# Designing personal micro-climates with workstation based air conditioning

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## ABSTRACT

Thermal comfort and indoor air quality have been the two most important perceptions of occupant satisfaction in US BOMA surveys since 1988 [1]. Due to the prevalence of open floor plans and the wide variety of thermal comfort preferences in an office, there is little hope that a 'one size fits all' approach is available.

Much has been made of the use of 'task' air conditioning to provide some degree of individual comfort control and to improve air change effectiveness. This paper discusses workstation-based microclimates and proposes methods of incorporating workstation based air conditioning into new and refurbished buildings. As a form of conclusion, there is a comparison of two installations and associated feedback from users.


## BACKGROUND

Modern offices often have an open-plan design, with almost all office work performed in a common, open space. The reasons for choosing open-plan designs include providing efficient and direct contacts among members of a team and catering for flexibility[2]. Open-plan offices also allow for a very efficient use of space.

The recent Future@Work Report by Wesley Corporate Health is an exemplary work. It outlines a series of items that workplaces can adopt to improve their productivity, not the least of which was providing temperature control to individuals [3].

Wyon (1996) estimated that providing ± 3°C of individual temperature control would increase work performance by 3% to 7% [4].

While these sources quote 'individual temperature control', it is the author's assertion that that the correct term is 'individual comfort control'. Adjusting the air temperature primarily affects the heat loss mechanism of convection (i.e. the body's ability to lose heat through convection).

Individual comfort control can be provided through various options. This paper is concerned about the use of the workstation to deliver conditioned air in a manner that permits adjustable direction and volume. It is the subtle air movement and improved convection heat transfer coefficients that create a powerful method of heat loss through convection.


Figure 1 The concept is to bring a portion of conditioned air down through a duct to an adjustable diffuser built into the workstation.

Disclaimer: – While the author was involved in the original development of UCI Task Air, it is worth noting that the work was purchased and there is no financial relationship between the author and any manufacturer. It is also worth acknowledging the contributions made by several other design consultancies such as NDY and Umow Lai to the development of an understanding of personal micro-climates.

At the time of writing, there were three Queensland-based suppliers of workstation air conditioning – UCI, QBI and Green Air.


Figure 2 A study of a Government office floor highlighting the wide variety of comfort experiences.

## THE HEART OF THE MATTER

A disadvantage of open plan offices is the 'thermostat war'. People have a wide variety of preferences for their thermal environment, subject to their clothing, fitness levels and diet (particularly alcohol and coffee intake). These 'non-technical' aspects of thermal comfort create challenges for HVAC plant to provide a space with no complaints.

The operative temperature (OT) is commonly considered the average of indoor temperature (ti) and the mean radiant temperature (tr). A calculus equation for operative temperature (OT) is based on the relative influence of heat exchange through convection and radiation with the surrounding environment.

$OT = \omega tr + ( 1 – ) ti$ [°C].

ω is a proportion coefficient based on air velocity (v = 0.05m/sω = 0.55; v = 0.25m/sω ω= 0.40). Hence, as a result of the research coming from heating-focused climates, we have often described OT as the "average of radiant and air temperatures". However, in cooling-focused climates (where airflow is higher), the significance of the indoor temperature is 25% more significant.

This OT equation is a distraction unless it is informally re-interpreted as follows:-

*For humans, in winter, control of radiant heat is a more effective comfort mechanism when air velocities are low, vice versa, raise air velocities and convection becomes a more significant comfort mechanism (i.e. for summer).*

The heart of the matter is that in a single temperature environment, such as open plan offices, the goal of accommodating the differences in people's preferences may be achieved most effectively through provision of adjustable air movement.

## PRODUCTIVITY AND THERMAL COMFORT

Seppanen, Faulkner, Fisk [5] presented a formulae for decrease in occupant performance caused by increases in operative temperatures. The % decrement in Productivity is represented as P (%) and indoor operative temperatures as OT. The formulae presented is as follows:

$P(\%) = (2x\ OT) – 50$

This is translated as 2% decrease in productivity for every 10°C rise in operative temperature above 25°C.

Whilst these are average values, the curve below portrays the result of work by Tan, Kosonen [6] on comfort analysis for different work tasks (typing and thinking).

The conclusion drawn is that warmer offices will affect some tasks such as typing, filing etc greater than they affect thinking.

