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November 28, 2011

Aniruddh Roy
Regulatory Engineer
Air-Conditioning, Heating, and Refrigeration Institute (AHRI)

Subject: AHRI Comments on Residential Zoned Air-Conditioning

Dear Mr. Roy,

Thank you for your comments concerning the revisions to Title 24 for 2013. We appreciate your participation at the meeting with us in Sacramento on August 18, 2011 and your subsequent written comments dated October 31, 2011. We acknowledge the receipt of AHRI and its members' comments and conclude that these comments do not warrant significant changes to the code change proposal.

We have thoroughly reviewed all the documents you have sent us including, but not limited to:

a) AHRI's comments on the use of ACCA Manual Zr in determining the amount of bypass air.
b) *Field Investigation of Carrier Residential Zoning System*. Kenney and Barbour, 1993 NAHB.
c) "Energy Implications of Blower Overrun Strategies for a Zoned Residential Forced Air System" Oppenheim, 1991 ASHRAE Transactions.
d) The presentation of Terry Strack concerning the Canadian Field Test of a new small zoned duct system.
e) Public Service Electric and Gas Company's *August Tip* to close doors and close registers on air conditioning systems.
f) AHRI Comments May 17, 2011.
g) AHRI Comments June 6, 2011.
h) AHRI Comments August 5, 2011.
i) AHRI Comments August 8, 2011.
j) AHRI Comments October 31, 2011.
k) Mr. Foster Comments October 31, 2011.

We have also reviewed the following documents concerning the performance of Residential Zoned Air Conditioning using automatic dampered duct systems:

a) Oppenheim, P. 1992. "Energy-Saving Potential of a Zoned Forced-Air Heating System." *ASHRAE Transactions*
b) Heflin, C. & F. Keller. 1993. "Steady-State Analysis of Single-Speed Residential Split Systems with Zoning Bypass." *ASHRAE Transactions,*

c) Leslie, N., & K. Kazmer. 1989. "Performance of a Residential Zoned Heating System in an Unoccupied Research House." *ASHRAE Transactions*
d) Temple, K. 2005. "Field Performance of a Zoned Forced-Air Cooling System in an Energy-Efficient Home." *ASHRAE Transactions*
e) Levins, W. December 1985. "Experimental Measurements of Heating Season Energy Savings from Various Retrofit Techniques on Three Unoccupied Houses." *Proceedings of the ASHRAE/DOE/BTECC/CIBSE Conference-Thermal Performance of the Exterior Envelopes of Buildings III*. From Heflin and Keller.
f) Levins, W. December 1989. "Measured Performance of Zoning in Single-Family Houses." *Proceedings of the ASHRAE/DOE/BTECC/CIBSE Conference.* Orlando, FL. From Heflin and Keller.
g) Lindeburg, M. 1990. *Mechanical Engineering Reference Manual*. Eighth Edition. Equation 10.66, Page 10-14. Professional Publications Inc. Belmont, CA.
h) Northwestern University. No Date. "Design of Vapor-Compression Refrigeration Cycles." Online document retrieved June 28, 2011 from: www.qrg.northwestern.edu/thermo/design-library/refrig/refrig.html
i) Shen, B., J. Braun, & E. Groll. 2004. "Other Steady-state Tests for ASHRAE Project" in Steady-state Tests1, Section Title: Series V. Ray W. Herrick Laboratories, The School of Mechanical Engineering, Purdue University. West Lafayette, IN.

We also reviewed the documentation supplied by Mr. Foster on the zoned installation in Sacramento and performed a site visit to a second zoned system in Sacramento suggested by Mr. Foster.

We also reviewed your presentation from our meeting at the Commission as well as the results of the survey documented in Proctor, J., R. Chitwood, & B. Wilcox. 2011. "Efficiency Characteristics and Opportunities for New California Homes (ECO)." Prepared for the California Energy Commission, publication pending. Report on Contract Number: PIR-08-019.

