"Passive Down Draft Evaporative Cooling:

The Applicability for Office space cooling in Banglore,India"

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ABSTRCT

The climate in Bangalore is characterized by low relative humidity and very high summer ambient temperatures. Space cooling is therefore required to achieve internal thermal comfort. Air-conditioning is the typical cooling solution, and accounts for about 65% of energy use in buildings in this region. This is a notable source of greenhouse gas emissions and coupled with their high-energy demand, alternative means of achieving space cooling would prove invaluable. This paper investigated the applicability of Passive Downdraught Evaporative Cooling (PDEC) in office buildings in this region by using a proposed PDEC system for a Incubation Center as a research vehicle. "Downdraught cooling is an energy efficient, and cost effective alternative to conventional air-conditioning for new and existing buildings" [2]. It is a well-tested system and the climatic conditions of Bangalore favor its application. This study was carried out in three phases; the first phase involved reducing the building cooling loads by appropriate solar control and improving the building envelope; the second phase was an evaluation and optimization of the proposed PDEC system; the third phase involved future-proofing the building by evaluating the performance of the system in the year 2100 using interpolated weather data. Internal comfort conditions were determined based on the adaptive comfort principle and the efficacy of the system was assessed by the percentage of resultant hourly internal temperatures achieved within the target comfort range when the PDEC system was in operation. The CFD analysis was done using FLUENT and the results showed the proposed PDEC system fulfilled the cooling requirements for more than 75% of the required periods (both for present-day and future climatic conditions). The study therefore lends credence to the applicability of PDEC as a viable cooling solution for office buildings in Bangalore and other regions with similar climatic conditions.

Keyword : *PDEC , Evaporative cooling, Energy Efficient, CFD Analysis.*

1. INTRODUCTION

Belgaum, the city of Bangalore, India is located at Latitude 16°25'7. 86" N and Longitude 74°47'35.15" E at . In summer, ambient temperatures often soar above 40°C, with mean monthly temperatures varying from of 27.3 – 38°C. The extremely high summer ambient temperatures require appropriate cooling systems to ensure thermal comfort for occupants in buildings.

Passive Downdraught Evaporative Cooling (PDEC) is one of the proven alternatives to conventional cooling as its operation requires low amounts of energy with significant reduction in CO2 emissions when compared with conventional Air-conditioners [2]. This study focuses on thermal comfort of the building occupants. Other related factors like amount and sourcing of water required for the PDEC system, and energy consumption figures are covered within the scope of this paper.

2. LITERATURE REVIEW

Different types of early designs for PDEC towers with spray systems have also been introduced as an advanced form of wind towers. Bahadori (1985) presented a new design of wind tower as illustrated in Figure 2.3 in order to improve the cooling capacity of wind towers. This new design included clay conduits throughout the tower shaft and a water spraying system at the top of the tower. In addition, the first modern application of a PDEC tower with a spray system was introduced at EXPO'92 in Seville, Spain as shown in Figure.1. It was intended to cool outdoor rest areas at the site. The height of the spray PDEC towers reached 30 m high, and fine water droplets up to

14 µm were injected at the top of the tower. The largest temperature drop of 12°C appeared within the first or second meter from the top when the smaller particles were sprayed, whereas temperature gradually decreased with bigger drops (Rodriguez et al., 1991.) These applications showed the possibility of the system as a means of low energy cooling, and were successful in drawing attention to passive cooling strategies. They, however, were inefficient in the cooling of buildings due to a lack of studies that can support advancing the best cooling performance of this particular system.

Figure 1 PDEC towers at Seville EXPO'92

(Source: Website, http://wikipedia.org)

Figure 2Torrenet Research Center

(Source: Website, http://archnet.org)

Initial studies have focused on field measurements in an attempt to advance the overall performance of these systems beyond the early system designs. Pearlmutter et al. (1996) demonstrated the importance of wind catchers and the size of water droplets. The scale model test illustrated that fine water drops accomplished better cooling performance. The study also revealed that the type of wind catcher significantly affected cooling performance (up to 35%). Etzion et al (1997) integrated a large spray PDEC tower, 4m × 4m × 12m, to the top of the atrium in Blaustein International Center for Desert Studies building located in a desert area near Beersheba, Israel. A small fan assisted the flow of air at the top of the PDEC tower. The maximum cooling output was 120kW, and a temperature drop of 14°C were observed. Ford et al. (1998) monitored the performance at the Torrent Research Center in Ahmedabad, India as shown in Figure 2. The PDEC systems achieved temperature drops between 10 and 14°C at the maximum outdoor air temperatures. Electrical energy savings reached 64% in comparison to an equivalent mechanically conditioned building. In addition, almost no occupants felt discomfort in the summer, and overall comfort levels were better than the equivalent air conditioning building. The authors also noted that improvements are necessary to control inconsistent airflow rates and overall performance. In summary, these applications have been shown to have economical environmental benefits and also identified that the main variables such as the type of wind catcher and the size of water drops have a substantial impact on the cooling performance of the spray PDEC tower. It was also shown that they are insufficient in the cooling capacity, inefficient in the use of water, and in need of adequate control algorithms. These studies, however, were limited to a specific condition such as temperature, tower configuration including wind catcher, and water flow rate, leading to a lack of a full understanding of the physical phenomena present in these systems.

Building applications of spray PDEC towers that have appeared as initial studies have proven the potential for these systems. The Interactive Learning Center (ILC) at Charles Sturt University in Australia in 2001 adopted a system as shown in Figure 3 (CADDET, 2002.) Webster-Mannison (2005) reported that the performance was poor at the beginning due to the ineffective design of the wind catcher, so wind deflectors and baffles were installed at the top to correct these problems. This also provided convective night cooling and treated rainfall was utilized as a water source. A maximum temperature reduction of 16.42°C was observed at an ambient air temperature of 42.28°C. This system, however, was unable to meet the cooling requirements for the space, so it was replaced with another cooling system.

Another example of a spray PDEC system is the Malta Stock Exchange (2001) that introduced a PDEC tower in conjunction with convective night ventilation to the central atrium space of this building as shown in Figure 4. The system met approximately 25% of the total cooling loads, and an operating costs reduction and low carbon dioxide emissions were observed.