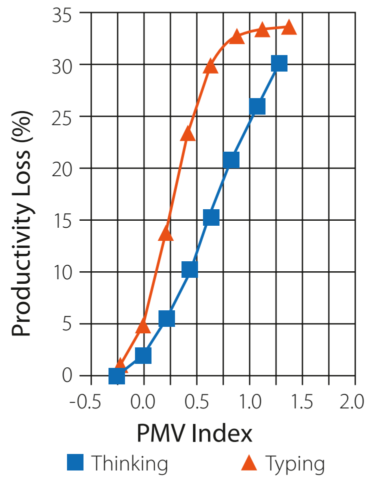



Figure 3 The graph quantifies a correlation between productivity and the thermal comfort indice PMV.

## PRODUCTIVITY AND AIR QUALITY

A disadvantage of open plan offices is the increased risk of sharing air-borne illnesses [7].

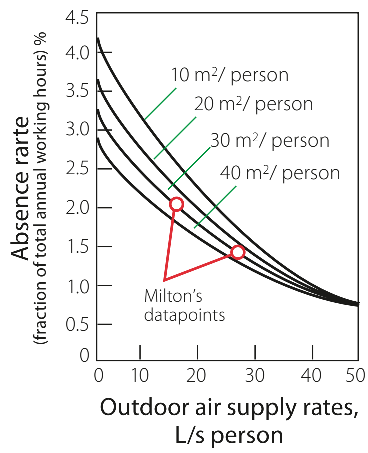



Figure 4 The increased density that open plan offices allow, tend to increase the absence rate. This is portrayed in the image above.

The relationship between ventilation rates (outdoor air supply rates) and respiratory diseases is indicated in the literature reviews [6,7,8], and is further supported by the theoretical model of airborne disease transmission [9]. Low rates of supplied outdoor air (and therefore low rates of dilution of bacteria) have been shown to result in a higher prevalence of respiratory diseases [6,7,8].

Often the majority of short-term absences are caused by respiratory diseases. According to Milton et al. [9], the prevalence of short-term sick leave by office workers was 50% higher with a lower ventilation rate of 12 L/s/p than it was with 24 L/s/p.

The work of Sepanen, Fisk reported a similar relationship between indoor air quality and productivity – 1-3% performance increase for every 10L/s/p increase, which peaked in significance at 15L/s/p but diminished to negligible effect by 45L/s/p.

## ENERGY AND INCREASED VENTILATION RATES

In general, increased ventilation rates represent increased HVAC energy consumption. Therefore technologies that bring about the benefits of increased ventilation rates while mitigating the energy penalties are highly desirable.

One key strategy for achieving this is to preferentially ventilate the breathing zone. Air diffusion systems that feed fresh air directly into the breathing zone either through a raised floor or a workstation will achieve this.

The parameter that measures the extent to which air is preferentially fed into the breathing zone is air change effectiveness (ACE).

## AIR QUALITY AND AIR CHANGE EFFECTIVENESS (ACE)

ASHRAE (1997) defines air change effectiveness as :-

$$ACE = \frac{\tau_n}{\tau_{avg}}$$

Where

$\tau_n$ represents the nominal time constant for fresh air in the space and where

$\tau_{avg}$ represents the average age of air in the breathing zone.

Faulkner, Fisk, Sullivan, Lee [10] tested desk based fresh-air delivery using mannequins and tracer gas and reported ACE values ranging between 1.4 and 2.7. The implication is that 10L/s delivered through their desk set-up will achieve the same breathable air quality as 14-27L/s/p delivered through well-designed conventional systems.

One of the other important conclusions from the Fisk et al is that increasing ventilation rates through the increasing velocities detrimentally affected ACE through increased mixing.

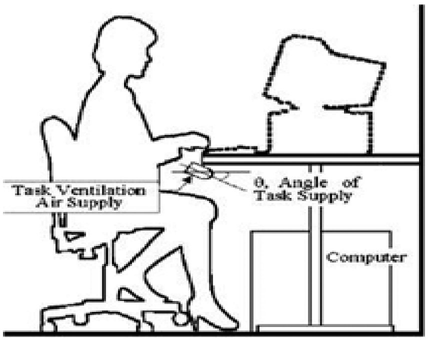



Figure 5 The image above is the test situation; which was the basis of Fisk's experiments.