Finally, we reviewed the data and results from the three systems tested and reported in Codes and Standards Enhancement Initiative (CASE) Residential Zoned Ducted HVAC Systems 2013 California Building Energy Efficiency Standards by the California Utilities Statewide Codes and Standards Team, August 2011.

After the above reviews we have concluded that:

- Residential Zoned HVAC systems using a bypass from the supply side to the return side of the duct system significantly reduces the efficiency of the air conditioner and reduces the efficiency of the gas furnace, also results in cycling on the limit switch for some of these furnaces.
- Residential Zoned HVAC systems using automatic dampers to reduce the airflow to one or more zones without an equal increase in airflow to the remaining zones results in reduced HVAC system efficiency.

- Reduced airflow and recirculated airflow through the coil are different versions of the same phenomenon, wherein the evaporator coil temperature drops and reduces the capacity and efficiency of the air conditioner.
- Residential Zoned HVAC systems can provide more even temperature distribution and potentially higher comfort than conventional single zoned systems.
- Residential Zoned HVAC systems have the potential of increasing the energy consumption in the home compared to single zoned systems.
- Residential Zoned HVAC systems under special circumstances (a high degree of isolation between zones, without a supply to return bypass, with aggressive set-back/set-up of the thermostat, and with full airflow delivered to the house) have the potential of reducing energy consumption in the home compared to single zoned systems.
- The Energy Commission will need to develop an appropriate method to test full variable speed (not multi-speed) air conditioner compliance with the proposed 350 CFM per ton minimum airflow. This minimum per ton airflow is appropriate for variable speed, multi-speed and single speed air conditioners. Multi-speed air conditioners should be able to use the Title 24 minimum airflow acceptance tests as written.

While major manufacturers have allowed bypasses for a long period, they are also well aware of the issues associated with their use. This is made clear in both their limitations on "Leaving Air Dry Bulb Temperature" and the paper by the senior engineer and director for split system development at Carrier Corporation. This paper (Heflin & Keller) discusses a series of laboratory tests of zoning bypasses on single speed residential air conditioners and heat pumps. The paper shows any amount of bypass (similar to any reduction in airflow) reduces the efficiency of the air conditioner. This paper states:

> "Capacity and EER drop significantly with increasing air bypass for both the air conditioner and heat pump. The capacity and the EER of the air conditioner decreased 47% and 46% respectively with an increase in bypass from 0% to 79% for DOE A test conditions."

Note that the reduction in capacity produces an almost equal reduction in efficiency. This is because the watt draw of the condensing unit changes very little as the indoor coil gets colder. Heflin & Keller, commenting on the field studies by Leslie & Kazmer, Levins, and Oppenheim, noted: "None of the studies employed a bypass duct." The report continues, "Moreover, the fact that the homes were unoccupied and zoning separation (closed doors) was maintained throughout testing caused energy losses to be minimized. Thus the documented field studies could be considered a 'best case scenario' in terms of energy savings." The report states:

> "Without setback/setup schedules, zoned systems typically used more energy than the unzoned systems...."

> "Most of the savings resulted from setback/setup."

Based on the above conclusions we intend to remove the performance compliance credit in Title 24 for Residential Zoned HVAC systems in cooling and not allow supply to return bypasses in any residential HVAC systems subject to the Title 24 regulations.

Our understanding is that there are currently no fully variable speed air conditioners being sold in California's residential HVAC market. The Energy Commission is very interested in working with potential manufacturers to ensure that these systems include a test mode for minimum airflow testing at partial speed, such that the capacity of the system is known at this reduced speed. Please communicate this to your members as appropriate.

Attached, please find detailed comments by our consultant John Proctor, who provided the literature review and technical support for this letter.

