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A Surprisingly Straightforward Solution

Eliminating Overcooling Discomfort While Saving Energy

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A large percentage of commercial buildings in North America use variable air volume (VAV) systems with reheat, and this system type is also common around the world. Summertime overcooling is widespread in such buildings [Mendell and Mirer 2009] and has received considerable media attention over the past few years. ASHRAE Research Project RP-1515, reported in this article, shows that much of today's overcooling originates in unsubstantiated engineering assumptions about the performance of VAV boxes and diffusers at low-flow setpoints. These assumptions are that low flows will cause diffusers to dump cooled air and create drafts around occupants, ventilation air will be poorly mixed, and VAV airflow control will become unstable or inaccurate. Together, they have resulted in VAV minimums being commonly set at 20% to 50% of maximum. ASHRAE RP-1515 and other recent research have shown each of these assumptions to be unwarranted, and that far lower minimums are desirable.

In RP-1515, buildings operated on corrected assumptions were found to reduce their pre-existing cold complaints by half while also saving energy. Reducing VAV box minimum airflow setpoints to ventilation minimum flow rates, often around 10% of maximum,

reduced total HVAC energy by 10% to 30%, which is remarkable for an inexpensive controls setpoint change that properly maintains outside air ventilation. There were no draft discomfort complaints during low flows, and the preexisting rate of occupant cold discomfort

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was cut in half. The new control sequences are applicable to all new and many existing VAV buildings.

Background

VAV box minimum airflow setpoints have tremendous energy implications. Simulations have suggested that lowering the minimum airflow setpoint to the levels needed for outside air ventilation (~10% of maximum flow) would reduce a conventional building's HVAC energy by 10% to 30% [Hoyt et al. 2014, Taylor et al. 2012]. However, conventional practice (minimums set between 20% to 50% of maximum flow) has been firmly based on long-standing concerns among designers and manufacturers about the indoor environmental quality under low minimums. In other words, will there be a downside to the indoor environmental quality under low minimum operation?

VAV minimum flow setpoints have been traditionally maintained at the higher levels because of three concerns held by practitioners and manufacturers:

1. VAV boxes might be unable to sense or control low flows;
2. Poor air quality might result from a combination of poor control and insufficient diffuser mixing; and
3. Low flows might cause the occupants to perceive draft discomfort from insufficient mixing of diffuser discharge air.

To address these concerns, diffuser manufacturers and ASHRAE *Handbook—Fundamentals* have for many years suggested that minimum VAV airflows be limited to 30% to 50% of design airflow. However, there was little research supporting the suggestions.

Concern 1: Recent research has addressed the stability and accuracy in Concern 1. Two studies of VAV terminal unit control at low flows found that a typical selection of VAV boxes control stably to between 5% and 15% of design flow [Dickerhoff and Stein, 2007, Liu et al. 2012].

These findings validated the existing California energy code and ASHRAE/IES Standard 90.1 requirements that limit VAV box minimums to not exceed 20% when ventilation requirements are met. Recently published ASHRAE Guideline 36 and Taylor et al. (2012) describe the associated VAV box control sequence (commonly called dual-maximum control) VAV box sizing, and calculations to determine minimum flow setpoints.

Concern 2 about room air distribution and ventilation effectiveness under low-flow conditions was examined

in the 1990s by numerous researchers who consistently found that ventilation effectiveness was maintained at low flows both in cooling and in low-temperature heating, [Persily & Dols 1991, Persily 1992, Offerman and Int-Hout 1988, Fisk, et al. 1997].

Concern 3: Given that low flows do not degrade VAV box control or room air mixing, there is still concern that occupants' *comfort* and their *perception of indoor air quality* (IAQ) are not well-maintained within the space when diffusers are supplying very low flow. The primary *comfort* concern was that insufficiently mixed cool air from diffusers will “dump” on occupants, producing cool draft sensations.

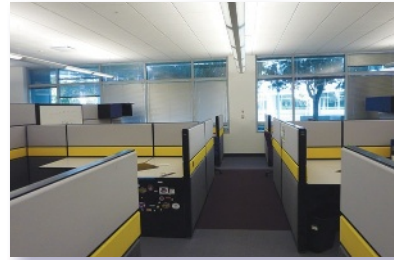
In cooling mode, diffuser discharge velocities at low airflows may not maintain the Coanda effect necessary to overcome the negative buoyancy of the cold air being discharged, causing cold supply air to drop into the space. The *air quality* concern is that outside air entering the room through the diffusers may, if insufficiently mixed, bypass the occupants and result in real or perceived bad air quality.

