FORUM

The effect of return air path on achieving air-change effectiveness for Green Star IEQ-2 Office Design using CFD simulations

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ABSTRACT

There has been a substantial demand for building developers to apply for a Green Star rating under the Green Building Council of Australia's (GBCA) Green Star rating scheme. One category is the IEQ-2 demonstrating adequate air change effectiveness (ACE) in the design stage. For the design assessment, this can only be demonstrated through computational fluid dynamics (CFD) modelling of the ventilation system and calculated in accordance with ASHRAE F25-1997 methodology.

Extensive CFD modelling of actual case studies has produced some interesting findings regarding the current beliefs of designers to achieve ACE. In particular this relates to how the ceiling diffusers are modelled, as well as the design return air path.

There are currently no Green Star guidelines available to assist CFD modellers with how to correctly perform this. Also, the GBCA rating tool prescribes conditions that seem to achieve a contrary objective of the Green Star intention. For example, the measuring of ACE at minimum turndown ratios in a variable volume system. In light of these shortcomings, it is suggested that there be a review of the current Green Star rating tool for the IEQ-2 credit.

Key words — **Computational fluid dynamics (CFD), air change effectiveness (ACE), indoor environmental quality (IEQ), local mean age of air (LMA), Green Building Council of Australia (GBCA)**

INTRODUCTION

The effectiveness of a ventilation system is determined not only by the air deployment, but just as equally by the return air path. It is quite common to use return air slots in light fittings, but this can be counterproductive in achieving the required level of ACE. In this paper the role of the return air path is examined in more detail.

The return air path plays an important role in facilitating the venting of old air. At the same time it should limit short circuiting of fresh supply air immediately into the return air system. Short circuiting of supply air into the return air path displaces older air that has exceeded its time limit within the space and hence reduces the ACE.

If return air slots are not used then typically egg crate or curved blade return air grilles are. The choice of quantity and location of these in order to achieve ACE is not intuitive by any account. A trial and error approach using the CFD code is required to determine the most suitable arrangement. The principle shall be demonstrated by way of an actual design case study.

AIR CHANGE EFFECTIVENESS

According to the GBCA's Green Star requirements (1) for IEQ-2 version 2 (and now version 3), two points can be achieved if it can be demonstrated that 90% or 95% of the NLA will have an ACE of greater than 0.95 when measured in accordance with ASHRAE F25-1997 (2). These measurements must be performed at minimum turndown ratios for a VAV system, at a height of 1m above floor level.

A summary of the procedure for calculating the ACE is outlined below.

Local air change effectiveness (LACE) is a non dimensional index and is defined as follows:

Local air change effectiveness (from ASHRAE F25-1997 Eq. 15)

$$\varepsilon_{I,L} = \frac{\tau_S}{\theta_{age,L}}$$

Where τ_S is the nominal time constant calculated by dividing the room volume by the supply air quantity.

$$\tau_S = \frac{V}{Q_{SA}}$$

$\theta_{age,L}$ is the age of the air at a specific location L. Of particular interest is the maximum age of air required to achieve an ACE of 0.95.

$$\theta_{age,L} = \frac{\tau_S}{Q_{SA}}$$

The local ACE shows the effectiveness of supply air delivery to a specific point in space. $\theta_{age,L}$ is obtained from the CFD calculations. An ACE value of 1.0 indicates that the air distribution system delivers air equivalent to that of a system with perfectly mixed air in the space. A value less than 1.0 shows less than perfect mixing with some degree of stagnation. A value greater than 1.0 suggests that a degree of displacement flow is present at that point.

The return air path is possibly the most critical aspect of the ventilation design when considering ACE. It is apparent from the CFD simulations that using return air slots is detrimental to the ventilation design. The alternative is to use several judiciously placed return air tiles, egg crate or otherwise.

However, the correct placement of these return air grilles is not intuitive, and behooves a CFD simulation in order to best locate them. The results of several CFD simulations will be presented in order to provide additional insight to designers for future consideration while designing these systems.

DIFFUSER CALIBRATION

Preferably the virtual diffusers should be calibrated, so that they perform in a similar fashion to that expected in a real installation. The GBCA do not specify any guidelines or stipulations as to what it expects to see from a CFD model. Hence, any diffuser performance is acceptable, and therefore can be influenced so as to bias the outcome in favour of achieving an acceptable ACE.