Sincerely,

Martha Brook, P.E.
Senior Mechanical Engineer
High Performance Buildings and Standards Development Office
California Energy Commission

Kenney & Barbour

This reference was supplied by the AHRI. It discusses a test of the NAHB Laboratory Test House operated with the following characteristics:

- A single speed blower
- An AFUE 91.5 furnace
- A single speed air conditioning condensing unit
- Five zones (two bedroom zones, one first floor living zone, and two basement zones)
- One of the two basement zones was conditioned in this study.
- When operated in the multi-zone mode, the thermostats in the zones were set up 5°F in cooling and down 5°F in heating during "unoccupied periods." Based on the occupant heat and moisture simulation data, the "unoccupied periods" appear to be: upstairs zone = 14.5 hours, downstairs bedroom zone = 8 hours, downstairs living zone = 11 hours.
- Air returns are present in every zone.

The test showed 34% increase in heating costs when the zoned system was operated with the basement zone conditioned.
The test showed a 29% reduction in cooling energy consumption with zoning and the temperature setpoint adjustments.
The test showed a problem with recovery time when the zones went from unoccupied to occupied (conditioned vs. temperature floating).
The report states:

> "Zoned systems are known to encourage energy conservation. This has resulted in agencies such as the California Energy Commission to provide performance credits for zoned heating and cooling systems."
> "Moreover, zoning can cause higher operating costs if thermostat setup/setback is not used; however, the level of comfort is dramatically increased over the central thermostat."
> "Studies have demonstrated that a multi-zone system will use more energy than a central thermostat system when a constant setpoint is used. A 35 percent increase was documented (Oppenheim 1991) as a direct result of a multi-zone system being more responsive to the cooling needs of the entire house... While there is an increase in energy consumption, a zone system does provide more uniform temperatures and better thermal comfort throughout the house than that offered by a central thermostat." [NOTE: This appears to be a misquote from the 1991 paper. The 1991 paper showed a 21% increase.]
> "Zoning can improve thermal comfort, especially in areas that are underheated or ground coupled. However, increased operating cost is required to achieve higher levels of thermal comfort."

> "Setback schedules can significantly reduce operating costs; however some degree of thermal discomfort should be expected."
> "Only in mild temperatures, outside air greater than 51°F, did the zones recover from the five degree setback. In all other cases, the zones did not recover to 71°F in the allotted two hours."

The cooling savings conclusions of the 1994 study are questionable due to two incongruities in the report. First, there is an unexplained, random distribution of air conditioner efficiency against outdoor temperature for the system operated as a whole house (single zone) system. But in the zoned operation, the study shows a typical air conditioner efficiency pattern against outdoor temperature. The reported efficiency of the unit as a whole house system was substantially lower than when operated as a zoned system in all but the highest temperatures. This is shown in Figure 1 (an overlay of the study's Figures 3.2.2 and 3.2.3).