The configuration above is slightly different to the workstation systems commercially available in Australia (refer to the image below). In the workstation (refer Fig. 6), cooled fresh air is delivered via a vertical blade to a horizontal plenum, in which diffusers are placed. In the workstation (refer Fig. 7), cooled fresh air is delivered via a pipe to a plenum, in which diffusers are placed.

CFD modeling (discussed later) portrayed a similar range of ACE values to those derived by Fisk.

Figure 6 In this workstation, cooled fresh air is delivered via a vertical blade to a horizontal plenum, in which diffusers are placed.

Figure 7 This system uses a ducted system distinct from the workstation

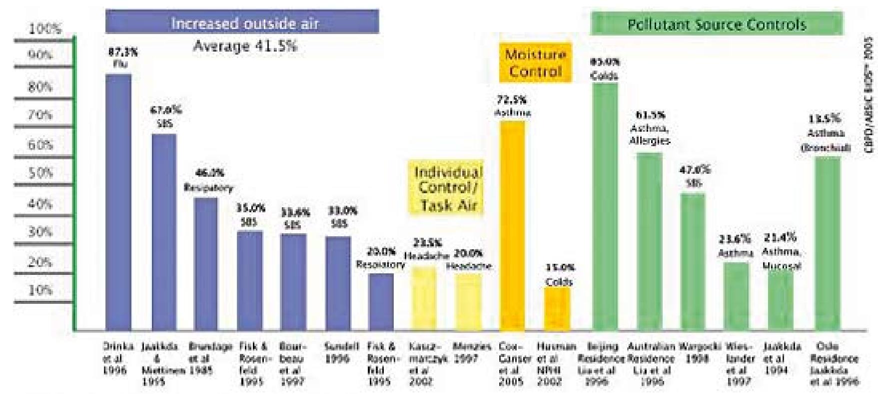
## PRODUCTIVITY IMPROVEMENT OPPORTUNITIES USING WORKSTATION AIR CONDITIONING

In the US Green Cities 2007 Conference, Jerry Yudelson presented the following Carnegie Mellon research into health gains from providing increased fresh air and individual control.

It is worth pointing out that the different strategies (increased outside air, task air, control and pollutant source controls) affected different health issues and that no one silver bullet is evident. In a July 2005 paper provided to UCI Interlink by this author, a design method was presented which utilised a combination of the above strategies including:

- Increased ventilation rates
- Individual control / task air
- Moisture control

In response to the Carnegie Mellon research and the GBCA Green Star Rating Tool Office Design V2, this method has been improved by the inclusion of pollutant source exhaust systems.




Source: Carnegie Mellon University Center for Building Performance, 2005

Figure 8 Carnegie Mellon literature review portraying the % reductions in health symptoms associated with various HVAC measures.

## DESIGN OF WORKSTATION AIR CONDITIONING (WAC)

It is easy to mistakenly consider WAC as a spot cooling system. That is understandable but it is an erroneous comparison. A key difference is that a spot cooling system is often the sole ventilation system with sufficient cooling power to generate a significantly more comfortable microclimate. WAC is more subtle – it is an extension to the air conditioning system that allows an individual to modify their local comfort primarily by modifying the air movement experienced on their skin. It only attempts to provide some local comfort control for people sitting at their task. Hence comfort consists of two layers – an ambient comfort level (sufficient for tasks where occupancy is transient) and task comfort (suited for individual taste and for long durations).

The key feature is that the supply of air through the WAC is used to meet the metabolic sensible and latent heat loads experienced by the occupant at desk level excluding ambient heat. This means that the WAC only caters for sensible and latent heats generated by metabolism. The ambient system caters for the provision of sensible heat or cooling to maintain ambient comfort.

| TASK LIGHTING | TASK AIR CONDITIONING (WAC) |
|---|---|
| Task lighting generally requires ambient lighting as a supplement. | Task air generally requires ambient air conditioning as a supplement. |
| Task lighting can reduce energy by reducing the intensity of ambient lighting. | Task air can reduce energy by reducing the intensity of ambient air conditioning. |
| Task lighting is only about adding light — you cannot make a space darker than the ambient by operating task lights. | Task air is only about adding cooling — you cannot make a space warmer than the ambient by operating task air. |
| Task lighting without an ambient lighting system produces discomfort (i.e. through contrast). | Task air without an ambient comfort system produces discomfort (i.e. through contrast). |
| Task lighting is provided to cater for the differences in people and the tasks they need light for. | Task air is provided to cater for the differences in people and their comfort preferences. |
| Task lighting is often providing light well above minimum levels of lighting. | Task air is often providing cooling and ventilation well above minimum levels for thermal comfort. |

Conceptually, there are many similarities between task air conditioning and task lighting. This is a helpful comparison.

