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February 27th, 2007 Workshop Report Single Zone VAV Systems

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Single Zone VAV Systems

2008 California Building Energy Efficiency Standards

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Overview

Complete the following table, providing a brief sentence or two for each category of information.

Description	This measure presents a prescriptive requirement for variable air volume control of unitary systems with two stages of cooling capacity (10 tons and above). 2-speed motors are proposed as the basis of this requirement variable speed driven fans will automatically comply.
Type of Change	This proposed measure is a new prescriptive requirement. It would add a new requirement to Section 144. It is an expansion of scope for the existing Standards. It would apply to new or replacement unitary and air-handling equipment. For this requirement all of the following changes would be necessary: **Title 24 Standards** • A new paragraph would be added to Section 144 of the Standards. • A corresponding acceptance test would be added to the existing requirement Section 125 (c) of the Standards. **ACM Manual** • Standard Design Systems 1 and 2 (2.5.2.4) would be changed to use VAV supply on all unitary and air handling equipment 10 tons and above. • Constant Volume Packaged HVAC Systems Acceptance in Appendix NJ (NJ 4.1) would be modified to include verification of reduced fan flow under the first stage of cooling. • Variable Air Volume System Outdoor Air Acceptance in Appendix NJ (NJ 3.1) would be modified to measure outdoor air with the fan at low speed. **Non-Residential Compliance Manual** • Changes would also be required in the compliance forms: o The existing MECH-2-A form would be modified to document the acceptance testing of the ventilation at low speed o The existing MECH-3-A form would be modified to document the acceptance testing of the fan speed controls, and o The existing MECH-2-C form would be expanded to document compliance with the requirement. • Information would be provided in Section 4.6 on how to meet this requirement. • Section 4.11 Mechanical Plant Check Documents would need to be updated to document the changes in the compliance forms noted above. • Section 4.11.9 Acceptance Requirement would need to be updated to document the changes in the acceptance tests and forms.

Energy Benefits	As detailed in the section "Analysis and Results" below, eQuest models of a simple 5 zone single story building were run in all 16 climate zones. The present value of the energy savings for 2-speed motors were evaluated for both 100%/50% motors and 100%/67% motors. The average (across all climate zones) TDV present value savings were: • $0.50 per square foot for the 100%/67% motors • $0.60 per square foot for the 100%/50% motors On a 7-1/2 ton unit using a standard 400 ft2/ton the incremental cost of these units would have to be less than: • $1,500 for the 100%/67% motors • $1,800 for the 100%/50% motors At a budgetary price of $500/ton, the 2 speed units would be cost effective up to a cost premium of nearly 50% more than the cost of a standard unit. A conservative estimate of the cost premium for 2 speed motors is closer to 1/5 of the unit cost (well below the LCC threshold). This measure provides energy savings for both 2-speed motors and variable speed drives but will only provide demand savings when implemented with variable speed drives. The energy benefits for the VSD driven fans were already established in a CEC report for the 2005 standards.
Non-Energy Benefits	This measure should have no adverse impact on the indoor air quality as the minimum position for ventilation will be adjusted for each fan speed. The measure will improve acoustical performance when the fans are running at low speed. The operation at low speed should increase the life of the bearings and motors.
Environmental Impact	This measure should have no adverse impacts on the environment.

Technology Measures	This measure largely requires products that are not currently on the market. However it can be implemented simply using off the shelf components. Specifically the 2-speed motor implementation has the following standard components: • 2-speed motors and starters • Relays to engage the low speed motor and switch the active outdoor air minimum potentiometer based on fan speed • 1 potentiometer for setting of the outdoor air minimum position Several custom AC/HP unit manufacturers already have variable speed driven fans on AC/HP units that would meet or exceed this requirement. We have worked with ARI's Unitary Large Engineering (ULE) Group and have achieved a consensus with the ARI equipment manufacturers that includes the following revisions to our July Workshop report: • That the requirement be proposed to the ASHRAE Standard 90.1 committee (it has) • That the requirement be based on a 2/3 speed motor (to prevent coil freezing) • That the minimum unit size be increased from 7-1/2 tons to 10 tons • That implementation be delayed to 2012.
Performance Verification	This measure requires only minor changes to the existing acceptance tests and forms and noted previously.
Cost Effectiveness	This measure passes the cost effectiveness test in all climates as mentioned previously and documented in detailed in the section "Analysis and Results" below.
Analysis Tools	This measure can be easily modeled using DOE2 program. Minor changes are needed in the default HVAC Systems 1 and 2 as documented previously.
Relationship to Other Measures	None of any significance.

