Air Conditioning for the Commonwealth Games – Meeting the Challenges

A view of the plant room at Indira Gandhi Sports Complex with 5800 TR total capacity of centrifugal chillers

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It was a race against time. Moving vast quantities of conditioned air through ductwork, some at heights of 30 metres to maintain comfort for some 7000 athletes and over 50,000 spectators from across the world in nine stadiums with a total cooling capacity of over 17,000 tons.

Amongst all the stadiums built for the Commonwealth Games 2010 in Delhi, the Indira Gandhi Indoor Stadium (IGI Stadium) and the SPM Swimming Pool Stadium were unique projects with technical specifications which required an innovative approach to achieve the desired conditions during the Games.

Indira Gandhi Indoor Stadium

This is a complete indoor stadium designed for Gymnastic events with a total area of 250,000 sq. ft., consisting of a spectator seating area for 22,000 persons and a performance or arena area where gymnastics are performed. The total heat load capacity and dehumidified air quantities calculated were:

	TR	CFM
Main seating area	2050	53,000
Performance/Arena area	300	17,000
Total	**2350**	**70,000**

The velocity of air movement had to be less than 0.5m/sec upto 20 feet height in the performance area as per International Federation Guidelines. Higher velocities would have disturbed the performance of the ribbon event in the Rythmic Gymnastic competition. With a total of 700,000 cfm air quantity being pumped inside the stadium, it became essential to rely on software design tools to ensure that the required velocity at the ground level in the performance area was achieved **first time right** as time was critical and there was no scope of re-working and balancing of air in ducts running at a height of 28 metres.

Design Philosphy and Equipment Selection

The IGI stadium is round with eight

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pylons placed at an equidistance from each other. These pylons are made at a height of 35 feet, and have AHU rooms to cool the entire stadium. Two AHUs have been installed for the main seating area and one AHU has been installed for the arena area. Since the height of AHU rooms is quite high, the duct level is also very high, 28m to be exact. Air is discharged through drum jet diffusers for both the arena as well as the main seating area. Part of the return air is taken back through a trench and a vertical shaft, and balance return air being taken back directly to the AHU rooms.

The Design Challenge

Since the gymnasts are supposed to perform using ribbons, apart from maintaining low temperature an extremely low air velocity was to be maintained so that the ribbon does not get disturbed due to high air velocity. Maintaining extremely low air velocity was a tough task as massive air quantities were being discharged in the arena area and that too at a high velocity using drum jet diffusers. In case the velocity increases beyond the specified limits, there was a huge risk of gymnasts getting disqualified.

CFD Analysis Adopted to Design the Air Distribution

In order to achieve the design conditions, we explored the possibility of using a tool which could assure us of obtaining the desired design conditions before finalizing our design. Accordingly, we went in for a design verification for our proposed design through a software technique "Computation Fluid Dynamics" (CFD). Since the games were to be held in October 2010, we went for this simulation study both for the peak load as well as for October, in order to obtain complete assurance of our design. (*See Page 54*).

SP Mukherjee Swimming Pool Stadium

The desired inside conditions for India's first Indoor Olympic Size Swimming Pool approved by the International Olympic Association were:

Summer & Monsoon

- Inside temperature: 22°C + 1.0°C with RH not more than 65% for VIP area, media area system control area on ground & 1st floor.
- Inside temperatgure: 25°C + 1.0°C with RH not more than 65% for spectator area, general area, outer concourse.
- Inside temperature: 28°C + 1.0°C with RH not more than 70% for warming and events swimming pool decks, changing rooms, shower rooms & inner corridor etc.

Winter Temperature

- Inside temperature : 20°C for all areas other than swimming pool sides.

These inside conditions are supposed to be met without any thermal barrier between the Swimming Pool Deck and the Spectator Area. Based on these design conditions, the total load worked out was 1600 TR and it was proposed to have 5x390 TR capacity screw chillers with one chiller working as standby.

In the deck area, ground floor racing pool and diving pool, floor mounted short height fan coil units were installed with fresh air supply from the ground floor AHU. Additional provision of a heating coil was considered for the fan coil units of the deck area to maintain the condition in winter in line with the pool temperature.