Diffuser calibration is not a trivial task. In all HVAC-specific CFD codes the diffusers are typically represented by simple geometric objects. Because initial velocity profiles are attached to the boundaries of the diffuser object (3) (4) (5), they don't represent exactly the jet discharge conditions. To obtain catalogue agreement of throw at both the 0.75m/s and 0.25m/s terminal velocities is highly unlikely. This is further convoluted by the fact that diffuser performance in most catalogues is based on interpolated or projected values, since it is impractical to test each diffuser at every flow rate.

Also, calibrating a diffuser at one flow rate does not necessarily guarantee that it is calibrated at other flow rates, in fact the converse is probably true. This is even truer if the supply air temperature is varied.

Most catalogue performance data does not take temperature into account, therefore the diffuser discharge is assumed to be isothermal. In reality, diffuser performance is highly dependent on the difference in temperature between the room temperature and the supply air temperature, especially at low flow rates typical of variable volume installations.

Isothermal jets have longer throw distances and experience a more sustained coanda effect than non-isothermal jets. There is therefore some confusion as to whether an isothermal simulation or one requiring heat transfer is required.

There seems little point in calibrating a diffuser with isothermal data, and then proceeding with a non-isothermal ACE evaluation. The particulars of diffuser calibration is the subject of a separate discussion and is not elaborated on here. This is because in the case study here, the linear slot diffusers located along the perimeter to absorb the fenestration heat load are used in an unconventional application.

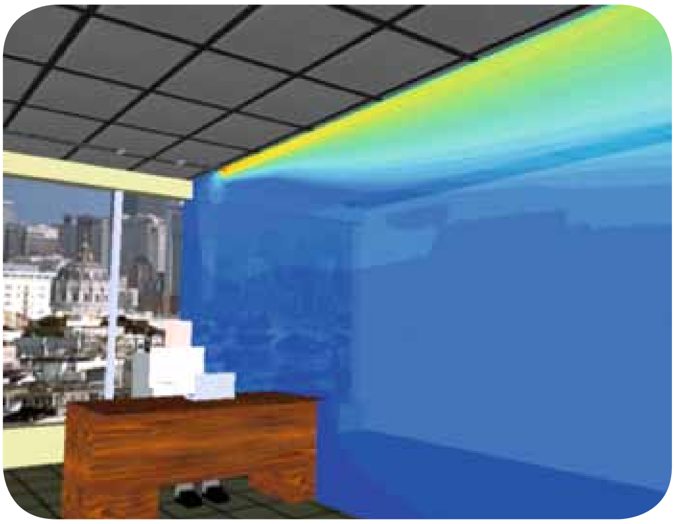

Figure 1: Isometric view of typical perimeter zone showing velocity contours of linear slot diffusers.

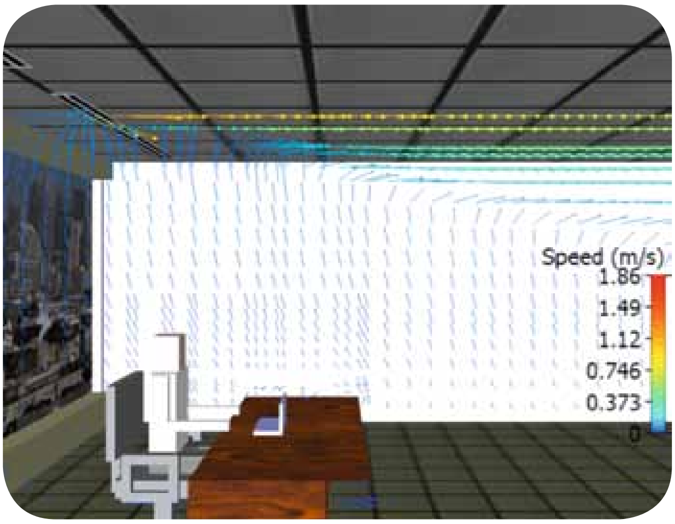

Figure 2: Elevation showing velocity vectors of room air movement due to diffuser induction

