ABSRACT

Effective air distribution in an indoor swimming pool environment using CFD and fabric duct systems.

Through the use of CFD (Computational Fluid Dynamics) it is intend to highlight the difficulties associated with designing an effective air distribution system in a facility requiring not only a comfortable people environment, but also an air design ensuring moisture-free surfaces of exposed walls and glass partitions.

This paper will look at:

- *Occupied zone comfort – a planned terminal velocity.*
- *Sweeping of exposed surfaces to ensure removal of moisture.*

The CFD simulations will be based on a fabric air distribution system allowing high flexibility of design with specific emphasis on:

- *Nozzle design*
- *Fabric design*
- *Duct air entrainment*
- *Controlled air throws*

The paper will be supported by realistic graphic representation of:

- *Air velocities (AV)*
- *Temperature gradient throughout space (TG)*
- *Recirculation Zone (RC)*

INTRODUCTION

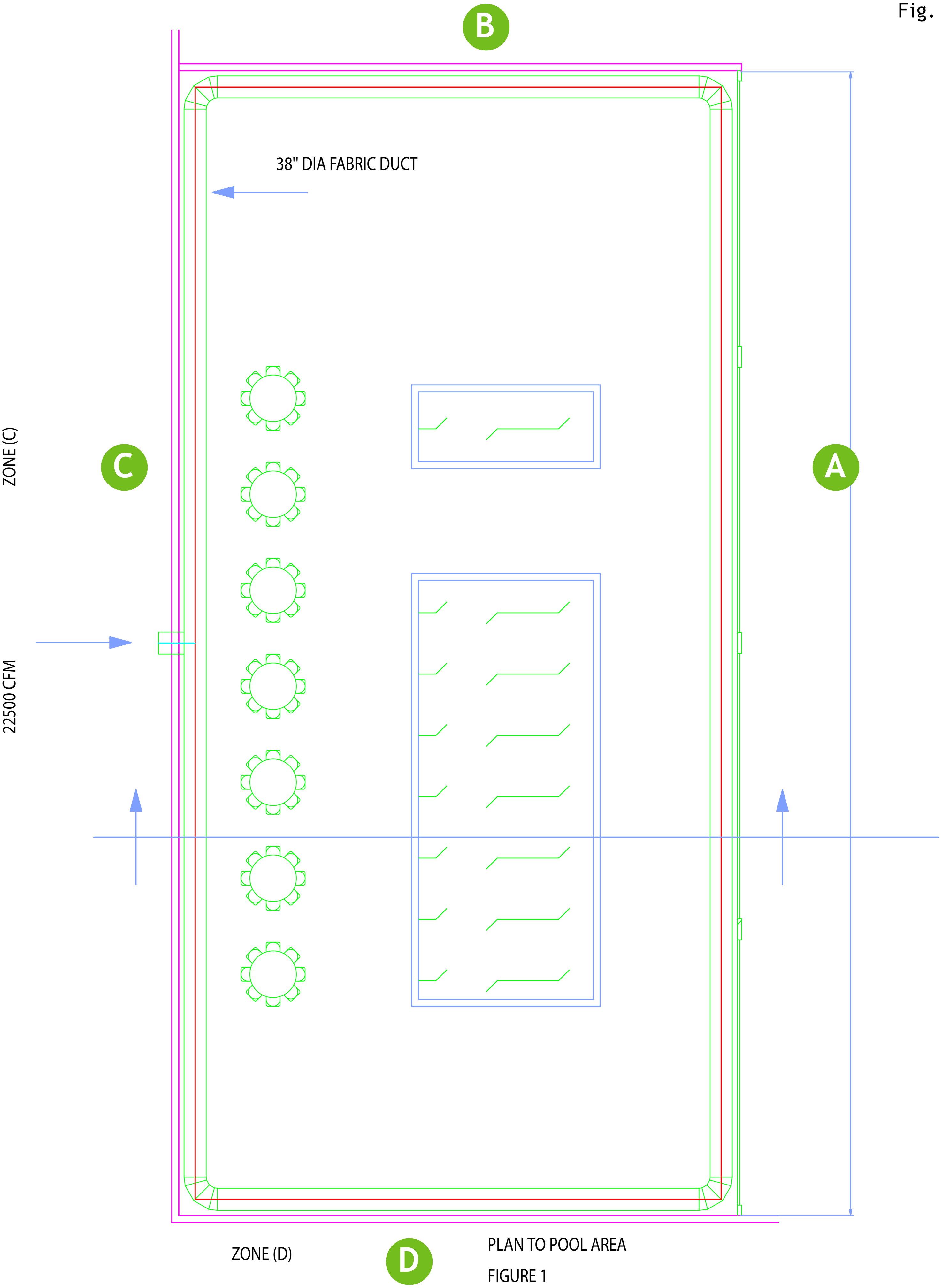
Indoor swimming pools are normally constructed with a large amount of glass areas in comparison to normal wall area. Architecturally the exterior building envelope, especially those that afford a view, are treated with significant expanses of glass in order to enhance the user image and bring about a feeling of bathing in the “open,” while actually being protected from the external environment by the building envelope and its air conditioning system.

In severe winter conditions, such as are experienced in the Northern parts of the USA, this form of structure and its consequent usage, puts a special emphasis not only on the air conditioning and dehumidification plant configuration, but also to a large degree on the air distribution system, which must be able to deliver specific amounts of air, at specific perimeter positions, at specific terminal velocities in order to combat formation of moisture on surfaces that may drop below Dew Point Temperature on winter design days.

Five separate perimeter zones, (Figure 1) each with a unique airflow requirement can be identified in the swimming pool under question, they are:

(A) Exterior window zone

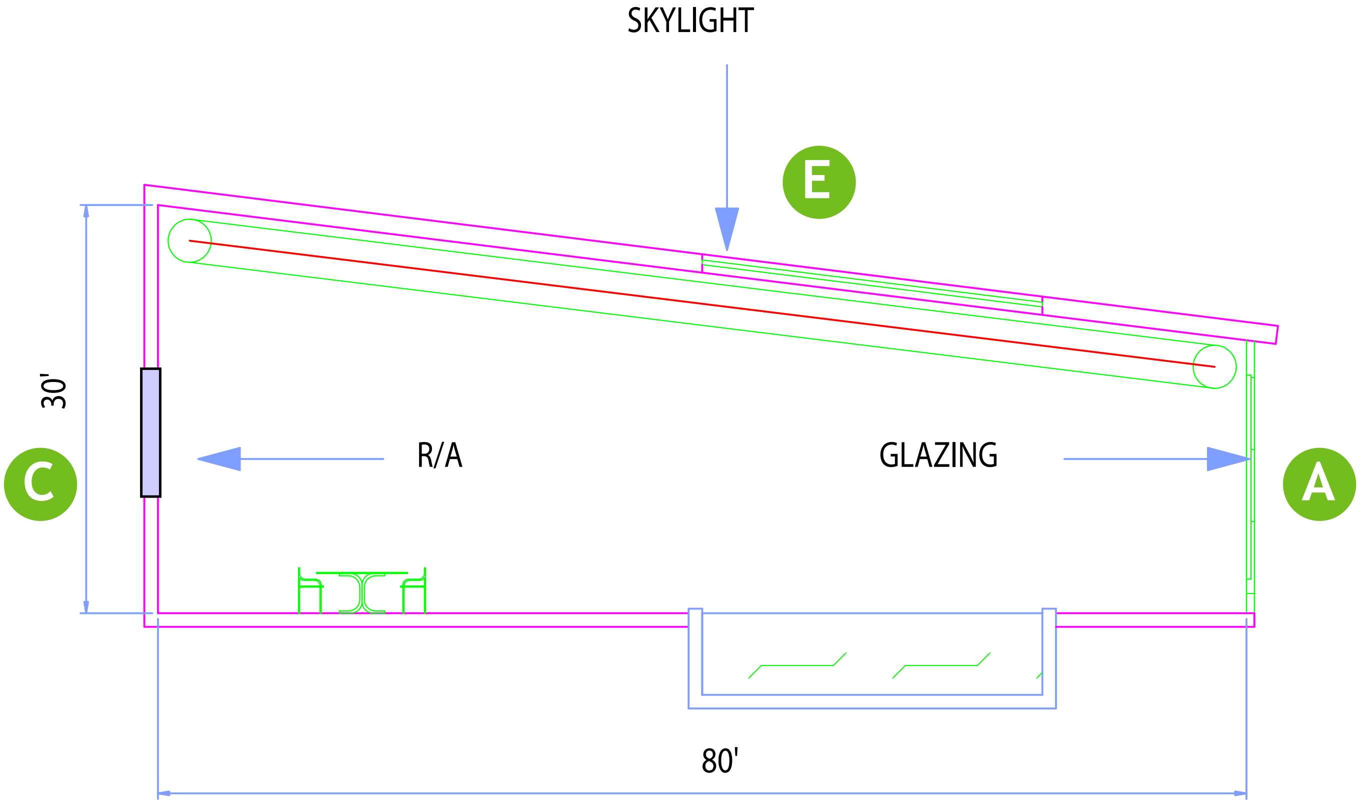
This zone needs careful consideration to ensure proper “air sweep” over the glass area in order to remove condensation during a design winter day. The air flow



PLAN TO POOL AREA

FIGURE 1

Fig. 1a



SECTION THRU POOL

FIGURE 1A

moving vertical down over the glass area will also move across the floor and eventually reach the edge of the main pool at a specific terminal velocity.

(B) Exterior wall zone
Air sweeping of the wall surface is required to remove any moisture that may be present during a design winter day.

(C) Interior wall zone
This is not considered a vertical zone and should be treated as a floor zone where consideration to people comfort is important.

(D) Interior wall zone
This zone requires little attention due to the absence of occupants and the little or no temperature difference across the wall.

(E) Roof/skylight zone
Similar to zone (A) the large glassed area needs continuous air sweeping to remove moisture.

AIR DISTRIBTUTION

To adequately cater for such a varied and specific airflow requirement as noted above, a fabric duct air distribution system was chosen. Typically such a system will be constructed of low permeable fabric equipped with high volume, high/medium velocity, air distribution devices consisting of air directional nozzles and linear vents, configured and positioned on the duct walls to ensure compliance with the design criteria as simulated and shown by a CFD calculation. A low permeable fabric is chosen so as to fulfill two important criteria:

(a) A low permeability ensures that the distribution system as a whole has a significant percentage of the air for use in air throws from nozzles and linear slots, rather than for duct wall controlled air leakage which may be desired in low velocity applications.

(b) The air leaking through the fabric walls effectively prevent condensation settling (during cooling) on the duct surfaces.

Best practise in the design of a fabric distribution system is to maintain a constant internal static pressure throughout the entire duct length. As the leakage rate of the fabric is directly dependent on the pressure difference between the duct interior and duct exterior, a virtually constant pressure such as is exhibited by a plenum type duct would result in an even airflow (cfm/ft^2) from the fabric. In zones where air is required to be delivered in larger quantities and in extended throws the airflow is augmented by using air directional nozzles and linear slots.

Current swimming pool designs with fabric duct distribution systems, arranges the fabric duct in a continuous loop generally following the space outline in order to enhance vertical surface air sweeping. (Figure 1)
Basic system requirement calls for a total conditioned air volume of 22,500 cfm

(+/- 4,0 volumetric air changes per hour) being supplied to the distribution duct.

We have chosen to look at the air distribution during a winter cycle only, and not through a full year with attendant summer simulations, as we believe that the distribution system is severely tested during cold weather due to the fact that this is the period when air sweeping is of importance.

COMPUTATIONAL FLUID DESIGN

Various forms for (CFD) calculation programs are now being used to combine previous empirical knowledge with the force of iterative power of modern computers. Coupled with enhanced graphics, it provides a powerful and predictive tool for air designers. Typically, a single air zone computation requires between 3,000 to 30,000 calculations at a processing speed of 14,0 GHZ.

Software : Fluent 6.1 Steady-state
Numerical Scheme : Segregated Solver
No. of grid points : 230,000
Type of Grid : Quad Pave Mesh
Turbulence Model : Standard (k-e) model

CFD predictions are normally supported by definite and qualitative field measurements for comparison purposes and in order to prove the predictive quality of the computerized calculations. In this instance this has not been possible as the building and its design is fictive.

The primary aim of using CFD is to look at overall air patterns and localized air streams in critical zones, as such, this paper does not address any issues concerning moisture removal but endeavours to show where dehumidified air should be applied in greater concentrations to combat the possible formation of vapour on exterior building surfaces.

