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AHRI Comments
on
Proposed Changes
CEC Title 24
Residential Zoned AC

California Statewide Utility Codes and Standards Program
04/12/2011 1 Residential Zoned AC Stakeholder Meeting #2
Bruce Wilcox April 12, 2011

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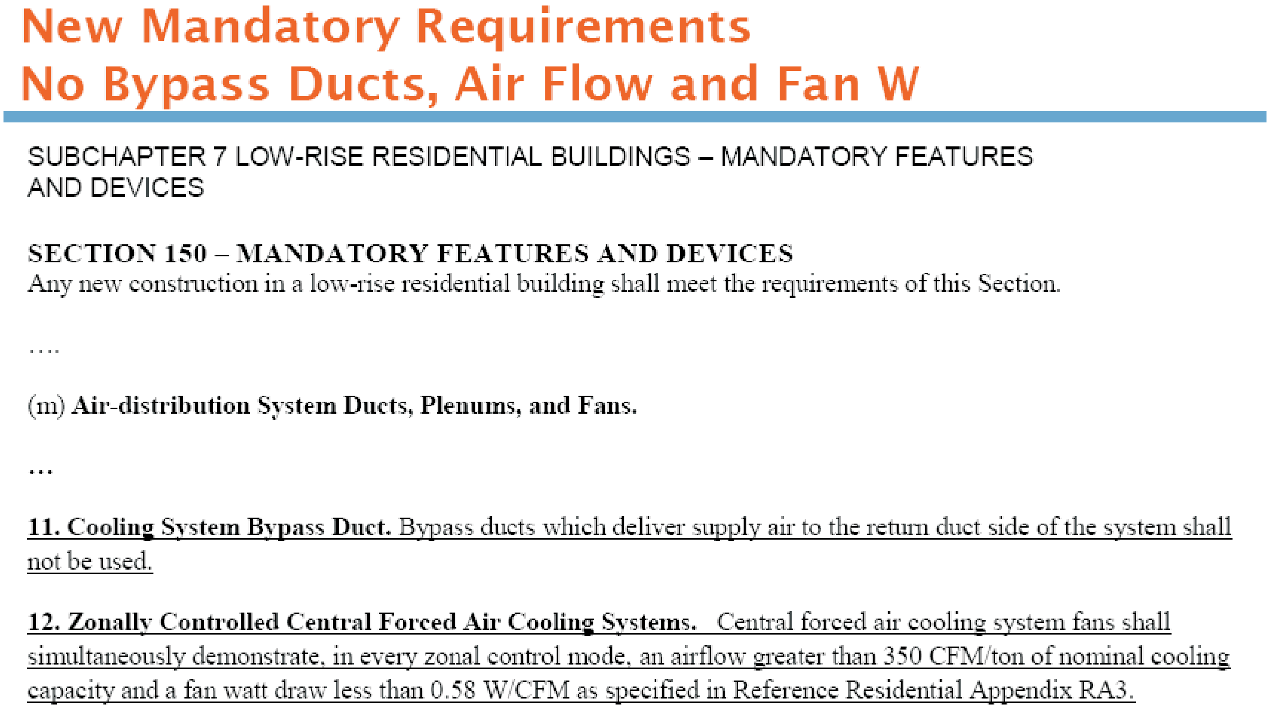
Response to Proposed Changes

CA Utilities 2013 Title 24 Stakeholder Meeting for Proposed Code Changes



New Mandatory Requirements
No Bypass Ducts, Air Flow and Fan W

SUBCHAPTER 7 LOW-RISE RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150 – MANDATORY FEATURES AND DEVICES
Any new construction in a low-rise residential building shall meet the requirements of this Section.

….

(m) **Air-distribution System Ducts, Plenums, and Fans.**

…

11. Cooling System Bypass Duct. Bypass ducts which deliver supply air to the return duct side of the system shall not be used.

12. Zonally Controlled Central Forced Air Cooling Systems. Central forced air cooling system fans shall simultaneously demonstrate, in every zonal control mode, an airflow greater than 350 CFM/ton of nominal cooling capacity and a fan watt draw less than 0.58 W/CFM as specified in Reference Residential Appendix RA3.

Cooling System Bypass Duct

Bypass ducts should not be banned. They are an effective air management tool, and the net affect on seasonal KWH is not known (for one simple system, or for a state-wide set of systems).

- The ban seems to be based on energy concerns.
- The sensible Btuh of supply air per KW of equipment power ratio does not relate to seasonal energy use.
- The rational for the ban is flawed.
- See Summary Item 4, and supporting detail

Low Limit for Blower Cfm

A low limit of 350 blower Cfm per cooling Ton for any zonal mode is consistent with the performance range for most cooling equipment, and is compatible with air relief strategies. In this regard, cooling Ton needs to be defined.

- There is a Cfm/Ton value for the AHRI rating test, for a given piece of equipment.
- These is an applied Cfm/Ton value for the summer design condition, for a given piece of equipment operating at a particular location.
- These is an applied Cfm/Ton value for any momentary operating condition, for a given piece of equipment operating at a particular location.

High Limit for Blower Watts

It may be that a high limit of 0.58 Watts per Cfm is consistent with the performance range for most cooling equipment and approved duct systems.

- OEM blower tables always provide Cfm vs. IWC values, but may not provide the corresponding Watt values.
- External static pressures may range from 0.10 to about 1.0; and airflow may range from about 600 Cfm to more than 2,000 Cfm.
- External resistance depends on external device and component resistance, and on duct run resistance (must be compatible with blower pressure).

Summary

Comments for Proposed Changes in CEC Code

This is a response to a set of CEC slides that cryptically summerize complex issues and concepts. Comments are made without knowledge of previous discussions and debates, and without knowledge of the documentation and supporting detail that justifies the suggestions and conclusions that appear on the slides.

Item 1 -- System Physics vs. Human Nature

What are the quality control conditions for comparing system performance and efficiency?

- For any installation there is a maximum system efficiency (no design or installation flaws); and a degraded efficiency (some combination of design and installation flaws).
- Quality assurance mandates should be based on observed knowledge of common design flaws and unapproved practices.
- System merit (comfort and efficiency) comparisons, and subsequent rule making, should be based on the *no design or installation flaws* scenario. In this regard, there may be more rules for air zoning vs. single zone.

Item 2 -- Slides Limited to Basic Zoned System

The slides appear to focus on a simple two-zone system that has (roughly) equal design Cfm values for zone supply air; and single speed equipment (one compressor speed, and one blower speed). This minimizes the design value for excess air (blower Cfm minus the smallest design Cfm value for the two zones).

- Two large zones minimum excess air, so this is the best scenario for simple single-speed equipment.
- Two large zones (minimum excess air) require less air relief measures, which may be some combination of bypass air, a dump zone, damper stops, and zone over blow.
- The slides only mention bypass air and over blow, and propose to ban bypass air.
- The Slide 21 solution (Figure 1) shows a duct system that has an undampered supply to each zone, and a dampered supply to each zone. There is no simple way to predict the behavior of this design.

  A zone may not need supply air, but some undetermined amount of supply air will be delivered to the zone (through the undamperd supply) when the zone damper is closed.

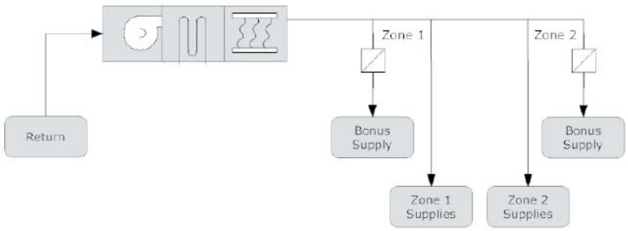


Figure 1

  The slide says that 1/.3 of the air will flow to the zone that does not need the air (three ducts open, one duct closed, each duct at 1/3 of the blower Cfm).

  How is this going to happen? What are the duct sizing rules (for a particular blower table and set of pressure-dissipating devices, for a particular duct run geometry, and for a particular set of duct fittings); and/or what are the air balancing rules (the slide does not show hand dampers)?

  If a zone thermostat is satisfied, and if 1/3 of the air continues to flow to this zone, how long will it take for zone temperature to drop to an unacceptable level; and how does this transient compare to the time it will take ro satisfy the calling zone thermostat?

  Air outlet performance (throw and noise) depends on make, model and size. Some guidance is need here.

  In general, how can practitioners be sure that the proposed (Figure 1) design will always deliver adequate performance for any operating condition?

Item 3 - Useful Measures and Features Ignored

The slides say nothing about dump zones, damper stops, selective throttling, and variations of a slave zone. The slides mention capacity control, with no subsequent comment or guidance.

- Zone systems are installed for comfort, and comfort depends on providing an adequate number of zones (as determined by architectural and construction attributes, and space use).
- A single-speed design will require some combination of air relief measures. In some cases, the number of zones may be less than desired.
- An up-scale design will use staged equipment (compressor and blower), or variable-speed

equipment (compressor and blower), and some combination of air relief measures. In this regard, capacity control reduces the amount of excess air, and allows more comfort zones.

- Some OEM's provide a complete system (central components and zoning components) that requires bypass air, and may have capacity control.
- Some OEM's provide a complete system (central components and zoning components) that has capacity control with no bypass air (selective throttling systems).
- Zone damper equipment vendors have various methods for adding zoning to a piece of central equipment. This includes all types of air relief measures, including bypass air.

Item 4 - Bypass Duct Banned

What is the rational for prohibiting bypass air? If this is an energy issue, see the Item 5 comments.

Bypass Utility

A properly designed zone damper system may require a set of air relief measures. Eliminating the bypass option will, in general, have an adverse effect on system performance.

