Experimental and Simulation based comparative analysis of UFAD and OHAD in Air-conditioning of room

Omprakash Ahirwar[1], Neeraj kumar Ahirwar[2], Ishwar Singh[3]

[1]*ahirwar.omprakash@gmail.com*

[3]*ishwar.manit@gmail.com*

Scope College of Engineering, Bhopal, M.P., India[1, 2, 3]

Abstract: This research compared the air use for under floor and over head air supply displacement ventilation system in a close chamber. It has several potential advantages compared to conventional overhead (OH) mixing systems. However, most of the energy simulation programs widely used by the industry are not able to represent two distinct features of UFAD systems: room air stratification and the underfloor supply plenum. This study reports a field study of simulation of the result analysis UFAD and OHAD system in terms of relative humidity, ventilation performance and temperature stratification one of the sources of energy use. Overall, the performance of UFAD was substantially better than would be expected for an overhead mixing ventilation system.

Keywords: UFAD, OHAD, Air-conditioning, CFD technology, Diffusers, Relative Humidity (%), Velocity (m/sec), Temperature(°C),

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I. INTRODUCTION

In this era of technology, humans have facing a serious shortage of resources. Saving energy has become the focus in countries around the world. In energy consumption, buildings section is the main energy consumer, among which air conditioning system is up to 60%～70%. There-fore, to save energy, the prospect of energy efficiency of air conditioning is very broad. In addition, as people's indoor retention time increase gradually, indoor air quality is directly related to the personnel health and work efficiency. Sick building syndrome caused by the bad indoor ventilation has aroused wide attention of all social sectors, so the improvement of the indoor air quality (IAQ) has become one of the problems which should be solved in air conditioning system.

Underfloor air distribution system (UFAD) is a mechanical air distribution strategy in which the conditioned air is primarily delivered to the zone from a pressurized plenum through floor-mounted diffusers. The benefits include indoor air quality, thermal comfort, and reduced energy use. The energy benefits depend on the climate conditions. These systems are increasingly popular alternatives to the traditional overhead systems, which attempt to condition the air in the whole volume of space.

Under-floor air distribution system has been used more and more widely in office buildings because of its superiority of flexibility, energy saving, lower investment, improvement of comfort and health, and satisfaction with individual requirement of local thermal environment control. In this paper first a review on the application and development of under-floor air condition system has been carried. Then an office room with under- floor air condition has been simulated to learn the indoor temperature field, velocity field and thermal comfort in the circumstances of under floor air distribution.

Through the simulation and analysis, when human feel the most comfortable in under floor air distribution room, parameters such as air temperature, air velocity and air supply

volume have been obtained. This research work aims to demonstrate how CFD technology can be used to under floor air distribution and overhead air distribution parameter like velocity, temperature, and different mole fraction relative etc, and compare them a practically.
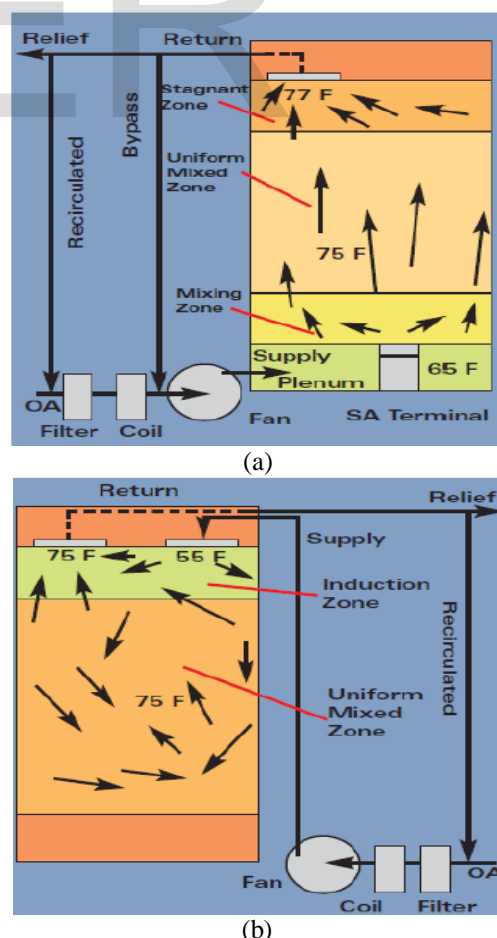

(a)

(b)

Figure 1: (a) UFAD and (b) OHAD system [22]

The systems are designed for the lower occupied zone only. The temperature conditions in the upper zone are allowed to float above normal comfort ranges. To avoid occupant discomfort, air is introduced into the space between 65°F and 68°F.