POOL SPACE DESIGN DATA AND CRITERIA

• Space temperature and relative humidity	80^{0}F/60%RH
• Pool water temperature	75^{0}F
• Ambient temperature	25^{0}F
• Expected inner surface temperature of external glazing and wall without air sweeping	50^{0}F
• Dew point temperature of surfaces at 80^{0}F/60%RH	65^{0}F
• Expected surface temperature after air sweeping	75^{0}F
• Glass area air flow(1)	3 to 5 cfm/ft^2
• Air velocity over pool surface(2)	10 to 30 fpm
• Air velocity in occupied zone (C)(3)	25 fpm
• External Windows construction	Double glazed
• Skylight construction	Double glazed
• External wall construction	Concrete block insulation and internal partitioning
• Ceiling construction	Smooth plaster

DUCT DESIGN DATA AND CRITERIA

Fabric permeability	1,8 cfm/ft^2 @ 0,5 InchWG
Duct size	38 Inch Diameter
Total air volume	22,500 cfm
½ loop air volume	11,250 cfm
Duct Inlet velocity	1,450 pfm
Duct Static pressure	0,4 InchWG
Fabric wall exit velocity	2,0 fpm @ 0,4 InchWG
Linear slot exit velocity	295 fpm @ 0,4 InchWG
Nozzle exit velocity	2,200 fpm @ 0,4 InchWG
Fabric wall air volume	8,800 cfm @ 0,4 InchWG
Total linear slot air volume	11,500 cfm @ 0,4 InchWG
Total nozzle air volume	2,200 cfm @ 0,4 InchWG
Supply air temperature	90^0F

Linear slots consist of a net like material with a high rate of air diffusion, approximately 3,400 cfm/ft^2 depending on duct static pressure.

Air directional nozzles generate long directional throws due to their engineered throat and deliver approximately 7 cfm depending on the duct static pressure.

Zone Air distribution equipment:
Zone A
- Single line of linear slot positioned at 150^0 165 ft. long x 1.0 inch wide – 3,872 cfm

Zone B
- Single line of linear slot positioned at 150^0 80 ft. long x 1.0 inch wide – 1,877 cfm

Zone C
- Single line of linear slot positioned at 150^0 165 ft. long x 1.0 inch wide – 3,872 cfm

Zone D
- Single line of linear slot positioned at 150^0 80 ft. long x 1.0 inch wide – 1,877 cfm

Zone E
- 300 air directional nozzles positioned in clusters to sweep skylights. Air sweep angle is 300^0 (10:00 o'clock)

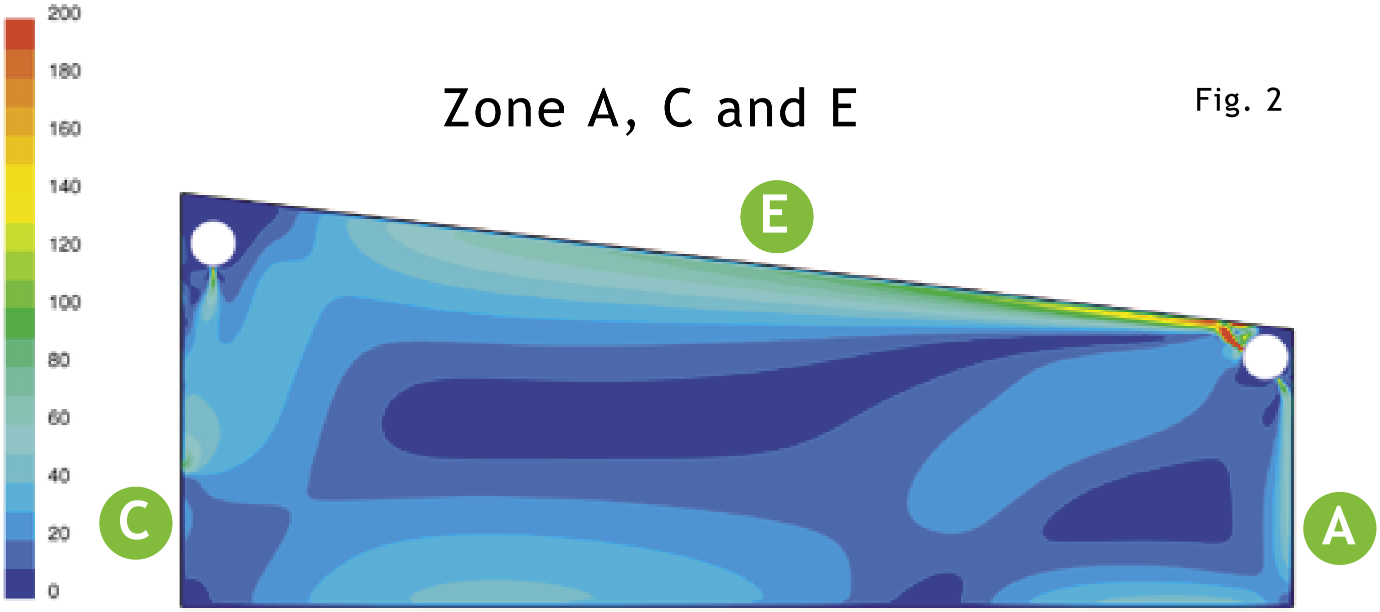
INDIVIDUAL ZONE DESIGN

Zone(A)

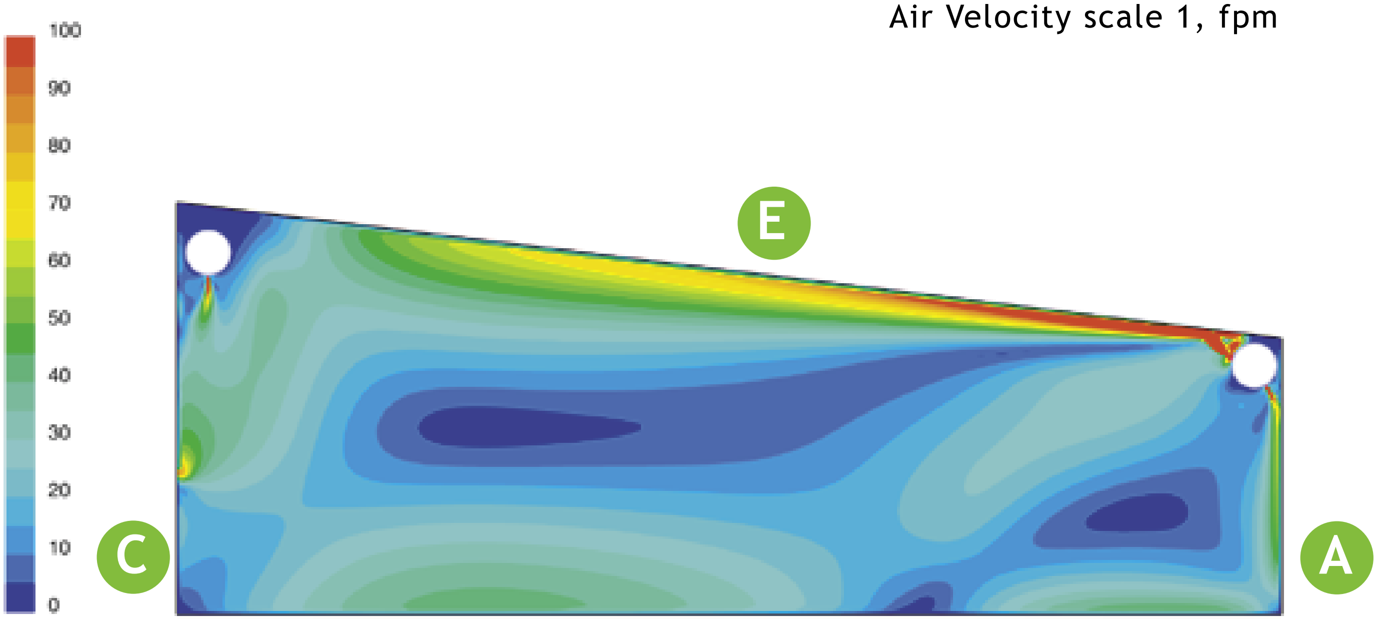
A continuous line of linear slot incorporated into the fabric wall of the duct supplies conditioned air over the full length (165 ft.) of the glazed/masonry external building envelope. The intention is to sweep the inner surface of the glass/wall to remove any moisture that may form as a result of low surface dew point temperature. The airflow, in the form of a narrow "curtain like" airdrop approximately 18 inches,