To meet the design conditions for the spectator area, no ducting was allowed by the International architects. For the spectator seating area from 3rd floor down to ground floor, vertical tower type AHUs complete with discharge plenum (acoustically insulated with mineral wool insulation) and a supply air register were fixed in a three tier formation. The supply air registers have perforated distribution plates having perforations of not less than 10 mm dia holes at center to center distance of 15 mm. The distribution plate is out of GI 18 gauge thickness. The distribution plate is fixed before the volume control damper to provide uniform flow of air over the entire surface of the register. The topmost registers cater for the 1st & ground floor spectators (a throw between 22 to 27 meters), the middle tier have a throw of between 8 to 21 meters and the bottom most registers have a throw of 7 to 8 meters. All AHUs have two speed motors to regulate the air as per requirements.

In order to achieve these critical design conditions we had to rely on a CFD analysis for the entire indoor area, similar to the analysis for the IGI Stadium, described on page 54.

Thyagaraj Stadium

This was the venue for the netball competition and has an installed capacity of 1323 TR, using an Exhaust Gas Fired Vapour Absorption Machine coupled with a gas fired turbine. This co-generation system provides the complete air conditioning system for the stadium almost free. Co-generation system has a 3 MW gas turbine coupled with the vapour absorption chiller.

The basic objective of this system is that once the games are over, power from the turbine will be supplied to the main electricity grid of Delhi. Chilled water available from VAM a will be supplied to the All India Institute of Medical Science which is situated 2 kms away from the stadium through underground piping. With this dual approach, this venue has become India's 'first green stadium' with a long-term objective of providing an energy efficient solution. In addition to VAM, there is a provision of 4x400 TR water cooled, electric driven screw chillers that are ECBC compliant.

The stadium is constructed on the "green building" concept in order to maintain minimal carbon foot prints. To achieve the same, in addition to the above, the following measures have been applied:

- Use of fly ash bricks for construction purpose.
- Effective and efficient rain water harvesting system.
- Use of solar energy by using solar panels which enables generation of 1 MW of electricity, which will be used within the building and also put into the grid.
- Use of specialised double glazed glasses that allow high light transmission but low heat transmission.
- Use of energy efficient lighting system.

Other Features and Highlights

Indira Gandhi Indoor Stadium

• Delhi's second-biggest air conditioning plant in a single infrastructure location, of 5800TR (1st being Delhi Airport) • VFDs for centrifugal chillers, pumps, cooling towers, AHUs • Engineered ozone system for indoor air quality, imported from Ruks of Canada • Insulated spiral ducts in double and lower construction at 30m height; 5 kms length, minimum 550 mm and maximum 1100 mm diamater

S P Mukherjee Swimming Pool Complex

• 1950 TR plant capacity • Custom-designed vertical AHUs with acoustic enclosures/grilles • Energy-efficient screw chillers with R-134a refrigerant, variable speed pumping system, VFDs for cooling tower and AHUs etc.

K D Jadav Wrestling Stadium

• Main feeder supply of chilled water from main plant room at a distance of 1 km. • VFDs for AHUS and variable speed pumping • Engineered ozone system for indoor air quality, imported from Ruks of Canada • Building Automation System for monitoring and control of HVAC system.

Velodrome (cycling) at Indira Gandhi Sports Complex

• Screw chillers with R-134a refrigerant (ECBC compliant), 1050 TR capacity • Double-skin AHUs with VFD for energy conservation. • Variable speed pumping system for energy conservation. • Engineered ozone system for indoor air quality, imported from Ruks Engineering, Canada. • Centralised Building Automation System to monitor & control HVAC system • The world's second-finest velodrome (after Beijing Olympic velodrome).

Jawaharlal Nehru Stadium

• Renovation/upgradation of facility. • 1280 TR energy-efficient screw chillers with R-134a refrigerant (ECBC compliant) • 418 CH.W. cassette units for space air conditioning • Variable speed pumping system for energy saving • IBMS commissioning with 20,000 data points from various agencies i.e. lighting, diesel generators, lifts. Total coordination required with other agencies for cassette unit installation • Silent AHUs for VVIP zone (including Queen's Box, and areas for Heads of State) • Conduiting & cabling of approx 15 km. • Grid piping in 2 km circumference.

Thyagaraj Sports Stadium

• Duct installation at 20m height • Grid piping of approx 3 kms. • Vapour Absorption Machine (1320 TR) delivered in 5 months from date of clearance. • Co-generation VAM (1320 TR) run by exhaust from CNG-fired turbine. • Energy-efficient (ECBC compliant) screw chillers (1600 TR) as standby • Variable speed pumping system for energy saving. • VFDs for cooling towers and AHUs

Vapour Absorption Machines

Never previously used in any sporting venue. The 1300 VAM was powered by hot exhaust from the stadium's 3MW gas turbine.

