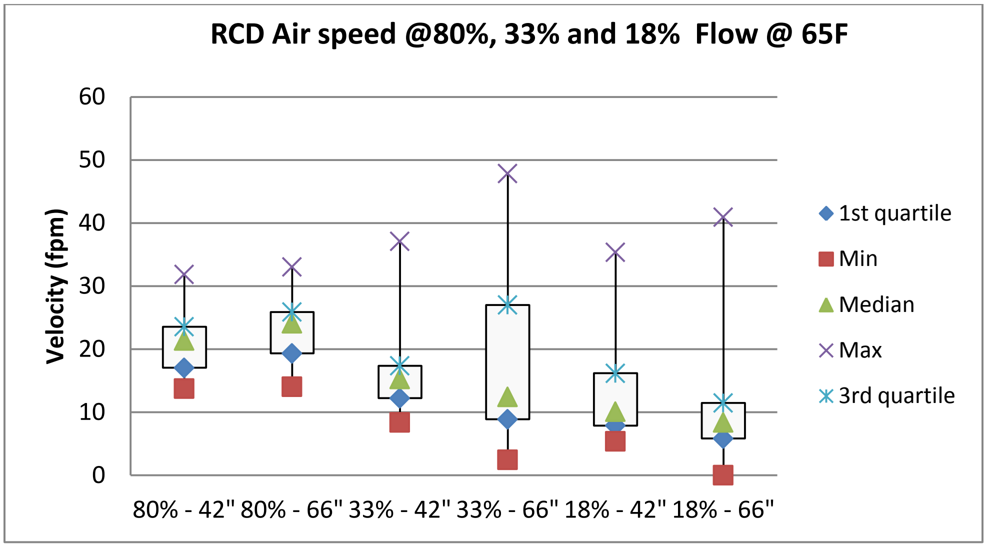
Velocity vs. Flow Rate @ 42" and 66" Height



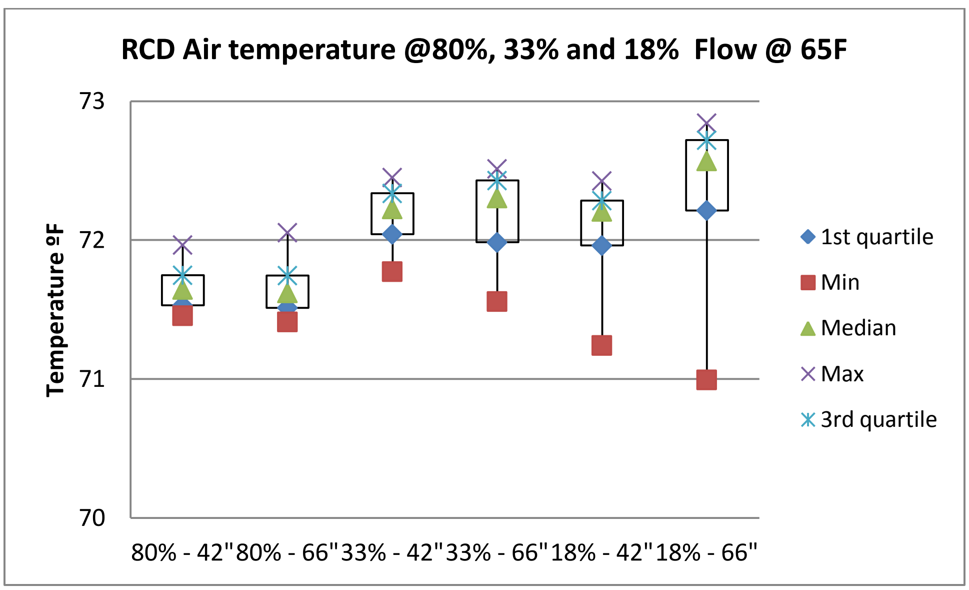
Temperature vs. Flow Rate @ 42" and 66" Height



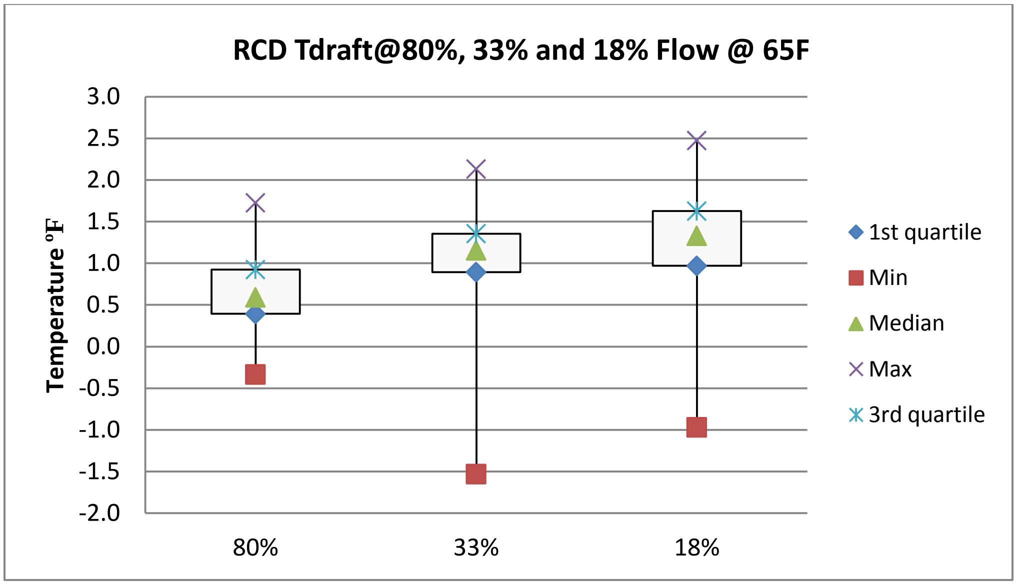
Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height



Velocity vs. Flow Rate @ 42” and 66” Height



Temperature vs. Flow Rate @ 42” and 66” Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

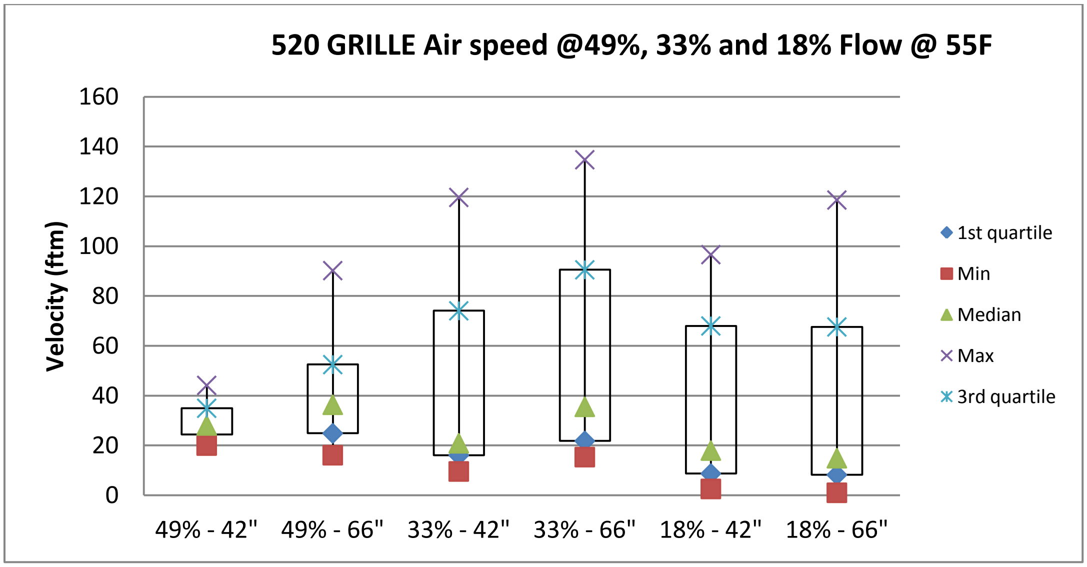
RCD (Exposed) Diffuser - Air Diffusion Performance Index

	55°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2
Average Room Temp (Tr)	71	72	70	71	70	70	71	71	71	71
Average Test Temp (Tac)	71	71	70	70	69	70	70	70	70	70
Average Velocity	26	25	25	18	20	16	20	15	15	16
ADPI	100		89		78		77		78	

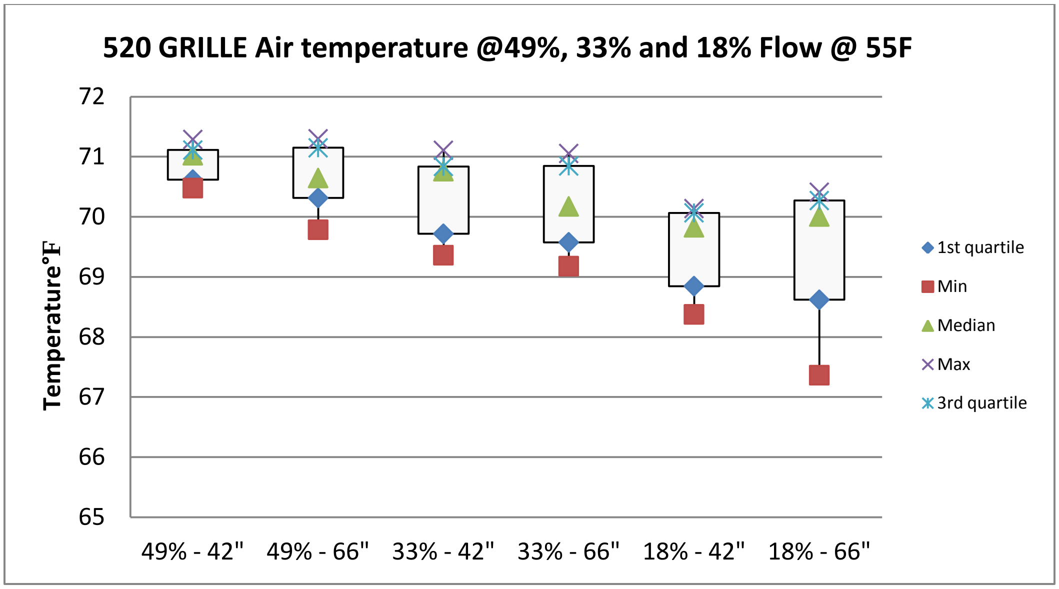
	65°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2	Pl ane 1	Pl ane 2
Average Room Temp (Tr)	72	72	71	71	72	72	71	71	73	73
Average Test Temp (Tac)	72	72	71	71	72	72	71	71	73	73
Average Velocity	21	21	17	17	16	15	17	16	13	13
ADPI	100		100		98		100		99	

520 Grille Diffuser

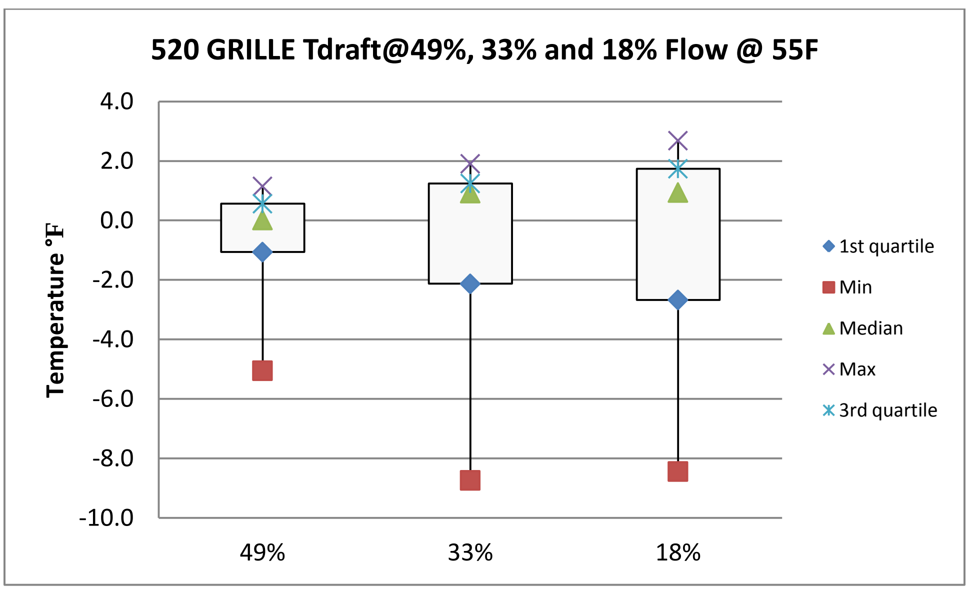
Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
520 grille	8 x 6	80-470	146	49%	55	72	300	790
			100	33%	55	72	300	540
			55	18%	55	72	300	290
520 grille	8 x 6	80-470	146	49%	65	72	300	290
			100	33%	65	72	300	275
			55	18%	65	72	300	135



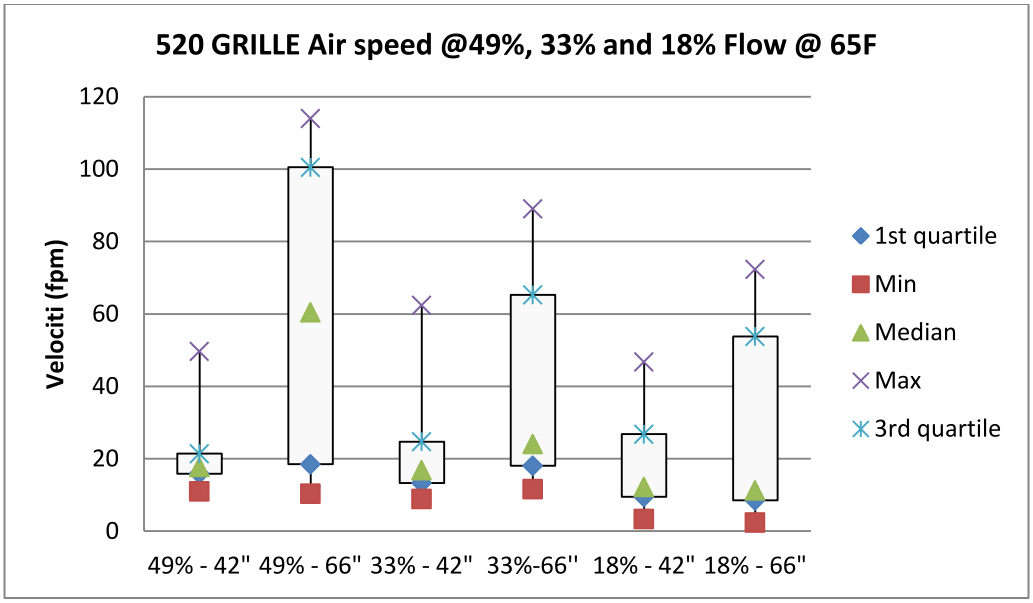
Velocity vs. Flow Rate @ 42" and 66" Height



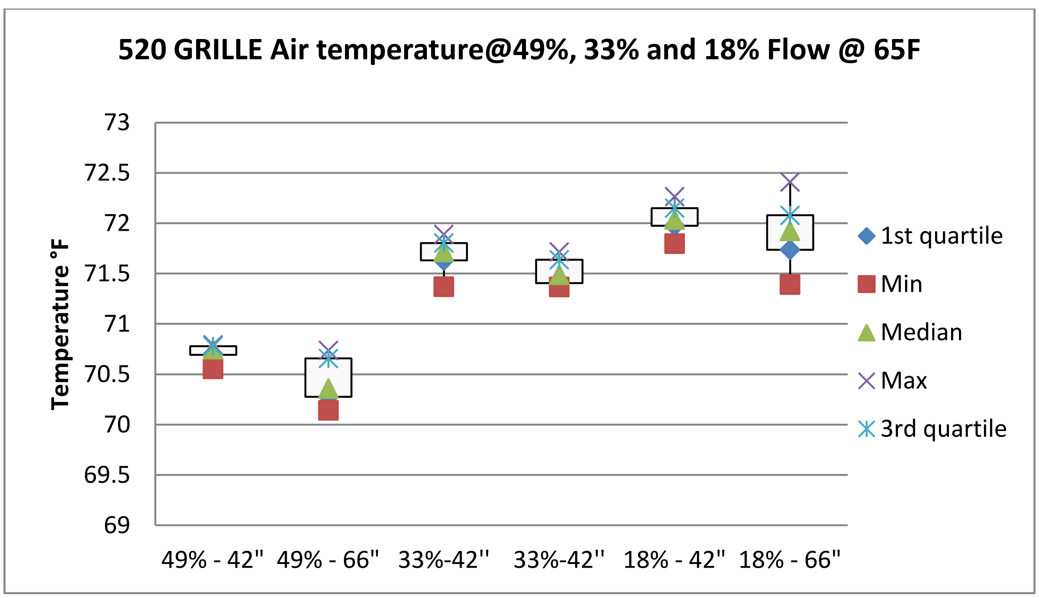
Temperature vs. Flow Rate @ 42" and 66" Height



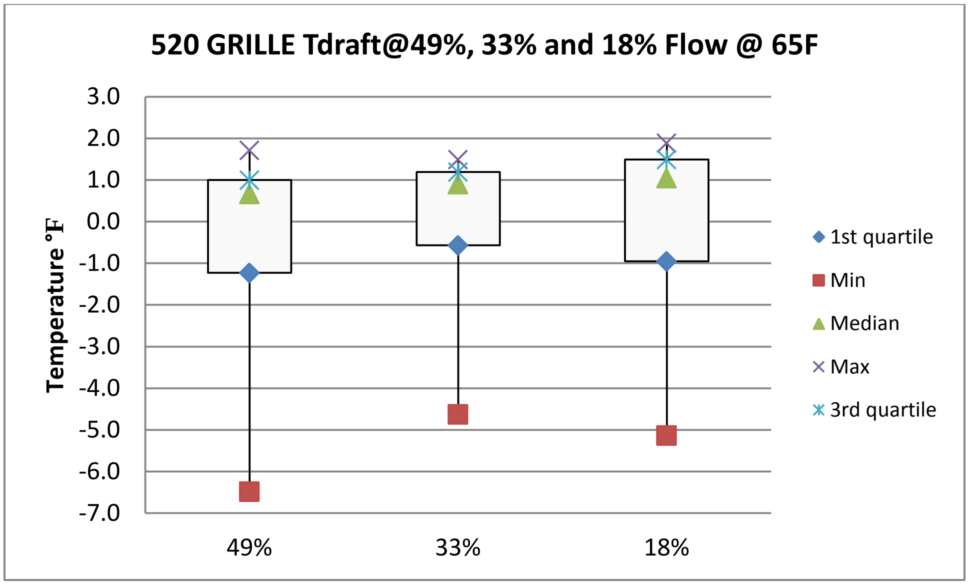
Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

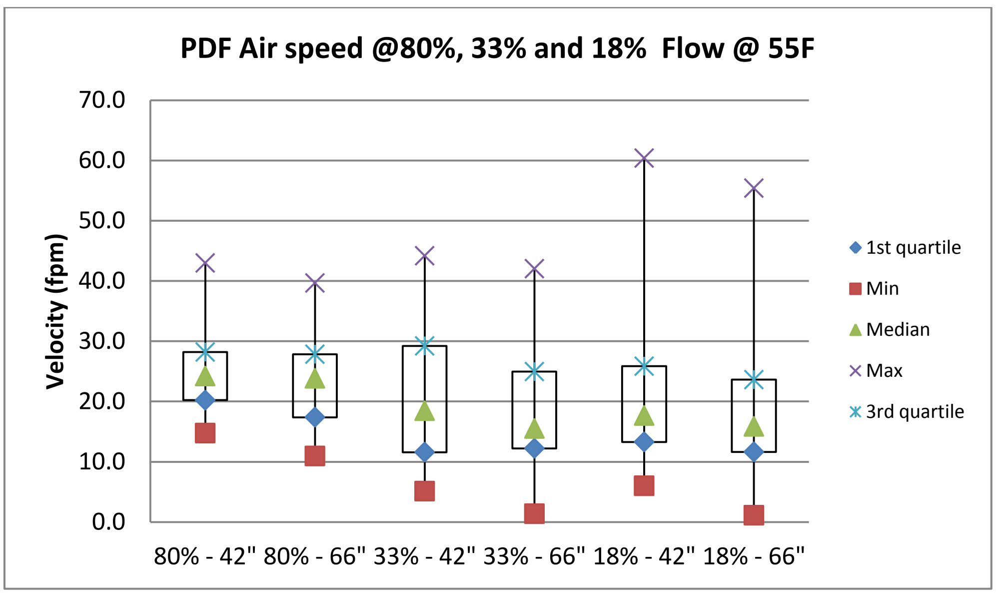
520 Grille - Air Diffusion Performance Index

	55°F			
	146 cfm	100 cfm	77 cfm	55 cfm
	Plane 1	Plane 1	Plane 1	Plane 1
Average Room Temp (Tr)	71	71	70	70
Average Test Temp (Tac)	71	70	70	69
Average Velocity	35	39	30	34
ADPI	93	82	85	60

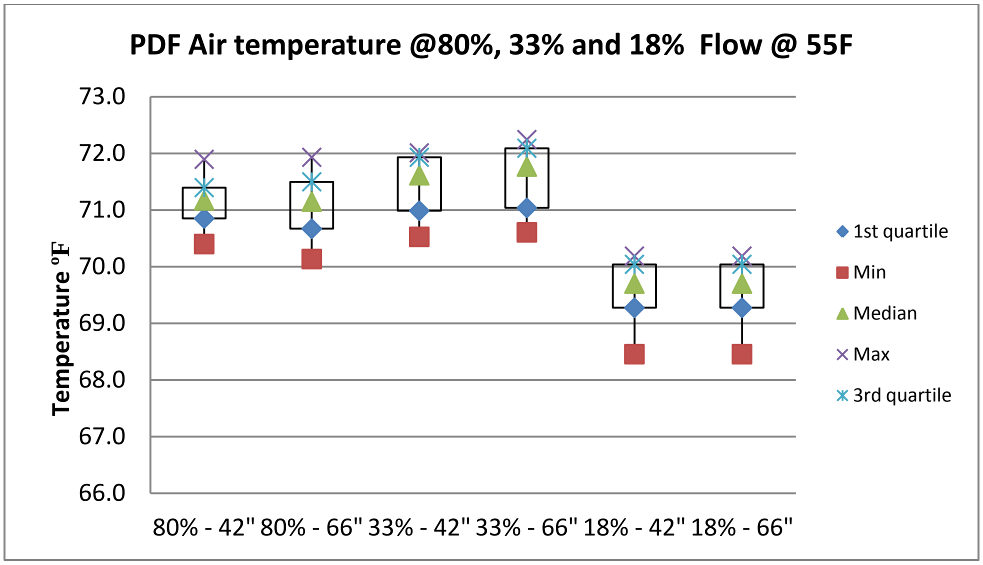
	65°F			
	146 cfm	100 cfm	77 cfm	55 cfm
	Plane 1	Plane 1	Plane 1	Plane 1
Average Room Temp (Tr)	71	72	71	72
Average Test Temp (Tac)	71	72	71	72
Average Velocity	35	27	27	19
ADPI	87	94	91	96

PDF 24X24 Diffuser

Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
PDF	24 x 24 8"Ø	105 -489	239	80%	55	72	300	1290
			100	33%	55	72	300	540
			55	18%	55	72	300	290
PDF	24 x 24 8"Ø	105 -489	239	80%	65	72	300	540
			100	33%	65	72	300	275
			55	18%	65	72	300	135



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height

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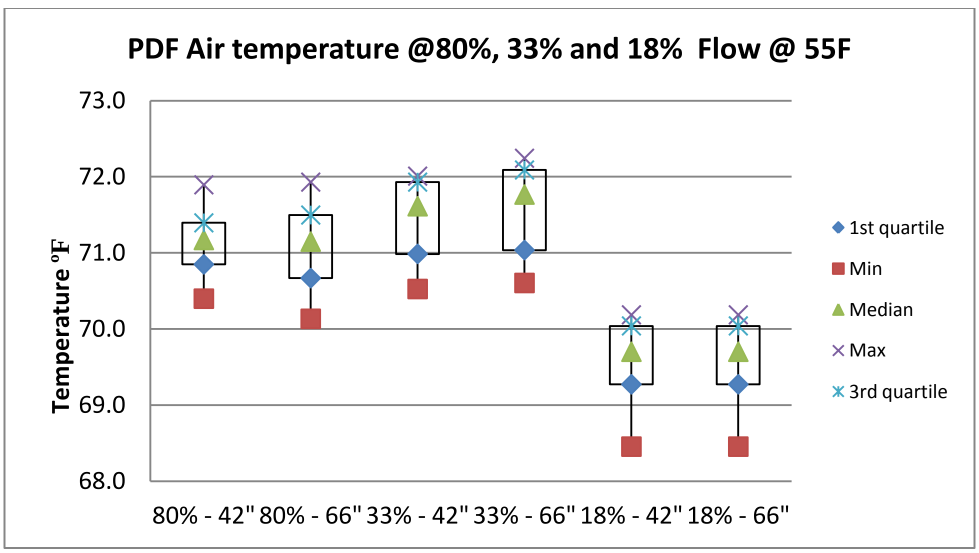
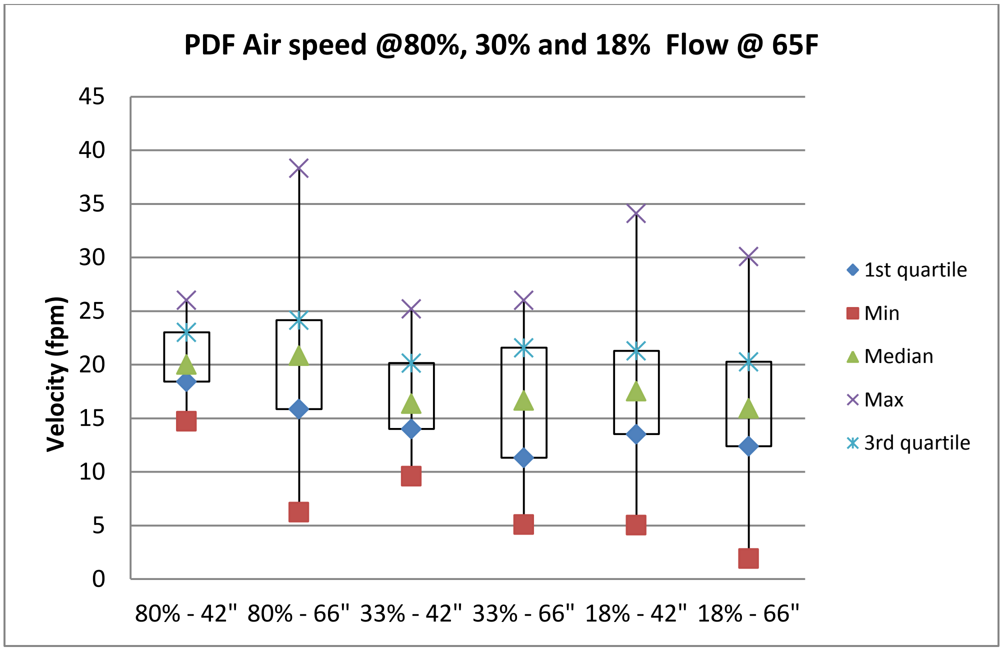
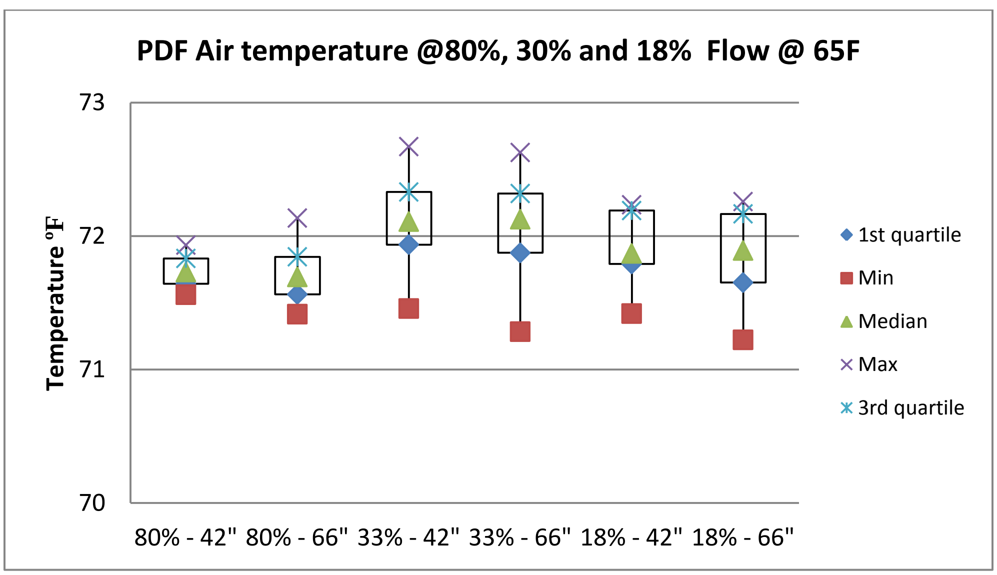


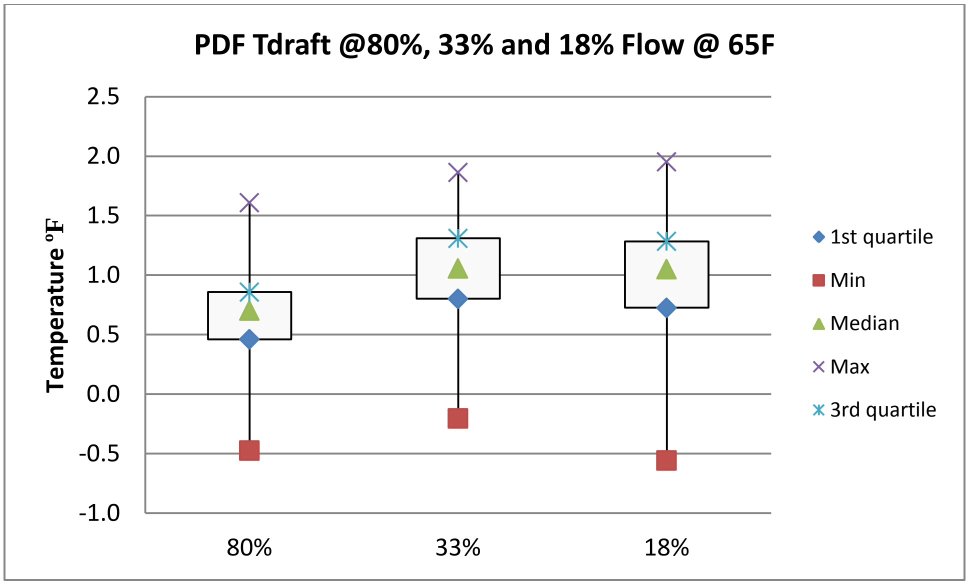
Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

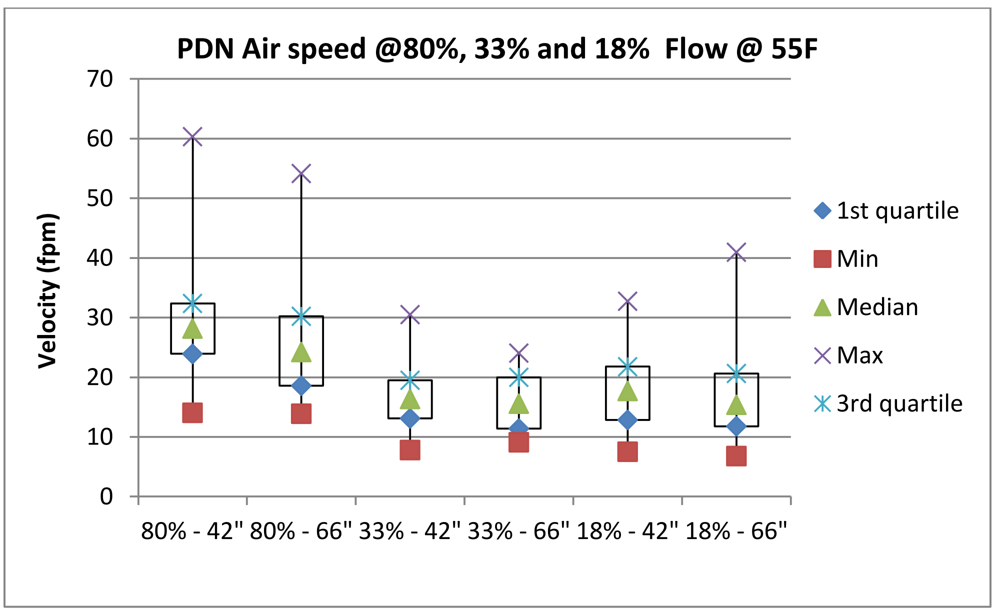
PDF 24X24 Diffuser - Air Diffusion Performance Index

	55°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2
Average Room Temp (Tr)	72	72	72	72	72	72	72	72	70	70
Average Test Temp (Tac)	71	71	71	71	71	72	72	72	69	70
Average Velocity	25	23	21	18	21	17	19	17	22	17
ADPI	100		99		99		99		98	

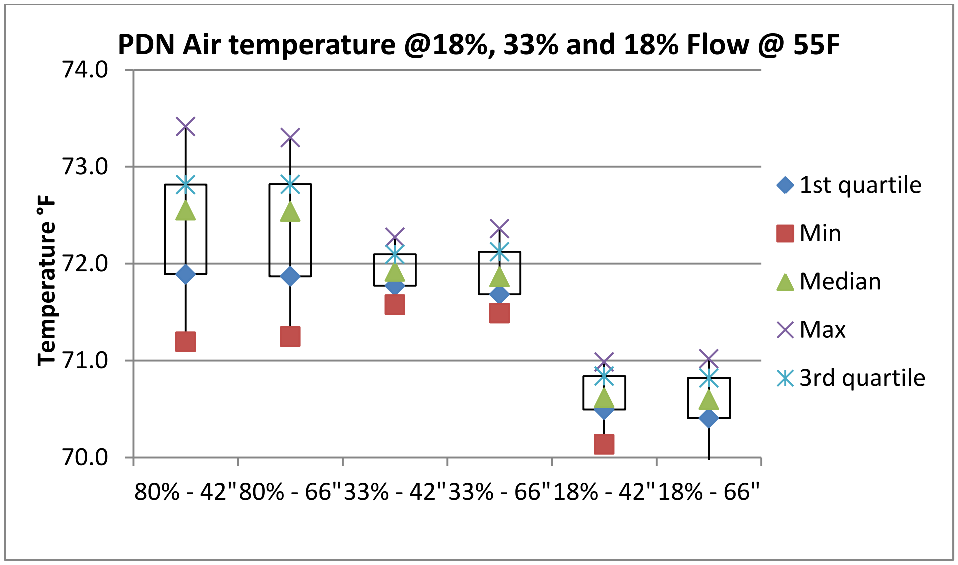
	65°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2
Average Room Temp (Tr)	72	72	72	72	72	73	72	72	72	72
Average Test Temp (Tac)	72	72	71	72	72	72	72	72	72	72
Average Velocity	21	20	16	14	15	16	16	14	16	16
ADPI	100		100		100		100		100	

PDN 24X24 Diffuser

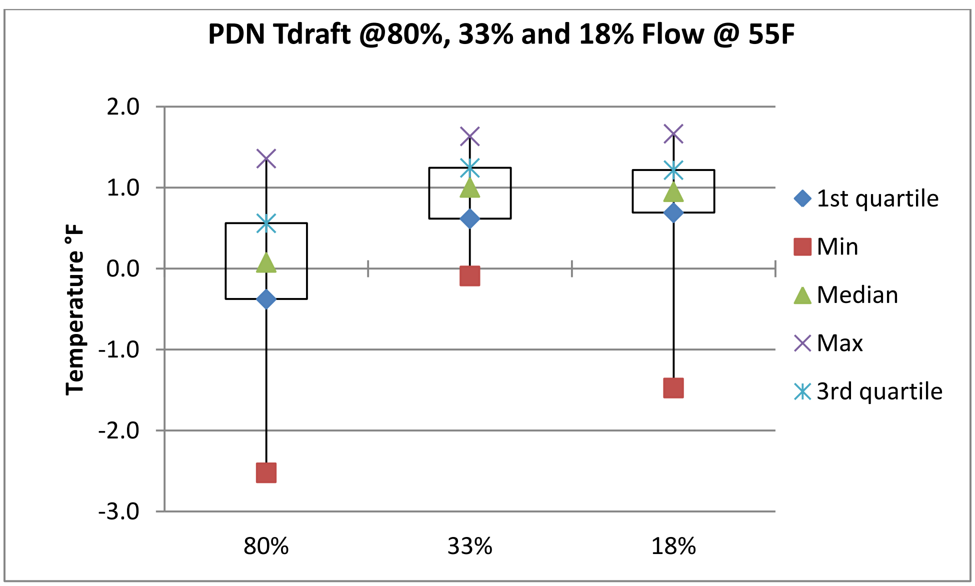
Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
PDN	24 x 24 8"Ø	105-489	239	80%	55	72	300	1290
			100	33%	55	72	300	540
			55	18%	55	72	300	290
PDN	24 x 24 8"Ø	105-489	239	80%	65	72	300	540
			100	33%	65	72	300	275
			55	18%	65	72	300	135