Zone A, C and E

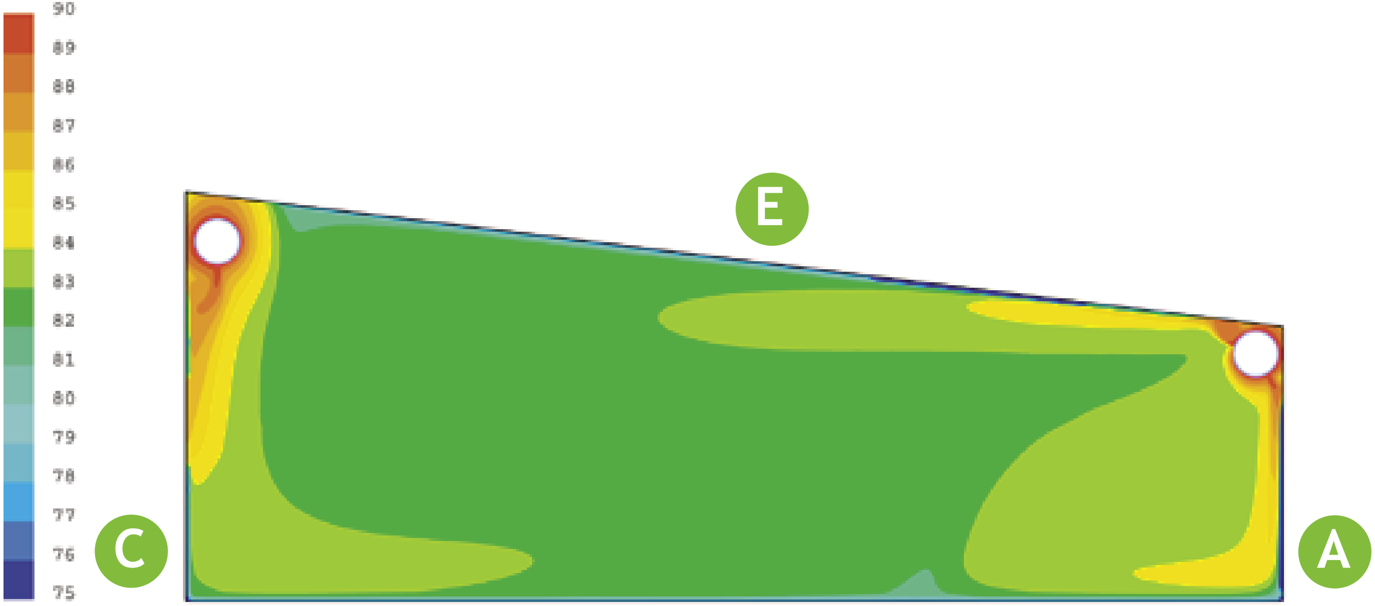
Fig. 2



Air Velocity scale 1, fpm



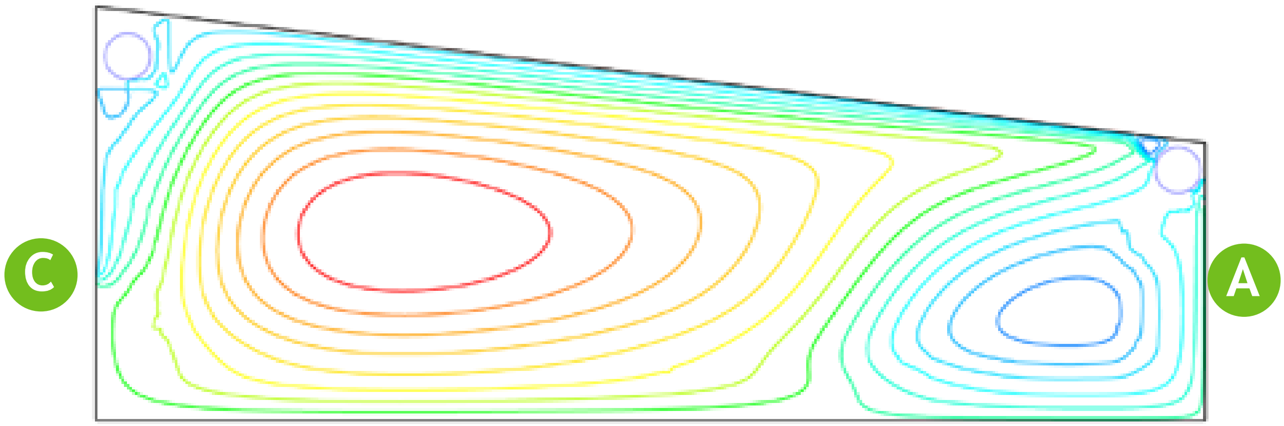
Air Velocity scale 2, fpm



Temperature Gradient °F

Zone A and C

Fig. 2A



Recirculation Zone, A and C

wide, and with an average core velocity of approximately 60 fpm, will after having moved past the glazed area, change direction across the pool deck and continue horizontally in an increasingly diffused path towards the pool edge. The linear slot is positioned on the duct wall at an angle of 150^0 (5.00 o'clock) and delivers a total of 3,872 cfm. The linear slot angle is carefully chosen in order to achieve (a) effective wall sweeping (Coanda effect), (b) prevention of air stream inducement into exit pattern generated by nozzles and (c) prevention of a diffused air pattern on wall leading to ineffective air sweeping.