For overhead air distribution system, cooled air enters the occupied zone through an inlet located at the ceiling level supplying a vertical downward inflow. Three different locations of the inlet diffuser are considered. For overhead air distribution system, the inlet is located on the ceiling with slower and cooler inflow. For overhead well mixed systems, one should select a unit with throw at max, and minimum, flow that meets ADPI guidelines based on diffuser spacing and T50 (throw to 50 fpm). Additionally, select for maximum mixing:

- Noise can be good.
- Dirt on the ceiling is not bad.
- Air Distribution Effectiveness (ADE) is a new term describing room air mixing, and is a parameter with all delivery methods.

II. UFAD SYSTEM DESIGN

The key UFAD system components that are unique to this system type are the raised floor and the floor diffusers. Figure 2 shows a typical raised floor construction where wood walls space length 2 meter and space width 1.2 meter, Ceiling height = 0.022 m, are supported on each corner by steel pedestals. Typical heights for raised floors are in the range of 12 to 15 inches from top of the structural floor to top of the raised floor. Many times the raised floor is made accessible so that data and other building services can be run in the supply plenum, although this is not always the case.

Figure 2: Typical Raised Floor Construction

A: The Diffusers

The diffusers are the other unique element of UFAD systems. Diffusers are passive HVAC elements that have no moving parts. The blades of the diffuser are arranged in a radial pattern and are designed with an outward throw angle. The concept behind the swirl is a high induction characteristic

that mixes cold supply air quickly with room air. The design airflow quantity for a swirl diffuser is usually around 85 cfm per diffuser at roughly 0.5" pressure drop. Air discharged through the diffuser generally reaches a velocity of 50 feet per minute somewhere in the range of 4 to 5 feet above the diffuser. There are basically two major types of UFAD diffusers: swirl and variable area. Figure 3 shows floor diffuser.

Figure 3: Typical floor diffusers

TABLE 1: UFAD DIFFUSER COMPARISON DATA

Model	Discharge Setting	Airflow [ft3/min]	Vertical Throw to 50 fpm [ft]	Clear Zone Radius [ft]
Swirl	Vertical	100	4 – 6	1.5
	Vertical	75	2.5 - 4.5	1.5
Variable Area	Vertical	150	8	2.0
	Full Spread	110	5	4.5

Both VA diffusers and swirl diffusers can be used in VAV applications of UFAD systems. With a VA diffuser, because the exposed area of diffuser plate varies proportionally to the airflow demand, the discharge velocity of the air leaving the diffuser stays relatively constant as the diffuser turns down. The momentum, mixing vs. buoyancy and stratification characteristic of a VA diffuser does not change nearly as much as a swirl diffuser as described above.

B: Mathematical Formulation

This chapter is a review of general theory of the governing equations for fluid flow. The governing equations of fluid flow are called the Navier-Stokes equations. In this section, concisely we will discuss the principles of the CFD with its components. Moreover, fundamental description of turbulence will be described. The Governing Equations are;

Mass Conservation Equation:
$$\frac{\partial \rho}{\partial t} + \nabla. \rho U = 0 \qquad (1)$$

Momentum Equation:
$$\frac{\partial \rho (u,v,w)^T}{\partial t} + (\nabla \rho U u, \nabla. \rho U v, \nabla. \rho U w)^T +$$
$$(-\frac{\rho w^2}{r}, \rho g, \frac{\rho u w}{r})^T = -\nabla \pi + \nabla. \tau \qquad (2)$$

Energy Equation:
$$\frac{\partial \rho h}{\partial t} + \nabla. \rho U h = \nabla. \lambda_e \nabla T - \nabla. q_{rad} + \nabla. \sum_i \rho h_i (T) D_e \nabla Y_i$$
$$(3)$$

Species Equation

$$\frac{\partial \rho Y_i}{\partial t} + \nabla . \rho U Y_i = \nabla . D_e \rho \nabla Y_i - R_i$$

$$(4)$$

The enthalpy h is defined by:

$$h = \sum_i Y_i h_i(T) \qquad (5)$$

Where $h_i(T)$, is the specific enthalpy of species i, includes the heat of formation of i. When needed, T is computed using h, Yi. Where Y, h, λ_e, ρ and R_i are the enthalpy mass fraction, effective diffusivity and the flow density and mass rate of consumption of species respectively.

C: Turbulence Model

Turbulence is simulated using the Standard k-ε model. In this model, the model transport equations are solved for two turbulence quantities i.e., k and ε. The Standard k-ε model turbulence model solves the flow based on the assumption that the rate of production and dissipation of turbulent flows are in near- balance in energy transfer. The k and ε equations are given by:

$$\frac{\partial \rho k}{\partial t} + \nabla . \rho U k = \nabla . (\alpha \mu \nabla . k) - R_{ij}\frac{\partial U_i}{\partial x_j} - \rho \epsilon \qquad (6)$$

$$\frac{\partial \rho \epsilon}{\partial t} + \nabla . \rho U \epsilon = \nabla . \left(\frac{\mu_t}{\sigma_t} + \mu\right) \nabla \epsilon - C_1 . \frac{\epsilon}{k} R_{ij}\frac{\partial U_i}{\partial x_j} - C_2 \rho \frac{\epsilon^2}{k}$$

$$(7)$$

The standard value of k-ϵ is used.

