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# *July 13th, 2006 Workshop Report DDC to the Zone Level 1: VAV Zone Minimums*

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# Overview

## Description

This CASE report addresses one of five separate measures that extend the control requirements of the standard. All five of these requirements are possible at a very small cost if the installed control system is direct-digital control (DDC) to the zone level. This initiative does not seek to require installation of DDC to the zone level, rather it extends the current philosophy of the prescriptive requirements such as supply static pressure reset (Section 144(c)2D) that state a functional requirement of the control system if it is designed for DDC to the zone level.

The measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-Conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes

2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).

3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).

4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.

5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

This specific report covers the VAV Zone Minimums.

Currently the standard allows reheat systems to have minimum flow rates of 30% of peak supply. This proposed change would require non-pnuematic reheat systems to have a minimum flow rate of no greater than 20% but allow these systems to reheat up to 50% of peak supply in heating mode. This would apply to any VAV reheat system (e.g. offices and universities). The proposed change would save considerable energy at almost no cost (e.g. DDC systems can easily be programmed with dual cooling/heating maximum flow rates) and improve comfort and indoor air quality by allowing better mixing in heating mode.

## Energy Benefits

Peak demand reductions are not anticipated but simulation has shown electrical energy savings of 0.66 kWh/ft2/year and natural gas savings of 17 kBtu/ft2/year. Using TDV electrical and gas energy rates, these savings are equivalent to $2.6/ft2/year. Detailed modeling assumptions and results are presented in Appendix A.

## Non-energy Benefits

Non-energy benefits include improved comfort and indoor air quality due to better air mixing in heating mode. Improved comfort and indoor air quality can of course lead to improvements in occupant health, productivity, and increased property valuation.

## Statewide Energy Impacts

[These will be completed at a later date.]

## Environmental Impact

No negative environmental impacts are anticipated .

[The emission factors will be calculated at a later date.]

## Type of Change

The proposed change would modify an existing prescriptive requirement. The ACM modeling rules would have to be altered slightly.

This change does not modify or expand the scope of the Standard. It simply increases the stringency of the standard and makes a new distinction between zones with direct digital controls (DDC) and all other zone controls (principally pneumatic and analog controls).

Minor changes would be required for the compliance forms that would require the applicant to indicate the type of zone controls and to list the heating maximum airflow as well as the cooling maximum and minimum flow rates.

## Technology Measures

### *Measure Availability and Cost*

This measure essentially requires the use of dual maximum control sequences for non-pneumatic systems. Dual maximum control logic that would satisfy this proposed requirement is available from all major control system manufacturer.

### *Useful Life, Persistence and Maintenance*

It is not anticipated that this measure would have any impact on the useful life or maintenance of VAV boxes. Savings are expected to persist for the life of the control system. Achieving the anticipated savings does depend on proper commissioning. The incremental cost of commissioning is included in the lifecycle cost analysis.

## Performance Verification

Designers will have to document the heating maximum airflow as well as the cooling maximum and the minimum. In addition designers should also be required to document the zone control sequences. They could either provide a schematic and/or narrative or choose from a list of possible options. This documentation could be part of the compliance forms or it could be something the designer must include on the plans.

## Cost Effectiveness

Lifecycle cost analysis has shown the measure to be highly cost effective with significant energy savings and minimal incremental first cost. The first cost consists of some additional test and balance and commissioning costs and the possible addition of a discharge air temperature sensor. However, most reheat systems today are already specified with VAV box discharge air temperature sensors.

## Analysis Tools

This measure can be easily modeled with DOE-2. Very minor adjustments would be required of the performance compliance software programs.

## Relationship to Other Measures

No anticipated impacts on other measures.

# Methodology

The zone minimum requirements in the current version of the standard are based on the single maximum control sequence used by most pneumatic VAV reheat systems (see Figure A). As cooling load decreases the airflow if reduced from the maximum airflow (on the far right side of the figure) down to the minimum flow. Then as heating is required the reheat valve is modulated to maintain the space temperature at setpoint.