Figure 3 ILC building in Australia

(Source: http://www.architecture.com.au)

Figure 4 Malta stock exchange building

(Source: http://www.ap.com.mt)

The Center for Global Ecology in Stanford, California adopted a spray PDEC tower in 2004 as shown in Figure 5, which is called a Katabatic Cooling Tower, in order to cool the lobby area. While no data regarding the performance of the system has been reported, the website of the center states that the katabatic cooling tower produces temperature drop of 14.4°C at an outdoor temperature of 29.4°C. Figure 6 shows another example of the application is a PDEC tower incorporated by Prajapati to the Inspector General of Police Complex in Gulbarga, Karnataka in 2005. Preliminary data indicate that temperature drops during a period of March through May were 12 to 13°C, and the simple payback period in comparison with an equivalent air-conditioned building was estimated to be approximately 5 years.

In short, a number of building applications of spray PDEC towers have been implemented during the early 2000s. The performance, however, as an alternative cooling system to a mechanical air conditioning system was insufficient even though overall the concept has improved. No application fully met the cooling demands of the space being conditioned by the PDEC system, and careful control of the PDEC system was needed to produce better cooling capacity. It is thus necessary to improve the understanding of the major phenomena within the tower and to investigate what additional parameters can significantly improve the cooling performance in detail.

Figure 5 PDEC tower in Stanford

(Source: web site http://www.aiatopten.org)

Figure 6 Inspector General of Police

(Source: JitenPrajapati, 2006)

Passive Downdraught Evaporative cooling (PDEC)

Origin:

Evaporative cooling has been applied in various forms for several centuries in different parts of the world, particularly in the Middle East where various techniques have been employed over time to encourage air movement and cooling in buildings. These methods include the use of wind catchers, wet woven 'Khus'mats hung over openings, as well as the use of scented water jars located in specially designed openings. These are designed strategically in such a way that they cool the air passing over them into the adjacent spaces. It is important to note that these traditional methods are still being used in some parts of the world to achieve cooling and they have worked satisfactorily.

Cooling Principle: Evaporative cooling relies on the principle that evaporation of water in an air stream leads to a reduction in the air temperature. This is due to the transfer of energy (required to induce evaporation) in the form of heat from the air to the water. Studies have shown that the cooling potential of a PDEC system is such that a temperature reduction of up to 80% of the difference between the Dry-bulb and Wet-bulb temperatures is achievable. This is shown in equation (1):

$$TT = TDB - 0.8(TDB - TWB) \quad (1)$$

Where:
TT = Tower supply air temperature
TDB = Ambient dry-bulb temperature
TWB= Ambient wet-bulb temperature

Downdraught cooling systems can generally be classified based on the method of generating the cool air. These include cooling towers, shower towers, porous media and misting towers .The misting tower system was proposed in the Incubation Center. It uses misting nozzles fitted at the top of the tower which spray water in the form of very tiny droplets. The small size of the water droplets sprayed greatly enhances the evaporation process. This is an efficient system as the amount of cooling achieved through evaporation generally increases with a decrease in the droplet size of water. "Recent developments in misting nozzle technology now allow evaporation at low pressure, making this the most efficient and cost effective system of downdraught evaporative cooling.

3. CASE STUDY

In this Paper Incubation center was taken as a research vehicle. This is Situated as Belgaum as stated as earlier.

A. The basis of design as given Under.

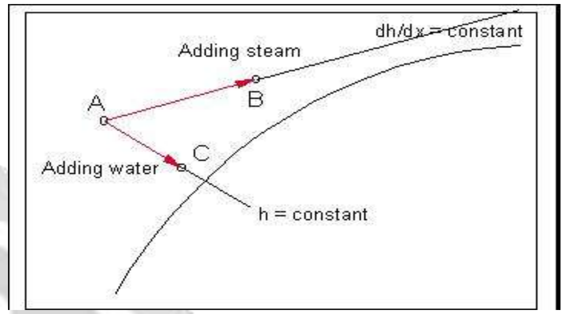
1) Inside Condition – 82.4℉ DBT, 71 ℉ WBT, 60 % RH.
2) Outside Condition - 100℉ DBT, 77 ℉ WBT, 35 % RH.
3) Occupancy – As Mention in Heat load Sheet.
4) Equipment Load- as Mention in Heat load Sheet.
5) Lighting Load – 1.0 Watt per Sq. Ft.
6) Fresh Air CFM - As per ASHRAE Standard or 1 Air Changes per Hour whichever higher.
7) Exposed Glass - Shaded ordinary medium color Glass with inside vanitian Blinds of Solar Heat Gain Co-efficient (SHGC) - 0.56 & U Value - 1.10 BTU / Hr. Sq.
8) Exposed Walls - With U-value - 0.36 BTU / Hr. Sq.
9) Roof - With U-value - 0.12 BTU / Hr. Sq.
10) All the partions were half partion.

B. Cooling Load Calculation.

The methodology used to calculate cooling requirement as follow.

Equations Used to Calculate Cooling Load

Load from Sunlit Roofs and Walls q1 = U-value × A × CLTD.
CLTDcorri = CLTDi + LM + (2% design DBT - 95 °F) Conductive Load through Windows
q2 = U-value × A × tmax(1 - (h-hmax) / w)2) dh Radiative Load through Windows
q3 = A × ∑CLFi × SHGFmax
Load due to Infiltration
q4 = 1.1 × IR × A × tmax × (1 - (h-hmax) / w)2) dh
Load due to Internal Heat Gain
q5 = heat gain from occupants × No. of occupants
Total Cooling Load = q1 + q2 + q3 + q4 + q5



Nomenclature:
U-value = coefficient of transmission (BTU/hr./ ft.2/°F)
A = area of surface (ft.2) CLTD = Coaling Load Temperature Difference (°F) LM = Latitude Month Correction (°F)
DBT = Dry-Bulb Temperature (°F)
tmax = difference between 2% design DBT and indoor temp.
h = hour of the day hmax = hour of day when tmax occurs
w = distance between hmax and h at the x-intercept
CLF = Cooling Load Factor for glass
SHGFmax = Maximum Solar Heat Gain Factor (BTU/ hr./ ft.2) IR = Infiltration Rate (cfm) 1.1 has units of Btu/hr/cfm × °F

HEAT LOAD SUMMURY SHEET

		AREA IN SQFT	HEIGHT IN ft	EQUIPMENT LOAD IN KW	OCCUPANCY	CFM
1	GROUND FLOOR	15635	12.00	45.00	300	64477
2	FIRST FLOOR	15635	12.00	45.00	300	67072
	Total	**31270**		**90.00**	**600**	**131549**

Now to cater whole volume Divide the Volume in 24 Shaft. Now just As per CFM required for cooling , calculate water consumption according to it for one shaft. Then just calculate it for 24 shaft .