D: Model formulation for the System

The numerical simulation of the ceiling air distribution (CAD) system and numerical simulation of the under floor air distribution (UFAD) system, based on the dimensions of the air conditioning of a room, is studied using a computational fluid dynamics (CFD) technique. The CAD system of the air conditioning of a room included three cone diffusers. The analysis of the experimental system is made and a simplified geometry of the air conditioning of a room for UFAD and CAD system simulation is generated .The initial computational domain data for simulating the CAD and UFAD systems of air conditioning of a room is shown in Figure 4 and Figure 5.

Parameters for test space of the air conditioning of a room were:

- Space length = 2.0 m
- Space width = 1.2 m
- Ceiling height = 0.022 m
- Plenum height =0 .022 m
- Space floor area = 1.47 m2
- Air diffusion performance index >80
- Room wall surface temp, Temp = 36 (°C).

Underfloor approachFresh air is delivered closer to the occupantsFloor-to-ceiling air flow pattern provides improved Indoor air quality in occupied zone (up to 6 ft [1.8 m]).Local air supply improves air motion, preventing sensation of stagnant air.The suppy air temperature can be 2-5°C higher than that in a ceiling based system.
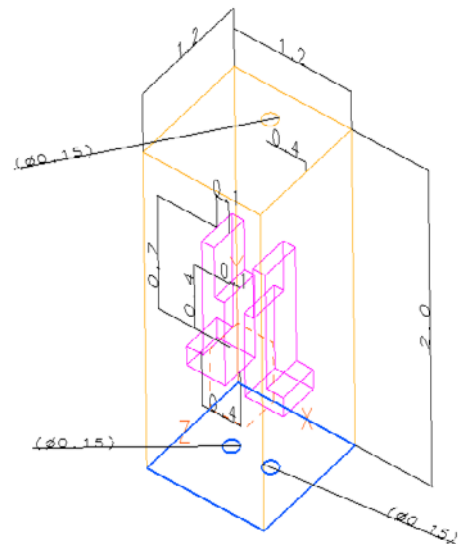

Figure 4: CAD model of Underfloor air distribution system

Overhead air distribution system supplying air standard approach Fresh air is delivered farther to the occupants.ceiling-to-ceiling air flow pattern provides improved Indoor air quality in occupied zone.The suppy air temperature can be 2-5°C higher than that in a ceiling based system
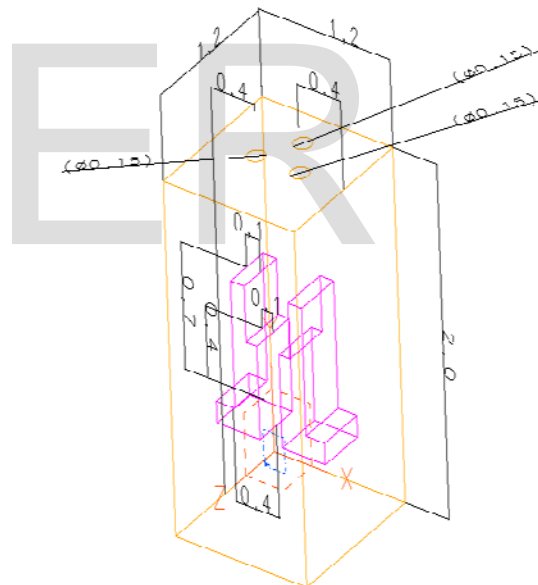

Figure 5: CAD model of over head air distribution system

E: Experimental Setup & Initial Boundary Conditions

The principle of this task compared the performance of UFAD and CAD systems. The conventional air distribution system has two ceiling diffusers, and one return air diffuser ceiling, as shown in Figure 6 and Figure 7. The UFAD system has an under floor plenum, and two floor diffusers, as shown in Figure 8 and Figure 9. The return air diffuser is the same as the CAD system.
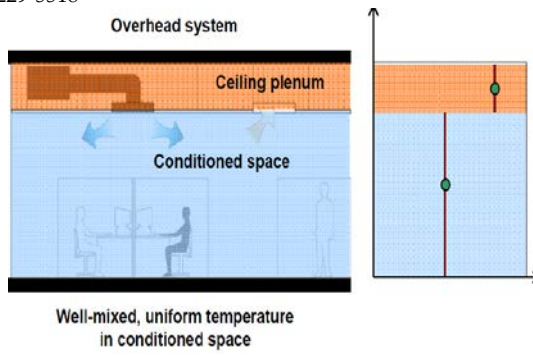
Figure 6: Model of Overhead air distribution system

