Design and Performance Characteristics of Swirl Diffuser for Air-Conditioning of An Automobile

[1]Dinesh Singh, [2]Pankaj Mishra

[1]*MTech Scholar, NIRT, Bhopal*

[2] *Pankaj Mishra, Associate Prof., NIRT, Bhopal*

Abstract— Swirl diffusers used in air-conditioning system for automobiles can create better air mixing to enhance inside air quality and help in achieving better human comfort. The variation in temperature in air conditioning system depends strongly on the flow characteristics produced by the diffuser outlet that vary considerably between different modelling set ups. In automobile sector it is very important to calculate the effect of variation in temperature of diffused air through swirl diffuser from a.c. with and without heat load. In this dissertation work, I have tried to reduce the variation in temperature of conditioned air and improvement in thermal human comfort by adopting different models of car swirl diffuser designed on pro-E software. After that I have made prototype wooden model of the car swirl diffuser to check its performance under different operating and flow conditions experimentally. The experiment has been performed inside an Alto 800 car with swirl diffuser model installed at the car a.c. outlet. The variation in temperature of diffused air form car swirl diffuser at different altitude and along longitudinal axis of car with the effect of heat load on temperature variation is determined. This experiment has been performed on three different models of car swirl diffuser having different slot angles of 12^0, 13^0 and 14^0. These experimental results will help us in comparing the performance of three different models of car swirl diffuser under different operating and flow conditions. It will also provide the designers a guideline in achieving better human comfort with car swirl diffuser.

Keywords - ACE-Air Change Effectiveness, Heat Load Capacity, Swirl motion, 12º Swirl Diffuser- Diffuser having slot with draft angle 12º, 13º Swirl Diffuser- Diffuser having slot with draft angle 13º, 14º Swirl Diffuser- Diffuser having slot with draft angle 14º,and Round and rectangular slots, Cross- section, Thermal comfort.

I. INTRODUCTION

Swirl air diffusers are used widely in air-conditioning systems for distribution of conditioned air inside a room and the air diffusion is very much depends on the characteristics of different diffuser designs. For distribution of conditioned air inside an automobile, swirling diffusers can be used and their performance can be analyzed. Modeling of the diffuser plays an important role in predicting airflow pattern in the car. Swirl diffusers are generally mounted at the outlet of a.c. inside a car. This device delivers conditioned air in the car space and allows the occupant to manually control both the volume and direction of the air flow. The diffuser is constructed of a durable, high impact, polycarbonate material. Delivering air from the swirl diffuser has an advantage of supplying fresh, cool, clean air directly into the occupied zone of the space, so heat and pollutants are not continuously circulated within the space as it happens in an overhead air distribution system. It will results in dissipation of heat and less concentration of pollutants in the occupied space in the lower level than those at the upper levels of the space. Ventilation is done through displacement as opposed to dilution.

The requirement of a good air distribution system is to supply clean and fresh air with less variation in temperature with height and different locations to provide better thermal comfort and high air quality in the occupant zone. In Asian and European countries, 30-50% of occupants have health problem because of bad air distribution system. Almost 30-40% of the energy produced has been spent on air distribution system in most of the developing countries.

Swirl diffusers are designed to provide effective air diffusion inside a car through specially designed swirl deflection slots to produce a highly turbulent radial air flow pattern that will induce better mixing of car air. This also results in rapid temperature equalization to give stable car conditions with minimum temperature gradients. The excellent high qualities of air from swirl diffusers enable designers to aim for a high value of Air Change Effectiveness (ACE). Swirl diffusers have recently become very popular because they generate radially high induction swirl air flow by drawing car air up into the supply air pattern to induce superior air mixing. Better mixing means better Air Change Effectiveness (ACE).

It is therefore required to study the characteristics of air distribution system with swirl diffuser inside a car under

different operating and flow conditions with high thermal load.

Experimental set-up:

It consists of three different models of swirl diffuser installed in the car for air distribution inside the car space. The conditioned air from air conditioner is supplied through the diffuser. A bulb of 1000W is placed inside the car to provide a heat load. Bulb is placed near the location Y2.

A temperature sensing instrument with six thermocouple wires is placed inside the car to measure the temperature at six locations vertically at a distance of 0.7 feet. There are six locations inside the car where readings of temperature have to be noted and the variation in temperature of air is to be studied.

3-D view of the experimental set-up and actual front view of the experimental set-up is shown below in Fig.1, Fig.2 and Fig.3.