Viewing the CFD generated Air Velocity and Temperature Gradient simulations (Figure 2), and the Recirculation Zone (Figure 2a) we see the following:

Air Velocities (AV):

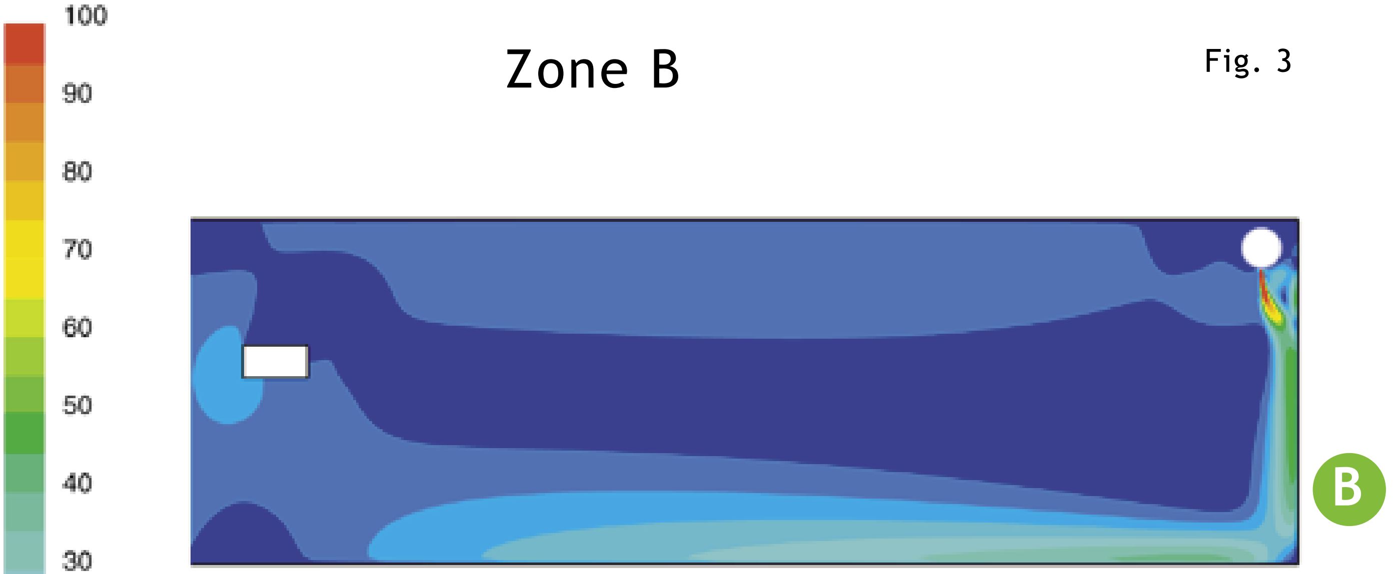
- Air velocity is down to 10 fpm, no more than 3 ft. from the wall, while the air moves over the wall/window surface at 50 fpm.
- Air velocities in the occupied zone (OZ) (6 ft. above FFL) lies between 50 fpm and 5 fpm
- Air velocities are generally higher closer to the floor than in the upper part of the (OZ) ranging from 5 fpm to 40 fpm.
- The air stream generated by the linear slot approaches the pool area (at floor level) at 40 fpm, and then, drops to 5 fpm over the pool center, thereafter accelerating to about 49 fpm after having crossed the pool surface.

Temperature Gradients (TG):

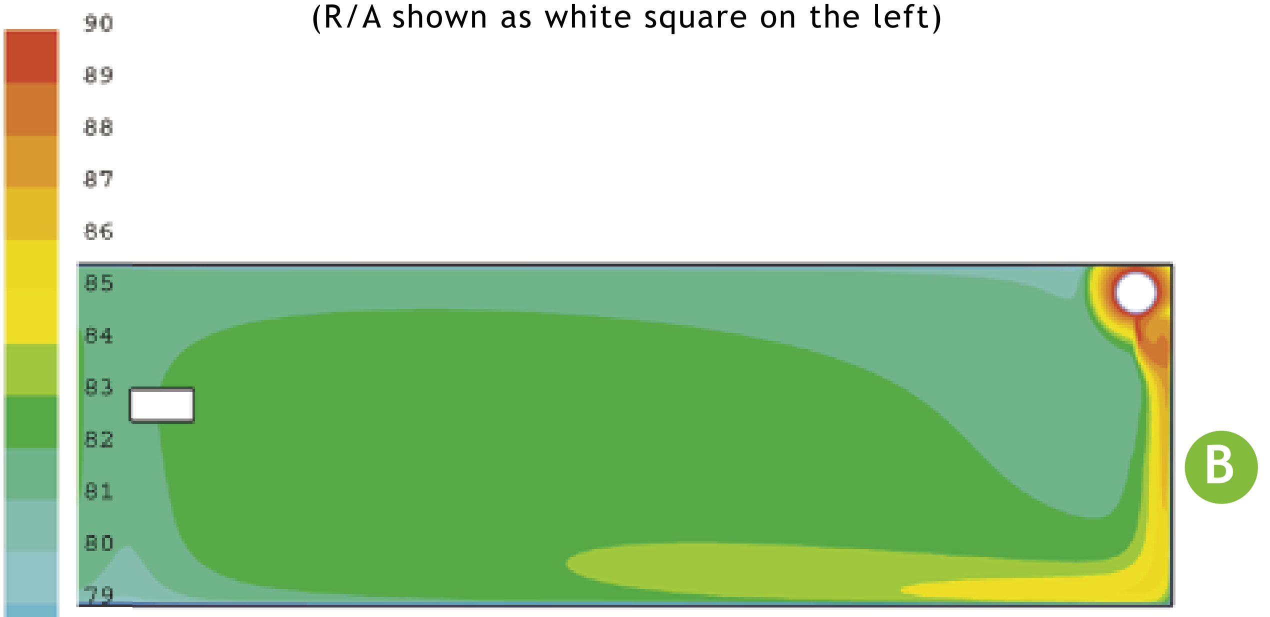
- The full height of the glazing (15 ft.) is shrouded in warm air at 85^0F
- The temperature in the OZ lies generally between 83 and 84^0F with a small zone of 82^0F air at the edge of the pool

Zone B

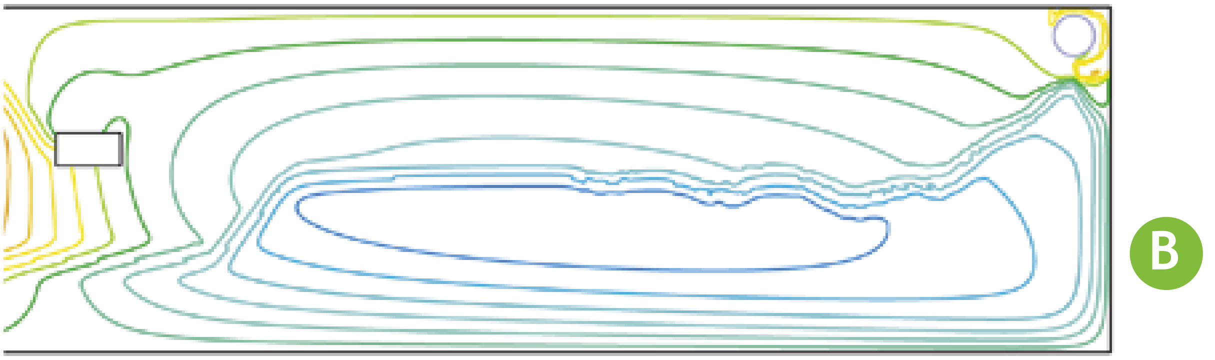
Fig. 3



Air Velocity Zone B. ½ section (Zone D not shown).
(R/A shown as white square on the left)



Temperature Gradient Zone B. ½ section (Zone D not shown).
(R/A shown as white square on the left)



½ Section. Recirculation Zone B (Zone D not shown).
(R/A shown as white square on the left).