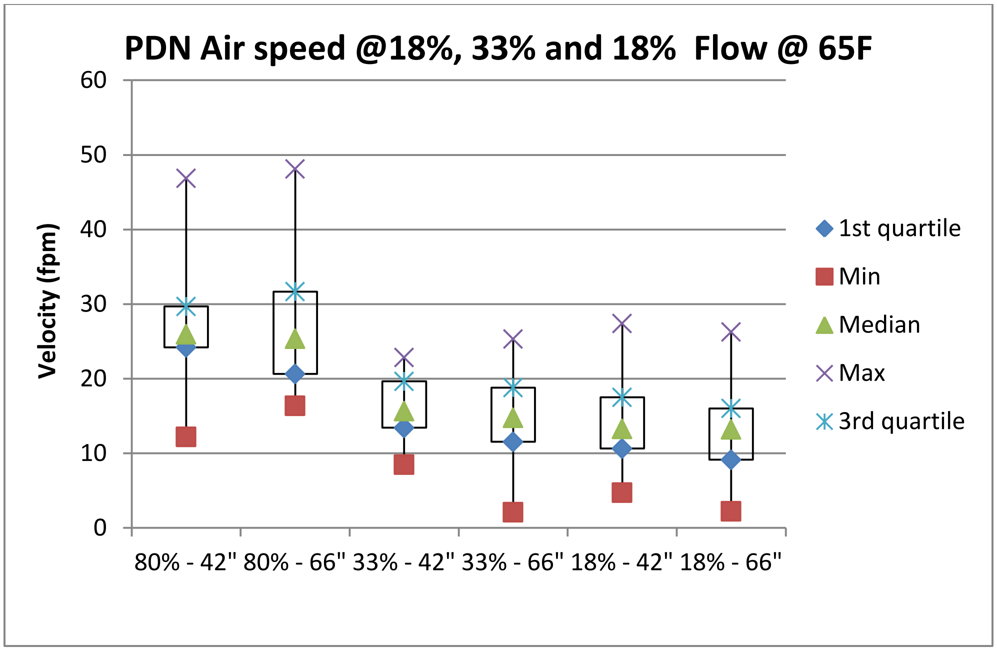
Velocity vs. Flow Rate @ 42" and 66" Height



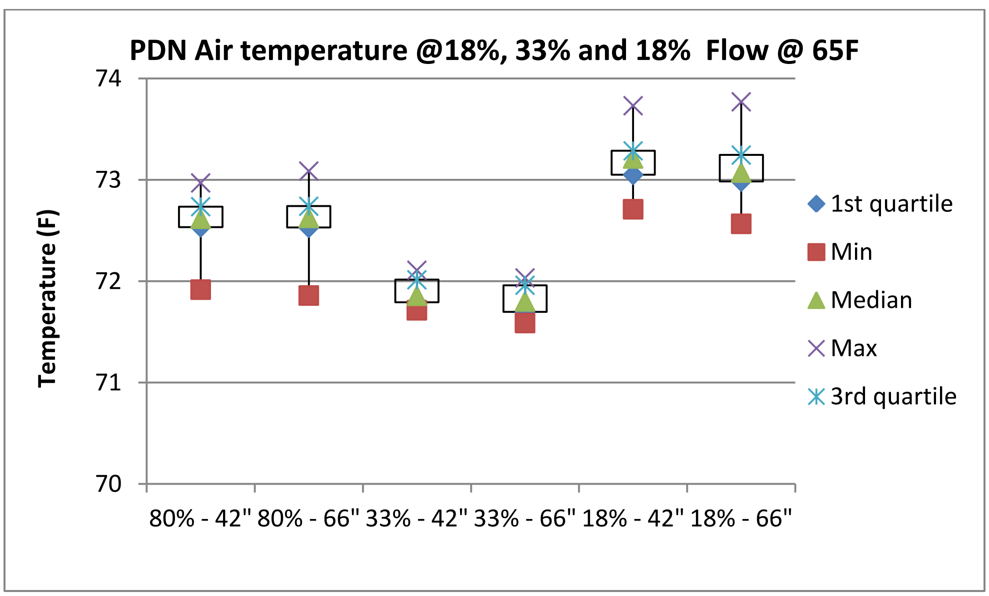
Temperature vs. Flow Rate @ 42” and 66” Height



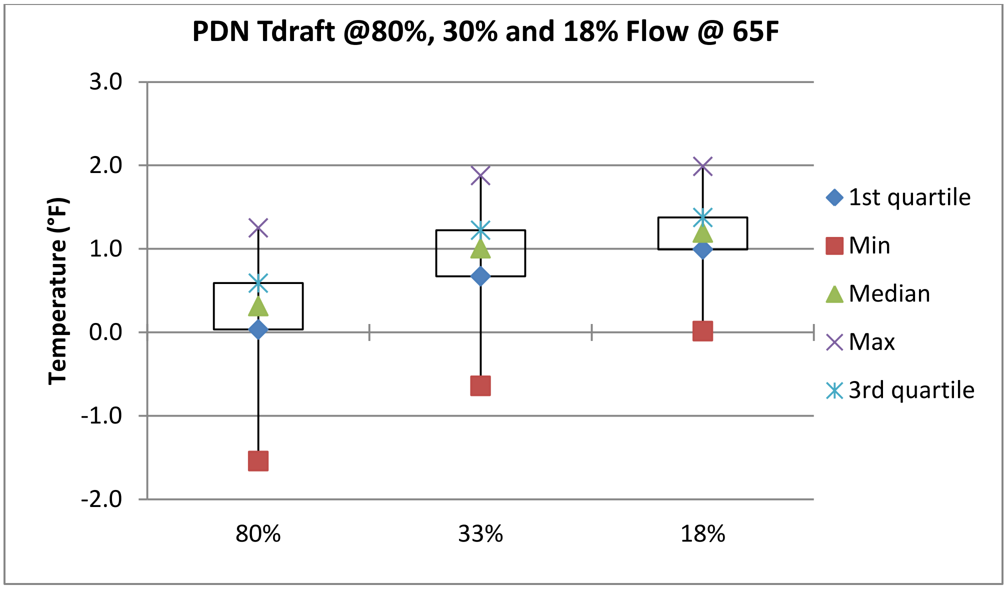
Draft Temperature vs. Flow Rate @ 4”, 24”, 42” and 66” Height



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

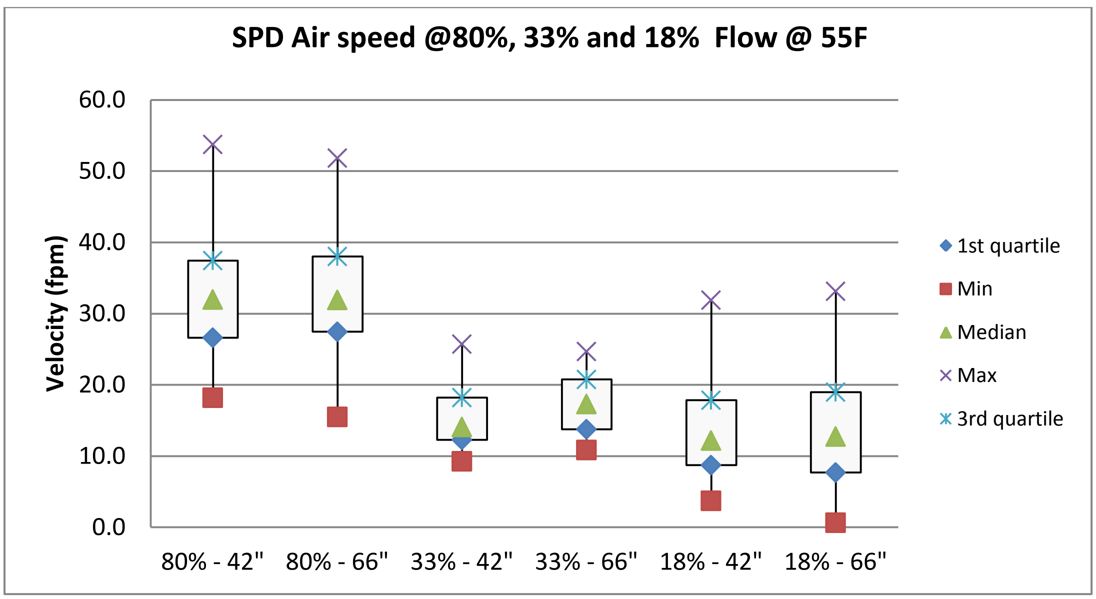
PDN 24X24 Diffuser - Air Diffusion Performance Index

	55°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2
Average Room Temp (Tr)	72	73	72	72	72	72	72	72	71	71
Average Test Temp (Tac)	72	73	72	72	72	72	71	72	70	71
Average Velocity	29	31	22	19	17	16	15	14	20	15
ADPI	100		99		100		99		100	

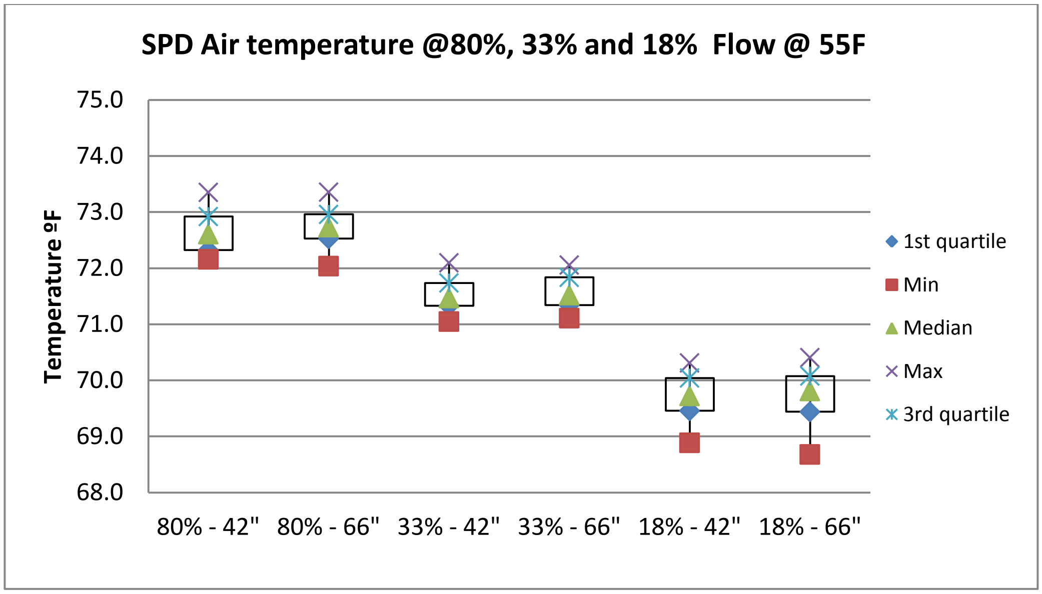
	65°F									
	239 cfm		146 cfm		100 cfm		77 cfm		55 cfm	
	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2	Plane 1	Plane 2
Average Room Temp (Tr)	73	73	72	72	72	72	71	71	73	73
Average Test Temp (Tac)	72	73	72	72	72	72	71	71	73	73
Average Velocity	26	26	16	18	18	17	17	16	13	14
ADPI	100		100		100		100		99	

SPD 24X24 Diffuser

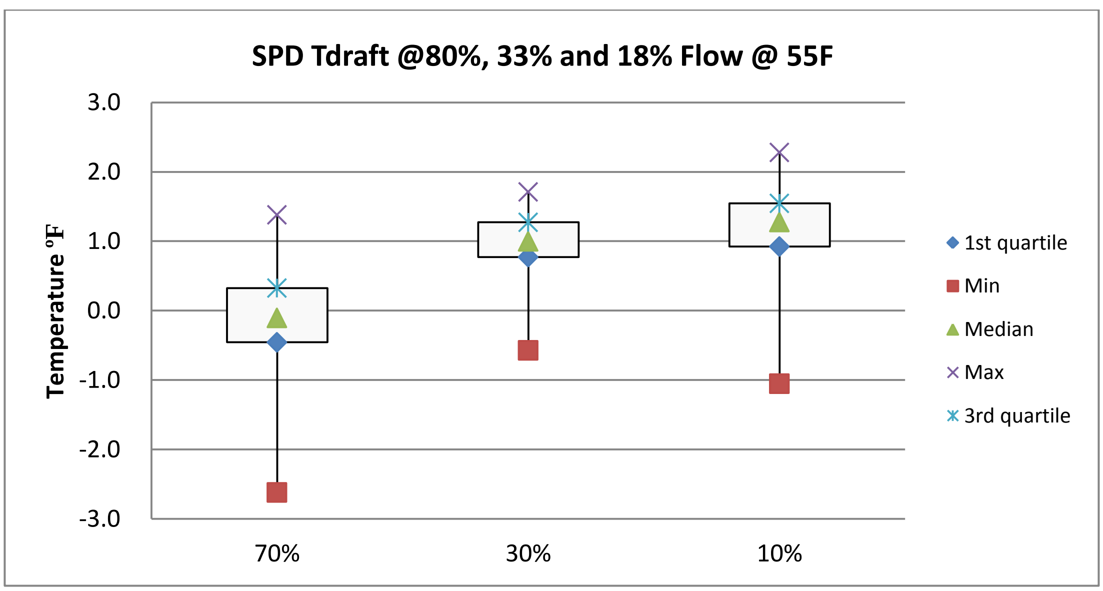
Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Area (ft²)	Load (Watts)
SPD	24 x 24 8"Ø	140 -550	239	80%	55	72	300	1290
			100	33%	55	72	300	540
			55	18%	55	72	300	290
SPD	24 x 24 8"Ø	140 -550	239	80%	65	72	300	540
			100	33%	65	72	300	275
			55	18%	65	72	300	135



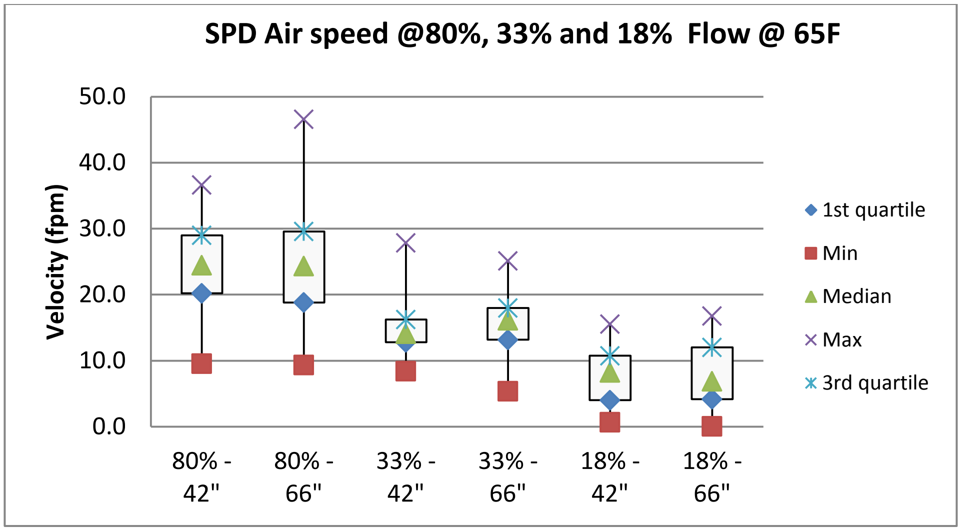
Velocity vs. Flow Rate @ 42" and 66" Height



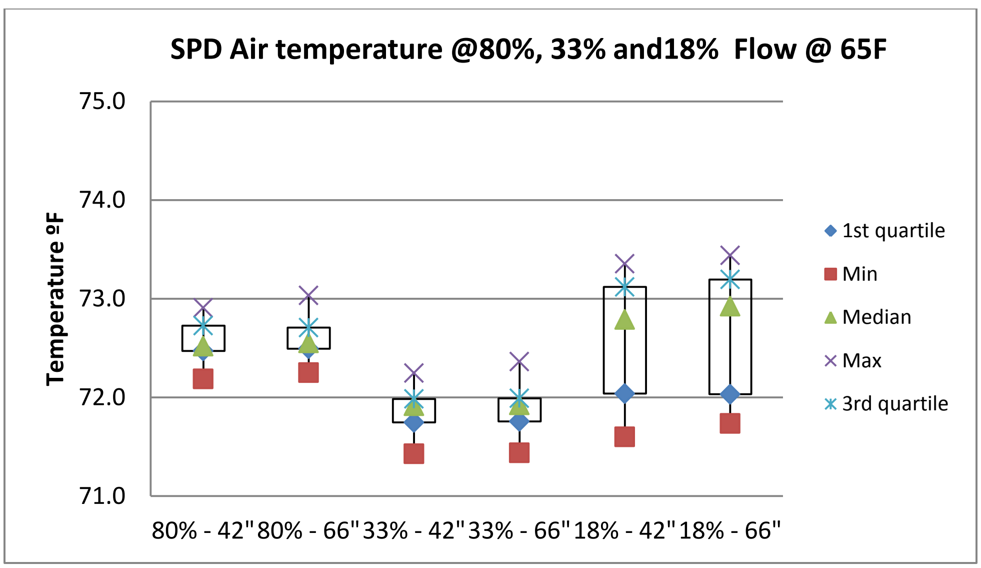
Temperature vs. Flow Rate @ 42" and 66" Height



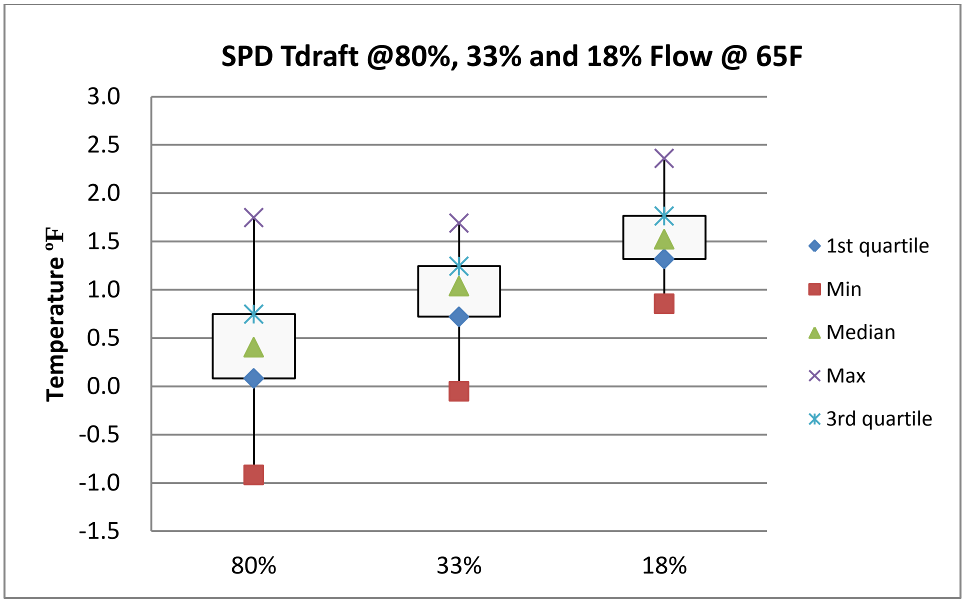
Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height



Velocity vs. Flow Rate @ 42" and 66" Height



Temperature vs. Flow Rate @ 42" and 66" Height



Draft Temperature vs. Flow Rate @ 4", 24", 42" and 66" Height

SPD 24X24 Diffuser - Air Diffusion Performance Index

	55°F					
	239 cfm		100 cfm		55 cfm	
	Plan e 1	Plan e 2	Plan e 1	Plan e 2	Plan e 1	Plan e 2
Average Room Temp (Tr)	73	73	72	72	70	70
Average Test Temp (Tac)	72	73	72	71	69	70
Average Velocity	31	33	16	15	16	13
Air Diffusion Performance Index	100		100		98	

	65°F					
	239 cfm		100 cfm		55 cfm	
	Plan e 1	Plan e 2	Plan e 1	Plan e 2	Plan e 1	Plan e 2
Average Room Temp (Tr)	72	73	72	72	73	72
Average Test Temp (Tac)	73	73	72	72	73	72
Average Velocity	24	25	18	15	9	7
Air Diffusion Performance Index	100		100		93	

Discussion

Inside this report, we analyzed the ADPI values at low flow rates (80%, 33%, and 10%) for six different diffusers. We observed that the temperature variations inside the room decreased the ADPI considerably at low flow rates. In fact, two diffusers were influenced so that the ADPI was not acceptable i.e. (ADPI<80), the RCD and 520 Grille. ADPI values as low as 77 and 73 respectively. Note that due to test equipment constraints, we could only reach a flow as low as 18%.

The ADPI value decrease only occurred when the supply temperature was as low as (55 °F). At (65°F) supply temperature the majority of the diffusers did not show change on their respective Air Diffusion Performance Index values. For PDN, PDF, SDB and SPD these values remained close to a 100. The 520Grille showed the lowest ADPI value of 60, making it the less likely to match the desired requirements of comfort. In conclusion, we foresee that the best candidates to operate at desired behavior are the PDF, PDN, SBD and SPD.

Lab technician: Michael Lim

H.2 Air Distribution Detailed Report with raw data

PRICE RESEARCH CENTER NORTH

LABORATORY TEST REPORT

638 Raleigh Street • Winnipeg, Manitoba • R3K 2Z9 • Canada

ASHRAE RP 1515 – (SDS 100 – RCDE – 520 Grille Diffuser – PDF – PDN-SPD)

Lab File Number X112

Test Setup

ROOM DIMENSION 20 X 15 X 9

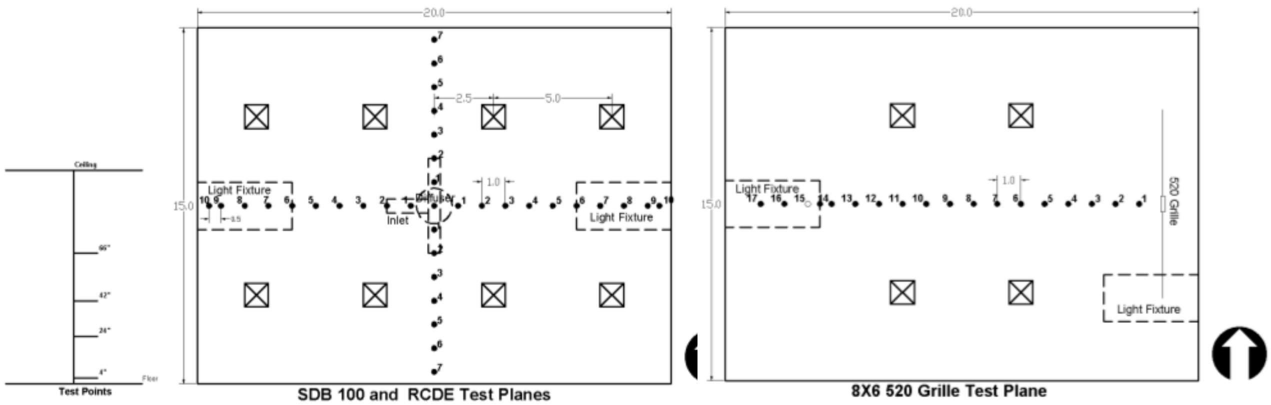
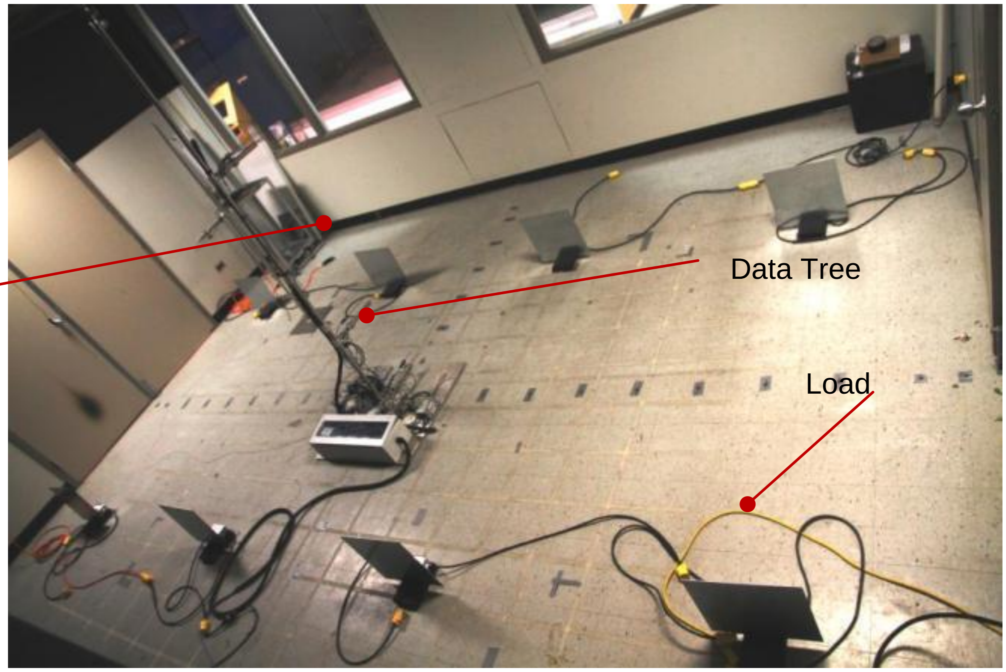
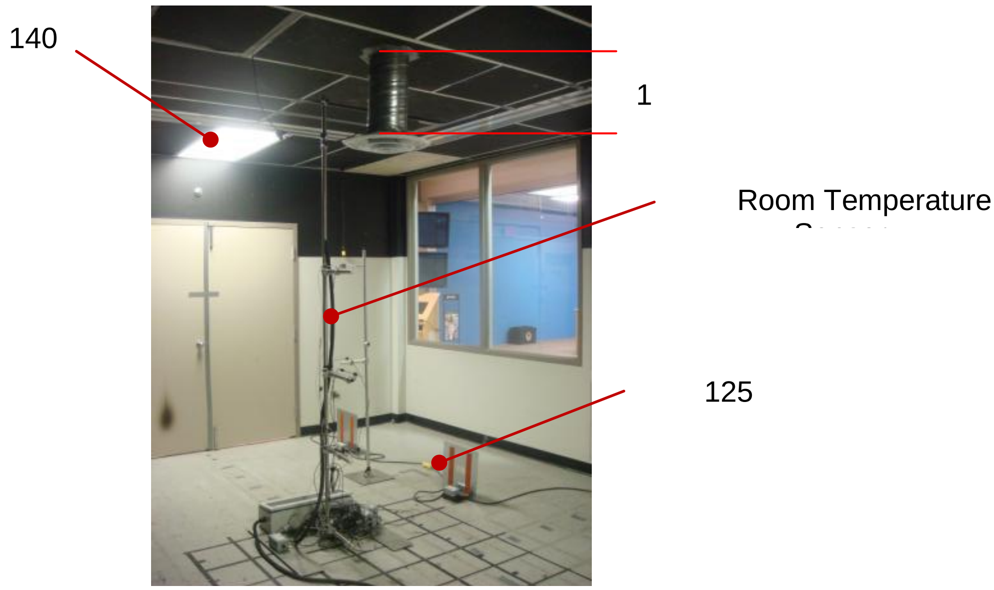


Figure 1: Measurement Points @4", 24", 42" and 66" height





8Ø RCDE Test Setup

8Ø RCDE Smoke pattern

48” SDB100 2 way Smoke pattern

8x6 520 Grille Test Setup

8x6 520 Grille Smoke pattern

Test Equipments

8.1.5

8.1.6 *Measurement Tree*

The measurement tree configuration and sensor heights are shown in Figure 1.

8.1.7 *Measurement Error*

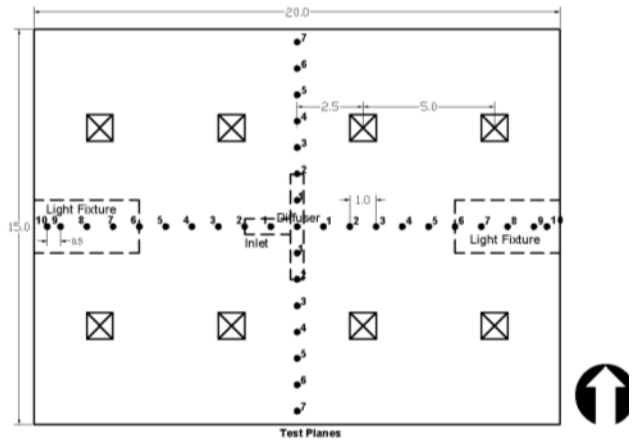
TSI Model 8475 (velocity): $\pm 3\%$ Reading + $\pm 1\%$ Full Scale
RTD Probe: ± 0.7 °F (± 0.4°C)

8.1.8 *Data Logging*

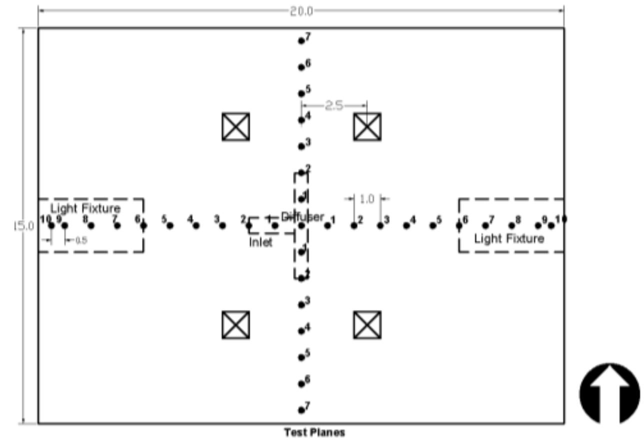
All readings were recorded every 30 seconds through the use of a data logger exporting data to an Excel spreadsheet. The measurement equipment added 10 Watts of loading to the room.

Test Results

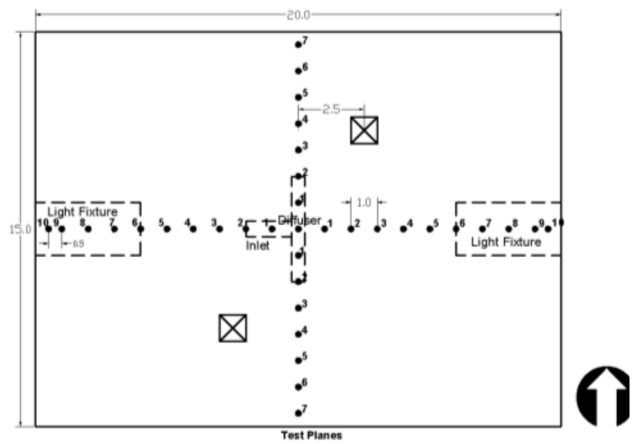
	ASHRAE RP 1515										
Test No.	Diffuser	Size (in. x in)	Range (cfm)	Supply Air Volume (cfm)	% Design	Supply Air Temp (°F)	Room Temp (°F)	Room Size (ft x ft)	Room Area (ft²)	Load (Watts)	Load
1	SDB 100	48" 2 SLOT 7"Ø	100-340	239	80%	55	72	20x15	300	1290	8 load simulator + 2 light fixture + data logger
2				146	49%	55	72	20x15	300	790	4 load simulator + 2 light fixture + data logger
3				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
4				77	26%	55	72	20x16	300	415	1 load simulator + 2 light fixture + data logger
5				55	18%	55	72	20x15	300	290	2 light fixture + data logger
6	SDB 100	48" 2 SLOT 7"Ø	100-340	239	80%	65	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
7				146	49%	65	72	20x15	300	290	2 light fixture + data logger
8				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
9				77	26%	65	72	20x15	300	150	1 light fixture + data logger
10				55	18%	65	72	20x16	300	135	1 load simulator + data logger
11	RCD (Exposed)	8"Ø	140-560	239	80%	55	72	20x15	300	1290	8 load simulator + 2 light fixture + data logger
12				146	49%	55	72	20x15	300	790	4 load simulator + 2 light fixture + data logger
13				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
14				77	26%	55	72	20x16	300	415	1 load simulator + 2 light fixture + data logger
15				55	18%	55	72	20x15	300	290	2 light fixture + data logger
16	RCD (Exposed)	8"Ø	140-560	239	80%	65	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
17				146	49%	65	72	20x15	300	290	2 light fixture + data logger
18				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
19				77	26%	65	72	20x15	300	150	1 light fixture + data logger
20				55	18%	65	72	20x16	300	135	1 load simulator + data logger
21	520 grille	8 x 6	80-470	146	49%	55	72	20x15	300	790	4 load simulator + 2 light fixture + data logger
22				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
23				77	26%	55	72	20x16	300	415	1 load simulator + 2 light fixture + data logger
24				55	18%	55	72	20x15	300	290	2 light fixture + data logger
25	520 grille	8 x 6	80-470	146	49%	65	72	20x15	300	290	2 light fixture + data logger
26				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
27				77	26%	65	72	20x15	300	150	1 light fixture + data logger
28				55	18%	65	72	20x16	300	135	1 load simulator + data logger
29	PDF	24 x 24 8"Ø	105-489	239	80%	55	72	20x15	300	1290	8 load simulator + 2 light fixture + data logger
30				146	49%	55	72	20x15	300	790	4 load simulator + 2 light fixture + data logger
31				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
32				77	26%	55	72	20x16	300	415	1 load simulator + 2 light fixture + data logger
33				55	18%	55	72	20x15	300	290	2 light fixture + data logger
34	PDF	24 x 24 8"Ø	105-489	239	80%	65	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
35				146	49%	65	72	20x15	300	290	2 light fixture + data logger
36				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
37				77	26%	65	72	20x15	300	150	1 light fixture + data logger
38				55	18%	65	72	20x16	300	135	1 load simulator + data logger
39	PDN	24 x 24 8"Ø	105-489	239	80%	55	72	20x15	300	1290	8 load simulator + 2 light fixture + data logger
40				146	49%	55	72	20x15	300	790	4 load simulator + 2 light fixture + data logger
41				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
42				77	26%	55	72	20x16	300	415	1 load simulator + 2 light fixture + data logger
43				55	18%	55	72	20x15	300	290	2 light fixture + data logger
44	PDN	24 x 24 8"Ø	105-489	239	80%	65	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
45				146	49%	65	72	20x15	300	290	2 light fixture + data logger
46				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
47				77	26%	65	72	20x15	300	150	1 light fixture + data logger
48				55	18%	65	72	20x16	300	135	1 load simulator + data logger
49	SPD	24 x 24 8"Ø	105-489	239	80%	55	72	20x15	300	1290	8 load simulator + 2 light fixture + data logger
50				100	33%	55	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
51				55	18%	55	72	20x15	300	290	2 light fixture + data logger
52	SPD	24 x 24 8"Ø	105-489	239	80%	65	72	20x15	300	540	2 load simulator + 2 light fixture + data logger
53				100	33%	65	72	20x15	300	275	1 load simulator + 1 light fixture + data logger
54				55	18%	65	72	20x16	300	135	1 load simulator + data logger



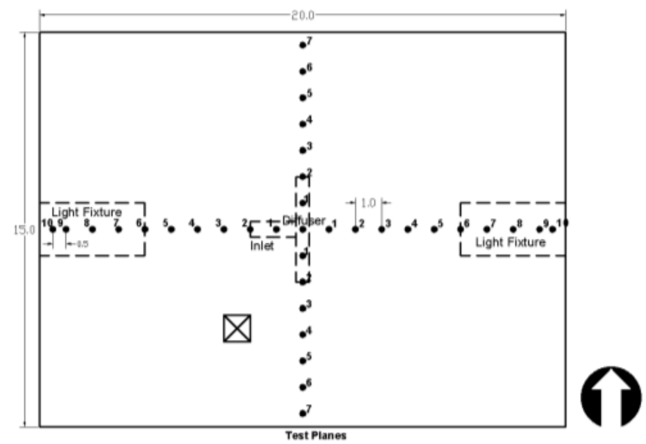
Test 1



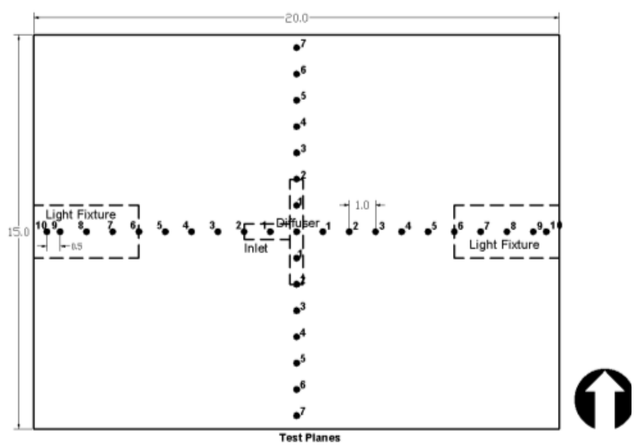
Test 2



Test 3



Test 4



Test 5

Test 1 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	55°F	72°F	20 x 15 x 9	1290 watts