It is apparent that a HVAC engineer needs to simultaneously consider comfort at both the task level and the ambient level for the WAC to be successful.

Heating can be provided through a task air system but it must be recognised that the occupant who wants additional cooling and air movement in summer will not appreciate any extra heating in winter. Therefore to avoid the occupant continually adjusting their diffuser during mild seasons it is suggested to have supply air temperatures remain at or just below 24°C in cool months for those perimeter zones in climates where heating has a dominant season.

## 'PLUG AND PLAY' DESIGN CONSIDERATIONS

'Plug and play' is meant to describe a level of design typical of fit out, where many variables governing ambient comfort design are already fixed.

For plug and play installation, the following approach is recommended:-

- Select 5L/s per diffuser and two diffusers per seat.
- Plenum pressure should be in the range of 8 Pa +/ – 1.5 Pa.
- Check supply air temperatures will not deviate between the range of 12°C and 24°C.
- 15°C is the ideal air temperature. This caters for 60W of cooling.
- Allow at least 1°C increase in both summer and winter set-points.
- Educate the users at the time of installation about the benefits and operation of the system.
- Check that the facility manager is aware that the cleaning of the internal surfaces is undertaken as part of the typical duct cleaning regime. Suggested method is to wipe surfaces with detergent.
- Ensure each flexible duct run has a spigot.

## 'ENGINEERED DESIGN' CONSIDERATIONS

Engineered design is meant to describe a level of design typical of new purpose-built buildings, where many variables governing ambient design can be adjusted.

The first step in designing any of the above systems is to determine the ambient conditions and the required task air quantity to ensure comfort in both the transient spaces and at the workstation. The ambient conditions can range between 25 and 27°C, it is important to start from a condition which will allow the task air system to improve conditions at the workstation.

The following are suggested design principles that should not be ignored:

1. If people are to have genuine control, the air supply temperature and pressure must not modulate but be kept constant. This provides the workstation diffuser with full authority over the comfort experience.
2. Cooling capacity 'per person' should match the metabolic load generated 'per person'. Hence, the internal latent loads should be satisfied by the dehumidified task air supply. The temperature difference and air flow rate should cool the averaged sensible heat from metabolism only. The ambient system accounts for the other internal loads.
3. The diffusers should be within arm's reach and vary the direction and strength of airflow.
4. In low metabolic rates (such as sitting at desks), velocities in excess of 0.5 m/s are unlikely to be considered comfortable for extended durations and should not form the basis of design or PMV calculations. Short durations of higher velocities may be acceptable (e.g. when people first arrive at work or from a higher metabolic rate activity).
5. Diffuser height should align with chest height and should avoid eye height.
6. Ambient comfort design range should be within 0.5 PMV of the task air PMV.
7. As task air generally provides cooling, the warmest comfort level is that provided by the ambient system. It is therefore appropriate to allow a slightly warmer ambient space (suggest 1.0°C warmer). This will diminish cooling energy but increase heating energy. With this consideration, it may be that an internal zone with low levels of radiated lighting energy may be completely served by task air. Those who prefer it warmer can accept the warmth of ambient conditions by turning off their task cooling.
8. The range of ambient thermal comfort seems to be between 0 PMV and +1 PMV to achieve a task comfort range of – 0.5 and +0.5PMV.
9. Surface temperatures in close proximity of desk occupants ought to be within 3.0°C of ambient air temperatures to diminish risk of radiation asymmetry. That is, surface temperatures ought to be between 28°C and 22°C to ensure comfort.
10. To increase air quantities per person, it is best to consider adding diffusers instead of increasing velocities.