Typically perimeter diffusers also discharge air towards the glazing with the intention of washing the warm ascending air downwards, thereby eliminating the heat load at the source, so to speak. In this application linear slot diffusers were arranged to discharge from the perimeter towards the building interior. Linear slot diffusers can achieve this by adjusting the internal geometry. Unfortunately, however, there is no catalogue data to estimate the throw performance in this configuration. It is considered that by discharging the diffuser jet away from the glazing, a strong vertical induction of warm air upwards will occur, thereby assisting the natural convective effect, rather than opposing it. The warm air is blended into the supply air locally at the diffuser face ensuring good mixing and eliminating the chances of draughts. The CFD simulations below demonstrate this principle.

MODEL CONSTRUCTION

The GBCA does not provide any guidelines or specifications as to how to perform an ACE study using CFD. This means that modelling choices are up to the discretion of the CFD modeller, and also that the results of various studies are not being compared on an equal basis. It is strongly suggested that the GBCA issue suitable guidelines as a matter of urgency.

There are many considerations, some subtle, but nonetheless important when performing a building CFD simulation. For example, should the ceiling void be included in the model? The ceiling void is an important part of the return air system, and therefore has a large influence on the ACE results.

Most of the typical slot return air light fittings have slots, on either side. Should these be individually modelled or can they be combined into a single larger slot? These are just some of the nuances involved in addressing the veracity of the ACE study.

CASE STUDY

The building is shown in Figure 3. It consists of two wings, east and west, connected by a central services block. The services block contains the lifts, cloakrooms and services plant rooms. Each wing is served by its own ACU, and return air is drawn back to the plant room via the ceiling plenum to a single return air duct truncated at the plant room, and linear slot-type light fittings. In this case the slots were modelled as a single slot located in the centre of the light fitting. The office space internal zones are ventilated with square diffusers, while the perimeter fenestration areas are served by linear slot diffusers. The design called for a 30% diffuser turn-down. The virtual diffusers were calibrated in a virtual test chamber, to achieve the specified catalogue performance. The two wings are completely independent, but share the same ventilation design principle. The simulation, therefore, was restricted to the East wing initially in order to save time, while various design scenarios were trialled.

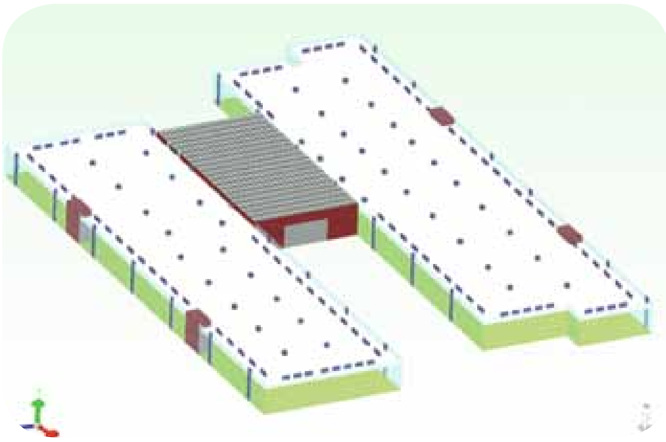

Figure 3: Architectural image of the case study building typical floor plan

EAST WING SIMULATION PROGRESSION

The RCP of the East wing is shown in Figure 4. Note the position of the return air duct in the top left-hand corner of the floor plan. The results of successive attempts to achieve the required ACE are shown below, beginning with the simulation of the original concept using the slot-return air light fittings.

The LMA of air corresponding to the time constant which obtains the 0.95 ACE is plotted on a two-colour scale in each case. The blue zones indicate the areas corresponding to a LMA