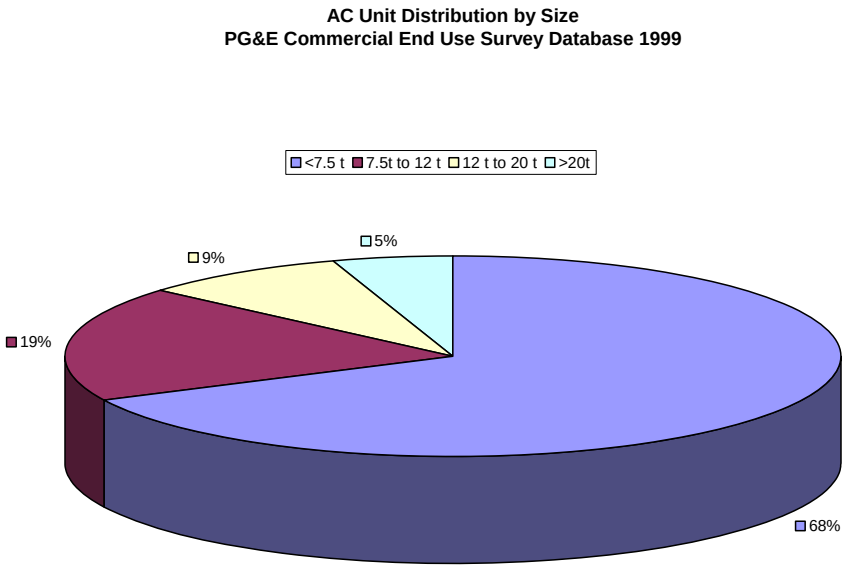
Methodology

Background and Survey

According to the US DOE 2003 Commercial Buildings Energy Consumption Survey (CBECS) approximately 40% of the commercial building conditioned floor space is conditioned by packaged (unitary) equipment[i]. PG&E Commercial End Use Survey (CEUS) shows packaged units as cooling approximately 2/3 of all commercial space[ii]. Of the units in the CEUS database, 70% are below 7.5

tons and nearly 20% are between 7.5 and 12 tons (see Figure 1)[iii]. As discussed below, almost all single zone units in this size range have constant speed fans.

Figure 1 - AC Unit Distribution by Size



For the past 5 years the author's company has been successfully applying VAV controls on single zone units serving large spaces with variable occupancies. For unitary equipment with DX cooling and either gas-furnace or heat pump heating variable air volume (VAV) controls using variable speed drives (VSD) are presently offered by the major manufacturers as a standard option. At present these are typically only offered on the larger unit sizes with the minimum size being in the 15 ton to 25 ton range (depending on manufacturer, see Table 1 below). One manufacturer, Aaon, currently offers variable speed drives on unitary equipment down to 2 tons. They can do this as they are using the Copeland digital scroll compressor.