Absorption Chiller fired by exhaust from gas turbine

Ozone System

Ozone system for Indoor Air Quality, never before used in large public sports arenas, effectively dealing with • odour control • fungus growth. • high CO_2 levels caused by the large crowd presence. • Installed at Delhi University Rugby Stadium • K D Jadav Wrestling Stadium • Indira Gandhi Indoor Stadium (gymnastics) • Velodrome (cycling) at Indira Gandhi Sports Complex.

Variable Refrigerant Flow (VRF) system with 'green' refrigerant R410a Installed at:

• Karni Singh Shooting Range (976 HP) • Velodrome at Indira Gandhi Sports Complex (492 HP) • Yamuna Sports Complex (426 HP).

VRF Systems

Chilled water piping at Thyagaraj Stadium

Chillers at Jawaharlal Nehru Stadium

Chillers at Indira Gandhi (IG) Sports Complex

Cooling towers at IG Sports Complex, Delhi's 2nd-largest HVAC installation

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CFD Analysis

(A part of the report)

Objective

- To understand the air flow profile within the IGI stadium
- To highlight the possible design improvement and the controlled air flow patterns
- To restrict air velocity in the arena area
- To evaluate and improve the internal air flow by changing the nozzle direction and return air path.
- To achieve the desired temperature and to verify the equipment selection
- To increase the comfort of the audience by maintaining a uniform temperature within the occupant height.

Methodology

The problem size was very large and the details of air movement pressure and temperature profiles were required with maximum possible accuracy. Another limitation was of tight time lines and getting a good and acceptable convergence of the solutions.

We started by building the flow domain where our air flow and thermal calculation needed to be performed, then moved to meshing or geometry discretization followed by assignment of boundary conditions. The next step was selection of the solution model and controls of solver convergence etc. and then post processing and results. The following sections describe the details of each of the above stated steps of the analysis.

Study Domain Identification

Since the geometry volume was too large, it was apparent that solution of such large size problem would require months with the available configuration of hardware we have at our disposal. Also, such kind of problem can be downscaled because the geometry is made of symmetric components (sectors of 360/8). In Indra Gandhi stadium, there were 8 AHU rooms all symmetric in the operational sizes (89256 CFM capacity) and also the heat load distribution of all 21500 or less people in the domain can be assumed to be uniformly distributed through out the seating area of the stadium. So we have divided the geometry in 1/8th of the actual air flow domains. See *Figure 1*.

Geometry Discretization/Meshing

The geometry discretization or fineness of meshing decides on what type of spatial accuracy is required with in the calculation domain. For example if we need to calculate or see the temperature of air flow profile near a diffuser the size of the mesh near the diffuser needs to be fine compare to the rest of the volume where we are not specifically targeting the profile. In *Figure 2* a meshed/descretized view of the geometry is shown. If one looks at this figure carefully, an understanding can be developed of where the mesh is fine and where it is kept normal. Since the density of mesh is directly proportional to the systems RAM usage so it is not possible to put very fine mesh every where in the volume. We were judicious about assigning the mesh size so as to reduce the computation time etc. The mesh type considered was tetrahedral in nature.

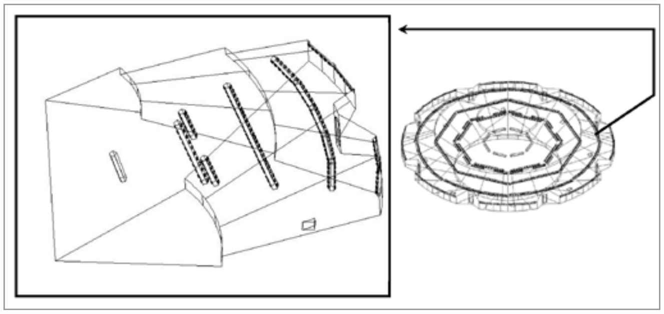

Figure 1: Problem Downscaling
This figure describes how 1/8 sector of the stadium volume was picked up as a representative calculation domain. The element properties for the sector volume are listed in the Table 1.

The identified area like the roof, seating area and the diffuser etc. were active in adding heat to the system. The heat load of the entire stadium was assigned to these surfaces to simulate the existence of people and associated heat liberation from them. Hence the area in blue which is the roof and the area in green in *Figure 2* is densely meshed to generate higher accuracy calculation. *Table 1* lists down the areas and the mesh sizes considered.