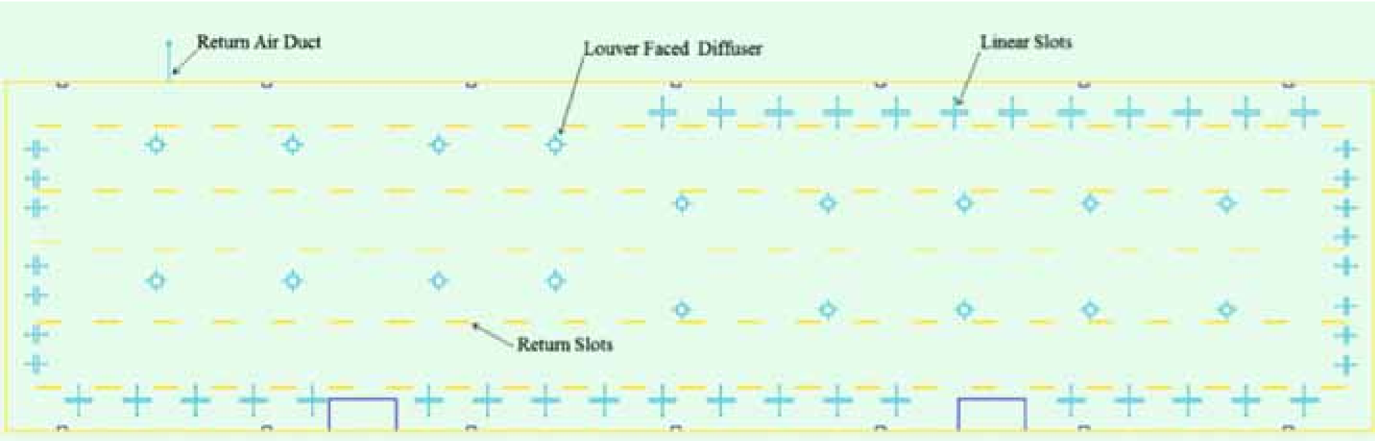

Figure 4: Reflected ceiling plan of the East Wing

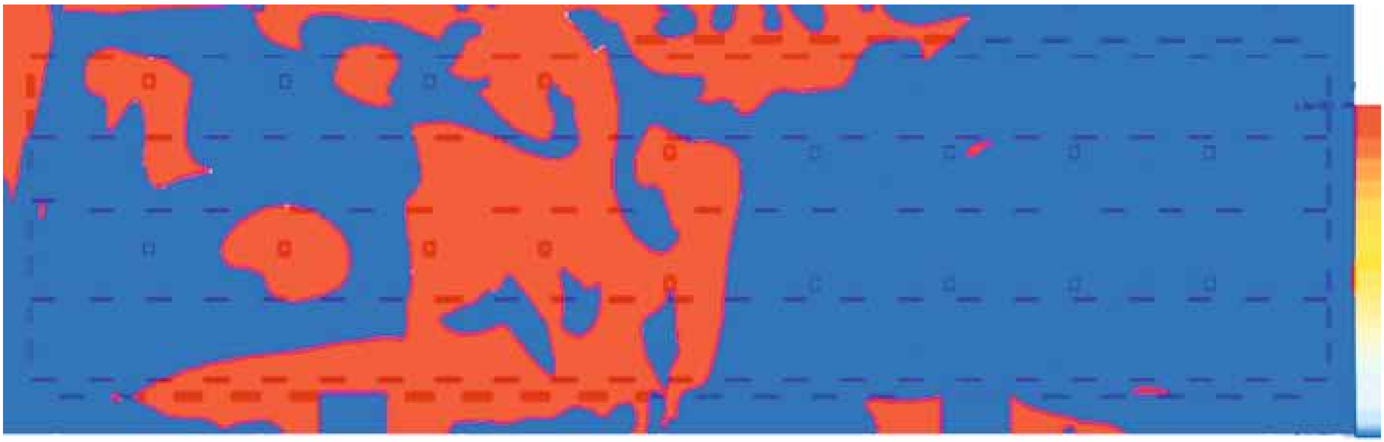

Figure 5: LMA of air at Time=1305.5s, original specification

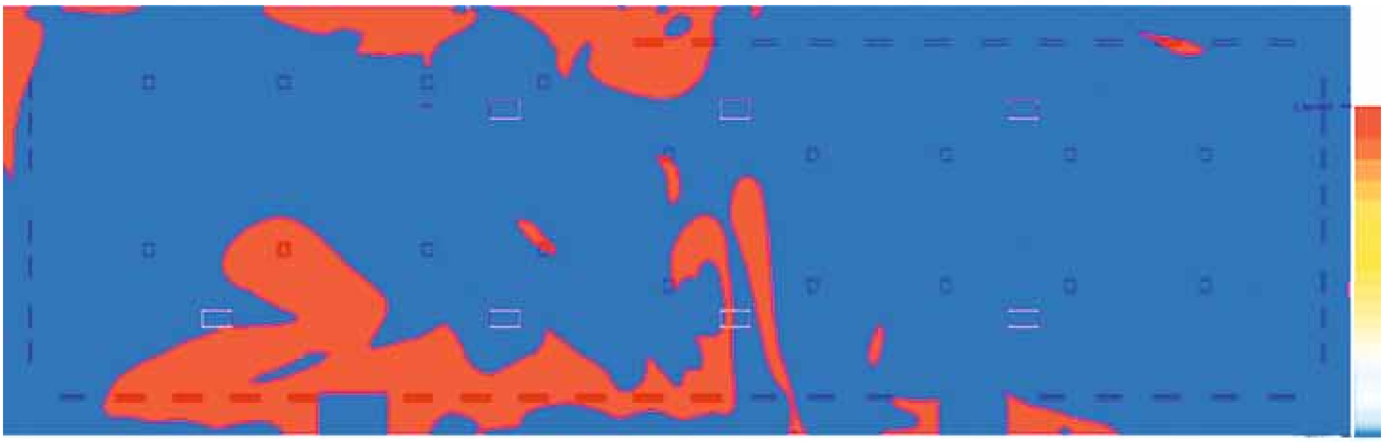

Figure 6: LMA of air at Time=1305.5s, Rev 1

that comply whilst the red zones do not. As can be seen in Figure 5, the initial concept resulted in a very poor ACE, approximately 55% say. It is interesting to note that the age of air is greatest in the left-hand half of the floor plan. This is because as the air is drawn towards the left-hand side, it ultimately ages before exiting the space. Clearly the easiest route for the returning air is through the occupied zone rather than through the ceiling void. The slots on the right hand side of the building are probably not contributing greatly to the return airflow path.

Figure 6 shows Rev 1, which is the case of removing the slots, and installing seven egg-crate return air grilles located around the building perimeter. A grill was not positioned in the top left-hand corner since it was thought that this would encourage too much air to be drawn through it, depriving the other grilles of performing effectively. As can be seen, the ACE has improved substantially, achieving possibly 80%. There still exists a large red zone in the bottom left hand corner. In order to eliminate it, an additional return air grille was located above it, and these results are shown in Figure 7, Rev 2.

Figure 7 shows that there has been no real improvement overall, although there has been an adjustment to the distribution of aged zones. At this point it was decided to try locating the seven