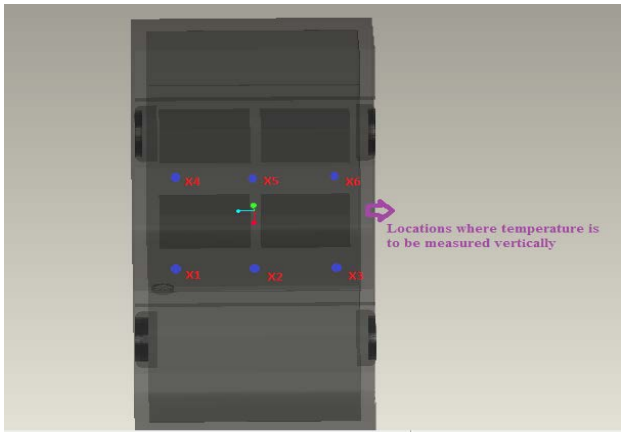

Fig.1 3-D view of the experimental set-up showing locations below car seat

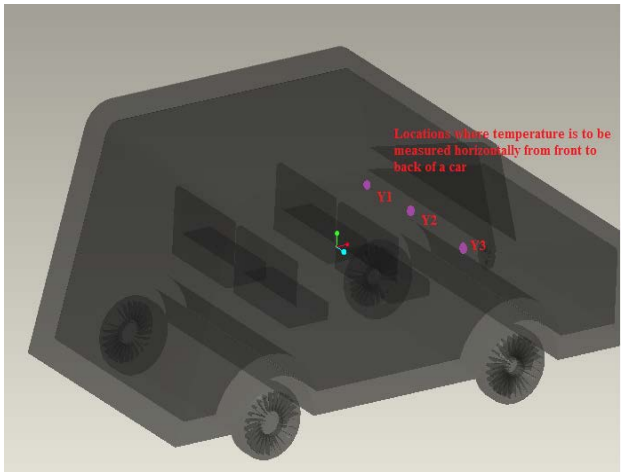

Fig.2 3D view of the experimental set-up showing locations at front of car

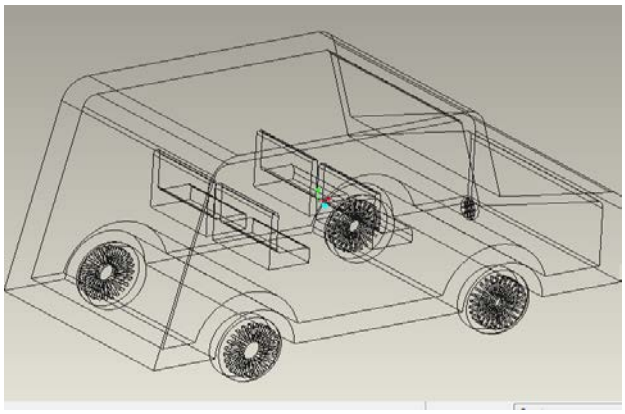

Fig.3 Wireframe model of the experimental set-up

Fig.4 Actual front view of the experimental set-up in installed position

II. DIFFERENT MODELS OF DIFFUSER

1. 12° Swirl Diffuser:

It is made of plywood of circular cross-section 80 mm diameters and thickness 8mm. Curved slots are cut on the top surface. Curved slots are cut with inner radius 75mm and outer radius 85mm. Curved slots are drafted through an angle of 120 for producing swirl action of diffused air. The draft in the slots is provided with the help of file.

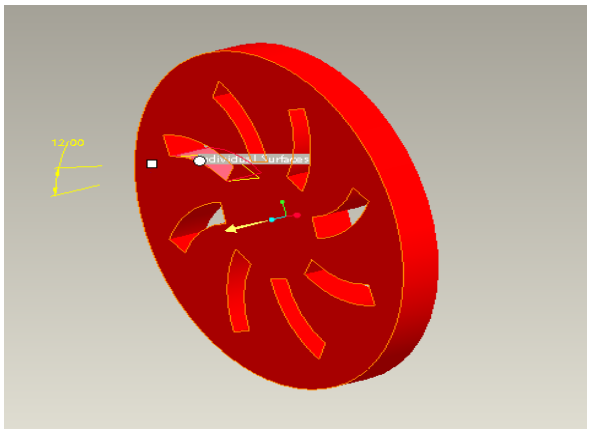

Fig.5 3D view of 12° Swirl Diffuser

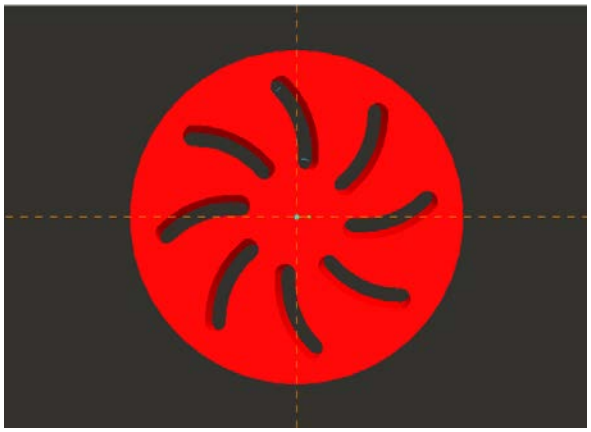

Fig.6 Top view of 12° Swirl Diffuser

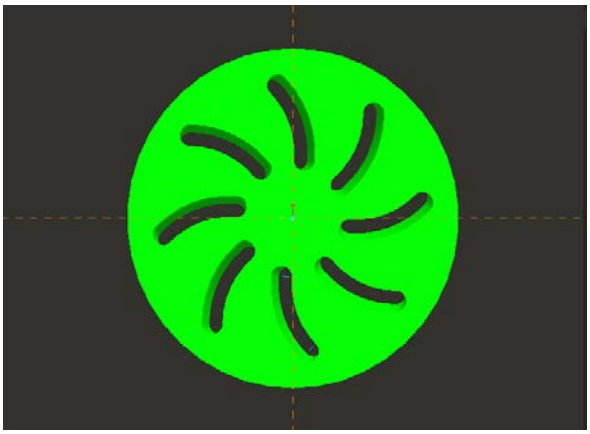

Fig.9 Top view of 13° Swirl Diffuser

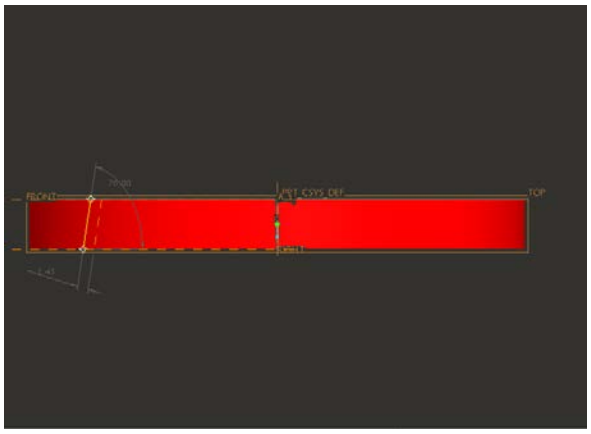

Fig.7 Front view of 12° Swirl Diffuser

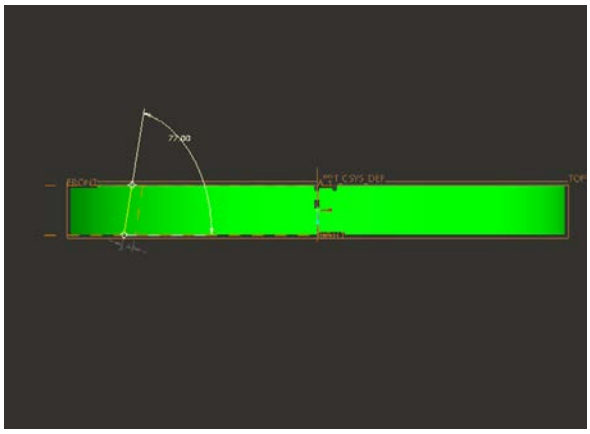

Fig.10 Front view of 13° Swirl Diffuser

2. 13° Swirl Diffuser:

It is made of plywood of circular cross-section 80 mm diameters and thickness 8mm. Curved slots are cut on the top surface. Curved slots are cut with inner radius 75mm and outer radius 85mm. Curved slots are drafted through an angle of 130 for producing swirl action of diffused air. The draft in the slots is provided with the help of file.