Here Water consumption for evaporative cooling is given by following Eqution.

The amount of water required to change the specific humidity can be calculated as

$$Mw = v \rho (x_C - x_A) \quad (1)$$

where

Mw = mass of added water (kg/s)

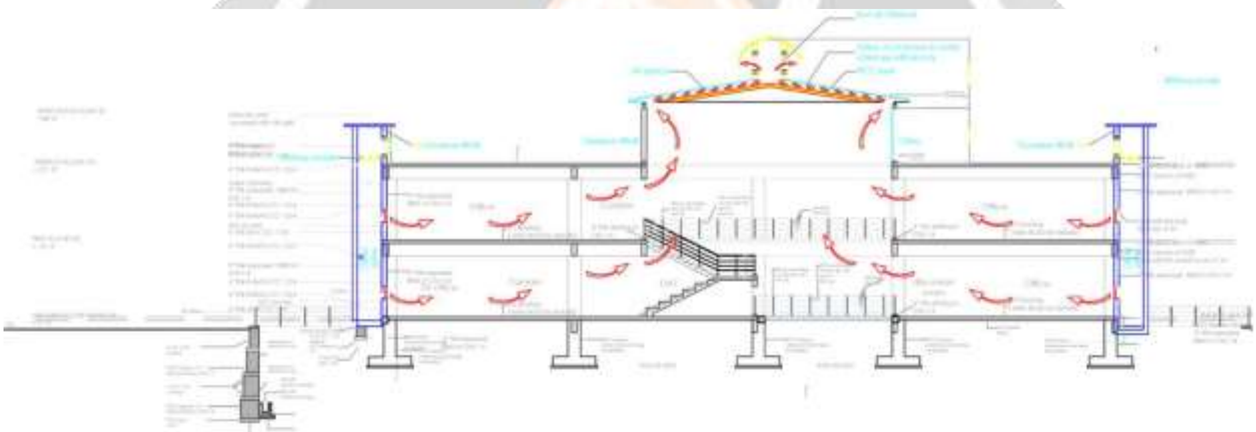
v = volume air flow (m3/s)

ρ = density of air - varies with temperature - 1.293 kg/m3 at 20oC (kg/m3)

x = humidity ratio (kgh2o/kgdry_air)

		5481	PER SHAFT CFM		Specific volume	
	V=	155.1180756	m3/m	v=	0.77	m3/kg
MAKEUPWATER REQUIREMENT	=	MASS FLOW RATE OF DRY AIR IN Kg/m x (w2---w1) x 60 kg/hr				
	=	201.4520462	0.00300	60		
	=	36.26136832	kg/hr			
	=	870.2728397	for 24 Shaft			
		6962.182718	for 8 hours working			
		1392436.544	200days			
		83,546	60rsper/1000Lt			

As shown in Above Figure the water requirement was calculated . and the Basic layout for building is given below , it contains two floor.



For Exhaust Air , in the middle Hot pocket menas solar chimney was created using Natural head. We can Use Small Fan at the Inlet of the Shaft . The Natural draft can be calculated as below Theory.

Natural Draft Head

The natural draft head can be calculated as

$dh_{mmH2O} = 1000\ h\ (\rho_o - \rho_r) / \rho_{h2o}$ (1)

Where

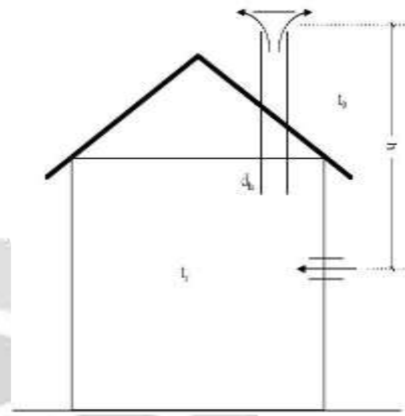
dh_{mmH2O} = *head in millimeter water column (mm* H_2O*)*

ρ_o = *density outside air (kg/m*^{3}*)*

ρ_r = *density inside air (kg/m*^{3}*)*

ρ_{h2o} = *density water (in general 1000 kg/m*^{3}*)*

h = height between outlet and inlet air (m)



Density and Temperature.

With air density *1.293 kg/m*^{3} at $0\ ^oC$ - the air density at any temperature can be expressed as

