

# MEMO

Date: May 24, 2013  
From: Daniel Harris  
To: All Reps  
Subject: **VAV vs. Active Chilled Beams in May ASHRAE Journal**

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Original AHRAE article can be found at this location.

<https://www.ashrae.org/resources--publications/periodicals/ashrae-journal/features/vav-reheat-versus-active-chilled-beams--doas>

The VAV Reheat Versus Active Chilled Beams & DOAS paper published in the May 2013 issue of the ASHRAE Journal covers an HVAC system design competition for a real office building at UC in Davis, California. The systems under evaluation are Active Chilled Beams with Dedicated Outdoor Air (ACB+DOAS), a Variable Air Volume system with Reheat (VAVR) and a hybrid of VAVR and ACB's.

Energy and cost modeling was performed for the three systems and the outcomes were published in the article.

The article concludes that the VAVR system uses 40% less energy than the ACB+DOAS and 33% less than a hybrid ACB+DOAS and VAVR together. The costs analysis shows the ACB+DOAS was \$62/ft<sup>2</sup> compared to \$25/ft<sup>2</sup> for the VAVR system. Both of these conclusions are highly questionable given the success thousands of buildings that have cost effectively used chilled beam technology to lower their operating energy while enhancing IAQ.

The reader does not have to venture far into the paper to discover the reasons for the high first and operating costs of the ACB+DOAS system.

It is interesting that the authors have chosen the primary air flow rate of 0.6 CFM/ft<sup>2</sup> for this analysis, whereas the VAVR system required 0.9 CFM/ft<sup>2</sup>. The ACB design shows a definite misapplication of the technology. Further examination of the building reveals the correct sizing of the primary airflow rate should have been 0.2 CFM/ft<sup>2</sup>. The paper chose (12) 8ft ACB's when the space should have had (4) 8ft ACB's. If the hybrid ACB+DOAS & VAVR system was chosen, this enables further reduction of the primary airflow rate to 0.08 CFM/ft<sup>2</sup>.

Additional reasons to explain the high costs and skewed energy performance are summarized below:-

- The ACB+DOAS supply air mains are sized for a lower velocity of 900 fpm compared to the VAVR system at 2,000 fpm. The reasons for this can only be to inflate the costs of the ductwork in the ACB system.
- 4-pipe ACB's were used, modern designs typically use 2-pipe ACB's with a primary air duct mounted coil to provide zone heat.
- The high primary air flow temperature of 63°F results in higher primary airflow rate further pushing up the energy costs.
- The paper had clearly used low performing ACB's thus pushing up the quantity and airflow rates.

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- There was no mention of energy recovery in the DOAS unit and the ACB system was constant volume primary air.
- The analysis was done with a district cooling system negating the benefits of a medium temperature water system with waterside economizers and higher efficiency chillers.
- The ACB+DOAS had a ducted return where the VAVR does not.
- Figure 10 in the paper is somewhat misleading in assuming that ALL zones are at part load at the same time. This does not happen in practice and the paper over estimates the energy savings of the fans.

This analysis has put the worst possible scenario ACB system against an unrealistic VAVR system. There should not be a battle about which system is the “winner” here in this analysis.... We are firm believers that Chilled Beams do not spell the end of VAV; in fact there are many projects (this building being analyzed being a perfect case) where the two technologies when combined together correctly provide the best energy saving, capital cost and IAQ. We feel the analysis provided in this paper and the miss application of both the VAVR and ACB system has intentionally skewed the facts of what is both practical and sensible in HVAC design.

Feel free to share your comments at this public forum on LinkedIn.