Table 1: The surface and volume mesh

S.No.	Element Name	Mesh Sizes (in Millimeters)
1	AHU Return on the wall	1000
2	Over-head Duct	1000
3	Arena Areas (Ground)	1000
4	The Over-head Diffuser Jets	100 (Since it is thermally active)
5	Passive Diffusers	1000
6	The Stadium Roof	500 (Since it is thermally active)
7	Seating area in the stadium	500 (Again thermally active area)
8	Symmetric boundary 1: The symmetry boundary condition is a boundary which acts as a mirror to the condition that prevails on its other side. This helps us create a boundary with our knowledge of the prevalent condition before hand	3000 (Since were not interested in the detail at this location)
9	Symmetric boundary 2 : same as above	3000 (Since were not interested in the detail at this location)
10	The inner duct which is acting as a return	100 (Pressure and velocity needs to be evaluated)
11	Walls in the stadium	500. (Considered adiabatic in few places)
12	The Volume Mesh Size	3000 with a smooth density transition of 1.2
13	The total number of Nodes in the volume	198954 Nodes

The Boundary Conditions & Domain Models

The modeling was done on a steady state basis but large volume indicated that it is more of a transient nature. The model solution algorithm was selected as shear stress transport (SST).

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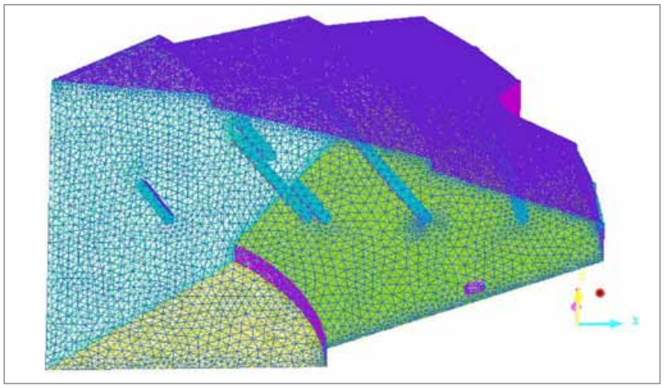

Figure 2: Meshing

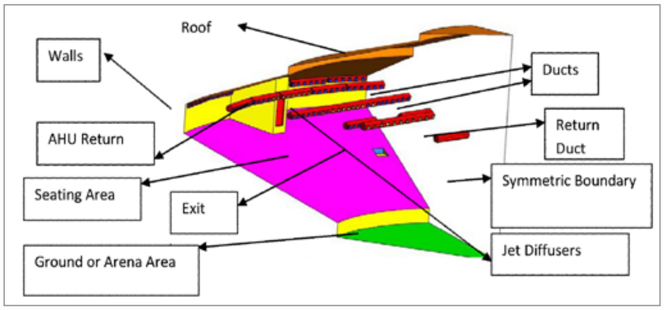

Figure 3: Boundary element details

Bouncy model was also applied to the study domain so as not to miss out the thermal stratification effect and the air flow requirement which might be dictated from that. The physical properties of air considered were of air at 25°C and average density of 1.2kg/m^3. *Table 2* lists down the boundary conditions specific to each element.

The Post Process

The post process includes plotting and understanding the results on the various points and surfaces. The objective of the analysis was to make sure that the velocity and temperature profiles at the arena and the seating location are as per the expectations. Just to benchmark and test the results and various modeling strategies which were applied, the pressure profile and equation imbalances were checked. The bouncy in the pressure profile was evident, which actually showed the behavior of thermal stratification in the study domain.

Various results related to the air flow behavior are highlighted and their interpretations are given in the following section of the report. The velocity profile in vertical plane, velocity vector profile in horizontal plane, temperature profile in both the vertical and horizontal plane are discussed.

The Velocity Profile

Figure 4 shows a velocity contour for a vertical section of the stadium volume. This contour exhibits the fact that the diffuser nozzles which were prescribed as per the Appendix A work well and they deliver the results as per the expectation.