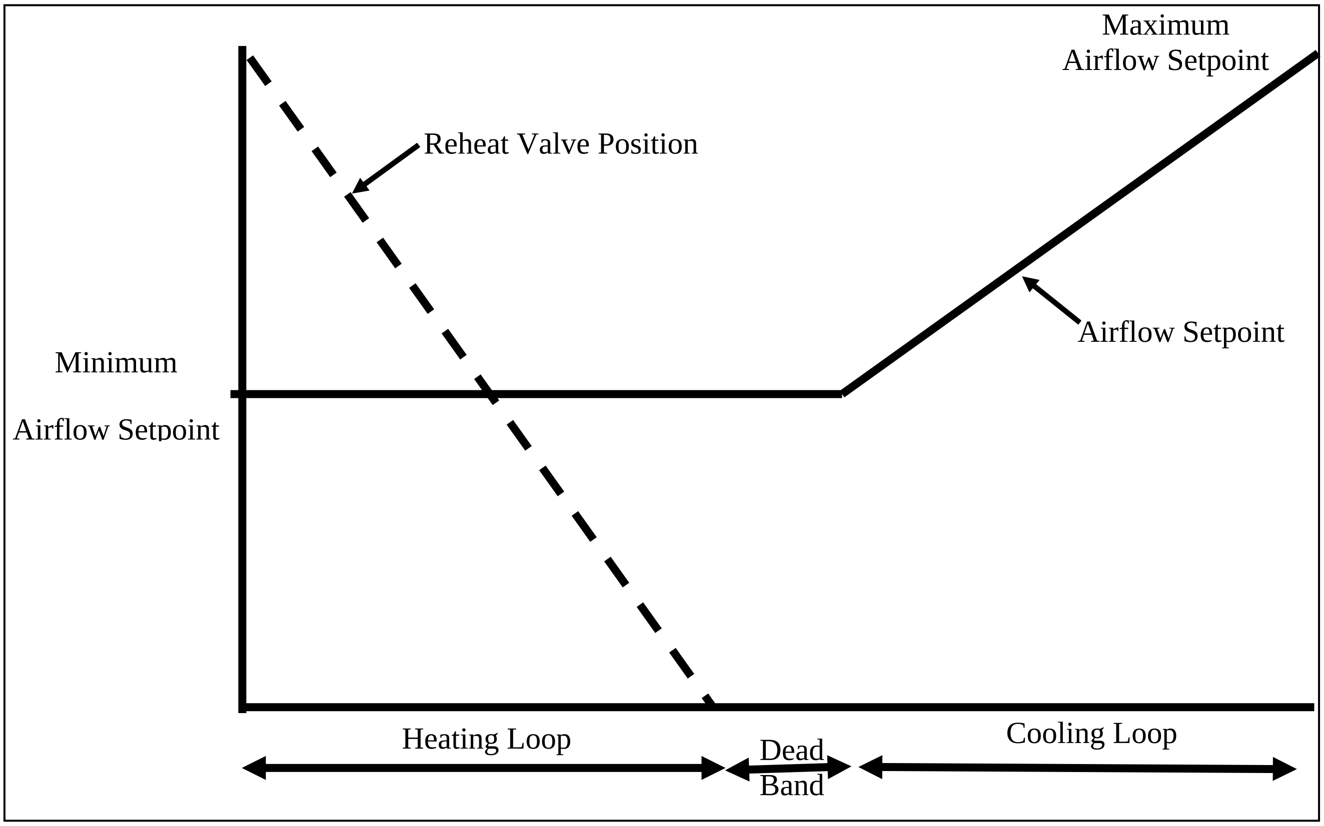
With this sequence the minimum flow rate in deadband (between heating and cooling) is also the flow rate in heating mode. The air flow in heating should be high enough that at design heating conditions the supply air is not too hot. If the supply air is too hot (e.g. greater than 90ºF) then the hot supply air may short-circuit and go back into the return air system without fully mixing in the space. Short-circuiting has several negative consequences including:

- Poor indoor air quality – According to ASHRAE Standard 62.1 (Ventilation for Acceptable Indoor Air Quality), Air Change Effectiveness is always 1.0 (good mixing) when the ceiling supply of warm air is less than 15ºF above the space temperature. When the supply air is greater than 15ºF above the space temperature then Air Change Effectiveness decreases, meaning that the supply air short-circuits to the return and does not remove pollutants from the space as well as systems with good mixing.

- Poor comfort – According to ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy), acceptable comfort conditions cannot be achieved if space vertical temperature stratification exceeds 5ºF. If short-circuiting occurs then the floor of a space will remain cold while the ceiling gets hot and stratification will exceed 5ºF.

- Poor temperature control – If short-circuiting occurs it may not be possible to achieve heating setpoint at the thermostat location.