In summary, it is a particularly useful comfort technology for zones which always require convective cooling (regardless of weather outside). Such zones include internal zones (all over the world) and perimeter zones in tropical and subtropical climates.

Care must be taken when locating task air alongside perimeters in heating-focused climes, particularly perimeters with substantial glazing. The variation in perimeter comfort caused by surface temperatures must be compensated by the ambient comfort system or the architecture.

## PROPOSED WAC DEHUMIDIFICATION

While the workstations are generally designed for disassembly and manual cleaning, it has been considered that using a dehumidified air supply is essential for long term hygiene, particularly in humid environs.

The proposed HVAC scheme from the new EPA Marine headquarters built by the Port of Brisbane is portrayed in Figure 9. The outside air is pre-dried and pre-cooled by an enthalpy wheel before entering two types of cooling. The first coil portion of CC01 uses 'warm' chilled water and is used to control leaving air temperature. The second coil portion of CC01 uses 'cold' chilled water and is used to control leaving air dew point. The final treatment is a sensible wheel that raises air temperature to 17°C and ensures a maximum duct RH is below 80%.

The WAC is used to supply sufficient dry air to control space humidity below 60%RH. If designed correctly, it will also

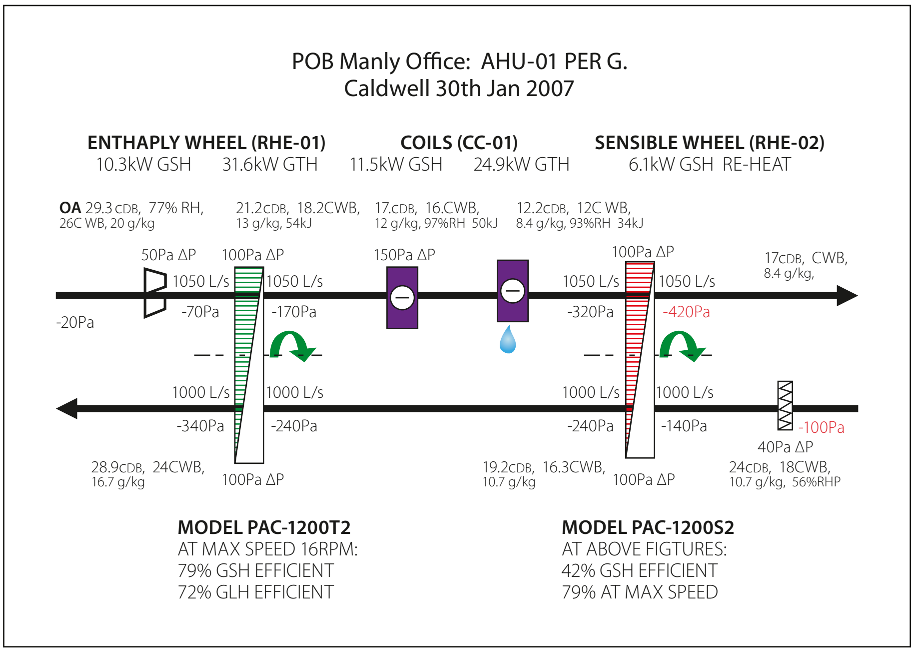



**Figure 9** Proposed dehumidification strategy for task air in tropical climates.

maintain relative humidity's in ambient comfort duct systems below 80%.

This allows the ambient HVAC system to operate very efficiently as it is no longer required to dehumidify. In this feature, it is not dissimilar to the SHAW method of air conditioning.

Given that people will sit at the workstations, churn is managed by simply relocating the WAC fresh air supply to suit their revised workstation location.

## PASSIVE CHILLED BEAMS AND CEILINGS

The use of task air is an ideal complimentary technology for passive chilled beams. There is minimal additional capital investment, as task air becomes the delivery method for the primary outside air. By supplying the primary outside air at the workstation, the feeling of air movement is created for the occupant and the air change effectiveness is increased.

The design of the passive chilled beam ambient system does not greatly alter. The passive chilled beams should be selected to maintain the ambient conditions. The higher ambient conditions will result in greater efficiency of the chilled beams due to the higher temperature difference.

The primary outside air is delivered through the task air system to provide individual comfort control, the outside air requirements, latent heat requirements and air movement.

As with all chilled beam systems, the primary outside system must address the latent heat capacity of the space to remove humidity and prevent condensation on the chilled beams.