3. 14° Swirl Diffuser:

It is made of plywood of circular cross-section 80 mm diameters and thickness 8mm. Curved slots are cut on the top surface. Curved slots are cut with inner radius 75mm and outer radius 85mm. Curved slots are drafted through an angle of 140 for producing swirl action of diffused air. The draft in the slots is provided with the help of file.

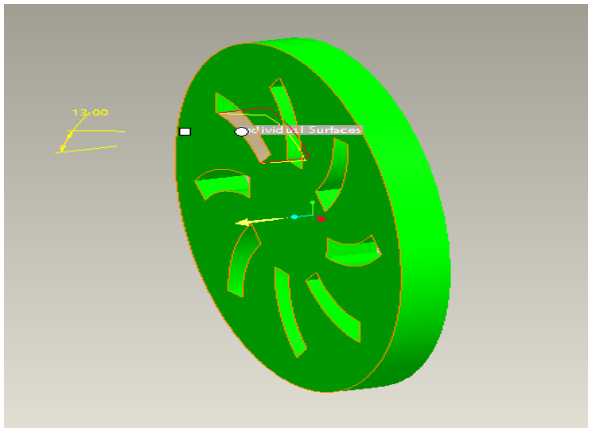

Fig.8 3D view of 13° Swirl Diffuser

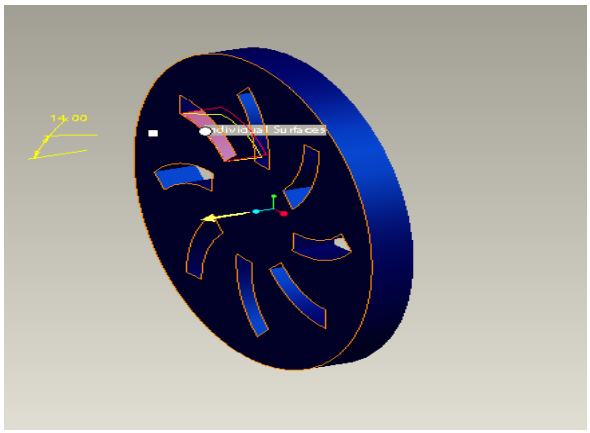

Fig.11 3D view of 14° Swirl Diffuser

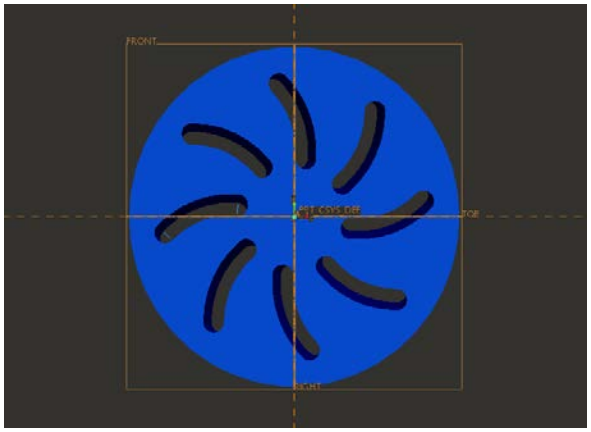

Fig.12 Top view of 14° Swirl Diffuser

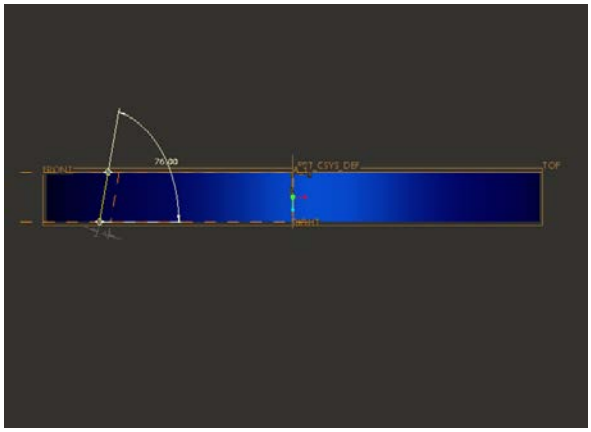

Fig.13 Front view of 14° Swirl Diffuser

Pro-e Design of different Swirl Diffuser:

Swirl Diffusers with different slot angles have been initially designed on Pro-e modeling software and then a prototype wooden model is made to check their performance experimentally under different operating and load conditions.