ASHRAE Research Project 1515 focused primarily on Concern 3. Office workers' thermal comfort and air quality satisfaction were evaluated in a set of field study buildings that researchers were able to operate alternately under conventional and reduced-minimum VAV flow setpoints, over a period of about two years. The energy savings from the lowered minimums were also measured. In parallel, extensive laboratory tests measured the mixing performance of a range of typical diffuser types, addressing both Concerns 2 and 3 by determining their air diffusion performance index (ADPI) and air change effectiveness (ACE). High values of ADPI and ACE were found at low cooling flows [Arens et al. 2015]. The energy and ventilation results are reported separately in [Arens et al. 2012, Arens et al. 2015].

The Study

This article focuses on how occupants of office buildings respond to lowered VAV minimum setpoints. In our field study we alternated between two VAV box minimum flow setpoint modes, conventional high-minimums and low-minimums, termed “high” and “low.” We fixed VAV minimums at 30% to represent high-minimum conventional practice, unless there were ventilation requirements calling for more

FIGURE 1 Yahoo! Buildings. Typical facade, floor plan (orange indicates open office), and open plan office interior.



airflow.* During low-minimum operation the VAV minimum setpoints were generally in the range of 10% to 20%, and were calculated using the approach described in the sidebar “Determination of Low-Minimum Mode Setpoint.” Thus, the results can be interpreted as a comparison between a standard practice case with 30% VAV minimums, and a retrofit case in which best-practice low minimum setpoints were applied.

Study Building Descriptions

The research team searched for buildings that would allow us to reprogram their VAV control systems to allow minimum VAV flow rates in all zones to be globally toggled between high and low. We also needed authorization to survey the buildings’ occupants repeatedly about their satisfaction with the indoor environment throughout the high and low minimum operation modes. We found: six buildings on the Yahoo! campus, Sunnyvale, Calif., consisting mostly of open-plan offices, and a county government legal office building in Martinez, Calif., consisting mostly of private offices.

Yahoo! Buildings

The Yahoo! buildings were built in 2001, totaling 980,000 ft² (91,000 m²) floor area. An overview of the typical building configuration is shown in *Figure 1*. The offices in Yahoo! are mostly cubicles in an open

Determination of Low-Minimum Mode Setpoint

The minimum setpoint for each VAV box was taken to be the larger of: (1) the minimum outside air rate determined by California Title 24 minimum ventilation requirements (the larger of 0.76 L/s·m² [0.15 cfm/ft²], or 7.1 L/s person [15 cfm/person]) or (2) lowest setpoint allowed by the VAV controller, or 6% to 10% of maximum depending on VAV box inlet size. This ensured that the minimum setpoint satisfied both the ventilation requirement and VAV box controllability.

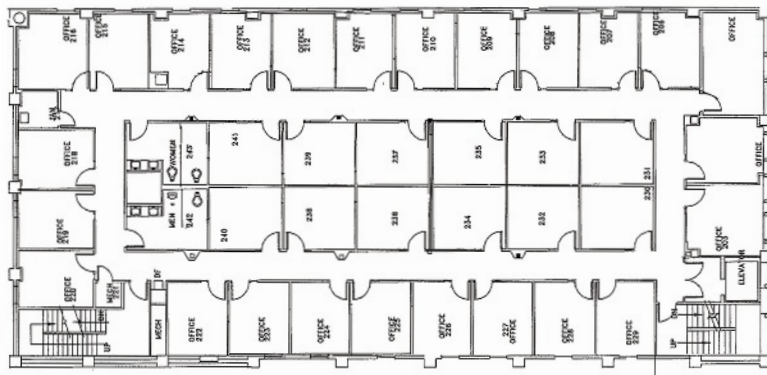
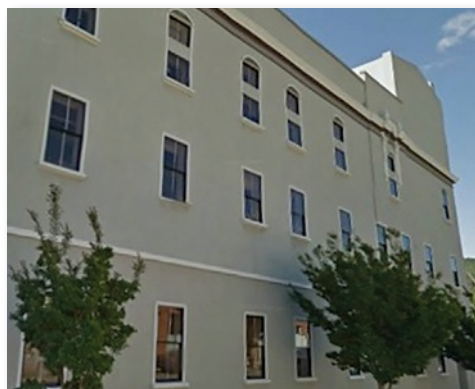
California Title 24 minimum ventilation rates were used to calculate minimums in the field study buildings. Previous analysis reported in Taylor et al. (2012) showed that the Title-24 rates meet or exceed ASHRAE Standard 62.1 ventilation requirements for multiple zone systems with recirculation. Recently published ASHRAE Guideline 36 requires that VAV minimums are determined within the controls sequence of operation, using engineer-specified zone ventilation rates, so that the VAV box controller limit is properly applied.