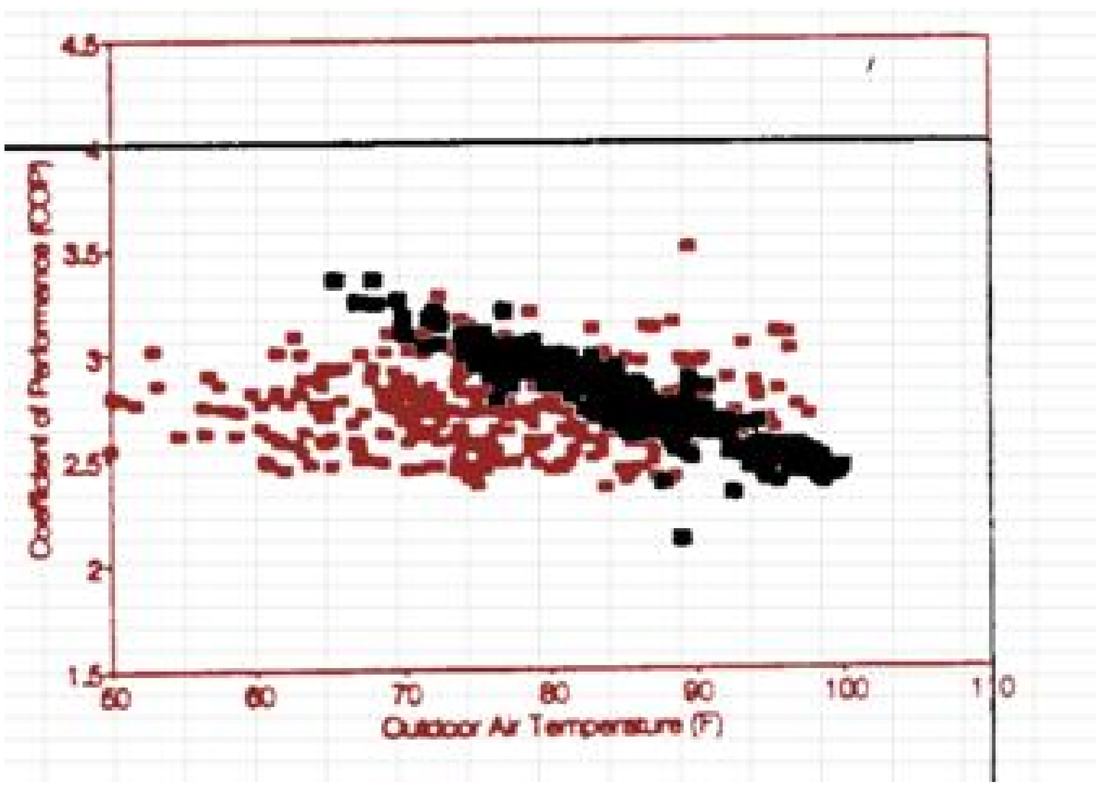

Figure 1. Overlay of AC Efficiency (watts cooling/watts energy consumed) in NAHB study

Whole house single zone operation in red; five zone operation in black

Second, the report states that "both systems experienced approximately the same percentage of hours in each temperature bin." However the graphs in the report show vastly different "Typical Record Year" temperature bins — a statistic that should be identical between the two graphs.

The study reported excess humidity (above 60% Rh) occurring in the zoned configuration twice as often as with the whole house configuration, There were over 400 occurrences in the basement and 130 occurrences in the first-floor bedroom in the multi-zoned configuration compared to 180 and 60 occurrences respectively in the whole house configuration.

Oppenheim

This reference was supplied by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). It discusses a test of the National Association of Homebuilders (NAHB) Laboratory Test House operated with the following characteristics:

- No bypass duct
- A variable speed blower
- A prototype modulating furnace
- A two-speed air conditioner condensing unit
- Three zones for cooling
- The basement was not conditioned.
- The thermostats in the two bedroom zones were set at a consistent 85°F, 15 hours a day every day (this was a set point temperature increase of 10°F for this unoccupied house).
- The first-floor living zone thermostat was set at a consistent 85°F, 9 hours a day every day.
- There is no mention of the presence of returns in the zones. They are assumed to be present since this is the same test house as was used in the Kenney and Barbour study.

The test showed 21% increase in energy consumption when no temperature setpoint adjustments were used.
The test showed a 16% reduction in energy consumption with the temperature setpoint adjustments.

Leslie & Kazmer

This reference discusses a test at a Laboratory Test House in Chicago, Illinois, operated with the following characteristics:

- No bypass duct
- A variable speed blower
- A modulating (variable capacity) 82% AFUE furnace
- A two-speed air conditioner
- Bedroom, common, and basement zones
- When operated in the heating multi-zone mode, the bedroom thermostats were set down 12°F for 10 daytime hours.

- Also when operated in the heating multi-zone mode, the basement thermostat was set down 12°F for 15 nighttime hours.
- Air returns are present in every zone.

The test showed 12% increase in heating energy consumption when the zoned system was operated with the basement zone conditioned.
The test showed a 1% reduction in heating energy consumption with zoning **and the temperature setpoint adjustments**.
The report states:

> "Zoned heating provided superior comfort compared to central heat, especially in the basement. However, the cost of providing this comfort was high."
> "A test of zoning without basement heat showed energy savings during cold weather but not during moderate weather."
> "Modulating the furnace during central heat reduced energy consumption during moderate weather but not during cold weather."