- Comfort is the primary reason for zoning. In this regard, the goal is to provide for precise temperature control for all rooms and spaces.

  Bypass air has no adverse effect on zone temperature control (zone Cfm matches zone load).

  Distributed relief (damper stops) and zone over blow conditionally diminish zone temperature control (zone supply air Cfm may not match zone load).

  A dump zone may be conditionally uncomfortable.

- Preferred temperature control may require three or more zones, but the air relief requirement increases with the number of zones.

  The critical zone is the zone that has the smallest design Cfm value.

  The number of zones determines critical zone Cfm.

  Eliminating the bypass air option may force a comfort-compromised zoning plan (zone consolidation).

- Two stage equipment (compressor and blower) reduces the air relief requirement, but does not automatically eliminate the need for a bypass duct.

Bypass Design and Operation

The purpose of the bypass duct is to assure adequate flow though the blower as zone dampers close. Momentary performance (bypass Cfm, cooling coil temperature, and system EER) depend on a set of environmental variables that apply to all system designs; and on a set of variables that apply to a particular system design.

- The low limit for bypass Cfm depends on a lot of issues (primarily on the OEM's blower data, the momentary Btuh of sensible cooling capacity per Cfm of coil air flow, and the OEM's low limit for discharge air temperature).
- The low limit for bypass air may be less than 10% of the blower Cfm, or more than 50% of the blower Cfm, depending on momentary circumstances; and on how the air zoning system is designed and controlled.

  Approved designs maximize momentary bypass effectiveness without causing central equipment problems.

  A bypass duct may be (necessarily) supplemented by some combination of damper stops, bypass duct, dump zone, and zone over blow.

  Bypass effectiveness also depends on appropriate airflow and temperature sensors, controls, and control strategy.

  There still is a lower limit to the size of the critical zone (as far as its design Cfm is concerned).

- A properly designed bypass system, will not, for worst-case conditions (critical zone damper open, all others closed), operate at less than the OEM's lower limit value, which may be 350 Cfm/Ton, or significantly more than 350 Cfm/Ton.

  Zone damper system controls should shut the system down (in a normal manner) before the OEM limit temperature control acts.

  Routine shut downs will not occur if the system is designed and installed correctly.

No Bypass Method

Selective throttling systems tend to be (or are) proprietary OEM packages. This design uses software or firmware code to control compressor capacity, blower Cfm, and zone over blow; and uses a comfort zone as a dump zone.

- These systems do not require a bypass duct, per proprietary design rules.
- The OEM's design rules may limit the number of zones (a comfort compromise).
- There may be proprietary duct layout and airway sizing rules.
- Using a comfort zone as a dump zone conditionally reduces zone temperature control (zone Cfm may not match zone load).

- Zone overblow should be reconciled with supply air outlet performance (re: air mixing and noise).

Item 5 -- Net Sensible EER

Isn't EER defined as momentary cooling equipment output for total (sensible plus latent) cooling Btuh divided by momentary power input in watts? Showing EER as supply air outlet output for sensible Btuh divided by the total electric energy input watts is technical sophistry.

- The reason for air zoning is improved temperature control for rooms and spaces. This is accomplished by reducing supply air Cfm to the zoned space.

  Sensible supply air Btuh per system input KW must decrease when zone dampers fulfill their mission.

  What else might we expect?
- What about latent capacity (some California climates produce latent loads).
- Using a sensible supply air Btuh to input KW ratio to compare zone damper systems with single zone constant volume systems is an apples and oranges exercise.

Momentary EER for Simple Air-Cooled Systems

Momentary EER equals the momentary equipment output capacity at the equipment (Btuh), divided by momentary power input to the equipment (KW).

- Momentary capacity equals the sum of the sensible and latent capacity, which depends on blower Cfm and cooling coil temperature.
- Momentary input power equals the sum of compressor power, outdoor fan power, and indoor blower power.

  Compressor power is affected by blower Cfm and cooling coil temperature.

  Outdoor fan power may be constant (not be affected by blower Cfm and cooling coil temperature).

  Indoor blower power depends on the type of blower motor (PSC or ECM), motor performance setting (speed tap or Cfm tap), and the amount of duct system resistance (produced by components, devices, straight runs, and fittings).

Startup Transient

System performance (and EER) continuously changes for some minutes after startup, then settles to a steady state condition. This affects single zone system and air zoned system efficiency a similar way (the consequences of possible differences in start-up Cfm are not argued here).

Momentary EER for a Simple Single Zone System

For one large zone, the thermostat set-point is maintained by on-off control. After startup, blower Cfm and blower power are constant (because duct system resistance is not a controlled variable), and cooling coil temperature is not affected by the action of a space thermostat.

- Cooling coil temperature and compressor power depend on outdoor temperature, and the condition of the entering air.
- Cooling coil temperature and compressor power depend on the momentary values for sensible and latent load.

Momentary EER for a Simple Zoned System

Thermostat set-points are maintained by adjusting zone damper position. After startup, blower Cfm and blower power depend on zone damper position, and bypass damper position (if applicable); and also depend on other air relief measures (see Item 3). For this design, cooling coil temperature is affected by the action of the zone thermostats, and bypass damper position (and other air relief measures).

The net affect on momentary EER is a complex issue. There are conditional tendencies, which may work in the same direction, or opposite directions.

- Blower motor power (watts) depends on blower speed, blower Cfm, airflow resistance within the cabinet, duct system resistance, blower efficiency, and blower motor efficiency.

  Blower Cfm tends to decrease, and system resistance tends to increase as zone dampers close.

  Blower Cfm tends to increase, and system resistance tends to decrease as a bypass damper opens.

  Air relief measures, in general, tend to stabilize blower Cfm and blower power.
- Refrigeration cycle efficiency and compressor power depend on cooling coil temperature.

  Cooling coil temperature tends to decrease as zone dampers close. This behavior is similar to a blower speed change (OEM performance data correlates sensible and latent capacity, and equipment KW, with blower Cfm).

  Cooling coil temperature rapidly decreases as the bypass damper opens (OEM performance data does not model this behavior).

  Other air relief measures have a much smaller affect on cooling coil temperature.

  If a zone damper system is properly designed and installed, there is a lower limit for cooling coil temperature, and a corresponding limit to Cfm/Ton (which may *be greater than 350 Cfm/Ton, depending on the OEM's value for low limit temperature, and other issues.)*

- Observing that system KW may change as zone dampers close is one thing. Calculating the aggregate impact of the issue is something else.

  The magnitude of the system KW change depends on the details of the scenario, so an investigation would consider a set of likely design scenarios (there would be a maximum, minimum and average value for the set)

  This gets messy. For example, OEM blower tables show that an increase in duct system resistance may translate to more blower power (say 10 Watts per 0.10 IWC), little change in blower power, or less blower power, depending on the product (this behavior needs to be investigated).

  This gets messy. How do we determine the compressor KW change per degree of cooling coil temperature change? Are we talking about a few watts, a 100 watts, or what? Is all equipment equal?

  OEM correction factors (per published performance data) for more or less blower Cfm show that cooling capacity is somewhat sensitive to Cfm (say a one or two percent per 100 Cfm), and that the input KW effect is less than the capacity effect.

  This gets messy, a calculation tool would have to deal with a large set of variables, and correctly estimate small changes in system performance (assuming input data is available, and accurate).

System Merit Depends on Seasonal KWH

System efficiency is a conditional and complex issue, but at the end of the day, overall system efficiency determines system KWH for a default cooling season.

If we are going to compare single zone efficiency with multi-zone efficiency, wouldn't we want to integrate momentary power draw over cooling season time?

$$\text{Seasonal KWH} = \Sigma\ KW_i \times \text{HOURS}$$

In other words, if both systems provide comfort to the best of their ability (everything sized correctly), compare single zone KWH for the season with multi-zone KWH for the season.

Item 6 - Energy Credit

As noted above, seasonal KWH depends on momentary KW integrated over seasonal time. For no set-up or set back, the net effect may be more KWH, less KWH or parity, compared to a single zone system. With set-up or set back, the likelihood of less KWH increases.

The slides only deal with simple single speed equipment and bypass air. Multi-speed equipment and other air relief strategies affect energy use.

- Generalized conclusions are not possible.
- A sophisticated calculation tool is needed to evaluate merit.

Item 7 - Supporting Detail

An effort was made to investigate and understand the information on the slides. Particularly, the slides that pertain to power an energy issues. The following pages provide comments on specific slides.

Supporting Detail

Comments on Most Slides

See also

Excel Spreadsheet -- OEM Data

Slide 3

Current Code

Current Code Requirements

- The prescriptive air flow requirement for 350 CFM/ton in every zonal mode, can be traded away.
- Performance credit (easier heating and cooling set points) for zonal systems capable of maintaining different set points in living and sleeping zones. Common return OK.
- No restrictions on system design, variable capacity control type, commissioning etc.

3.1 Prescriptive Air Flow Comment

Is 350 Cfm/Ton a minimum default value, or a mandatory operating value? Does this apply to single zone systems and air zoning systems, or just for air zoning systems? What is the justification for the 350 Cfm/Ton value?

- The appropriate Cfm/Ton value depends on latent load. In this regard, a colder coil provides more latent capacity.
- 400 Cfm/Ton, or more, provides adequate latent capacity for all USA cities that do not have an unusually large coincident wet-bulb temperature for the summer design dry-bulb temperature (Charleston, SC, for example).
- 500 Cfm/Ton, or more, may be appropriate for a dry-coil climate.
- A substantial amount of HVAC equipment may not be designed to operate at 350 Cfm/Ton (assuming proper refrigerant charge).
- The OEM provides a minimum Cfm per Ton value. If the OEM value is greater than 350 Cfm/Ton, the OEM value supercedes code (due to the laws of physics).
- If a practitioner is ignorant about this issue, he can violate the OEM's guidance by complying with code.
- What does "350 Cfm/Ton in every zonal mode, can be ***traded away***" mean?