Plane North > South > East > West

Measurement points	Average Temperature (°F)					Average Velocity (ft/min)			
	4"	24"	42"	66"	Room	4"	24"	42"	66"
N1 (1 ft from mid of diffuser)	72	73	73	73	73	36	40	42	27
N2 (2 ft from mid of diffuser)	73	73	73	73	73	30	37	44	46
N3 (3 ft from mid of diffuser)	72	73	73	73	73	35	49	51	42
N4 (4 ft from mid of diffuser)	72	73	73	73	73	53	35	17	18
N5 (5 ft from mid of diffuser)	72	72	73	73	73	53	30	30	32
N6 (6 ft from mid diffuser)	72	73	73	73	73	64	32	23	28
N7 (6.5 ft from mid of diffuser)	72	73	73	73	73	54	25	13	17
S1 (1 ft from mid of diffuser)	72	73	73	73	74	27	34	31	25
S2 (2 ft from mid of diffuser)	73	73	73	73	73	17	31	35	31
S3 (3 ft from mid of diffuser)	73	73	73	73	73	28	35	27	27
S4 (4 ft from mid of diffuser)	73	73	73	73	73	19	29	34	25
S5 (5 ft from mid of diffuser)	73	73	73	73	73	39	27	27	28
S6 (6 ft from mid of diffuser)	73	73	73	74	73	34	19	23	31
S7 (6.5 ft from mid of diffuser)	73	73	73	73	73	43	24	20	23
E1 (1 ft from mid of diffuser)	73	73	73	73	74	31	37	49	45
E2 (2 ft from mid of diffuser)	73	73	73	73	73	33	39	41	39
E3 (3 ft from mid of diffuser)	72	73	73	73	74	27	32	42	35
E4 (4 ft from mid of diffuser)	72	72	73	73	73	28	27	28	21
E5 (5 ft from mid of diffuser)	72	73	73	73	73	30	25	13	24
E6 (6 ft from mid of diffuser)	72	72	72	73	73	39	33	15	19
E7 (7 ft from mid of diffuser)	72	73	73	73	73	30	34	28	29
E8 (8 ft from mid of diffuser)	72	73	73	73	74	32	36	38	39
E9 (9 ft from mid of diffuser)	72	72	72	72	73	33	49	57	58
E10 (9.5 ft from mid of diffuser)	72	72	72	72	73	28	34	61	63
Middle of room	72	73	73	73	73	25	39	40	41
W1 (1 ft from	72	73	73	73	73	24	35	42	31

mid of diffuser)									
W2 (2 ft from mid of diffuser)	72	73	73	73	73	27	33	29	22
W3 (3 ft from mid of diffuser)	72	73	73	73	74	28	29	24	24
W4 (4 ft from mid of diffuser)	72	73	73	73	73	29	18	26	26
W5 (5 ft from mid of diffuser)	72	73	73	73	73	37	14	23	28
W6 (6 ft from mid of diffuser)	72	73	73	73	73	35	19	22	32
W7 (7 ft from mid of diffuser)	72	73	73	73	73	34	14	21	26
W8 (8 ft from mid of diffuser)	72	73	74	74	74	40	18	22	23
W9 (9 ft from mid of diffuser)	72	73	73	73	73	43	26	23	43
W10 (9.5 ft from mid of diffuser)	72	73	73	72	73	40	63	71	70

Test 2 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	55°F	72°F	20 x 15 x 9	790 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	15	21	19	16
N2 (2 ft from mid of diffuser)	72	72	72	72	72	17	25	22	22
N3 (3 ft from mid of diffuser)	72	72	72	72	72	14	29	32	29
N4 (4 ft from mid of diffuser)	72	72	72	72	72	15	21	27	23
N5 (5 ft from mid of diffuser)	72	72	72	72	72	33	26	28	33
N6 (6 ft from mid diffuser)	72	72	72	72	72	25	21	20	23
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	45	35	34	16
S1 (1 ft from mid of diffuser)	72	72	72	72	72	35	20	22	16
S2 (2 ft from mid of diffuser)	72	72	72	72	72	17	18	25	22
S3 (3 ft from mid of diffuser)	72	72	72	72	72	27	37	40	24
S4 (4 ft from mid of diffuser)	72	72	72	72	72	19	28	30	22

S5 (5 ft from mid of diffuser)	72	72	72	72	72	30	24	19	31
S6 (6 ft from mid of diffuser)	72	72	72	72	72	33	35	33	21
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	36	42	36	29
E1 (1 ft from mid of diffuser)	72	72	72	72	72	22	23	18	9
E2 (2 ft from mid of diffuser)	72	72	72	72	72	27	15	15	14
E3 (3 ft from mid of diffuser)	71	72	72	72	72	19	22	18	20
E4 (4 ft from mid of diffuser)	71	72	72	72	72	27	19	18	20
E5 (5 ft from mid of diffuser)	71	72	72	72	72	32	24	22	19
E6 (6 ft from mid of diffuser)	71	72	72	72	72	28	22	20	25
E7 (7 ft from mid of diffuser)	71	72	72	72	72	29	31	28	32
E8 (8 ft from mid of diffuser)	71	72	72	72	72	27	18	21	40
E9 (9 ft from mid of diffuser)	71	72	72	71	72	21	31	38	31
E10 (9.5 ft from mid of diffuser)	71	71	71	71	72	22	42	49	43
Middle of room	72	72	72	71	72	20	15	18	25
W1 (1 ft from mid of diffuser)	71	72	72	71	72	21	20	25	24
W2 (2 ft from mid of diffuser)	71	72	72	71	72	18	21	17	18
W3 (3 ft from mid of diffuser)	71	72	72	72	72	23	18	10	19
W4 (4 ft from mid of diffuser)	71	72	72	71	72	18	31	41	39
W5 (5 ft from mid of diffuser)	71	72	72	71	72	25	16	21	29
W6 (6 ft from mid of diffuser)	72	72	72	71	72	22	22	32	38
W7 (7 ft from mid of diffuser)	71	72	72	71	72	29	14	14	18
W8 (8 ft from mid of diffuser)	71	72	72	71	72	29	32	46	61
W9 (9 ft from mid of diffuser)	71	72	71	71	72	29	42	47	44
W10 (9.5 ft from mid of diffuser)	71	72	71	71	72	37	43	39	24

Test 3 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	71	71	71	71	71	12	21	14	15
N2 (2 ft from mid of diffuser)	71	71	71	71	71	17	13	11	15
N3 (3 ft from mid of diffuser)	71	71	71	71	71	9	17	20	13
N4 (4 ft from mid of diffuser)	71	71	71	71	71	14	19	15	12
N5 (5 ft from mid of diffuser)	71	71	71	71	71	14	8	9	10
N6 (6 ft from mid diffuser)	71	71	71	71	71	18	22	25	22
N7 (6.5 ft from mid of diffuser)	71	71	71	71	71	17	20	25	21
S1 (1 ft from mid of diffuser)	71	71	71	71	71	13	19	12	8
S2 (2 ft from mid of diffuser)	71	71	71	71	71	16	14	14	15
S3 (3 ft from mid of diffuser)	71	71	71	71	71	16	14	15	20
S4 (4 ft from mid of diffuser)	71	71	71	71	71	14	18	18	11
S5 (5 ft from mid of diffuser)	71	71	71	71	71	13	14	15	13
S6 (6 ft from mid of diffuser)	71	71	71	71	71	18	15	16	25
S7 (6.5 ft from mid of diffuser)	71	71	71	71	71	24	20	18	21
E1 (1 ft from mid of diffuser)	71	71	71	71	71	15	14	12	11
E2 (2 ft from mid of diffuser)	71	71	71	71	71	19	18	18	21
E3 (3 ft from mid of diffuser)	71	71	71	71	71	16	10	16	21
E4 (4 ft from mid of diffuser)	71	71	71	71	71	17	11	16	15
E5 (5 ft from mid of diffuser)	71	71	71	71	71	21	14	16	20
E6 (6 ft from mid of diffuser)	71	71	71	71	71	25	13	12	22
E7 (7 ft from mid of diffuser)	71	71	71	71	71	24	14	11	14
E8 (8 ft from mid of diffuser)	71	71	71	71	71	24	23	30	22

E9 (9 ft from mid of diffuser)	71	71	71	71	71	43	24	25	26
E10 (9.5 ft from mid of diffuser)	71	71	71	71	71	35	38	29	25
Middle of room	71	71	71	71	71	22	14	7	12
W1 (1 ft from mid of diffuser)	71	71	71	71	71	15	13	15	16
W2 (2 ft from mid of diffuser)	71	71	71	71	71	16	10	12	14
W3 (3 ft from mid of diffuser)	71	71	71	70	71	17	23	31	33
W4 (4 ft from mid of diffuser)	71	71	71	70	71	20	12	15	23
W5 (5 ft from mid of diffuser)	71	71	71	70	71	21	15	22	22
W6 (6 ft from mid of diffuser)	71	71	71	70	71	21	20	26	23
W7 (7 ft from mid of diffuser)	71	71	71	71	71	18	19	27	28
W8 (8 ft from mid of diffuser)	71	71	71	71	71	21	18	22	26
W9 (9 ft from mid of diffuser)	71	71	71	71	71	13	17	17	14
W10 (9.5 ft from mid of diffuser)	71	71	71	71	71	12	27	31	19

Test 4 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	55°F	72°F	20 x 15 x 9	415 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	20	13	10	10
N2 (2 ft from mid of diffuser)	72	72	72	72	72	13	27	21	17
N3 (3 ft from mid of diffuser)	72	71	71	71	72	11	22	22	17
N4 (4 ft from mid of diffuser)	72	72	71	71	72	20	14	11	12
N5 (5 ft from mid of diffuser)	72	71	71	72	72	24	14	17	4
N6 (6 ft from mid diffuser)	71	71	71	71	72	17	23	20	27
N7 (6.5 ft from mid of diffuser)	72	71	71	71	72	19	20	22	21
S1 (1 ft from mid of diffuser)	72	72	72	72	72	20	20	15	10
S2 (2 ft from mid of diffuser)	72	72	72	72	72	21	20	20	14

S3 (3 ft from mid of diffuser)	72	72	72	72	72	21	13	17	3
S4 (4 ft from mid of diffuser)	72	72	72	72	72	26	17	17	20
S5 (5 ft from mid of diffuser)	72	72	72	72	72	16	21	24	24
S6 (6 ft from mid of diffuser)	72	72	72	72	72	25	22	25	22
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	28	28	28	24
E1 (1 ft from mid of diffuser)	72	72	72	72	72	17	19	16	15
E2 (2 ft from mid of diffuser)	71	72	71	71	72	19	17	16	19
E3 (3 ft from mid of diffuser)	71	71	71	71	72	21	8	6	11
E4 (4 ft from mid of diffuser)	71	71	71	72	72	23	17	19	19
E5 (5 ft from mid of diffuser)	71	71	71	71	72	24	20	24	21
E6 (6 ft from mid of diffuser)	71	71	71	71	72	20	35	38	37
E7 (7 ft from mid of diffuser)	71	71	71	71	72	21	20	32	34
E8 (8 ft from mid of diffuser)	71	71	71	71	72	21	32	34	23
E9 (9 ft from mid of diffuser)	71	71	71	71	71	12	17	25	18
E10 (9.5 ft from mid of diffuser)	71	71	71	71	71	24	21	25	12
Middle of room	71	71	71	71	72	18	21	16	1
W1 (1 ft from mid of diffuser)	71	71	71	71	72	16	17	14	13
W2 (2 ft from mid of diffuser)	71	72	71	71	72	17	23	13	9
W3 (3 ft from mid of diffuser)	71	72	72	71	72	18	11	18	7
W4 (4 ft from mid of diffuser)	71	72	72	71	72	19	15	19	11
W5 (5 ft from mid of diffuser)	71	72	72	71	72	25	12	13	13
W6 (6 ft from mid of diffuser)	71	72	72	71	72	25	12	9	14
W7 (7 ft from mid of diffuser)	71	72	72	71	72	32	14	17	19
W8 (8 ft from mid of diffuser)	71	72	72	72	72	31	12	10	17
W9 (9 ft from mid of diffuser)	71	72	72	72	72	30	11	8	13
W10 (9.5 ft from mid of diffuser)	71	72	72	72	72	27	27	30	18

Test 5 Conditions – SDB100 2 way Diffuser:

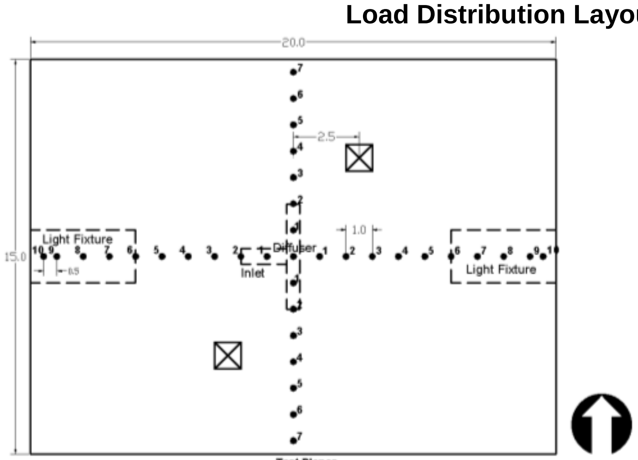
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

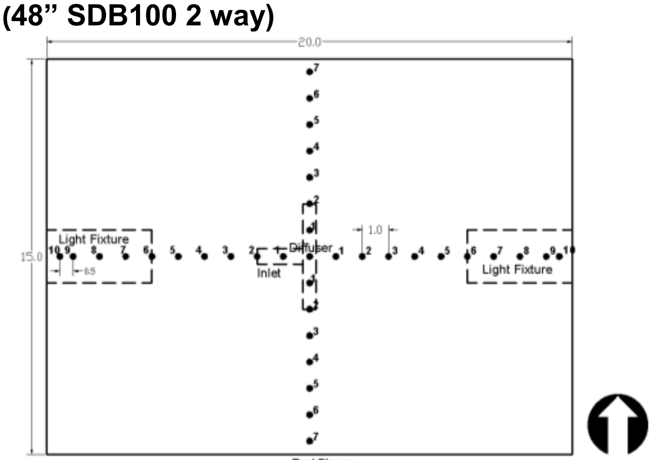
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	71	71	71	71	72	17	18	18	9
N2 (2 ft from mid of diffuser)	71	71	71	71	72	15	17	15	11
N3 (3 ft from mid of diffuser)	71	71	71	71	72	14	20	20	17
N4 (4 ft from mid of diffuser)	71	71	71	71	72	13	19	17	14
N5 (5 ft from mid of diffuser)	71	71	71	71	72	15	8	12	5
N6 (6 ft from mid diffuser)	71	71	71	71	72	16	16	16	14
N7 (6.5 ft from mid of diffuser)	71	71	71	71	72	16	19	21	18
S1 (1 ft from mid of diffuser)	71	71	71	71	72	12	10	11	5
S2 (2 ft from mid of diffuser)	71	71	71	71	72	11	18	15	8
S3 (3 ft from mid of diffuser)	71	71	71	71	72	13	10	6	9
S4 (4 ft from mid of diffuser)	71	71	71	71	72	12	12	10	10
S5 (5 ft from mid of diffuser)	71	71	71	71	72	13	11	15	8
S6 (6 ft from mid of diffuser)	71	71	71	71	72	21	21	20	13
S7 (6.5 ft from mid of diffuser)	71	71	71	71	72	20	23	22	19
E1 (1 ft from mid of diffuser)	71	71	71	71	72	14	11	9	10
E2 (2 ft from mid of diffuser)	71	71	71	71	72	17	14	13	8
E3 (3 ft from mid of diffuser)	71	71	71	71	72	18	11	15	13
E4 (4 ft from mid of diffuser)	71	71	71	71	72	18	10	12	11
E5 (5 ft from mid of diffuser)	71	71	71	71	72	21	13	23	26
E6 (6 ft from mid of diffuser)	71	71	71	71	72	18	17	26	31
E7 (7 ft from mid of diffuser)	71	71	71	71	72	17	15	27	29

E8 (8 ft from mid of diffuser)	71	71	71	71	72	13	24	27	18
E9 (9 ft from mid of diffuser)	71	71	71	71	72	23	13	12	5
E10 (9.5 ft from mid of diffuser)	71	71	71	71	72	16	19	18	17
Middle of room	71	71	71	71	72	16	19	11	9
W1 (1 ft from mid of diffuser)	71	71	71	71	72	18	9	6	10
W2 (2 ft from mid of diffuser)	71	71	71	71	72	17	11	12	19
W3 (3 ft from mid of diffuser)	71	71	71	71	72	16	10	9	8
W4 (4 ft from mid of diffuser)	71	71	71	71	72	17	13	11	10
W5 (5 ft from mid of diffuser)	71	71	71	71	72	18	9	13	26
W6 (6 ft from mid of diffuser)	71	71	71	71	72	23	10	11	25
W7 (7 ft from mid of diffuser)	71	71	71	71	72	23	10	13	23
W8 (8 ft from mid of diffuser)	71	71	71	71	72	25	16	15	14
W9 (9 ft from mid of diffuser)	71	71	71	71	72	25	17	14	16
W10 (9.5 ft from mid of diffuser)	71	71	71	71	72	30	31	20	18

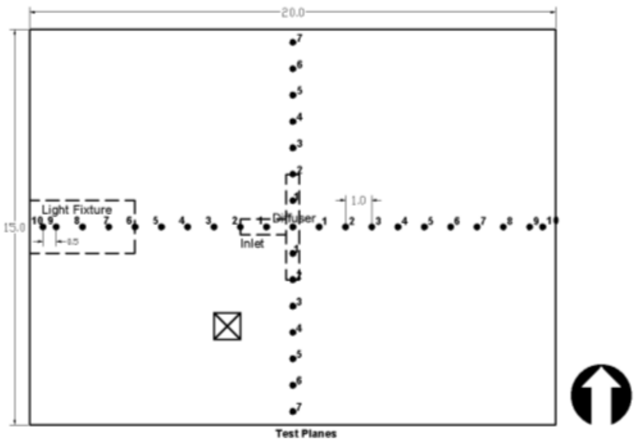
Load Distribution Layout (48" SDB100 2 way)



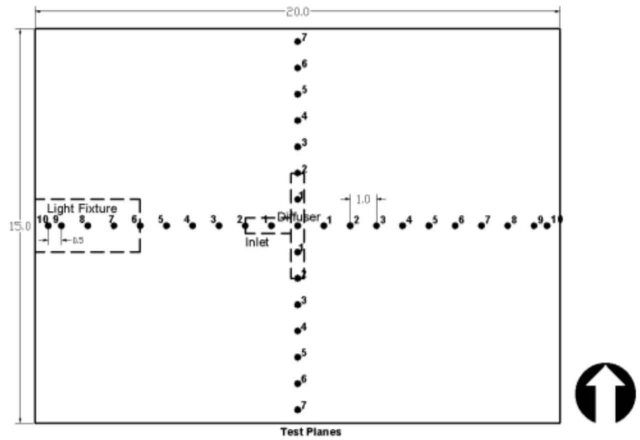
Test 6



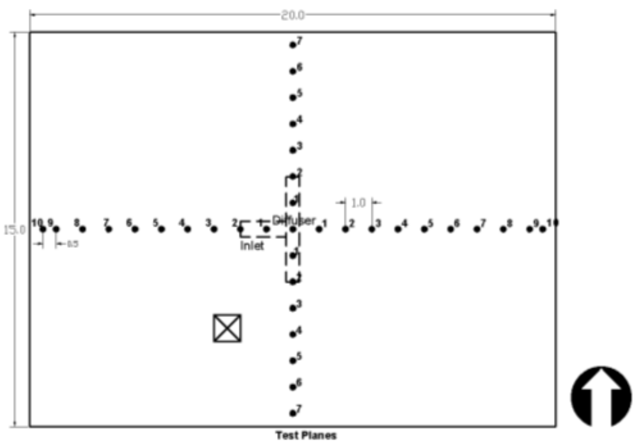
Test 7



Test 8



Test 9



Test 10

Test 6 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	65°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	71	72	19	32	43	40
N2 (2 ft from mid of diffuser)	72	72	72	72	72	25	42	47	38
N3 (3 ft from mid of diffuser)	72	72	72	72	72	44	45	28	28
N4 (4 ft	72	72	72	72	72	51	39	21	23

from mid of diffuser)									
N5 (5 ft from mid of diffuser)	72	72	72	72	72	24	42	52	42
N6 (6 ft from mid diffuser)	72	72	72	72	72	63	31	20	27
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	43	48	26	25
S1 (1 ft from mid of diffuser)	72	72	72	72	72	22	44	46	39
S2 (2 ft from mid of diffuser)	72	72	72	72	72	38	51	37	28
S3 (3 ft from mid of diffuser)	72	72	72	72	72	16	44	49	39
S4 (4 ft from mid of diffuser)	72	72	72	72	72	25	22	37	43
S5 (5 ft from mid of diffuser)	72	72	72	72	72	26	31	42	41
S6 (6 ft from mid of diffuser)	72	72	72	72	72	33	21	27	27
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	30	26	26	28
E1 (1 ft from mid of diffuser)	72	72	72	72	72	43	40	29	23
E2 (2 ft from mid of diffuser)	72	72	72	72	72	20	36	39	36
E3 (3 ft from mid of diffuser)	72	72	72	72	72	28	38	46	41
E4 (4 ft from mid of diffuser)	72	72	72	72	72	30	30	21	31
E5 (5 ft from mid of diffuser)	72	72	72	72	72	31	34	22	24
E6 (6 ft from mid of diffuser)	72	72	72	72	72	36	22	22	27
E7 (7 ft from mid of diffuser)	72	72	72	72	72	37	19	13	13
E8 (8 ft from mid of	72	72	72	72	72	34	23	10	14

diffuser)									
E9 (9 ft from mid of diffuser)	72	72	72	72	72	28	29	26	34
E10 (9.5 ft from mid of diffuser)	72	72	72	72	72	26	57	68	74
Middle of room	72	72	72	72	72	28	38	43	36
W1 (1 ft from mid of diffuser)	72	72	72	72	72	24	38	46	39
W2 (2 ft from mid of diffuser)	72	72	72	72	72	26	25	28	39
W3 (3 ft from mid of diffuser)	72	72	72	72	72	33	28	27	32
W4 (4 ft from mid of diffuser)	72	72	72	72	72	33	23	21	19
W5 (5 ft from mid of diffuser)	72	72	72	72	72	36	19	20	21
W6 (6 ft from mid of diffuser)	72	72	72	72	72	40	16	17	15
W7 (7 ft from mid of diffuser)	72	72	72	72	72	47	23	25	13
W8 (8 ft from mid of diffuser)	72	72	72	72	72	43	21	20	14
W9 (9 ft from mid of diffuser)	72	72	72	72	72	41	40	38	42
W10 (9.5 ft from mid of diffuser)	72	72	72	72	72	35	81	92	117

Test 7 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	65°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	13	27	33	28
N2 (2 ft from mid of diffuser)	72	72	72	72	72	13	23	28	24

N3 (3 ft from mid of diffuser)	72	72	72	72	72	23	27	28	18
N4 (4 ft from mid of diffuser)	72	72	72	72	72	31	20	16	14
N5 (5 ft from mid of diffuser)	72	72	72	72	72	35	25	14	18
N6 (6 ft from mid diffuser)	72	72	72	72	72	48	22	6	11
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	38	19	9	10
S1 (1 ft from mid of diffuser)	72	72	72	72	72	19	28	26	18
S2 (2 ft from mid of diffuser)	72	72	72	72	72	15	27	29	25
S3 (3 ft from mid of diffuser)	72	72	72	72	72	19	26	27	21
S4 (4 ft from mid of diffuser)	72	72	72	72	72	20	27	24	27
S5 (5 ft from mid of diffuser)	72	72	72	72	72	24	18	14	11
S6 (6 ft from mid of diffuser)	72	72	72	72	72	19	16	22	20
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	21	19	24	30
E1 (1 ft from mid of diffuser)	72	72	72	72	72	24	27	18	15
E2 (2 ft from mid of diffuser)	72	72	72	72	72	24	27	18	12
E3 (3 ft from mid of diffuser)	72	72	72	72	72	22	26	25	20
E4 (4 ft from mid of diffuser)	72	72	72	72	72	25	31	20	9
E5 (5 ft from mid of diffuser)	72	72	72	72	72	25	20	10	17
E6 (6 ft from mid of diffuser)	72	72	72	72	72	23	26	25	16
E7 (7 ft from mid of diffuser)	72	72	72	72	72	23	26	22	20
E8 (8 ft from mid of diffuser)	72	72	72	72	72	20	29	20	23
E9 (9 ft from mid of diffuser)	72	72	72	72	72	20	17	21	17
E10 (9.5 ft from mid of diffuser)	72	72	72	72	72	14	34	37	39
Middle of room	72	72	72	72	72	21	21	22	18
W1 (1 ft from mid of diffuser)	72	72	72	72	72	18	20	20	21
W2 (2 ft from mid of diffuser)	72	72	72	72	72	21	15	15	16
W3 (3 ft from mid of diffuser)	72	72	72	72	72	22	16	12	16

W4 (4 ft from mid of diffuser)	72	72	72	72	72	23	12	17	19
W5 (5 ft from mid of diffuser)	72	72	72	72	72	24	18	18	17
W6 (6 ft from mid of diffuser)	72	72	72	72	72	27	8	1	10
W7 (7 ft from mid of diffuser)	72	72	72	72	72	27	15	13	11
W8 (8 ft from mid of diffuser)	72	72	72	72	72	25	13	12	15
W9 (9 ft from mid of diffuser)	72	72	72	72	72	28	33	35	46
W10 (9.5 ft from mid of diffuser)	72	72	72	71	72	21	51	58	71

Test 8 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	17	22	18	16
N2 (2 ft from mid of diffuser)	72	72	72	72	73	19	17	17	15
N3 (3 ft from mid of diffuser)	72	72	72	72	73	20	29	30	20
N4 (4 ft from mid of diffuser)	72	72	72	72	73	19	28	25	14
N5 (5 ft from mid of diffuser)	72	72	72	72	73	16	30	28	21
N6 (6 ft from mid diffuser)	72	72	72	72	73	16	22	18	14
N7 (6.5 ft from mid of diffuser)	72	72	72	72	73	16	24	29	26
S1 (1 ft from mid of diffuser)	72	73	73	72	73	12	21	22	18
S2 (2 ft from mid of diffuser)	73	73	73	72	73	14	20	19	14
S3 (3 ft	73	73	73	72	73	16	20	15	14

from mid of diffuser)									
S4 (4 ft from mid of diffuser)	73	73	73	73	73	21	18	23	18
S5 (5 ft from mid of diffuser)	73	73	73	73	73	16	17	22	20
S6 (6 ft from mid of diffuser)	73	73	73	73	73	15	16	17	16
S7 (6.5 ft from mid of diffuser)	73	73	73	73	73	15	20	25	25
E1 (1 ft from mid of diffuser)	72	72	72	72	73	22	15	15	10
E2 (2 ft from mid of diffuser)	72	72	72	72	73	15	18	22	17
E3 (3 ft from mid of diffuser)	72	72	72	72	73	22	13	9	6
E4 (4 ft from mid of diffuser)	72	72	72	72	73	23	16	15	12
E5 (5 ft from mid of diffuser)	72	72	72	72	73	23	18	13	6
E6 (6 ft from mid of diffuser)	72	73	72	72	73	24	9	10	13
E7 (7 ft from mid of diffuser)	72	73	73	72	73	25	15	15	17
E8 (8 ft from mid of diffuser)	72	73	73	72	73	24	5	10	16
E9 (9 ft from mid of diffuser)	72	73	73	72	73	15	25	27	31
E10 (9.5 ft from mid of diffuser)	72	73	72	72	73	14	27	31	40
Middle of room	72	73	72	72	73	21	21	20	23
W1 (1 ft from mid of diffuser)	72	73	72	72	73	18	20	21	21
W2 (2 ft from mid of diffuser)	72	72	72	72	73	23	28	31	26
W3 (3 ft from mid of diffuser)	72	72	72	72	73	23	25	29	22

W4 (4 ft from mid of diffuser)	72	72	72	72	73	22	20	24	20
W5 (5 ft from mid of diffuser)	72	73	72	72	73	20	9	14	12
W6 (6 ft from mid of diffuser)	72	73	72	72	73	19	12	13	14
W7 (7 ft from mid of diffuser)	72	73	73	73	73	18	12	9	14
W8 (8 ft from mid of diffuser)	72	73	73	73	73	16	7	11	21
W9 (9 ft from mid of diffuser)	73	73	73	73	73	20	19	14	15
W10 (9.5 ft from mid of diffuser)	73	73	73	73	73	22	29	31	36

Test 9 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	65°F	72°F	20 x 15 x 9	150 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	13	19	23	21
N2 (2 ft from mid of diffuser)	72	72	72	72	72	21	10	13	16
N3 (3 ft from mid of diffuser)	72	72	72	72	72	16	17	18	17
N4 (4 ft from mid of diffuser)	72	72	72	72	72	23	11	11	10
N5 (5 ft from mid of diffuser)	72	72	72	72	72	24	14	16	9
N6 (6 ft from mid diffuser)	72	72	72	72	72	29	20	20	7
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	24	16	18	19
S1 (1 ft	72	72	72	72	72	15	16	19	15

from mid of diffuser)								
S2 (2 ft from mid of diffuser)	72	72	72	72	72	14	24	25	17
S3 (3 ft from mid of diffuser)	72	72	72	72	72	29	12	16	7
S4 (4 ft from mid of diffuser)	72	72	72	72	72	15	14	16	15
S5 (5 ft from mid of diffuser)	72	72	72	72	72	20	15	15	11
S6 (6 ft from mid of diffuser)	72	72	72	72	72	18	19	15	15
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	21	22	21	19
E1 (1 ft from mid of diffuser)	72	72	72	72	72	17	20	20	17
E2 (2 ft from mid of diffuser)	72	72	72	72	72	18	10	10	10
E3 (3 ft from mid of diffuser)	72	72	72	72	72	19	10	12	17
E4 (4 ft from mid of diffuser)	72	72	72	72	72	20	14	12	9
E5 (5 ft from mid of diffuser)	72	72	72	72	72	21	5	7	2
E6 (6 ft from mid of diffuser)	72	72	72	72	72	18	10	8	5
E7 (7 ft from mid of diffuser)	72	72	72	72	72	19	15	9	15
E8 (8 ft from mid of diffuser)	72	72	72	72	72	16	21	28	29
E9 (9 ft from mid of diffuser)	72	72	72	72	72	18	26	32	29
E10 (9.5 ft from mid of diffuser)	72	72	72	72	72	13	27	33	34
Middle of room	72	72	72	72	72	17	20	19	15
W1 (1 ft from mid of diffuser)	72	72	72	72	72	18	18	20	16

W2 (2 ft from mid of diffuser)	72	72	72	72	72	20	15	19	15
W3 (3 ft from mid of diffuser)	72	72	72	72	72	18	25	16	11
W4 (4 ft from mid of diffuser)	72	72	72	72	72	19	16	20	18
W5 (5 ft from mid of diffuser)	72	72	72	72	72	18	13	15	15
W6 (6 ft from mid of diffuser)	72	72	72	72	72	17	17	16	8
W7 (7 ft from mid of diffuser)	72	72	72	72	72	20	18	19	12
W8 (8 ft from mid of diffuser)	72	72	72	72	72	18	17	15	10
W9 (9 ft from mid of diffuser)	72	72	72	72	72	19	14	13	19
W10 (9.5 ft from mid of diffuser)	72	72	72	72	72	16	21	27	32

Test 10 Conditions – SDB100 2 way Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

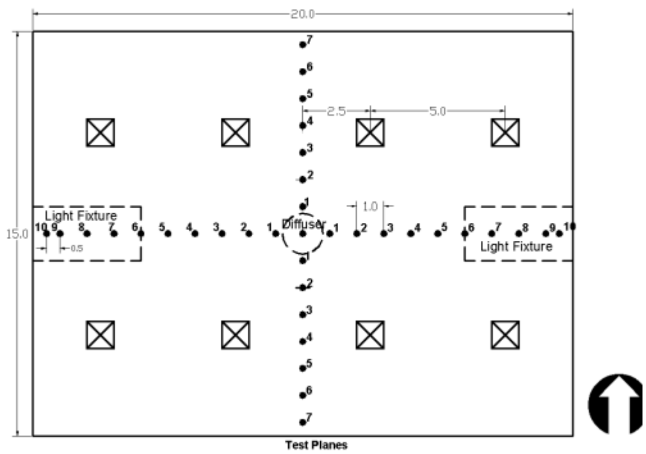
Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	16	12	12	11
N2 (2 ft from mid of diffuser)	72	72	72	72	72	13	16	15	16
N3 (3 ft from mid of diffuser)	72	72	72	72	72	17	13	15	15
N4 (4 ft from mid of diffuser)	72	72	72	72	73	15	17	16	14
N5 (5 ft from mid of diffuser)	72	72	72	72	73	19	14	15	12
N6 (6 ft from mid diffuser)	72	72	72	72	73	27	20	15	16
N7 (6.5 ft from mid of diffuser)	72	72	72	73	73	24	26	20	13
S1 (1 ft from mid of diffuser)	72	73	73	73	73	11	11	10	8

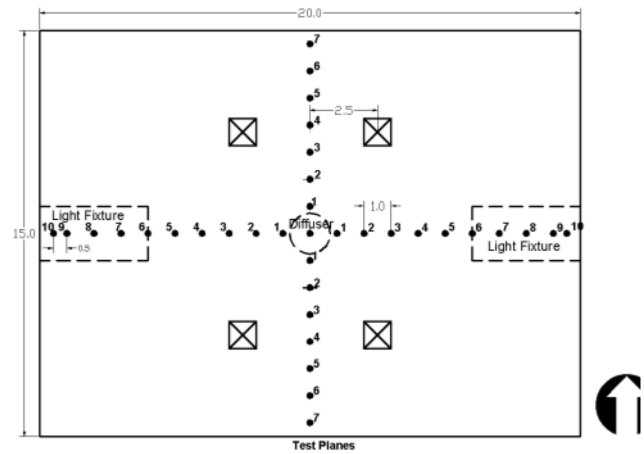
S2 (2 ft from mid of diffuser)	73	73	73	73	73	16	17	18	11
S3 (3 ft from mid of diffuser)	72	73	73	73	73	13	11	15	15
S4 (4 ft from mid of diffuser)	73	73	73	73	73	15	14	17	22
S5 (5 ft from mid of diffuser)	73	73	73	73	73	17	18	17	21
S6 (6 ft from mid of diffuser)	73	73	73	73	73	16	16	16	21
S7 (6.5 ft from mid of diffuser)	73	73	73	73	73	11	18	19	18
E1 (1 ft from mid of diffuser)	73	73	73	73	73	11	17	12	9
E2 (2 ft from mid of diffuser)	73	73	73	73	73	14	11	9	4
E3 (3 ft from mid of diffuser)	73	73	73	73	73	16	14	11	11
E4 (4 ft from mid of diffuser)	73	73	73	73	73	17	11	8	10
E5 (5 ft from mid of diffuser)	73	73	73	73	73	20	9	13	6
E6 (6 ft from mid of diffuser)	73	73	73	73	73	20	10	7	7
E7 (7 ft from mid of diffuser)	73	73	73	73	73	17	11	12	22
E8 (8 ft from mid of diffuser)	73	73	73	73	73	18	13	16	23
E9 (9 ft from mid of diffuser)	73	73	73	72	73	19	28	33	28
E10 (9.5 ft from mid of diffuser)	73	73	73	73	73	18	30	30	17
Middle of room	73	73	73	73	73	13	16	13	5
W1 (1 ft from mid of diffuser)	73	73	73	73	73	19	12	13	16
W2 (2 ft from mid of diffuser)	73	73	73	73	73	14	20	21	15
W3 (3 ft from mid of diffuser)	73	73	73	73	73	14	15	15	8
W4 (4 ft from mid of diffuser)	73	73	73	73	73	15	19	17	14
W5 (5 ft from mid of diffuser)	73	73	73	73	73	16	14	17	12
W6 (6 ft from mid of diffuser)	73	73	73	73	73	18	11	13	14
W7 (7 ft from mid of diffuser)	73	73	73	73	73	12	14	12	19
W8 (8 ft from mid of diffuser)	73	73	73	73	73	16	20	20	16
W9 (9 ft from mid of diffuser)	73	73	73	73	73	14	19	24	24
W10 (9.5 ft from mid of	73	73	73	73	73	17	23	21	15

diffuser)									