[http://www.linkedin.com/groups/Article-in-May-2013-ASHRAE-4421993.S.240903431?qid=803d7c67-94f8-4541-b847-f555b9661dc0&trk=group\\_most\\_popular-0-b-ttl&goback=%2Egde\\_4421993\\_member\\_240903431%2Egmp\\_4421993](http://www.linkedin.com/groups/Article-in-May-2013-ASHRAE-4421993.S.240903431?qid=803d7c67-94f8-4541-b847-f555b9661dc0&trk=group_most_popular-0-b-ttl&goback=%2Egde_4421993_member_240903431%2Egmp_4421993)

The following pages contain a detailed response and analysis of the above summary:

## **The VAV versus Active Chilled Beams + DOAS Debate. May 2013 Issue of the ASHRAE Journal.**

The VAV Reheat Versus Active Chilled Beams & DOAS paper published in the May 2013 issue of the ASHRAE Journal covers an HVAC system design competition for a real office building at UC in Davis, California. The systems under evaluation are Active Chilled Beams with Dedicated Outdoor Air (ACB+DOAS), a Variable Air Volume system with Reheat (VAVR) and a hybrid of VAVR and ACB's.

Energy and cost modeling was performed for the three systems and the outcomes were published in the article.

### Unusual Design Parameters

The reader does not have to venture far into the paper to expose the reasons for the high first and operating costs of the ACB+DOAS system.

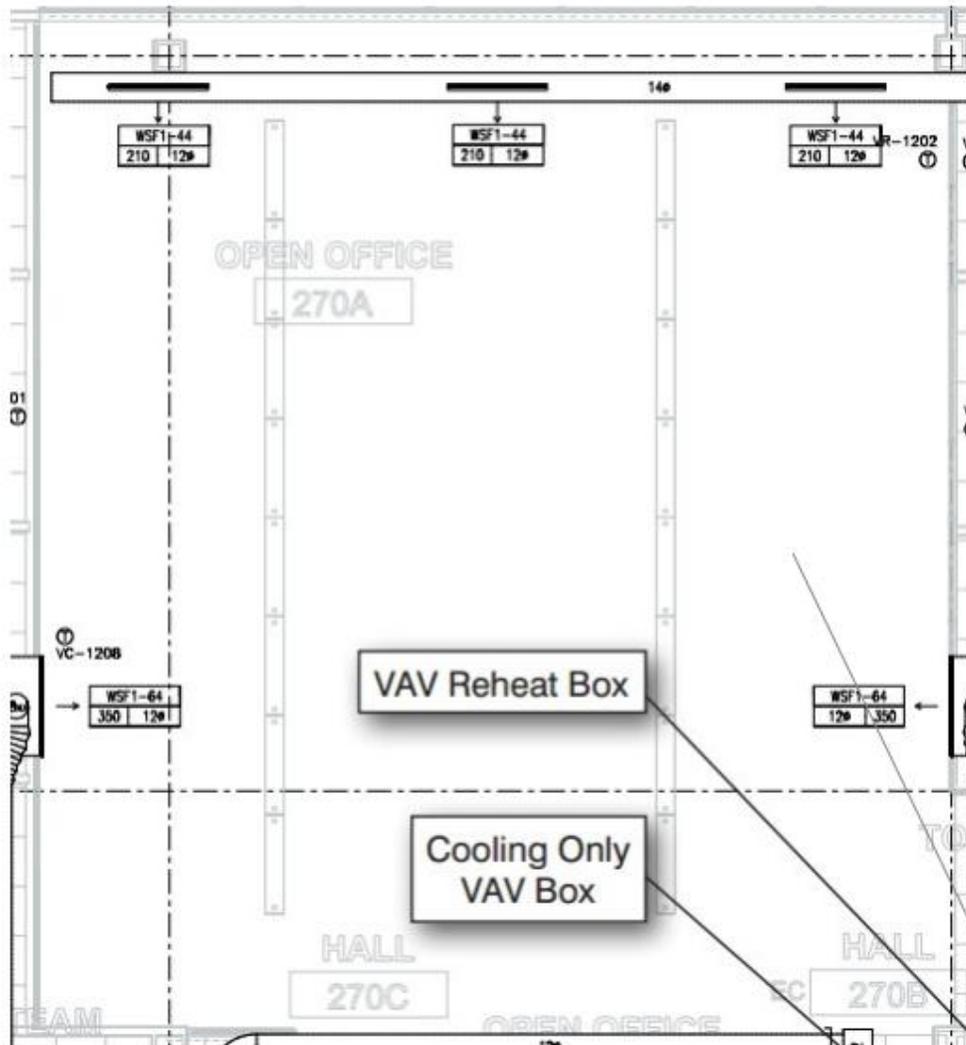
It is interesting that the authors have chosen the primary air flow rate of 0.6 CFM/ft<sup>2</sup> for this analysis. Such a high primary airflow rate is not typical for a building of this type. The high primary airflow rate is the root cause of the outcomes of this paper.