3.2 Energy Credit Comment

There are two issues here, which are, different set points, and a common return.

- It is possible that less than whole house conditioning will reduce energy use. Additional comments are provided for the **Code Change Proposal** slide.
- It may be that the return duct system affects energy use, but this may be hard to model. However, there is a significant performance issue.

  Return air from one zone should not affect the thermostat in another zone.

3.3 System Design Comment

There are many strategies for controlling zone temperatures and maintaining suitable equipment operating conditions. In this regard, the devil is in the details.

- The strategy depends on the zone that has the smallest supply Cfm requirement (which depends on zoning decisions).
- The strategy depends on OEM capacity control, and the high or low limit temperature for each capacity stage.
- The strategy depends on the OEM's blower motor type, and its controls.
- The strategy depends on the type of zone dampers (open-close or modulating).
- The strategy depends on the type of zoning controls, sensors and logic.
- The technical issues are manageable, and there are appropriate design procedures.
- It is reasonable to say that energy use is affected by the attributes of a zoning system's design and controls, but quantifying this for all common applications may be impossible.

Slide 4

Typical Practice

Single System with Dampered Supply Ducts

- Return ducts are not zoned
- Single speed compressors and fans cannot modulate to track load
- Supply air flow is low, particularly with one zone calling
- Bypass ducts (short circuit from supply into return) are common
- Results -- low EER

4.1 Return Duct Comment

Return air from one zone should not affect the thermostat in another zone; provide an adequate number of returns (a system design issue).

4.2 Single Speed Comment

The size of the **critical zone** (smallest design value for supply air Cfm) is limited by single speed equipment. If the design is correct, the blower Cfm will not be less than the OEM's low limit value (which may be as low as 350 Cfm/Ton, or more than 350 Cfm/Ton), and the temperature of the air leaving the equipment will be within the OEM's approved range.

- It is assumed that "single speed" implies a PSC blower (vs. and ECM blower)?
- Zoning controls could change PSC blower speed, but this may not be common.
- PSC blower curves tend to be relatively steep, so equipment Cfm does not change much if the system operating point stays on the approved part of the OEM's fan curve.
- Adequate air relief measures are normally required (damper stops, bypass duct, over blow; for example).
- Single stage equipment tends to be compatible with two zones that have similar design values for supply air Cfm.

4.3 Low Supply Air Flow Comment

What does low supply airflow mean?

- The whole point of air zoning is to reduce zone airflow at reduced zone load (to maintain the desired zone temperature).
- If the PSC blower speed does not change. If the blower curve is steep (typical), and if the operating point stays on the approved part of the OEM's blower curve, the acceptable variation in blower Cfm is relatively small.
- If zone airflow is significantly reduced, and if acceptable blower Cfm change is small, adequate air relief measures keep equipment airflow relatively constant.

4.4 Bypass Duct Comment

The momentary amount of bypass duct relief depends on momentary operating circumstances. There are design procedures for determining worst-case (minimum) Cfm and best case (maximum) Cfm. Approved designs maximize momentary bypass effectiveness without causing central equipment problems.

- A bypass duct may be (necessarily) supplemented by some combination of damper stops, bypass duct, dump zone, and zone over blow.
- Bypass effectiveness also depends on appropriate airflow and temperature sensors, controls, and control strategy.
- There still is a lower limit to the size of the critical zone (as far as its design Cfm is concerned).

4.5 EER Comment

What does EER mean, and what does low mean?

- EER is a momentary value (vs. SEER).
- Is EER equal to the total momentary equipment output capacity (Btuh) divided by total momentary input power (KW)?

  Momentary capacity equals the sum of the sensible and latent capacity?

  Momentary input power equals the sum of compressor power, outdoor fan power, and indoor blower power?
- Throttled zone air, and bypass air, tend to reduce evaporator coil temperature, which lowers refrigeration cycle efficiency. So, compressor efficiency, and system EER, depend on momentary evaporator coil temperature.

  The magnitude of this effect varies with the amount of bypass air, which depends on the momentary operating scenario for a given dwelling at a particular location, *served by a given cooling unit that has a given amount of excess capacity, and a given set of performance data.*

How important is this effect for the complete set of California homes (what percentage of cooling season KHW does it account for)?

- It may be that the outdoor fan KW is not significantly affected by the action of the zone dampers and a bypass duct (no effect on system EER)?
- For a constant PSC speed setting, the indoor blower KW tends to increase somewhat as external airflow resistance increases, so there is a small affect on system EER.

  Blower Cfm decreases to the extent that the operating point stays on the blower curve. This may be something like a 100 Cfm (maybe less, depending on how the air relief measures work).

  A change of 100 Cfm as external resistance increases may translate to something like 25 Watts.

  How important is this effect for the complete set of California homes (what percentage of cooling season KHW does it account for)?
- Is there a computer model that computes momentary EER for a given type of dwelling (zoning scenario), for a given equipment make-model-size, for a given amount of excess capacity, for a given air-relief strategy, for a particular location?

  If so, does it compute the dwelling's SEER?

  Then, is there a matrix of SEER values for a set of common dwellings, and cooling system designs, applied to a set of differentiated locations?

  Then, is there a statistical average for the preceding item?

  Then, how does this compare to the average seasonal SEER for a matrix of single zone scenarios?
- A poorly designed single zone, constant volume, system may operate at a coil temperature that just as cold as a properly designed zoned system with a bypass duct (assuming that both operate with no safety trips).

  A single zone system may spend more hours near the low limit temperature because low airflow is a constant condition.

  For a bypass system, coil temperature gets warmer as bypass Cfm decreases.

  There may be run-time issues and start-up issues to investigate (single-zone vs. multizone)?

Slide 5

Proposed Changes

Zoned A/C Code Change Proposals

- Prohibit bypass ducts
- Eliminate the current zonal AC performance compliance credit.
- Mandatory air flow and fan Watt verification in all zonal cooling modes.

5.1 Bypass Duct Comment

What is the rational for prohibiting bypass ducts? If this is an energy issue, see the 4.4 EER comment.

The purpose of the bypass duct is to assure adequate flow though the blower as zone dampers close. The low limit for bypass Cfm depends on a lot of issues (primarily on the OEM's blower data, the momentary Btuh of cooling capacity per Cfm of coil air flow, and the OEM's low limit for discharge air temperature).

- The low limit for bypass air may be less than 10% of the blower Cfm, or more than 50% of the blower Cfm, depending on momentary circumstances; and on how the air zoning system is designed and controlled.
- In other words, momentary bypass Cfm, cooling coil temperature, and system EER depend on a set of environmental variables that apply to all system designs; and on a set of variables that apply to a particular system design.

A properly designed bypass system, will not, for worst-case conditions (critical zone damper open, all others closed), operate at less than the OEM's lower limit value, which may be 350 Cfm/Ton, or significantly more than 350 Cfm/Ton.

- Zone damper system controls should shut the system down (in a normal manner) before the OEM limit temperature control acts.
- Routine shut downs will not occur if the system is designed and installed correctly.

A properly designed zone damper system may require a set of air relief measures. Eliminating the bypass option will, in general, have an adverse effect on system performance.

- Comfort is the primary reason for zoning. In this regard, the goal is to provide for precise temperature control for all rooms and spaces.

  Bypass air has no adverse effect on zone temperature control (zone Cfm matches zone load).

  Distributed relief (damper stops) and zone over blow conditionally reduce zone temperature control (zone Cfm may not match zone load).

  A dump zone may be conditionally uncomfortable.

- Preferred temperature control may require three or more zones, but the air relief requirement increases with the number of zones.

  The number of zones determines critical zone Cfm.

  Eliminating the bypass air option may force a comfort-compromised zoning plan (zone consolidation).

- Two stage equipment (compressor and blower) reduces the air relief requirement, but does not automatically eliminate the need for a bypass duct.
- Selective throttling systems (reduce compressor capacity and blower Cfm, and use a comfort zone as a dump zone) are proprietary OEM packages.

  They do not require a bypass duct, per proprietary design rules.

  The OEM's design rules may limit the number of zones (a comfort compromise).

  Using a comfort zone as a dump zone conditionally reduces zone temperature control (zone Cfm may not match zone load).

- A bypass duct is an important, effective and common air management tool.

  No adverse affect on zone temperature control.

  Significant method for stabilizing blower Cfm and external static pressure (reduces blower operating point excursions).

  The pressure drop for the bypass circulation path (for full bypass Cfm) is no larger than the pressure drop for the zone circulation path that has the most airflow resistance (all circulation paths are in parallel).

  An OEM zoning product (turnkey system) may be designed for capacity control (blower and compressor), with a bypass duct.

  Many zone damper vendor products utilize bypass air.

5.2 Zonal Credit Comment

It is possible that less than whole house conditioning will reduce energy use. However, there should be a way to identify favorable set-up, set-back scenarios (considering climate, envelop performance, primary equipment performance, and zoning equipment performance); and a way to estimate energy savings and dollar savings.

- One obvious issue (among many) is minimum set-back and set-up duration.

  Thermal mass that has cooled down has to be reheated, and vise versa.

  For humid climates, moisture absorbed during set-up has to be removed during recovery; and, entering wet-bulb affects coil performance during recovery.

- Energy use depends on the type of equipment that is used for set-back recovery (heat pump only; electric coil and heat pump; electric coil only; or furnace only).
- We assume that the home owner will use an effective set-up, set-back schedule.