Levins

These two papers addressed severe zoning wherein the returns and supplies were fully blocked off and towels were placed under the doors. Levins concluded: "Temperatures in closed-off rooms floated with the outdoor temperature variations, but no savings were observed in the overall heat pump electrical usage or in the house cooling load."

Heflin & Keller

The authors of this paper were the senior engineer and director for split system development at Carrier Corporation. This paper discusses a series of laboratory tests of zoning bypasses on single speed residential air conditioners and heat pumps. The data from the tests are in Appendix B.
Figure 2 shows the loss of efficiency from recirculating air through a bypass. The left hand axis shows the percentage of efficiency relative to no bypass. The bottom axis displays the percentage airflow providing cooling or heating to the conditioned space. When 50% of the air is bypassed, the efficiency falls to 77% of its full value or a 23% loss in efficiency.
This paper did not present data on the reduction in sensible heat ratio as the amount of bypass increases. It is well known, however, that the recirculation bypass ducts reduce the sensible heat ratio and that the sensible energy efficiency ratio (EER) drops faster than the total EER, as plotted in Figure 2.

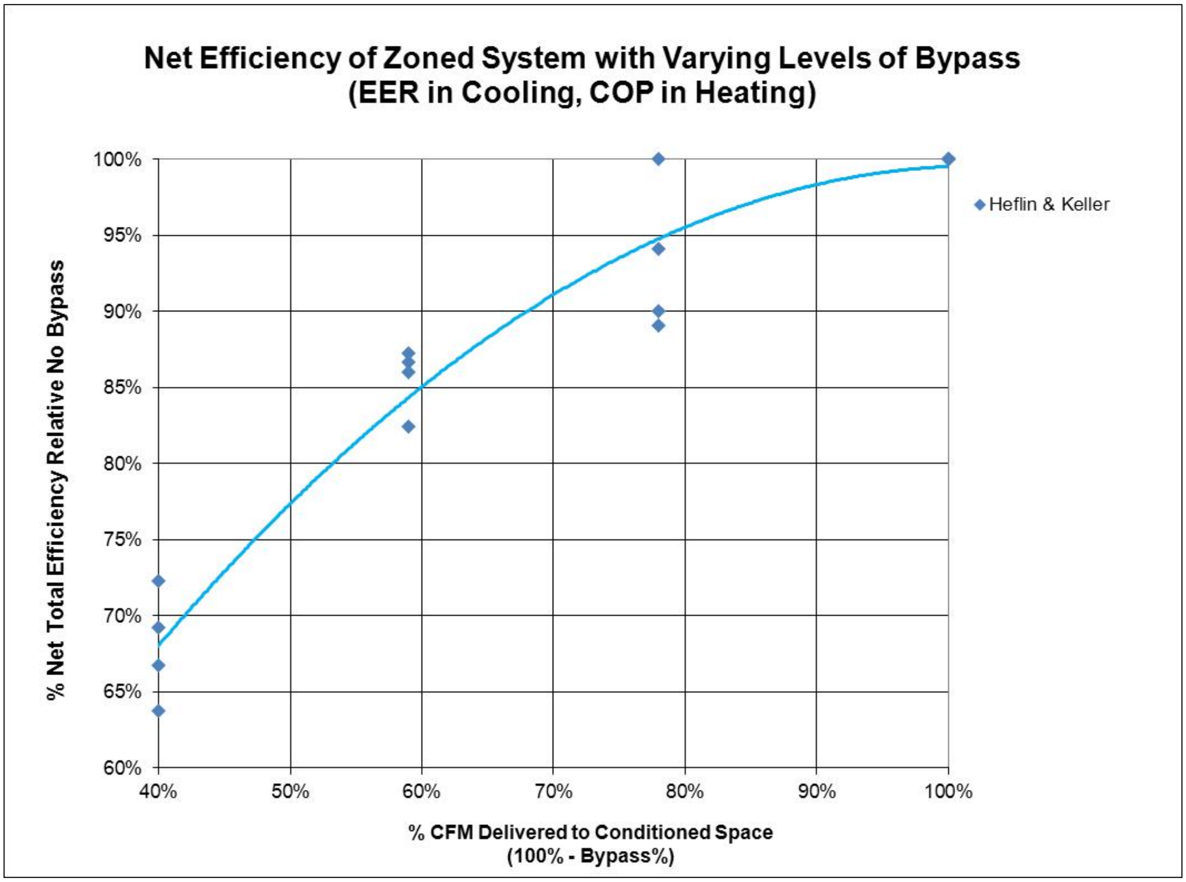

Figure 2. Net Zoned System Efficiency with Bypass (Carrier Lab Data)

This paper states:

> "Capacity and EER drop significantly with increasing air bypass for both the air conditioner and heat pump. The capacity and the EER of the air conditioner decreased 47% and 46% respectively with an increase in bypass from 0% to 79% for DOE A test conditions."

Note that the reduction in capacity produces an almost equal reduction in efficiency. This is because the watt draw of the condensing unit changes very little as the indoor coil gets colder.

Heflin & Keller, commenting on the field studies by Leslie & Kazmer, Levins, and Oppenheim, noted: "None of the studies employed a bypass duct." The report continues, "Moreover, the fact that the homes were unoccupied and zoning separation (closed doors) was maintained throughout testing caused energy losses to be minimized. Thus the documented field studies could be considered a 'best case scenario' in terms of energy savings."