## CONVENTIONAL AIR DISTRIBUTION – RETROFIT

Task air can be retrofitted into conventional variable air volume (VAV) systems. While it is recommended that fan assisted VAV boxes be utilised to create the desired supply air temperature and control the pressure, pressure independent boxes have been used with success.

The design of the VAV ambient system does not greatly alter. The VAV boxes should be selected to maintain the ambient conditions. The higher ambient conditions will result in greater efficiency of the air handling units due to the higher temperature difference.

Dumping should be also managed through diffuser selection.

## CONVENTIONAL AIR DISTRIBUTION + TASK AIR 100% OUTSIDE AIR

For new installations, ambient system can be either a VAV or constant volume (CV) conventional air distribution system, with no outside air (other than economy cycle). The task air system is then a 100% outside air system that supplies fresh treated air to the workstation.

## HOW DOES THIS GET COMMISSIONED?

Considering commissioning is a fundamental design activity. During testing it was found that the plenum pressure provided a reasonably accurate measure of air quantity for a particular grille type.

**Figure 10** Pressure at 5L/s/diffuser


**Figure 11** Pressure at 7.5L/s/diffuser

For an air quantity of 7.5L/s/diffuser, a plenum pressure of 10Pa is required. It is envisaged that two diffusers would be utilised per person to achieve 15L/s/person.

## HOW COULD THIS BE RETROFITTED?

In the following sketch, a retrofit to existing VAV mechanical plant is shown. The necessary air conditions such as a stable supply air conditions are assumed to be supplied by the plant. Stable air pressures and temperatures are generally found in VAV zones that supply internal zones.