$\rho = (1.293\ kg/m^3)\ (273\ K) / (273\ K + t)$ (2) or

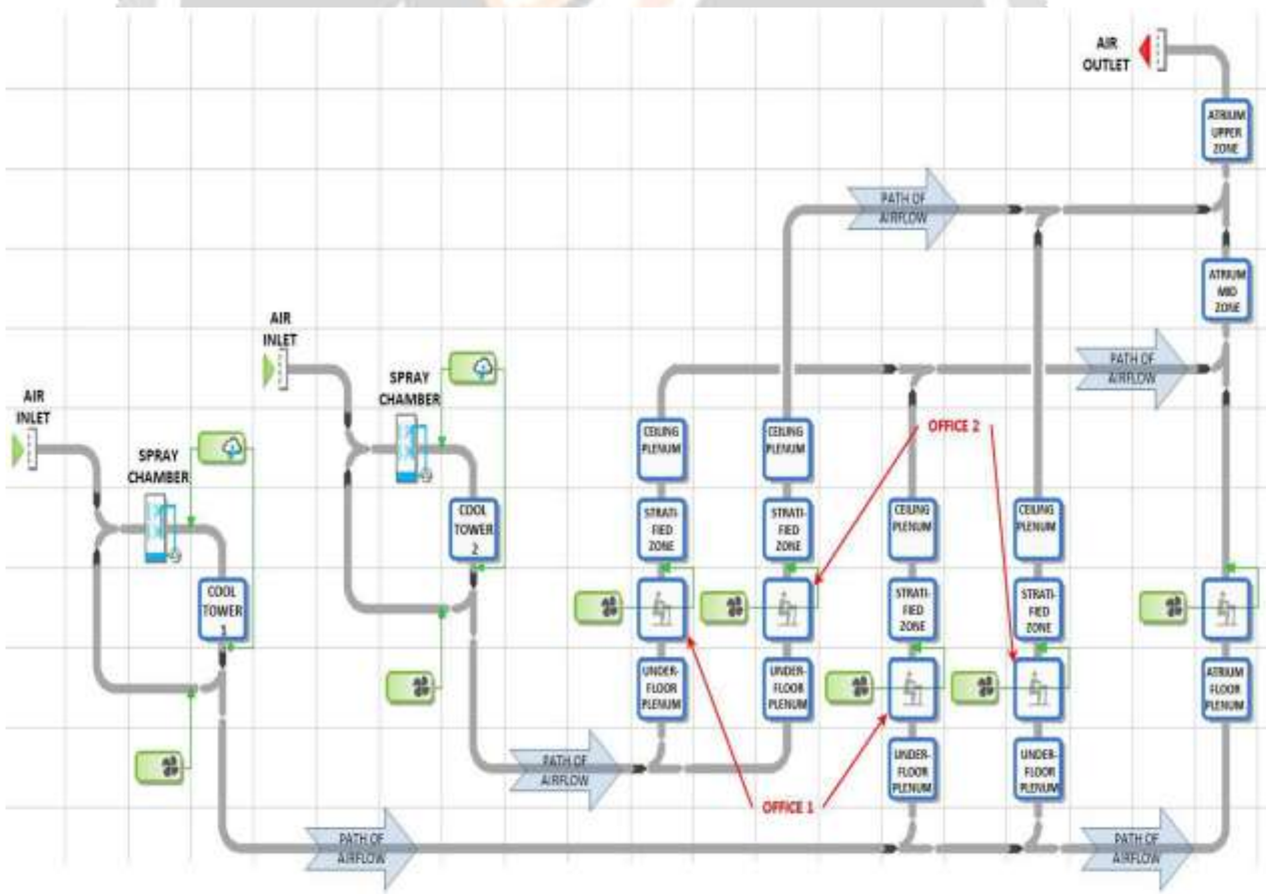
$\rho = 353 / (273 + t)$ (2b)

where

ρ = *density of air (kg/m*^{3}*)*

t = the actual temperature (^oC*)*

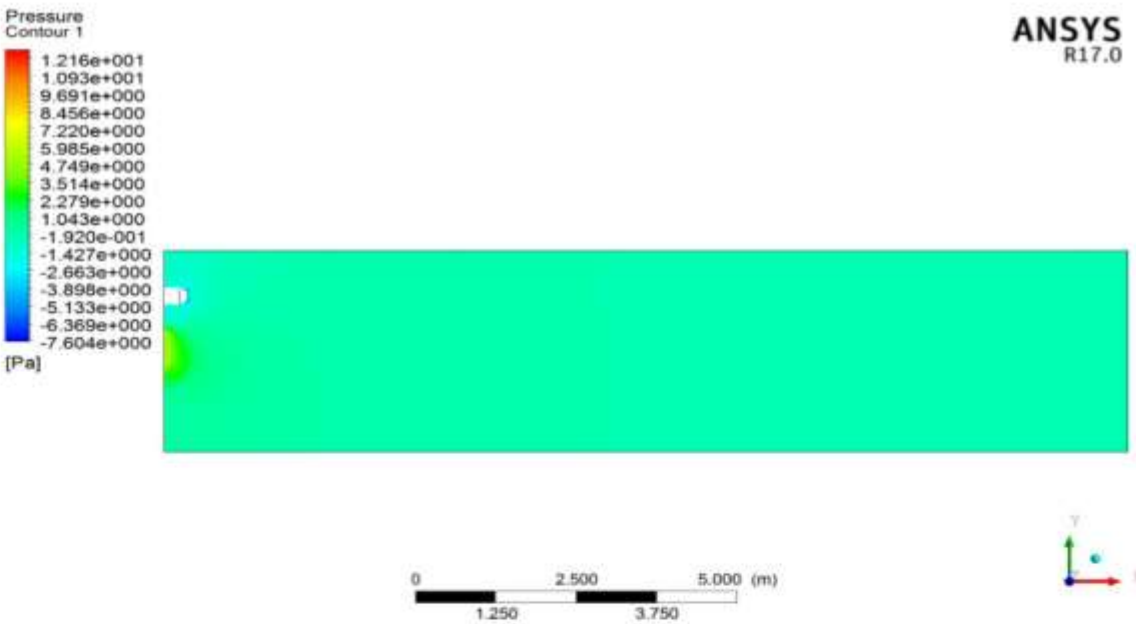
Air Flow Path was like Below.