interior plan, with two types of partitions, high and low. Plaque diffusers are used throughout. There were 3,850 employees in total during the testing.

There are 1,073 VAV zones on the campus, of which 254 are cooling only, 246 are fan powered, and 573 have

* Higher minimums were required for ventilation in 10% of zones, in which minimums ranged from 35% to 45% of maximum.

FIGURE 2 Ferry Building façade and typical floor plan.



reheat coils. Cooling-only VAV boxes typically serve interior zones. A controls contractor was hired to automate the change in minimum flow setpoints for all 1,017 VAV boxes so the research team could quickly switch the whole campus between high and low minimum settings. The existing BAS system from a common vendor in the region was configured to record all VAV zone trends at 1 minute intervals, for the entire two-year study period (2010 to 2012).

Ferry Building

A county government office building, the Contra Costa County legal office is named “Ferry Building” (Figure 2). It is a 2100 m² (20,000 ft²) historical theater building 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. The building has 22 VAV zones of which four are cooling-only VAV and the rest are VAV with hot water reheat. The diffusers are perforated with blades in face. The VAV minimums were changed once midpoint through the 19-month study.

New VAV Box Minimum Flow Setpoints

New low-minimum mode setpoints for all study sites were calculated as described in the sidebar “Determination of Low-Minimum Mode Setpoint.”

Minimum flow-fraction (the ratio of the minimum airflow setpoint to the maximum “design cooling” airflow setpoint) was calculated for every zone.[†] Minimum flow-fractions are summarized below for both high and low test conditions for both study sites. Differences in minimum flow-fraction come primarily from differences in cooling design flow and secondarily from differences in zonal ventilation requirements.

Figure 3 shows the distribution of minimum flow-fractions in Yahoo! zones for both the high- and low-minimum test conditions. It can be seen that 10% to 15% flow-fraction is the dominant setpoint under the low condition.

Figure 4 shows the minimum flow-fractions in all 22 Ferry Building zones for both the high- and low-minimum test conditions. The original minimum flow rates were high, ranging from 35% to 50%. The new low-minimum mode setpoints resulted in an approximately 75% reduction in minimum flow across all VAV boxes.

Testing Schedule

We switched the VAV minimums between high and low several times during the one-and-a-half-year study. Although the intensive surveys of occupants took place during short intervals within this period, the whole period was used for measuring energy consumption.

The timelines shown in Figures 5 and 6 summarize when

[†] We use minimum flow-fraction in this article because it is the most common way to describe VAV box minimum flow setpoints, but it is a misleading metric because the fraction is highly dependent on the design cooling flow. For example, consider offices spaces in California with code-required minimum ventilation of 0.76 L/s·m² (0.15 cfm/ft²): a glazed west facing perimeter zone with high load may have a design cooling flow of 12.6 L/s·m² (2.5 cfm/ft²) and an interior zone with low loads may have a design cooling load of 3.0 L/s·m² (0.6 cfm/ft²). At minimum ventilation these two zones have minimum flow-fractions of 6% and 25%. Thus use of the minimum flow-fraction to determine VAV setpoints can lead to excessive flow, particularly when zones have high design flow either due to high loads or from conservative sizing assumptions. A better metric for VAV minimum flow is flow divided by floor area (L/s·m² or cfm/ft²) since it is more closely related to ventilation requirements.

these changes occurred for the Yahoo! buildings and Ferry Building.