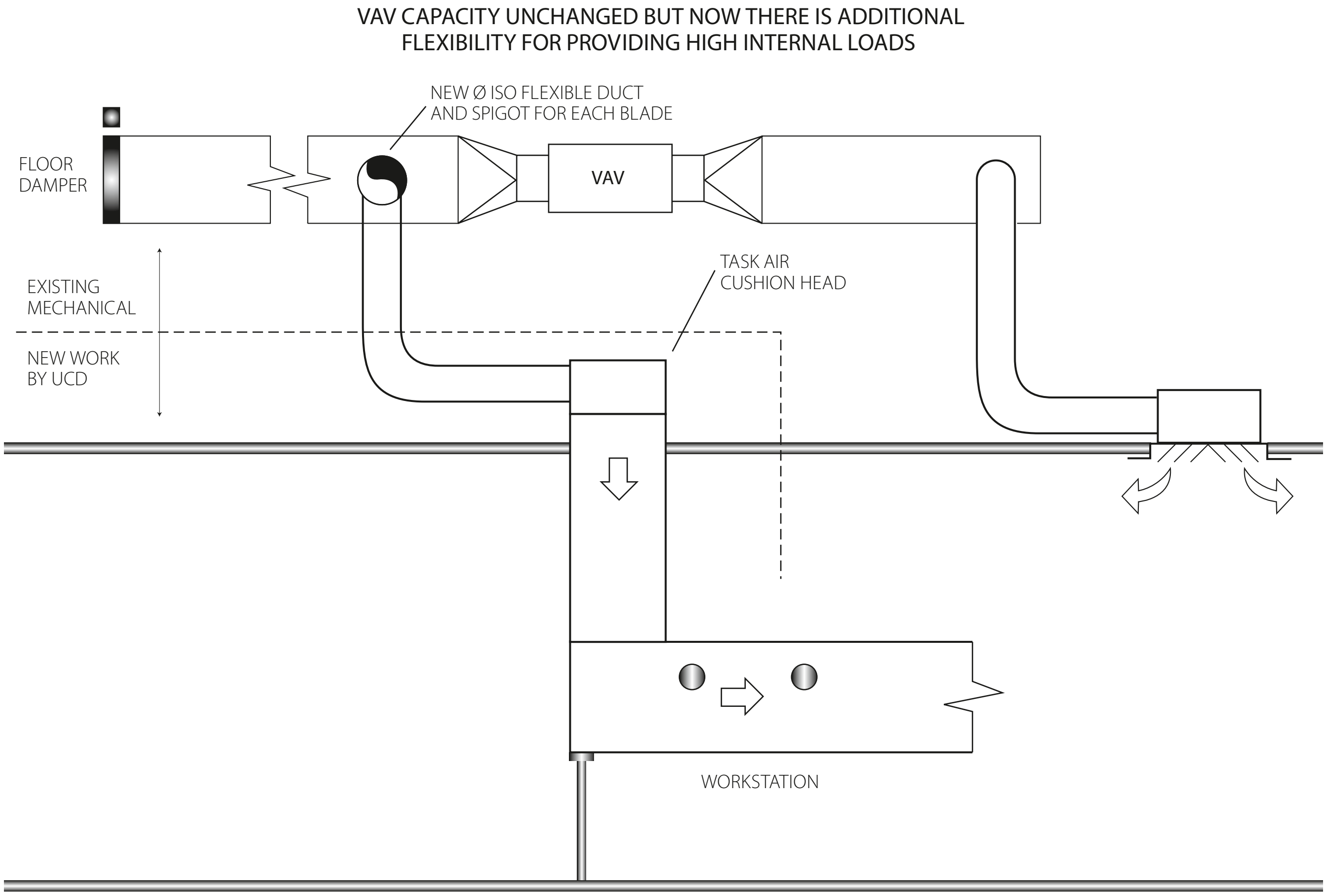



**Figure 12 Conventional Retrofit of VAV system to allow task air. Note the trade delineation between the workstation provider and the mechanical trade.**

A spigot from upstream of the VAV will have access to the necessary static pressure to deliver the air through the workstation cushion head and blade. Standard (NATSPEC) workmanship and materials are assumed.

## CFD STUDIES

CFD studies have been completed to determine appropriate ventilation strategies for office projects.

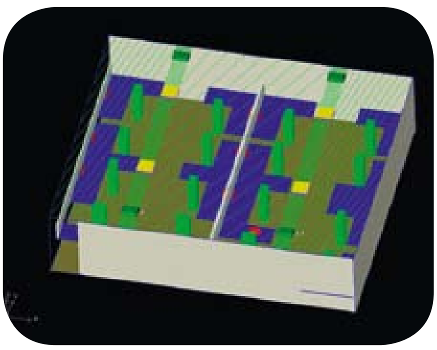


**Figure 13 The outline of the CFD model is shown here. In this model, three sides are glazed perimeters. Further details are available upon request.**

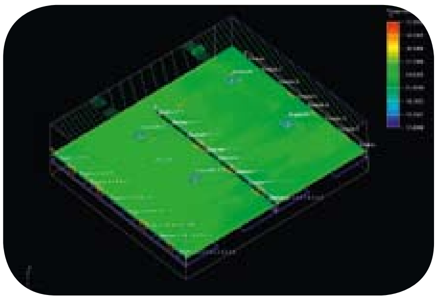


**Figure 14 This image shows a relatively even temperature.**

The purpose of these images is to portray how a range of PMVs (i.e. a range of comfort conditions) can be provided at a relatively constant temperature (25°C) by simply diverting diffuser direction. In the figures that follow, blue = – 0.5 PMV or lower and orange = +0.25PMV.

In this model, 15L/s/p is supplied at 17°C.

## INSTALLATIONS TO DATE

The Riparian Plaza fit out of Moore Stephens (January 2006) was the first installed using the detail portrayed in Figure 12. In hindsight it was

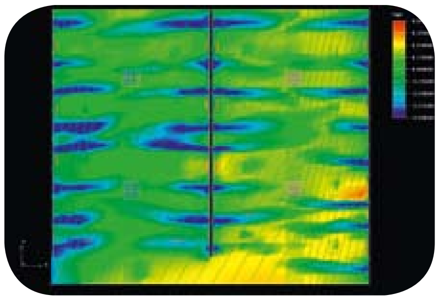


**Figure 15 This slide shows the effect of the air movement in generating lower PMV scores.**

commissioned with too much air being delivered at the workstations (>15l/p). Anecdotal comments from the users indicate most appreciate the task air system, while some find it a bit too breezy. There have been minimal complaints back to the contractors for the normal 'too hot', 'too cold' pockets in the fit out as those who have found it too breezy can control their individual area by turning off the task air.

The lessons learnt included:

- Less air may be better
- We need to have control over the ambient set points to lift them above 23°C.