Table 2: A list of the proposed boundary conditions applied to simulate the air flow

The Boundary Conditions per pillion
Total Capacity 256 TR, 67244 cfm (38.07 kgs or 67244 cfm of air @14°C supply & 12.46 kgs or 22012 cfm of return)

S.No.	Element Name	Boundary Details in Respective Units
1	AHU Return on the wall	Outlet Boundary : opening on -200 Pa (19.95 kg/s, 35232 cfm or 52% of the total return/pillion)
2	Over-head Duct Surface	Adiabatic (as it was told that this surface is insulated) used for approximate heat load distribution
3	Arena Areas (Ground)	30 W/m^2 of sensible and latent heat injection into the system
4	The Over-head Diffuser i.e. rings 1, 2,3,4,5. etc.	Inlet Boundary: Static pressure of 450 Pa, Peak profile tip Velocity of 5 m/s and (0.286 Kg/s or 505 cfm) / diffuser. Catering 256 TR @ 14°C
5	Passive Diffusers	Adiabatic
6	The stadium Roof	Heat transfer coefficient of 0.9 W/m^2 .°C @ out side surface temperature of 50°C
7	Seating area in the stadium	150 W/m^2 sensible and 120 W/m^2 of latent heat injection into the system
8	Symmetric boundary 1	Boundary Type : Symmetry
9	Symmetric boundary 2	Boundary Type : Symmetry
10	The arena ducts which are acting as a return i.e. ring 6.	Outlet Boundary : Static pressure on -400 Pa and 12.46 kg/s (22012 cfm)
11	The trench	Outlet Boundary : 5.66 Kg/s (10000 cfm) used for 14 % of return air/ Pillion
12	Walls in the stadium	Heat transfer coefficient of 2.0 W/m^2 °C @ out side temperature of 45°C

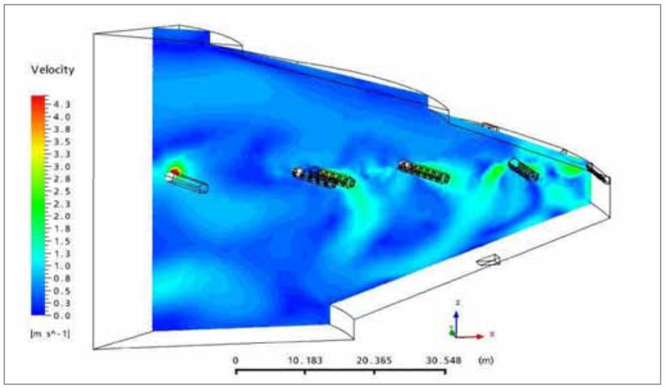

Figure 4: Velocity profile in vertical

The direction of the diffuser nozzles was decided based on the fact that two corresponding nozzles facing each other from two consequent rings should face each other incoming stream and reduce the velocity after striking each other. Hence the low velocity cold air falls down and warm air rises up easily.

Temperature Profile

The temperature profile of a section plane is shown in *Figure 5*. If we look at the section plane carefully it is evident that if we resort to lower velocities from the diffuser nozzles, higher

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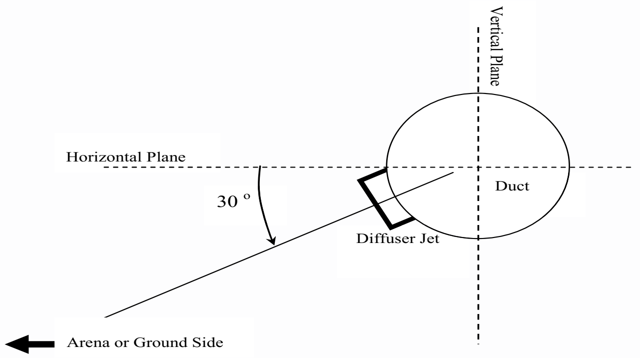
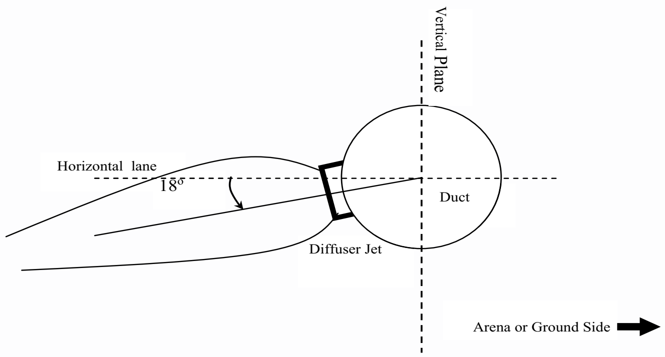
Appendix A : Angle of Throw