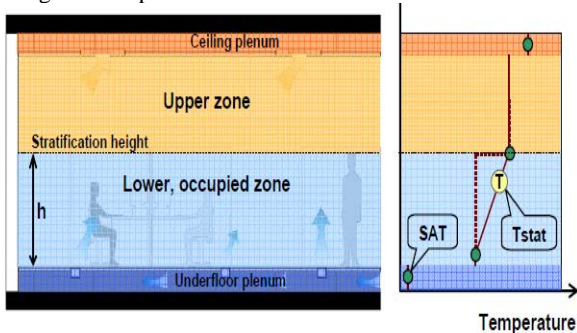Figure 7: Experimental model of Overhead air distribution system

Figure 8: Model of Underfloor air distribution system

Figure 9: Experimental model of UFAD system

The meshing of UFAD and OHAD systems are shown in Figure 10 and Figure 11 respectively with following details. No .of nodes are 2342 and No. of element are 1605.
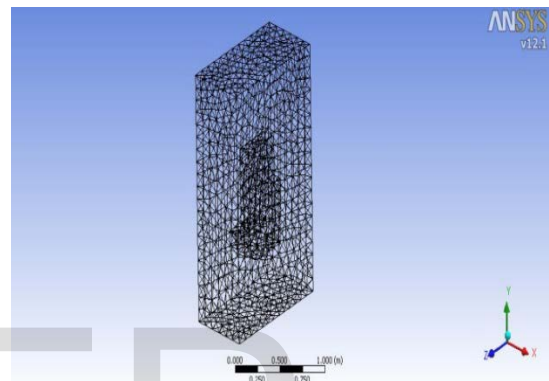
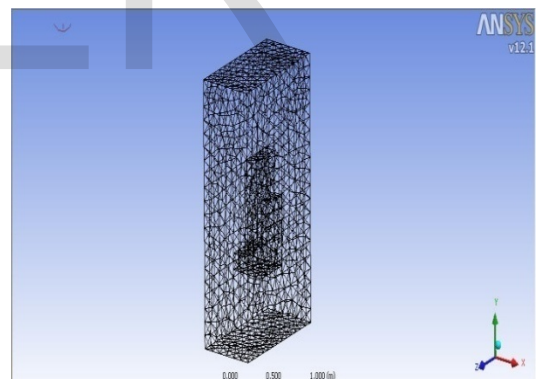

Figure 10: Meshing of under floor air distribution system

Figure 11: Meshing of overhead air distribution system

TABLE 2: INITIAL BOUNDARY CONDITIONS

Air Distribution System	Underfloor	Overhead
Inlet temperature of air	$20°C$	$18°C$
Inlet speed of air	1.0 m/s	0.6 m/s
Inlet direction	Vertical upward	Vertical downward

Human body temperature considers is $40°C$. Sidewall temperature considers is $36°C$. Ceiling temperature considers is $36°C$. Floor temperature considers is $36°C$. Turbulent intensity is 1% and turbulent viscosity ratio is 1 and the Pressure of air in outlet condition is atmospheric pressure and gauge pressure is zero.

F: Problem Solution

The following Solution method is as follows:

a) Pressure of air consider as atmospheric pressure
Energy equation:

$$\frac{\delta}{\delta x_j}\left(\rho u_j C_p T\right) = \frac{\delta}{\delta x_j}\left(\lambda \frac{\delta T}{\delta x_j} - \rho \overline{u_j' T'}\right) \qquad (8)$$

Where ρ is the density, μ is the viscosity, p is the pressure, C_P is the specific heat capacity, λ is the thermal conductivity.

Momentum equation:

$$\frac{\delta}{\delta x_j}\left(\rho U_i U_j\right) = -\frac{\delta P}{\delta x_i} + \frac{\delta}{\delta x_j}\left(\mu\left(\frac{\delta U_i}{\delta x_j} + \frac{\delta U_j}{\delta x_i}\right) - \rho \overline{u_i' u_j'}\right) - \rho g_i \qquad (9)$$

Where ρ is the density, μ is the viscosity, p is the pressure, C_P is the specific heat capacity, λ is the thermal conductivity.

b) Turbulent kinetic energy turbulence dissipation

The specific turbulence dissipation ω is the rate at which turbulence kinetic energy is converted into thermal internal energy per unit volume and time. Sometimes the specific turbulence dissipation, ω, is also referred to as the mean frequency of the turbulence. This is mainly based on dimensional analysis. The SI unit of ω is 1/s.