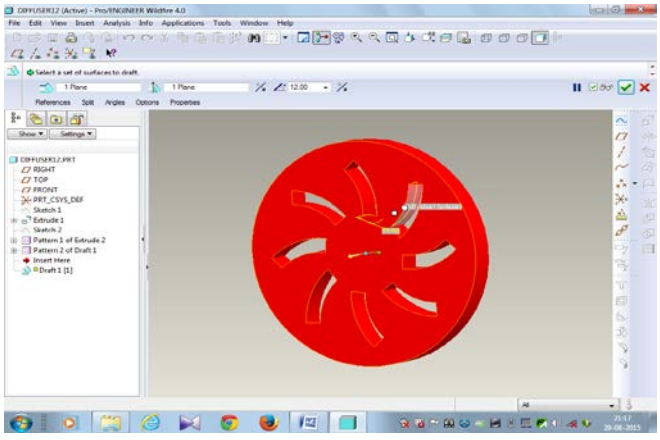

Fig.14 Pro-e model of 12° Swirl Diffuser

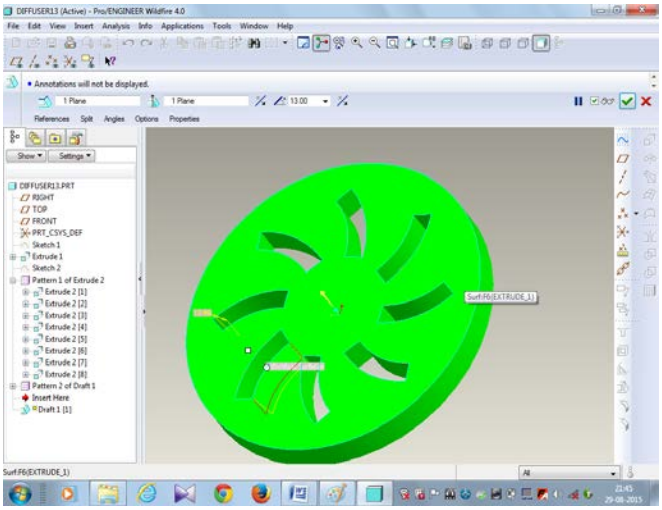

Fig.15 Pro-e model of 13° Swirl Diffuser

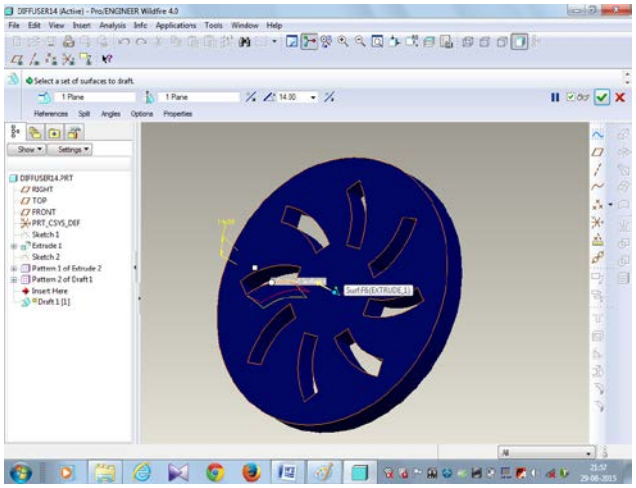

Fig.16 Pro-e model of 14° Swirl Diffuser

III. EXPERIMENTAL RESULTS

The main results of the experiment are tabulated at nine locations inside the car with and without heat load. Locations are taken along X-axis and Y-axis inside a car. These locations are equally spaced and are at a distance of 1 foot from each other.

The supply air temperature from the air-conditioner is 18.4°C at a flow rate of 0.2m^3/s. The heat load is applied inside the car with the help of bulb of load capacity 1000W.

Various temperature readings are noted at location Y1, Y2, Y3, X1, X2, X3, X4, X5 and X6 with load and without load. The experiment has been performed with all three models of swirl diffuser.

These experimental results will help us in comparing the performance of three different models of swirl diffuser under different operating and flow conditions. Results have been plotted graphically between temperature and height from the

roof level of car. Graphs have also been plotted between temperature and distance from the front panel of car from front to back. It will also provide the designers a guideline in achieving better human comfort and best performance with swirl diffuser used in air conditioning system of a car.

The graphs plotted between temperature and height at various locations indicates that variation in temperature with height as well as from front to back of a car is less with 13° swirl diffuser. The result also shows that variation in temperature reduces as we move away from the heat source. Due to swirl action produced by the diffuser temperature equalization is almost achieved inside the car at different locations with and without heat load.

The variation in temperature at location Y2 and X2 are comparatively more than the other location due to presence of heat load. This happens due to presence of heat source at location Y2 and X2.

Air Temperature Measurement:

Air temperature is measured spontaneously at each location under different operating conditions. Inlet and return air temperature are 18.4°C and 23.6°C for 12° swirl diffuser, 18.4°C and 22.4°C for 13° swirl diffuser and 18.4°C and 23.8°C in case of 14° swirl diffuser respectively.

A uniform temperature distribution is observed. The highest temperature gradient is found at location Y2. In the upper occupied zone there is small temperature gradient due to good mixing of air in the upper region.

The temperature at various locations is tabulated and the graphical results are shown below.

Experimental Readings:

Initial Car Temperature = 32°C

Car Temperature with load 1000W with air conditioner in off condition= 38°C

At location Y1

Load= No load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	22	20	22
2	1.4	23	21	22
3	2.1	23	21	23
4	2.8	24	22	23
5	3.5	24	22	23
6	4.2	24	22	24

At location Y1

Load= 1000W load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	22	22	23
2	1.4	23	25	25
3	2.1	25	25	25
4	2.8	25	24	23
5	3.5	25	25	23
6	4.2	26	25	24

At location Y2

Load= No load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	21	21	22
2	1.4	23	22	24
3	2.1	24	23	24
4	2.8	23	22	22
5	3.5	24	23	23
6	4.2	26	24	25

At location Y2

Load= 1000W load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	22	22	22
2	1.4	24	25	25
3	2.1	25	26	26
4	2.8	26	26	25
5	3.5	28	28	28
6	4.2	29	28	30

At location Y3

Load= No load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	21	22	21
2	1.4	23	23	23
3	2.1	23	23	23
4	2.8	22	22	22
5	3.5	23	23	23
6	4.2	24	23	26

At location Y3
Load= 1000W load with a.c.

S.No.	Distance from front of car (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	23	22	22
2	1.4	25	25	25
3	2.1	26	25	25
4	2.8	26	23	24
5	3.5	28	26	26
6	4.2	30	25	28

At location X1
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	23	27
2	1.4	24	23	23
3	2.1	22	22	20
4	2.8	23	23	24
5	3.5	22	23	23
6	4.2	21	21	22

At location X1
Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	25	24	25
2	1.4	23	24	23
3	2.1	23	22	23
4	2.8	25	25	25
5	3.5	24	24	24
6	4.2	22	21	21

At location X2
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	23	26
2	1.4	22	23	22
3	2.1	21	22	20
4	2.8	23	22	24
5	3.5	22	22	24
6	4.2	19	20	21

At location X2
Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	25	25
2	1.4	23	25	23
3	2.1	22	23	23
4	2.8	23	25	24
5	3.5	22	24	24
6	4.2	20	21	21

At location X3
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	22	24
2	1.4	22	22	23
3	2.1	22	21	22
4	2.8	22	21	24
5	3.5	23	22	24
6	4.2	21	21	22