Occupant Surveys

Web-based surveys were administered repeatedly to the buildings' occupants, approximately two to three times per day, to gather people's subjective perceptions of indoor environmental quality (IEQ) issues at the time of the survey. Comparison of concurrent physical measurements allow causal effects to be determined. The survey measures occupants' responses to thermal comfort, local body part discomfort, air movement perception, perceived indoor air quality, and acoustical satisfaction. Two representative survey questions are shown in Figure 7. Any negative votes on the seven-point satisfaction scale (e.g., -3, -2, -1) count as "dissatisfied" in our analysis.

The survey also includes branching questions that appear whenever occupants enter a dissatisfied 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 pertaining to low VAV airflows.

The survey was administered in the six office buildings on the Yahoo! Campus during the cool season from Dec. 2 through Dec. 23, 2010, and during the warm season from Sept. 29 through Oct. 26, 2011 (Figure 5). 7,330 individual responses were received from 432 occupants during the cool season, and 2,100 responses from 83 occupants during the warm season (Table 1).

In the Ferry Building, surveys were conducted only during the warm season from Sept. 22 through Oct. 21, 2011 (Figure 6), since we were unable to access the building before March 2011. This survey received 996 individual votes from 61 occupants (Table 1). The survey questionnaire was conducted three times per day,

FIGURE 3 Yahoo! minimum setpoints used in the high and low test conditions.

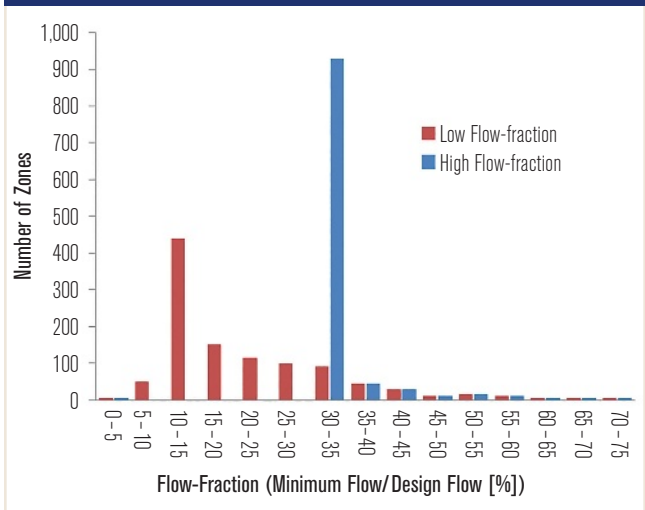


FIGURE 4 Ferry Building setpoints used in the high and low test conditions.

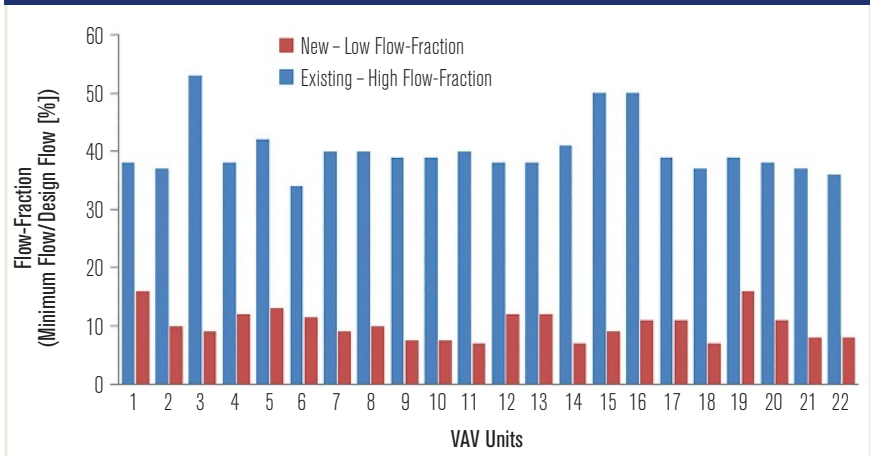


FIGURE 5 Yahoo! Building testing schedule.