Table 1 - AC Unit Manufacturers with Existing Unitary VAV DX Equipment

Manufacturer	**Minimum VAV Unit Size**
Trane	20 ton
McQuay	15 ton
Carrier	20 ton
York	25 ton
Dunham Bush	15 ton
Aaon	2 tons (they have digital scroll compressors)

Most packaged units in the 7-1/2 ton to 20 ton range have multiple stages of compression (typically 2). The standard two stage cooling thermostat operates either the economizer or first stage of compression on the first stage of cooling and the second stage of compression on the second stage of cooling. The economizer is selected on the first stage call for cooling if it is below its lockout temperature. If the economizer is locked out the first stage compressor cycles as required to meet the space cooling set point. The authors propose that it would be relatively easy for the major manufacturers to provide 2-speed motors on the supply fans in this size range with the fan running on low speed if the first stage of cooling is engaged and high speed if when the second stage of cooling is engaged. To do this the manufacturers would only have to add the following components:

- Two-speed motor
- Two-speed motor starter
- Relays to control the motor speed at each stage and to switch the active OSA minimum potentiometer
- A new OSA minimum potentiometer for when the fan is on low speed

The authors surveyed the product line managers of the major manufacturers (Trane, McQuay, Carrier and York) to ask the following questions:

Survey Questions for the Major HVAC Manufacturers

We are writing to get your reaction to a proposed code change for California's Title 24 energy code (the 2008 version). Under contract to the CEC we are investigating a requirement for VAV fan control on single zone units with multiple compressors. For units ~25 tons and larger most manufacturers already offer VSDs as a standard option. Between 7-1/2 tons and 20 tons we are considering a requirement based on 2 speed motors (either 100%/50% or 100%/67%). A unit with a VSD would automatically comply in this size range.

We have several questions for you:

1. *If this was a requirement in the 2008 version of the Title 24 standard, would your company be able to have either a 2-speed or variable-speed unit available for sale by 1/1/2008?*
2. *If we move forward, what is the minimum fan speed on the low stage of cooling (Y1) that you think you could comfortably support (50% or 67%)?*
3. *Would your company support, be neutral or oppose this proposed requirement if it moves forward?*

The responses varied by manufacturer. They are summarized below:

- One of the manufactures has not responded to date (neither negative nor positive)
- The remaining three responded positively to the proposed requirement.
    - One fully supports the proposed requirement as written down to 7-1/2 tons with two speed motors.
    - One supports a requirement based on VSD fan control down to 12 tons. They prefer that this take effect on 1/1/2009.

- The last supports the proposal down to 15 tons by 1/1/2008 but would like the 7-1/2 ton to 12 ton units to be delayed until 1/1/2009.

In summary all of the respondents would support a limit of 12 tons if the implementation were delayed to 1/1/2009. Two of the three respondents would support this down to 7-1/2 tons if the implementation were delayed to 1/1/2009.

To be conservative in our analysis of this measure we simulated single zone systems with 2-speed motors both at 100%67% speed and at 100%/50% speed. The savings and possibly first costs would increase if VSDs were used to control the supply fan motor. The incremental costs (list price) for two speed motors in the range of 2 horsepower are approximately $125 to $150 over fixed speed motors. The results of our simulations are presented in Table 1 below. Using the average costs across all climate zones the incremental costs of a 2-speed 7-1/2 ton AC unit could be up to approximately $1,500 and still be justified through the TDV cost savings. It should be noted that a 7-1/2 ton unit will typically cost in the neighborhood of $3,750 (using $500 per ton). The real cost of the components and labor for a 2-speed system are more likely in the $500 to $800 range.

Table 2 – Simulation Results[iv]