At location X3
Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	24	24
2	1.4	24	24	23
3	2.1	23	24	23
4	2.8	23	23	24
5	3.5	24	24	24
6	4.2	22	23	23

At location X4
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	25	23	24
2	1.4	24	23	23
3	2.1	23	22	21
4	2.8	24	22	23
5	3.5	24	21	23
6	4.2	23	20	22

At location X4

Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	25	24	24
2	1.4	24	25	23
3	2.1	25	24	23
4	2.8	25	25	24
5	3.5	24	25	25
6	4.2	23	23	23

At location X5
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	25	24	26
2	1.4	24	23	24
3	2.1	24	23	23
4	2.8	24	23	24
5	3.5	23	22	24
6	4.2	23	22	22

At location X5
Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	28	28	29
2	1.4	28	28	29
3	2.1	28	26	27
4	2.8	26	26	26
5	3.5	25	25	25
6	4.2	23	23	23

At location X6
Load= No load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	24	23	24
2	1.4	23	22	23
3	2.1	23	22	21
4	2.8	23	23	23
5	3.5	23	22	23
6	4.2	22	22	21

At location X6
Load= 1000W load with a.c.

S. No.	Height (ft.)	Temperature (^{0}C)		
		12^0	13^0	14^0
1	0.7	26	25	26
2	1.4	26	26	27
3	2.1	25	24	24
4	2.8	26	25	25
5	3.5	25	25	25
6	4.2	24	23	22

IV. GRAPHICAL REPRESENTATION OF RESULTS

The following graph shows the variation in temperature with height and along horizontal distance from front to back of car at different locations.

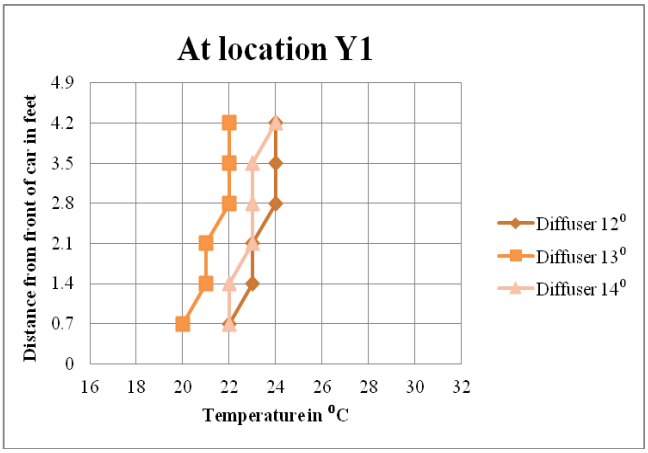

Fig.17 Variation in temperature vs. distance from front of car in feet at location Y1 without load.

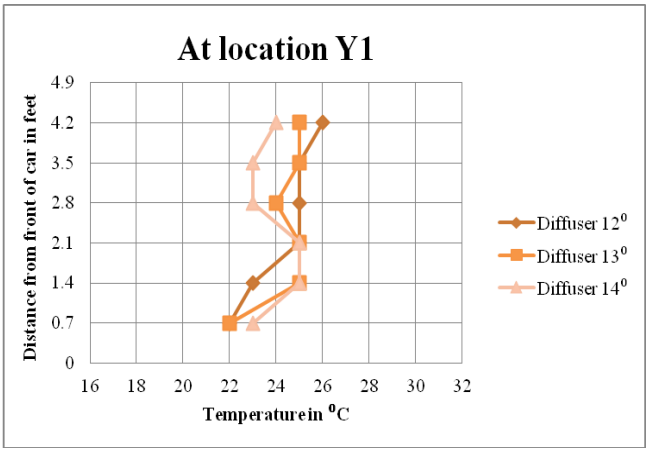

Fig.18 Variation in temperature vs. distance from front of car in feet at location Y1 with load 1000W.

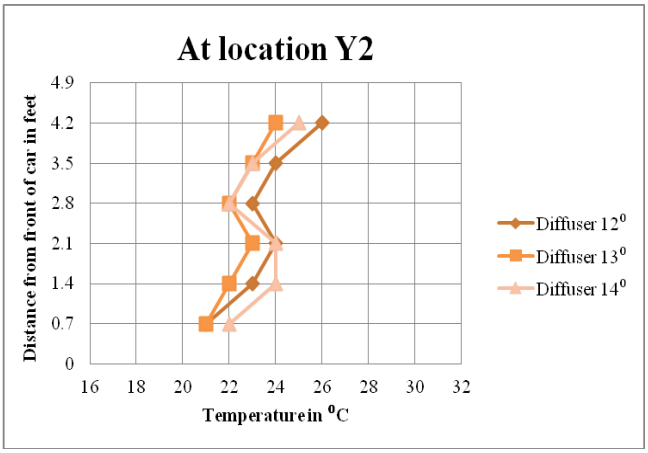

Fig.19 Variation in temperature vs. distance from front of car in feet at location Y2 without load.

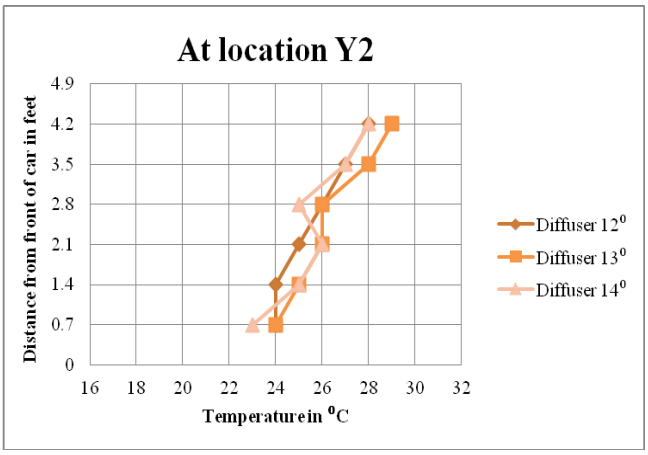

Fig.20 Variation in temperature vs. distance from front of car in feet at location Y2 with load 1000W.