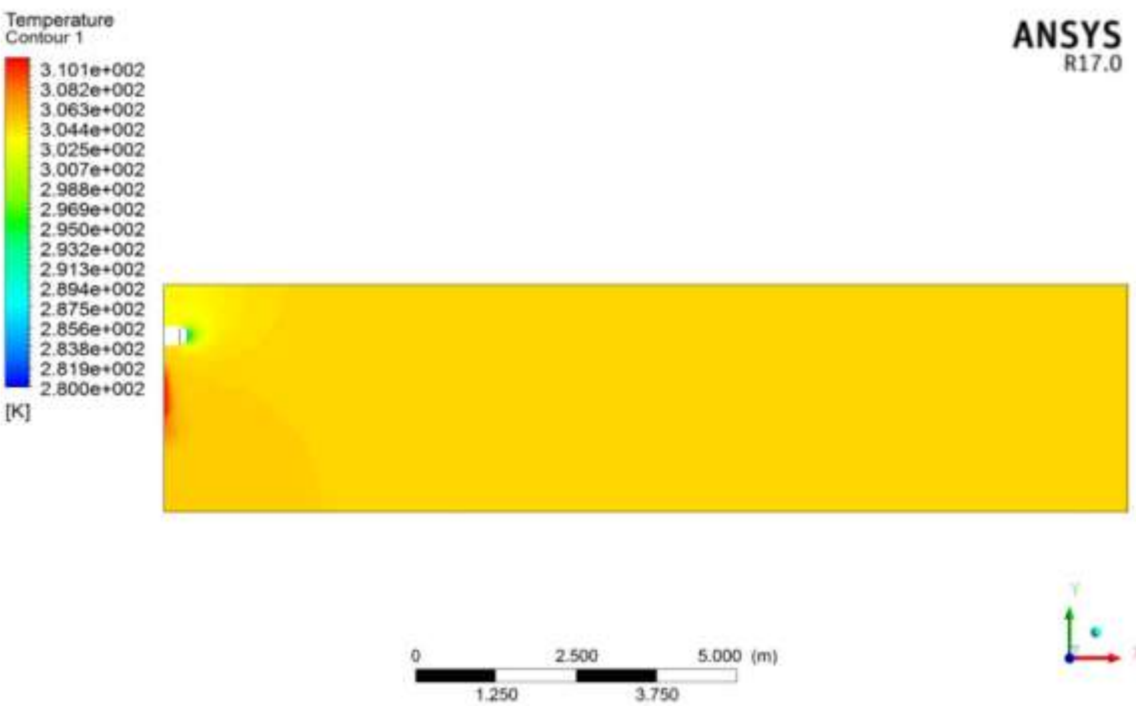


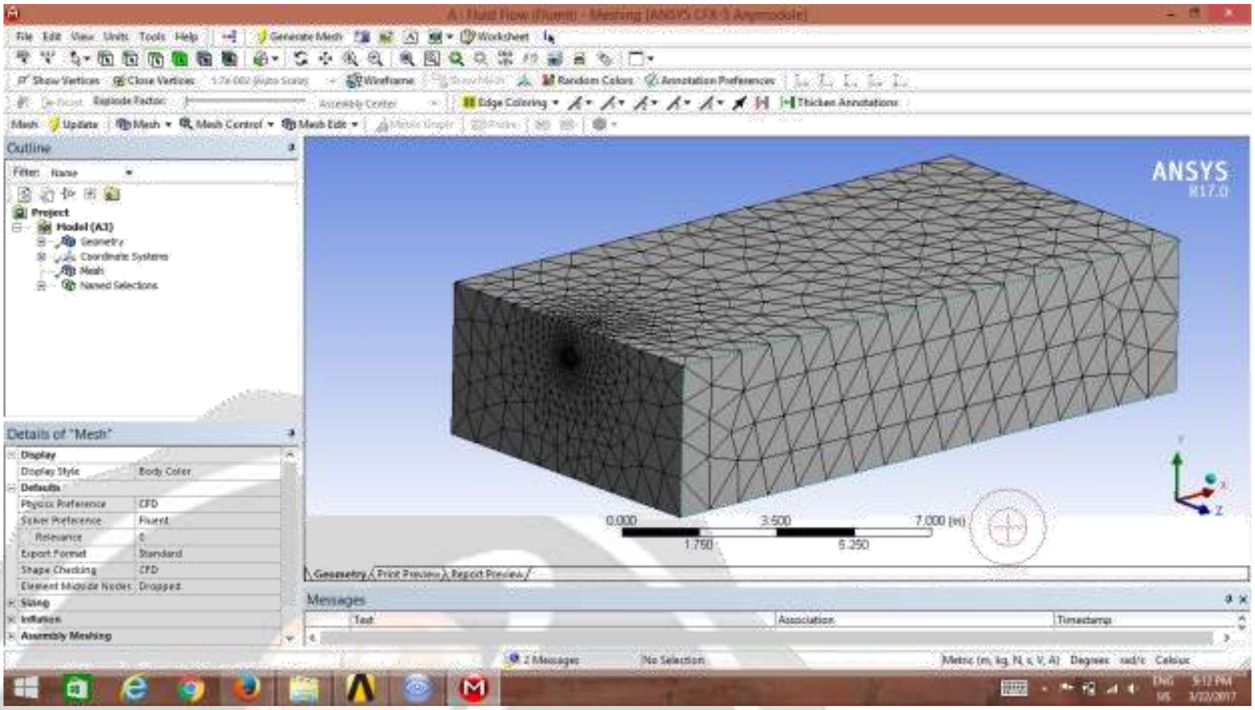
3.1 CFD Analysis

The design was tested in the by CFD analysis by ANSYS software. In this Analysis we consider the area which served by one shaft. And we took three cases in the Selection of Nozzles in Inlet Shaft. The temp Distribution and Pressure was given in the result in below figures.

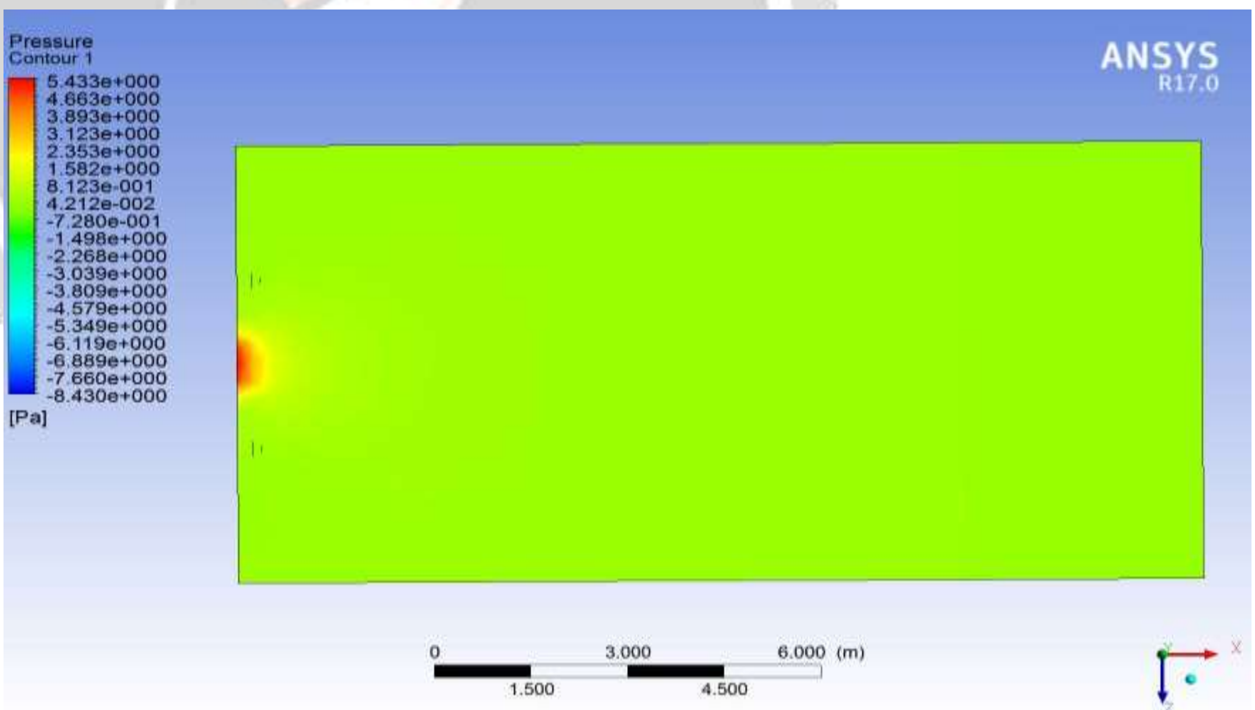
1) With One nozzle in one shaft.