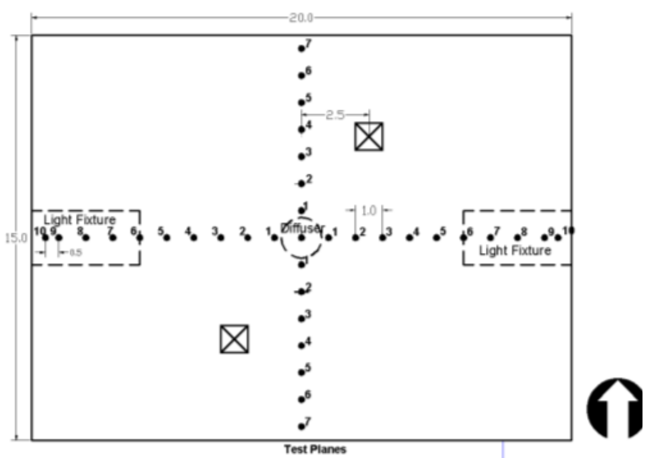
Load Distribution Layout – 8”Ø RCD (Exposed) Diffuser



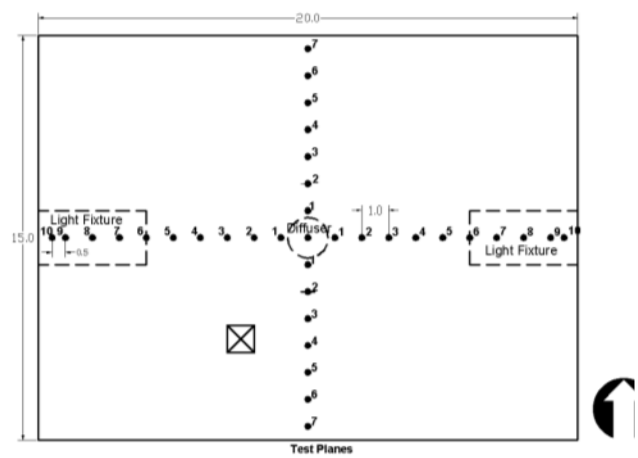
Test 11



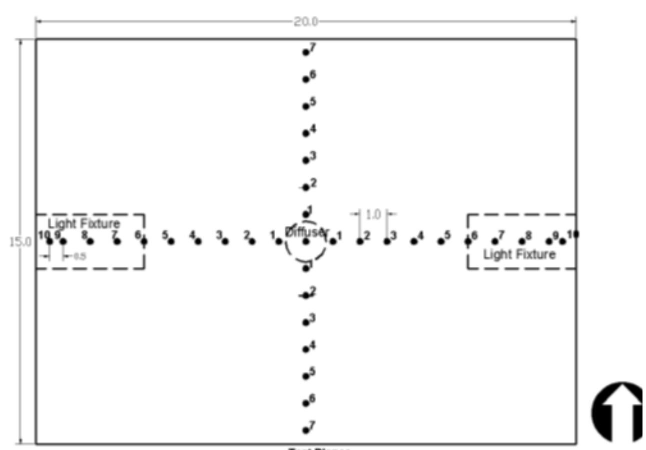
Test 12



Test 13



Test 14



Test 15

Test 11 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	55°F	72°F	20 x 15 x 9	1290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	70	71	71	71	71	40	30	18	25
N2 (2 ft from mid of diffuser)	70	71	71	71	71	14	19	21	30
N3 (3 ft from mid of diffuser)	71	71	71	71	71	25	19	24	25
N4 (4 ft from mid of diffuser)	71	71	71	71	71	22	17	19	23
N5 (5 ft from mid of diffuser)	71	71	71	71	71	25	22	21	29
N6 (6 ft from mid diffuser)	71	71	71	71	71	26	25	22	27
N7 (6.5 ft from mid of diffuser)	71	71	71	71	71	21	23	19	16
S1 (1 ft from mid of diffuser)	70	71	71	71	71	38	29	26	30
S2 (2 ft from mid of diffuser)	70	71	71	71	71	19	23	23	29
S3 (3 ft from mid of diffuser)	70	71	71	70	71	28	28	32	43
S4 (4 ft from mid of diffuser)	70	71	71	70	71	23	21	28	31
S5 (5 ft from mid of diffuser)	70	70	70	70	71	19	29	33	34
S6 (6 ft from mid of diffuser)	70	70	70	70	71	27	33	29	23
S7 (6.5 ft from mid of diffuser)	70	70	70	70	71	17	28	41	26
E1 (1 ft from mid of diffuser)	70	71	71	71	71	21	24	25	32
E2 (2 ft	71	71	71	71	71	28	18	21	31

from mid of diffuser)									
E3 (3 ft from mid of diffuser)	71	71	71	71	71	24	23	26	32
E4 (4 ft from mid of diffuser)	71	71	71	71	71	20	26	31	26
E5 (5 ft from mid of diffuser)	71	71	71	71	72	26	21	31	37
E6 (6 ft from mid of diffuser)	71	71	71	71	72	32	30	25	36
E7 (7 ft from mid of diffuser)	71	71	71	71	71	19	18	18	19
E8 (8 ft from mid of diffuser)	71	71	71	71	71	18	27	20	19
E9 (9 ft from mid of diffuser)	71	71	71	71	71	21	28	32	24
E10 (9.5 ft from mid of diffuser)	71	71	71	72	71	17	26	34	32
Middle of room	71	71	71	71	71	28	24	21	34
W1 (1 ft from mid of diffuser)	70	71	71	71	72	31	34	33	33
W2 (2 ft from mid of diffuser)	70	71	72	72	72	37	20	22	28
W3 (3 ft from mid of diffuser)	71	71	72	71	72	32	21	19	27
W4 (4 ft from mid of diffuser)	71	72	72	71	72	45	23	15	29
W5 (5 ft from mid of diffuser)	71	71	71	71	72	52	19	18	36
W6 (6 ft from mid of diffuser)	71	71	72	72	72	48	15	19	25
W7 (7 ft from mid of diffuser)	71	71	71	72	72	29	17	19	21
W8 (8 ft from mid of diffuser)	71	71	71	71	71	15	19	12	12
W9 (9 ft from mid of diffuser)	71	71	71	71	71	19	16	24	24

W10 (9.5 ft from mid of diffuser)	71	71	71	71	72	23	22	29	24

Test 12 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	55°F	72°F	20 x 15 x 9	790 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	69	69	69	68	70	22	47	47	40
N2 (2 ft from mid of diffuser)	69	69	69	70	70	26	32	39	40
N3 (3 ft from mid of diffuser)	69	70	70	70	70	23	21	15	15
N4 (4 ft from mid of diffuser)	69	70	70	71	70	20	14	12	22
N5 (5 ft from mid of diffuser)	70	70	70	71	70	14	15	21	18
N6 (6 ft from mid diffuser)	70	70	70	71	70	14	11	15	28
N7 (6.5 ft from mid of diffuser)	70	70	70	71	70	11	11	13	10
S1 (1 ft from mid of diffuser)	69	69	69	68	70	22	52	50	54
S2 (2 ft from mid of diffuser)	69	69	69	69	70	23	36	33	58
S3 (3 ft from mid of diffuser)	69	70	70	70	70	32	25	25	25
S4 (4 ft from mid of diffuser)	69	70	70	70	70	30	22	17	24
S5 (5 ft from mid of diffuser)	70	70	71	71	70	22	16	17	26
S6 (6 ft from mid of diffuser)	70	70	71	71	70	16	19	22	25
S7 (6.5 ft	70	70	70	71	70	14	25	18	20

from mid of diffuser)									
E1 (1 ft from mid of diffuser)	69	69	69	68	70	24	52	55	38
E2 (2 ft from mid of diffuser)	69	70	69	69	70	20	33	49	45
E3 (3 ft from mid of diffuser)	69	70	70	70	71	22	14	15	14
E4 (4 ft from mid of diffuser)	69	70	70	70	71	16	13	17	12
E5 (5 ft from mid of diffuser)	70	70	70	71	71	12	18	14	9
E6 (6 ft from mid of diffuser)	70	70	70	71	71	10	14	12	9
E7 (7 ft from mid of diffuser)	70	70	70	71	71	11	12	15	6
E8 (8 ft from mid of diffuser)	70	70	70	71	70	11	11	13	4
E9 (9 ft from mid of diffuser)	70	70	70	71	70	12	19	9	9
E10 (9.5 ft from mid of diffuser)	70	70	70	71	70	19	20	18	12
Middle of room	69	69	69	69	70	20	47	52	51
W1 (1 ft from mid of diffuser)	69	69	69	68	71	23	56	54	50
W2 (2 ft from mid of diffuser)	69	70	70	70	71	28	42	38	43
W3 (3 ft from mid of diffuser)	69	70	70	70	71	26	20	19	21
W4 (4 ft from mid of diffuser)	70	70	70	71	71	19	11	15	6
W5 (5 ft from mid of diffuser)	70	70	70	71	70	18	8	9	10
W6 (6 ft from mid of diffuser)	70	70	70	71	71	14	5	9	9
W7 (7 ft from mid of diffuser)	70	70	70	71	71	12	9	7	10

W8 (8 ft from mid of diffuser)	70	70	70	71	71	11	9	12	8
W9 (9 ft from mid of diffuser)	70	70	70	71	71	12	18	17	10
W10 (9.5 ft from mid of diffuser)	70	70	70	71	71	15	17	14	8

Test 13 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	68	68	68	68	70	24	66	64	41
N2 (2 ft from mid of diffuser)	68	69	69	70	70	23	33	25	28
N3 (3 ft from mid of diffuser)	69	69	69	70	70	20	12	11	12
N4 (4 ft from mid of diffuser)	69	69	69	70	70	15	10	8	4
N5 (5 ft from mid of diffuser)	69	70	70	70	70	11	10	7	6
N6 (6 ft from mid diffuser)	69	70	70	70	70	13	7	5	8
N7 (6.5 ft from mid of diffuser)	69	70	70	70	70	15	12	4	2
S1 (1 ft from mid of diffuser)	68	69	69	68	70	25	71	65	37
S2 (2 ft from mid of diffuser)	68	69	69	69	70	20	38	39	40
S3 (3 ft from mid of diffuser)	69	69	69	70	70	25	14	14	13
S4 (4 ft from mid of diffuser)	69	70	70	70	70	19	14	16	23
S5 (5 ft	69	70	70	70	70	15	7	8	8

from mid of diffuser)									
S6 (6 ft from mid of diffuser)	69	70	70	70	70	11	12	12	8
S7 (6.5 ft from mid of diffuser)	70	70	70	70	70	10	21	21	9
E1 (1 ft from mid of diffuser)	69	69	69	68	70	30	61	58	45
E2 (2 ft from mid of diffuser)	69	70	70	70	70	24	12	14	37
E3 (3 ft from mid of diffuser)	69	70	70	70	70	15	12	21	25
E4 (4 ft from mid of diffuser)	69	70	70	71	70	15	14	13	13
E5 (5 ft from mid of diffuser)	70	70	70	71	70	13	12	12	14
E6 (6 ft from mid of diffuser)	70	70	70	71	70	11	15	10	11
E7 (7 ft from mid of diffuser)	70	70	70	71	70	11	14	8	12
E8 (8 ft from mid of diffuser)	70	70	70	71	70	9	6	7	5
E9 (9 ft from mid of diffuser)	70	70	70	71	70	13	16	11	8
E10 (9.5 ft from mid of diffuser)	69	69	69	69	70	14	16	14	2
Middle of room	69	69	69	68	70	22	56	64	39
W1 (1 ft from mid of diffuser)	69	69	69	68	70	30	64	64	50
W2 (2 ft from mid of diffuser)	69	70	69	69	70	23	16	13	18
W3 (3 ft from mid of diffuser)	69	70	70	70	70	23	14	10	7
W4 (4 ft from mid of diffuser)	69	70	70	71	71	14	15	9	3
W5 (5 ft from mid of diffuser)	70	70	70	71	71	13	11	11	8

W6 (6 ft from mid of diffuser)	70	70	70	71	70	15	12	9	9
W7 (7 ft from mid of diffuser)	70	70	70	71	70	15	8	4	3
W8 (8 ft from mid of diffuser)	70	70	70	71	71	11	6	2	4
W9 (9 ft from mid of diffuser)	70	70	70	71	71	26	7	9	4
W10 (9.5 ft from mid of diffuser)	70	70	70	71	71	18	14	13	9

Test 14 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	55°F	72°F	20 x 15 x 9	415 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	69	69	69	68	71	37	54	55	48
N2 (2 ft from mid of diffuser)	69	70	70	70	71	31	37	30	17
N3 (3 ft from mid of diffuser)	69	70	70	70	71	16	9	9	3
N4 (4 ft from mid of diffuser)	69	70	70	71	71	12	11	8	0
N5 (5 ft from mid of diffuser)	70	70	70	71	71	11	9	1	6
N6 (6 ft from mid diffuser)	70	70	70	70	71	8	9	10	7
N7 (6.5 ft from mid of diffuser)	70	70	70	70	71	8	16	13	7
S1 (1 ft from mid of diffuser)	68	69	68	68	71	37	85	79	43
S2 (2 ft from mid of diffuser)	68	69	69	69	71	25	41	36	19
S3 (3 ft	69	69	70	70	71	21	20	13	20

from mid of diffuser)									
S4 (4 ft from mid of diffuser)	70	70	70	71	71	17	9	6	11
S5 (5 ft from mid of diffuser)	70	70	70	71	71	13	7	6	5
S6 (6 ft from mid of diffuser)	70	70	70	71	71	13	10	4	7
S7 (6.5 ft from mid of diffuser)	70	70	70	71	71	21	23	23	14
E1 (1 ft from mid of diffuser)	69	69	69	69	71	35	59	58	54
E2 (2 ft from mid of diffuser)	69	70	70	70	71	27	10	10	7
E3 (3 ft from mid of diffuser)	69	70	70	70	71	19	18	16	15
E4 (4 ft from mid of diffuser)	69	70	70	70	71	13	14	16	10
E5 (5 ft from mid of diffuser)	69	70	70	71	71	9	8	13	9
E6 (6 ft from mid of diffuser)	70	70	70	71	71	8	6	9	8
E7 (7 ft from mid of diffuser)	70	70	70	70	71	10	6	7	14
E8 (8 ft from mid of diffuser)	70	70	70	71	71	10	9	4	7
E9 (9 ft from mid of diffuser)	70	70	70	70	71	12	8	8	2
E10 (9.5 ft from mid of diffuser)	70	70	70	70	71	19	13	13	4
Middle of room	69	68	68	68	71	27	72	69	43
W1 (1 ft from mid of diffuser)	69	69	69	68	71	33	43	46	53
W2 (2 ft from mid of diffuser)	69	70	70	70	71	22	10	8	11
W3 (3 ft from mid of diffuser)	69	70	70	70	71	19	3	8	5

W4 (4 ft from mid of diffuser)	70	70	70	70	71	13	12	12	9
W5 (5 ft from mid of diffuser)	70	70	70	71	71	12	15	13	6
W6 (6 ft from mid of diffuser)	70	70	70	71	71	18	11	8	9
W7 (7 ft from mid of diffuser)	70	70	70	71	71	19	13	10	7
W8 (8 ft from mid of diffuser)	70	70	70	71	71	19	10	5	2
W9 (9 ft from mid of diffuser)	70	70	70	71	71	18	9	7	0
W10 (9.5 ft from mid of diffuser)	70	70	70	71	71	12	12	12	10

Test 15 Conditions – RCD (Exposed) Diffuser:

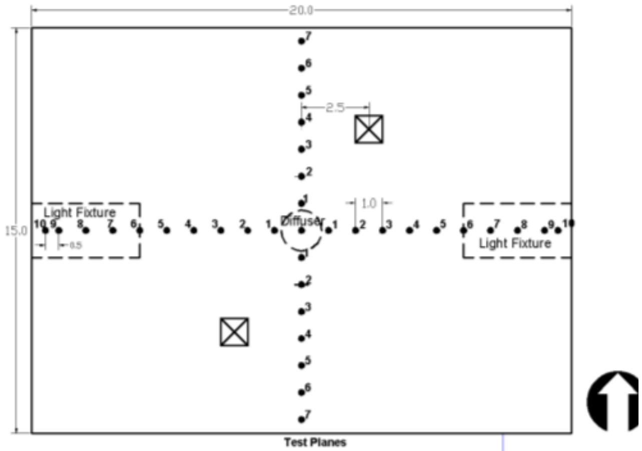
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

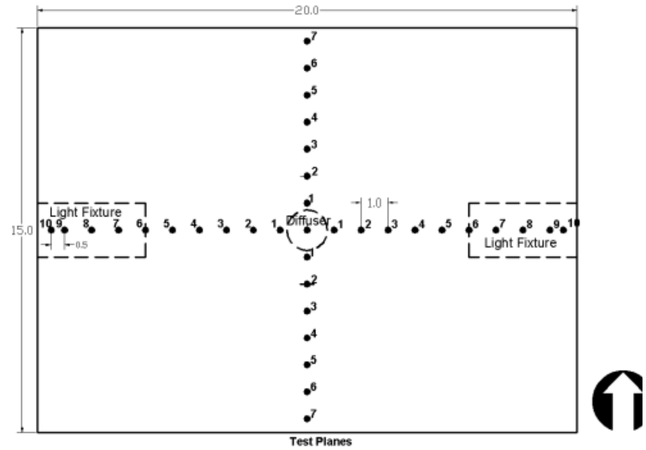
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	68	69	69	68	71	38	53	55	51
N2 (2 ft from mid of diffuser)	69	70	70	69	71	23	9	4	2
N3 (3 ft from mid of diffuser)	69	70	70	70	71	15	6	5	7
N4 (4 ft from mid of diffuser)	70	70	70	71	71	10	10	10	6
N5 (5 ft from mid of diffuser)	70	70	70	71	71	9	8	0	9
N6 (6 ft from mid diffuser)	70	70	70	71	71	11	9	6	2
N7 (6.5 ft from mid of diffuser)	70	70	70	71	71	10	13	12	4
S1 (1 ft from mid of diffuser)	69	69	69	69	71	40	54	55	51
S2 (2 ft from mid of diffuser)	69	70	70	70	71	25	24	15	3
S3 (3 ft from mid of diffuser)	69	70	70	70	71	20	14	13	11
S4 (4 ft from	69	70	70	70	71	11	12	9	5

mid of diffuser)									
S5 (5 ft from mid of diffuser)	70	70	70	70	71	9	9	7	4
S6 (6 ft from mid of diffuser)	70	70	70	71	71	7	10	10	5
S7 (6.5 ft from mid of diffuser)	70	70	70	71	71	12	14	10	11
E1 (1 ft from mid of diffuser)	68	69	69	68	70	36	57	55	45
E2 (2 ft from mid of diffuser)	69	70	70	70	71	23	10	9	11
E3 (3 ft from mid of diffuser)	69	70	70	70	71	15	12	15	13
E4 (4 ft from mid of diffuser)	69	70	70	71	71	15	16	15	16
E5 (5 ft from mid of diffuser)	70	70	70	71	71	14	16	14	12
E6 (6 ft from mid of diffuser)	70	70	71	71	71	10	9	9	8
E7 (7 ft from mid of diffuser)	70	70	70	71	70	12	11	10	10
E8 (8 ft from mid of diffuser)	70	70	70	71	71	9	12	14	12
E9 (9 ft from mid of diffuser)	70	70	70	71	71	13	15	13	7
E10 (9.5 ft from mid of diffuser)	70	70	70	71	71	13	16	11	8
Middle of room	69	68	68	68	71	40	82	79	59
W1 (1 ft from mid of diffuser)	69	70	69	69	71	37	65	63	60
W2 (2 ft from mid of diffuser)	69	69	69	69	71	27	13	11	8
W3 (3 ft from mid of diffuser)	69	70	70	70	71	14	8	9	7
W4 (4 ft from mid of diffuser)	69	70	70	70	71	8	8	9	2
W5 (5 ft from mid of diffuser)	69	70	70	70	71	6	10	6	9
W6 (6 ft from mid of diffuser)	70	70	70	70	71	12	12	12	9
W7 (7 ft from mid of diffuser)	70	70	70	70	71	14	9	9	9
W8 (8 ft from mid of diffuser)	70	70	70	70	71	16	18	15	7
W9 (9 ft from mid of diffuser)	70	70	70	70	71	15	12	10	6
W10 (9.5 ft from mid of diffuser)	70	70	70	70	71	10	14	16	14

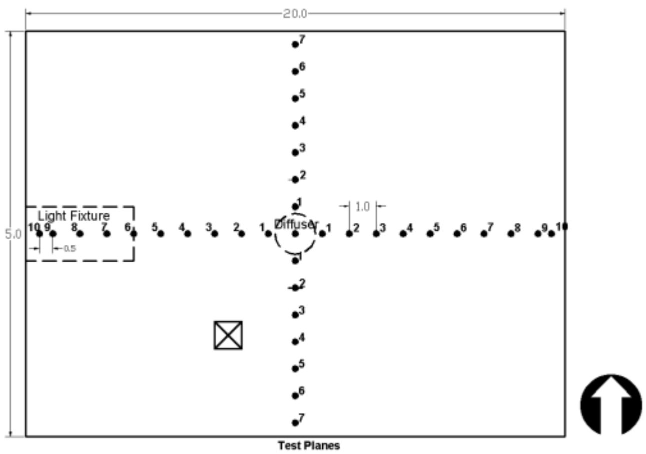
Load Distribution Layout – 8”Ø RCD (Exposed) Diffuser



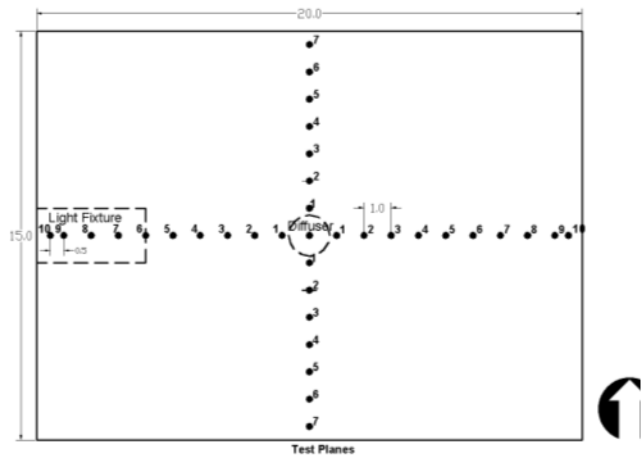
Test 16



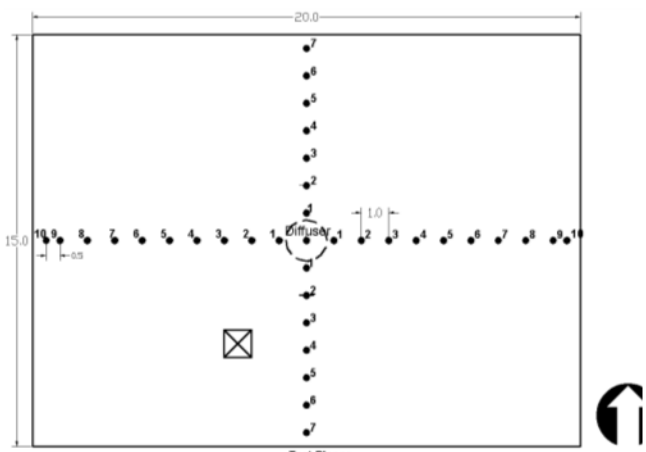
Test 17



Test 18



Test 19



Test 20

Test 16 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	65°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

Measurement points	Average Temperature (°F)					Average Velocity (ft/min)			
	4"	24"	42"	66"	Room	4"	24"	42"	66"
N1 (1 ft from mid of diffuser)	71	71	71	71	72	17	18	19	26
N2 (2 ft from mid of diffuser)	71	72	71	71	72	20	15	14	19
N3 (3 ft from mid of diffuser)	71	72	72	72	72	19	18	19	26
N4 (4 ft from mid of diffuser)	71	72	72	72	72	23	25	24	31
N5 (5 ft from mid of diffuser)	72	72	72	72	72	16	18	21	27
N6 (6 ft from mid diffuser)	72	72	72	72	72	11	20	24	16
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	24	23	27	33
S1 (1 ft from mid of diffuser)	72	72	72	72	72	19	16	17	26
S2 (2 ft from mid of diffuser)	71	72	72	72	72	17	23	24	29
S3 (3 ft from mid of diffuser)	71	72	72	72	72	17	22	27	20
S4 (4 ft from mid of diffuser)	71	72	72	72	72	14	20	22	26
S5 (5 ft from mid of diffuser)	71	71	72	72	72	21	24	32	32
S6 (6 ft from mid of diffuser)	71	72	72	72	72	20	17	18	16
S7 (6.5 ft from mid of diffuser)	71	72	72	72	72	13	18	23	19
E1 (1 ft from mid of diffuser)	71	72	72	71	72	9	21	24	25
E2 (2 ft from mid of diffuser)	71	71	71	71	72	19	15	15	25
E3 (3 ft from mid of	71	71	72	72	72	29	24	17	17

diffuser)									
E4 (4 ft from mid of diffuser)	71	71	72	72	72	28	26	17	22
E5 (5 ft from mid of diffuser)	71	72	72	72	72	29	23	15	23
E6 (6 ft from mid of diffuser)	71	72	72	72	72	22	23	23	26
E7 (7 ft from mid of diffuser)	71	72	72	72	72	20	19	19	26
E8 (8 ft from mid of diffuser)	72	72	72	72	72	15	24	23	19
E9 (9 ft from mid of diffuser)	72	72	72	72	72	16	13	17	25
E10 (9.5 ft from mid of diffuser)	72	72	72	72	72	10	21	27	21
Middle of room	71	72	72	72	72	17	23	24	34
W1 (1 ft from mid of diffuser)	71	71	71	71	72	26	19	23	28
W2 (2 ft from mid of diffuser)	71	71	71	71	72	26	13	16	25
W3 (3 ft from mid of diffuser)	71	72	71	71	72	18	24	22	23
W4 (4 ft from mid of diffuser)	71	72	72	71	72	20	26	26	22
W5 (5 ft from mid of diffuser)	71	72	72	72	72	20	23	21	26
W6 (6 ft from mid of diffuser)	71	72	72	72	72	27	22	22	23
W7 (7 ft from mid of diffuser)	71	72	72	72	72	19	19	15	16
W8 (8 ft from mid of diffuser)	71	72	72	72	72	27	14	14	16
W9 (9 ft from mid of diffuser)	71	72	72	72	72	17	22	20	14
W10 (9.5 ft from mid of diffuser)	72	72	72	72	72	13	19	23	24

Test 17 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	65°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	4"	24"	42"	66"	Room	4"	24"	42"	66"
N1 (1 ft from mid of diffuser)	71	71	71	71	71	19	16	19	21
N2 (2 ft from mid of diffuser)	71	71	71	71	71	18	16	18	22
N3 (3 ft from mid of diffuser)	71	71	71	71	71	15	15	20	28
N4 (4 ft from mid of diffuser)	71	71	71	71	71	13	14	14	24
N5 (5 ft from mid of diffuser)	71	71	71	71	71	11	15	15	15
N6 (6 ft from mid diffuser)	71	71	71	71	71	14	14	12	12
N7 (6.5 ft from mid of diffuser)	71	71	71	71	71	13	19	16	10
S1 (1 ft from mid of diffuser)	71	71	71	71	72	16	18	17	17
S2 (2 ft from mid of diffuser)	71	71	71	71	72	17	18	16	20
S3 (3 ft from mid of diffuser)	71	71	71	71	72	19	17	17	14
S4 (4 ft from mid of diffuser)	71	71	71	71	72	13	15	10	23
S5 (5 ft from mid of diffuser)	71	71	71	71	72	14	21	18	21
S6 (6 ft from mid of diffuser)	71	71	71	71	72	12	20	24	9
S7 (6.5 ft from mid of diffuser)	71	71	71	71	72	16	13	19	11
E1 (1 ft from mid of	71	71	71	71	72	10	16	15	20

diffuser)									
E2 (2 ft from mid of diffuser)	71	71	71	71	72	13	13	17	26
E3 (3 ft from mid of diffuser)	71	71	71	71	71	15	18	20	20
E4 (4 ft from mid of diffuser)	71	71	71	71	71	11	15	16	19
E5 (5 ft from mid of diffuser)	71	71	71	71	71	16	17	20	26
E6 (6 ft from mid of diffuser)	71	71	71	71	71	17	12	12	12
E7 (7 ft from mid of diffuser)	71	71	71	71	71	12	10	9	14
E8 (8 ft from mid of diffuser)	71	71	71	71	71	11	11	13	17
E9 (9 ft from mid of diffuser)	71	71	71	71	71	19	19	21	26
E10 (9.5 ft from mid of diffuser)	71	72	71	71	71	14	17	24	28
Middle of room	71	71	71	71	71	14	16	18	24
W1 (1 ft from mid of diffuser)	71	71	71	71	71	20	20	17	23
W2 (2 ft from mid of diffuser)	71	71	71	71	71	24	13	14	16
W3 (3 ft from mid of diffuser)	71	71	71	71	71	24	21	19	22
W4 (4 ft from mid of diffuser)	71	71	71	71	71	26	15	13	12
W5 (5 ft from mid of diffuser)	71	71	71	71	71	21	10	9	16
W6 (6 ft from mid of diffuser)	71	71	71	71	72	18	12	11	13
W7 (7 ft from mid of diffuser)	71	71	71	71	72	20	17	15	10
W8 (8 ft from mid of diffuser)	71	71	71	71	72	15	14	15	11

W9 (9 ft from mid of diffuser)	71	71	71	71	72	20	21	24	20
W10 (9.5 ft from mid of diffuser)	71	71	71	71	72	17	17	21	19

Test 18 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	72	72	72	72	72	14	13	14	29
N2 (2 ft from mid of diffuser)	72	72	72	72	72	6	13	17	20
N3 (3 ft from mid of diffuser)	72	72	72	72	72	12	11	15	27
N4 (4 ft from mid of diffuser)	72	72	72	72	72	13	12	12	8
N5 (5 ft from mid of diffuser)	72	72	72	72	72	11	10	12	12
N6 (6 ft from mid diffuser)	72	72	72	72	72	10	12	14	13
N7 (6.5 ft from mid of diffuser)	72	72	72	72	72	11	17	16	3
S1 (1 ft from mid of diffuser)	72	72	72	72	72	13	27	20	32
S2 (2 ft from mid of diffuser)	72	72	72	72	72	20	17	25	48
S3 (3 ft from mid of diffuser)	72	72	72	72	72	15	14	22	32
S4 (4 ft from mid of diffuser)	72	72	72	72	72	17	13	11	12
S5 (5 ft	72	72	72	72	72	13	14	17	15

from mid of diffuser)									
S6 (6 ft from mid of diffuser)	72	72	72	72	72	10	16	18	14
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	14	19	24	21
E1 (1 ft from mid of diffuser)	72	72	72	72	72	20	26	28	35
E2 (2 ft from mid of diffuser)	72	72	72	72	72	13	15	22	32
E3 (3 ft from mid of diffuser)	72	72	72	72	72	16	12	15	10
E4 (4 ft from mid of diffuser)	72	72	72	72	72	14	13	15	10
E5 (5 ft from mid of diffuser)	72	72	72	72	72	11	14	12	9
E6 (6 ft from mid of diffuser)	72	72	72	72	72	11	16	17	8
E7 (7 ft from mid of diffuser)	72	72	72	72	72	18	16	13	12
E8 (8 ft from mid of diffuser)	72	73	72	72	72	15	18	13	5
E9 (9 ft from mid of diffuser)	72	72	72	73	72	18	14	16	15
E10 (9.5 ft from mid of diffuser)	72	72	72	72	72	20	11	13	10
Middle of room	72	72	72	72	73	10	12	16	23
W1 (1 ft from mid of diffuser)	72	72	72	72	72	19	39	37	31
W2 (2 ft from mid of diffuser)	72	72	72	72	72	14	12	11	27
W3 (3 ft from mid of diffuser)	72	72	72	72	73	15	9	8	7
W4 (4 ft from mid of diffuser)	72	72	72	72	73	12	12	13	10
W5 (5 ft from mid of diffuser)	72	72	72	72	73	10	14	10	2

W6 (6 ft from mid of diffuser)	72	72	72	72	73	13	17	16	9
W7 (7 ft from mid of diffuser)	72	72	72	72	73	14	11	10	8
W8 (8 ft from mid of diffuser)	72	72	72	72	72	17	14	15	14
W9 (9 ft from mid of diffuser)	72	72	72	72	72	16	13	16	14
W10 (9.5 ft from mid of diffuser)	72	72	72	72	72	9	8	12	10

Test 19 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	65°F	72°F	20 x 15 x 9	150 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	70	71	70	70	72	14	33	32	23
N2 (2 ft from mid of diffuser)	71	71	71	71	72	13	16	17	23
N3 (3 ft from mid of diffuser)	71	71	71	71	72	9	17	16	19
N4 (4 ft from mid of diffuser)	71	71	71	71	72	10	7	9	3
N5 (5 ft from mid of diffuser)	71	71	71	71	72	9	6	8	1
N6 (6 ft from mid diffuser)	71	71	71	71	72	8	9	8	10
N7 (6.5 ft from mid of diffuser)	71	71	71	71	72	12	17	19	19
S1 (1 ft from mid of diffuser)	71	71	71	71	72	23	29	33	21
S2 (2 ft from mid of diffuser)	71	71	71	71	72	12	13	17	33
S3 (3 ft	71	71	71	71	72	17	12	16	11

from mid of diffuser)									
S4 (4 ft from mid of diffuser)	71	71	71	71	72	12	13	11	10
S5 (5 ft from mid of diffuser)	71	71	71	71	72	10	8	11	12
S6 (6 ft from mid of diffuser)	71	71	71	71	72	11	14	15	14
S7 (6.5 ft from mid of diffuser)	71	71	71	71	72	22	18	21	17
E1 (1 ft from mid of diffuser)	71	71	71	71	72	17	27	27	29
E2 (2 ft from mid of diffuser)	71	71	71	71	72	15	14	16	16
E3 (3 ft from mid of diffuser)	71	71	71	71	72	12	9	10	13
E4 (4 ft from mid of diffuser)	71	71	71	72	72	10	7	10	8
E5 (5 ft from mid of diffuser)	71	71	71	72	72	11	14	12	11
E6 (6 ft from mid of diffuser)	71	71	71	72	72	9	9	4	5
E7 (7 ft from mid of diffuser)	71	71	71	71	72	10	12	13	9
E8 (8 ft from mid of diffuser)	71	71	71	71	72	13	10	8	11
E9 (9 ft from mid of diffuser)	71	72	71	71	72	12	12	13	13
E10 (9.5 ft from mid of diffuser)	71	72	71	71	72	12	19	18	14
Middle of room	71	71	71	71	72	14	19	24	27
W1 (1 ft from mid of diffuser)	71	71	71	71	72	13	36	32	20
W2 (2 ft from mid of diffuser)	71	71	71	71	72	18	14	13	17
W3 (3 ft from mid of diffuser)	71	71	71	71	72	14	6	8	9

W4 (4 ft from mid of diffuser)	71	71	71	71	72	10	13	8	6
W5 (5 ft from mid of diffuser)	71	71	71	71	72	10	10	11	10
W6 (6 ft from mid of diffuser)	71	71	71	71	72	14	12	13	5
W7 (7 ft from mid of diffuser)	71	71	71	71	72	18	13	8	2
W8 (8 ft from mid of diffuser)	71	71	71	71	72	18	11	13	12
W9 (9 ft from mid of diffuser)	71	71	71	71	72	11	10	7	9
W10 (9.5 ft from mid of diffuser)	71	71	71	71	72	14	14	18	20

Test 20 Conditions – RCD (Exposed) Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

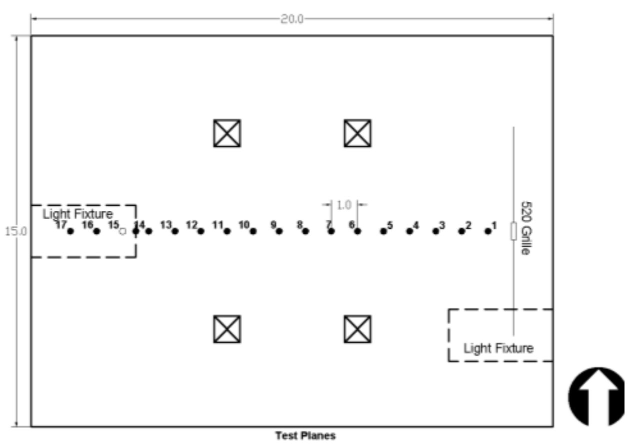
Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (1 ft from mid of diffuser)	71	71	71	71	72	21	31	33	30
N2 (2 ft from mid of diffuser)	71	72	72	72	72	14	7	9	11
N3 (3 ft from mid of diffuser)	72	72	72	72	72	7	6	7	7
N4 (4 ft from mid of diffuser)	72	72	72	72	72	8	10	8	2
N5 (5 ft from mid of diffuser)	72	72	72	73	72	8	10	10	10
N6 (6 ft from mid diffuser)	72	72	72	73	72	8	8	10	0
N7 (6.5 ft from mid of diffuser)	72	72	72	73	72	10	9	7	7
S1 (1 ft	72	72	72	72	72	24	31	35	41

