Chilled beams or variable air volume?

It seems the era of energy efficient building has brought with it a trend in HVAC design, where technologies that have been in use for years such as variable air volume (VAV) are being passed over in favour of new technologies such as chilled beams. EcoLibrium® speaks with proponents of both technologies to get a better picture of the market.

**EcoLibrium®**: John, you have written a paper for this issue of EcoLibrium® about VAV systems (see page 22) standing the test of time. How have you come to this position?

**Smeed**: Most but not all the VAV systems I have designed have been dual conduit systems, avoiding reheat penalties. I consider that such VAV systems provide numerous favourable characteristics that are absent in typical chilled beam commercial office building system designs, including competitive capital cost; excellent dehumidification and secondary air movement; code complying, energy beneficial minimum outside air quantity; outside air ‘free cooling’ cycle and simple smoke hazard management, while providing economical individual office temperature control and the flexibility to provide layout change for tenancy variations.

VAV also avoids extensive pressure water piping directly over tenanted spaces. The chilled beam system with obvious fan energy benefit over a well designed VAV system appears to offer no technical or likely life cycle cost justification for its application.

**EcoLibrium®**: Barry, your company supplies technology for both systems. What do chilled beams offer that VAV systems cannot?

**Abboud**: The main benefits are four fold. Chilled beams provide superior comfort conditions over VAV systems. Chilled beam systems operate for equivalent cooling capacities delivered using 25-30% of the air quantity a VAV system must deliver for maximum cooling (lower fan energy). They do this more efficiently (ie. use less energy; a plus for the environment), and potentially reduce the ‘overall building construction cost’ in terms of $/m² of nett lettable area.

**EcoLibrium®**: Brian, your firm has used both technologies frequently. What is your experience with chilled beams?

**Schmidt**: In 2000 in Brisbane, we recognised the immense benefits of chilled beam application from a theoretical point of view. We converted our board room to passive chilled beams and experimented extensively with settings over the next few years. This involved manipulation of chilled water supply temperature, condensation control and comfort experiences over a wide range of circumstances.

Subsequently, a further quasi-experimental application of passive chilled beams was designed for the new offices of architects Donovan Hill. Both remain in successful daily operation.

The first real commercial application was at the Kelvin Grove campus of the Queensland University of Technology (QUT) in their Institute of Health and Biomedical Innovation (IHBl) building. This multi-level research facility of offices and laboratories surrounding an open atrium is completely cooled by passive chilled beams (approximately 8,000m²).

There were two attributes that drove this decision and have since been validated — lowest possible energy costs and highest possible air quality.

**EcoLibrium®**: Wayne, you’ve had success with a hybrid VAV system. What advantages does it offer?

**Ryan**: VAV systems offer flexibility in design and application, simplicity in commissioning and servicing, deliverance of the highest quality standards of air conditioning and lower energy usage than chilled beams.

This is supported by actual measurement of fan, cooling and heating energy on two refurbished floors of a 10 level building in Adelaide and with energy modeling performed with thermal analysis software (TAS) on the same building and in which a VAV, active chilled beams with code minimum outdoor air rate and a passive chilled beam with 100% improvement on code minimum outdoor air rate were compared. The chosen VAV system for the refurbishment is 20% more efficient than the chilled beams and has demonstrated that together with
lighting and appliance upgrades 20% better than five star ABGR whole building is achievable.

The chosen VAV system comprises induction VAV (IVAV) connected to an air handling unit configured with the Shaw Method of Air Conditioning, which the consulting engineers, System Solutions, refer to as a hybrid VAV system.

EcoLibrium®: Why have VAV systems fallen out of favour, particularly in relation to sustainable building projects?

Smeed: Possibly due to market pressure to reduce cost, the air conditioning industry in Australia has come to commonly accept as ‘standard industry practice’ a VAV design approach that, in a single duct VAV system configuration, with extensive use of reheat and fan assisted VAV boxes tend to negate the original design logic of the generic VAV system. As a result, we have a situation which has justifiably led to VAV falling from favour when energy efficiency is applied as an important criterion in HVAC system choice.