The report states:

> "Without setback/setup schedules, zoned systems typically used more energy than the unzoned systems...."
>
> "Most of the savings resulted from setback/setup."

Temple

This reference discusses a test of a new townhouse in Pittsburg, Pennsylvania, which operated with the following characteristics:

- No bypass duct
- A variable speed blower
- A two-speed air conditioner
- Bedroom, common, and basement zones
- Three zones
- Air returns are present in two zones.

The test showed 6% increase in cooling energy consumption when the system was operated with zoned control.

Rutkowski (ACCA Manual Zr)

Air Conditioning Contractors of America is producing a manual titled "Zoned Comfort Systems for Residential Low-Rise Buildings" (Rutkowski 2011). The manual, which is currently in a public review draft, includes an equation (Figure 3) for estimating the supply dry bulb temperature based on the bypass factor and other operating conditions. The equation assumes a sensible heat ratio of 1.0, which is not achieved in the field. The result is an overestimate of the sensible cooling delivered to the house.
While the equation produces an overly optimistic view of the sensible capacity of an air conditioner operating with a bypass, plotting the results of that equation shows that the reduction in efficiency from a bypass is approximately 31% for a 50% bypass. Figure 4 shows the numbers from that calculation for a 3 ton unit with 1050 CFM through the unit and varying levels of bypass. The results are plotted in Figure 5 and compared to the field data for unit #2.

LDB (°F) = (-17.0 x BPF² -10.5 x BPF + 52.3) + 0.19 x (OAT - 95) + 0.6(EDB₀ - 75) + 0.57 x (28.5 - B/C)*

$$LDB\ (^\circ F) = (-17.0 \times BPF^2 - 10.5 \times BPF + 52.3) + 0.19 \times (OAT - 95) + 0.6 \times (EDB_o - 75) + 0.57 \times (28.5 - B/C)$$

Where:
Cooling coil sensible heat ratio = 1.0
LDB = Settled dry-bulb temperature of leaving air
BPF = Bypass factor under investigation
OAT = Outdoor air dry-bulb temperature
EDB_o = Entering dry-bulb temperature, just before the bypass damper opens
B/C = Btuh per blower Cfm for the AHRI rating condition (total Btuh for a specified blower Cfm at 95°F OAT; 80°F EDB and 67°F EWB)