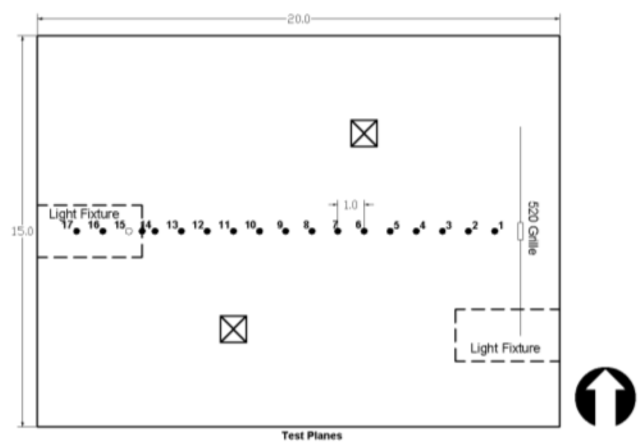
from mid of diffuser)									
S2 (2 ft from mid of diffuser)	72	72	72	72	72	18	10	11	14
S3 (3 ft from mid of diffuser)	72	72	72	72	72	19	8	17	21
S4 (4 ft from mid of diffuser)	72	72	72	72	72	16	17	19	15
S5 (5 ft from mid of diffuser)	72	72	72	72	72	12	12	17	8
S6 (6 ft from mid of diffuser)	72	72	72	72	72	10	13	13	10
S7 (6.5 ft from mid of diffuser)	72	72	72	72	72	17	16	21	12
E1 (1 ft from mid of diffuser)	72	72	72	72	72	20	27	30	30
E2 (2 ft from mid of diffuser)	72	72	72	72	72	15	9	9	7
E3 (3 ft from mid of diffuser)	72	72	72	73	72	12	12	12	10
E4 (4 ft from mid of diffuser)	72	72	72	73	73	15	15	15	10
E5 (5 ft from mid of diffuser)	72	72	72	73	72	13	12	11	11
E6 (6 ft from mid of diffuser)	72	72	72	73	72	14	14	11	9
E7 (7 ft from mid of diffuser)	72	72	72	73	72	13	11	9	8
E8 (8 ft from mid of diffuser)	72	72	72	73	72	7	9	7	9
E9 (9 ft from mid of diffuser)	72	72	72	73	72	15	13	8	4
E10 (9.5 ft from mid of diffuser)	72	72	72	73	72	12	13	16	8
Middle of room	72	72	72	72	72	14	43	47	32
W1 (1 ft from mid of diffuser)	72	72	72	72	72	18	32	35	20

W2 (2 ft from mid of diffuser)	72	72	72	73	72	18	8	5	11
W3 (3 ft from mid of diffuser)	72	72	72	73	72	11	20	15	8
W4 (4 ft from mid of diffuser)	72	72	72	73	73	10	16	7	5
W5 (5 ft from mid of diffuser)	72	72	72	73	72	11	15	9	6
W6 (6 ft from mid of diffuser)	72	72	72	73	73	11	11	10	5
W7 (7 ft from mid of diffuser)	72	72	72	73	73	11	9	8	8
W8 (8 ft from mid of diffuser)	72	72	72	73	73	13	6	7	6
W9 (9 ft from mid of diffuser)	72	72	72	73	73	9	8	8	2
W10 (9.5 ft from mid of diffuser)	72	72	72	73	72	10	4	10	2

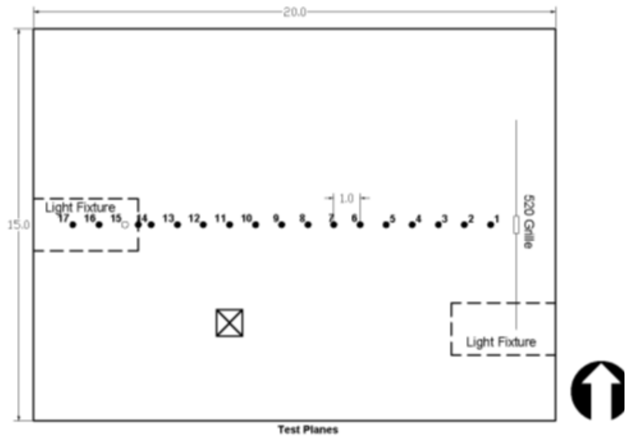
Load Distribution Layout - 520 Grille 8x6



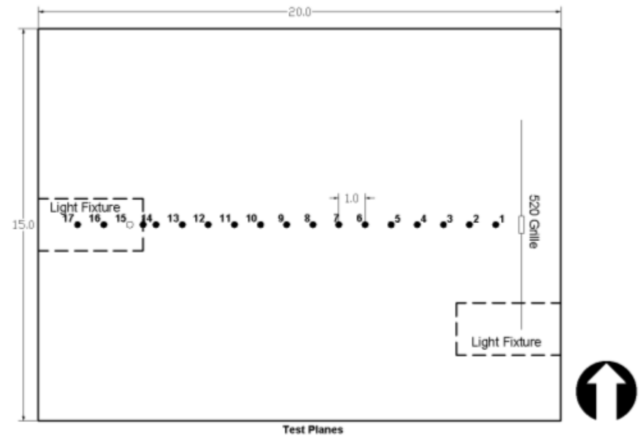
Test 21



Test 22



Test 23



Test 24

Test 21 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	55°F	72°F	20 x 15 x 9	790 watts

Plane East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	71	71	71	71	71	28	23	21	22
E2 (2 ft from wall)	71	71	71	71	71	21	24	20	16
E3 (3 ft from wall)	71	71	71	71	71	33	30	24	26
E4 (4 ft from wall)	71	71	71	71	71	31	34	27	24
E5 (5 ft from wall)	71	71	71	71	71	24	32	29	27
E6 (6 ft from wall)	71	71	71	71	71	23	25	21	21
E7 (7 ft from wall)	71	71	71	71	71	43	36	29	29
E8 (8 ft from wall)	71	71	71	71	71	43	30	30	37
E9 (9 ft from wall)	71	71	71	71	71	38	25	37	49
E10 (10 ft from wall)	70	71	71	71	71	49	34	27	37
E11 (11 ft from wall)	70	71	71	70	71	47	36	36	56
E12 (12 ft from wall)	70	71	71	70	71	55	25	34	66
E13 (13	70	71	71	70	71	41	31	37	90

ft from wall)									
E14 (14 ft from wall)	70	71	71	70	71	59	27	31	73
E15 (15 ft from wall)	70	71	71	70	71	63	27	24	36
E16 (16 ft from wall)	70	71	70	70	71	62	24	27	40
E17 (17 ft from wall)	70	70	71	71	71	63	34	44	39

Test 22 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	71	71	71	71	71	22	19	21	21
E2 (2 ft from wall)	71	71	71	71	71	19	21	20	18
E3 (3 ft from wall)	71	71	71	71	71	17	17	22	19
E4 (4 ft from wall)	71	71	71	71	71	15	23	18	22
E5 (5 ft from wall)	71	71	71	71	71	13	12	11	15
E6 (6 ft from wall)	71	71	71	70	71	15	16	14	38
E7 (7 ft from wall)	71	71	71	70	70	17	12	10	33

E8 (8 ft from wall)	71	71	71	70	71	13	14	12	53
E9 (9 ft from wall)	71	71	71	70	71	19	22	20	108
E10 (10 ft from wall)	71	71	71	69	71	16	21	35	135
E11 (11 ft from wall)	71	71	71	69	71	31	13	18	121
E12 (12 ft from wall)	71	71	70	69	71	32	23	63	103
E13 (13 ft from wall)	70	70	69	70	71	20	64	115	78
E14 (14 ft from wall)	70	70	69	70	70	32	48	80	73
E15 (15 ft from wall)	70	70	69	70	70	29	106	120	27
E16 (16 ft from wall)	70	70	70	71	71	41	51	72	50
E17 (17 ft from wall)	70	70	70	71	71	45	66	76	25

Test 23 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	55°F	72°F	20 x 15 x 9	415 watts

Plane East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	70	71	71	71	70	19	13	15	14
E2 (2 ft from wall)	70	71	71	71	70	16	12	14	17
E3 (3 ft from wall)	71	71	71	71	70	20	15	14	24
E4 (4 ft from wall)	71	71	71	71	70	21	18	17	30
E5 (5 ft from wall)	71	71	71	71	70	15	20	9	24
E6 (6 ft from wall)	70	71	71	70	70	22	12	15	29
E7 (7 ft from wall)	70	70	70	69	70	18	15	15	56

E8 (8 ft from wall)	70	71	71	69	70	16	18	23	96
E9 (9 ft from wall)	70	70	70	69	70	13	12	27	80
E10 (10 ft from wall)	70	70	70	69	70	19	15	29	90
E11 (11 ft from wall)	70	70	70	69	70	18	19	59	82
E12 (12 ft from wall)	70	70	69	70	70	21	43	63	30
E13 (13 ft from wall)	70	70	69	70	70	27	77	81	18
E14 (14 ft from wall)	70	70	70	71	70	29	40	44	26
E15 (15 ft from wall)	70	70	70	71	70	29	68	59	10
E16 (16 ft from wall)	70	70	70	71	70	33	58	26	10
E17 (17 ft from wall)	69	70	70	71	70	42	40	21	17

Test 24 Conditions – 520 Grille 8x6:

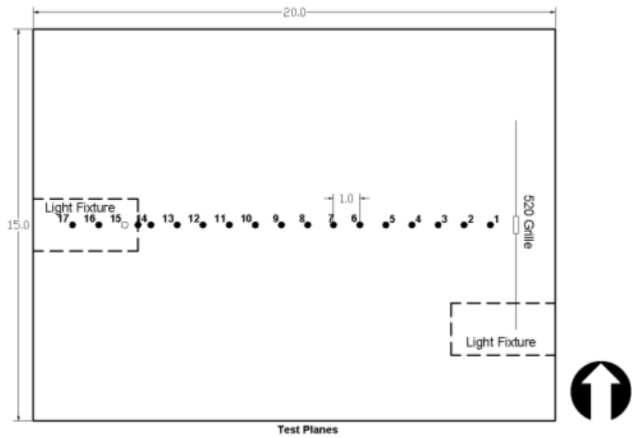
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

Plane East > West

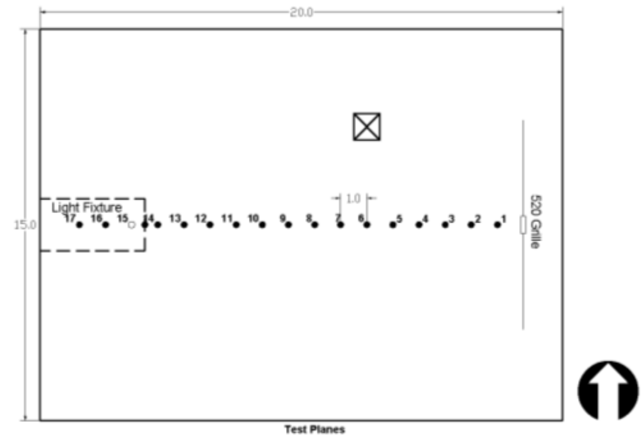
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	70	70	70	70	70	15	20	22	21
E2 (2 ft	70	70	70	70	70	17	13	6	2

from wall)									
E3 (3 ft from wall)	70	70	70	70	70	17	11	3	1
E4 (4 ft from wall)	70	70	70	70	70	20	15	10	11
E5 (5 ft from wall)	70	70	70	69	70	20	14	9	55
E6 (6 ft from wall)	70	70	70	68	70	21	7	13	81
E7 (7 ft from wall)	70	70	70	68	70	19	5	29	118
E8 (8 ft from wall)	70	70	69	67	70	14	29	63	119
E9 (9 ft from wall)	70	70	69	68	70	20	33	73	89
E10 (10 ft from wall)	69	69	69	69	70	23	37	79	43
E11 (11 ft from wall)	69	69	68	70	70	32	84	97	24
E12 (12 ft from wall)	69	68	69	70	70	32	89	75	17
E13 (13 ft from wall)	69	69	69	70	70	40	90	42	13
E14 (14 ft from wall)	69	69	70	70	70	57	72	27	9
E15 (15 ft from wall)	69	69	70	70	70	60	43	14	10
E16 (16 ft from wall)	69	70	70	70	70	65	18	8	8
E17 (17 ft from wall)	69	70	70	70	70	60	19	6	4

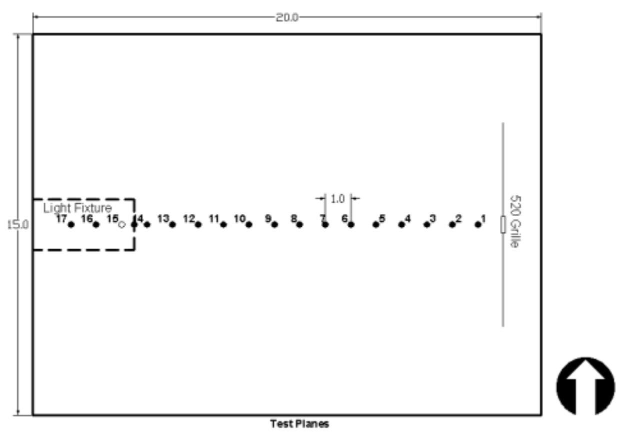
Load Distribution Layout - 520 Grille 8x6



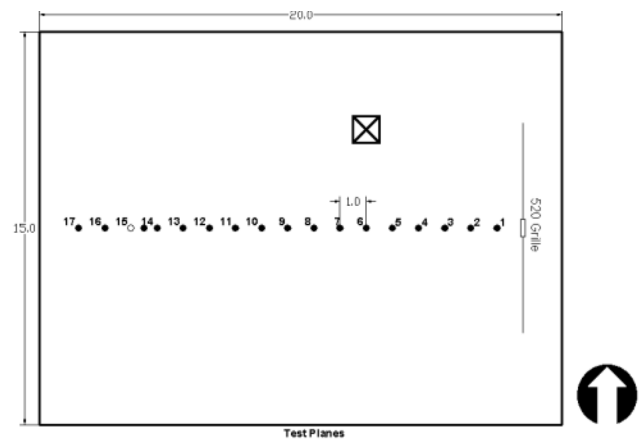
Test 25



Test 26



Test 27



Test 28

Test 25 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	65°F	72°F	20 x 15 x 9	290 watts

Plane East > West

Measurement points	Average Temperature (°F)					Average Velocity (ft/min)			
	4"	24"	42"	66"	Room	4"	24"	42"	66"
E1 (1 ft from wall)	71	71	71	71	70	22	21	22	20
E2 (2 ft from wall)	71	71	71	71	70	15	16	18	18
E3 (3 ft from wall)	71	71	71	71	70	25	26	17	13
E4 (4 ft from wall)	71	71	71	71	70	18	9	11	12
E5 (5 ft from wall)	71	71	71	71	71	25	19	16	10
E6 (6 ft from wall)	71	71	71	71	71	27	16	13	19
E7 (7 ft from wall)	71	71	71	71	71	33	23	16	26
E8 (8 ft from wall)	71	71	71	71	71	39	20	17	42
E9 (9 ft from wall)	71	71	71	70	71	36	20	16	79
E10 (10 ft from wall)	71	71	71	70	71	37	16	20	97
E11 (11 ft from wall)	71	71	71	70	71	42	24	21	104
E12 (12 ft from wall)	71	71	71	70	71	55	16	18	114
E13 (13 ft from wall)	71	71	71	70	71	60	19	18	96
E14 (14 ft from wall)	71	71	71	70	71	56	19	21	111
E15 (15 ft from wall)	71	71	71	70	71	55	13	30	107
E16 (16 ft from wall)	71	71	71	70	71	60	13	22	91
E17 (17 ft from wall)	71	71	71	70	71	58	21	50	91

Test 26 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	71	71	71	71	71	16	16	13	12
E2 (2 ft from wall)	71	72	71	71	71	15	17	21	17
E3 (3 ft from wall)	72	72	72	72	71	16	15	14	19
E4 (4 ft from wall)	72	72	72	72	71	14	16	14	19
E5 (5 ft from wall)	72	72	72	72	71	15	17	17	17
E6 (6 ft from wall)	72	72	72	72	71	20	16	13	15
E7 (7 ft from wall)	72	72	72	72	72	17	11	13	22
E8 (8 ft from wall)	72	72	72	72	72	27	17	21	20
E9 (9 ft from wall)	72	72	72	72	72	31	17	9	26
E10 (10 ft from wall)	72	72	72	71	72	38	16	17	26
E11 (11 ft from wall)	72	72	72	71	72	32	13	17	55
E12 (12 ft from wall)	72	72	72	71	72	42	18	13	38
E13 (13 ft from wall)	72	72	72	71	72	40	12	19	89
E14 (14 ft from wall)	72	72	72	71	72	43	13	29	80
E15 (15 ft from wall)	72	72	72	71	72	42	19	39	76
E16 (16 ft from wall)	72	72	72	71	72	35	31	61	77
E17 (17 ft from wall)	72	72	72	72	72	20	43	62	40

Test 27 Conditions – 520 Grille 8x6:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	65°F	72°F	20 x 15 x 9	150 watts

Plane East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measure ment points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	72	72	72	72	71	15	13	13	10
E2 (2 ft from wall)	72	72	72	72	71	12	11	10	7
E3 (3 ft from wall)	72	72	72	72	71	21	18	13	11
E4 (4 ft from wall)	72	72	72	72	71	13	12	7	10
E5 (5 ft from wall)	72	72	72	72	71	17	15	9	14
E6 (6 ft from wall)	72	72	72	71	71	11	14	13	21
E7 (7 ft from wall)	71	72	71	71	71	15	12	11	49
E8 (8 ft from wall)	72	72	72	71	71	10	12	12	68
E9 (9 ft from wall)	72	72	71	71	71	14	10	19	75
E10 (10 ft from wall)	72	72	71	70	71	10	15	18	90
E11 (11 ft from wall)	72	72	71	71	71	10	19	38	74
E12 (12 ft from wall)	72	72	71	71	71	14	19	43	74

E13 (13 ft from wall)	72	71	71	71	71	14	37	65	45
E14 (14 ft from wall)	71	71	71	71	71	24	39	52	26
E15 (15 ft from wall)	71	71	71	71	71	24	50	75	23
E16 (16 ft from wall)	71	71	71	71	71	27	55	46	23
E17 (17 ft from wall)	71	71	71	71	71	24	56	56	25

Test 28 Conditions – 520 Grille 8x6:

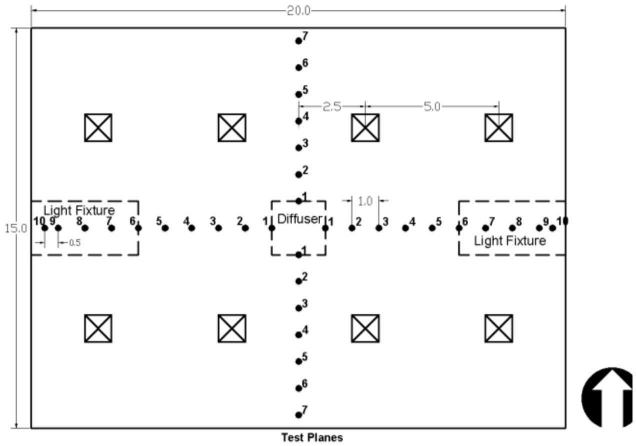
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

Plane East > West

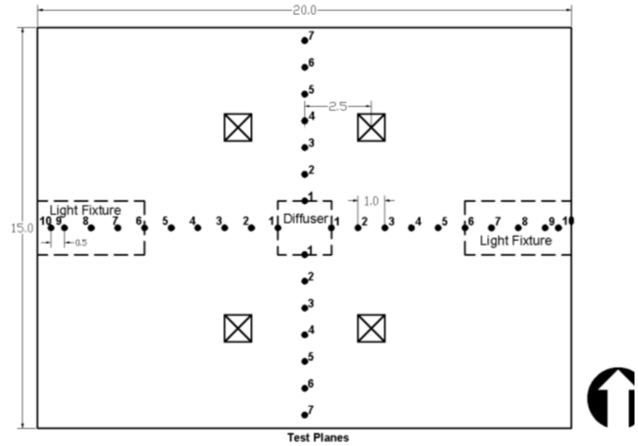
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
E1 (1 ft from wall)	72	72	72	72	72	11	7	9	2
E2 (2 ft from wall)	72	72	72	72	72	4	9	3	5
E3 (3 ft from wall)	72	72	72	72	72	12	10	10	8
E4 (4 ft from wall)	72	72	72	72	72	10	12	12	9
E5 (5 ft from wall)	72	72	72	72	72	10	9	9	9
E6 (6 ft from wall)	72	72	72	72	72	5	11	9	23

E7 (7 ft from wall)	72	72	72	72	72	9	13	12	13
E8 (8 ft from wall)	72	72	72	72	72	11	12	11	64
E9 (9 ft from wall)	72	72	72	71	72	14	12	12	52
E10 (10 ft from wall)	72	72	72	71	72	13	13	30	72
E11 (11 ft from wall)	72	72	72	72	72	17	16	40	56
E12 (12 ft from wall)	72	72	72	72	72	17	12	30	47
E13 (13 ft from wall)	72	72	72	72	72	25	11	24	55
E14 (14 ft from wall)	72	72	72	72	72	23	46	47	9
E15 (15 ft from wall)	72	72	72	72	72	24	21	13	2
E16 (16 ft from wall)	72	72	72	72	72	28	21	12	10
E17 (17 ft from wall)	72	72	72	72	72	22	24	17	13

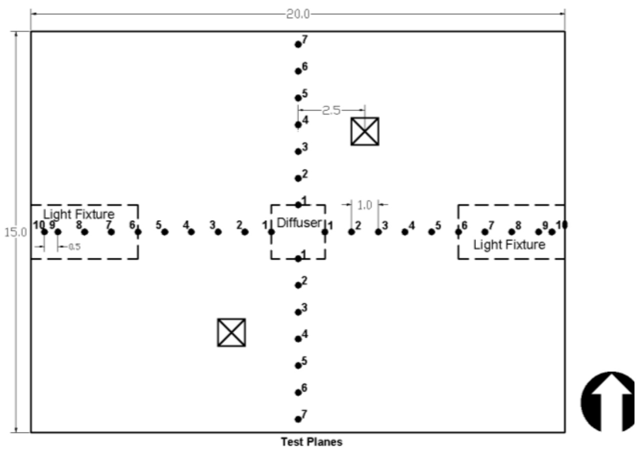
Load Distribution Layout - PDF Diffuser



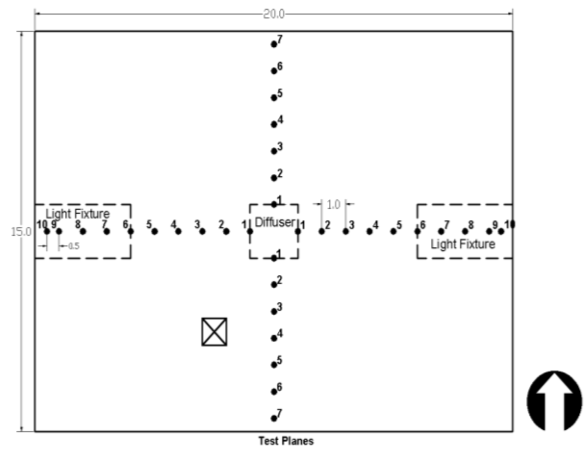
Test 29



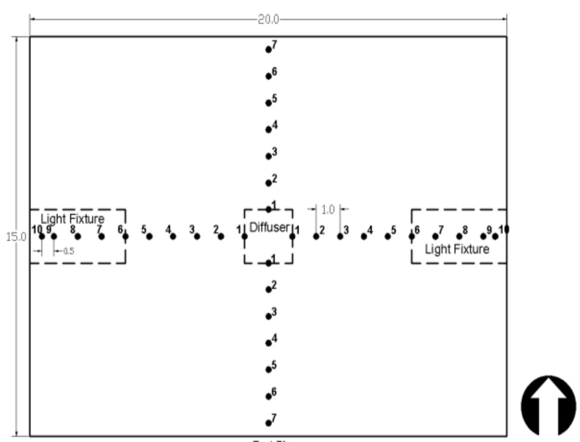
Test 30



Test 31



Test 32



Test 33

Test 29 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	55°F	72°F	20 x 15 x 9	1290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	25	16	19	16
N2 (1 ft from diffuser)	71	72	71	71	72	27	37	28	25
N3 (2 ft from diffuser)	70	71	71	71	72	28	28	22	15
N4 (3 ft from diffuser)	70	71	71	70	72	20	27	31	31
N5 (4 ft from diffuser)	70	71	71	70	72	30	20	25	28
N6 (5 ft from diffuser)	70	71	70	70	71	23	24	26	27
N7 (5.5 ft from diffuser)	70	70	70	70	72	20	24	24	25
S1 (Edge of diffuser)	71	71	71	71	72	23	18	19	21
S2 (1 ft from diffuser)	71	71	71	71	72	25	43	43	40
S3 (2 ft from diffuser)	71	71	71	71	72	17	27	27	27
S4 (3 ft from diffuser)	71	71	71	71	72	21	15	30	32
S5 (4 ft from diffuser)	71	71	71	71	72	22	23	29	36
S6 (5 ft from diffuser)	71	71	71	71	72	18	20	19	27
S7 (5.5 ft from diffuser)	71	71	71	71	72	13	22	24	33
E1 (Edge of diffuser)	70	71	71	70	72	28	19	25	29
E2 (1 ft from diffuser)	71	71	71	71	72	24	32	22	24
E3 (2 ft from diffuser)	71	71	71	71	72	21	25	28	22
E4 (3 ft from diffuser)	71	71	71	71	71	41	29	30	22
E5 (4 ft from diffuser)	71	71	71	71	71	31	25	15	17
E6 (5 ft from diffuser)	71	71	72	72	71	38	28	31	24
E7 (6 ft from diffuser)	71	72	72	72	72	34	29	31	25
E8 (7 ft from diffuser)	71	72	72	72	72	29	24	25	30
E9 (8 ft	71	72	72	72	72	39	22	24	22

from diffuser)									
E10 (8.5 ft from diffuser)	71	71	71	71	72	27	25	26	24
W1 (Edge of diffuser)	71	71	71	71	72	24	20	28	27
W2 (1 ft from diffuser)	71	71	71	71	72	15	21	22	17
W3 (2 ft from diffuser)	71	71	71	71	72	19	16	22	18
W4 (3 ft from diffuser)	71	71	71	72	72	13	21	18	24
W5 (4 ft from diffuser)	71	71	71	72	72	14	20	24	14
W6 (5 ft from diffuser)	71	71	71	72	72	17	17	20	19
W7 (6 ft from diffuser)	71	71	71	72	72	15	23	20	12
W8 (7 ft from diffuser)	71	71	71	71	72	15	20	16	14
W9 (8 ft from diffuser)	71	71	71	71	72	19	21	19	11
W10 (8.5 ft from diffuser)	71	71	71	71	72	17	21	22	17

Test 30 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	55°F	72°F	20 x 15 x 9	790 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	70	72	15	27	35	31
N2 (1 ft from diffuser)	71	71	71	71	72	18	21	30	18
N3 (2 ft from diffuser)	71	71	71	71	72	17	13	24	20
N4 (3 ft from diffuser)	71	71	71	71	72	16	23	31	30
N5 (4 ft from diffuser)	71	71	71	72	72	15	14	11	18
N6 (5 ft from diffuser)	71	71	71	72	71	15	16	20	24
N7 (5.5 ft from diffuser)	71	71	71	72	72	12	17	25	29
S1 (Edge	71	71	71	70	71	15	27	31	33

of diffuser)									
S2 (1 ft from diffuser)	71	71	70	71	72	15	24	35	18
S3 (2 ft from diffuser)	71	71	71	71	72	19	20	14	20
S4 (3 ft from diffuser)	71	71	71	71	72	17	20	22	21
S5 (4 ft from diffuser)	71	71	71	72	71	16	15	14	20
S6 (5 ft from diffuser)	71	71	71	72	72	11	17	17	16
S7 (5.5 ft from diffuser)	71	71	71	72	72	18	25	29	30
E1 (Edge of diffuser)	71	71	71	71	72	11	19	22	28
E2 (1 ft from diffuser)	71	71	71	71	72	17	18	15	19
E3 (2 ft from diffuser)	71	71	71	71	72	19	17	23	28
E4 (3 ft from diffuser)	71	71	71	71	72	26	22	16	24
E5 (4 ft from diffuser)	71	71	71	72	72	21	15	12	12
E6 (5 ft from diffuser)	71	71	71	72	72	15	12	14	9
E7 (6 ft from diffuser)	71	71	72	72	72	14	11	8	10
E8 (7 ft from diffuser)	71	72	71	72	72	15	11	18	16
E9 (8 ft from diffuser)	72	72	72	72	72	12	18	16	16
E10 (8.5 ft from diffuser)	71	71	71	72	72	14	21	17	17
W1 (Edge of diffuser)	71	71	71	71	72	14	26	35	37
W2 (1 ft from diffuser)	71	71	71	71	72	16	15	29	28
W3 (2 ft from diffuser)	71	71	71	71	72	12	28	36	39
W4 (3 ft from diffuser)	71	71	71	71	72	17	18	20	21
W5 (4 ft from diffuser)	71	71	71	72	72	15	17	13	8
W6 (5 ft from diffuser)	71	72	72	72	72	15	12	11	17
W7 (6 ft from diffuser)	71	72	72	72	72	12	9	16	18
W8 (7 ft from diffuser)	71	72	72	72	72	13	15	13	16

W9 (8 ft from diffuser)	71	71	71	72	72	11	12	12	18
W10 (8.5 ft from diffuser)	72	72	72	72	72	14	19	20	11

Test 31 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	16	31	37	23
N2 (1 ft from diffuser)	71	71	71	71	72	16	23	27	30
N3 (2 ft from diffuser)	71	71	71	71	72	18	22	32	32
N4 (3 ft from diffuser)	71	71	71	71	72	18	18	17	12
N5 (4 ft from diffuser)	71	71	71	72	72	15	12	11	16
N6 (5 ft from diffuser)	71	72	72	72	72	12	14	13	13
N7 (5.5 ft from diffuser)	71	72	72	72	72	13	12	18	21
S1 (Edge of diffuser)	71	71	71	71	72	18	36	41	38
S2 (1 ft from diffuser)	71	71	71	71	72	20	36	40	27
S3 (2 ft from diffuser)	71	71	71	71	72	21	29	34	41
S4 (3 ft from diffuser)	71	71	71	71	72	18	18	19	12
S5 (4 ft from diffuser)	71	71	71	72	72	17	10	11	13
S6 (5 ft from diffuser)	71	71	72	72	72	13	15	16	14
S7 (5.5 ft from diffuser)	71	72	72	72	72	11	22	22	18
E1 (Edge of diffuser)	71	71	71	71	72	16	33	44	42
E2 (1 ft from diffuser)	71	71	71	71	72	16	24	33	24
E3 (2 ft from diffuser)	71	71	71	71	72	19	16	19	25

E4 (3 ft from diffuser)	71	72	72	72	72	19	16	18	17
E5 (4 ft from diffuser)	72	72	72	72	72	15	11	11	6
E6 (5 ft from diffuser)	72	72	72	72	72	14	15	19	15
E7 (6 ft from diffuser)	72	72	72	72	72	12	16	14	15
E8 (7 ft from diffuser)	72	72	72	72	72	8	11	10	15
E9 (8 ft from diffuser)	72	72	72	72	72	13	18	19	13
E10 (8.5 ft from diffuser)	72	72	72	72	72	24	19	23	20
W1 (Edge of diffuser)	71	71	71	71	72	18	36	44	41
W2 (1 ft from diffuser)	71	71	71	71	72	21	16	17	12
W3 (2 ft from diffuser)	71	72	72	72	72	17	19	20	19
W4 (3 ft from diffuser)	72	72	72	72	72	18	11	9	15
W5 (4 ft from diffuser)	72	72	72	72	72	15	8	5	1
W6 (5 ft from diffuser)	72	72	72	72	72	14	13	13	9
W7 (6 ft from diffuser)	72	72	72	72	72	13	10	9	10
W8 (7 ft from diffuser)	72	72	72	72	72	12	12	8	13
W9 (8 ft from diffuser)	72	72	72	72	72	15	15	12	10
W10 (8.5 ft from diffuser)	72	72	72	72	72	18	23	24	22

Test 32 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	55°F	72°F	20 x 15 x 9	415 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	17	36	36	29
N2 (1 ft from diffuser)	71	71	71	71	72	16	27	29	17

N3 (2 ft from diffuser)	71	72	72	72	72	17	16	14	22
N4 (3 ft from diffuser)	71	72	72	72	72	14	13	12	9
N5 (4 ft from diffuser)	72	72	72	72	72	14	12	10	12
N6 (5 ft from diffuser)	72	72	72	72	72	11	9	12	13
N7 (5.5 ft from diffuser)	72	72	72	72	72	10	12	12	8
S1 (Edge of diffuser)	71	71	71	71	72	17	42	49	43
S2 (1 ft from diffuser)	71	72	71	71	72	20	21	23	13
S3 (2 ft from diffuser)	71	72	72	72	72	19	25	21	33
S4 (3 ft from diffuser)	71	72	72	72	72	18	10	9	21
S5 (4 ft from diffuser)	72	72	72	73	72	15	10	14	28
S6 (5 ft from diffuser)	72	72	72	72	72	13	15	18	15
S7 (5.5 ft from diffuser)	72	72	72	72	72	20	21	19	22
E1 (Edge of diffuser)	71	71	71	72	72	19	27	32	33
E2 (1 ft from diffuser)	71	71	71	71	72	21	19	19	17
E3 (2 ft from diffuser)	71	72	72	72	72	19	16	10	10
E4 (3 ft from diffuser)	71	72	72	72	72	16	20	16	9
E5 (4 ft from diffuser)	71	72	72	72	72	14	17	13	11
E6 (5 ft from diffuser)	72	72	72	72	72	12	15	12	10
E7 (6 ft from diffuser)	72	72	72	72	72	14	20	14	14
E8 (7 ft from diffuser)	72	72	72	72	72	18	13	19	13
E9 (8 ft from diffuser)	72	72	72	72	72	23	14	17	15
E10 (8.5 ft from diffuser)	72	72	72	72	72	13	17	16	20
W1 (Edge of diffuser)	72	71	71	71	72	21	39	43	35
W2 (1 ft from diffuser)	71	71	71	71	72	24	20	18	23
W3 (2 ft from diffuser)	71	71	71	71	72	19	12	11	12

W4 (3 ft from diffuser)	71	72	72	72	72	16	12	13	10
W5 (4 ft from diffuser)	72	72	72	72	72	15	15	10	9
W6 (5 ft from diffuser)	72	72	72	72	72	17	12	7	9
W7 (6 ft from diffuser)	72	72	72	72	72	14	11	15	7
W8 (7 ft from diffuser)	72	72	72	72	72	15	16	14	10
W9 (8 ft from diffuser)	72	72	72	72	72	20	12	10	15
W10 (8.5 ft from diffuser)	72	72	72	72	72	21	18	23	23

Test 33 Conditions – PDF Diffuser:

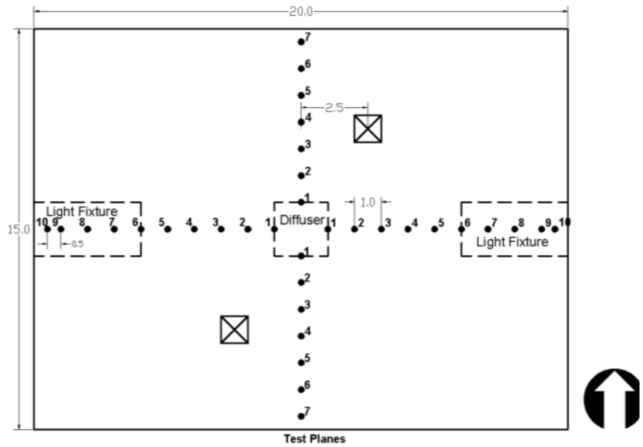
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