Recirculation Zone (RZ):

- Two distinct recirculation zones are generated by the air distribution system with zone centers at approximately 10 ft. above FFL and evenly distributed over the pool space width.
- There appears no area which is devoid of airflow.
- Matching the (AV), (TG) and (RZ) simulations we note an area of air direction transition (sheer) close to the edge of the pool which clearly shows up as low temperature and low velocity areas.

Zone(B)

To ensure adequate air sweeping of the external wall in this zone, a continuous linear slot is positioned at 180^0 (6:00 o'clock) Although the slot is not actually aimed at the wall, a general stream of air clings to the wall through the action of the Coanda effect. Again we see here a fairly narrow air stream confining its relative high velocity to a limited stream width.
Viewing the CFD generated Air Velocity and Temperature Gradient simulations and the Recirculation Zone (Figure 3) we see the following:

Air Velocities (AV):

- Air streams down the wall at 45 fpm taking up a narrow band of medium velocity, while no more than 3 ft. from the wall the air moves at a low velocity of 5 fpm.
- Across the floor air moves from Zone B to wards the return air grille (Half way up the end wall) at layers of velocity ranging from 40 to 20 fpm depending on the level above the FFL slowing down to 5 fpm directly under the return air grille.

Temperature Gradients (TG):

- The exterior wall zone is enshrouded in warm air at 86^0F over it full height, with nominally higher temperatures 90^0F appearing near the upper part of the wall.
- Tongues of air at 85^0F reaches across the floor; while the general temperature in the OZ is in the region of 82^0F, with a relatively cold zone directly under the return air grille of 77^0F.

Recirculation Zone (RZ):

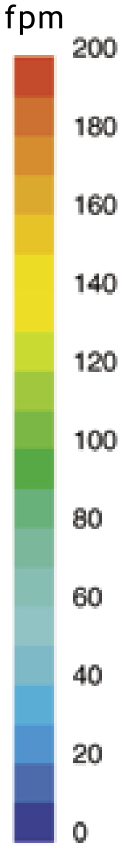
- A zone of little air movement can be seen appearing directly under the return air grille, this coincides with the low temperature and air velocity noted earlier.
- A large area of little air movement appears generally across the space, lying approximately 10 to 15 ft. above FFL. Again this coincides well with the low velocity appearing in the AV simulation.

Zone (C)

This zone, being an interior wall zone between the main building; maintained at normal indoor temperatures and the pool space, requires no air sweeping as the danger of moisture settlement is minimal. For the purpose of this paper we treat this zone as a horizontal zone, where air conditions in the OZ is of