5.3 Air Flow and Fan Watt Test Comments

What is the rational for fan watt testing? This could get complicated and time consuming. How does this correlate with annual energy use?

There may be two-zones to more than four zones. There are PSC blowers, ECM blowers, and variable speed blowers (and blower speed changes). There are open-close zone dampers and modulating zone dampers. There are various methods of air relief, plus selective throttling. There are various types of air relief controls and control logic, plus OEM proprietary selective throttling strategies. There is a significant range of OEM low limit values for cooling Cfm and discharge air temperature. There is one stage equipment, staged equipment, and variable speed equipment. Etc.

- Blower motor power (watts) depends on blower speed, blower Cfm, airflow resistance within the cabinet, duct system resistance, blower efficiency, and blower motor efficiency.
- Blower power may be relatively constant for a single zone system operating at one speed.

  Duct airways are sized (by duct slide rule) for design day airflow rates, and a design friction rate value.

  See the Duct Design sidebar.

- Blower power varies for a zone damper system.

  Duct airways are sized (or oversized) for design day airflow rates.

  Duct airways may larger to compensate for control damper pressure drop.

  Duct run, duct fitting, and device resistance (coil, filter, etc.) decrease at reduced air flow (zone damper resistance increases).

- Does the code limit blower Watts? If so, does the code just assume that proper duct design/sizing procedures can produce adequate airflow without exceeding the blower power limit for any set of circumstances?

  Larger duct airways and aerodynamic fittings tend to compensate for limited blower power, but this may not be a viable solution for all scenarios.

Duct Design

The design friction rate value depends on the **available static pressure** for straight runs and fittings, and on the **total effective length** of the longest circulation path (straight run lengths plus fitting equivalent lengths).

The **available static pressure** equals the blower table **external static pressure** minus the pressure drop for components and devices **that were not in place** when the blower was tested (supply grille, return grille, hand damper, accessory filter, cooling coil added to a furnace, for example).

If proper duct sizing procedures are not used, airways tend to be too small, and fittings tend to be inefficient, so blower power is more than what it would be for a correct design.

- A PSC blower may be set to a higher speed setting (this may, or may not, provide the desired air flow rate).
- An ECM blower will automatically speed up, perhaps to its static pressure limit, and maximum watts. If the normal speed increase does not fix the problem, the Cfm setting can be increased (if not already at its maximum value).

The concept of one blower watt value for all duct systems, no matter what, is questionable. The goal should be appropriate blower power for a given set of circumstances.

- Fittings have a significant affect on system resistance.(use efficient fittings).
- Cooling coils that have the same cooling capability may have significantly different pressure drop values for the desired blower Cfm (0.05 IWC to more than 0.10 IWC).
- Accessory components have a significant affect on system resistance. In this regard, an small-particle filter may add more resistance than an open zone damper.

- For zone damper systems, there is momentary blower power (KW), and seasonal energy use (KWH).

  Seasonal KWH depends on many variables (all the issues mentioned above and on the preceding pages).

  Is there a computer model for seasonal KWH?

  Is there a way to compare seasonal KWH for a representative set of zone damper systems with the seasonal KWH for a representative set of single zone systems?

Slide 6

Home Survey

California New Home Energy Survey

We have completed the survey of a sample of 80 new 2007 CA homes and found:

- AC systems have low capacity and efficiency
- Cooling air flow lower than the standard in 60% of systems
- Cooling duct pressures are very high
- Cooling fan watts are high
- MF duct leakage is very high, SF is pretty good

6.1 General Comment

This is a response to items on a slide show. This format uses a few words to summerize complex issues, observations and concepts. This is ok, but responses are based on assumptions pertaining to what the presentation is actually trying to say. Responses are not based on historical knowledge of related reports, documents, and hearing/meeting discussions.

6.2 Low Capacity Comment

On average, across the country, the way things are done do not correlate with the way things should be done. Investigations by various persons and organizations support these conclusions:

- Cooling equipment has significant excess capacity (when installed equipment size is compared to an aggressive ***Manual J*** load).
- Cooling equipment delivers less than its full capacity because of incorrect practices (refrigerant charge, excessive duct resistance, and duct efficiency issues).
- Cooling equipment performance is affected by return duct issues (conduction and leakage affects sensible and latent capacity at the equipment cabinet).
- A room, space or zone may have deficient capacity, even if the central equipment has excess capacity (usually a duct design and installation issue; and/or an air balancing issue).
- In general, installed capacity is excessive, and delivered capacity (at the cabinet, and for some collection of rooms and rooms and spaces) is deficient.

6.3 Low Efficiency Comment

On average, across the country, the way things are done do not correlate with the way things should be done.

- Duct system design and installation is the biggest issue when ducts are installed in an unconditioned space (this affects equipment efficiency and distribution efficiency).
- Refrigerant charge is a significant issue.
- Maintenance is an issue (air-side components must be clean, refrigerant must not be contaminated or restricted).
- The preceding items are much more important than a few points in published SEER, which applies to test chamber conditions that may not, and usually do not, simulate the operating condition at a home site.

  Maximum achievable SEER varies with climate and system design conditions.

  The maximum achievable SEER may be less than or greater than the published SEER value

  High efficiency equipment with poor design and installation may be less efficient than average efficiency equipment with good design and installation; regardless of climate.

6.4 High Duct Pressure Comment

The OEM's blower curve is what it is, but the resistance curve for necessary air-side components and duct runs depend on the practitioners's design method and installation practice.

- Aerodynamically inefficient fittings cause unnecessary resistance to airflow.
- Undersized airways cause unnecessary resistance to airflow.
- Proper airflow depends on the climate situation (this may be 400 Cfm per nominal AHRI ton, or less; to 500 Cfm per nominal AHRI ton, or more).
- It is assumed that "duct pressure" means available static pressure for supply and return distribution.

  Inefficient duct fittings and undersized airways unnecessarily increase system operating pressure.

  Required and/or desired air-side components produce a necessary increase system operating pressure.

There is no magic number for maximum system operating pressure, but proper design and installation will minimize this on a case by case basis.

- OEM efforts to compensate for practitioner/owner ignorance and negligence can be counter productive. ECM blowers increase system operating pressure when fittings are inefficient, when duct airways are too small, and when air-side components are dirty.

6.5 Fan Watts Comment

It is true that fan watts tend to be excessive on a case-by-case basis. However, there is no magic number for maximum fan watts. See 6.4 comment.

Fan watts is a complex conditional variable for zone damper systems. There is a peak value (which affects power draw, and an average value (which affects seasonal energy use). Trying to sort this out is a can of worms. See the 5.3 comment.

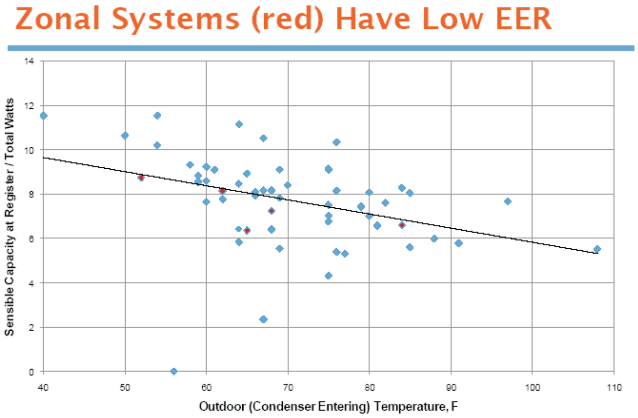
6.6 Duct Efficiency Comment

Not sure what MF duct leakage means and what SF means, but the industry knows that duct system efficiency has a significant affect on comfort, equipment performance, energy use, and operating cost.

- Ducts should be in the conditioned space to the extent possible (considering technical and economic issues).
- Ducts in an unconditioned space must be sealed to the appropriate standard, and insulated to at least R-6, and preferably to R-8. A vapor retarding jacket may be required for humid climates.
- Every effort should be made to minimize the surface area of duct runs in an unconditioned space.
- ***Manual J*** (MJ8) procedures reward efficient duct systems, and severely penalize inefficient duct systems.

Slide 8

Zoned Systems have High Low EER



8.1 EER Comment

Isn't EER defined as momentary cooling equipment output in Btuh divided by momentary energy input in watts? Showing EER as supply air outlet output Btuh divided by the total electric energy input watts is sophistry.

- The reason for air zoning is improved temperature control for rooms and spaces. This is accomplished by reducing supply air Cfm to the zoned space.

  Supply air Btuh per system input KW must decrease when zone dampers fulfill their mission.

  What else might we expect (are tests really necessary to verify this behavior)?

  Using the supply air Btuh to input KW ratio to compare zone damper systems with single zone constant volume systems is an apples and oranges exercise.

- What about latent capacity (some California climates produce latent loads).

- Seasonal system efficiency for a zoned system can be compared to a single-zone system.

  Published equipment SEER is not relevant (it does not model a particular set of circumstances, except by chance; and a given piece of cooling equipment may serve a single-zone system, or a zone damper system.

  System SEER must be scenario specific (depends on local weather data, architectural and structural attributes, comfort system capabilities, equipment performance maps, control strategy, etc.).

  SEER must correlate with the real issue, which is seasonal KWH and peak momentary KW.

- What are the quality control conditions for comparing system SEER?

  For any installation there is a maximum system SEER (no design or instillation flaws); and a degraded SEER (some combination of design and installation flaws).

  System merit should be based on the no design or installation flaws scenario.

  Quality assurance mandates should be based on statistical data for observed design flaws and unapproved practices. In this regard, there may be more mandates for air zoning vs. single zone.

- Momentary EER merit (no design or installation flaws) depends on performance attributes that affect single zone systems and zone damper systems.