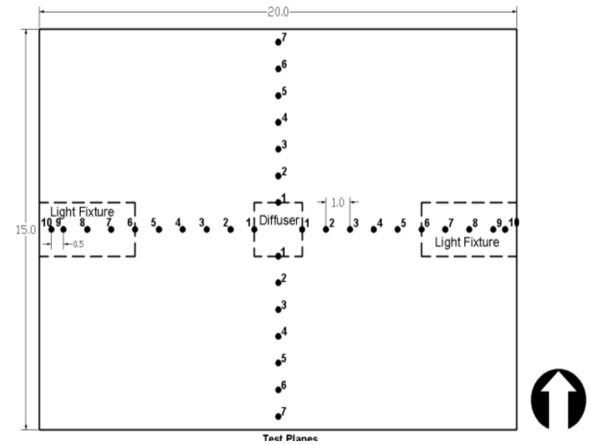
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	69	69	69	69	70	21	27	33	24
N2 (1 ft from diffuser)	69	69	69	69	70	19	26	24	23
N3 (2 ft from diffuser)	69	70	70	69	70	18	15	19	12
N4 (3 ft from diffuser)	69	70	70	70	70	19	15	12	9
N5 (4 ft from diffuser)	70	70	70	70	70	13	9	6	11
N6 (5 ft from diffuser)	70	70	70	70	70	12	16	14	17
N7 (5.5 ft from diffuser)	70	70	70	70	70	15	16	18	16
S1 (Edge of diffuser)	69	69	69	69	70	27	58	60	55
S2 (1 ft from diffuser)	69	69	68	68	70	20	40	49	38
S3 (2 ft from diffuser)	69	69	69	69	70	26	26	38	36
S4 (3 ft from diffuser)	69	69	69	69	70	17	19	34	30
S5 (4 ft from diffuser)	69	69	69	69	70	16	18	18	11

S6 (5 ft from diffuser)	69	69	69	70	70	13	14	12	12
S7 (5.5 ft from diffuser)	69	70	70	70	70	16	18	14	11
E1 (Edge of diffuser)	69	69	69	69	70	25	34	33	36
E2 (1 ft from diffuser)	69	69	69	69	70	22	26	27	34
E3 (2 ft from diffuser)	69	69	69	69	70	21	18	18	16
E4 (3 ft from diffuser)	69	70	70	70	70	20	9	9	5
E5 (4 ft from diffuser)	69	70	70	70	70	18	11	8	8
E6 (5 ft from diffuser)	70	70	70	70	70	13	10	10	1
E7 (6 ft from diffuser)	70	70	70	70	70	14	15	18	15
E8 (7 ft from diffuser)	70	70	70	70	70	15	19	16	9
E9 (8 ft from diffuser)	70	70	70	70	70	16	15	22	14
E10 (8.5 ft from diffuser)	70	70	70	70	70	21	18	18	16
W1 (Edge of diffuser)	70	70	70	70	70	22	25	27	25
W2 (1 ft from diffuser)	69	70	69	69	70	22	13	17	16
W3 (2 ft from diffuser)	69	70	69	69	70	20	17	15	18
W4 (3 ft from diffuser)	69	70	70	69	70	18	13	14	17
W5 (4 ft from diffuser)	70	70	70	70	70	14	11	12	15
W6 (5 ft from diffuser)	70	70	70	70	70	13	15	14	17
W7 (6 ft from diffuser)	70	70	70	70	70	17	12	13	15
W8 (7 ft from diffuser)	70	70	70	70	70	13	13	14	20
W9 (8 ft from diffuser)	70	70	70	70	70	13	20	23	16
W10 (8.5 ft from diffuser)	70	70	70	70	70	12	17	22	24

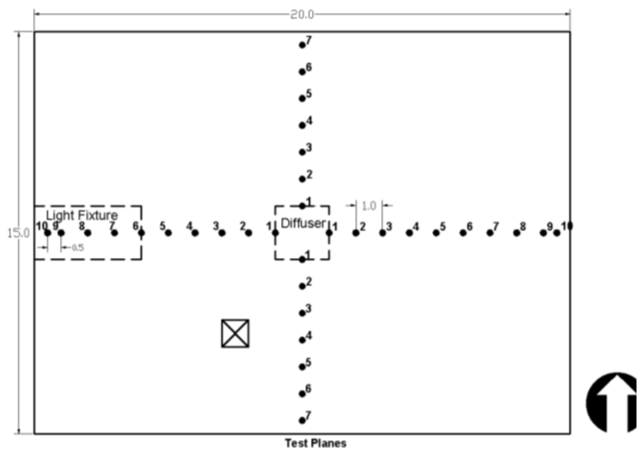
Load Distribution Layout- PDF Diffuser



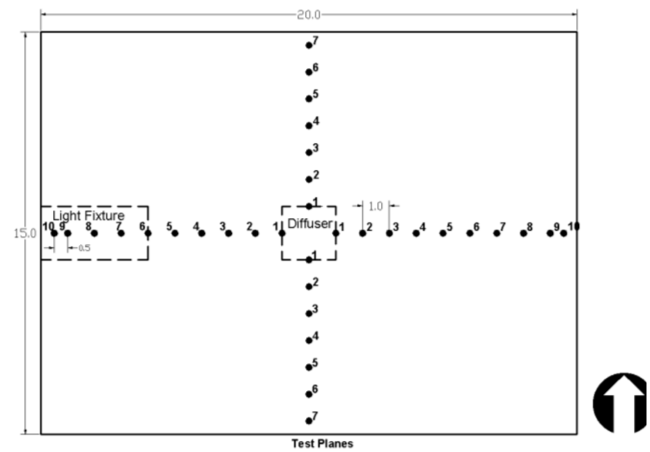
Test 34



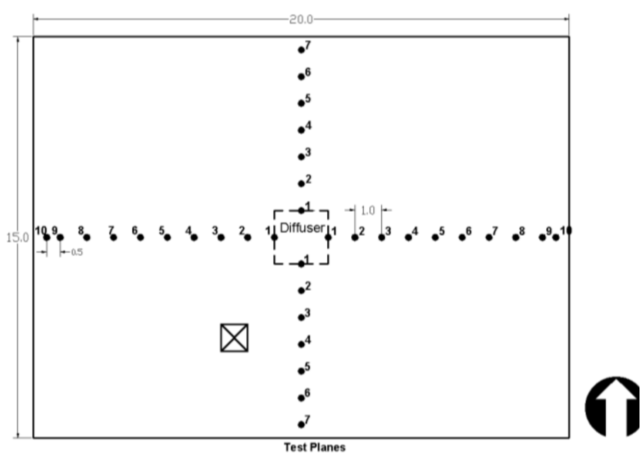
Test 35



Test 36



Test 37



Test 38

Test 34 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	65°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	71	72	14	21	25	25
N2 (1 ft from diffuser)	72	72	72	72	72	14	17	20	19
N3 (2 ft from diffuser)	72	72	72	72	72	21	18	21	24
N4 (3 ft from diffuser)	72	72	72	71	72	13	17	21	24
N5 (4 ft from diffuser)	72	72	72	72	72	18	22	25	31
N6 (5 ft from diffuser)	72	72	72	72	72	24	22	21	21
N7 (5.5 ft from diffuser)	72	72	72	72	72	23	21	22	21
S1 (Edge of diffuser)	72	72	72	72	72	24	19	18	17
S2 (1 ft from diffuser)	72	72	72	72	72	21	23	18	16
S3 (2 ft from diffuser)	72	72	72	72	72	15	25	24	21
S4 (3 ft from diffuser)	72	72	72	72	72	16	21	22	19
S5 (4 ft from diffuser)	72	72	72	72	72	20	16	19	26
S6 (5 ft from diffuser)	72	72	72	72	72	27	20	21	38
S7 (5.5 ft from diffuser)	72	72	72	72	72	21	21	24	28
E1 (Edge of diffuser)	72	72	72	72	72	16	18	19	14
E2 (1 ft from diffuser)	72	72	72	72	72	16	20	17	22
E3 (2 ft from diffuser)	72	72	72	72	72	23	20	25	16
E4 (3 ft from diffuser)	72	72	72	72	72	19	26	20	23
E5 (4 ft from diffuser)	72	72	72	72	72	32	21	17	16
E6 (5 ft from diffuser)	72	72	72	72	72	31	24	19	12
E7 (6 ft from diffuser)	72	72	72	72	72	23	15	20	23
E8 (7 ft from diffuser)	72	72	72	72	72	26	23	19	23
E9 (8 ft from diffuser)	72	72	72	72	72	30	26	19	27

E10 (8.5 ft from diffuser)	72	72	72	72	72	25	19	26	31
W1 (Edge of diffuser)	72	72	72	72	72	18	22	22	6
W2 (1 ft from diffuser)	72	72	72	72	72	19	21	20	20
W3 (2 ft from diffuser)	72	72	72	72	72	23	21	16	18
W4 (3 ft from diffuser)	72	72	72	72	72	21	25	16	9
W5 (4 ft from diffuser)	72	72	72	72	72	21	24	24	16
W6 (5 ft from diffuser)	72	72	72	72	72	18	21	19	16
W7 (6 ft from diffuser)	72	72	72	72	72	19	26	17	16
W8 (7 ft from diffuser)	72	72	72	72	72	25	22	15	13
W9 (8 ft from diffuser)	72	72	72	72	72	18	19	24	22
W10 (8.5 ft from diffuser)	72	72	72	72	72	16	16	20	24

Test 35 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	65°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	13	17	18	9
N2 (1 ft from diffuser)	71	72	71	71	72	18	10	16	36
N3 (2 ft from diffuser)	71	72	71	71	72	14	15	23	24
N4 (3 ft from diffuser)	71	72	71	71	72	15	13	21	21
N5 (4 ft from diffuser)	72	72	72	71	72	12	15	20	26
N6 (5 ft from diffuser)	72	72	72	71	72	12	13	15	17
N7 (5.5 ft	71	72	72	71	72	17	9	15	22

from diffuser)									
S1 (Edge of diffuser)	72	72	71	71	72	4	11	16	19
S2 (1 ft from diffuser)	71	71	71	71	72	13	12	18	14
S3 (2 ft from diffuser)	71	71	71	71	72	12	21	24	16
S4 (3 ft from diffuser)	71	71	71	71	72	12	9	10	14
S5 (4 ft from diffuser)	71	72	71	71	72	12	14	13	15
S6 (5 ft from diffuser)	71	71	71	71	72	14	17	13	10
S7 (5.5 ft from diffuser)	72	71	71	71	72	10	23	23	24
E1 (Edge of diffuser)	71	71	71	71	72	11	18	3	15
E2 (1 ft from diffuser)	71	71	71	71	72	16	18	17	11
E3 (2 ft from diffuser)	71	72	71	71	72	11	18	15	8
E4 (3 ft from diffuser)	72	72	72	72	72	13	15	12	5
E5 (4 ft from diffuser)	72	72	72	72	72	11	13	14	12
E6 (5 ft from diffuser)	72	72	72	72	72	18	12	9	9
E7 (6 ft from diffuser)	72	72	72	72	72	15	16	15	15
E8 (7 ft from diffuser)	72	72	72	72	72	18	16	15	13
E9 (8 ft from diffuser)	72	72	72	72	72	17	12	16	10
E10 (8.5 ft from diffuser)	72	72	71	72	72	19	15	19	15
W1 (Edge of diffuser)	72	72	72	71	72	13	17	14	12
W2 (1 ft from diffuser)	71	72	72	71	72	16	12	11	11
W3 (2 ft from diffuser)	72	72	72	72	72	13	11	9	10
W4 (3 ft from diffuser)	72	72	72	72	72	15	12	9	11
W5 (4 ft from diffuser)	72	72	72	72	72	11	11	9	10
W6 (5 ft from diffuser)	72	72	72	72	72	12	14	11	9
W7 (6 ft from diffuser)	72	72	72	72	72	12	12	13	9

W8 (7 ft from diffuser)	72	72	72	72	72	13	16	17	16
W9 (8 ft from diffuser)	72	72	72	72	72	13	19	21	23
W10 (8.5 ft from diffuser)	72	72	72	72	72	11	21	24	25

Test 36 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	71	72	14	12	21	18
N2 (1 ft from diffuser)	72	72	71	71	72	16	12	22	24
N3 (2 ft from diffuser)	72	72	72	71	72	16	20	25	24
N4 (3 ft from diffuser)	72	72	72	71	72	12	17	21	24
N5 (4 ft from diffuser)	72	72	72	72	72	14	15	14	16
N6 (5 ft from diffuser)	72	72	72	72	72	13	11	14	9
N7 (5.5 ft from diffuser)	72	72	72	72	72	15	16	14	10
S1 (Edge of diffuser)	72	72	72	72	72	14	17	17	17
S2 (1 ft from diffuser)	72	72	72	72	72	11	10	12	5
S3 (2 ft from diffuser)	72	72	72	72	72	14	14	10	19
S4 (3 ft from diffuser)	72	72	72	72	72	11	12	10	10
S5 (4 ft from diffuser)	72	72	72	72	72	12	11	10	15
S6 (5 ft from diffuser)	72	72	72	72	72	16	18	17	20
S7 (5.5 ft from diffuser)	72	72	72	72	72	18	18	20	21
E1 (Edge of diffuser)	72	72	72	72	73	12	17	22	26
E2 (1 ft from diffuser)	72	72	72	72	73	15	16	19	22

E3 (2 ft from diffuser)	72	72	72	72	73	11	11	15	14
E4 (3 ft from diffuser)	72	72	72	72	73	12	15	17	15
E5 (4 ft from diffuser)	72	72	72	72	73	12	19	15	10
E6 (5 ft from diffuser)	72	72	72	72	73	14	18	18	9
E7 (6 ft from diffuser)	72	72	72	72	73	17	17	15	9
E8 (7 ft from diffuser)	72	72	72	72	72	14	20	20	20
E9 (8 ft from diffuser)	72	72	72	72	72	19	15	16	20
E10 (8.5 ft from diffuser)	72	72	72	72	72	16	15	16	20
W1 (Edge of diffuser)	72	72	72	72	73	15	24	25	25
W2 (1 ft from diffuser)	72	72	72	72	73	13	16	22	22
W3 (2 ft from diffuser)	72	72	72	72	73	11	13	16	23
W4 (3 ft from diffuser)	72	72	72	72	73	12	11	11	11
W5 (4 ft from diffuser)	72	72	72	72	73	17	13	14	14
W6 (5 ft from diffuser)	72	72	72	72	73	14	13	10	12
W7 (6 ft from diffuser)	73	73	72	72	73	13	15	20	12
W8 (7 ft from diffuser)	73	73	73	73	73	11	12	12	15
W9 (8 ft from diffuser)	73	73	73	73	73	14	13	15	18
W10 (8.5 ft from diffuser)	73	73	73	73	73	15	18	20	17

Test 37 Conditions – PDF Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	65°F	72°F	20 x 15 x 9	150 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	72	72	71	72	18	16	21	25

N2 (1 ft from diffuser)	71	71	71	72	72	10	16	14	9
N3 (2 ft from diffuser)	72	72	72	72	72	12	14	14	19
N4 (3 ft from diffuser)	72	72	72	72	72	14	16	23	19
N5 (4 ft from diffuser)	72	72	72	72	72	15	13	17	8
N6 (5 ft from diffuser)	72	72	72	72	72	15	17	14	8
N7 (5.5 ft from diffuser)	72	72	72	72	72	10	12	12	20
S1 (Edge of diffuser)	72	72	72	71	72	19	27	33	33
S2 (1 ft from diffuser)	72	72	72	71	72	19	9	13	16
S3 (2 ft from diffuser)	72	72	72	72	72	12	11	11	10
S4 (3 ft from diffuser)	72	72	72	72	72	15	18	24	25
S5 (4 ft from diffuser)	72	72	72	72	72	13	16	24	26
S6 (5 ft from diffuser)	72	72	72	72	72	10	9	5	10
S7 (5.5 ft from diffuser)	72	72	72	72	72	10	16	20	19
E1 (Edge of diffuser)	72	72	72	72	72	12	15	14	14
E2 (1 ft from diffuser)	72	72	72	72	72	16	10	10	11
E3 (2 ft from diffuser)	72	72	72	72	72	18	23	22	14
E4 (3 ft from diffuser)	72	72	72	72	72	15	9	12	6
E5 (4 ft from diffuser)	72	72	72	72	72	13	8	7	5
E6 (5 ft from diffuser)	72	72	72	72	72	14	12	15	16
E7 (6 ft from diffuser)	72	72	72	72	72	11	15	19	19
E8 (7 ft from diffuser)	72	72	72	72	72	18	19	19	17
E9 (8 ft from diffuser)	72	72	72	72	72	14	19	21	16
E10 (8.5 ft from diffuser)	72	72	72	72	72	17	18	20	23
W1 (Edge of diffuser)	72	72	72	72	72	14	16	21	16
W2 (1 ft from diffuser)	72	72	72	72	72	12	13	8	9

W3 (2 ft from diffuser)	72	72	72	72	72	12	10	7	8
W4 (3 ft from diffuser)	72	72	72	72	72	13	10	11	10
W5 (4 ft from diffuser)	72	72	72	72	72	13	7	7	9
W6 (5 ft from diffuser)	72	72	72	72	72	12	12	7	11
W7 (6 ft from diffuser)	72	72	72	72	72	17	16	16	13
W8 (7 ft from diffuser)	72	72	72	72	72	16	17	13	13
W9 (8 ft from diffuser)	72	72	72	72	72	16	13	13	16
W10 (8.5 ft from diffuser)	72	72	72	72	72	11	12	20	17

Test 38 Conditions – PDF Diffuser:

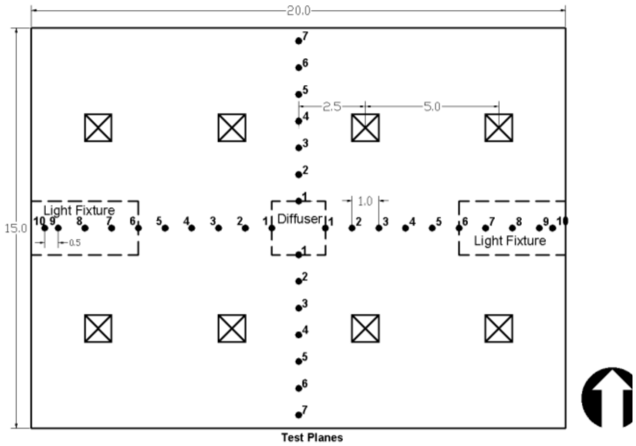
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

Plane North > South > East > West

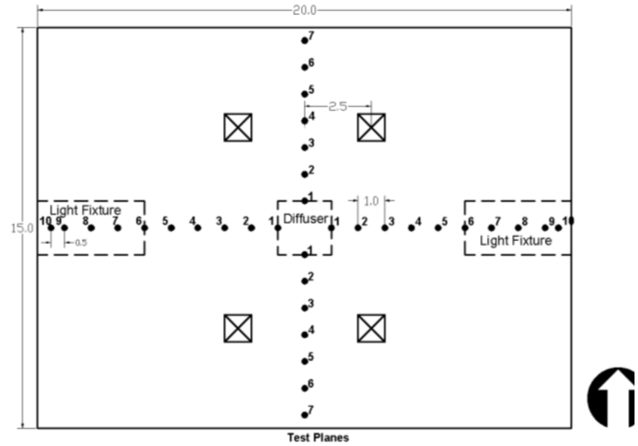
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	13	11	18	16
N2 (1 ft from diffuser)	72	72	72	72	72	11	18	20	20
N3 (2 ft from diffuser)	72	72	72	72	72	16	9	5	15
N4 (3 ft from diffuser)	72	72	72	72	72	14	19	17	13
N5 (4 ft from diffuser)	72	72	72	72	72	12	16	13	16
N6 (5 ft from diffuser)	72	72	72	72	72	14	16	16	17
N7 (5.5 ft from diffuser)	72	72	72	72	72	12	17	18	23
S1 (Edge of diffuser)	72	72	72	72	72	26	10	15	14
S2 (1 ft from diffuser)	72	72	72	72	72	13	22	25	25
S3 (2 ft from diffuser)	72	72	72	72	72	13	18	26	28
S4 (3 ft from diffuser)	72	72	72	72	72	15	12	24	28

S5 (4 ft from diffuser)	72	72	72	72	72	15	12	10	10
S6 (5 ft from diffuser)	72	72	72	72	72	15	13	14	13
S7 (5.5 ft from diffuser)	72	72	72	72	72	20	19	18	15
E1 (Edge of diffuser)	72	72	72	72	72	14	24	22	19
E2 (1 ft from diffuser)	72	72	72	72	72	16	10	13	16
E3 (2 ft from diffuser)	72	72	72	72	72	11	14	11	7
E4 (3 ft from diffuser)	72	72	72	72	72	13	15	16	11
E5 (4 ft from diffuser)	72	72	72	72	72	18	18	21	16
E6 (5 ft from diffuser)	72	72	72	72	72	21	20	19	12
E7 (6 ft from diffuser)	72	72	72	72	72	16	18	18	14
E8 (7 ft from diffuser)	72	72	72	72	72	17	16	15	20
E9 (8 ft from diffuser)	72	72	72	72	72	15	19	20	18
E10 (8.5 ft from diffuser)	72	72	72	72	72	17	16	20	19
W1 (Edge of diffuser)	72	72	71	71	72	9	30	34	30
W2 (1 ft from diffuser)	71	72	71	71	72	12	29	30	22
W3 (2 ft from diffuser)	72	72	71	71	72	13	18	21	16
W4 (3 ft from diffuser)	72	72	72	72	72	9	14	16	12
W5 (4 ft from diffuser)	72	72	72	72	72	10	11	9	6
W6 (5 ft from diffuser)	72	72	72	72	72	11	11	10	2
W7 (6 ft from diffuser)	72	72	72	72	72	12	15	7	15
W8 (7 ft from diffuser)	72	72	72	72	72	18	14	14	11
W9 (8 ft from diffuser)	72	72	72	72	72	12	18	22	23
W10 (8.5 ft from diffuser)	72	72	72	72	72	13	17	24	21

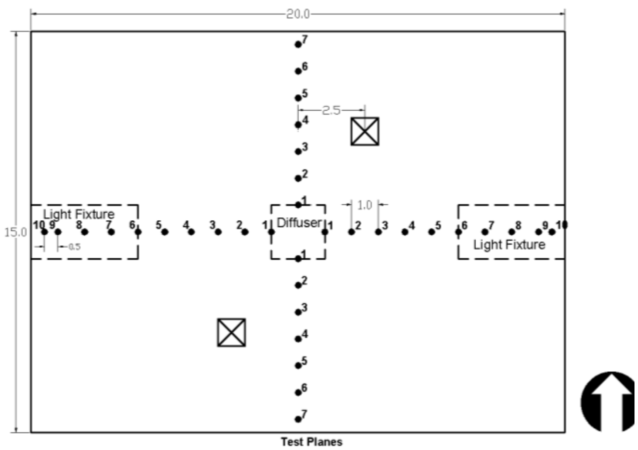
Load Distribution Layout- PDN Diffuser



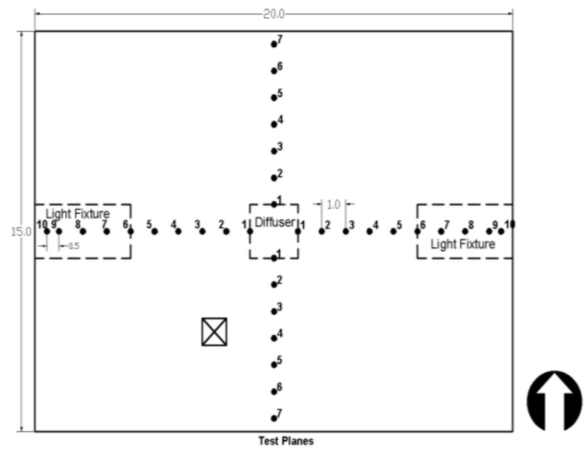
Test 39



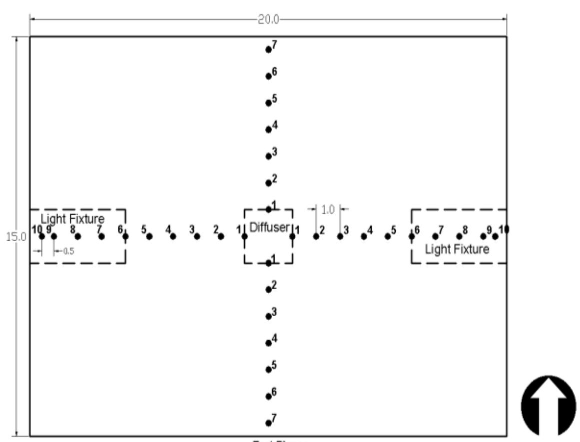
Test 40



Test 41



Test 42



Test 43

Test 39 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	55°F	72°F	20 x 15 x 9	1290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	72	72	72	72	24	24	29	33
N2 (1 ft from diffuser)	71	71	71	71	72	28	32	27	19
N3 (2 ft from diffuser)	71	71	71	71	72	28	36	34	30
N4 (3 ft from diffuser)	71	71	71	71	72	24	25	31	24
N5 (4 ft from diffuser)	71	71	71	72	72	16	23	28	31
N6 (5 ft from diffuser)	71	72	72	72	72	23	31	25	34
N7 (5.5 ft from diffuser)	71	72	72	72	72	29	34	21	22
S1 (Edge of diffuser)	72	72	72	72	72	25	26	33	28
S2 (1 ft from diffuser)	72	72	72	72	72	25	35	32	26
S3 (2 ft from diffuser)	72	72	72	72	73	30	33	28	21
S4 (3 ft from diffuser)	72	72	72	72	73	26	29	25	24
S5 (4 ft from diffuser)	72	72	72	72	73	28	28	23	33
S6 (5 ft from diffuser)	72	72	72	72	73	24	32	25	30
S7 (5.5 ft from diffuser)	72	72	72	72	73	24	43	60	54
E1 (Edge of diffuser)	72	72	72	72	73	32	34	35	35
E2 (1 ft from diffuser)	72	72	73	72	73	32	37	35	34
E3 (2 ft from diffuser)	72	72	73	73	73	44	35	36	29
E4 (3 ft from diffuser)	72	72	73	73	73	43	35	31	24
E5 (4 ft from diffuser)	72	72	73	73	73	40	39	23	17
E6 (5 ft from diffuser)	72	73	73	73	73	48	46	26	17
E7 (6 ft from diffuser)	72	73	73	73	73	45	43	27	14
E8 (7 ft from diffuser)	72	73	73	73	73	48	41	32	21
E9 (8 ft from diffuser)	72	73	73	73	73	39	19	23	22

E10 (8.5 ft from diffuser)	72	73	73	73	73	46	29	30	25
W1 (Edge of diffuser)	72	73	73	73	73	21	31	31	26
W2 (1 ft from diffuser)	72	72	72	73	73	31	31	31	27
W3 (2 ft from diffuser)	72	72	72	73	73	46	30	25	22
W4 (3 ft from diffuser)	72	73	73	73	73	47	21	19	23
W5 (4 ft from diffuser)	72	73	73	73	73	41	30	14	17
W6 (5 ft from diffuser)	72	73	73	73	73	50	39	16	16
W7 (6 ft from diffuser)	72	73	73	73	73	51	40	29	15
W8 (7 ft from diffuser)	72	73	73	73	73	46	49	41	18
W9 (8 ft from diffuser)	72	73	73	73	73	53	21	19	18
W10 (8.5 ft from diffuser)	72	73	73	73	73	47	29	25	26

Test 40 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	55°F	72°F	20 x 15 x 9	790 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	72	71	71	72	16	14	16	16
N2 (1 ft from diffuser)	71	71	71	71	72	18	15	17	18
N3 (2 ft from diffuser)	71	72	72	72	72	21	19	22	24
N4 (3 ft from diffuser)	72	72	72	72	72	17	16	20	27
N5 (4 ft from diffuser)	72	72	72	72	72	16	19	15	23
N6 (5 ft from diffuser)	72	72	72	72	72	17	21	23	24
N7 (5.5 ft from diffuser)	72	72	72	72	72	17	14	20	24
S1 (Edge of diffuser)	72	72	72	72	72	34	18	19	22
S2 (1 ft	72	72	72	72	72	29	18	17	23

from diffuser)									
S3 (2 ft from diffuser)	72	72	72	72	72	20	22	20	16
S4 (3 ft from diffuser)	72	72	72	72	72	32	24	30	35
S5 (4 ft from diffuser)	72	72	72	72	72	34	25	28	29
S6 (5 ft from diffuser)	72	72	72	73	72	30	22	29	30
S7 (5.5 ft from diffuser)	72	72	73	73	72	22	24	28	31
E1 (Edge of diffuser)	72	72	72	72	72	19	21	18	23
E2 (1 ft from diffuser)	72	72	72	72	72	18	19	20	23
E3 (2 ft from diffuser)	72	72	72	72	72	23	20	16	23
E4 (3 ft from diffuser)	72	72	72	72	72	25	18	12	17
E5 (4 ft from diffuser)	72	72	72	72	72	20	18	17	22
E6 (5 ft from diffuser)	72	72	72	72	72	26	26	13	20
E7 (6 ft from diffuser)	72	72	72	72	72	21	18	21	30
E8 (7 ft from diffuser)	71	72	71	71	72	21	19	15	34
E9 (8 ft from diffuser)	71	72	71	71	72	22	30	27	36
E10 (8.5 ft from diffuser)	72	72	72	72	72	19	23	30	30
W1 (Edge of diffuser)	72	72	72	72	72	11	16	17	18
W2 (1 ft from diffuser)	72	72	72	72	72	19	16	20	21
W3 (2 ft from diffuser)	72	72	72	72	72	16	18	14	8
W4 (3 ft from diffuser)	72	72	72	72	72	18	17	11	15
W5 (4 ft from diffuser)	72	72	72	72	72	15	23	16	14
W6 (5 ft from diffuser)	72	72	72	72	72	21	14	8	14
W7 (6 ft from diffuser)	72	72	72	72	72	19	16	13	13
W8 (7 ft from diffuser)	72	72	72	72	72	30	19	8	4
W9 (8 ft from diffuser)	72	72	72	72	72	15	13	18	18

W10 (8.5 ft from diffuser)	72	72	72	72	73	17	19	19	34

Test 41 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	16	15	11	17
N2 (1 ft from diffuser)	72	72	72	72	72	19	17	14	19
N3 (2 ft from diffuser)	72	72	72	72	72	12	15	16	9
N4 (3 ft from diffuser)	72	72	72	72	72	13	19	16	10
N5 (4 ft from diffuser)	72	72	72	72	72	13	12	17	14
N6 (5 ft from diffuser)	72	72	72	72	72	17	16	21	23
N7 (5.5 ft from diffuser)	72	72	72	72	72	17	19	17	12
S1 (Edge of diffuser)	72	72	72	72	72	15	18	20	24
S2 (1 ft from diffuser)	72	72	72	72	72	28	8	12	15
S3 (2 ft from diffuser)	72	72	72	72	72	22	15	21	23
S4 (3 ft from diffuser)	72	72	72	72	72	27	13	18	18
S5 (4 ft from diffuser)	72	72	72	72	72	26	22	18	13
S6 (5 ft from diffuser)	72	72	72	72	72	27	20	15	14
S7 (5.5 ft from diffuser)	72	72	72	72	72	26	27	21	11
E1 (Edge of diffuser)	72	72	72	72	72	25	19	20	18
E2 (1 ft from diffuser)	72	72	72	72	72	21	20	23	18
E3 (2 ft from diffuser)	72	72	72	72	72	18	14	13	11
E4 (3 ft from diffuser)	72	72	72	72	72	20	7	14	24
E5 (4 ft from	72	72	72	71	72	21	12	12	22

diffuser)									
E6 (5 ft from diffuser)	72	72	72	72	72	19	12	15	14
E7 (6 ft from diffuser)	72	72	72	72	72	12	10	16	12
E8 (7 ft from diffuser)	72	72	72	72	72	18	23	18	19
E9 (8 ft from diffuser)	72	72	72	72	72	26	26	21	21
E10 (8.5 ft from diffuser)	72	72	72	72	72	24	28	31	23
W1 (Edge of diffuser)	72	72	72	72	72	13	8	8	11
W2 (1 ft from diffuser)	72	72	72	72	72	12	16	16	11
W3 (2 ft from diffuser)	72	72	72	72	72	12	16	15	11
W4 (3 ft from diffuser)	72	72	72	72	72	21	19	11	9
W5 (4 ft from diffuser)	72	72	72	72	72	12	8	12	16
W6 (5 ft from diffuser)	72	72	72	72	72	12	20	19	11
W7 (6 ft from diffuser)	72	72	72	72	72	18	19	18	15
W8 (7 ft from diffuser)	72	72	72	72	72	11	13	13	20
W9 (8 ft from diffuser)	72	72	72	72	72	14	15	16	19
W10 (8.5 ft from diffuser)	72	72	72	72	72	17	14	19	20

Test 42 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	55°F	72°F	20 x 15 x 9	415 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	10	11	16	17
N2 (1 ft from diffuser)	71	71	71	71	72	16	16	17	17
N3 (2 ft from diffuser)	71	71	71	71	72	10	10	10	21
N4 (3 ft from diffuser)	71	71	71	71	72	9	7	19	16

N5 (4 ft from diffuser)	71	71	71	71	72	16	12	18	30
N6 (5 ft from diffuser)	71	71	71	71	72	16	17	23	28
N7 (5.5 ft from diffuser)	71	71	71	71	72	13	14	15	20
S1 (Edge of diffuser)	71	71	71	71	72	13	17	15	17
S2 (1 ft from diffuser)	71	71	71	71	72	18	13	11	13
S3 (2 ft from diffuser)	71	71	71	71	72	15	12	12	13
S4 (3 ft from diffuser)	71	71	71	71	72	14	17	13	9
S5 (4 ft from diffuser)	71	71	71	71	72	23	13	12	13
S6 (5 ft from diffuser)	71	71	71	71	72	18	16	12	16
S7 (5.5 ft from diffuser)	71	71	71	71	72	16	16	16	12
E1 (Edge of diffuser)	71	71	71	71	72	17	13	13	9
E2 (1 ft from diffuser)	71	71	71	71	72	11	10	14	22
E3 (2 ft from diffuser)	71	71	71	71	72	13	10	12	17
E4 (3 ft from diffuser)	71	71	71	71	72	11	15	16	18
E5 (4 ft from diffuser)	71	71	71	71	72	13	13	14	16
E6 (5 ft from diffuser)	71	71	71	72	72	13	12	8	11
E7 (6 ft from diffuser)	72	72	71	72	72	13	16	9	16
E8 (7 ft from diffuser)	72	72	72	72	72	13	14	15	1
E9 (8 ft from diffuser)	72	72	72	72	72	15	17	19	17
E10 (8.5 ft from diffuser)	72	72	72	72	72	19	17	18	15
W1 (Edge of diffuser)	72	72	71	71	72	18	15	11	16
W2 (1 ft from diffuser)	72	72	71	71	72	12	14	15	11
W3 (2 ft from diffuser)	72	72	71	71	72	10	15	13	15
W4 (3 ft from diffuser)	72	72	71	71	72	10	10	18	22
W5 (4 ft from diffuser)	72	72	71	71	72	15	16	23	26

W6 (5 ft from diffuser)	72	72	72	72	72	10	11	10	16
W7 (6 ft from diffuser)	72	72	72	72	72	10	10	11	15
W8 (7 ft from diffuser)	72	72	72	72	72	9	14	14	13
W9 (8 ft from diffuser)	72	72	72	72	72	14	14	18	16
W10 (8.5 ft from diffuser)	72	72	72	72	72	16	18	19	17

Test 43 Conditions – PDN Diffuser:

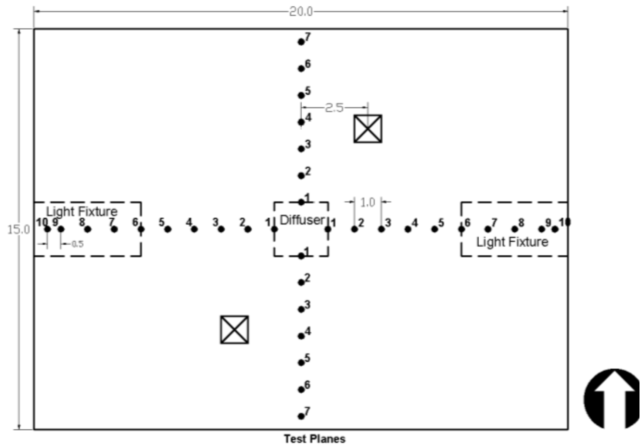
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