Typical chilled beam system designs are based on primary air system reduction of 65-70% compared to VAVR. This is one of the reasons that chilled beams have been proven to save energy by transferring cooling capacity from the air side to the more efficient water side system.

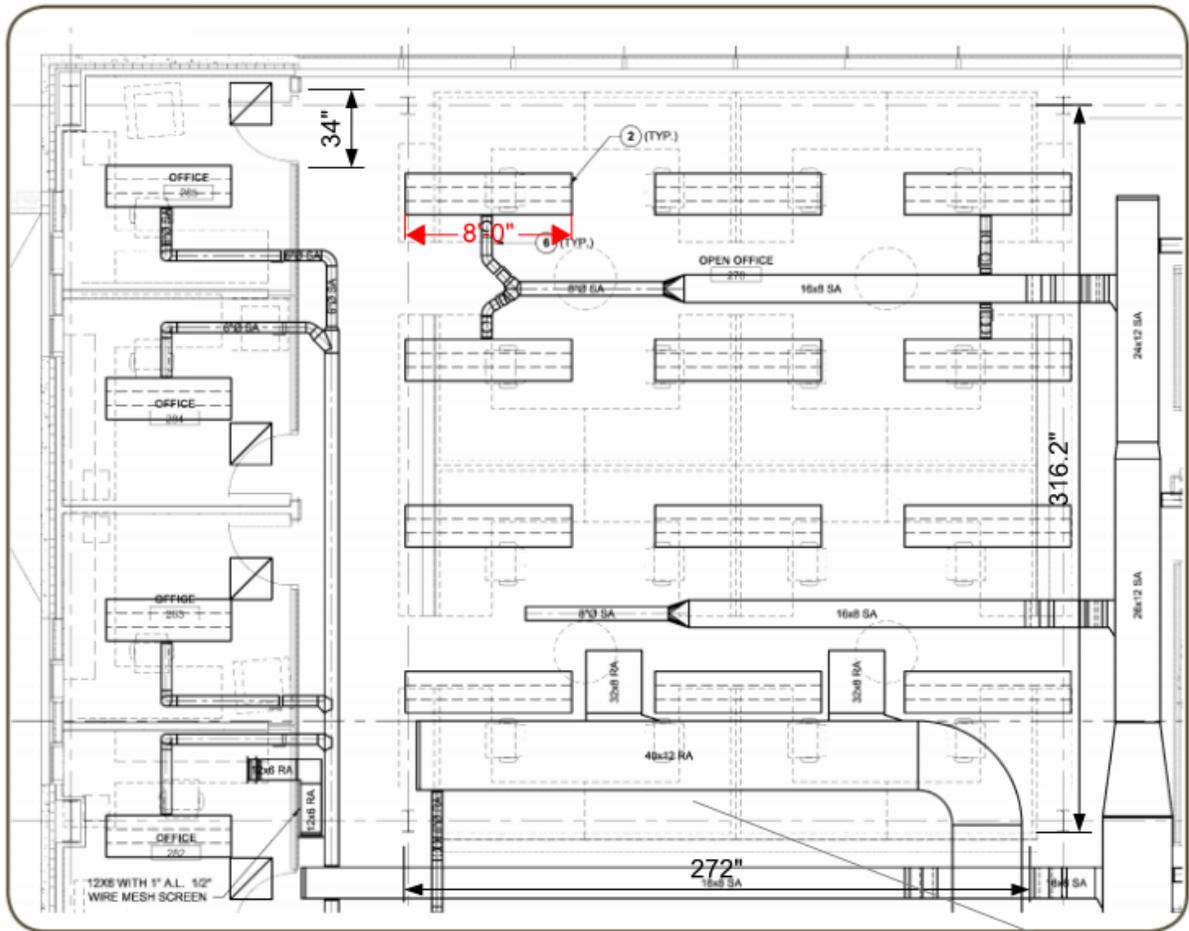
It is therefore unclear why in this paper the authors have utilized 0.6 CFM/ft<sup>2</sup> (ACB+DOAS) that can clearly be designed with approximately 0.2 CFM/ft<sup>2</sup>, suggesting a misapplication of the ACB design.