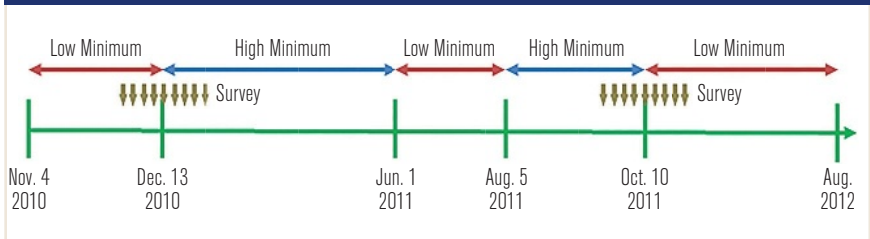
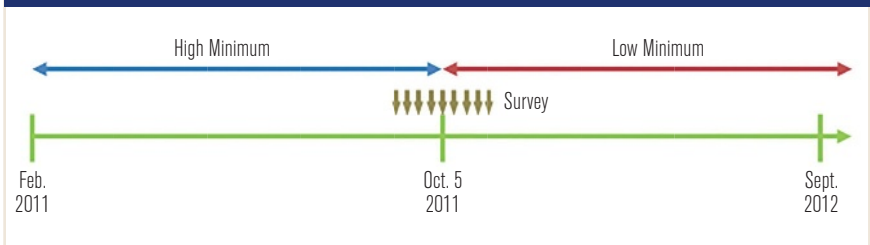


FIGURE 6 Ferry Building testing schedule.



normally around 10 a.m., 2 p.m., and 4 p.m. About the middle of each survey period, the minimum flow-fraction was switched between high and low setpoints (occupants were not notified of the change). The schedules of the high/low minimum setpoints during the occupant survey period, together with the number of participants and number of responses, are shown in *Table 1*.

Results

Flow Rate, Loads, & Temperature Under High & Low Minimum VAV Operations

Observed Flow Rates. *Figure 8* characterizes the distribution of actual measured flow-fractions in the Yahoo! buildings and the Ferry Building, during all hours of high- and low-minimum operation. The values may be compared to the corresponding setpoint values given in *Figure 3* and *Figure 4*, showing that zones operate close to their minimum setpoint most of the time.

Zone Air Temperatures. Lowering the minimum flow setpoints increased the room temperature. In the warm season, the average air temperatures in the mornings was increased by 0.2°C (0.4°F) in Yahoo! buildings and 0.6°C (1.2°F) in the Ferry Building. Afternoon temperatures increased 0.3°C (0.6°F) in Yahoo! buildings and 1.5°C (2.7°F) in the Ferry Building. In the cool season, the Yahoo! buildings' morning average air temperatures increased 0.3°C (0.6°F) and afternoon temperatures 0.5°C (0.9°F). Relative humidities throughout the entire study were moderate, below 50%.

Occupant Comfort: Repetitive Surveys, Administered Before and After The Intervention

Temperature Satisfaction. *Figure 9* and *Table 2* compare

FIGURE 7 Survey questions for satisfaction with thermal comfort and thermal sensation.

1. How satisfied are you with your thermal comfort in your workspace right now?
 Very satisfied [thumbs up icon] [color scale from green to red] [thumbs down icon] 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

TABLE 1 Survey periods under high/low minimum operation modes.

	LOW MINIMUM	HIGH MINIMUM	NUMBER OF RESPONSES	NUMBER OF PARTICIPANTS
Yahoo! Cool Season	Dec. 2 – 13, 2010	Dec. 13 – 23, 2011	7,330	432
Yahoo! Warm Season	Oct. 10 – 26, 2011	Sep. 29 – Oct. 10, 2011	2,100	83
Ferry Building Warm Season	Oct. 6 – 21, 2011	Sept. 22 – Oct. 5, 2011	996	61

the temperature satisfaction between high and low minimum operation for the three surveys (Yahoo! warm season, Yahoo! cool season, and the Ferry Building warm season).

When the minimum flow-fraction was reduced from high to low, the *warm-season* dissatisfaction rates were reduced by 47%, both in the six Yahoo! buildings and in the Ferry Building. During the *cool season*, the six Yahoo! buildings all show unchanged dissatisfaction rates between the two minimum flow rate operation modes.

FIGURE 8 Flow-fraction distributions during occupied hours.