  Total capacity, sensible capacity, coil sensible heat ratio, and input KW depend on coil Cfm, outdoor temperature, entering wet-bulb, and entering dry-bulb.

  Input KW equals compressor KW, outdoor fan KW and blower KW (plus some controls power).

  There is a data set for each capacity stage (when applicable).

- Momentary EER merit may depend on issues that are peculiar to zone damper systems.

  For constant blower RPM, blower pressure and blower motor KW tend to increase as zone dampers close; but bypass air, damper stops, dump zone, over blow and selective throttling affect the amount of change in blower pressure, and blower KW.

  There is a significant difference in the way a PSC blower and an ECM blower react to an increase in duct system resistance (KW increases as the PSC operating point moves up the fan curve, or KW increases as the ECM motor speeds up).

  Reduced Cfm across the cooling coil (air relief measures do not completely compensate for throttled zone dampers) lowers coil temperature, and decreases refrigeration cycle efficiency.

  Using a bypass duct to maintain airflow across the cooling coil lowers coil temperature, and decreases refrigeration cycle efficiency.

- See Sections 4.4, 5.3, 6.3 and 6.5 for related comments.

8.2 Comments on the Low EER Graph

There are three markers at average, or close to average. There is one marker that is somewhat below average. There is one marker that is significantly below average. There are a lot of other markers that are much worse than the zoned system markers.

It looks like the tests were conducted for the outdoor condition that existed when the technician arrived at the home site. This has some affect on equipment power draw, and considerable affect on equipment run time. This also has an effect on supply air temperature at the outlets (attic ducts, for example). For zoned systems, this has an affect on supply Cfm at the outlets.

- Momentary power draw (KW) may be zero, or a positive value (which is a conditional variable).
- Annual energy use (KWH) depends on momentary power draw (KW) integrated over seasonal use time (hours).
- Seasonal energy output at the registers depends on momentary values for supply air temperatures and supply air Cfm, integrated over seasonal use time.
- A momentary snapshot does not summarize seasonal performance.

For zone damper systems, momentary outdoor temperature and solar gain have a significant effect on all attributes of system operation. Single zone systems also are affected, but blower Cfm and room supply air Cfm are constant. These tests do not evaluate these issues.

Duct system efficiency should be comparable when a zone damper system is compared to a one-zone system.

- Same location, same floor plan, same construction, same direction for the front door.
- All duct systems correctly designed for their transport load, as far as surface area is concerned.
- All duct systems sealed to the same standard, and insulated to the same standard.

Were all these systems single stage systems, or did some systems have capacity control (for blower and/or compressor performance)? This would have a significant affect on momentary system performance.

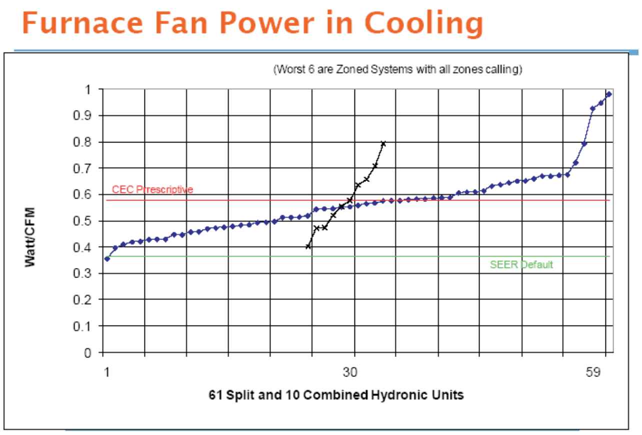
These tests may not be sensitive to equipment installation issues. Was the central equipment correctly sized or oversized? Was Cfm per nominal AHRI ton equivalent for one zone and multzone tests? Is refrigerant charge correct for one zone and multizone tests?

These tests do not seem to be apples-to-apples, as far as the issues that affect momentary system efficiency are concerned. And, the presentation implies that momentary efficiency is equivalent to seasonal efficiency.

This testing effort is affected by too many variables to pass judgement on air zoning. If all the marks on the graph were the same color, which ones should we be most concerned about, and why?

Slides 9 and 10

Zoned Systems have High Watts per Cfm



Furnace Fan Power in Cooling

9.1 and 10.1 Comments

This testing effort is affected by too many variables to pass judgement on air zoning.

Everything else being equal, a zone damper system has some additional flow resistance because of its zone dampers. However, this may not explain the size of the spike in Watts/Cfm for zone damper systems. In this regard, do we know how the installed attributes of the six zone damper duct systems, and their blowers, compare with approved design procedures?

- Is this an unavoidable system attribute issue?
- Is this an avoidable installed performance issue (practitioners must know how to correctly design and install zoned duct systems)?
- It may be (on a case by case basis), that careful design and proper installation can compensate for the pressure drop though open zone dampers.
- Item 6.4 and 6.5 comments are relevant to this slide.
- Did anyone check to see if all the zone dampers were actually wide open?

For air zoning, Watts/Cfm is a conditional variable. A comparison of the seasonal average for single-zone systems and multizone systems may be of more interest.

- For PSC blowers, the operating point moves along the blower curve as zone dampers operate. Blower speed changes are possible (depends on the controls and control strategy).
- For ECM blowers, the motor speeds up as zone dampers close. Blower Cfm set point changes are probable (depends on the controls and control strategy).
- True variable speed blowers tend to minimize fan power because RPM is reduced as zone dampers close.

If system Cfm is measured at the supply air outlets, how much did the supply ducts leak for each test?

- Supply outlet Cfm = Blower discharge Cfm - Supply duct leakage Cfm
- Is the prescriptive Watt/Cfm value for supply outlet Cfm, or for blower Cfm?

Slide 12

Bypass Duct Relief

How Zoning with Bypass Works

In Theory:

- With all zones calling, the bypass damper closes and bypass has no effect. All zones get the design air flow
- When only one zone calls, whatever isn't delivered to that zone is bypassed to the return to maintain coil air flow.

Actually

- Mixing in bypass air lowers the return air temperature entering the cooling coil and this ALWAYS significantly lowers the EER.
- Because of dampers and extra ducts the air flow is typically very low even when all zones are calling.
- Extra dampers and ducts make systems more prone to construction error and failures are common.

12.1 How Bypass Works Comment

Maximum bypass air Cfm is conditional. The momentary bypass Cfm value may vary from less than 10% of the momentary blower Cfm (which may be staged), to more than 50% of the momentary blower Cfm.

- The bypass Cfm demand depends on the smallest design Cfm for the various zones (the critical zone).
- A larger critical zone Cfm translates to less bypass Cfm (for a given floor plan, two large zones are easier to deal with than four zones).
- Total air relief may use some combination of a bypass duct, damper stops, a dump zone (or undamped rooms), and critical zone overblow.
- The air relief strategy must prevent a blower problem, or a discharge air temperature limit problem, when the critical zone is the only open zone (appropriate design procedures are available).
- If the bypass duct has a counter weight damper, it can only react to the worst-case scenario. So, if acceptable bypass Cfm varies from 10% to 50% of blower Cfm, the counterweight is set for 10%.

  Because there is no feed back control.

  If the counterweight is set for more than 10% (for a 10% scenario) there may be controlled shutdowns or nusance temperature trips.

  For controlled shutdowns, zoning controls shut the equipment down (in a normal manner), even if the zone thermostat is calling for conditioned air (this is a shall, as far as proper design is concerned).

  Nusance temperature trips occur when OEM safety controls are forced to act. The system may not restart unless controls are reset (this is a shall-not happen, as far as proper design is concerned).

  Controlled shutdowns depend on momentary operating conditions. A limited number of occurrences may not be noticed by the occupants.

  There is no procedure for predicting the number of controlled shutdowns for a particular system, in a particular home, at a particular location.
- If the bypass damper has feedback control (based on blower static pressure and discharge air temperature), the damper opens to the maximum position that will not cause a pressure or temperature problem. In other words, bypass Cfm is conditionally maximized, and system airflow resistance is conditionally minimized.
- The bypass damper should not be used for air balance.

  A hand damper in the bypass duct reconciles bypass path resistance with zone path resistance (hand dampers also are required for zone paths).

  Some designs use a bypass airway size that causes high bypass air velocity (2,500 to 4,000 Fpm). Noise may be an issue, and design procedures tend to be rule-of-thumb (a rigorous sizing procedure is mathematically challenging for day-to-day work).

12.2 EER Comment

A colder coil does reduce refrigeration cycle efficiency, but this is not the only issue. See Section 8.1.

12.3 Dampers and Extra Ducts Comment

Open control dampers do add an increment of airflow resistance. Efficient fittings and proper duct system design and airway sizing can minimize the effect.

- If the dwelling has zone load diversity (for time of day), *all zones calling* is not a normal operating condition.
- Proper system design procedures and duct sizing procedures provide adequate airflow for all possible load scenarios.

- What does extra ducts mean?

  The design value for duct system resistance depends on the total effective length of the longest circulation path. It makes no difference if there are two shorter paths or ten shorter paths.

  Over sizing duct airways (as recommended by some vendors) reduces system resistance for all operating conditions.

- Air zoning system design and installation is more complex than single zone design.

  Single zone system and multi-zone systems are equally vulnerable to load calculation, equipment sizing, duct airway sizing, and air outlet selection errors.

  Comprehensive air-zoning guidance is available.

  Design work peculiar to air-zoning involves zone selection, excess air management strategy and calculations; and if used, bypass duct design.

  OEM's and zone damper vendors provide comprehensive installation instructions.

- From the code point of view (and from the home owner point of view) quality control is a "how do you control human behavior" issue, not a technical issue. In this regard, home owners are culpable, and/or innocent victims.

  They may want the lowest price.