There is no strict mathematical definition of the specific turbulence dissipation, ω. Instead it is most often defined implicitly using the turbulence kinetic energy, k and the turbulence dissipation, ε:

$$\omega = \frac{\epsilon}{k\beta^*} \qquad (10)$$

Where β^* a model is constant, most often set to:

$$\beta^* = C_\mu = 0.09$$

Please note that some models/codes instead use a different definition without the model constant:

$$\omega = \frac{\epsilon}{k} \qquad (11)$$

Solution initialization- Solution initialization at inlet condition
Run calculation-Number of iteration is 500

RESULTS

A: Result of Underfloor Air Distribution System

TABLE 3: EXPERIMENTAL RESULTS OF UFAD SYSTEM

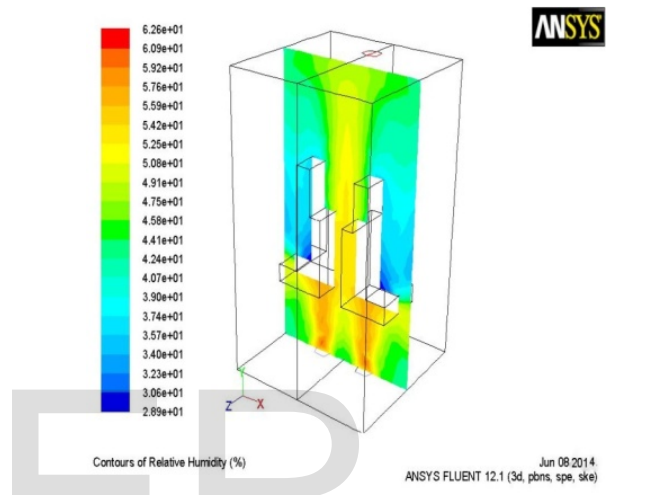| S. No	Time (min)	Temp (°C)	RH (%)	Velocity (m/s)	Height (m)	Power (Kwh)
1	30 min	25	47	1.5	.4	1122.5
		24.5	49	2.1	.8	
		25	50	1.7	1.2	
		27	51	1.5	1.6	
2	30 min	26	50	1.6	.4	1123.2
		24	49	2.1	.8	
		25	52	1.6	1.2	
		26	51	1.5	1.6	
3	30 min	24	50	1.6	.4	1123.9
		25	52	3.4	.8	
		25	53	1.7	1.2	
		26	52	1.4	1.6	
4	30 min	24	49	1.6	.4	1124.6
		25	52	3.5	.8	
		25	51	1.6	1.2	
		26	52	1.2	1.6	
5	30 min	24	49	1.7	.4	1125.3
		25	50	2.1	.8	
		25	53	1.6	1.2	
		26	52	1.6	1.6	

Figure 12: Analysis of Relative humidity (%) in under floor air distribution system

(a)

(b)

Figure 13: (a) Simulated Graph and (b) Experimental based Graph between Position & Relative Humidity (%) in UFAD system

(b)

Figure 15: (a) Simulated Graph & (b) Experimental based Graph between Position and Velocity (m/s) in UFAD system

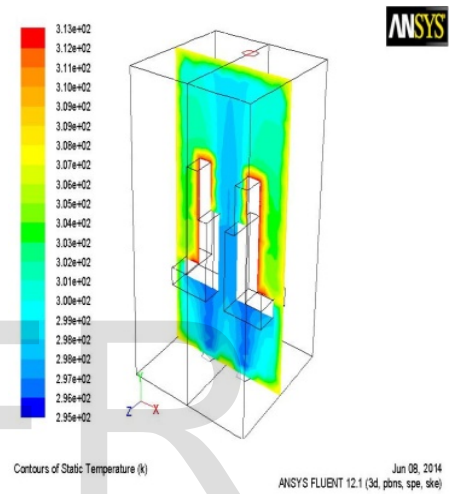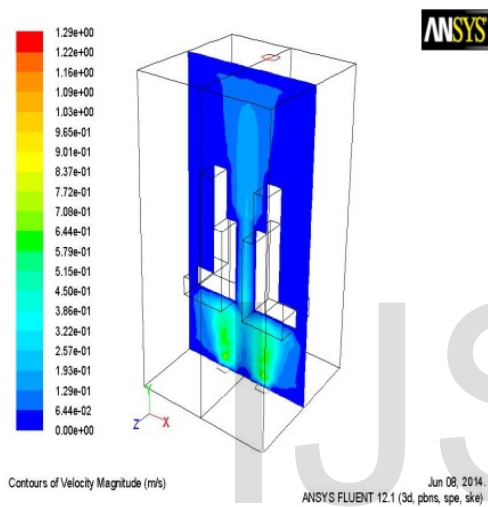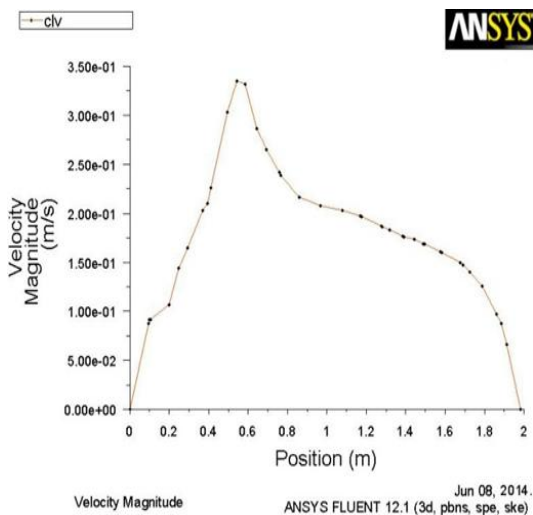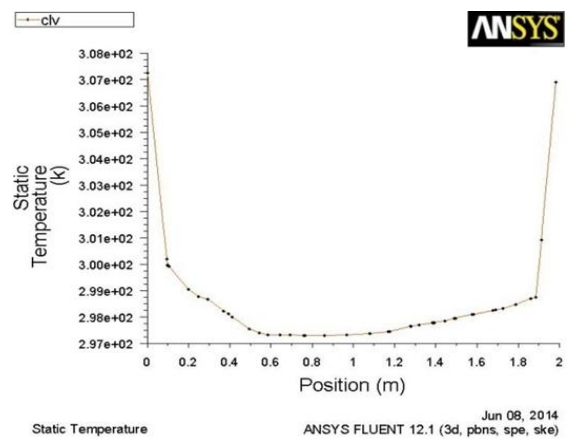