*Figure A. Single Maximum Zone Control Sequence*




Faced with the risks of short-circuiting, many designers routinely disregard the 30% minimum requirement. It is very common for designed to list 30% minimums on code compliance documents and then to change the minimums to 40% or 50% before the controls are set up.

With a high minimum flow setpoint, zones are often overcooled in deadband mode. This forces the zone into heating mode and results in wasted reheat energy. It is not uncommon for a building to have boilers running all summer long to provide reheat to zones with such high minimum flow rates.

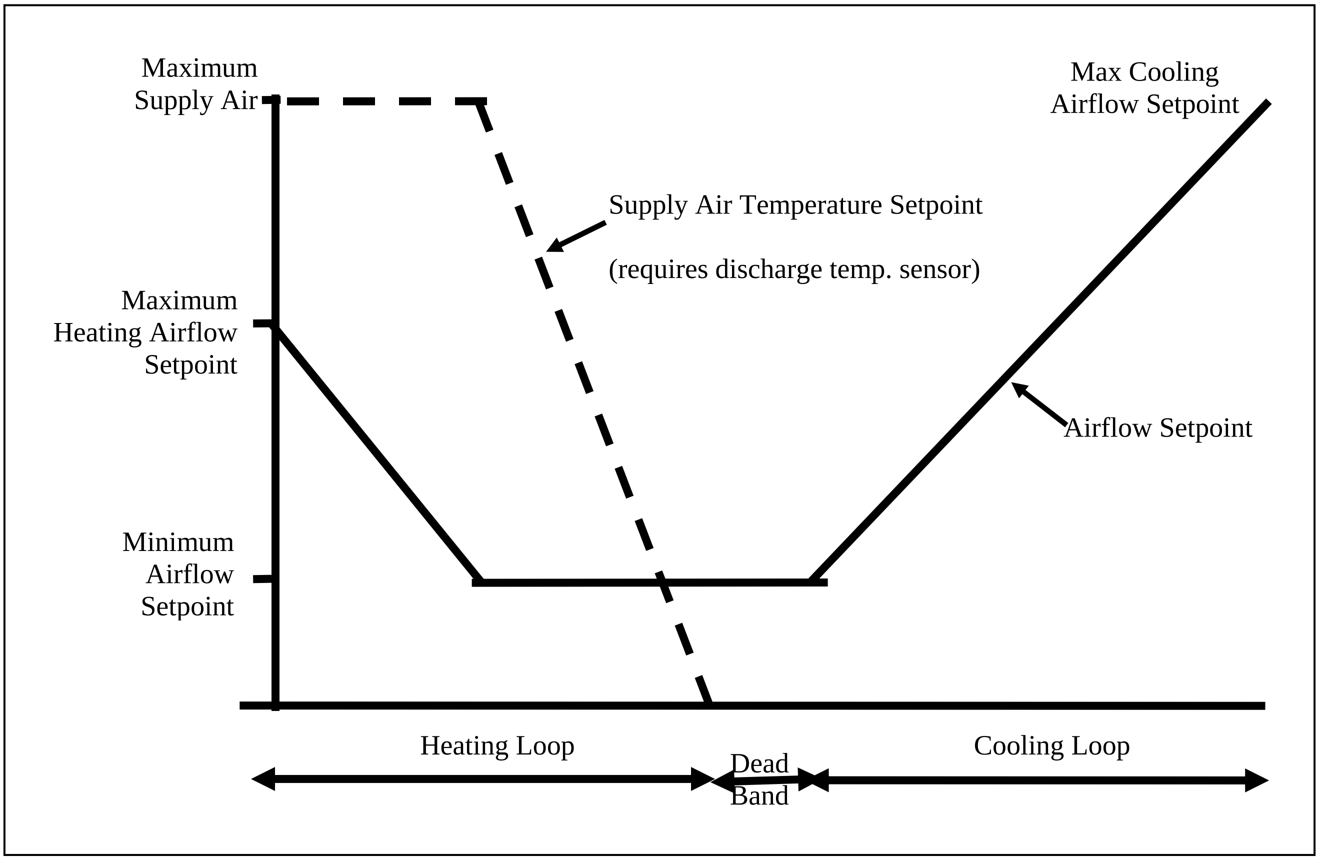
Figure B illustrates a dual maximum zone control sequence. Airflow is reduced from cooling maximum airflow to minimum airflow as cooling load goes down. As the zone goes into heating mode the discharge air temperature setpoint is reset from minimum temperature (e.g. 55ºF) to maximum temperature (e.g. 85ºF). If more heating is required then the airflow is reset from the minimum up to the heating maximum. With a dual maximum zone control sequence, the airflow in deadband is lower than the airflow at full heating. The minimum flow needs to only be high enough to satisfy the ventilation requirements, which are typically 10% or less for most perimeter zones.