The recent SHOC fit out for Main Roads Department (Queensland Government) was much more successful.

**Figure 16** The Moore Stephens task air installation was appreciated by the males but the workforce was predominantly female.

The airflow was reduced down to 10L/s/p and raised the ambient set point up to 240C. The project manager has provided the following feedback:

Main Roads was the first Queensland Government department to install task air into a fit out and is aiming for a Green Building Council Interior Fit-out Green Star Accreditation. The installing company easily installed task air into an existing building (1967) with an approximately 10 year old air conditioning system. Task air only add an extra 2% to the overall cost of the fit out but the benefits to the occupants and Green Star points outweigh the small installation cost.

The occupants moved into the new fit out on June 30, 2008. The consultant and workstation company provided training to the occupants on how to use task air and what task air could deliver to them. The staff finds that controlling the outlet at their workstation is very empowering. The current feedback by the occupants has been very positive, noting that the floor feels fresher and more comfortable with no hot or cold pockets through out the level.

As many facilities managers and building owners know, the most complained about item in any office is the air conditioning. The building owner of SHOC has not received any complaints about task air or the air conditioning in the main workstation area for level 6 since occupation.

A research project into the implied indoor air quality improvement at this fit out is due to commence in September. The project will be undertaken by Dr Scott Drake, senior lecturer, Faculty of Architecture Building and Planning, University of Melbourne.

The equipment providers on this project were UCI, mechanical design and specification; Cundall and installers; James L Williams.

## CONCLUSION

The motivation for using WAC is to achieve very high levels of occupant satisfaction, not typical of open plan offices. In recognising it is impossible to provide a 'one size fits all' ambient temperature condition, the designer needs to reconsider the influence of air movement on OT and how a variety of comfort experiences can be created.

The purpose of this paper was to present a proposed design strategy for incorporating WAC into current HVAC designs. A wide variety of research implies that increased fresh air rates, increased air change effectiveness and individual temperature control can lead to demonstrable improvements in productivity and internal environment quality. This is reflected by the GBCA Green Star rating tool Office Design. The author advocates the consideration of WAC as a means of minimising comfort complaints.

The two case studies provide further lessons: 1) we must manage and adjust the ambient comfort to make it warmer and 2) 10L/s/p appears to be a better rate than 15L/s/p.

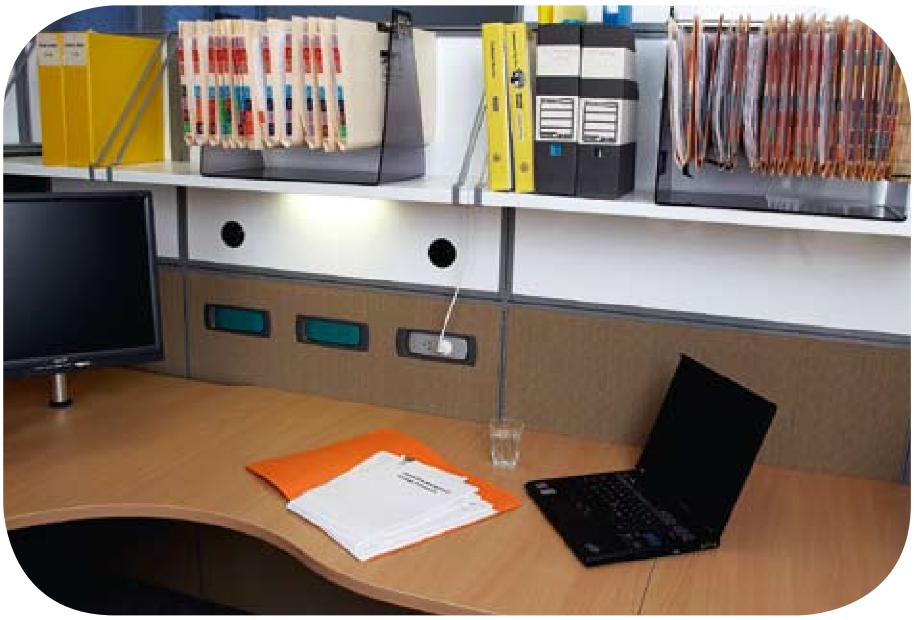


**Figure 17** Main Roads Department fit out detail.

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