### Comparison Using Typical ACB Design Parameters

The typical floor plan shown of the subject building comprises an open plan office space. Perimeter diffusers were used for the VAVR system and a (12) 8ft long ACB's were used in the designers Chilled Beam configuration as shown below. There are some considerable errors in the ACB design layout and sizing. Had this system been designed with typical ACB design parameters, only (4) 8ft long ACB's @ 85 CFM are required to meet the load and provide adequate air distribution to the open plan office, as opposed to (12) 8ft long ACB's. This results in a total primary airflow rate of 340 CFM (0.2CFM/ft<sup>2</sup>) for the zone as opposed to 1,330 CFM (0.8 CFM/ft<sup>2</sup>) that the VAVR system requires at peak load. This 75% reduction in primary air flow rate is typical of a properly applied, well designed ACB system. To further reduce energy consumption, application of VAV units can be used to lower the primary airflow during part load conditions.



Total floorplate VAVR airflow = 1330 CFM  
Cooling load =  $1330 \times 1.08 \times 20 = 28728$



**Cooling Load = 1330 x 1.08 x 20**  
**= 28728 BTUH**  
**4 x 8' long chilled beams @ 85 CFM (340 CFM)**  
**= 26% of VAVR Airflow**

The paper claims that part load for this office building is 40% of the peak load, therefore the zone VAVR requirement would be 532 CFM (40% of 1,330 CFM) compared to 340 CFM for a constant volume ACB design, almost 65% more airflow than the ACB primary airflow rate. However, if we consider delivering the primary air to the beams using variable volume, the ACB primary air system can be turned down to the ventilation rate (120 CFM or 20 CFM per person). This again brings primary airflow of the ACB system down to 26% of the part load VAVR design.

Using the occupancy density rate of 275 ft<sup>2</sup> per person as shown in the paper, there would be approximately 6 people and a latent load of less than 1,200 BTUH (including infiltration) for the 1,600 ft<sup>2</sup> sample zone. This can be accomplished with just 90 CFM of ventilation air with a moisture content of 49.7 gr/lb if the room humidity is allowed to rise to around 54% RH.

If we now compare apples with apples, we can see that in reality the ACB+DOAS system should have been sized for a maximum primary airflow of 0.22 CFM/ft<sup>2</sup> instead of 0.6 CFM/ft<sup>2</sup>. If the beams are supplied with VAV primary air, the system could turn down to ventilation rate during part load condition which is around 0.08 CFM/ft<sup>2</sup>.

Why has the ACB+DOAS system been designed with such an unusually large primary air system and why is the design so expensive? These are difficult questions to answer without examining the design documents, but there are some clues in the paper which are discussed below:-

### The use of 4-pipe chilled beams

For a given primary airflow rate, 4-pipe chilled beams deliver far less cooling and heating capacity than 2-pipe. The result is more chilled beams and/or more primary air is required to satisfy the cooling loads. Modern designs typically use 2-pipe chilled beams and heat the primary air with duct mounted zone coils which significantly reduces pipework costs.

### The use of 63°F primary air

Warmer primary air results in more chilled beams and/or higher primary airflow rate for a given cooling load due to the lost cooling contribution from the primary air.

When combined, these factors have a significant impact on first cost and efficiency. The typical floor zone would require around 500 CFM or 0.31 CFM/ft<sup>2</sup> using 4-pipe beams and 63F primary air, the air could still be turned down with VAV but a significant portion of the ACB benefits are lost using these design parameters.