Figure 14: Analysis of Air Velocity in Under floor air distribution system
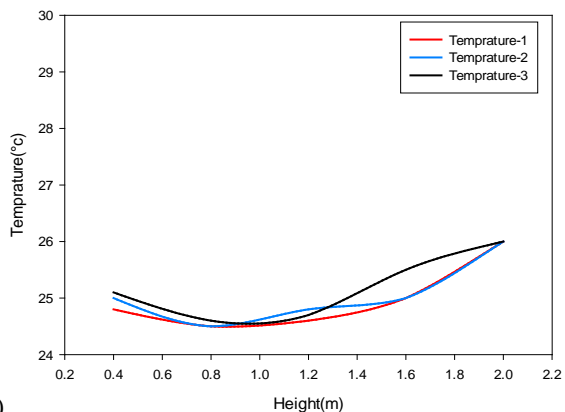

Figure 16: Analysis of air Temperature in UFAD system

(a)

UFAD Temprature Graph

(a)

(a)

Figure 17: (a) Simulated Graph & (b) Experimental based graph
between Position and Temperature (^{o}C) in UFAD systems
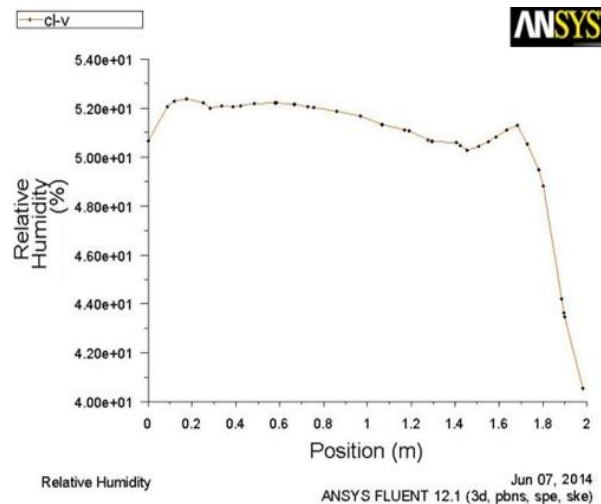
B: Result of Overhead Air Distribution System

TABLE 4: EXPERIMENTAL RESULTS OF OHAD SYSTEM
Sub Meter Reading-Initial Reading:-1115.1 Kwh

| S. No	Time (min)	Temp (°c)	Rh (%)	Velocity (m/s)	Height (m)	Power (kwh)
1	30 min	25	51	5.1	.4	1116
		25	48	5.6	.8	
		26	51	6	1.2	
		28	45	6.6	1.6	
2	30 min	24	52	5.1	.4	1116.9
		25.1	51	5.5	.8	
		26	52	5.8	1.2	
		28	44	7.2	1.6	
3	30 min	23	53	5.	.4	1117.8
		25.2	52	5.6	.8	
		26	52	6	1.2	
		28	45	7.2	1.6	
4	30 min	24	52	5.1	.4	1118.7
		25	52	5.5	.8	
		25	51	6	1.2	
		28	45	6.9	1.6	
5	30 min	25	52	5.1	.4	1119.6
		25	51	5.6	.8	
		26.2	52	6	1.2	
		28	45	7.2	1.6	