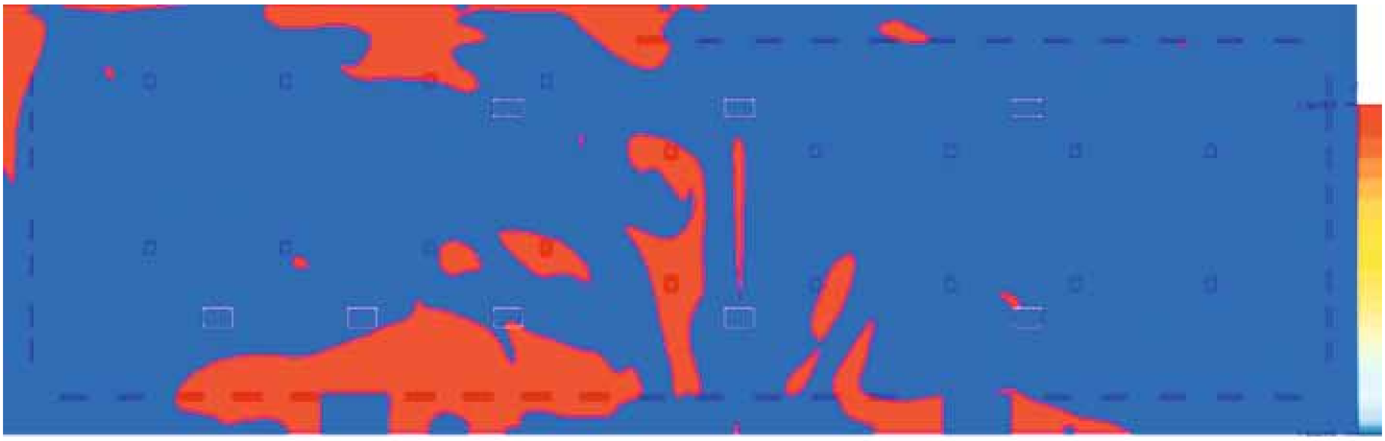

Figure 7: LMA of air at Time=1305.5s, Rev 2

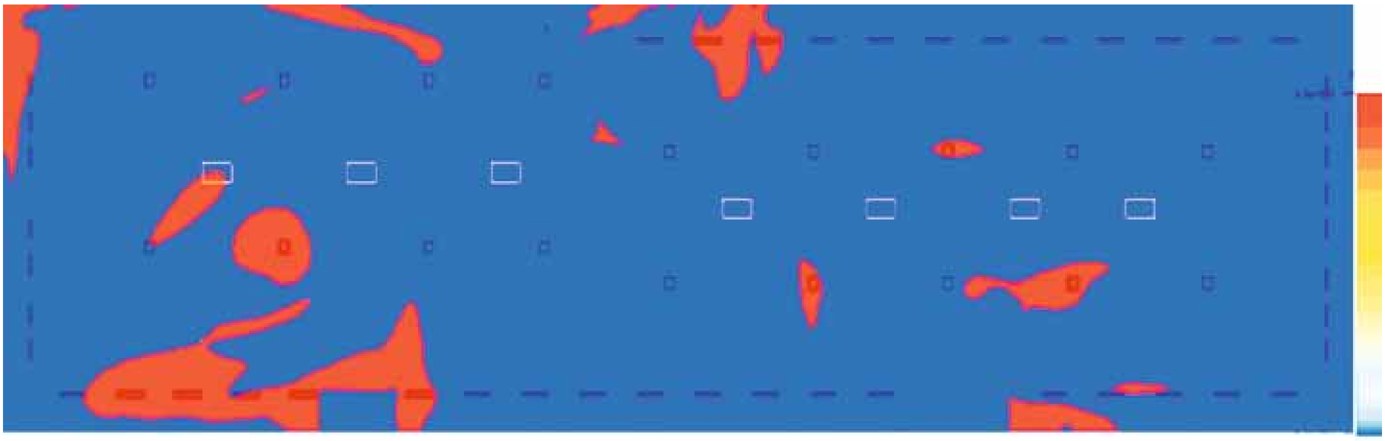

Figure 8: LMA of air at Time=1305.5s, Rev 3

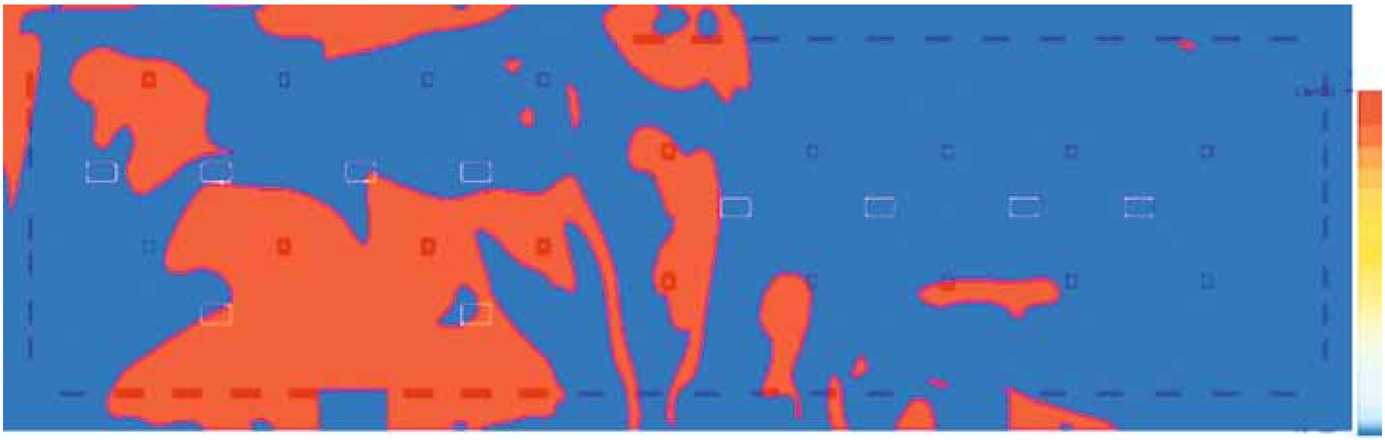

Figure 9: LMA of air at Time=1305.5s, Rev 4

egg crates in the centre of the zones, rather than along the perimeters, and this result is shown in Figure 8, i.e. Rev 3.