The minimum flow setpoint should also be high enough to prevent “dumping”. Dumping is when the supply air does not have sufficient velocity to mix with room air and a jet of cold air can “dump” on occupants. Research by Fisk (Fisk, 1997) and Bauman (Bauman, 1995) found that acceptable comfort and mixing can be maintained even with the most inexpensive diffusers at 25% flow. They did not test below 25% but their research implies that acceptable comfort and mixing can be maintained below 25% as well. It should also be noted that much of the time when a zone is in deadband it is because the zone is unoccupied. Comfort is obviously not an issue in unoccupied zones.

The minimum flow setpoint should also be high enough that the VAV box can stably and accurately maintain the flow setpoint without excessive repositioning of the damper. Recent research by Dickerhoff and Stein (2006), has shown that stability and accuracy can be maintained down to approximately 10% of design flow.

With low minimums, zones are not overcooled nearly as often as with a single maximum scheme, which results in tremendous reheat energy savings. With dual maximum control sequences it is usually possible to shut off the boiler system for the entire summer season.

*Figure B. Dual Maximum Zone Control Sequence.*

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# Results

Describe the results of the research. What was learned? How is it relevant to the standards? Results are not all computational. Some results are based on market share of equipment and applicability of measure limited to certain applications.

## Energy and Cost Savings

The energy savings of this measure were estimated with a simulation model of a typical office building in Climate Zone 12. According to the model, switching from a 30% minimum to a 20% minimum resulted in annual electrical energy savings of 0.66 kWh/ft2/year and natural gas savings of 17 kBtu/ft2/year. Using TDV electrical and gas energy rates, these savings are equivalent to $2.6/ft2/year. Detailed modeling assumptions and results are presented in Appendix A.

### Cost-effectiveness

Dual maximum control sequences are available from most DDC control system vendors at no additional cost relative to single maximum control sequences. While not required, a good dual maximum control sequence should include discharge air temperature control. This requires a discharge air temperature sensor. In a single maximum control scheme the hot water valve is controlled directly by the thermostat so a discharge air temperature sensor is not required. Discharge air temperature sensors are commonly specified by designers because they are a valuable troubleshooting tool. Building engineers find them very helpful. However, for the sake of argument, we can assume that this measure results in designers adding discharge air temperature sensors. Such a sensor adds about $200 to the cost of a zone or about $0.50/ft2 for a typical 400 ft2 zone.

In addition to the discharge sensor, it is also anticipated that this measure will result in about $100/zone of additional test and balance and commissioning expenses. This results in a total incremental cost of $0.75/ft2, which is considerably less than the $2.61/ft2 of TDV energy savings predicted by the energy model.

### Statewide Energy Savings

[To be completed at a later date]

## Recommendations

Modify existing prescriptive requirement 144(d) to allow the dual maximum VAV box controls and to remove some of the existing exceptions that no longer are required. The rationale for the new “dual maximum” 50% / 20% Exception 1.A is fully explained in the sections above. The rationale for the removal of the 0.4 CFM/ft2 exception and the 300 CFM exceptions is described below:

The 0.4 cfm/ft2 exception is deleted because it implies that a minimum air speed in the occupied space is required for comfort. ASHRAE Standard 55, however, indicates that no minimum air speed is required for comfort. Furthermore, 0.4 cfm/ft2 does not guarantee any particular air speed because 0.4 cfm/ft2 can be a small fraction (e.g. 10%) or a large fraction (e.g. 50%) of the design flow rate and thus can result in a low or high air speed.

The 300 cfm exception is deleted because the situation that it was intended to address has been largely eliminated by the new 50% exception described above. This criterion was intended to address the following applications: the occasional small zone in a VAV reheat system for which 30% is insufficient to handle heating loads, such as spaces with large north facing glass areas.