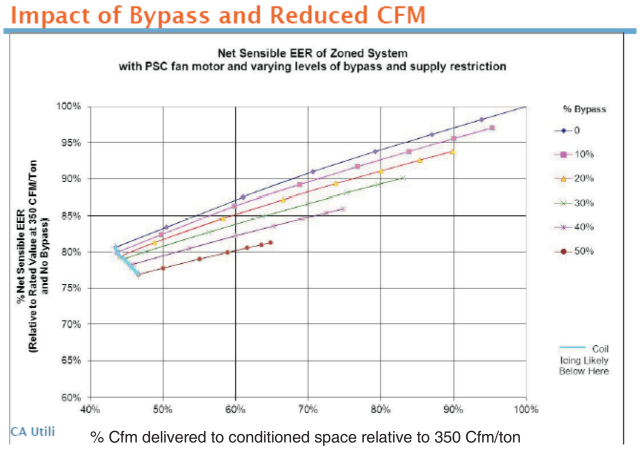
  Even if they do not want the lowest price, they do not know what questions to ask.

12.4 General Comment

The air zoning issue is too complex for the Slide 12 statements. Much more thought and work is required.

Slide 15

Zoned Air Conditioning Model


Impact of Bypass and Reduced CFM

15.1 General Comment

No information about the model's capabilities, sensitivities, and mechanics provided.

It looks the model applies to a compressor and PSC blower operating at one speed.

- Shouldn't bypass air Cfm (per graph notes) plus Cfm delivered to the conditioned space (per x-axis label) equal 100%?
- Why are the bypass air models lines instead of single dots (for example, 20% bypass would have one EER value for 80% Cfm to the space)?

If this slide is consistent with Slide 8 (Sensible Capacity at the Register), EER is defined as supply air Btuh divided by system KW. **See Section 8.1 for comments on this practice.**

If full flow (100% blower Cfm) is 350 Cfm/Ton, and if there is no bypass air, the graph shows that coil Cfm drops to 245 Cfm/Ton at 70% flow, and to 175 Cfm/Ton at 50% flow. Can cooling equipment tolerate this behavior?

- OEM's have a lower limit for the Cfm per Ton value.
- The OEM's low temperature safety limits Cfm/Ton, depending on the operating condition.

15.2 More 350 Cfm/Ton Comments

Why is 350 Cfm/Ton used (for this slide, and through out the presentation)?

- This is an uncommon result for properly sized equipment (typically 400 Cfm/Ton, or more, when expanded OEM data is used to make sure that sensible and latent capacity is compatible with sensible and latent load for the indoor and outdoor conditions on a summer design day).

  A dry climate favors more than 450 Cfm/Ton. Many California locations are very dry, or relatively dry.

  Locations like Charleston, SC, New Orleans, LA; and Mobile, AL favor 400 Cfm/Ton or less, for a colder coil and more latent capacity (not applicable to California).

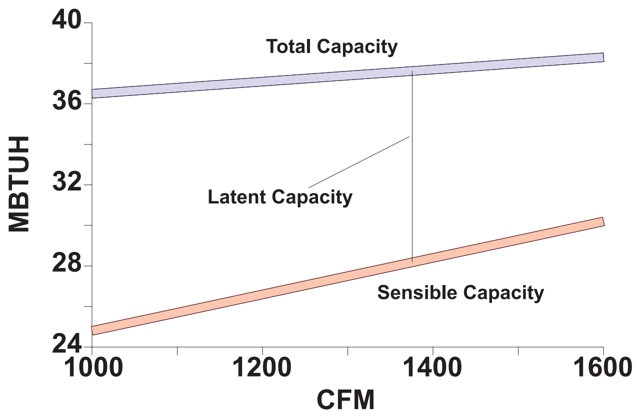
  There may be equipment that cannot operate at 350 Cfm/Ton.

  Low Cfm per Ton translates to a smaller value for maximum bypass air (explained later).

15.2 Cooling Capacity Vs. Blower Cfm Comment

Cooling performance detail varies somewhat, depending on make and model, but capacity vs. blower Cfm tendencies are similar across product lines, as indicated by the following graph .

- Continuous operation with a wet coil.
- For a dry coil, sensible capacity is approximately
- equal to total capacity.
- It would be useful if there was a line for refrigeration cycle power (compressor KW + outdoor fan KW) .
- Blower KW vs. Cfm depends on what causes the Cfm change (change blower speed, or vary duct system resistance at constant speed).



15.3 EER Comments for 0% Bypass

OEM performance data correlates system KW with variations in coil Cfm. For example, refer to the performance data for a York cooling unit (see the attached Excel file).

- The system tab shows cooling performance values for five PSC blower speed settings (Cfm), and for five sets of outdoor-entering conditions (a sub set of the actual OEM data set).

  *Total Capacity per Watt (TC/Watt) generally increases somewhat as blower **speed** and Cfm decrease.*

  *Sensible Capacity per Watt (SC/Watt) generally decreases (a little more than the change in total capacity Watts) as blower **speed** and Cfm decrease (as demonstrated by the preceding graph).*

Conditional Blower KW

OEM performance data notes say that system KW includes compressor KW, outdoor fan KW, **and indoor blower KW**. In this regard, a system KW change due to a blower speed change may not be equivalent to a system KW change due to a duct system resistance change at constant blower speed.

- Compressor KW and outdoor fan KW may not be affected if a blower Cfm change is caused by a blower motor speed change, or by a throttled zone damper.
- If we had blower KW values for each blower speed-Cfm scenario, they could be subtracted from the system KW values.
- Then for a given duct system resistance scenario, blower KW for a Cfm-IWC set could be read from the OEM's blower table, and added to the compressor KW and the outdoor fan KW.
- Then system KW values could be calculated for Cfm-IWC scenarios caused by zone damper movement.

Blower KW for OEM Data

The cooling performance data for the York unit does not provide values for indoor blower KW, but the corresponding blower table has blower KW values, so a rough blower KW value can be subtracted from the system KW.

- Assume the cooling system KW values are for 0.20 IWC of external static pressure (OEM's tend to choose defaults that minimize KW values).

  For 95/80/67, at 1,050 Cfm, the cooling system data shows 3.1 KW. At 1,025 Cfm and 0.20 IWC, the blower table shows 0.158 KW. So the KW for the compressor and outdoor fan is about 2.942 KW.

  For 95/80/67, at 1,350 Cfm, the cooling system data shows 3.2 KW. At 1,370 Cfm and 0.20 IWC, the blower table shows 0.305 KW. So the KW for the compressor and outdoor fan is about 2.895 KW.

  So for 95/80/67, it looks like 2.92 KW (average 2.942 and 2.895) is the compressor and outdoor fan KW.

- The following KW values apply to the compressor and outdoor fan when the math from the preceding bullet is applied to the (95/80/67); (95/80/57); (95/75/57); (85/80/57); and (85/75/57) scenarios.

  95°F OAT, 67°F EWB = 2.92 KW > 2.9 KW
  95°F OAT, 57°F EWB = 2.87 KW > 2.9 KW
  85°F OAT, 57°F EWB = 2.47 KW > 2.5 KW

- OEM data shows that changes in the blower Cfm setting have a very small affect on system KW, and changes in outdoor temperature have some affect (10% to 15% per 10°F) on system KW.

  For 95/80/67, at 1,050 Cfm, the York cooling system data shows 3.1 KW. At 1,350 Cfm, the data shows 3.2 KW.

  the red markers on the Excel spreadsheet's Data tab show similar behavior.

Air Zoning Affects System KW

The primary difference for system KW for single zone vs. air zoning may be due to blower KW, and to cooling coil temperature.

- As far as compressor KW is concerned, outdoor temperature has a similar affect on single zone systems, and air zoned systems.
- Blower power changes as zone dampers operate. Blower power is constant for single zone, constant volume systems.
- Cooling coil temperature affects refrigeration cycle efficiency. Cooling coil temperature depends on zone damper movement, the type of air relief, and the amount of air relief.

Blower KW for the Design Cooling Load

When a one-zone system is compared to multi-zone system, there may not be much difference in blower Cfm for the summer design condition.

- The block load for the conditioned space is used for equipment sizing. This load is the same for single zone systems and multi-zone systems (it takes credit for time of day diversity, if the dwelling has diversity).
- See the Blower tab on the Excel spread sheet.

  Assume the duct system is designed for 1,400 Cfm (based on matching OEM performance data to the sensible and latent cooling loads for 1,350 Cfm capacity data).

Say that the total effective length of the longest circulation path is 400 feet (a reasonable value for straight runs and fittings).

If a single zone constant Cfm system is designed for 0.40 IWC of external static pressure, the airway sizing friction rate is 0.05 IWC/100Ft , which is too low; and there are 413 blower Watts (see cells B18 to E28).

If a single zone constant Cfm system is designed for 0.60 IWC of external static pressure, the airway sizing friction rate is 0.10 IWC/100Ft, which is ok; and there are 530 blower Watts (see cells H18 to K28).

If zone dampers are added to the system, an open zone damper produces an additional 0.10 IWC of resistance (roughly). If the zone damper system is designed for 0.60 IWC of external static pressure, the airway sizing friction rate is 0.08 IWC/100Ft, which is ok; and there are 530 blower Watts (see cells M18 to Q28).

- So at full air flow on a design day, there may be no difference in blower KW (single zone vs. air zoning), but one-zone airways will be sized for 0.10 IWC /100Ft vs. 0.08 IWC /100Ft for zoning.

  Note that it may not be possible to operate at 500 blower Watts, or less, for a one-zone or multizone system. To get to 400 Watts, the total effective length of the straight runs and fittings must be reduced from 400 feet to 250 feet, which may not be possible if the 400 foot value is based on efficient fitting use.