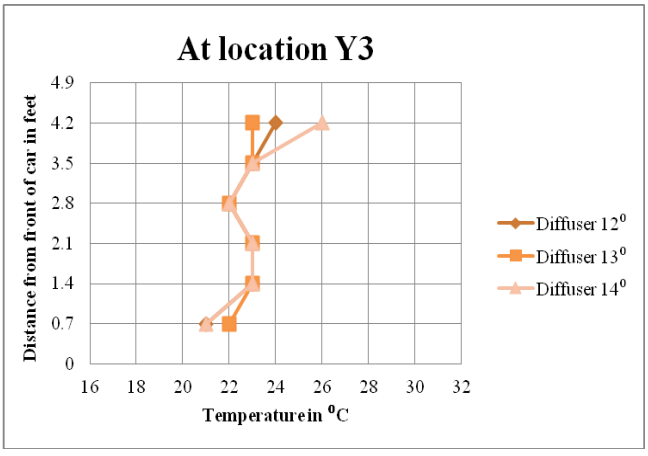

Fig.21 Variation in temperature vs. distance from front of car in feet at location Y3 without load.

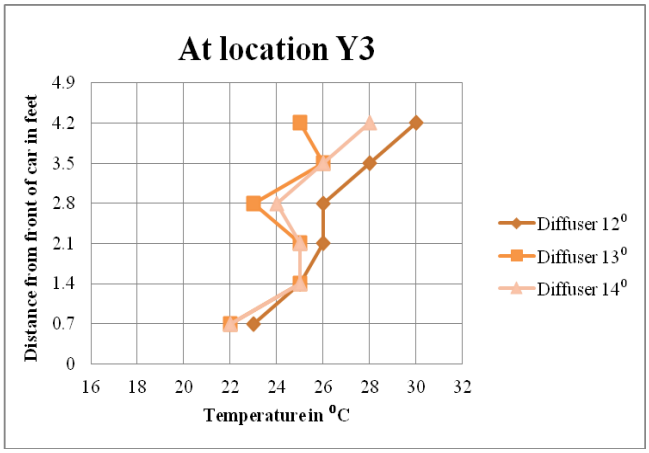

Fig.22 Variation in temperature vs. distance from front of car in feet at location Y3 with load 1000W.

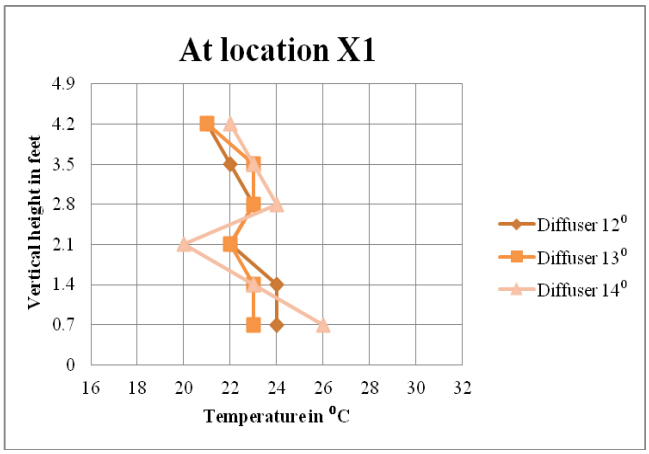

Fig.23 Variation in temperature vs. height at location X1 without load.

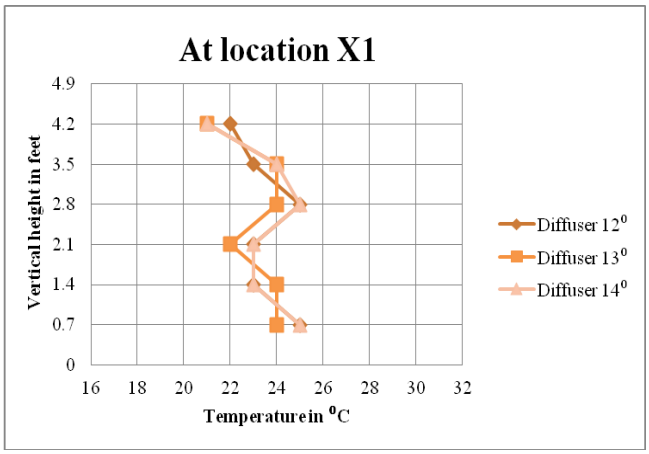

Fig.24 Variation in temperature vs. height at location X1 with load 1000W.

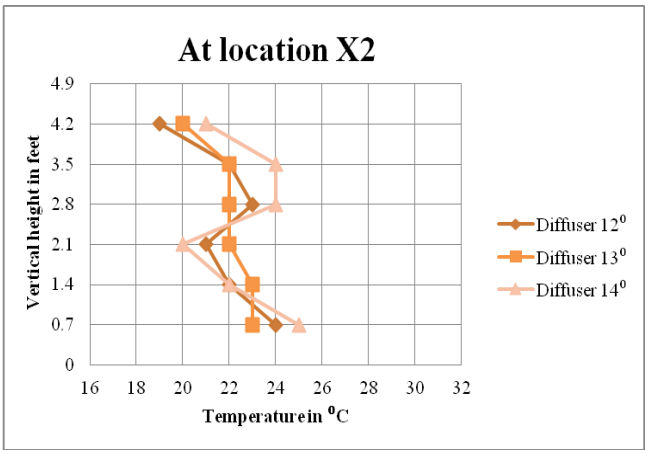

Fig.25 Variation in temperature vs. height at location X2 without load.

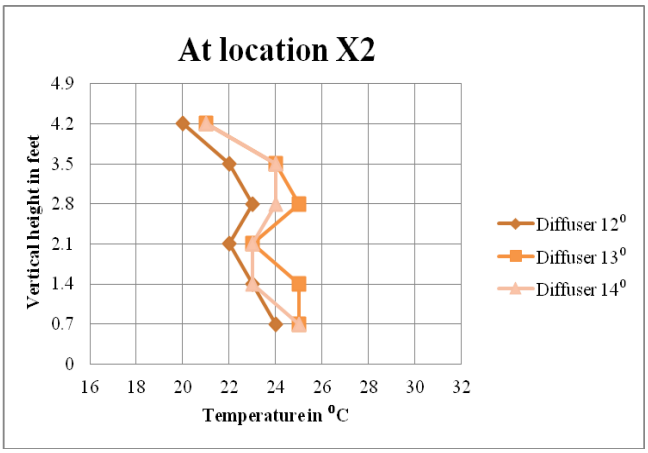

Fig.26 Variation in temperature vs. height at location X2 with load 1000W.