Locating the return air grilles in the centre shows a much better result, with the ACE approximately 80%. There are scattered zones of red, particularly in the bottom left-hand corner. Therefore, in order to reduce the red in this zone, two egg crate grilles were located in this vicinity. In addition, an extra egg crate was positioned in the top left-hand corner as well, resulting in 10 egg crates in total.

Figure 9 i.e. Rev 4, shows the result of this layout. Clearly the ACE has worsened considerably. One can now surmise that increasing the number of return air grilles actually worsens the ACE. Also, the placement of a return air grille above an area of poor ACE doesn't necessarily have any direct bearing on the ACE in that zone. Clearly the location of return air grilles is not subject to intuitive logic or experience.

However, realising that fewer return air grilles leads to better ACE, the number was reduced to four, located in the central zones as shown in Figure 10, Rev 5. As can be seen, the ACE is vastly better, between 90-95% of the floor area. Now that a design recipe is available, this logic was applied to the west zone, and the result for the entire building floor plan is shown in Figure 11.

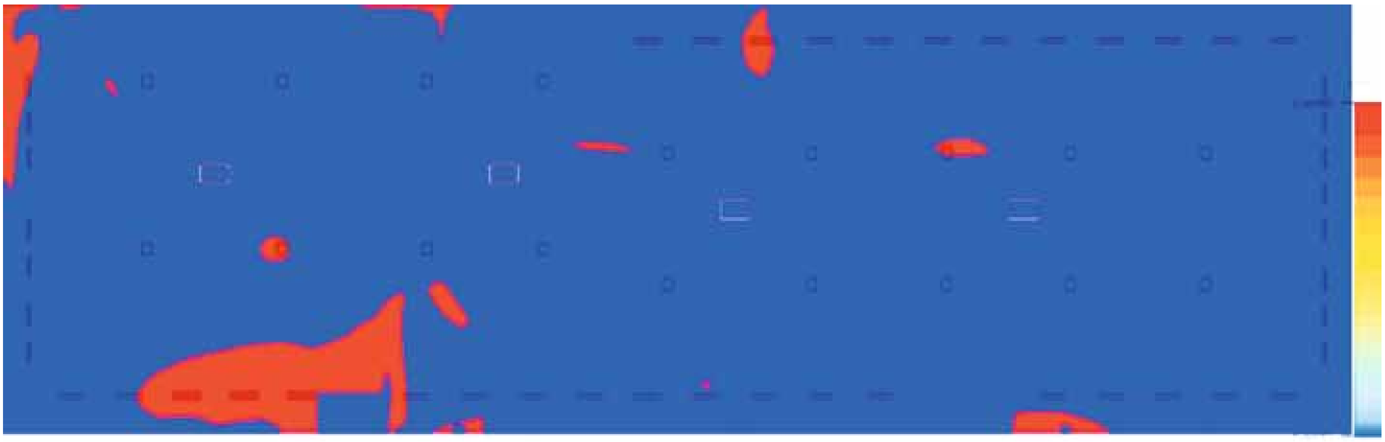

Figure 10: LMA of air at Time=1305.5s, Rev 5

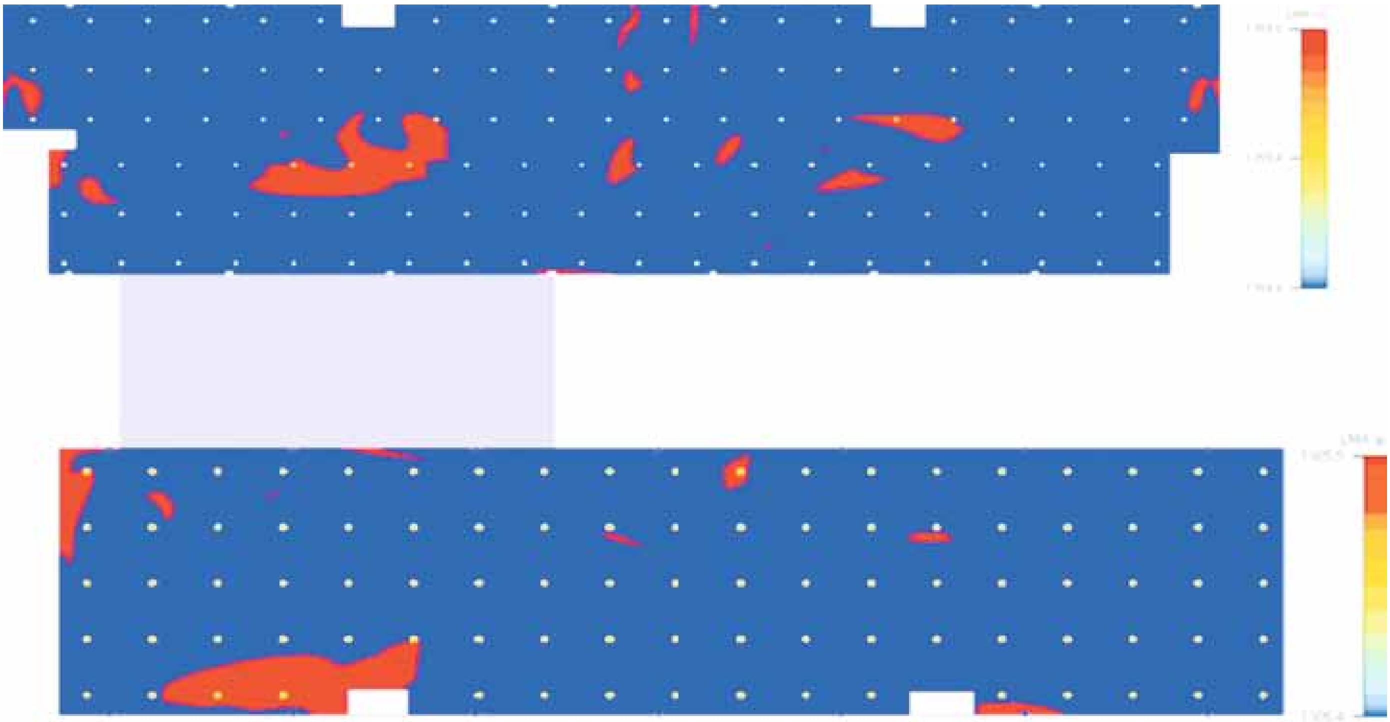

Figure 11: Contour plots of LMA for the West (top) and East (bottom) wings

CONCLUSIONS