Accuracy

Figure 7-2 and the settled air temperature equation are for a specific piece of 2010 air-cooled equipment. The

Figure 3. ACCA Manual Equation

% CFM to Residence	100%	90%	80%	70%	60%	50%
BPF	0	0.1	0.2	0.3	0.4	0.5
OAT (°F)	95	95	95	95	95	95

EDB (°F)	75	75	75	75	75	75
B/C	32	32	32	32	32	32
LDB (°F)	50.3	49.1	47.5	45.6	43.4	40.8
Temperature Split (°F)	24.7	25.9	27.5	29.4	31.6	34.2
CFM	1050	945	840	735	630	525
CapS (BTUh)	28,004	26,449	24,925	23,318	21,511	19,389
Relative Sensible Capacity	100%	94%	89%	83%	77%	69%

Figure 4. Inputs and Results from ACCA Equation

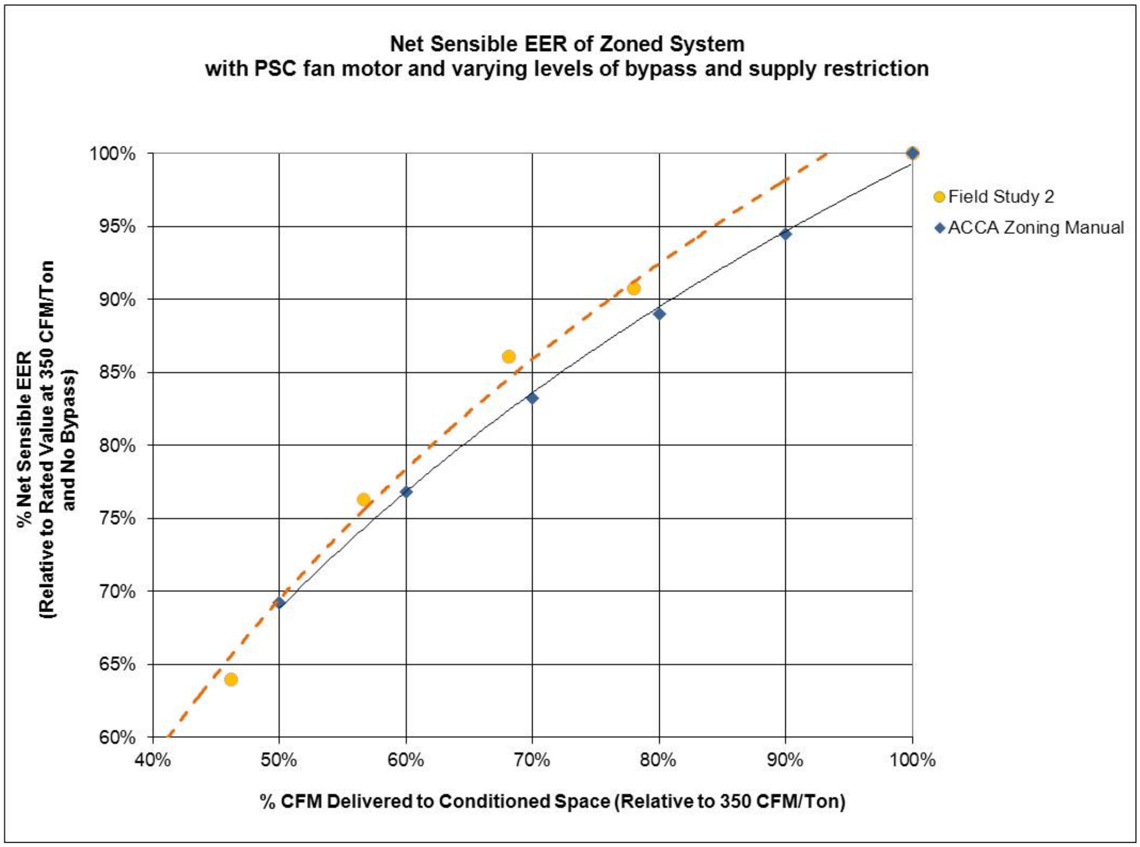

Figure 5. ACCA Manual Z Equation Approximates Field Unit 2

Literature Review Summary

The Heflin and Keller paper illustrates the severe penalty associated with bypass ducts. From the literature review, it is also clear that **even without a bypass duct** and even with modulating furnaces or air conditioners, the savings from zoned systems are far from certain. In many studied cases the energy consumption increases with the use of the zoned systems.