The prime misconception is that such a ‘standard industry practice’ VAV design is identifiable with the original, energy efficient VAV design concept when it has become commonly degraded to little other than a variation to the terminal reheat system concept rather than a genuine VAV system.

Ryan: There are common misconceptions about VAV systems including cold air dumping, poor air circulation particularly during heating and VAV turndown, energy inefficiency due to high potential for simultaneous cooling and reheat and spatial limitations.

With retrofits, however, spatial limitations are seldom an issue and for new buildings the current practice is to reduce sensible cooling loads through better building design, hence air conditioning ducting can be minimised such that the marginal difference in ceiling space requirements for VAV and chilled beams is very low if any at all. All of these misconceptions have been overcome with the hybrid VAV.

EcoLibrium®: John, you believe there are some common design and application errors in VAV systems that adversely impact on energy efficiency. What are they?

Smeed: The errors that adversely and unnecessarily affect energy efficiency in VAV systems are the use of ‘constant volume’ supply air outlets such as air-light troffers which limits the turndown, without ‘dumping’, to approximately 50% design flow rate, whereas VAV air outlets can satisfactorily turndown to less than 25% design flow rate with the attendant loss of available fan energy savings.

Secondly, the application of fan assisted VAV boxes to compensate for the lack of constant volume type outlet turndown; using low efficiency fans and imposing fan energy penalties that negate the logic of the VAV concept.

Thirdly, the application of low quality, low cost ‘flap damper’ type VAV boxes, the operation of which is problematic and contributory to unsatisfactory operation in conjunction with the use of constant volume outlet, in preference to the use of available and more expensive, but technically sound, VAV boxes plus proper VAV outlet or the use of self-actuating VAV outlets.

Finally, the extensive application of reheat to simplify zoning arrangement of ‘single duct’ VAV systems that characteristically operate as a ‘terminal reheat’ system with reduced reheat penalty through reducing air flow rate.
I do not think this is true. A low energy building in what applications do chilled beam systems feature work best in my experience, which is mainly in a Schmid: VAV systems in energy efficiency? work best? In these instances, do they always outperform known technologies and could also be referred to as 'state of the hybrid IVAV system I’ve described embraces adaptation of shift is required to deliver energy efficiencies, however the Ryan: knowledge to assist in delivering the right outcome at the consequence of our social perceptions, and some marketing Abboud: appropriate. I think that the use of the term 'state in providing tenants with the 'latest system' is a marketing system for no other reason than seeing commercial benefit Smeed: these tend not to be commercial CBD. is readily achieved without high technology ingredients, but these tend not to be commercial CBD. Schmidt: I do not think this is true. A low energy building is readily achieved without high technology ingredients, but Smeed: Justifying the application of a particular HVAC system for no other reason than seeing commercial benefit in providing tenants with the 'latest system' is a marketing matter not engineering. I think that the use of the term 'state of the art' in the air conditioning industry is too often used when ‘different from current practice’ would have been more appropriate. Abboud: There is an element of this, which is more a consequence of our social perceptions, and some marketing push. However, nothing beats good systems and applications knowledge to assist in delivering the right outcome at the right cost. Ryan: This has been driven by a perception that a ‘paradigm shift’ is required to deliver energy efficiencies, however the hybrid VAV system I’ve described embraces adaptation of known technologies and could also be referred to as ‘state of the art’. EcoLibrium®: In what applications do chilled beam systems work best? In these instances, do they always outperform VAV systems in energy efficiency? Schmidt: A well encapsulated environment makes chilled beams work best in my experience, which is mainly in a sub-tropical climate such as Brisbane. The critical issue of humidity control to eliminate condensation risk is difficult in EcoLibrium®: What have chilled beams become so widely adopted in low energy projects?