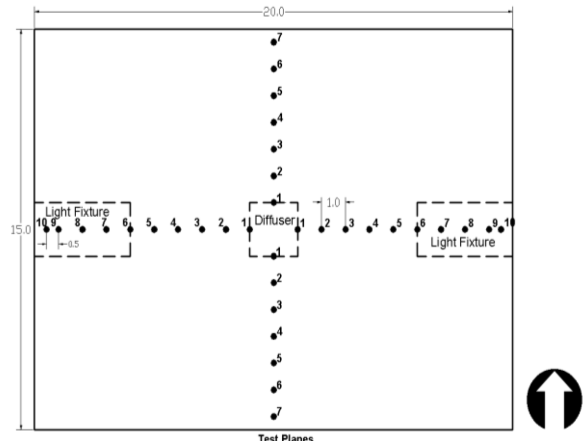
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	70	71	13	17	23	21
N2 (1 ft from diffuser)	71	71	70	70	71	15	16	13	12
N3 (2 ft from diffuser)	71	71	71	70	71	13	20	13	7
N4 (3 ft from diffuser)	71	71	71	70	71	12	19	18	16
N5 (4 ft from diffuser)	71	71	71	70	71	12	14	19	21
N6 (5 ft from diffuser)	71	71	71	71	71	14	18	25	19
N7 (5.5 ft from diffuser)	71	71	71	71	71	17	24	25	25
S1 (Edge of diffuser)	71	71	70	70	71	21	19	33	33
S2 (1 ft from diffuser)	70	71	70	70	71	19	18	27	32
S3 (2 ft from diffuser)	70	70	70	70	71	18	22	30	41
S4 (3 ft from diffuser)	70	70	70	70	71	22	22	32	30
S5 (4 ft from diffuser)	70	70	70	70	71	18	18	16	15
S6 (5 ft from diffuser)	70	70	70	70	71	23	15	13	10
S7 (5.5 ft from diffuser)	70	70	70	70	71	18	19	16	12
E1 (Edge of	70	71	71	71	71	11	12	11	13

diffuser)									
E2 (1 ft from diffuser)	71	71	71	71	71	14	18	20	20
E3 (2 ft from diffuser)	71	71	71	71	71	12	18	16	13
E4 (3 ft from diffuser)	71	71	71	71	71	10	9	12	12
E5 (4 ft from diffuser)	71	71	71	71	71	12	12	11	14
E6 (5 ft from diffuser)	71	71	71	71	71	12	14	13	15
E7 (6 ft from diffuser)	71	71	71	71	71	15	16	20	17
E8 (7 ft from diffuser)	71	71	71	71	71	15	12	17	19
E9 (8 ft from diffuser)	71	71	71	71	71	21	16	20	18
E10 (8.5 ft from diffuser)	71	71	71	71	71	19	21	24	24
W1 (Edge of diffuser)	71	71	71	70	71	16	19	18	21
W2 (1 ft from diffuser)	71	71	71	70	71	22	18	15	14
W3 (2 ft from diffuser)	70	71	71	71	71	24	12	12	11
W4 (3 ft from diffuser)	71	71	71	71	71	21	11	10	11
W5 (4 ft from diffuser)	71	71	71	71	71	18	11	8	9
W6 (5 ft from diffuser)	71	71	71	71	71	12	10	11	11
W7 (6 ft from diffuser)	71	71	71	71	71	12	16	18	10
W8 (7 ft from diffuser)	71	71	71	71	71	9	13	18	15
W9 (8 ft from diffuser)	71	71	71	71	71	14	19	21	20
W10 (8.5 ft from diffuser)	71	71	71	71	71	17	18	20	19

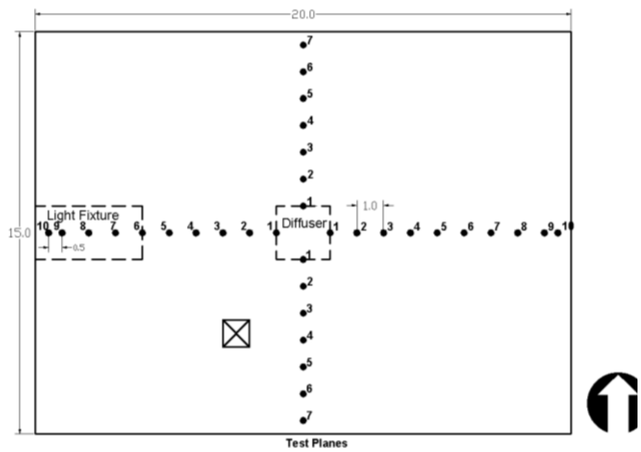
Load Distribution Layout- PDN Diffuser



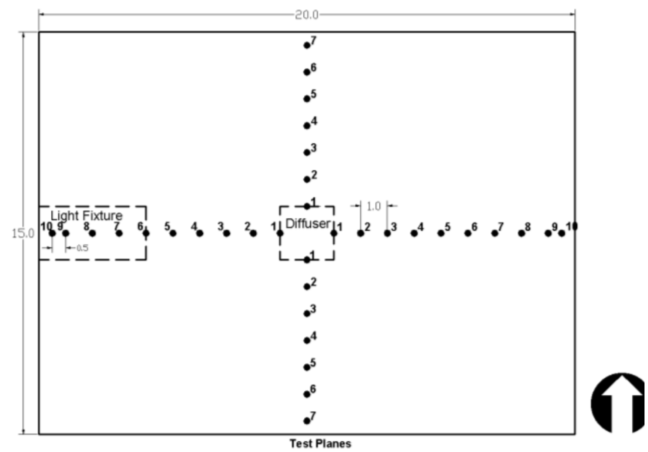
Test 44



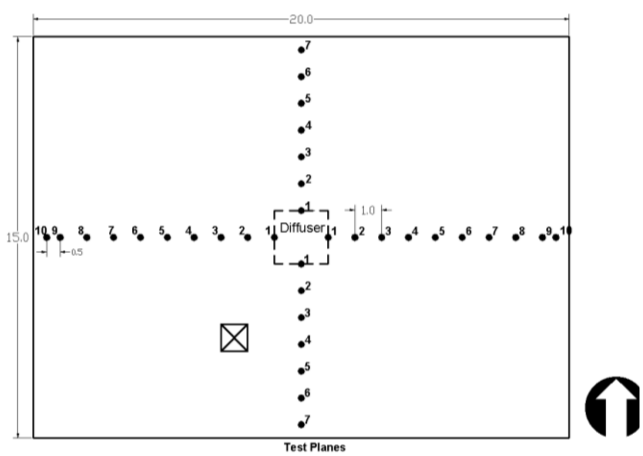
Test 45



Test 46



Test 47



Test 48

Test 44 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	65°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	22	22	27	28
N2 (1 ft from diffuser)	72	72	72	72	72	25	30	30	20
N3 (2 ft from diffuser)	72	72	72	72	72	25	23	24	19
N4 (3 ft from diffuser)	72	72	72	72	72	21	22	22	19
N5 (4 ft from diffuser)	72	72	72	72	72	23	17	20	26
N6 (5 ft from diffuser)	72	73	73	73	73	24	35	31	27
N7 (5.5 ft from diffuser)	72	73	73	73	73	29	37	28	34
S1 (Edge of diffuser)	72	73	73	73	73	19	21	22	31
S2 (1 ft from diffuser)	72	73	73	73	73	37	22	24	37
S3 (2 ft from diffuser)	72	73	73	73	73	22	24	25	33
S4 (3 ft from diffuser)	72	73	73	73	73	21	25	28	38
S5 (4 ft from diffuser)	72	73	73	73	73	26	24	24	24
S6 (5 ft from diffuser)	72	73	73	73	73	21	19	33	21
S7 (5.5 ft from diffuser)	72	73	72	72	73	36	20	47	48
E1 (Edge of diffuser)	72	73	73	73	73	23	20	25	20
E2 (1 ft from diffuser)	72	73	73	73	73	27	28	27	23
E3 (2 ft from diffuser)	72	73	73	73	73	33	33	27	21
E4 (3 ft from diffuser)	72	73	73	73	73	28	27	27	16
E5 (4 ft from diffuser)	72	73	73	73	73	32	25	24	18
E6 (5 ft from diffuser)	72	73	73	73	73	31	28	24	19
E7 (6 ft from diffuser)	73	73	73	73	73	25	28	12	22
E8 (7 ft from diffuser)	72	73	73	73	73	32	26	16	29
E9 (8 ft from diffuser)	72	73	73	73	73	18	41	36	46

E10 (8.5 ft from diffuser)	72	73	73	73	73	20	24	38	40
W1 (Edge of diffuser)	72	73	73	73	73	32	15	24	31
W2 (1 ft from diffuser)	73	73	73	73	73	20	24	25	25
W3 (2 ft from diffuser)	72	73	73	73	73	27	31	30	21
W4 (3 ft from diffuser)	73	73	73	73	73	19	28	28	32
W5 (4 ft from diffuser)	72	73	73	73	73	28	31	30	32
W6 (5 ft from diffuser)	72	73	73	73	73	26	30	28	19
W7 (6 ft from diffuser)	72	73	73	73	73	26	31	24	21
W8 (7 ft from diffuser)	72	72	73	73	73	23	25	25	27
W9 (8 ft from diffuser)	72	73	73	73	73	14	27	24	25
W10 (8.5 ft from diffuser)	72	73	73	73	73	18	28	32	26

Test 45 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
146 cfm	65°F	72°F	20 x 15 x 9	290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	12	17	17	16
N2 (1 ft from diffuser)	72	72	72	72	72	15	17	12	15
N3 (2 ft from diffuser)	72	72	72	72	72	16	12	17	17
N4 (3 ft from diffuser)	72	72	72	72	72	14	17	20	16
N5 (4 ft from diffuser)	72	72	72	72	72	15	15	16	19
N6 (5 ft from diffuser)	72	72	72	72	72	13	16	20	18
N7 (5.5 ft from diffuser)	72	72	72	72	72	12	12	13	12
S1 (Edge of diffuser)	72	72	72	72	72	22	6	9	9

S2 (1 ft from diffuser)	72	72	72	72	72	19	11	6	5
S3 (2 ft from diffuser)	72	72	72	72	72	24	15	13	13
S4 (3 ft from diffuser)	72	72	72	72	72	28	16	17	12
S5 (4 ft from diffuser)	72	72	72	72	72	22	14	9	12
S6 (5 ft from diffuser)	72	72	72	72	72	26	21	16	15
S7 (5.5 ft from diffuser)	72	72	72	72	72	26	18	26	29
E1 (Edge of diffuser)	72	72	72	72	72	26	14	10	16
E2 (1 ft from diffuser)	72	72	72	72	72	29	11	4	16
E3 (2 ft from diffuser)	72	72	72	72	72	34	17	12	19
E4 (3 ft from diffuser)	72	72	72	72	72	22	16	18	22
E5 (4 ft from diffuser)	72	72	72	72	72	20	16	22	21
E6 (5 ft from diffuser)	72	72	72	72	72	17	11	11	13
E7 (6 ft from diffuser)	72	72	72	72	72	22	21	17	21
E8 (7 ft from diffuser)	72	72	72	72	72	18	20	22	17
E9 (8 ft from diffuser)	72	72	72	72	72	22	21	16	13
E10 (8.5 ft from diffuser)	72	72	72	72	72	19	26	30	31
W1 (Edge of diffuser)	72	72	72	72	72	29	13	13	16
W2 (1 ft from diffuser)	72	72	72	72	72	15	15	12	15
W3 (2 ft from diffuser)	72	72	72	72	72	19	23	19	19
W4 (3 ft from diffuser)	72	72	72	72	72	19	24	15	14
W5 (4 ft from diffuser)	72	72	72	72	72	16	17	15	14
W6 (5 ft from diffuser)	72	72	72	72	72	28	23	14	12
W7 (6 ft from diffuser)	72	72	72	72	72	17	13	13	12
W8 (7 ft from diffuser)	72	72	72	72	72	22	23	23	17
W9 (8 ft from diffuser)	72	72	72	72	72	18	19	23	21

W10 (8.5 ft from diffuser)	72	72	72	72	72	16	9	11	17

Test 46 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	28	11	2	10
N2 (1 ft from diffuser)	72	72	72	72	72	32	23	14	13
N3 (2 ft from diffuser)	72	72	72	72	72	23	20	10	9
N4 (3 ft from diffuser)	72	72	72	72	72	23	20	17	18
N5 (4 ft from diffuser)	72	72	72	72	72	30	12	12	13
N6 (5 ft from diffuser)	72	72	72	72	72	24	19	16	15
N7 (5.5 ft from diffuser)	72	72	72	72	72	27	19	21	21
S1 (Edge of diffuser)	72	72	72	72	72	15	18	20	14
S2 (1 ft from diffuser)	72	72	72	72	72	13	20	23	13
S3 (2 ft from diffuser)	72	72	72	72	72	12	13	11	10
S4 (3 ft from diffuser)	72	72	72	72	72	15	14	12	11
S5 (4 ft from diffuser)	72	72	72	72	72	23	14	16	17
S6 (5 ft from diffuser)	72	72	72	72	72	16	20	23	22
S7 (5.5 ft from diffuser)	72	72	72	72	72	22	22	24	26
E1 (Edge of diffuser)	72	72	72	72	72	14	23	18	14
E2 (1 ft from diffuser)	72	72	72	72	72	20	17	20	18
E3 (2 ft from diffuser)	72	72	72	72	72	15	20	24	15
E4 (3 ft from diffuser)	72	72	72	72	72	16	15	18	17

E5 (4 ft from diffuser)	72	72	72	72	72	14	14	11	18
E6 (5 ft from diffuser)	72	72	72	72	72	16	14	15	18
E7 (6 ft from diffuser)	72	72	72	72	72	19	18	13	15
E8 (7 ft from diffuser)	72	72	72	72	72	13	12	14	16
E9 (8 ft from diffuser)	72	72	72	72	72	15	16	17	19
E10 (8.5 ft from diffuser)	72	72	72	72	72	16	18	25	25
W1 (Edge of diffuser)	72	72	72	72	72	28	22	13	8
W2 (1 ft from diffuser)	71	72	72	72	72	25	19	17	15
W3 (2 ft from diffuser)	71	72	72	72	72	26	10	10	18
W4 (3 ft from diffuser)	71	72	72	72	72	27	13	8	16
W5 (4 ft from diffuser)	71	72	72	72	72	26	9	12	14
W6 (5 ft from diffuser)	71	72	72	72	72	31	11	15	22
W7 (6 ft from diffuser)	71	72	72	72	72	31	16	8	14
W8 (7 ft from diffuser)	71	72	72	72	72	27	8	10	13
W9 (8 ft from diffuser)	71	72	72	72	72	28	14	15	13
W10 (8.5 ft from diffuser)	71	72	72	72	72	28	14	13	17

Test 47 Conditions – PDN Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
77 cfm	65°F	72°F	20 x 15 x 9	150 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	71	33	13	11	13
N2 (1 ft from diffuser)	71	71	71	71	71	37	12	8	11
N3 (2 ft from diffuser)	71	71	71	71	71	34	14	13	10

N4 (3 ft from diffuser)	71	71	71	71	71	36	20	10	10
N5 (4 ft from diffuser)	71	71	71	71	71	37	15	12	9
N6 (5 ft from diffuser)	71	71	71	71	71	33	19	14	13
N7 (5.5 ft from diffuser)	71	71	71	71	71	27	21	17	13
S1 (Edge of diffuser)	71	71	71	71	71	22	14	16	19
S2 (1 ft from diffuser)	71	71	71	71	71	21	18	12	19
S3 (2 ft from diffuser)	71	71	71	71	71	18	17	12	17
S4 (3 ft from diffuser)	71	71	71	71	71	15	13	13	18
S5 (4 ft from diffuser)	71	71	71	71	71	14	18	14	17
S6 (5 ft from diffuser)	71	71	71	71	71	15	14	17	18
S7 (5.5 ft from diffuser)	71	71	71	71	71	16	19	17	21
E1 (Edge of diffuser)	71	71	71	71	71	11	9	8	11
E2 (1 ft from diffuser)	71	71	71	71	71	15	12	9	16
E3 (2 ft from diffuser)	71	71	71	71	71	17	16	14	16
E4 (3 ft from diffuser)	71	71	71	71	71	12	13	17	20
E5 (4 ft from diffuser)	71	71	71	71	71	12	12	15	16
E6 (5 ft from diffuser)	71	71	71	71	71	11	17	11	16
E7 (6 ft from diffuser)	71	71	71	71	71	17	14	11	7
E8 (7 ft from diffuser)	71	71	71	71	71	16	13	8	10
E9 (8 ft from diffuser)	71	71	71	71	71	22	17	23	27
E10 (8.5 ft from diffuser)	72	71	71	71	71	28	24	28	24
W1 (Edge of diffuser)	71	71	71	71	71	16	11	10	18
W2 (1 ft from diffuser)	71	71	71	71	71	18	14	14	13
W3 (2 ft from diffuser)	71	71	71	71	71	18	15	4	12
W4 (3 ft from diffuser)	71	71	71	71	71	26	13	9	12

W5 (4 ft from diffuser)	71	71	71	71	71	26	14	13	16
W6 (5 ft from diffuser)	71	71	71	71	71	30	10	10	20
W7 (6 ft from diffuser)	71	71	71	71	71	32	13	11	20
W8 (7 ft from diffuser)	71	71	71	71	71	29	11	12	14
W9 (8 ft from diffuser)	71	71	71	71	71	29	13	10	18
W10 (8.5 ft from diffuser)	71	71	71	71	71	27	14	14	16

Test 48 Conditions – PDN Diffuser:

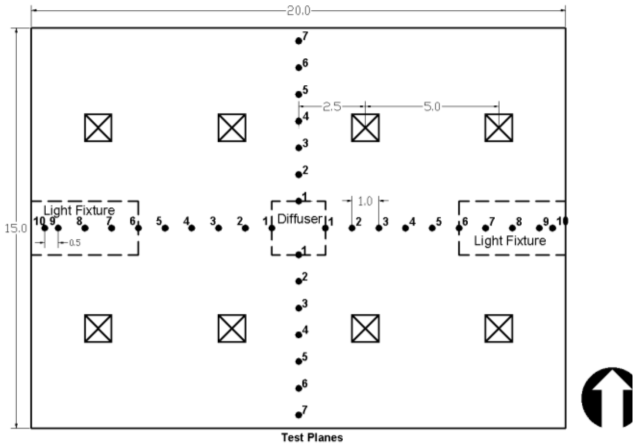
Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

Plane North > South > East > West

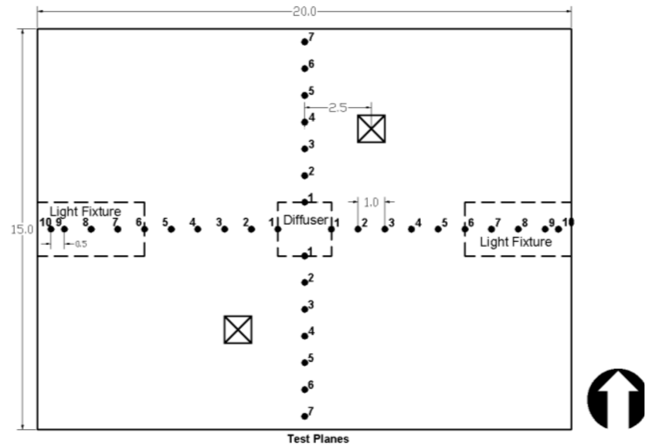
	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	73	73	73	73	73	11	17	18	15
N2 (1 ft from diffuser)	73	73	73	73	73	15	11	15	13
N3 (2 ft from diffuser)	73	73	73	73	73	17	11	12	15
N4 (3 ft from diffuser)	73	73	73	73	73	11	11	17	16
N5 (4 ft from diffuser)	73	73	73	73	73	10	13	22	18
N6 (5 ft from diffuser)	73	73	73	73	73	11	10	12	9
N7 (5.5 ft from diffuser)	73	73	73	73	73	11	11	12	14
S1 (Edge of diffuser)	73	73	73	73	73	17	6	8	7
S2 (1 ft from diffuser)	73	73	73	73	73	13	13	9	13
S3 (2 ft from diffuser)	73	73	73	73	73	13	12	14	12
S4 (3 ft from diffuser)	73	73	73	73	73	14	9	11	14
S5 (4 ft from diffuser)	73	73	73	73	73	14	9	13	9
S6 (5 ft from diffuser)	73	73	73	73	73	15	14	14	14
S7 (5.5 ft	73	73	73	73	73	15	15	18	22

from diffuser)									
E1 (Edge of diffuser)	73	73	73	73	73	11	10	10	5
E2 (1 ft from diffuser)	73	73	73	73	73	12	9	12	9
E3 (2 ft from diffuser)	73	73	73	73	73	14	11	10	12
E4 (3 ft from diffuser)	73	73	73	73	73	11	5	5	2
E5 (4 ft from diffuser)	73	73	73	73	73	11	5	12	12
E6 (5 ft from diffuser)	73	73	73	73	73	10	9	5	9
E7 (6 ft from diffuser)	73	73	73	73	73	11	14	16	15
E8 (7 ft from diffuser)	73	73	73	73	73	15	22	23	22
E9 (8 ft from diffuser)	73	73	73	73	73	23	20	18	16
E10 (8.5 ft from diffuser)	73	74	73	73	73	16	21	27	25
W1 (Edge of diffuser)	73	73	73	73	73	12	12	14	11
W2 (1 ft from diffuser)	73	73	73	73	73	16	13	17	12
W3 (2 ft from diffuser)	73	73	73	73	73	14	13	12	15
W4 (3 ft from diffuser)	73	73	73	73	74	12	15	19	26
W5 (4 ft from diffuser)	73	73	73	73	74	10	14	21	24
W6 (5 ft from diffuser)	73	73	73	73	74	16	14	7	7
W7 (6 ft from diffuser)	73	73	73	73	74	15	16	13	6
W8 (7 ft from diffuser)	73	74	73	73	74	19	13	13	13
W9 (8 ft from diffuser)	73	74	74	74	74	13	13	8	5
W10 (8.5 ft from diffuser)	73	74	74	74	74	15	14	15	16

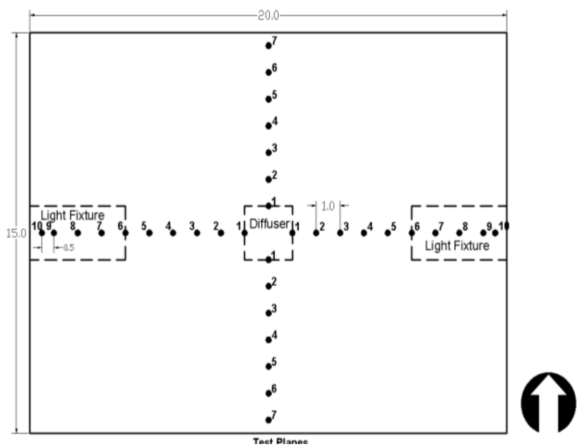
Load Distribution Layout- SPD Diffuser



Test 49



Test 50



Test 51

Test 49 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	55°F	72°F	20 x 15 x 9	1290 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	73	28	31	30	30
N2 (1 ft from diffuser)	72	72	72	73	73	31	35	39	38
N3 (2 ft from diffuser)	72	72	72	73	73	27	28	37	32
N4 (3 ft from diffuser)	72	72	72	73	73	35	22	19	24
N5 (4 ft from diffuser)	72	72	72	73	73	34	30	21	19
N6 (5 ft from diffuser)	72	72	72	73	73	34	23	18	21
N7 (5.5 ft from diffuser)	72	72	72	72	73	22	46	54	52
S1 (Edge of diffuser)	72	72	73	73	73	30	34	34	35
S2 (1 ft from diffuser)	72	72	72	73	73	23	28	30	29
S3 (2 ft from diffuser)	72	72	73	73	73	31	32	34	36
S4 (3 ft from diffuser)	72	72	73	73	73	22	29	34	32
S5 (4 ft from diffuser)	73	73	73	73	73	40	32	30	29
S6 (5 ft from diffuser)	72	72	73	73	73	24	19	19	20
S7 (5.5 ft from diffuser)	73	73	72	72	73	28	33	47	47
E1 (Edge of diffuser)	72	73	73	73	73	31	34	41	38
E2 (1 ft from diffuser)	72	73	73	73	73	41	43	38	33
E3 (2 ft from diffuser)	72	73	73	73	73	31	35	42	41
E4 (3 ft from diffuser)	72	73	73	73	73	36	37	37	32
E5 (4 ft from diffuser)	72	72	73	73	73	34	33	37	42
E6 (5 ft from diffuser)	72	72	72	72	73	42	31	26	22
E7 (6 ft from diffuser)	72	72	72	73	73	42	24	21	16
E8 (7 ft from diffuser)	72	72	72	72	73	39	25	22	15
E9 (8 ft from diffuser)	72	72	72	72	73	44	30	39	45

E10 (8.5 ft from diffuser)	72	72	72	72	73	57	25	28	50
W1 (Edge of diffuser)	72	73	73	73	73	27	18	30	32
W2 (1 ft from diffuser)	72	73	73	73	73	27	18	30	32
W3 (2 ft from diffuser)	73	73	73	73	73	31	27	34	27
W4 (3 ft from diffuser)	73	73	73	73	73	24	30	36	34
W5 (4 ft from diffuser)	73	73	73	73	73	28	30	35	31
W6 (5 ft from diffuser)	73	73	73	73	73	26	34	37	36
W7 (6 ft from diffuser)	73	73	73	73	73	40	26	29	28
W8 (7 ft from diffuser)	73	73	73	73	73	40	26	29	28
W9 (8 ft from diffuser)	73	73	73	73	73	44	26	21	29
W10 (8.5 ft from diffuser)	73	73	73	73	73	49	20	27	42

Test 50 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	55°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	72	72	72	11	11	9	12
N2 (1 ft from diffuser)	72	72	72	72	72	13	14	16	17
N3 (2 ft from diffuser)	72	72	72	72	72	12	18	22	21
N4 (3 ft from diffuser)	72	72	72	72	72	17	17	18	21
N5 (4 ft from diffuser)	72	72	72	72	72	14	17	16	24
N6 (5 ft from diffuser)	72	72	72	72	72	18	12	17	18
N7 (5.5 ft from diffuser)	72	72	72	72	72	15	18	18	24
S1 (Edge of diffuser)	72	72	72	72	72	16	15	18	18
S2 (1 ft from	72	72	72	72	72	16	13	13	14

diffuser)									
S3 (2 ft from diffuser)	72	72	72	72	72	19	12	15	20
S4 (3 ft from diffuser)	72	72	72	72	72	20	12	13	20
S5 (4 ft from diffuser)	72	72	72	72	72	18	11	11	11
S6 (5 ft from diffuser)	72	72	72	72	72	19	13	12	15
S7 (5.5 ft from diffuser)	71	71	71	71	72	24	24	26	25
E1 (Edge of diffuser)	72	71	71	71	72	11	10	11	12
E2 (1 ft from diffuser)	71	71	71	71	72	12	10	13	15
E3 (2 ft from diffuser)	71	71	71	71	72	14	13	15	19
E4 (3 ft from diffuser)	71	71	71	71	72	16	13	16	22
E5 (4 ft from diffuser)	71	71	71	71	72	15	11	14	17
E6 (5 ft from diffuser)	71	71	71	71	72	14	13	10	16
E7 (6 ft from diffuser)	71	72	71	72	72	13	14	19	11
E8 (7 ft from diffuser)	71	71	71	72	72	15	16	14	15
E9 (8 ft from diffuser)	71	72	71	72	72	25	18	21	20
E10 (8.5 ft from diffuser)	71	71	71	71	72	27	20	24	22
W1 (Edge of diffuser)	71	71	71	71	71	19	13	14	18
W2 (1 ft from diffuser)	71	71	71	71	72	12	13	13	15
W3 (2 ft from diffuser)	71	71	71	71	72	19	12	12	17
W4 (3 ft from diffuser)	71	71	71	71	72	18	13	14	21
W5 (4 ft from diffuser)	71	71	71	71	71	15	8	12	13
W6 (5 ft from diffuser)	71	71	71	71	71	12	9	12	13
W7 (6 ft from diffuser)	71	71	71	72	71	14	11	12	13
W8 (7 ft from diffuser)	71	71	71	72	71	15	11	13	13
W9 (8 ft from diffuser)	71	71	72	72	71	25	20	19	18

W10 (8.5 ft from diffuser)	71	71	71	72	72	27	21	22	18

Test 51 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	55°F	72°F	20 x 15 x 9	290 watts

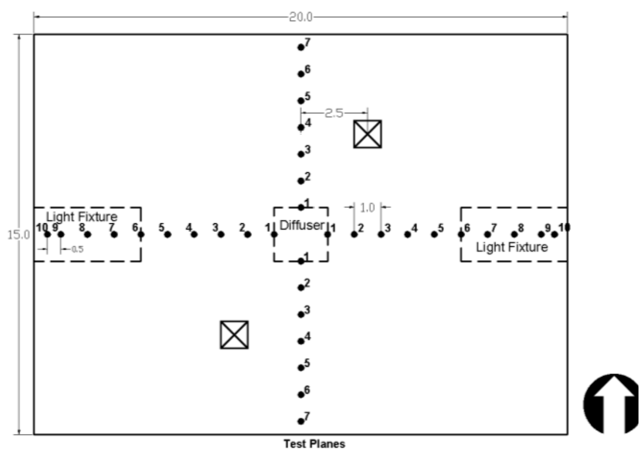
Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	69	69	69	69	70	27	26	25	24
N2 (1 ft from diffuser)	69	69	69	69	70	26	24	30	27
N3 (2 ft from diffuser)	69	69	69	69	70	33	13	15	22
N4 (3 ft from diffuser)	69	69	69	69	70	22	21	23	17
N5 (4 ft from diffuser)	69	69	69	69	70	25	5	4	8
N6 (5 ft from diffuser)	69	69	69	70	70	17	9	10	1
N7 (5.5 ft from diffuser)	69	69	69	70	70	19	21	23	18
S1 (Edge of diffuser)	69	70	69	69	70	13	12	16	20
S2 (1 ft from diffuser)	70	70	70	69	70	10	11	10	7
S3 (2 ft from diffuser)	70	70	70	70	70	11	14	10	11
S4 (3 ft from diffuser)	70	70	70	70	70	13	12	6	2
S5 (4 ft from	70	70	70	70	70	12	12	10	10

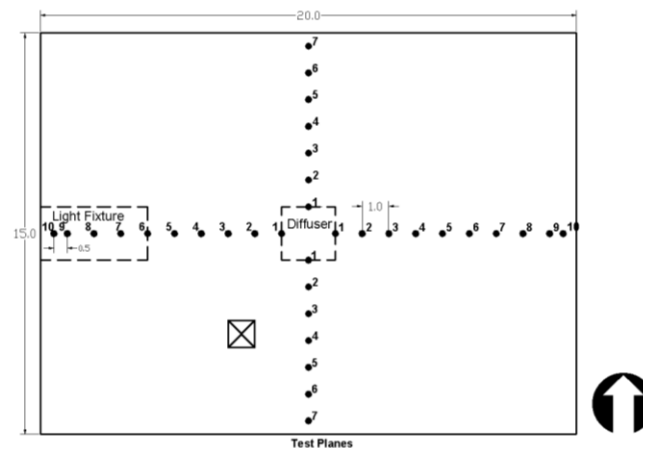
diffuser)									
S6 (5 ft from diffuser)	70	70	70	70	70	17	14	15	10
S7 (5.5 ft from diffuser)	70	70	70	70	70	12	15	20	20
E1 (Edge of diffuser)	69	69	69	69	70	16	31	32	33
E2 (1 ft from diffuser)	69	69	69	69	70	19	9	8	5
E3 (2 ft from diffuser)	70	70	70	70	70	11	11	5	6
E4 (3 ft from diffuser)	70	70	70	70	70	15	10	9	9
E5 (4 ft from diffuser)	70	70	70	70	70	13	9	8	14
E6 (5 ft from diffuser)	70	70	70	70	70	13	4	12	12
E7 (6 ft from diffuser)	70	70	70	70	70	12	11	11	13
E8 (7 ft from diffuser)	70	70	70	70	70	15	9	13	14
E9 (8 ft from diffuser)	70	70	70	70	70	17	12	15	17
E10 (8.5 ft from diffuser)	70	70	70	70	70	17	19	15	16
W1 (Edge of diffuser)	70	70	70	70	70	16	20	25	27
W2 (1 ft from diffuser)	70	70	70	70	70	20	25	27	23
W3 (2 ft from diffuser)	70	70	70	70	70	14	6	9	9
W4 (3 ft from	70	70	70	70	70	12	8	8	10

diffuser)									
W5 (4 ft from diffuser)	70	70	70	70	70	13	2	5	5
W6 (5 ft from diffuser)	70	70	70	70	70	12	3	12	14
W7 (6 ft from diffuser)	70	70	70	70	70	15	8	11	8
W8 (7 ft from diffuser)	70	70	70	70	70	12	7	7	7
W9 (8 ft from diffuser)	70	70	70	70	70	16	12	14	14
W10 (8.5 ft from diffuser)	70	70	70	70	70	16	13	14	12

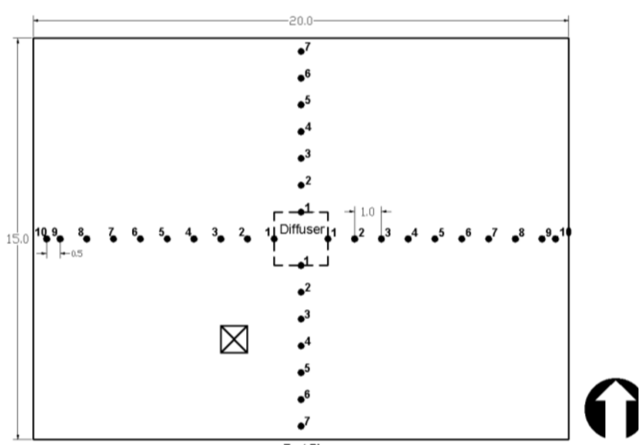
Load Distribution Layout- SPD Diffuser



Test 52



Test 53



Test 54

Test 52 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
239 cfm	65°F	72°F	20 x 15 x 9	540 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	22	29	31	31
N2 (1 ft from diffuser)	72	72	72	72	72	19	24	22	20
N3 (2 ft from diffuser)	72	72	72	73	72	18	22	25	29
N4 (3 ft from diffuser)	72	72	72	72	72	16	20	29	25
N5 (4 ft from diffuser)	72	72	72	73	72	16	31	33	31
N6 (5 ft from diffuser)	72	72	72	73	72	13	22	27	21
N7 (5.5 ft from diffuser)	72	72	72	72	72	25	17	27	34
S1 (Edge of	72	72	72	72	73	17	23	24	26

diffuser)									
S2 (1 ft from diffuser)	72	72	72	72	73	26	28	29	28
S3 (2 ft from diffuser)	73	73	73	73	73	16	23	28	23
S4 (3 ft from diffuser)	73	73	73	73	73	19	21	25	24
S5 (4 ft from diffuser)	73	73	73	73	73	21	21	20	26
S6 (5 ft from diffuser)	73	73	73	73	72	15	25	23	30
S7 (5.5 ft from diffuser)	73	73	73	73	72	16	13	21	47
E1 (Edge of diffuser)	73	73	73	73	73	19	24	24	25
E2 (1 ft from diffuser)	72	72	72	72	73	25	26	22	20
E3 (2 ft from diffuser)	72	72	72	72	73	31	27	15	13
E4 (3 ft from diffuser)	72	72	72	72	73	29	25	25	21
E5 (4 ft from diffuser)	72	72	72	73	73	37	27	25	25
E6 (5 ft from diffuser)	72	72	72	73	73	34	23	24	24
E7 (6 ft from diffuser)	72	72	72	73	73	34	18	19	18
E8 (7 ft from diffuser)	72	73	73	73	73	35	21	20	15
E9 (8 ft from diffuser)	72	73	73	73	73	25	23	29	24
E10 (8.5 ft from	72	73	73	73	73	37	20	32	40

diffuser)									
W1 (Edge of diffuser)	72	73	73	73	73	26	18	21	24
W2 (1 ft from diffuser)	72	73	73	73	73	26	28	30	24
W3 (2 ft from diffuser)	72	72	72	73	73	32	25	19	18
W4 (3 ft from diffuser)	72	72	73	73	73	36	31	29	28
W5 (4 ft from diffuser)	72	73	73	73	73	41	27	22	17
W6 (5 ft from diffuser)	72	73	73	73	73	34	21	20	18
W7 (6 ft from diffuser)	73	73	73	73	73	34	20	15	16
W8 (7 ft from diffuser)	73	73	73	73	73	27	16	10	9
W9 (8 ft from diffuser)	73	73	73	73	73	21	24	37	33
W10 (8.5 ft from diffuser)	73	73	73	73	73	36	15	35	44