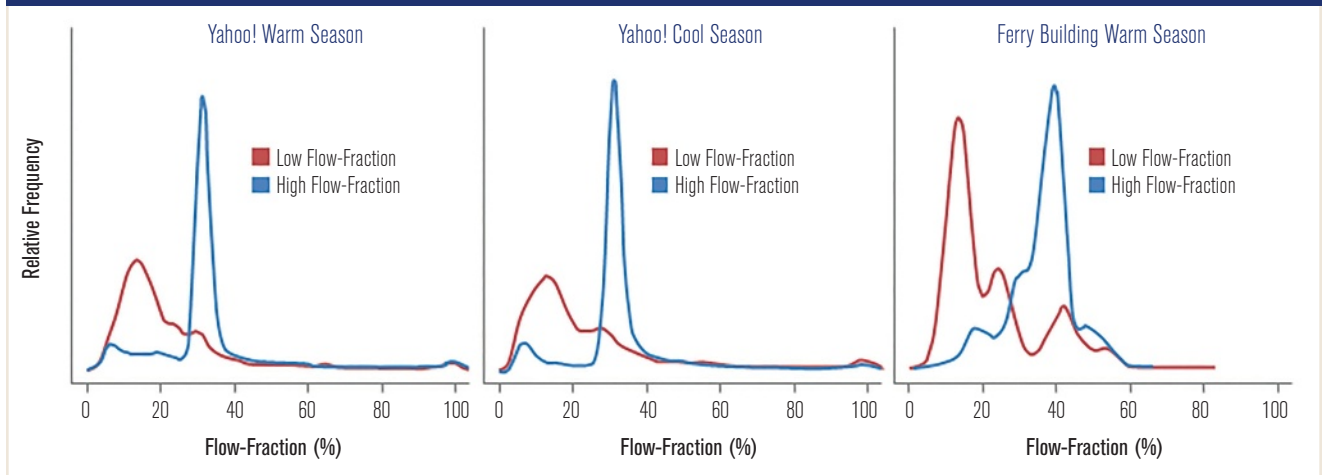
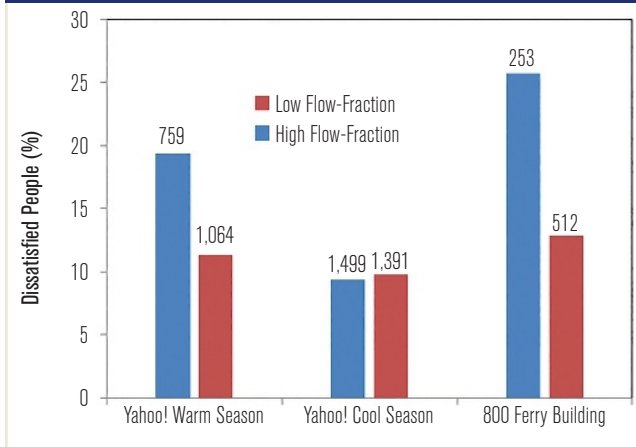


FIGURE 9 Comparison of temperature dissatisfaction rates under high and low minimum operation modes for the three surveys. Labels on each bar indicate the number of surveys.



Thermal Sensation Distribution. Why did satisfaction improve when we might have expected no change or a slight reduction in satisfaction? Analysis of thermal sensation surveys shows a significant change in occupants’ sensation of “coldness” between high and low minimum operation, suggesting that overcooling largely explains the differences in satisfaction. *Table 3* shows the reduction in occupants’ “cold,” “cool,” or “slightly cool” sensations, 13% in Yahoo! warm season, 22% in Ferry Building warm season, and 3% in Yahoo! cool season.

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-handling unit (AHU) is not changed. Only the volume of recirculated air is decreased, resulting in a higher fraction of outdoor air in the primary air stream. Therefore, there is very little change in actual indoor air quality as measured by the fresh air volume delivered to the occupants.

However, if diffusers at low flows do not deliver air appropriately, the air quality in the occupied parts of the space may diminish. The survey includes occupants’ perception of perceived air quality. Analyzing the same set of data used for determining temperature satisfaction in *Figure 9* we found that air quality perception closely followed the temperature satisfaction results. Perceived air quality in the warm season surveys was significantly improved in both the Yahoo! buildings and the Ferry Building when the minimum flow setpoint was reduced, and unchanged for the two modes of operations in the Yahoo! cool season.

TABLE 2 Summary of dissatisfaction rates for temperatures under high and low minimum operation modes for the three surveys.

SURVEY	HIGH MINIMUM (% DISSATISFIED)	LOW MINIMUM (% DISSATISFIED)
Yahoo! Warm Season	19.8%	10.5%
Yahoo! Cool Season	9.3%	9.4%
Ferry Building	21.7%	11.5%

TABLE 3 Summary of occupant cold sensation under high and low minimum operation modes for the three surveys. Percentages include occupants who voted “cold,” “cool,” or “slightly cool” on the 7 point sensation scale in *Figure 7*.