	Savings Per SF of Space		Threshold Cost for 7-1/2ton unit	
Climate Zone	67% Fan	50% Fan	67% Fan	50% Fan
CTZ01	$ 0.76	$ 0.95	$ 2,300.00	$ 2,800.00
CTZ02	$ 0.40	$ 0.51	$ 1,200.00	$ 1,500.00
CTZ03	$ 0.40	$ 0.51	$ 1,200.00	$ 1,500.00
CTZ04	$ 0.71	$ 0.88	$ 2,100.00	$ 2,600.00
CTZ05	$ 0.55	$ 0.69	$ 1,700.00	$ 2,100.00
CTZ06	$ 0.58	$ 0.73	$ 1,700.00	$ 2,200.00
CTZ07	$ 0.46	$ 0.58	$ 1,400.00	$ 1,700.00
CTZ08	$ 0.39	$ 0.49	$ 1,200.00	$ 1,500.00
CTZ09	$ 0.40	$ 0.50	$ 1,200.00	$ 1,500.00
CTZ10	$ 0.39	$ 0.49	$ 1,200.00	$ 1,500.00
CTZ11	$ 0.34	$ 0.43	$ 1,000.00	$ 1,300.00
CTZ12	$ 0.58	$ 0.72	$ 1,700.00	$ 2,200.00
CTZ13	$ 0.34	$ 0.43	$ 1,000.00	$ 1,300.00
CTZ14	$ 0.43	$ 0.54	$ 1,300.00	$ 1,600.00
CTZ15	$ 0.59	$ 0.74	$ 1,800.00	$ 2,200.00
CTZ16	$ 0.51	$ 0.63	$ 1,500.00	$ 1,900.00
Maximum	$ 0.76	$ 0.95	$ 2,300.00	$ 2,800.00
Minimum	$ 0.34	$ 0.43	$ 1,000.00	$ 1,300.00
Average	$ 0.49	$ 0.61	$ 1,468.75	$ 1,837.50

We assessed the cost effectiveness of 2-speed motors on the 7-1/2 ton unit as the cost savings only improve with larger units. This is due to the fact that the TDV energy costs scale directly with the unit size but the first cost premium for the 2-speed motors and controls (based on the metric of $/ton installed) decrease with unit size. The labor and most components remain the same regardless of unit size. Only the cost premium of 2-speed motors and starters increase with unit capacity. A survey of prices from the Granger's catalog indicate that this cost premium for the motors is less than linear

with size of the motor (e.g. the cost premium for a 2 hp motor is significantly less than twice that of 1 hp motor).

We did not do additional analysis for the threshold for the VSDs as this was already covered in the study Part IV: Measure Analysis and Life-Cycle Cost for the 2005 California Building Energy Efficiency Standards[v]. This report clearly showed that VSDs are cost effective in all climates for variable air volume systems down to 5hp. Since the manufacturers don't have VSD products on smaller single zone units yet we recommend setting the threshold for VSDs to 12 tons. This is based on the manufacturer's responses to our survey. All respondents have indicated that they can provide VSDs on units down to 12 tons by 1/1/2009.

Subsequent meetings with ARI's Unitary Large Engineering (ULE) Group

After our July 2006 report on this measure we received some comments from the industry. In attempt to resolve the comments we approached ARI to set up a series of net meetings to discuss the proposal and to seek consensus. We had two net meetings with the ARI ULE group on December 7th 2006 and January 24th 2007. The results of these meetings was a consensus of the participants with the following revisions:

- That the requirement be proposed to the ASHRAE Standard 90.1 committee
- That the minimum unit size be increased from 7-1/2 tons to 10 tons
- That the requirement be based on a 2/3 speed motor (to prevent coil freezing)
- That implementation be delayed to 2012.

The author took this measure to the ASHRAE Standard 90.1 HVAC subcommittee at the ASHRAE Winter Meeting in Dallas (January 2007) and they have given this proposal a number 1 priority. The other items are contained in the modified proposed text below.

Analysis and Results

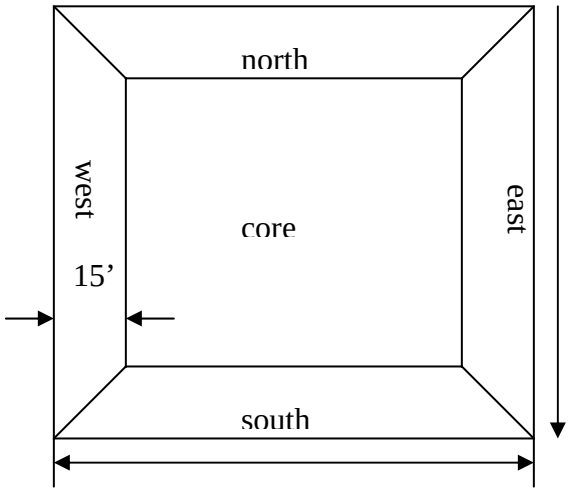
The results shown above were computed in eQuest using a five-zone single story building (see Figure 2). The building was 100' by 100' with a 15' depth to the perimeter zones. The building was provided with a 40% window to wall ratio. The envelopes and glazing characteristics for each climate zone were taken from the 2005 Title 24 prescriptive tables. Similarly the Title24 lighting, equipment and occupancy densities and schedules were taken from the ACM. The fan power was taken from the prescriptive fan power limits for constant volume systems. The only thing that differed between the base case and proposed cases was the fan speed and power.