Air Velocity zone A & E

Fig. 4



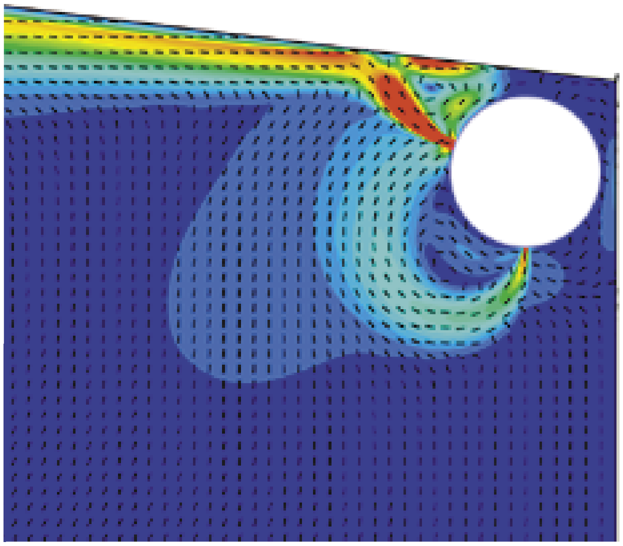


fig. 4a Detail

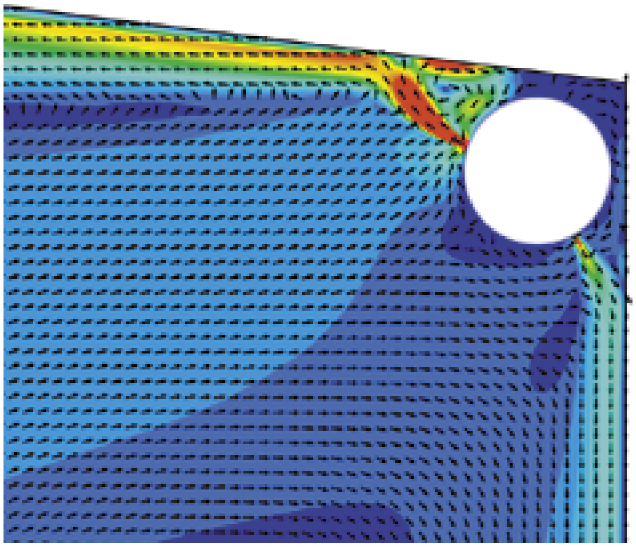


fig. 4b Detail

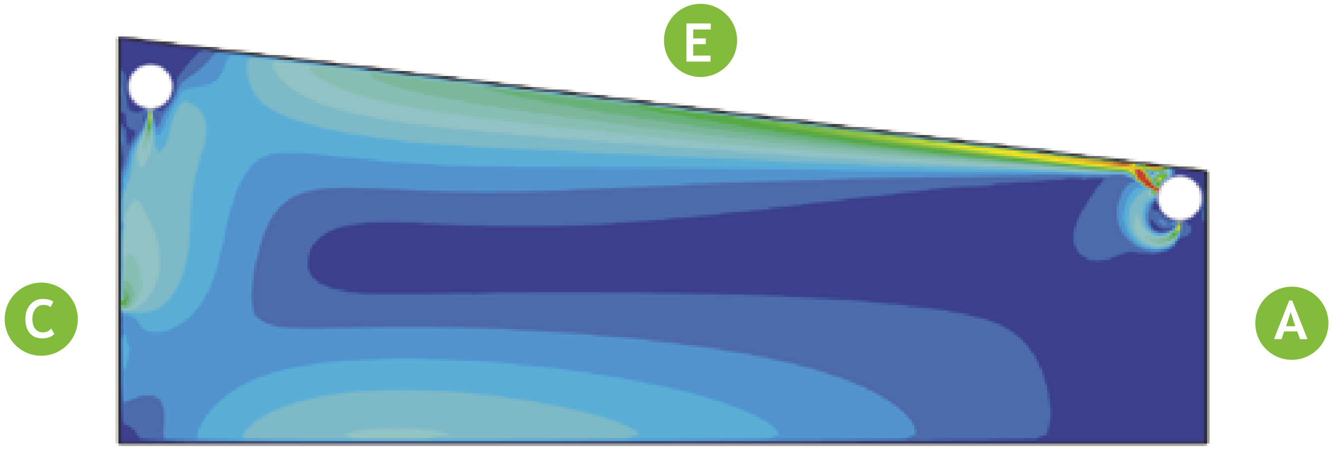


fig. 4c Air Velocity Zone A & E

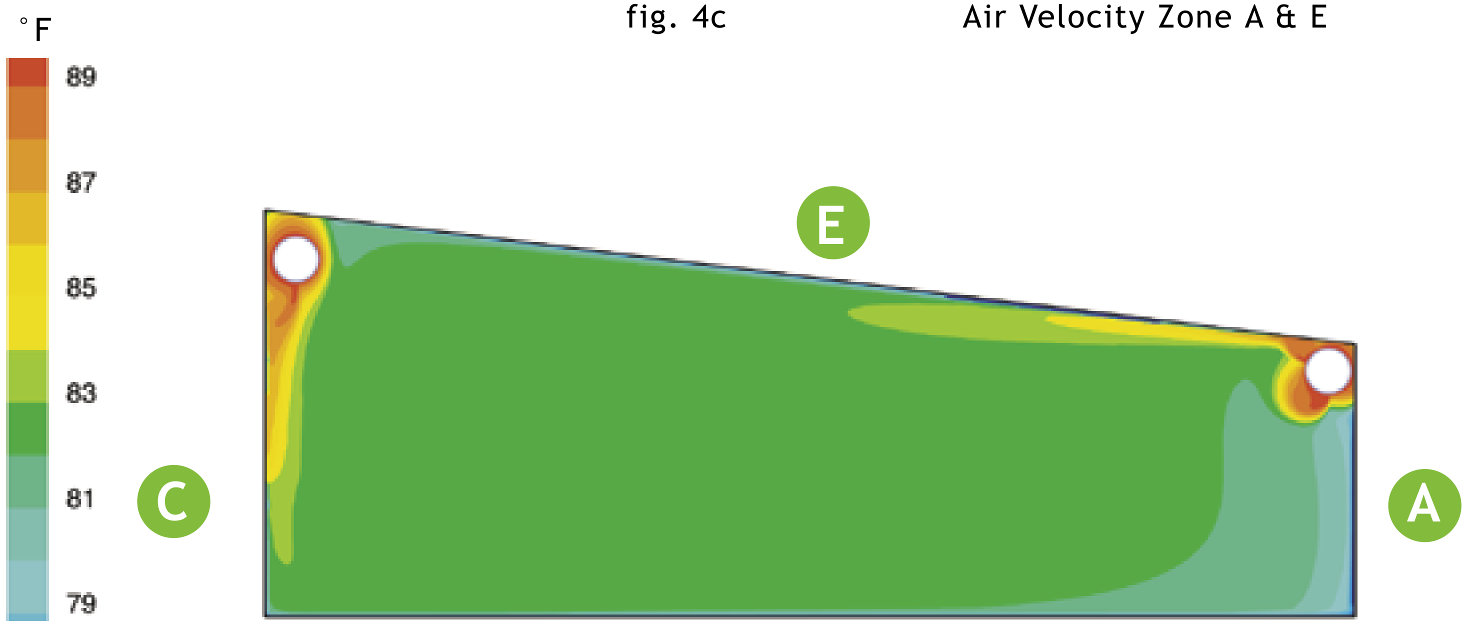


fig. 4d Temperature Gradient Zone A / E

higher importance than the sweeping of walls and glazed areas. (Figures 2)
As this zone is occupied by people sitting at leisure; we would generally look for an average AV in this zone of 25 fpm in order to satisfy a comfort level determined by (clo) and (met) as proposed by Professor P.O. Fanger

Her again we see a simple continuous line of linear slot in the overhead duct being sufficient to maintain conditions some 20 ft. below the duct itself. The slot runs full length of the zone and is positioned at 180^0 (6.00 o'clock), delivering 3,872 cfm.

Air Velocity (AV)

- The slot is positioned at 180^0 (6:00 o'clock) and shows typical wall clinging characteristics. A minor spot of high velocity (75 fpm) terminates on the wall approximately 4 ft. above the OZ.

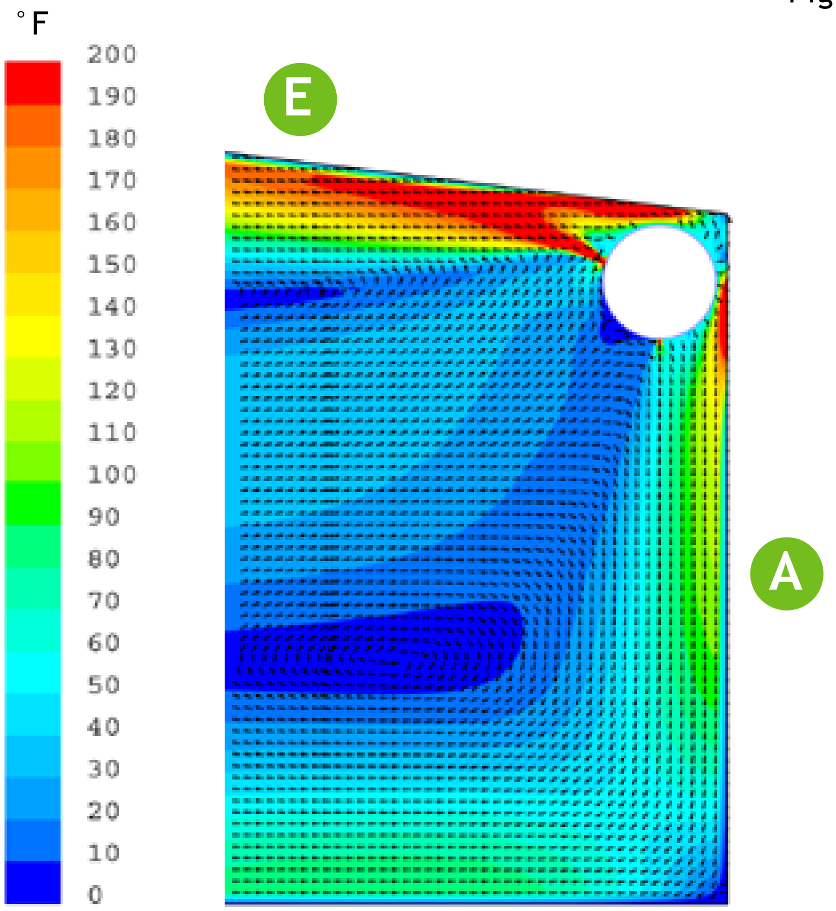
Temperature Gradient (TG)

- An average temperature of 83^0F appears across the zone.