Field Measured Performance of Zoned AC Systems

Rick Chitwood measured HVAC characteristics of 80 new California homes for the Efficiency Characteristics and Opportunities for New California Homes (ECO) project (Proctor, Chitwood & Wilcox 2011). That randomized survey included 10 dampered multi-zoned systems. Nine of the systems were two-zone systems and one was a three-zone system.

As displayed in Figure 6 and Figure 7, the ECO project found that the multi-zoned systems had significantly lower airflow and higher watt draws than single zoned systems. The differences were always significant at the .05 level. The result of the low airflow and high fan watts is reduced capacity and efficiency (both sensible and total).

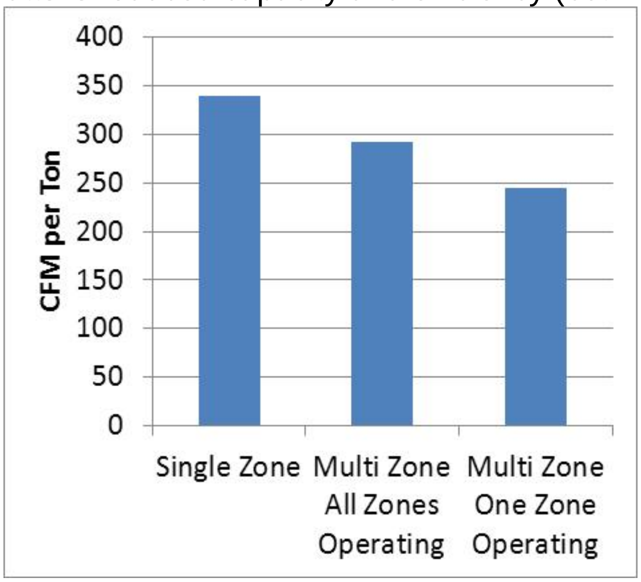

Figure 6. Airflow Reduction with Multi-Zoned HVAC Systems

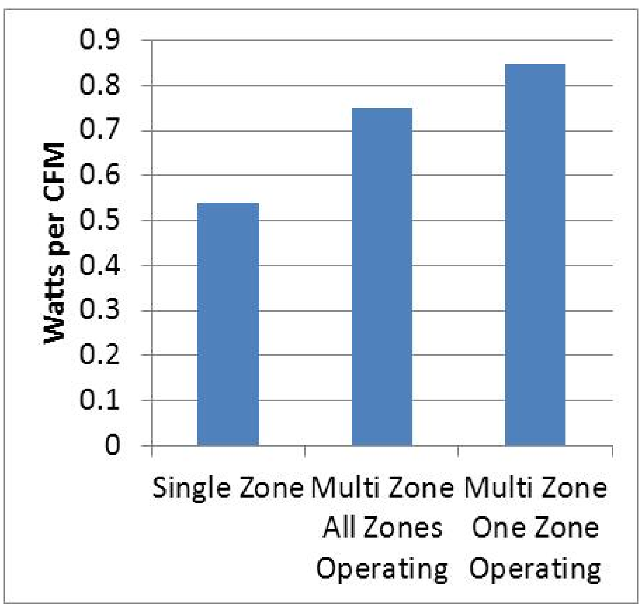

Figure 7. Normalized Fan Watt Draw Increase with Multi-Zoned HVAC Systems

Three of the zoned systems were studied intensively to confirm the energy savings potential. The details of this follow-up investigation are in Section **Error! Reference source not found.**.