For each run, the unit size was taken as 1.21% greater than the maximum hourly load. The fan speed for the proposed cases were put on low speed (either 50% or 67% as appropriate) in the following conditions:

- Whenever the coil load was less than 50% of the design capacity (to simulate two equally sized compressors) and the economizer was at minimum position, and
- When the economizer could provide 100% of the cooling

Both of these conditions are when only the stage 1 thermostat would be engaged. The fan ran at full (100%) speed at all other occupied conditions.

Figure 2 - Five Zone Model



Recommendations

Based on our research we recommend that a new prescriptive requirement be added to require variable air volume supply fan control on all unitary and air-handling units with a cooling capacity of 7-1/2 tons and larger. For units with a cooling capacity of 12 tons and above, the requirement will be based on VSD controlled fans. For units 7-1/2 tons up to 12 tons, the requirement will be based on 2-speed motors.

Proposed New Standard Prescriptive Requirement

144(l) **Variable air volume control for single zone systems. Effective January 1/2012 all unitary air conditioning equipments and air-handling units with mechanical cooling capacity at ARI conditions greater than or equal to 110,000 Btu/hr that serve single zones shall be designed for variable supply air volume with their supply fans controlled by two-speed motors, variable speed drives, or equipment that has been demonstrated to the Executive Director to use no more energy. The supply fan controls shall modulate to a minimum of two-thirds of the full fan speed at low cooling demand.**

Proposed Changes to the Existing Standard Requirement 125(c)

125 (c) Variable Air Volume System Acceptance. Before an occupancy permit is granted for a newly constructed building or space, or a new space-conditioning system serving a building or space is operated for normal use, all variable speed fans serving the building or space shall be certified as

meeting the Acceptance Requirements for Code Compliance, as specified by the Nonresidential ACM Manual. A Certificate of Acceptance shall be submitted to the building department that:

1. Certifies plans, specifications, installation certificates, and operating and maintenance information meet the requirements of Part 6.

2. Certifies that the fans meet:

A. the requirements of Section 144 (c) 2 and 144(x) for variable air volume systems installed to comply with the Prescriptive Approach; or

B. the requirements of Sections 144 (c) 2 B, 144 (c) 2 C, ~~and~~ 144 (c) 2 D, and 144 (x) for variable air volume systems installed to comply with Section 141.

Proposed Changes to the ACM Manual Section 2.5.2.4

2.5.2.4 Standard Design Systems

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Table N2-11 – System #1 and System #2 Descriptions

System Description: Packaged Single Zone with Gas Furnace/Electric Air Conditioning (#1) or Heat Pump (#2)

Supply Fan Power: See Section 2.5.3.5

Supply Fan Control:

- Constant volume < 10 tons
- Variable volume with 2 speed motor >= 10 tons

Min Supply Temp: 50 < T < 60 DEFAULT: 55

Cooling System: Direct expansion (DX)

Cooling Efficiency: Minimum SEER or EER based on equipment type and output capacity of proposed unit(s). Adjusted EER is calculated to account for supply fan energy.

Maximum Supply Temp: 85 < T < 110 DEFAULT: 100

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Proposed Changes to the ACM Manual Section NJ4.1

NJ.4.1 Constant Volume Packaged HVAC Systems Acceptance

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NJ.4.1.2 Equipment Testing

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Step 3: If there is an economizer, simulate cooling load and economizer operation, if applicable, during occupied condition (e.g. by setting time schedule to include actual time and placing thermostat cooling setpoint below actual temperature). Verify and document the following:

· Supply fan operates continually during occupied condition.