Recirculation Zone (RC)

- The zone is well served by air flows, a spot of low and largely unpredictable air activity appears at low level in the corner between wall and floor.

Fig. 4e



Temperature Gradient

Zone (D) (not examined)

Zone(E)

As the skylights are relatively far from the fabric duct (40 ft.) it was decided to employ air directional nozzles in lieu of linear slots, as the nozzles will generate a longer and more penetrating throw than slots. The slots are positioned at an angle of 300^0 (10:00 o'clock) on the fabric wall, and are clustered over the duct length so as to produce specific air throws onto each separate segment of skylight (4 in all spaced evenly over the length of the pool enclosure) The air stream, upon leaving the nozzles at a velocity of 2,200 fpm sets up a confined zone of low pressure near the duct wall thereby inducing all of the air "leaking" through the fabric, but also trying to induce the air leaving the linear slot placed below at 150^0 (5:00 o'clock). The nozzle air stream commences to cling to the smooth ceiling within approx. 2 ft. from exiting the nozzles and continuous to flow in a regular pattern up and along the ceiling where it enters the lower part of the skylight at a velocity of 70 pfm.
Viewing the CFD generated Air Velocity and Temperature Gradient simulations (Figure 2), and the Recirculation Zone (Figure 2a) we see the following:

Air Velocities (AV):

- Air enters the lower part of the skylight zone at 75 fpm and gradually reduces in velocity such that at the upper part of the zone, the velocity has dropped to 45 fpm, continuing on, this air stream finally ends about 3 ft. from the fabric duct over Zone (C) at a terminal velocity of 5 fpm, insufficient in velocity to disturb this zone.

Temperature Gradients (TG):

- The general temperature of the air streaming under the skylight is 82^0F

Recirculation Zone (RZ):

- The air stream contours are close and regular showing a concentrated and regular airflow over this Zone.

Zone (A) and Zone (C) share a common duct and due to the proximity of the two types of air distribution devices it presents an interesting problem which is specifically highlighted by the CFD simulations. The exit velocity of the nozzle is some 7.5 times higher (2,200 to 295) in magnitude than that of the linear slots. If the slot were to be positioned at 180^0 (6:00 o'clock), circumferentially it would only be 39 inches from the nozzles. This would (Figure 4a) result in all of the slot air being drawn sideways and upwards into the nozzle air, leaving no air sweeping of the glazed area below with resultant loss of moisture removal in Zone A. A combination of high induction rate of the nozzles, with the low leakage rate of the fabric (1,8 cfm/ ft^2 @ 0,5 InchWG), and low fabric exit velocity (2 fpm) makes the short-circuiting of the slot air stream possible.
There are two ways in which to rectify this problem:

(a) By repositioning the linear slots from 180^0 to 150^0 the whole air pattern in the confined zone around the fabric duct changes drastically. (Figure 4b) The two exit zones are now 49 inches apart circumferentially; a 25% increase in the distance has effectually separated the air streams such that they perform as two distinct and individual flow patterns.

(b) By increasing the fabric duct wall leakage rate from 1.8 cfm/ft^2 to 54 cfm/ft^2 would increase the fabric exit velocity from 2 fpm to 60 fpm, an effective increase rate of 3000%. This local zone around the duct, extending in a circular pattern from the duct wall and out approximately 12” is now buffered by air at high velocity (60 fpm) emanating from the duct wall (primary air) and acting in the general direction of both the nozzle stream as well as the slot stream, rather than still air at (2.0 fpm) imparting sufficient air volume to be induced by the nozzle stream preventing inducement of the slot stream. A further aid in assisting air entrainment to the two high velocity streams is the fact that the excess air from the duct wall collects in the corner between the sloped ceiling and the exterior wall. Here it is basically trapped by the fabric duct itself and attains a high velocity as it passes vertically down towards the glazed area, and horizontally towards the ceiling. Both of these high velocity streams of primary air acts in conjunction with the intention of the slot and nozzle. (Figure 4e)

A short-circuiting of air as represented by the linear slot position 180^0 (6:00 o’clock) would result in dramatically different Air Velocity in Zone (A), with simultaneous consequences for Zone (B) (Figure 4c) The AV in the glazed zone would be virtually non existent dropping to a low figure of 5 fpm effectively negating any intended sweeping action. It should also be noted that a core of relative high velocity air (some 50 fpm) exists towards Zone B resulting in a wide spread of AV across the pool deck. The resultant TG (Figure 4d) shows a temperature zone stretching across the height of the glazing, some 6 inches wide, of 75^{0}F, where previously the air stream core temperature reached 86^{0}F

CONCLUSION

When viewing the various AV’s and TG’s it is noted that the warm dehumidified air is being put to good use where it is most required, leaving virtually no stratification of hot air under the roof. Local circular zones of hot air (90^{0}F) shows clearly being confined near the duct walls where air is being expelled at a steady rate through the fabric. This hot air however has little chance of stratifying as the high velocity exit air streams from the slots and the nozzles entraining all of this air and conveying it to the desired zones.

The temperatures across the pool space varies between 82^{0}F and 85^{0}F as primary and secondary air mixes well, leaving only a few relative cold spots, mostly where there is no occupancy or need for air sweeping.

The circumferential positioning, and choice of air diffusion devices for the fabric duct cannot be an arbitrary decision made in isolation from the space configuration, glazing position and general architecture of the pool space. The various simulations show clearly the fine differences in slot position required to either render the air distribution system successful in its intention, or to make it virtually impossible to deliver air as intended.

Any CFD calculation can in isolation from factual field measurements only present a picture of intentions and predictions. The accuracy of air flows, velocities, air pattern generation and other factors presented in this paper is thus only of an approximate character. CFD and fabric air distribution systems are a relatively recent phenomenon and the intention of this paper is to combine theory with practise. A certain amount of practical experience therefore forms the basis for parts of this paper.

NOTES

(1) *Glass airflow* – current industry practice
(2) *Air velocity over pool surface* - current industry practice