### Low Performance Active Chilled Beams

There is a possibility that the ACB+DOAS design was laid out with low performance European design active chilled beams. Some of the European manufacturers offer compact chilled beams with low density coils that are not suitable for use in some USA buildings. These beams are designed for the European market where sensible loads are generally lower. When used in the USA, this style of beam sometimes requires far more primary air to drive the induction process to achieve the space sensible loads.

So clearly the ACB+DOAS system first costs in the competition design will be higher. The paper claims a 240% premium. This is not typical, most modern chilled beam designs compare favorably with VAV systems although some have a premium of up to 10-15%. Over budget chilled beam designs are usually caused by using 4-pipe beams, oversized primary air, overzealous control design, high chilled beam density or the bidding mechanical contractor's unfamiliarity with the system.

### Some other issues/omissions were found with the paper

#### **There is no mention of using energy recovery on the ACB+DOAS.**

*"A primary airflow rate of 0.3 cfm/ft<sup>2</sup> is about the lowest possible with an ACB+DOAS system to meet latent loads with the primary air and the sensible loads with the chilled beams."*

Incorrect statement. The latent loads are identical for all 3 systems. The latent loads come from people occupancy and infiltration so they are the same for all systems. If the author is trying to imply that that the humidity must be more tightly controlled in the building with chilled beams then this would only be partly factual, in reality most chilled beam systems are designed to allow the room humidity to drift up to around 55% RH with the chilled water temperature being selected accordingly.

*"In economizer conditions, the ACB+DOAS design also has higher mechanical cooling loads because it does not have an air economizer while the VAVR design does have an air economizer and thus benefits from economizer free cooling."*

If the VAVR system has an airside economizer can the ACB-DOAS system have one?

### Condensation

ACB systems have a proven track record of safe operation without condensation occurring on the coil. This can be achieved with minimal controls. In fact the VAVR system is just as likely if not more likely to have condensation occurring on the 55°F un-insulated sections of duct or diffuser plenums as they are exposed to what is likely more humid ceiling plenum air with little air circulation. The coil in the ACB has an entering chilled water temperature of 57°F and as the water travels through the tubes it continues to pick up heat, increasing the surface temperature of the tubes and fins. The coil tubes and fins are continually washed with 75°F room air ensuring less

chance of condensation occurring on the coil than on un-insulated sections of the primary air system in the VAVR system.

### Duct sizing

There should be similar duct sizing velocities for all three options. Using less than half the duct velocity for the ABC option is inconsistent. The Hybrid system should have been sized with the same duct sizing velocities as the VAVR system to keep a fair comparison.

### It's not VAV vs. ACB

There should not be a battle about which system is the “winner” here in this analysis.... We are firm believers that Chilled Beams do not spell the end of VAV, in fact there are many projects (this building being analyzed being a perfect case) where the two technologies when combined together correctly provide the best energy saving, capital cost and IAQ. We feel the analysis provided in this paper and the miss application of both the VAVR and ACB system has intentionally skewed the facts of what is both practical and sensible in HVAC design. We would encourage your feedback and discussion on this topic via your preferred channels. There is an interesting discussion that is taking place at the following linked in thread.

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## **Holistic HVAC Design, Segundo Services Center, UC Davis, CA. April 2013 Issue of the ASHRAE Journal**

The May 2013 Article comparing ACB+DOAS with VAVR raises even more questions when read alongside an article published in the previous month of the ASHRAE Journal, “Holistic HVAC Design, Segundo Services Center, UC Davis, CA” which covers the benefits of an ACB+DOAS design of a completed building with metered energy results and came second place in the ASHRAE Technology Awards. Some points worth mentioning are below:-

- Hybrid VAV and Chilled Beam Design
- 2-Pipe chilled beam used on the perimeter, VAV on the interior
- 100% Outdoor Air (DOAS)
- Primary airflow rate 0.5 CFM ft<sup>2</sup> with VAV turndown to ventilation rate
- Heat recovery used on the DOAS
- Demand control ventilation used
- High performance building envelope
- Metered electricity and steam use
- The overall building height was reduced, reducing the construction costs which more than offset the additional first costs of the HVAC system
- Metered electrical energy consumption 38% of 90.1-2004 baseline and significantly lower than the energy model produced for the building
- LEED Gold Building