Abboud: There have been a significant number of buildings calling for ratings of 4.5 star ABGR and higher. Chilled beams deliver this outcome with greater margin than VAV systems, and importantly have proven to deliver such outcomes with ease. In addition, there is an element of prestige in designing, installing, commissioning and marketing a chilled beam project.

Moreover, once committed to a chilled beam concept some developers are attracted by the prospect of lower slab-to-slab heights, enabling them to deliver more nett lettable areas for similar façade costs — hence the $/m² nett lettable area expression I used earlier. Lower slab-to-slab dimensions are less likely with high efficiency VAV systems (such as five star ABGR VAV systems) due to the larger ductwork infrastructure requirements for VAV systems.

EcoLibrium®: There seems to be a view that ‘state of the art’ is better in low energy building design. How has this come about?

Schmidt: There is no doubt that beam mechanical costs are I would expect beams to typically use 30% less energy than VAV.

Abboud: Active chilled beams will always outperform VAV in the perimeter zones. Said another way, the greater your room heat loads the greater the energy saving. One needs ‘value’ engineering in their systems in keeping with the overall building needs.

Digressing a little, my company sees great value opportunities in the use of hybrid systems, such as active beams in the perimeter, and optimised VAV in the centre zones.

Schmidt: I think that too often there is an assumption that the only possible system options are VAV and passive chilled beam. Each application should also be tested against active chilled beam, multi zone, single zone, VRV, etcetera. Most buildings have features which favour one system over others.

EcoLibrium®: What are the cost implications of chilled beam versus VAV?

Smeed: There is currently an extraordinary difference in capital cost between the application of VAV and chilled beam systems. Indicative 2006-7 comparative NFA rates for substantial, multi-storey commercial office building air conditioning appear to be approximately $430/m² for chilled beam system and $250/m² for VAV.

In the 20 storey, 20,000m² NFA example considered in my paper (see page 22), after ensuring that the chilled beam values were favourably considered so as not to weight comparisons in favour of VAV, the capital cost differences were so great that even extreme extension of the payback period could not provide a favourable life cycle cost for the chilled beam system compared with VAV.

Schmidt: Beams cost more at present than VAV, and there are several reasons for this. Over time I expect the difference to reduce.

However, analysis I have done which account for the savings in riser or air handling room size, less façade and less acoustic treatment, frequently result in the initial total capital cost being similar. If not, in particular cases simple payback is achieved well within normally accepted economic benchmarks.

Abboud: There is no doubt that beam mechanical costs are higher than VAV. Earlier, I touched on the prospect of beams delivering a ‘lower building cost’ when expressed in terms of total building cost $/m² nett lettable. This expression is important.

Going further, a cost — benefit analysis and ‘total life cycle’ analysis is what good business decisions should be based on. The benefits of higher revenue streams far outweigh costs. For example, good tenant comfort leads to happier tenants, leading to less churn, and a higher rental income stream. This is coupled with the prospect of more nett-lettable area being available per floor plate, and potentially per building envelope.

More importantly, tenants are seeking buildings with lower environmental footprints, and are willing to pay for it.

EcoLibrium®: When designed ‘properly’, how do chilled beams compare with VAV systems in energy efficiency?

Schmidt: I would expect beams to typically use 30% less energy than VAV.
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Smeed: I do not believe that what has come to be accepted as ‘standard industry practice’ in VAV design is what should be accepted as a ‘proper’ VAV design. I would suggest that a VAV design that avoids the errors mentioned earlier can be treated as a ‘proper’ VAV design and I consider that such a system can readily offset the chilled beam fan energy advantage when analysed on a total annual cost or life cycle cost basis.

Ryan: In March this year, the South Australian Government commissioned the energy modeling of a number of air conditioning systems on an existing government owned building, with a net lettable floor area of 14,500 square metres.

A hybrid IVAV system was found to be 18% more efficient than the modeled passive chilled beam system, with this calculation supported through actual measurement of fan, cooling and heating energy?