· Supply fan operates at low speed on first stage cooling and on high speed for second stage cooling

· Refer to the ECONOMIZERS acceptance requirements section for testing protocols.

· No heating is provided by the unit.

Step 4: If there is no economizer, simulate cooling load during occupied condition (e.g. by setting time schedule to include actual time and placing thermostat cooling setpoint below actual temperature). Verify and document the following:

· Supply fan operates continually during occupied condition.

· Compressor(s) stage on.

· Supply fan operates at low speed on first stage cooling and on high speed for second stage cooling

· No heating is provided by the unit.

· Outside air damper is open to the minimum position.

Proposed Changes to the ACM Manual Section NJ3.1

NJ.3 Outdoor Air

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NJ.3.1.2 Equipment Testing

Step 1: If the system has an outdoor air economizer, force the economizer high limit to disable economizer control (e.g. for a fixed drybulb high limit, lower the setpoint below the current outdoor air temperature)

Step 2: Minimum OSA at minimum supply fan speed:

- For multiple zone systems, d~~D~~rive all VAV boxes to the greater of the minimum airflow or 30% of the total design airflow.
- For single zone system, drive supply fan to minimum fan speed.

Verify and document the following:

- Measured outside airflow CFM corresponds to no less than 90% of the total value found on the Standards Mechanical Plan Check document MECH-3, Column H or Column I (which ever is greater).
- System operation stabilizes within 15 minutes after test procedures are initiated (no hunting).

Step 3: Minimum OSA at full supply fan speed:

- For multiple zone systems, d~~D~~rive all VAV boxes to achieve design airflow.

- For single zone system, drive supply fan to minimum fan speed.

Verify and document the following:

- Measured outside airflow CFM corresponds to no less than 90% of the total value found on Standards Mechanical Plan Check document MECH-3, Column H or Column I (which ever is greater).
- System operation stabilizes within 15 minutes after test procedures are initiated (no hunting).

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Material for Compliance Manuals

Due to time constraints, only a summary of the non-residential compliance manual changes are provided here:

- Changes would be required in the compliance forms:
  - The existing MECH-2-A form would be modified to document the acceptance testing of the ventilation at low speed
  - The existing MECH-3-A form would be modified to document the acceptance testing of the fan speed controls, and
  - The existing MECH-2-C form would be expanded to document compliance with the requirement.
- Information would be provided in Section 4.6 on how to meet this requirement.
- Section 4.11 Mechanical Plant Check Documents would need to be updated to document the changes in the compliance forms noted above.
- Section 4.11.9 Acceptance Requirement would need to be updated to document the changes in the acceptance tests and forms.

Acknowledgements

This analysis and report was produced by Jeff Stein, Anna Zhou and Mark Hydeman of Taylor Engineering, LLC, Alameda, California under contract to the Architectural Energy Corporation. This work was funded by the California Energy Commission under their Codes and Standards group.

Bibliography and Other Research

References and citations are provided in the end notes below.

Appendices

If appropriate, use one or more appendices to present lengthy data tables, referenced studies, or other information that would otherwise disrupt the flow of the report.

[i] 2003 data obtained from CBECs website at http://www.eia.doe.gov/emeu/cbecs/cbecs2003/public_use_2003/2003microdat.html.
[ii] Commercial Building Survey, Summary Report to the CEC, June 23, 1997 PG&E Energy Research and Analysis.
[iii] From PG&E's 1999 Commercial End Use Survey database. A copy of this data was provided by Martha Brook of the CEC.
[iv] Table threshold costs are based on 400 ft2 per ton. Note that at $500/ton these threshold costs represent approximately a 50% premium for the unit (base costs are $3,750 for a 7-1/2 ton unit).
[v] Part IV: Measure Analysis and Life Cycle Cost for the 2005 California Building Energy Efficiency Standards. August 13th, 2002. California Energy Commission. P400-02-014.