### Proposed Standards Language

**Section 144 (d)**
**Space-conditioning Zone Controls**. Each space-conditioning zone shall have controls that prevent:
1. Reheating; and
2. Recooling; and
3. Simultaneous provisions of heating and cooling to the same zone, such as mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled, either by cooling equipment or by economizer systems.

**EXCEPTION 1 to Section 144 (d):** Zones served by a variable air-volume system that is designed and controlled to reduce, to a minimum, the volume of reheated, recooled, or mixed air supply as follows. ~~For each zone, this minimum volume shall be no greater than the largest of the following:~~

A. For each zone with direct digital controls, this minimum volume shall be no greater than the following:

1. 50 percent of the peak supply volume during heating.
2. No greater than the largest of the following in the dead band:
    a. 20 percent of the peak supply volume; or
    b. The minimum required to meet the ventilation requirements of Section 121

B. For each zone without direct digital controls, this minimum volume shall be no greater than the largest of the following:

1. 30 percent of the peak supply volume; or
2. The minimum required to meet the ventilation requirements of Section 121

~~A. 30 percent of the peak supply volume; or~~
~~B. The minimum required to meet the ventilation requirements of Section 121; or~~
~~C. 0.4 cubic feet per minute (cfm) per square foot of conditioned floor area of the zone; or~~
~~D. 300 cfm.~~

**EXCEPTION 2 to Section 144 (d):** Zones with special pressurization relationships or cross-contamination control needs.

**EXCEPTION 3 to Section 144 (d):** Zones served by space-conditioning systems in which at least 75 percent of the energy for reheating, or providing warm air in mixing systems, is provided from a site-recovered or site-solar energy source.

**EXCEPTION 4 to Section 144 (d):** Zones in which specific humidity levels are required to satisfy process needs.

**EXCEPTION 5 to Section 144 (d):** Zones with a peak supply-air quantity of 300 cfm or less.

### Alternate Calculation Manual

[to be developed at a later date]

## Bibliography and Other Research

ASHRAE Standard 62.1-2004 "Ventilation for Acceptable Indoor Air Quality"

ASHRAE Standard 55-2004 "Thermal Environmental Conditions for Human Occupancy"

Bauman, Fred, Charlie Huizenga, Tengfang Xu, and Takashi Akimoto. 1995. Thermal Comfort With A Variable Air Volume (VAV) System. Center for Environmental Design Research, University of California, Berkeley, California. Presents research on ADPI for diffusers over a range of flows.

Dickerhoff, Darryl, Jeff Stein, 2006. This is a research project at the PG&E Energy Center on The Stability and Accuracy of VAV Boxes at Low Flow. Results will not be published until October 2006. Preliminary results are available upon request from jstein@taylor-engineering.com .

Fisk, W.J., D. Faulkner, D. Sullivan, and F.S. Bauman. "Air Change Effectiveness And Pollutant Removal Efficiency During Adverse Conditions." Indoor Air; 7:55-63. 1997.Denmark: Munksgaard.

Mark Hydeman, Steve Taylor, Jeff Stein, *Advanced Variable Air Volume System Design Guide*, California Energy Commission publication number P500-03-082-A-11, October 2003. http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-11.PDF

Persily A.K. and Dols W.S. "Field measurements of ventilation and ventilation effectiveness in an office/library building", Indoor Air, Vol 3, 1991.

Persily A.K. "Assessing ventilation effectiveness in mechanically ventilated office buildings," International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo, 1992

Offerman F.J, Int-Hout D. Ventilation effectiveness and ADPI measurements of a forced air heating system," ASHRAE Transactions 94(1), 1988. pp. 694-704.

Jeff Stein, *Specifying VAV Boxes*, HPAC Magazine, October 2005.

Steve Taylor, Jeff Stein, "Sizing VAV Boxes", *ASHRAE Journal*, March 2004.

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# Appendices

# Appendix A. Modeling Assumptions and Results

A five zone office building eQuest model with total area of 10,000 square feet was built to evaluate annual Utility cost savings from reducing VAV box minimum damper position from 30% to 20%.

Figure 1shows the dimension of the model.