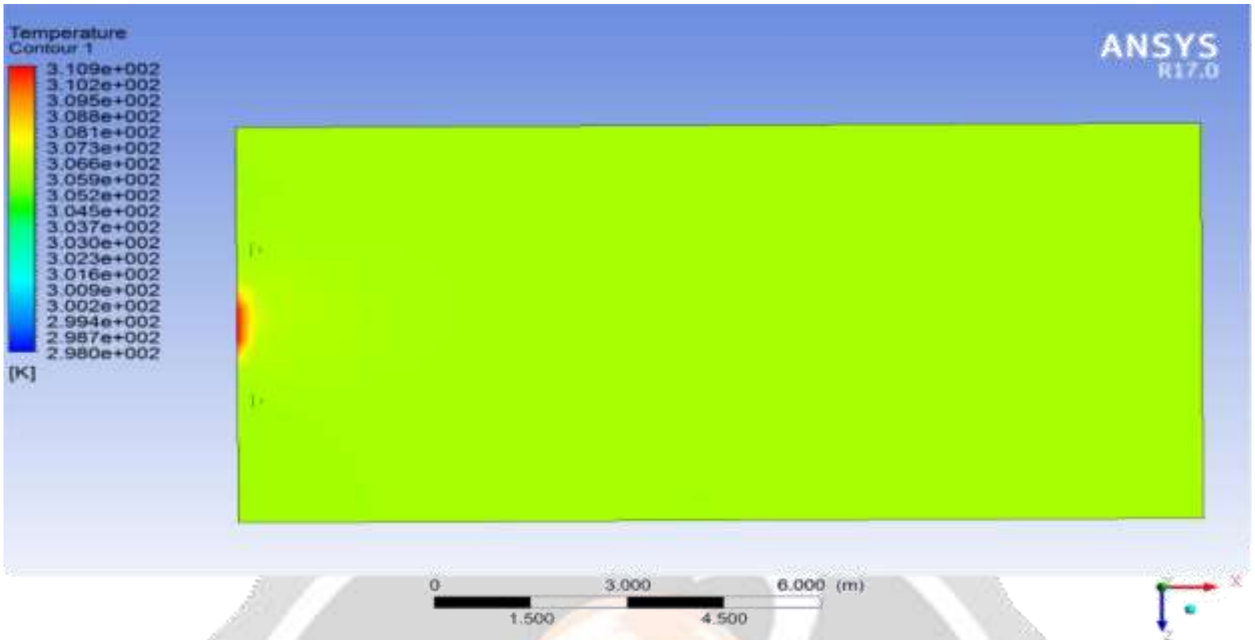


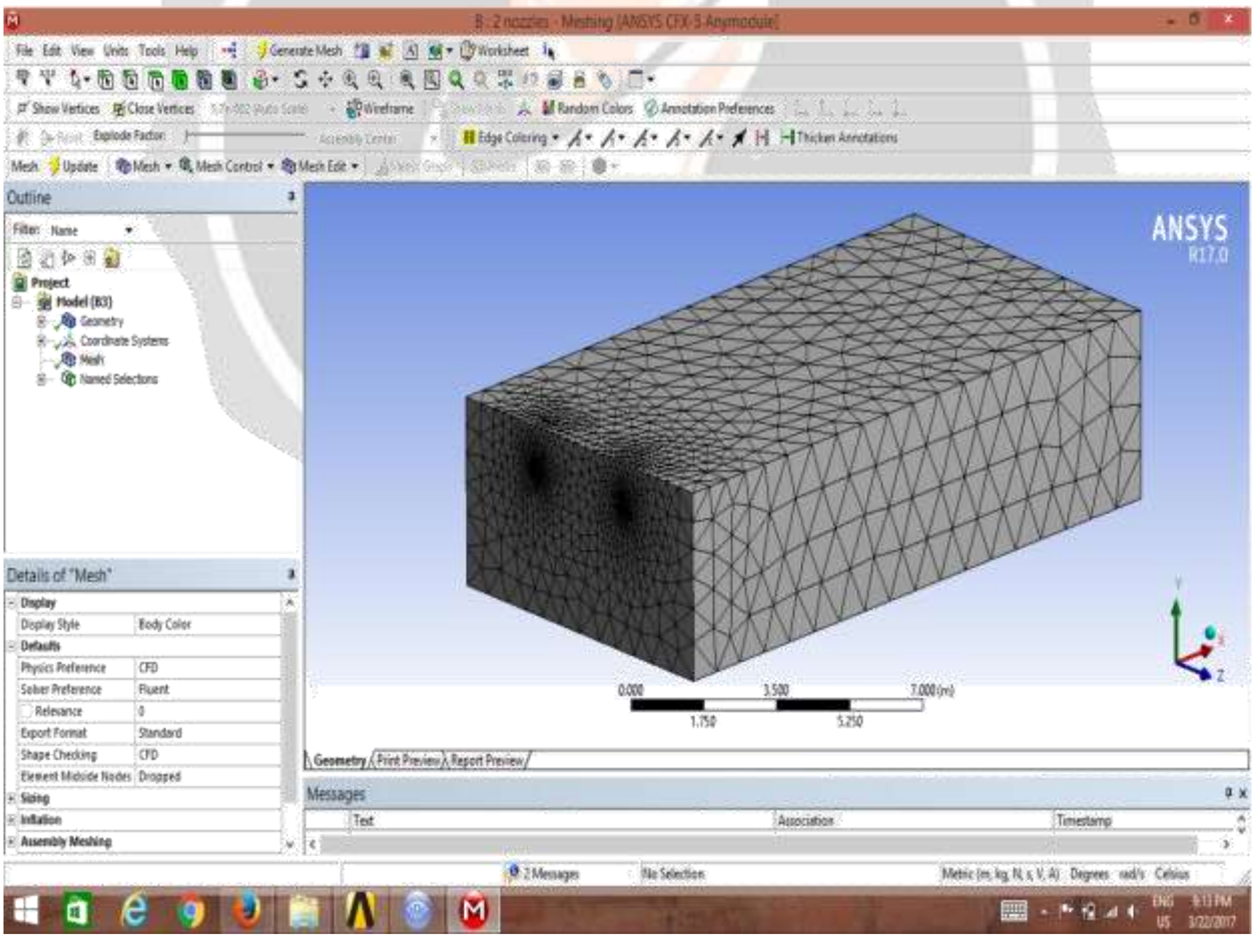




2) with 2 nozzles in one shaft having same mass flow rate of water.




Temperature
Contour 1
3.109e+002
3.102e+002
3.095e+002
3.088e+002
3.081e+002
3.073e+002
3.066e+002
3.059e+002
3.052e+002
3.045e+002
3.037e+002
3.030e+002
3.023e+002
3.016e+002
3.009e+002
3.002e+002
2.994e+002
2.987e+002
2.980e+002
[K]
ANSYS
R17.0
0
3.000
6.000 (m)
1.500
4.500