OHAD Relative Humidity Graph
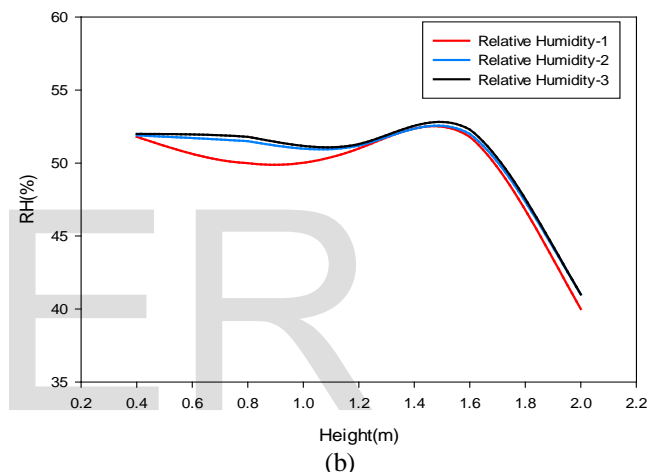
(b)

Figure 19: (a) Simulated Graph & (b) Experimental based Graph
between Position and Relative Humidity (%)) in Overhead air
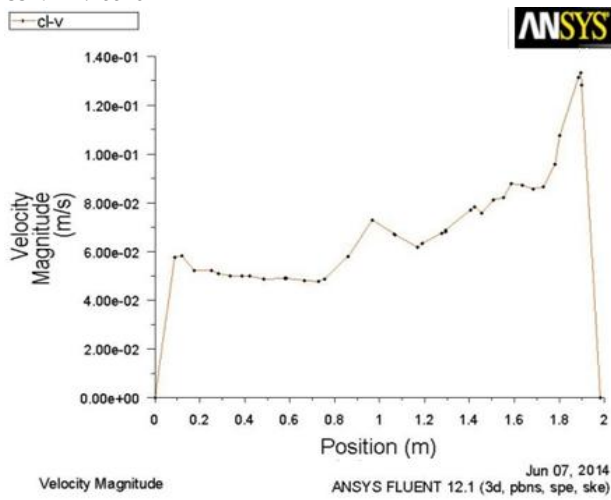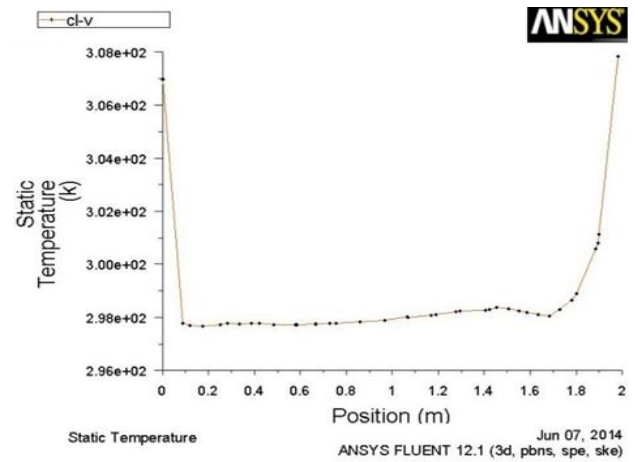distribution system
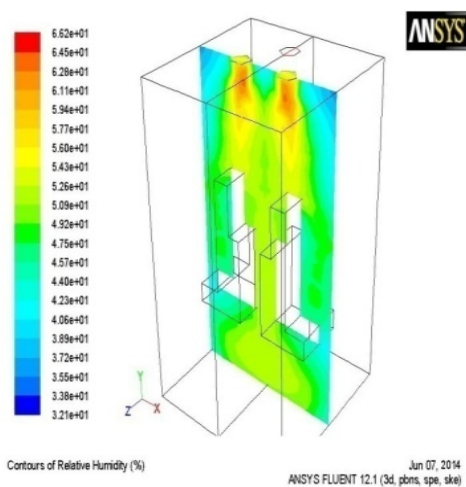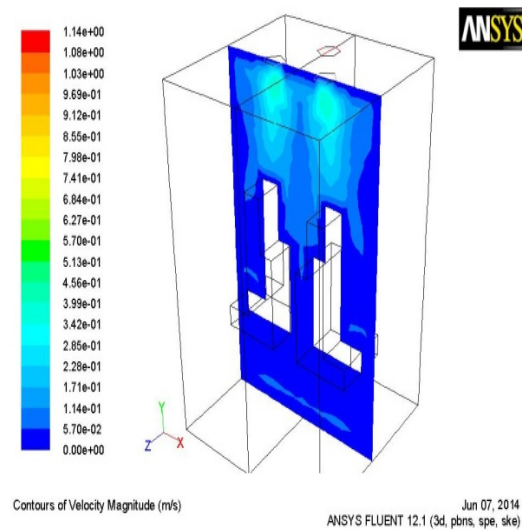
Figure 18: Analysis of Relative Humidity (%) in Overhead air
distribution system