SURVEY	HIGH MINIMUM GOLD VOTES	LOW MINIMUM GOLD VOTES	REDUCTION IN GOLD VOTES
Yahoo! Warm Season	37%	24%	13%
Yahoo! Cool Season	25%	22%	3%
Ferry Building	38%	16%	22%

Sense of Air Movement. A primary concern about low minimum operation has been that people near diffusers may sense draft (unwanted air movement). The assumption was that under low flows the Coanda effect may cease to function, and that cool supply air would drop down unmixed onto the occupants below. To address this concern, we grouped people by flow-fraction (<30%, 30% to 40%, and >90%) and surveyed 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. In the Yahoo! buildings there was little or no difference in people’s sense of air movement between flow-fractions below 30% compared to 30% to 40%. It was under high flow-fraction (>90%) that the population perceiving the air movement as “moderate” and “strong” nearly doubled. In the Ferry Building, the sense of air movement was higher when the flow-fraction was 30% to 40% than when the flow-fraction was below 30% (there was no data for flow-fraction >90%). These results contradict our original concern about dumping at low flows. It did not occur, and the sensation of air movement only appeared near design maximum cooling airflow.

This research project also included laboratory studies of air movement and ADPI that showed the same results for a wide variety of diffuser types: less air speed (all below draft limits) at low flow and more air movement at high flow. In addition, the discharge air temperatures

observed in the field study across a wide range (12°C to 24°C [55°F to 75°F]) did not have a strong influence on sensation and comfort. Details are presented in Appendix C of the RP-1515 report.

Discussion

RP-1515 focused on the comfort and energy effects of reducing VAV minimum setpoints. A major finding of the project is that reduced flow minimums not only save energy (as expected), but significantly reduce occupant discomfort from summer overcooling (this was unexpected, though it might seem obvious in retrospect). The prevalence of low space cooling loads such as observed in this project's buildings is not uncommon and has been reported on in other studies. High prevalence of low cooling loads provide the reason that low minimums are necessary and would save energy. They may also be the general explanation for the summer overcooling that is now endemic in the U.S. A load analysis in the studied buildings showed that the lowest minimum flows required for meeting minimum ventilation rates are still higher than what is needed to meet loads for significant amounts of time in the cooling season. When space loads are lower than the cooling delivered to the zone at minimum flow, the zone will overcool, driving temperatures down to the heating setpoint (e.g., 21°C [70°F]) if the zone has reheat, or colder in zones without reheat. Per ASHRAE Standard 55, occupants are likely to find temperatures below about 23°C (74°F) too cool when wearing lightweight summer clothing. Building operators and engineers typically do not think that the zone heating setpoints are the temperature that occupants will experience during summer cooling conditions—but this is the case with high minimum flow setpoints.

Although summer overcooling is probably primarily caused by excessively high zone minimum flow setpoints, the following secondary considerations will also impact the level of overcooling: level of supply air temperature reset, heating setpoint (during the summer), existence of reheat coils at VAV boxes, and lockout of reheat during summer (a common practice).

Surveys showed no complaints of draft during low flows, and laboratory ADPI studies confirmed that measured air speeds in the occupied zone are low at minimum flows and only increase near the cooling design airflow. Counter to the common engineering assumption

that cold-air dumping is a risk at low flows, it does not occur. We explain these results as follows: At high air-flow near design cooling maximum, air delivered to the space has an overall higher momentum and associated maximum throw distance, causing higher air movement in the occupied zone and increased potential for colliding air streams (between diffusers or with architectural/structural features) that deflect airflow to the occupied zone. At low flow with low momentum the cool air mixes with room air as it separates from the ceiling, rather than coherently dumping into the occupied zone.

In this study, perceived air quality improved during the summer as thermal comfort improved from the reduced overcooling. This result supports recent research that perceived air quality is related to occupant thermal comfort and not to cold temperatures (Zhang et al. 2011).