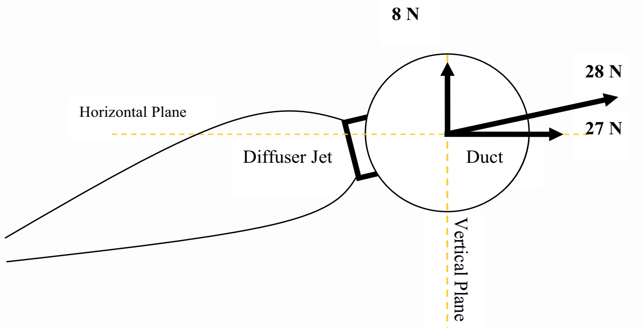


 # Ring1 towards ground, ring2 towards ground, ring3 towards ground and AHU side and 4 towards AHU sides needs to follow the above angles



 # Ring2 towards AHU side, ring5 towards ground side needs to follow the above angles

Appendix B : Reactive Force



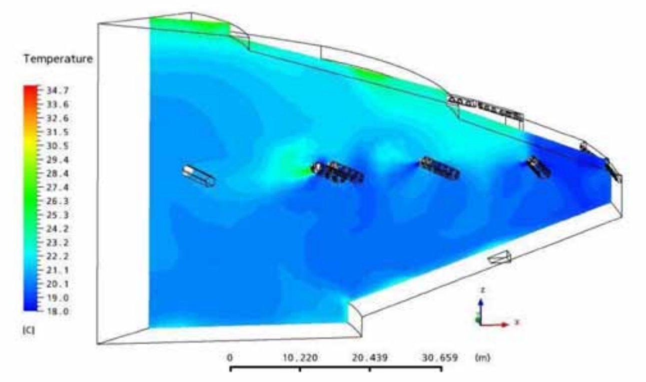
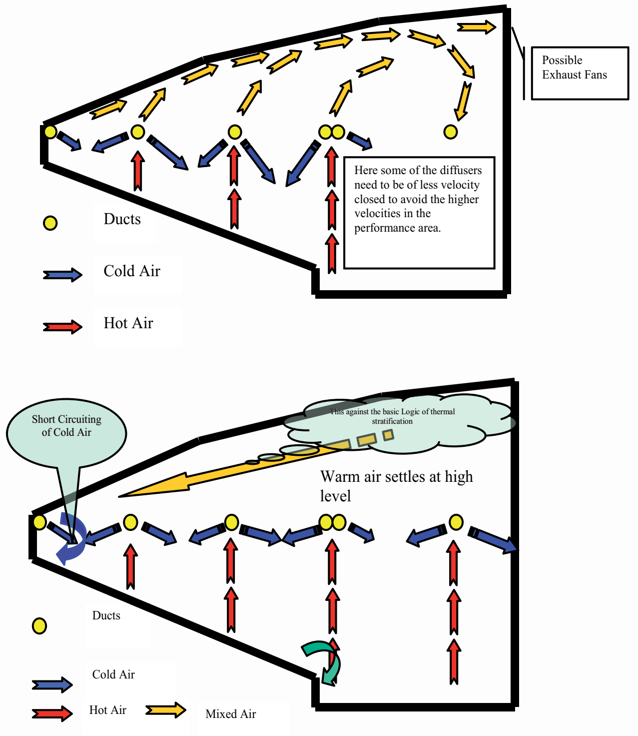


Figure 5: Temperature profile

Appendix C : Basis of Design Air Flow Design - Concept Illustration



thermal stratification is achieved. Still with current profile velocity of 7 m/s the thermal stratification is maintained.

The higher parts of the stadium are warmer than the part nearer to the seating and ground area. This has been achieved by following the diffuser angles described in appendix A.

Conclusions & Recommendations

The entire analysis is done using the usual methods of computational fluid dynamics. The important out comes of the simulation are listed in Appendix A and Appendix B. Appendix C describes the basis or the logic of the entire design which was considered for the design approach. If we were to elaborate, the basis of the design was to maintain the thermal stratification in the space and not to create unwarranted turbulence and hence the air velocity. By keeping a certain angle of throw from the diffuser nozzles, we were able to achieve an acceptable air velocity profile in the arena and the seating area. The details of the angle can be seen in Appendix A (Angle of Throw). Similarly an important parameter which needs to be looked at this point of time is the reactive force on the duct when the diffuser nozzles are throwing the air at peak flow rate, then there is a good bit of thrust, which might alter the approach to the support design. The details of the thrust are described in Appendix B.

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