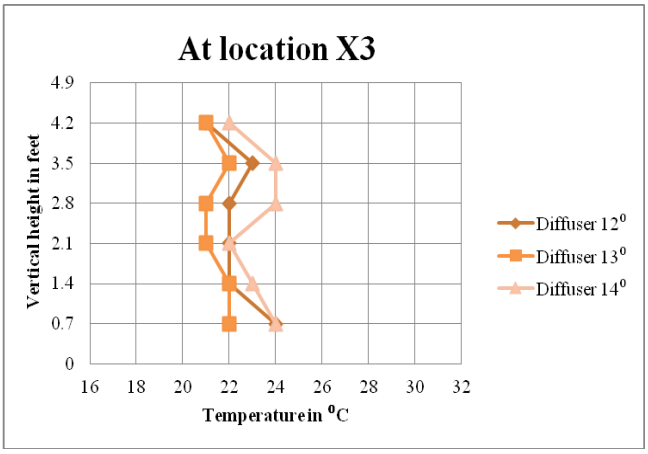

Fig.27 Variation in temperature vs. height at location X3 without load.

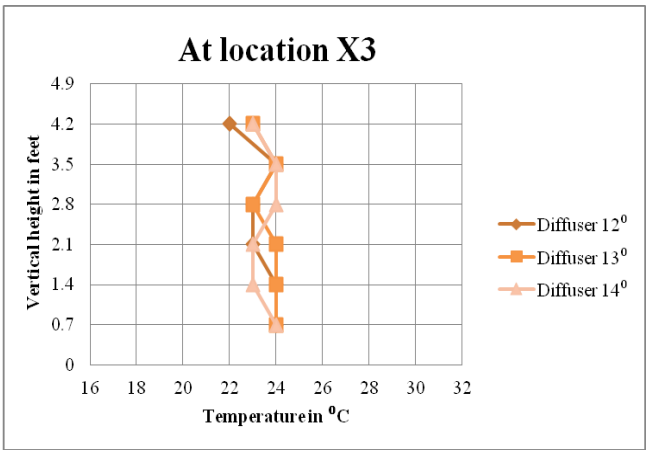

Fig.28 Variation in temperature vs. height at location X3 with load 1000W.

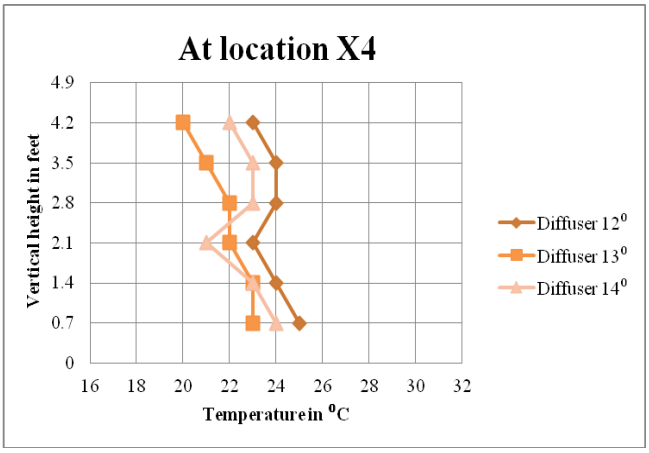

Fig.29 Variation in temperature vs. height at location X4 without load.

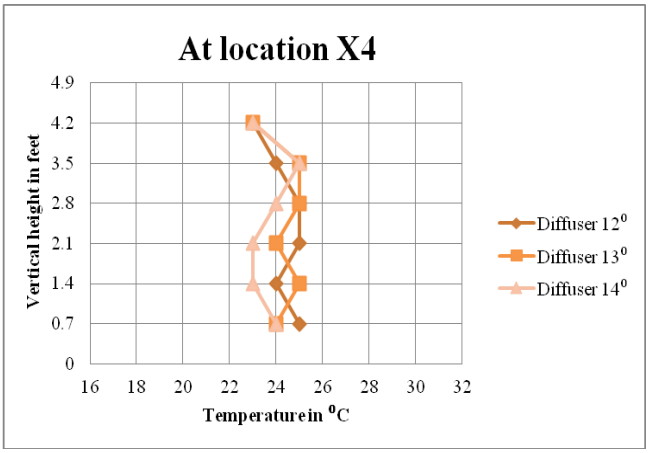

Fig.30 Variation in temperature vs. height at location X4 with load 1000W.

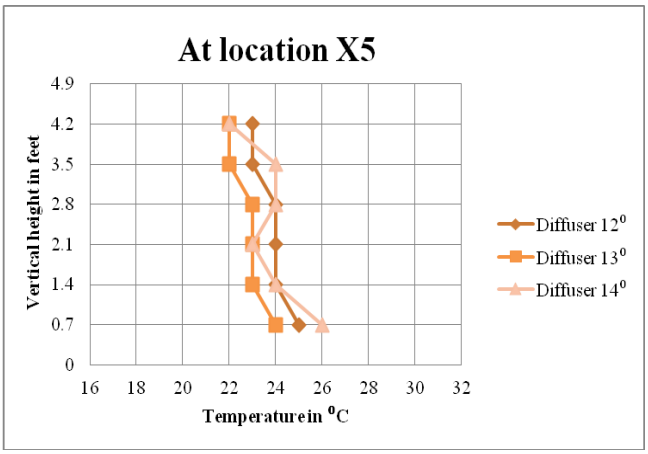

Fig.31 Variation in temperature vs. height at location X5 without load.