Abboud: As indicated early, it’s conceivable to design a five star ABGR with both systems, but for projects requiring higher energy efficiency than five star ABGR, chilled beams come into their own.

EcoLibrium®: How does each system fit within the Green Star and AGBR environmental rating schemes? Is one given preference over the other?

Abboud: The Green Star program has highlighted main areas it considers important. It’s a commonly held view that it is not perfect, but it has done a wonderful task in encouraging debate and pursuit of better designs.

I don’t believe one system is given preference.

Smeed: In observing that a Green Star rating point is given for doubling the minimum code outside air quantity requirement, I would suggest that to give credit for imposing an energy penalty can only logically be viewed as indirectly showing a technically unjustified preference for the chilled beam system and in so doing, masking the chilled beam design concept deficiency of requiring higher than necessary minimum outside air quantity for its operation.

Unless one argues that AS1668.2 minimum outside air requirements are unsound, the awarding of a Green Star point for use of excess minimum outside air is certainly unwarranted and is considered an anomaly that should be corrected when next the Green Star system is reviewed.

Schmidt: An energy rating such as AGBR is one component of a Green Star rating. Neither VAV nor chilled beam is given any preference, but the results of proven energy models are published to achieve ratings.

Ryan: Six points are available for five star ABGR and an additional three points for each 20% improvement. The IVAV hybrid system will achieve three points more than chilled beam systems and these points more than offset those additionally claimed for chilled beams such as IEQ-1 ventilation rates. The hybrid system can also gain a credit point under IEQ-15 Mould Prevention because this requirement can easily be incorporated without any energy penalty.

EcoLibrium®: Besides energy efficiency and financial considerations, are there any other benefits to either system?

Ryan: The hybrid system I have described provides other benefits such as easily accommodating occupancy CO2 measurement and control strategies; an integrated economy cycle; static pressure resetting control strategy based upon system demand; reduced cooling tower water and chemical usage due to 50% cooling reduction and a 15 to 25% peak electrical load reduction.

Abboud: Chilled beams offer three distinct advantages — efficiency, potentially lower building cost ($/m² nett lettable area) as discussed, and superior comfort.

According to ASHRAE, comfort is a combination of temperature control, humidity control and good air flow in the occupied zone. Once you have good air flow (0.125 – 0.25 m/s) then the ASHRAE comfort ‘envelope’ applies, and people should feel comfortable at room set points of say 24°C.

Chilled beams, specifically active chilled beams, deliver this delicate balance of good air flow (in fact it is fixed at design), temperature control (secondary cooling coil) and humidity control (primary cooling from central AHU plant).

VAV systems by their nature vary the air flow to satisfy room cooling loads, and consequently, humidity control is compromised, and the air flow could drift lower than 0.125m/s.

When this occurs, occupants will not feel as comfortable at 24°C room set point, hence why many buildings operate at approx 22°C throughout the year, yet we all know what this does to our room loads, and consequent fan power and energy consumed. The consequences are increased cost, and more energy.

Schmidt: Chilled beams do offer other benefits. Air quality and ceiling space have already been mentioned, and ongoing maintenance is another benefit. A disadvantage of beams is ready availability and Australian content, generally.

Smeed: It should be noted that after decades of substantial applied research invested in providing quantifiable means of achieving and measuring effective air movement within air conditioned space such as Air Diffusion Performance Index (ADPI), which have become well accepted as fundamentally important in terms of ‘comfort’ and indoor air quality, we know that their sound incorporation into a system design achieves excellent IAQ and ‘comfort’ results in the air conditioned space. A well designed VAV system will meet all of these air movement design criteria.

However, in the application of chilled beam systems to commercial office building comfort air conditioning, we have a design approach which completely disregards these air important air movement design criteria.

If one accepts those design criteria to be valid and valuable, the chilled beam system departure from proven air movement design techniques presents a logical basis for questioning the virtues of such a system design for commercial office building air conditioning in Australia.