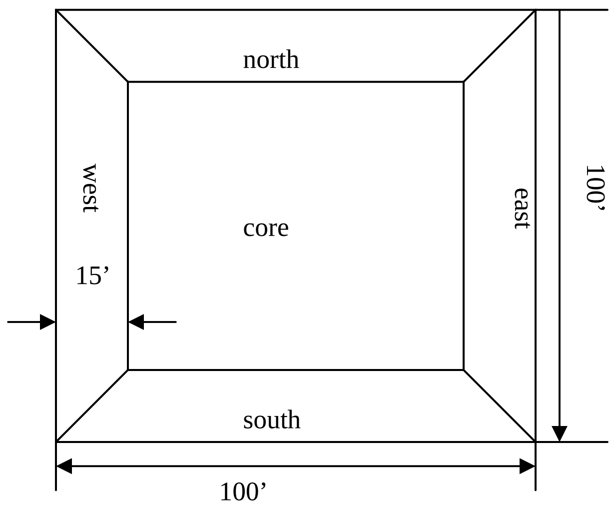



*Figure 1 Model dimensions*

The building envelope consists of R-19 metal frame roof and R-19 metal frame wall with 40% window wall ratio. All windows use double pane clear glazing.

The building was modeled to be occupied from 6:00 am to 7:00 pm Monday through Friday and was closed on Saturday, Sundays and holidays. Building internal loads consist of an average 84 sf per person occupancy density, 1.15 w/sf lighting power densities and 1.5 w/sf equipment power density. Figure 2 shows the modeled occupancy schedule. Lighting, equipment schedule follows the occupancy schedule.

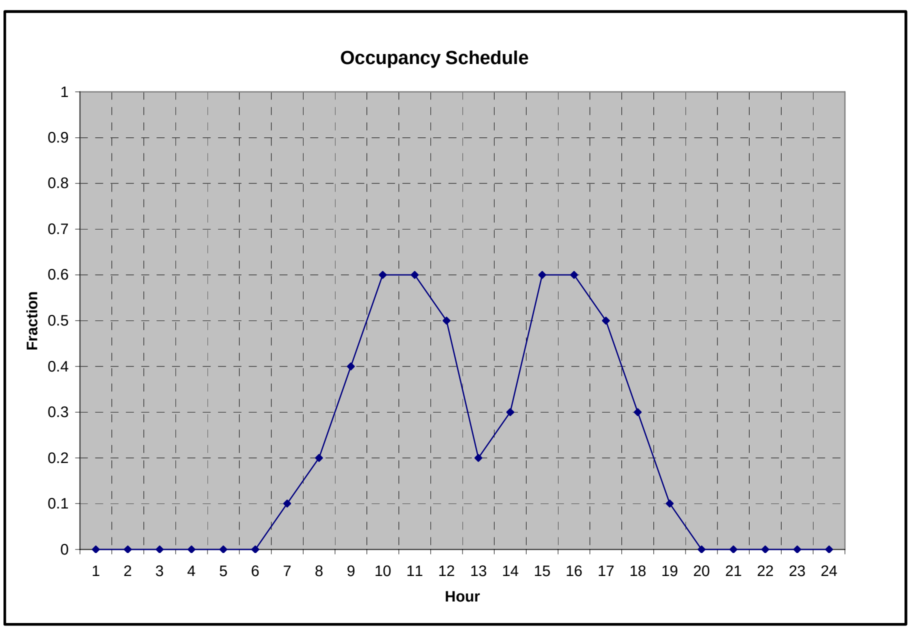



*Figure 2 Occupancy schedule*

The building is conditioned by a packaged VAV system with hot water reheats at VAV boxes. Room temperature setpoints are 73/81 for cooling and 70/64 for heating during occupied and unoccupied hours. HVAC system turns on one hour before and after the occupancy. The HVAC system supplies 55 degree F cold air and 95 degree F hot air to the space to meet the buildings air conditioning needs.

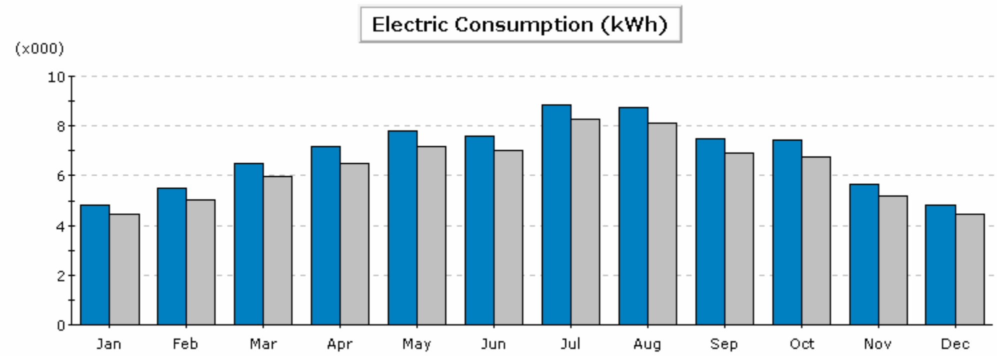
Parametric runs with the following parameter changes were carried out to evaluate the energy saving potential of reducing VAV box minimal damper position from 30% to 20%. Table 1 listed the difference between the runs.