Blower KW Vs. System Resistance

For no air relief measures, blower Cfm decreases, and external static pressure increases as zone dampers close. When this happens, the air power equation provides a theoretical value for blower watts.

$$Watts = 745.7 \times Cfm \times AFR / (6,356 \times EFF)$$

Where:
Cfm = Blower Cfm
AFR = Air flow resistance (IWC)
AFR = External resistance + Internal resistance
  Internal resistance is produced by blower cabinet components, and the entrance and exit resistance.
  $AFR_2 = AFR_1 \times (CFM_2 / CFM_1)^2$
EFF = The net efficiency for the blower and its motor
  EFF is not published with OEM blower data

Actual blower watts may be read from the OEM's blower table. This may not be consistent with the air power equation (assuming the OEM data is correct).

- For example, see the Blower tab on the Excel spreadsheet (for a York blower).

  The table at the top of this page summarizes the York blower data for Watts vs. ESP.

Blower Speed	**External Static Pressure (IWC)**									
	0.2		**0.4**		**0.6**		**0.8**		**1.0**	
	W	Δ	**W**	Δ	**W**	Δ	**W**	Δ	**W**	Δ
L	158	-	175	17	-	-	-	-	-	-
L/M	237	-	260	23	283	23	307	24	-	-
M	305	-	330	25	354	24	377	23	397	20
M/H	-	-	413	-	436	23	454	18	460	6
H	-	-	-	-	530		538	8	521	-17

Note that Watt steps are about 23 KW for 0.20 IWC pressure steps at low to medium speed; but this pattern does not apply to higher speeds.

Note that blower KW changes can be small or negative when the blower is pushed to its aerodynamic limits (presumed reason for erratic performance at high speed).

- Similar, behavior is demonstrated by the blower table for an American Standard blower (see cell O3 on the Excel spreadsheet -- Data tab).
- The blower table for a Lennox multi-speed, direct drive blower (see cell B85 on the Excel spreadsheet data tab) tells a significantly different story. In this case, blower Cfm and watts significantly decrease as external static pressure increases for any blower speed setting.
- So for throttling zone dampers with no bypass air, it looks like the fan power change can be positive (about 0.1 KW per 0.1 IWC for most blower speeds settings), negligible or negative for some higher speed setting), or consistently negative at any blower speed (for the Lennox furnace blower).
- Blower power changes, and the rate of change vs. external static pressure change seems to depend on the product, and the blower speed setting; and the difference in behavior seems to be significant. This requires more investigation.

Compressor KW Vs. Coil Airflow

We are talking about the 0% bypass scenario, so cooling coil temperature tends to decrease as supply air Cfm is throttled; but for no bypass Cfm (or other air relief measures), the effect is similar to reducing blower speed.

- The OEM performance data on the Excel spreadsheet (System tab) shows what happens to system KW as coil Cfm drops, but the values include blower power.
- The discussion at the lower left of the preceding page shows what happens to Compressor power

and outdoor fan power as blower air flow drops from 1,350 Cfm to 1,050 Cfm.

For 95/80/67, at 1,350 Cfm, the cooling system data shows 3.2 KW. At 1,370 Cfm and 0.20 IWC, the blower table shows 0.305 KW. So the KW for the compressor and outdoor fan is about 2.895 KW.

For 95/80/67, at 1,050 Cfm, the cooling system data shows 3.1 KW. At 1,025 Cfm and 0.20 IWC, the blower table shows 0.158 KW. So the KW for the compressor and outdoor fan is about 2.942 KW.

For the York unit, it looks like a 300 cfm drop in coil airflow produces an 0.05 KW increase in compressor and outdoor fan power.

- So for a 22% decrease in York coil Cfm, it looks like Compressor plus outdoor fan power may increase by something like 1%.

  Blower% = (1,350 - 1,050) / 1,350 = 22%
  KW% = (2.924 - 2.895) / 2.924 = 1%

  The red markers on the Excel spreadsheet's Data tab show similar behavior.

15.4 Additional Comments for 0% Bypass

For the upper boundary (the 0% bypass line), it looks like the bypass damper is locked tight, and supply Cfm is reduced.

- The markers imply that supply air Cfm was modulated from 100% to 45%.

  Does the model use a representative model of a PSC blower curve? If so, is it steep? What are the upper and low limits for the approved operating range?

  If PSC performance is modeled, will the duct system operating point stay on the PSC blower curve as zone dampers close?

  Blower curves tend to be fairly steep. It is hard to believe that the operating point stays on the approved part of the blower curve for such a large change in blower Cfm.

- Supply Cfm goes down (significantly), as KW draw goes up (marginally), so % sensible EER goes down. What do we really learn here? Even if the denominator (KW) is constant (best case), making the numerator (sensible) smaller always makes sensible EER smaller.

- The coil is already operating near its low limit at 350 Cfm/Ton at 100% supply air Cfm, then Cfm is reduced.

  The maximum Cfm reduction depends on sensible Btuh capacity per Cfm of flow (B/C ratio).

  Sensible Btuh per Cfm and leaving air temperature depend on outdoor temperature (equipment capacity increases as outdoor temperature decreases).

  Sensible Btuh per Cfm and leaving air temperature depend on coil sensible heat ratio (the worst case is 1.00).

  The maximum Cfm reduction also depends on the OEM's value for low limit temperature (this may range from about 38°F to about 50°F).

- What were the values for the B/C ratio at AHRI rating conditions, the scenario's's outdoor temperature and coil sensible heat ratio, and the OEM's low limit temperature?

- If conditional sensible capacity and limit temperature are modeled, does the leaving air temperature stay above the OEM's low limit all the way down to 45% Cfm?

15.5 EER Comments for Bypass Air

Cooling coil temperature affects refrigeration cycle efficiency. Cooling coil temperature depends on zone damper movement, the type of air relief, and the amount of air relief. Air relief tends to stabilize blower Cfm, and blower KW.

- Bypass air produces a temperature ramp for leaving air (supply air at the coil). This transient will settle to a steady value in a matter of minutes. The settled value must not be less than the OEM's low limit value.

- The maximum bypass air Cfm for a given operating condition depends on sensible Btuh capacity per Cfm of coil air flow (B/C ratio).

  Sensible Btuh per Cfm depends on outdoor temperature (equipment capacity increases as outdoor temperature decreases).

  Sensible Btuh per Cfm depends on coil sensible heat ratio (the worst case is 1.00).

  The maximum bypass air Cfm value increases as the B/C ratio decreases (outdoor air temperature at the condenser gets warmer, and/or outdoor moisture increases the latent load on the cooling coil).

  350 Cfm/Ton at full air flow is not deniable.

- The maximum bypass air Cfm also depends on the OEM's value for low limit temperature (this may range from about 38°F to about 50°F).

- If bypass air is properly managed, the coil temperature will vary from a minimum, to a no bypass air value.

  With proper bypass damper design and controls, the minimum value will never be less than a degree or two warmer than the OEM's low limit value.

  The no bypass value is approximately equal to the single zone value.

Leaving air temperature is momentary event, so the affect on system efficiency must be integrated over seasonal time. A crude scope of work is provided here (for constant speed equipment).

- Define a default cooling season.
- Estimate the seasonal operating hours for a single zone system, and a capacity-equivalent zoned system.
- Estimate the average leaving air temperature for a default cooling season for a single zone system, and a capacity-equivalent zoned system.
- Determine relationship between leaving air temperature and compressor KW.
- Use average leaving air temperatures to compute average compressor KW values for a single zone system, and a capacity-equivalent zoned system.
- Compute and compare the seasonal KWH for a single zone system, and a capacity-equivalent zoned system.

Bypass air tends to stabilize momentary blower pressure and Cfm, and momentary blower KW. So, bypass air, (and other air relief measures) tend to equalize blower KW for a zone damper system vs. a single zone system.

- Bypass air, by itself, may not provide sufficient air management (correct design procedures produce an appropriate set of air relief measures for a given set application details).
- For sufficient air management, momentary zoned blower Cfm and pressure tends to be similar to momentary single-zone blower Cfm and pressure (increased back-pressure caused by zone damper closure is relieved by the air management strategy, and system Cfm is relatively constant).
- So, the primary difference (single zone vs. zoned) in system resistance is the pressure drop for an open zone damper.
- An open zone damper increases the design value for duct system resistance. This tends to increase blower KW, on a seasonal basis if duct airway size is not adjusted.
- If ***Manual D*** is used to size duct airways, the design friction rate for airway sizing will be somewhat smaller for a zone damper system, compared to no zoning.
- A smaller friction rate translates to larger airways for a zoned system, so zoned duct resistance will be comparable to a single zone system (see cells G18 to Q29 on the Excel spreadsheet -- Blower tab).

15.6 Additional Comments for Bypass Air

For the bypass curves, bypass air is incrementally increased from 0% to 50%. Then for each curve, it looks like modulating zone dampers move from some open position toward closed.

- Look at the 50% bypass curve. If 50% of the system air is bypassed, how can the supply Cfm to the conditioned space be greater than 50%? The other curves show the same behavior.
- Is the chart saying that the EER curves for bypass air Cfm are progressively lower than the no bypass curve because bypass air causes a lower coil temperature?
- The coil is already operating near its low limit at 350 Cfm/Ton at 100% supply air Cfm, then bypass air is activated.

  The maximum bypass Cfm value depends on sensible Btuh capacity per Cfm of flow.

  Sensible Btuh per Cfm and leaving air temperature depend on outdoor temperature (coil capacity increases as outdoor temperature decreases).

  Sensible Btuh per Cfm and leaving air temperature depend on coil sensible heat ratio (the worst case is 1.00).