Test 53 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
100 cfm	65°F	72°F	20 x 15 x 9	275 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	71	71	71	71	72	27	21	18	18
N2 (1 ft from diffuser)	72	72	72	72	72	21	12	15	20
N3 (2 ft from diffuser)	72	72	72	72	72	25	12	18	21
N4 (3 ft from	72	72	72	72	72	22	10	19	24

diffuser)									
N5 (4 ft from diffuser)	72	72	72	72	72	21	11	15	21
N6 (5 ft from diffuser)	72	72	72	72	72	21	15	14	18
N7 (5.5 ft from diffuser)	72	72	72	72	72	18	13	13	23
S1 (Edge of diffuser)	72	72	72	72	72	25	17	18	11
S2 (1 ft from diffuser)	72	72	72	72	72	27	19	16	17
S3 (2 ft from diffuser)	72	72	72	72	72	29	21	15	9
S4 (3 ft from diffuser)	72	72	72	72	72	25	20	13	14
S5 (4 ft from diffuser)	72	72	72	72	72	29	16	10	16
S6 (5 ft from diffuser)	72	72	72	72	72	26	19	14	17
S7 (5.5 ft from diffuser)	72	72	72	72	72	29	23	16	16
E1 (Edge of diffuser)	72	72	72	72	72	20	18	21	18
E2 (1 ft from diffuser)	72	72	72	72	72	17	14	14	15
E3 (2 ft from diffuser)	72	72	72	72	72	18	16	15	5
E4 (3 ft from diffuser)	72	72	72	72	72	22	22	15	16
E5 (4 ft from diffuser)	72	72	72	72	72	15	13	13	13
E6 (5 ft from diffuser)	72	72	72	72	72	15	12	8	12
E7 (6 ft from diffuser)	72	72	72	72	72	16	14	13	13
E8 (7 ft from diffuser)	72	72	72	72	72	14	19	19	18
E9 (8 ft from diffuser)	72	72	72	72	72	14	13	11	13
E10 (8.5 ft from diffuser)	72	72	72	72	72	10	24	28	25
W1 (Edge of diffuser)	72	72	72	72	72	21	14	12	18
W2 (1 ft from diffuser)	72	72	72	72	72	16	13	15	17
W3 (2 ft from diffuser)	72	72	72	72	72	18	12	13	13
W4 (3 ft from diffuser)	72	72	72	72	72	14	11	11	17

W5 (4 ft from diffuser)	72	72	72	72	72	15	12	13	12
W6 (5 ft from diffuser)	72	72	72	72	72	15	13	14	15
W7 (6 ft from diffuser)	72	72	72	72	72	12	13	13	14
W8 (7 ft from diffuser)	72	72	72	72	72	13	12	14	13
W9 (8 ft from diffuser)	72	72	72	72	72	13	11	14	14
W10 (8.5 ft from diffuser)	72	72	72	72	72	17	14	16	18

Test 54 Conditions – SPD Diffuser:

Supply Air Volume	Supply Temp	Room Temp	Room Size	Room Load
55 cfm	65°F	72°F	20 x 15 x 9	135 watts

Plane North > South > East > West

	Average Temperature (°F)					Average Velocity (ft/min)			
Measurement points	**4"**	**24"**	**42"**	**66"**	**Room**	**4"**	**24"**	**42"**	**66"**
N1 (Edge of diffuser)	72	72	72	72	72	3	4	11	10
N2 (1 ft from diffuser)	72	72	72	72	72	3	8	11	14
N3 (2 ft from diffuser)	72	72	72	72	72	10	11	6	1
N4 (3 ft from diffuser)	72	72	73	73	73	9	5	11	7
N5 (4 ft from diffuser)	72	73	73	73	73	9	10	12	14
N6 (5 ft from diffuser)	72	73	73	73	73	11	13	16	17
N7 (5.5 ft from diffuser)	73	73	73	73	73	7	10	12	14
S1 (Edge of diffuser)	73	73	73	73	73	4	7	4	5
S2 (1 ft from diffuser)	73	73	73	73	73	10	10	7	10
S3 (2 ft from diffuser)	73	73	73	73	73	12	9	11	16
S4 (3 ft from diffuser)	73	73	73	73	73	12	11	9	4
S5 (4 ft from diffuser)	73	73	73	73	73	4	7	9	5
S6 (5 ft from diffuser)	73	73	73	73	73	6	7	3	6
S7 (5.5 ft from	73	73	73	73	73	4	9	13	14

diffuser)									
E1 (Edge of diffuser)	73	73	73	73	73	11	10	13	10
E2 (1 ft from diffuser)	73	73	73	73	73	7	8	9	8
E3 (2 ft from diffuser)	73	73	73	73	73	14	10	7	10
E4 (3 ft from diffuser)	72	72	72	73	72	4	3	1	3
E5 (4 ft from diffuser)	72	72	73	73	72	11	8	8	7
E6 (5 ft from diffuser)	72	73	73	73	73	6	8	6	3
E7 (6 ft from diffuser)	72	73	73	73	73	7	7	1	1
E8 (7 ft from diffuser)	73	73	73	73	73	5	7	4	0
E9 (8 ft from diffuser)	73	73	73	73	73	6	9	4	4
E10 (8.5 ft from diffuser)	73	73	73	73	73	7	4	5	3
W1 (Edge of diffuser)	72	72	72	72	72	10	9	12	14
W2 (1 ft from diffuser)	72	72	72	72	72	10	9	6	9
W3 (2 ft from diffuser)	72	72	72	72	72	13	9	9	10
W4 (3 ft from diffuser)	72	72	72	72	72	10	10	11	14
W5 (4 ft from diffuser)	72	72	72	72	72	11	11	4	5
W6 (5 ft from diffuser)	72	72	72	72	72	9	6	9	6
W7 (6 ft from diffuser)	72	72	72	72	72	14	10	8	7
W8 (7 ft from diffuser)	72	72	72	72	72	11	6	3	4
W9 (8 ft from diffuser)	72	72	72	72	72	8	7	8	5
W10 (8.5 ft from diffuser)	71	72	72	72	72	4	3	1	0

Lab technician: Michael Lim

H.3 Air Change Effectiveness Report

PRICE RESEARCH CENTER NORTH

LABORATORY TEST REPORT

638 Raleigh Street • Winnipeg, Manitoba • R3K 2Z9 • Canada

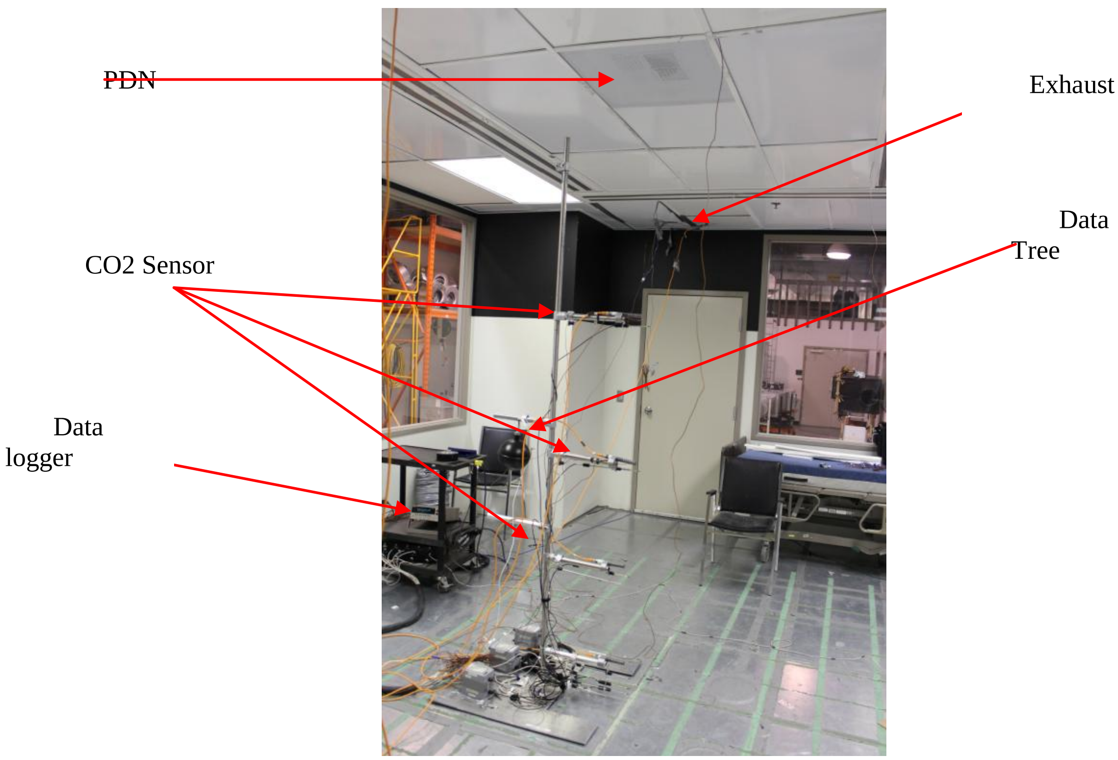
RP 1515 (PDN – SDB 100) Air Change Effectiveness ACE

Lab File Number X112

January 4, 2013

Test Setup

ROOM DIMENSION 20 X 16 X 9



CO2 Sensor location

Test Results

Test#1 Conditions

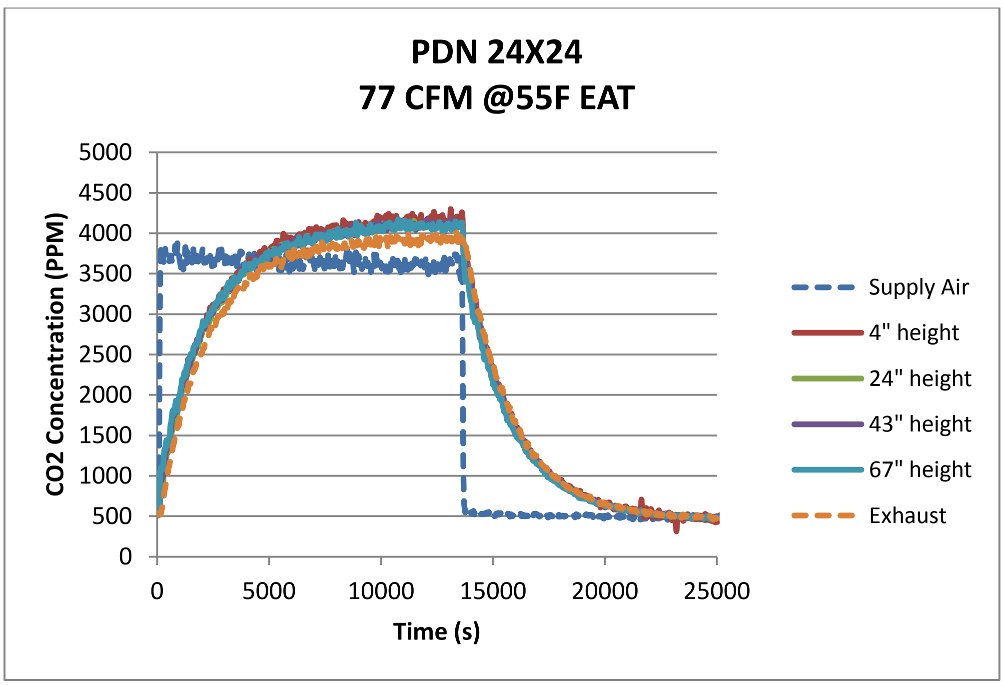
Supply Air Volume - 77 cfm
Supply Air Temperature - 55°F
Room temperature- 71°F

Exhaust Air Volume - 77 cfm
Ave. Exhaust Air Temperature – 71.7°F

Space load - 416 watts

	ACE			
	4" height	24" height	43" height	67" height
Step Up	1.07	1.07	1.10	1.13
Decay	1.00	1.04	1.05	1.08

	Average Age of Air				
	4" height	24" height	43" height	67" height	Exhaust
Step Up	1186.8	1192.9	1158.6	1122.3	1272.0
Decay	-8393.7	-8057.4	-7994.1	-7738.2	-8379.1



CO2 Concentrations for step up and decay method at supply, exhaust, 4”, 24”, 43 and 67” height

Test#2 Conditions

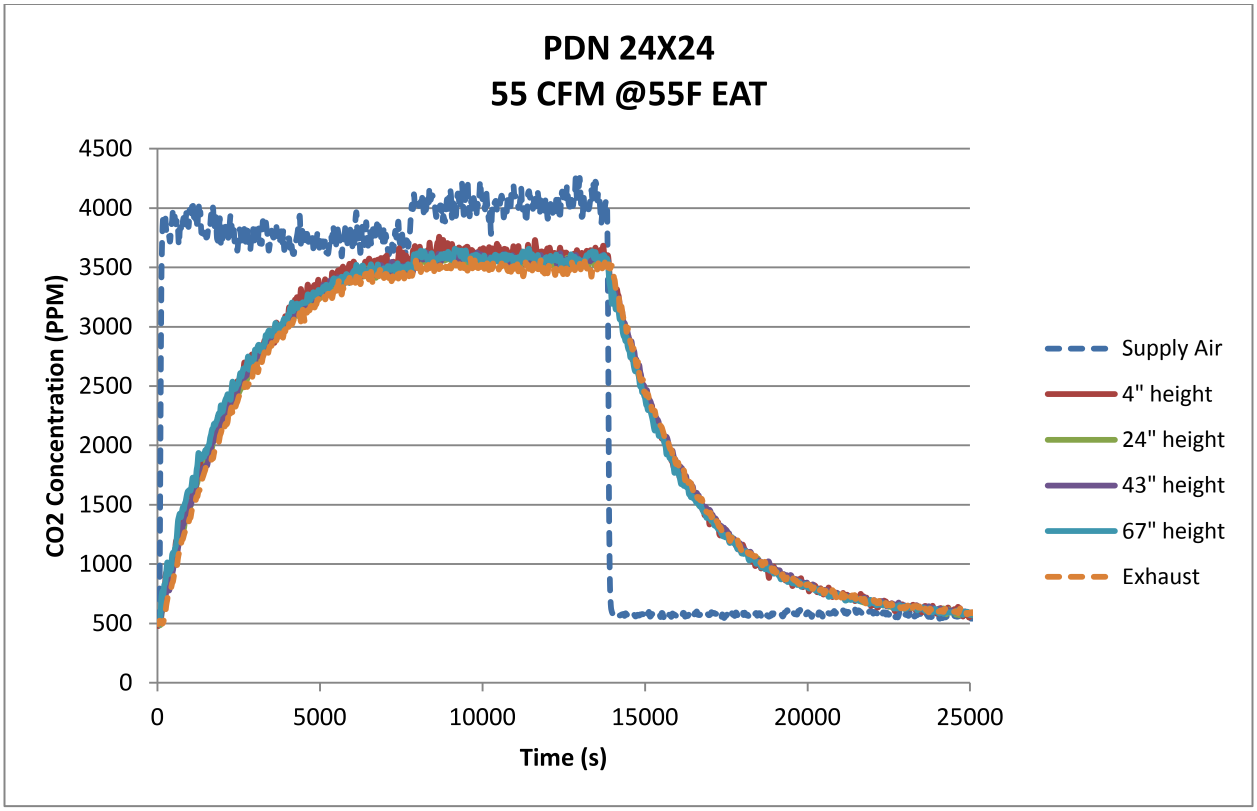
Supply Air Volume - 55 cfm
Supply Air Temperature - 55°F
Room temperature- 71.7°F

Exhaust Air Volume - 55 cfm
Ave. Exhaust Air Temperature - 72°F

Space load - 290 watts

	ACE			
	4" height	24" height	43" height	67" height
Step Up	1.06	1.03	1.03	1.10
Decay	1.02	1.02	1.01	1.03

	Average Age of Air				
	4" height	24" height	43" height	67" height	4" height
Step Up	1398.8	1435.0	1432.9	1345.7	1477.1
Decay	-6979.3	-7029.7	-7084.4	-6895.1	-7135.6



CO2 Concentrations for step up and decay method at supply, exhaust, 4", 24", 43 and 67" height

Test#3 Conditions

Supply Air Volume - 30 cfm
Supply Air Temperature - 58°F
Room temperature- 72°F

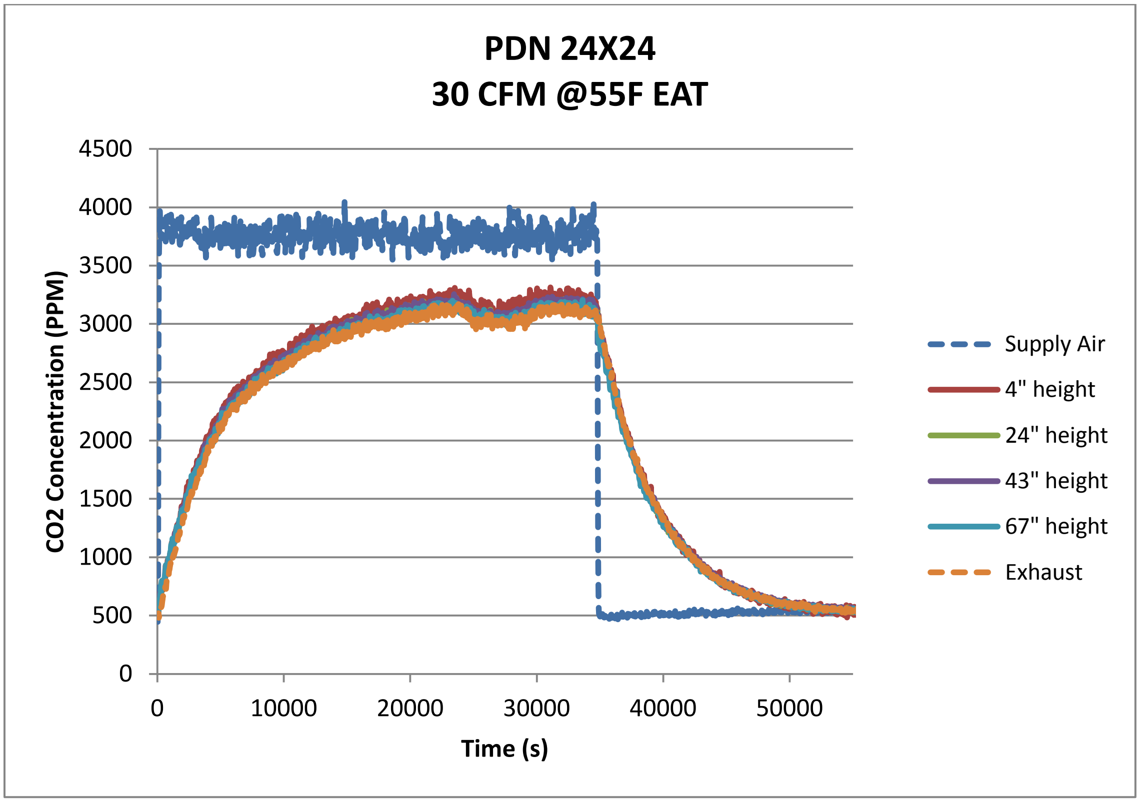
Exhaust Air Volume - 30 cfm
Ave. Exhaust Air Temperature – 72.6°F

Space load - 130 watts

	ACE			
	4" height	24" height	43" height	67" height
Step Up	1.04	1.03	1.04	1.04
Decay	0.99	1.01	1.03	1.03

	Average Age of Air				
	4" height	24" height	43" height	67" height	Exhaust
Step Up	2548.3	2567.5	2539.5	2538.3	2645.4

Decay	-10882.8	-10667.7	-10509.6	-10459.4	-10804.0



CO2 Concentrations for step up and decay method at supply, exhaust, 4", 24", 43 and 67" height

Test#4 Conditions

Supply Air Volume - 90 cfm
Supply Air Temperature - 87°F
Room temperature- 70.8°F

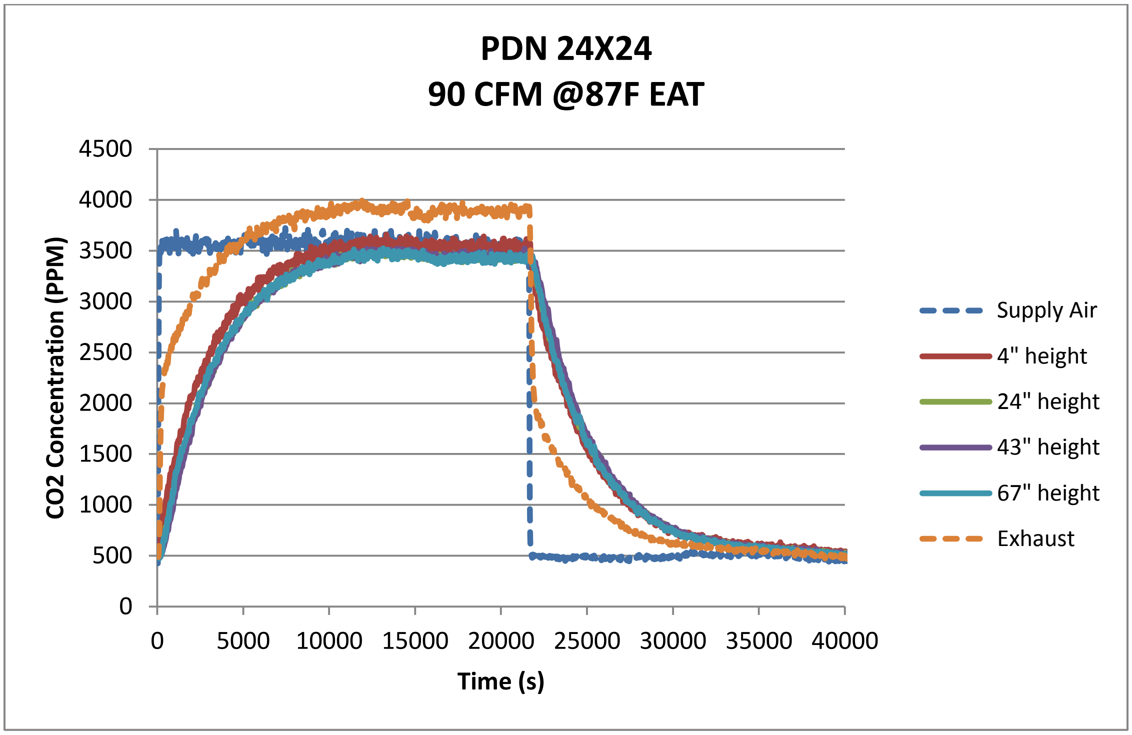
Exhaust Air Volume - 90 cfm
Ave. Exhaust Air Temperature – 75.25°F

Cold Chamber Temp: -13°F

	ACE			
	4" height	24" height	43" height	67" height
Step Up	0.56	0.50	0.48	0.51
Decay	0.67	0.62	0.60	0.61

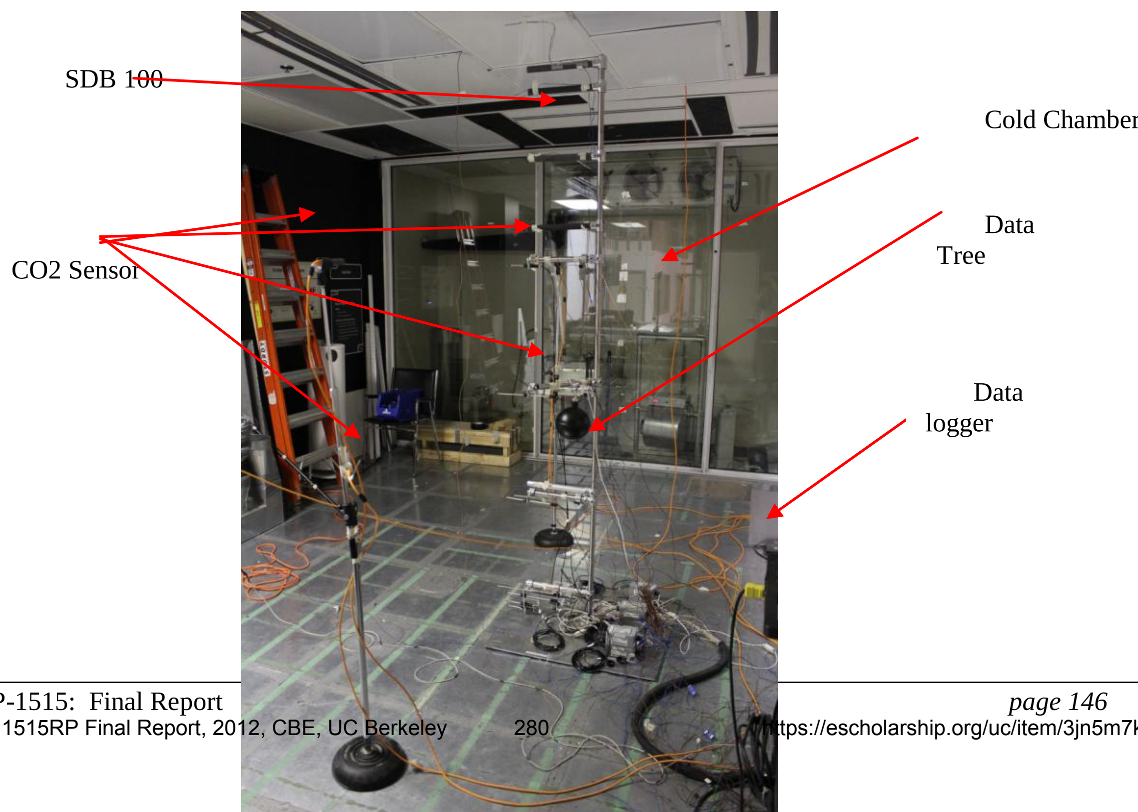
	Average Age of Air				
	4" height	24" height	43" height	67" height	Exhaust
Step Up	1837.7	2075.5	2150.6	2028.4	1038.2

Decay	-9536.1	-10333.6	-10705.4	-10415.5	-6372.0



CO2 Concentrations for step up and decay method at supply, exhaust, 4", 24", 43 and 67" height

SDB100 2 SLOT



CO2 Sensor location

Test#5 Conditions

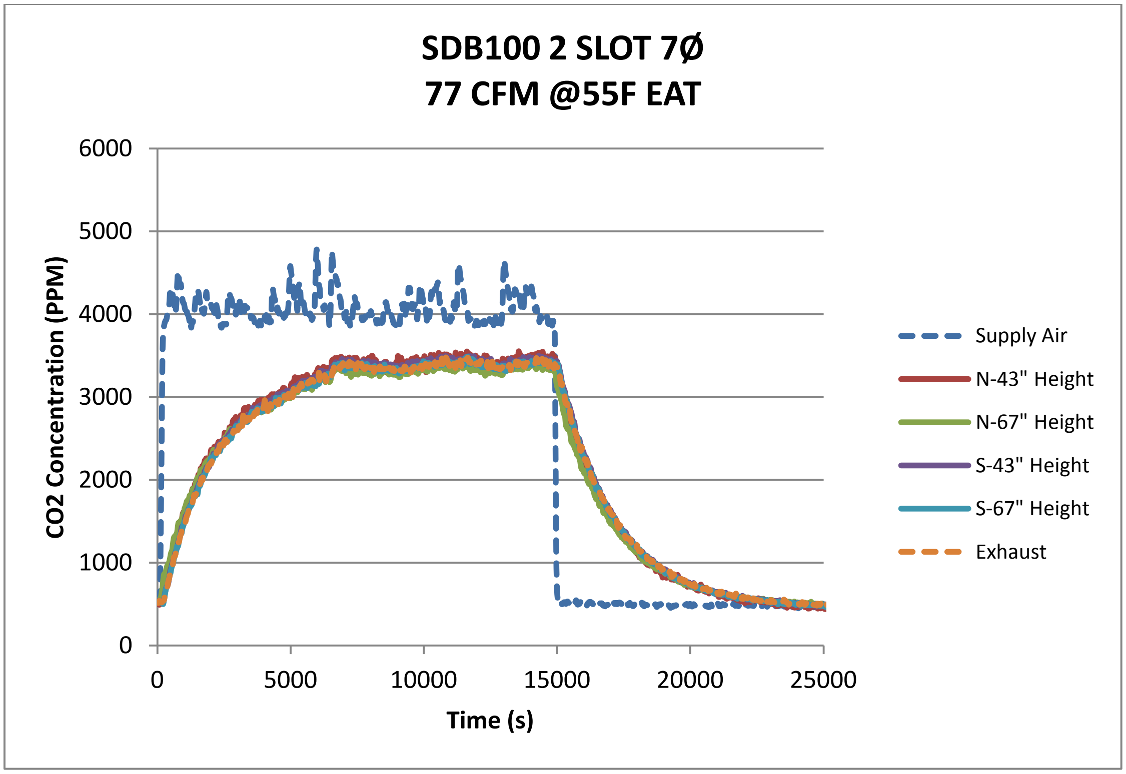
Supply Air Volume - 77 cfm
Supply Air Temperature - 55°F
Room temperature- 70°F

Exhaust Air Volume - 77 cfm
Ave. Exhaust Air Temperature – 71°F

Space load - 416 watts

	ACE			
	N-43" Height	N-67" Height	S-43" Height	S-67" Height
Step Up	1.06	1.10	1.00	1.00
Decay	0.97	1.10	0.96	0.98

	Average Age of Air				
	N-43" Height	N-67" Height	S-43" Height	S-67" Height	Exhaust
Step Up	1389.6	1330.4	1461.4	1463.2	1468.7
Decay	-7422.3	-6576.8	-7532.3	-7391.2	-7236.1



CO2 Concentrations for step up and decay method at supply, exhaust, N-43”, N-67”, S-43” and S-67” height

Test#6 Conditions

Supply Air Volume - 55 cfm
Supply Air Temperature - 55°F
Room temperature- 72°F

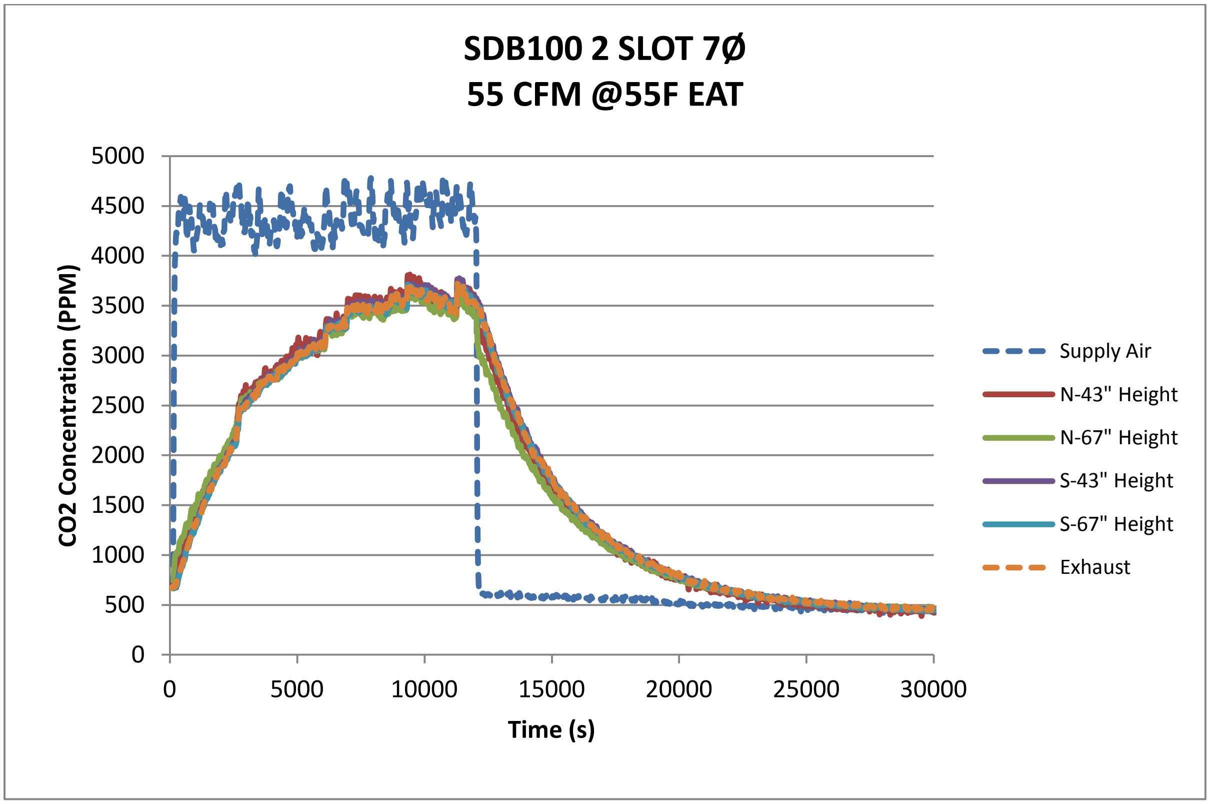
Exhaust Air Volume - 55 cfm
Ave. Exhaust Air Temperature – 73°F

Space load - 290 watts

	ACE			
	N-43" Height	N-67" Height	S-43" Height	S-67" Height
Step Up	1.05	1.11	0.99	0.98
Decay	0.99	1.16	0.98	0.98

	Average Age of Air				
	N-43" Height	N-67" Height	S-43" Height	S-67" Height	Exhaust
Step Up	1484.5	1400.4	1579.3	1584.2	1560.3
Decay	-17868.6	-15218.1	-18107.6	-18047.2	-

					17716.4



CO2 Concentrations for step up and decay method at supply, exhaust, N-43", N-67", S-43" and S-67" height

Test#7 Conditions

Supply Air Volume - 30 cfm
Supply Air Temperature - 57°F
Room temperature- 72°F

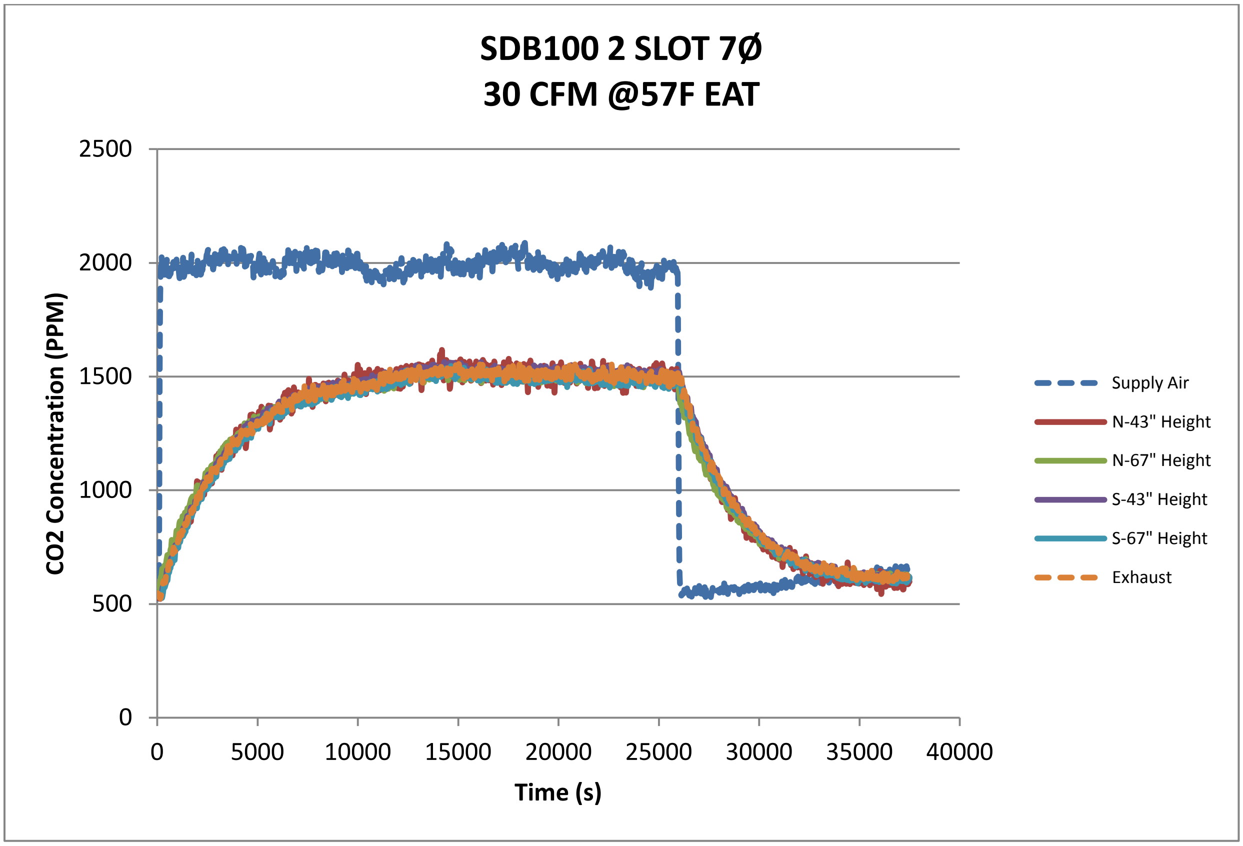
Exhaust Air Volume - 55 cfm
Ave. Exhaust Air Temperature – 73°F

Space load - 130 watts

	ACE			
	N-43" Height	N-67" Height	S-43" Height	S-67" Height
Step Up	1.01	1.09	0.99	0.99
Decay	0.99	1.12	0.97	0.99

	Average Age of Air				
	N-43" Height	N-67" Height	S-43" Height	S-67" Height	Exhaust

Step Up	1624.5	1506.6	1662.0	1656.8	1646.5
Decay	-2109.2	-1862.1	-2148.3	-2116.5	-2086.8



CO_2 Concentrations for step up and decay method at supply, exhaust, N-43”, N-67”, S-43” and S-67” height

[redacted]

Lab technician: Michael Lim

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