Outline
Project
Model (B3)
Geometry
Coordinate Systems
Mesh
Named Selections
Details of "Mesh"
Display
Display Style
Body Color
Defaults
Physics Preference
CFD
Solver Preference
Fluent
Relevance
0
Export Format
Standard
Shape Checking
CFD
Element Midside Nodes
Dropped
Sizing
Inflation
Assembly Meshing
ANSYS
R17.0
0.000
3.500
7.000 (m)
1.750
5.250
Geometry
Print Preview
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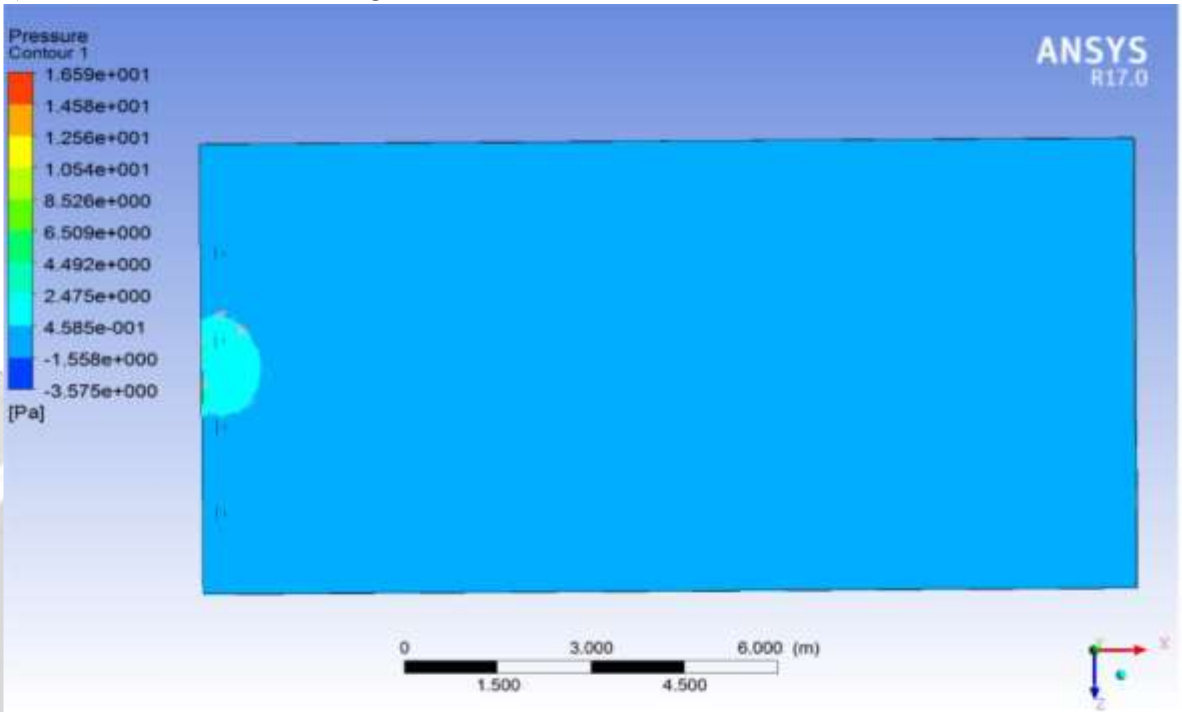
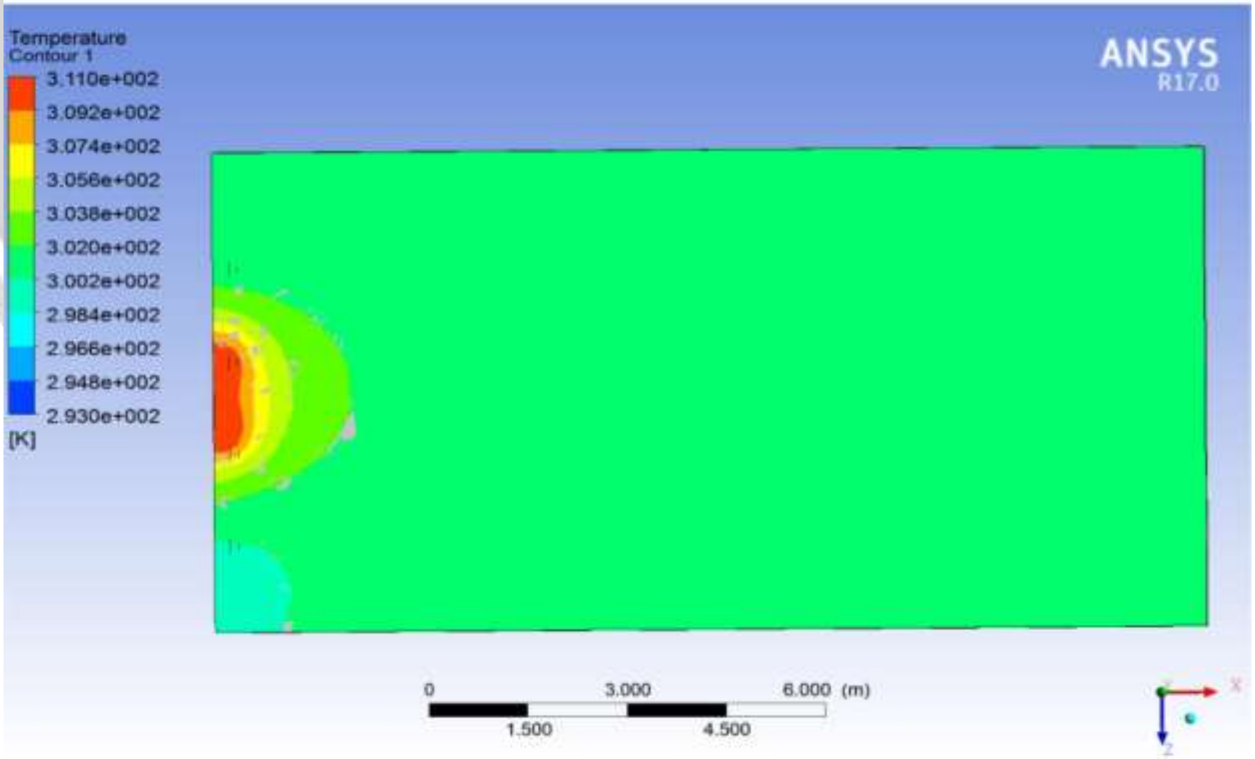
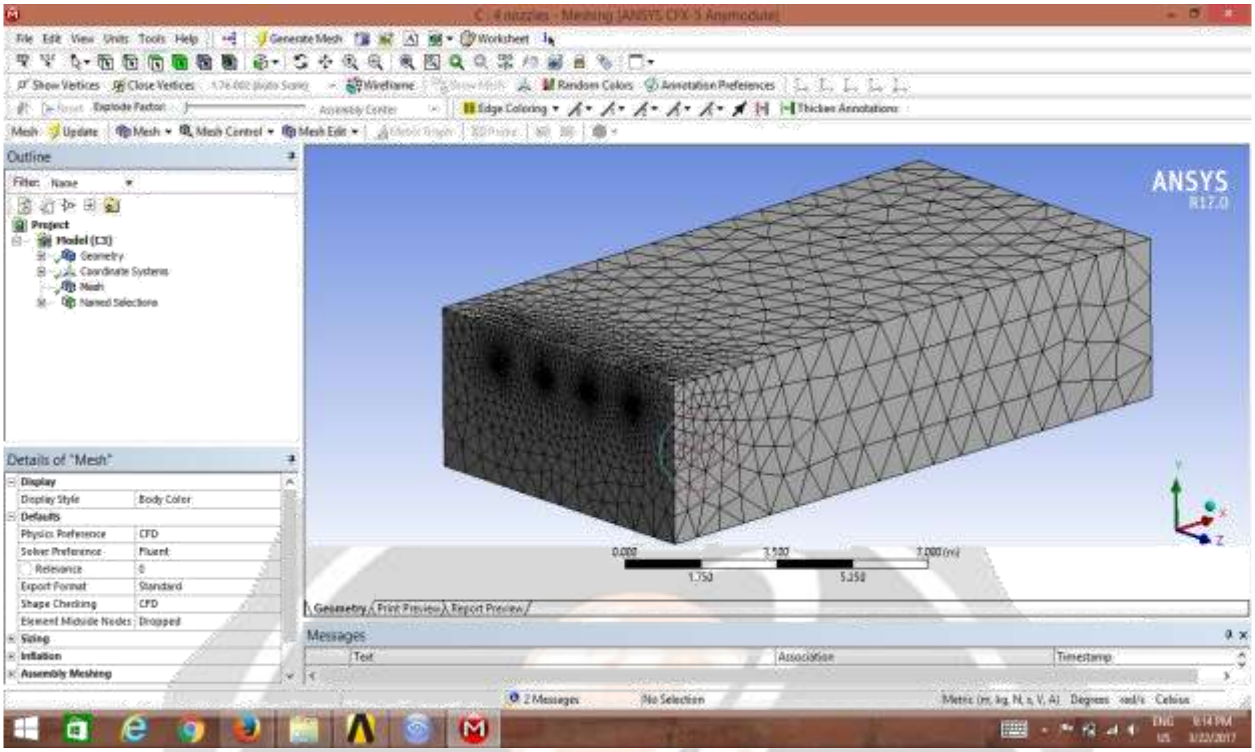
Messages
Text
Association
Timestamp

3) With 4 nozzles in one shaft having same water flow rate.







4 . CONCLUSION

The results from this study have shown that the space cooling requirements for the Incubation Center were met by using Four Nozzles in one Shaft of PDEC system. Based on the results obtained from CFD analysis, it can be concluded that PDEC is a viable solution for Office space cooling in Belgaum, taking into consideration all the parameters Required for a proper functioning of the system as stated in this paper. Apart from the cooling potential Demonstrated in this study, it has the added benefit of a significant reduction in the overall building energy Consumption as well as CO2 emissions. This limited study has opened up immense Opportunities for further research on this subject and the authors have identified the following areas for further Investigation and flow rates can be investigated in more detail.

From this Result we can say that there was 30 % reduction in cooling load as compared to Conventional Air-conditioning system.

Also This system is saves 80 to 85% energy consumption used by conventional Air condition System. So This PDEC system is Eco-Friendly system.

There was some negative points like Consumption of more water and Capital Cost was high. But In the Areas were water is available there was no issue. And Also Capital cost is increased around 12-15 % of Civil Construction of Shafts. But operating Cost is so low so That Return of Payback is Small time.

So Finally I can conclude that Spray PDEC towers have more potential than the other types of PDEC technology. The traditional wind tower has been improved by adding evaporative devices at the very top of it. As a result, significant improvements in the cooling performance of advanced types of wind towers have been accomplished. The majority of PDEC studies and building applications are on spray PDEC towers since they produce better cooling output and respond faster than the other systems.

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