*Table 1 Parametric Run Inputs*

| | Basecase control (30% minimal VAV damper position) | Proposed control (20% minimal VAV damper position |
|---|---|---|
| Minimal Zone Flow Ratio | 0.3 | 0.2 |
| Minimal Fan Flow ratio | 0.3 | 0.2 |
| Minimal Unit Unload Ratio | 0.25 | 0.2 |

The model was run using the weather data representing Sacramento, CA (climate zone 12) which is a relatively hot climate.

**Figure 3 and Figure 4 shows the annual electrical energy and natural gas savings. By reducing VAV box minimal damper position, an 6600 kWh/year (0.66 kWh/sf/year) annual electrical energy savings and 170 MBtu/year (17 kBtu/sf/year) natual gas savings can be achieved. Using TDV electrical and gas energy rate for Climate Zone 12, these savings equivalent to $26,146 /year ($2.6/sf/year) operation cost savings.** Source of TDV cost rate used in calculation can be found at:
http://www.energy.ca.gov/title24/2008standards/documents/E3/index.html

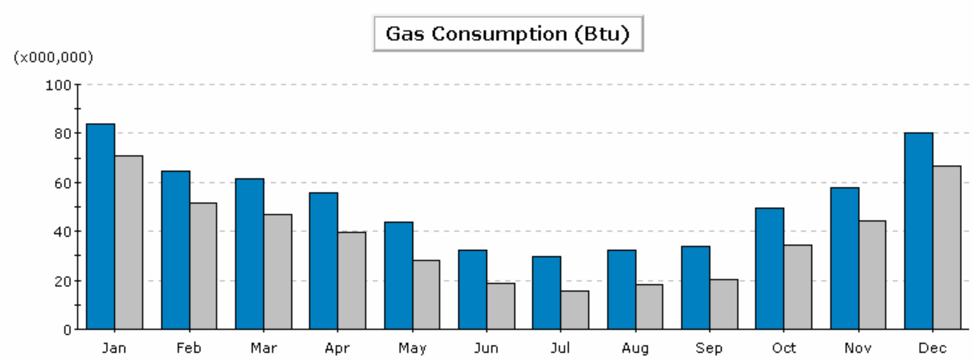



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run 1. | 4.82 | 5.48 | 6.51 | 7.15 | 7.81 | 7.61 | 8.86 | 8.72 | 7.51 | 7.42 | 5.66 | 4.81 | 82.36 |
| Run 2. | 4.48 | 5.02 | 5.94 | 6.51 | 7.15 | 7.00 | 8.25 | 8.10 | 6.91 | 6.76 | 5.16 | 4.46 | 75.76 |
| Run 3. | | | | | | | | | | | | | |
| Run 4. | | | | | | | | | | | | | |
| Run 5. | | | | | | | | | | | | | |

1. Five Zone VAV-RH-detail - Baseline Design (06/29/06 @ 17:12)
2. Five Zone VAV-RH-detail - 1 (06/29/06 @ 17:12)

*Figure 3 Annual Electrical Energy Savings*

1. Five Zone VAV-RH-detail - Baseline Design (06/29/06 @ 17:12)
2. Five Zone VAV-RH-detail - 1 (06/29/06 @ 17:12)




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run 1. | 83.80 | 64.40 | 61.71 | 55.71 | 43.67 | 32.08 | 29.64 | 32.36 | 33.93 | 49.73 | 57.94 | 80.41 | 625.39 |
| Run 2. | 70.64 | 51.70 | 47.01 | 39.84 | 28.10 | 18.77 | 15.67 | 18.20 | 20.46 | 34.15 | 44.27 | 66.41 | 455.22 |
| Run 3. | | | | | | | | | | | | | |
| Run 4. | | | | | | | | | | | | | |
| Run 5. | | | | | | | | | | | | | |

*Figure 4 Annual Natural Gas Savings*