  The maximum bypass Cfm value also depends on the OEM's value for low limit temperature (this may range from about 38°F to about 50°F).
- What were the values for outdoor temperature, coil sensible heat ratio, B/C ratio. and low limit temperature?
- What were the values for the B/C ratio at AHRI rating conditions, the scenario's's outdoor temperature and coil sensible heat ratio, and the OEM's low limit temperature?
- If conditional capacity and limit temperature are modeled, it would have to be very hot outdoors (say 105°F), and the OEM's low limit value would have to be about 38°F to 40°F, for 40% to 50% bypass air with no limit trip at 350 Cfm/Ton.

15.7 Comment on Momentary EER

If air zoning is applied to single speed equipment (compressor and OSC blower), the momentary sensible capacity at the supply air outlets depends on supply air temperature and outlet Cfm, and the momentary equipment KW depends on many variables.

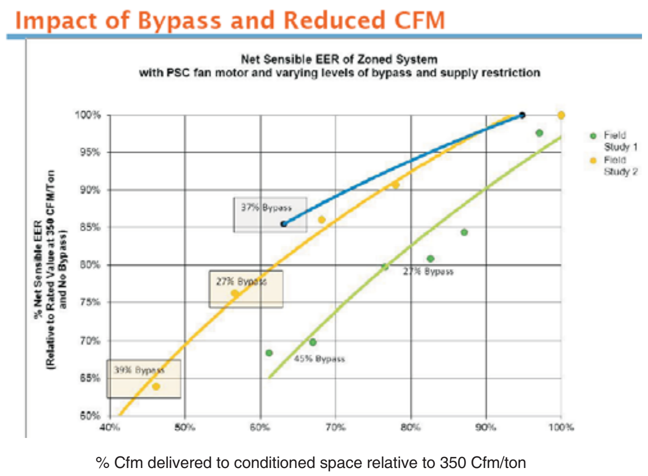
If we are going to compare single zone efficiency with multi-zone efficiency, wouldn't we want to integrate momentary power draw over cooling season time?

$$\Sigma\ KW_i \times HOURS$$

In other words, if both systems provide comfort to the best of their ability (everything sized correctly), compare single zone KWH for the season with multi-zone KWH for the season.

Slide 16

Zoned Air Conditioning Data



16.1 General Comments

The title indicates that this is output from field tests. No information about the test procedure provided.

If this slide is consistent with Slide 8 (Sensible Capacity at the Register), EER is defined as supply air Btuh divided by system KW. **See Section 8.1 for comments on this practice.**

16.2 Understanding the Graph

What is this graph trying to say. Some questions provided here.

- Assume the blue line is for Field Study 3?
- Is 100% Cfm equal to the measured on-site blower Cfm with all zone dampers open, and the bypass closed?
- Shouldn't bypass air Cfm (per graph notes) plus Cfm delivered to the conditioned space (per x-axis label) equal 100%?

  What does "Relative to 350 Cfm per Ton" have to do with it?

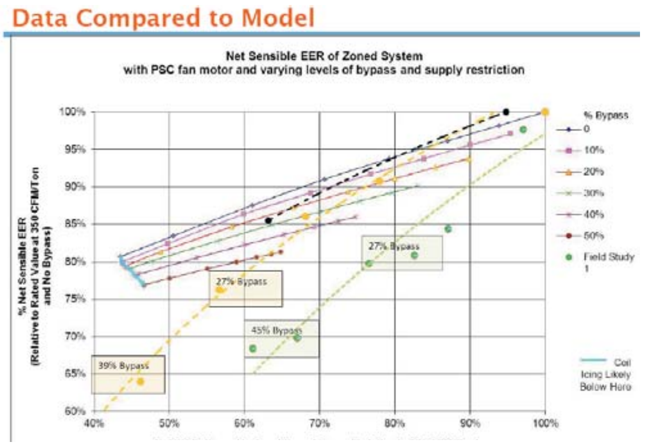
  Was the actual, measured on-site Cfm/Ton equal to, or different than 350 Cfm/Ton?
- There is a blue 37% bypass dot that shows 63% space Cfm and 86% EER; and an orange 39% bypass dot that shows 47% space Cfm and 64% EER.

  If bypass air is about 38%, why wouldn't the space Cfm be about the same for both cases (at 62%)?

  Same issue for the green 27% dot and the orange 27% dot.
- The graph shows the same general behavior as the model, but what else could happen if EER is defined as Btuh at the supply air outlets divided by input KW?
- All the comments for Slides 8, 9, 10, 12 and 15 apply here.

Slide 17

Zoned Air Conditioning



Data Compared to Model

% Cfm delivered to conditioned space relative to 350 Cfm/ton

17.1 General Comments

The model and the tests are not compatible. Which one is correct?

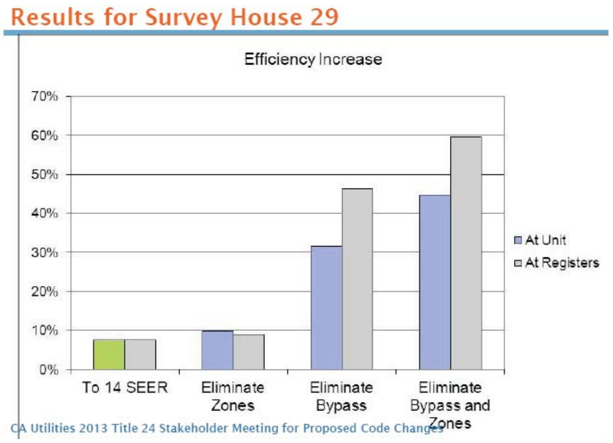
With no explanation for what slides 15 and 16 actually mean, it is not possible to comment on slide 17.

If this slide is consistent with Slide 8 (Sensible Capacity at the Register), EER is defined as supply air Btuh divided by system KW. **See Section 8.1 for comments on this practice.**

All the comments for Slides 8, 9, 10, 12 and 15 apply here.

Slide 18

Zoned Air Conditioning


Results for Survey House 29

CA Utilities 2013 Title 24 Stakeholder Meeting for Proposed Code Changes

18.1 General Comments

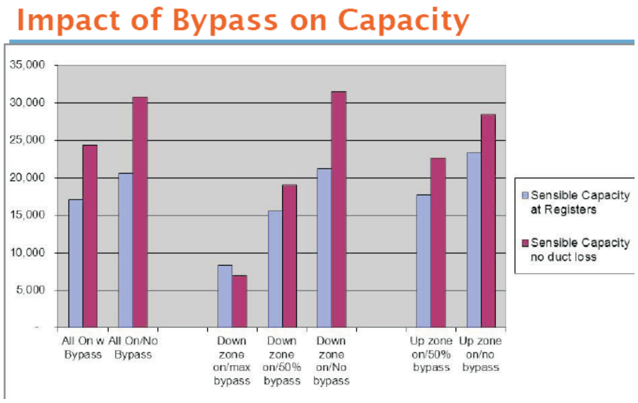
No explanation for the slides, so:

- How is efficiency defined.

  Seasonal or momentary?
  At unit = Total Btuh out / KW in?
  At registers = Sensible Btuh out / KW to unit?
- What does "To 14 SEER" mean? Is this the base case (single zone unit)?
- Wouldn't eliminating zones automatically eliminate Bypass?
- Do not know enough about the graph to comment.

Slide 19

Zoned Air Conditioning

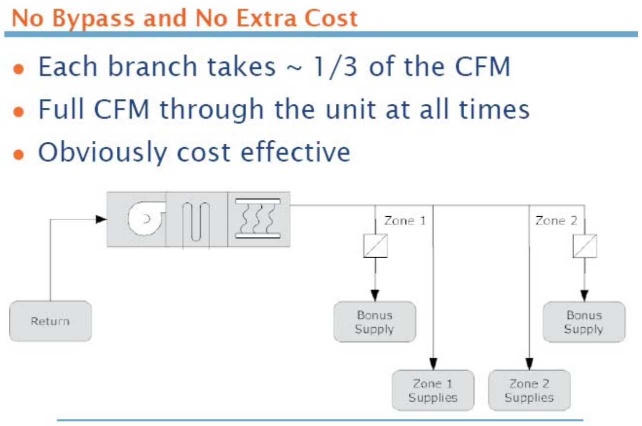

Impact of Bypass on Capacity

19.1 General Comments

No explanation for the slide, so it is not possible to comment on the slide. However; this is the first slide that says something about duct loss, so the complexity of the issues (and the explanation) are significantly increased.

Slide 21

Zonal AC System



No Bypass and No Extra Cost

- Each branch takes ~ 1/3 of the CFM
- Full CFM through the unit at all times
- Obviously cost effective

21.1 General Comments

The Slide 21 solution (Figure 1) shows a duct system that has an undampered supply to each zone, and a dampered supply to each zone. There is no simple way to predict the behavior of this design.

- A zone may not need supply air, but some undetermined amount of supply air will be delivered to the zone (through the undamped supply) when the zone damper is closed.
- The slide says that 1/.3 of the air will flow to the zone that does not need the air (three ducts open, one duct closed, each duct at 1/3 of the blower Cfm).
- How is this going to happen? What are the duct sizing rules (for a particular blower table and set of pressure-dissipating devices, for a particular duct run geometry, and for a particular set of duct fittings); and/or what are the air balancing rules (the slide does not show hand dampers)?
- If a zone thermostat is satisfied, and if 1/3 of the air continues to flow to this zone, how long will it take for zone temperature to drop to an unacceptable level; and how does this transient compare to the time it will take ro satisfy the calling zone thermostat?
- Air outlet performance (throw and noise) depends on make, model and size. Some guidance is need here.
- In general, how can practitioners be sure that the proposed (Figure 1) design will always deliver adequate performance for any operating condition?