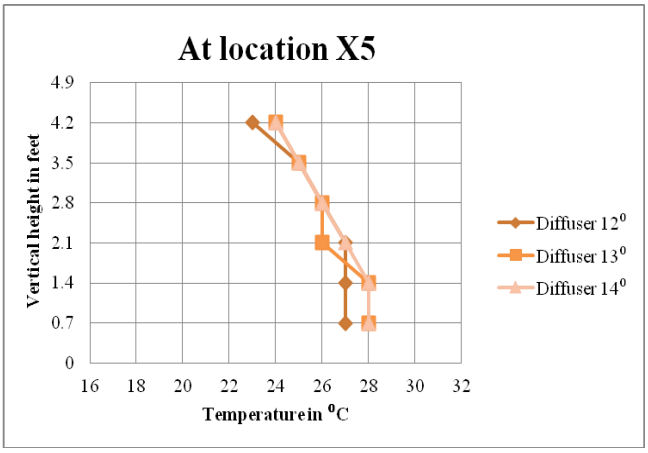

Fig.32 Variation in temperature vs. height at location X5 with load 1000W.

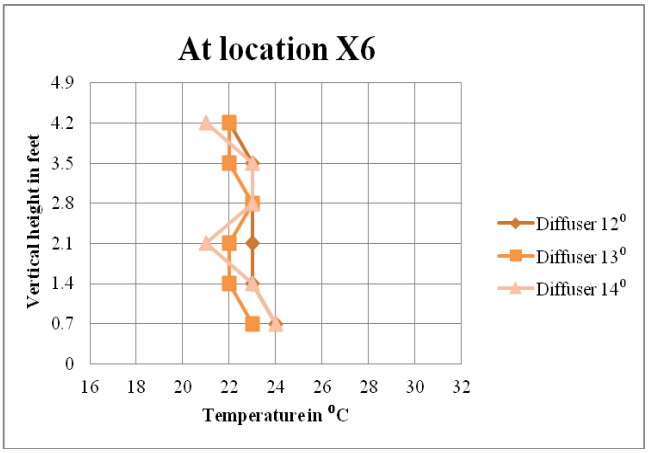

Fig.33 Variation in temperature vs. height at location X6 without load.

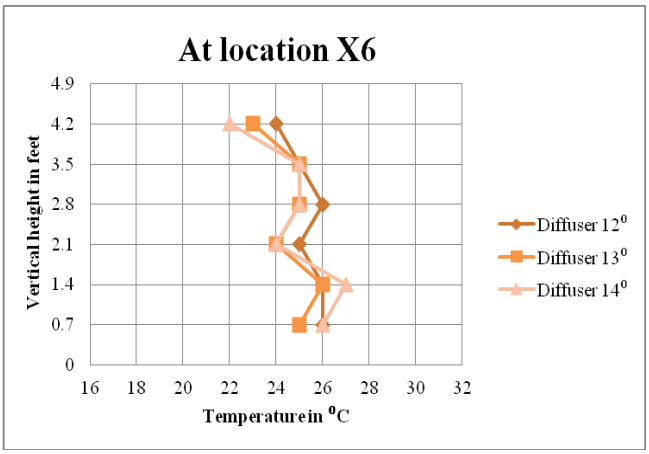

Fig.34 Variation in temperature vs. height at location X6 with load 1000W.

V. CONCLUSIONS

The results from this study shows that a car installed with swirl diffuser at the outlet of a.c. can improve air quality because the contaminant concentration in the breathing zone is lower than that of mixing system. It helps us in comparing the performance of three different types of swirl diffuser under different operating and flow conditions. Due to swirl action produced more unidirectional flow was created, the slow recirculation at the occupant zone was eliminated for the floor-supply ventilation and the risk of cross contamination can be effectively reduced. The system with the swirl diffusers can provide a better comfort level than that with the perforated panels due to the mixing by the diffusers.

This study helps in selecting optimum models for swirl diffuser under different operating conditions. We can improve the Air Change Effectiveness and human comfort by varying the slot design angle of diffuser. It will results in better mixing of air inside the car and the variation in temperature of air inside a car will be reduced. We can achieve better human comfort and proper ventilation by using swirl diffuser for air distribution inside a car.

REFERENCES

[1] Ehsan Tavakoli, Reza Hosseini, Large eddy simulation of turbulent flow and mass transfer in far-field of swirl diffusers, December 2012, ELSEVIER, Science Direct.

[2] Kwang Ho Lee, Sang Min Kim, Jong Ho Yoon, Supply air temperature impact in underfloor air distribution systems under Korean climatic conditions: Energy, humidity and comfort, October 2012, ELSEVIER, Science Direct.

[3] Xue, G., Lee, K., Jiang, Z. and Chen, Q. 2012. Thermal environment in indoor spaces with under-floor air distribution systems: 2. Determination of design parameters (RP-1522).Submitted to HVAC&R Research.

[4] B. Sajadi, M.H. Saidi, A. Mohebbian, Numerical investigation of the swirling air diffuser: Parametric study and optimization, January 2011, ELSEVIER, Science Direct.

[5] Allison, C. and North, B. 2011. Achieving Air- Change Effectiveness for Green Star IEQ-2 Office Design with CFD simulations. Diffuser Performance, Ecolibrium, February 2011, pp. 28-34.

[6] Jae-Hyung Kim and Heuy-Dong Kim, Effect of diffuser angle on the discharge coefficient of miniature critical nozzles, May 2010, Springer.

[7] Liu Jinping, Wu Yanfang, Experimental study on airflow fluctuation characteristic of an underfloor air supply terminal unit, July 2010, ELSEVIER, Science Direct.

[8] B. Sajadi, M.H. Saidi, A. Mohebbian, Numerical investigation of the swirling air diffuser: parametric study and optimization, Energy and Buildings 43 (2011) 1329–1333.

[9] Lee, K.S., Zhang, T., Jiang, J., and Chen, Q. 2009. Comparison of airflow and contaminant distributions in rooms with traditional displacement ventilation and under-floor air distribution systems – RP-1373. ASHRAE Transactions 115 (2).

[10] Lee, K.S., Xue, G., Jiang, Z., and Chen, Q. 2012. "Thermal environment in indoor spaces with under-floor air distribution systems: 1. Impact of design parameters (1522-RP)," HVAC&R Research, 18(6), 1182–1191.

[11] Josephine Lau, Qingyan Chen, Floor-supply displacement ventilation for workshops, January 2006, ELSEVIER, Science Direct.

[12] Mohammed A. Aziz, Ibrahim A.M. Gad, El Shahat F.A. Mohammed, Ramy H. Mohammed, Experimental and numerical study of influence of air ceiling diffusers on room air flow characteristics, September 2012, ELSEVIER, Science Direct.