The results of this study demonstrated that it is highly unlikely to achieve the required ACE if slot return air grilles in the light fittings are used to vent air back into the ceiling. The ACE can be vastly improved by the use of only a few judiciously place return air grilles. Of course, for aesthetic considerations, they need not be egg crates, curved blade return air grilles could equally be used.

The quantity and placement of these return air grilles is not subject to intuition. A CFD study is required to determine the most suitable design parameter. CFD simulations are quite complex and subject to numerous subtleties in modelling interpretation. It seems that the GBCA does not have any guidelines or standards assisting modellers in performing this task. It is hoped that these studies will focus attention on this lack of standardisation among CFD simulations in the HVAC industry. ▮

REFERENCES

1. Australia, Green Building Council of www.gbca.org.au. [Online] 2008.
2. *ASHRAE. Fundamentals.* 1997.
3. The Box Method – a practical procedure for introduction of an air terminal device in CFD calculation. Nielson, PV. Denmark : Aaborg University, 1997.
4. "The Velocity Characteristics of Ventilated Rooms", Nielson, PV, Restivo, A and Whitelaw, J H. 1978, *Journal of Fluid Engineering*, Vol. 100, pp. 291-8.
5. "Description of supply openings in numerical models for room air distribution", Nielson, PV. 1992;98(1), *ASHRAE Transactions,* pp. 963–71.

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