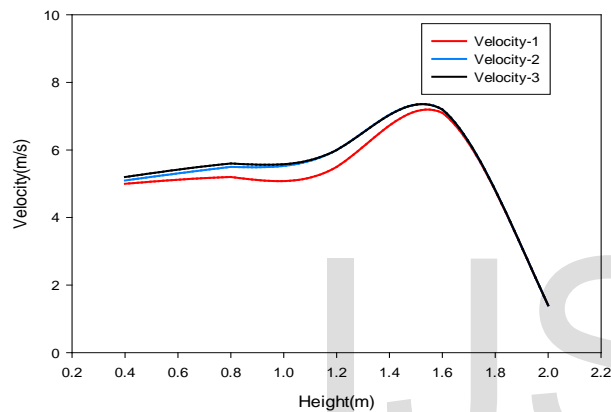Figure 20: Analysis of air Velocity in Overhead air distribution
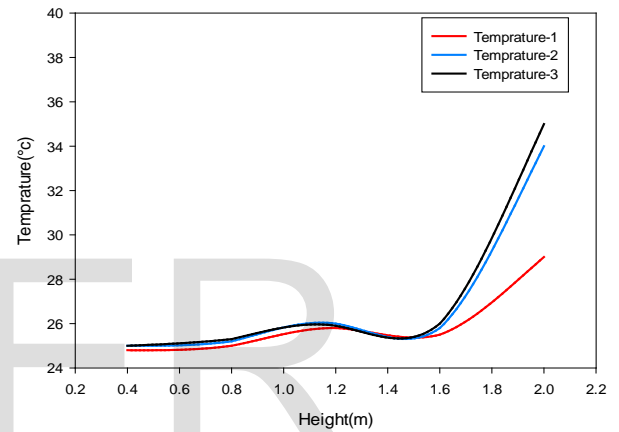system

(a)

OHAH Velocity Graph

Figure 21: (a) Simulated Graph & (b) Experimental based graph between Position and Velocity (m/s)) in Overhead air distribution system

(a)

OHAD Temprature Graph

Figure 23: (a) Simulated Graph & (b) Experimental based Graph between position and temperature (^{O}C) in OHAD system
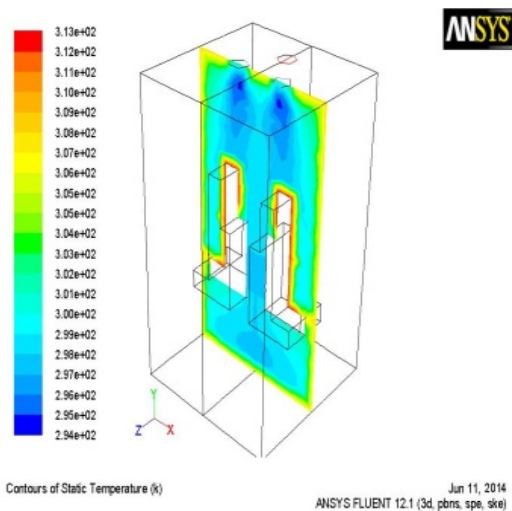
C: Comparative analysis of energy consumption

TABLE 5: COMPARISON OF ENERGY CONSUMPTION

Air Distribution System	Under Floor	Over head	Energy Saving
Power consumption for cooling the occupied space	1.4 KWh	1.8 KWh	22%

D: Comparative Analysis of UFAD & OHAD system

TABLE 6: ANALYSIS BASED COMPARATIVE VARIATION BETWEEN UFAD & OHAD

Air Distribution System	Under floor Variation	Overhead Variation	
Relative Humidity (%)	3-5	2-8	
Velocity (m/sec)	0.8-2.1	0.2-1.7	
Temperature(°C)	2-3	3-6	

Figure 22: Analysis of air Temperature in Overhead air distribution system

CONCLUSIONS

Generally speaking, both systems will allow for good occupant comfort. Control for the underfloor system is achieved through the use of adjustable diffusers. It is easy to add or remove diffusers as needed without the use of specialized equipment or technicians. The overhead system does not offer the same level of flexibility as the under floor system .UFAD allow for maximum flexibility during staff movement in building layouts without being restricted by the design of the HVAC and electrical systems. The schematic model that is completed to compare the energy consumption on the systems shows that UFAD is more energy efficient then OHAD systems and by allowing personal control of the local thermal environment. Experimental results are in good agreement with simulated results which validates the design strategy and the UFAD system. In future systems have to be designed and operated in such a manner that they produce hot and cold complaints similar to existing conventional systems despite the potential to achieve better comfort performance in UFAD systems.

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