Since the adoption of California Title 24-2008 and ASHRAE/IES Standard 90.1-2013, VAV zone minimum flow-fractions in new construction have been required to not exceed 20%. This research shows that much lower minimums, as low as the minimum ventilation rate (often 5% to 15%), do not have negative impacts on occupants. These results, along with results from recent research into VAV box controllability and stability at low flow suggest that energy codes and standards could adopt even more stringent VAV minimum criteria. However, a large proportion of existing buildings are still operating at higher minimums, up to 50%. There is a significant opportunity for cost-effective existing building retrofits that reduce VAV minimums by simply adjusting setpoints in buildings with zone controllers capable of dual-maximum control, resulting in reduced energy use and improved comfort.

Research on minimum flows could have far-reaching implications: to changes in the *ASHRAE Handbook*, to manufacturers' literature, to the way engineers calculate minimum flow rates, and to Standards 90.1, 62.1 and 55.

Discussion of Other Causes of Overcooling

While this research revealed a significant explanation for why VAV reheat systems overcool in the summer, there are other causes of overcooling to consider, many of which were suggested at a 2012 ASHRAE Winter Conference session on overcooling (ASHRAE Seminar 14).

1. Space temperature setpoints in North America

are generally lower than comfort standards recommend (ASHRAE Standard 55, ISO 7730). Various reasons include: thermal preferences of managers wearing suits with higher clothing insulation, setpoints adjusted by people entering the building with temporarily elevated metabolic rates and need for heat dissipation, operators pre-cool because they fear overshoot when a large number of people enter a conference room, control for worst case while assuming people can add clothing layers if needed, a status symbol that associates affluence or building quality with the ability to air condition, and a potential bias among operators to worry more about hot complaints than cold complaints.

2. Fixed year-round space temperature setpoints are typically biased towards a winter comfort zone, not accounting for the fact that occupants wear lighter clothing in the summer. Note that ASHRAE Standard 55-2017 includes a model for predicting seasonal changes in clothing insulation that can be used to seasonally reset space temperature setpoints.

3. Influence of solar radiation on occupant comfort in perimeter zones and thermostat settings based on those occupants. Recent changes to ASHRAE Standard 55 now capture the large influence that solar radiation has on perimeter zone occupants, even with interior shading (“Sunlight and Indoor Thermal Comfort,” *ASHRAE Journal*, July 2018, by Arens et. al.). The comfort zone for occupants influenced by solar radiation can be significantly colder than the zone for all other occupants in the same zone not influenced by solar radiation.

4. Occupants are often not given control over their thermostat leading to hypersensitivity. Research has shown occupants with control are much less sensitive to temperature variations and accept a wider comfort zone.

5. HVAC system design issues: dehumidification without sufficient reheat. Poor zoning such as combined perimeter and interior spaces with the thermostat in the perimeter. Oversized constant volume DX equipment. Poor air distribution such as airstreams colliding with beams that deflect air downward to occupied zones before it mixes. Extreme VAV zone oversizing based on conservative design standards that further reduce zone turn-down when fixed flow-fractions are used.

Conclusions

Six Yahoo! buildings and the Ferry Building were tested to determine comfort and energy use when the

minimum flow rate setpoints were reduced from high (conventional level: 30% to 50%) to low (minimum ventilation rate or controllable minimum: ~10% to 20%).

Occupant surveys in the Yahoo! buildings and Ferry Building support 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, there was significantly improved thermal comfort under low minimum operation. The dissatisfaction rate found under high minimum operation was reduced by 47% in both summer studies in Yahoo! buildings and the Ferry Building. The comfort improvements are mostly due to a reduction in summer overcooling, as the zones have more capability to turn down at low load conditions. Zones with high minimums “push” the zone down to the heating setpoint (e.g., 21°C [70°F]) even in warm weather when occupants are likely wearing light summer clothing. Per ASHRAE Standard 55 and ISO 7730, occupants are likely to find temperatures below about 23°C (74°F) too cool when wearing light-weight summer clothing.

We encountered no evidence of draft sensation at low flow rates. In fact, upending the Coanda hypothesis that diffusers will dump at low flow, 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.

This study suggests that much of today’s widespread overcooling of buildings might be corrected by lowering conventional VAV minimum flow setpoints. Most new buildings and many existing buildings are likely to improve comfort while also reducing energy use by reducing VAV minimum flow setpoints close to minimum ventilation rates. This research and a number of other recent research projects have shown that there is no reason to use VAV box minimum airflow setpoints above the ventilation rate when dual-maximum VAV box controls are used.

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