



# Characteristics of Ultrafine Particles released From Laser Printers

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# Outline

**1. Introduction**

**2. Experimental Setup**

**3. Results and Discussion**

**\* Printing center**

**\* Chamber Study**

**4. Conclusions**



# 1. Introduction

**EPA\* and WHO rank today's indoor air quality as one of the top five risks for public health**

❖ EPA studies of human exposure to air pollutants indicate that indoor air levels of many pollutants may be 2-5 times, and occasionally more than 100 times, higher than outdoor levels.

❖ Particulate Matter is considered as one of the critical pollutants of concern by EPA.

**We spend 90 % of our time indoors**



**Increased levels of airborne particulate pollution**



**Increased need for healthy indoor air**

What is the cause for increased level of airborne particulate pollution?....



# 1. Introduction

## Common indoor particulate pollution.

- Pollutants from outdoor to indoor (e.g: traffic.)

Ref: Koponen et al.,(1998), D.H.Benett (2006)

- Re-circulation of indoor air (eg: Air-condition)

Ref: Uduman et al.,(2002) ,Kolari et al.,(2005),

- Building Materials and Furnishing

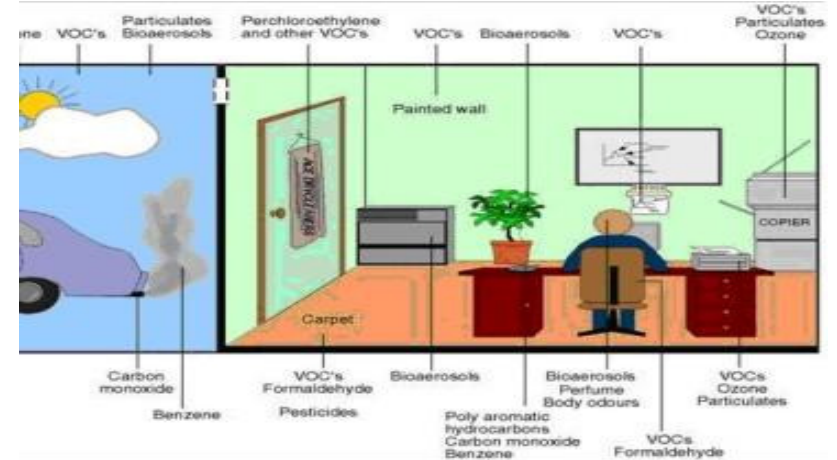
Ref: M.Wensing et al., (2005)

- Indoor occupant activities.(e.g: vacuuming)

Ref: Ferro et al., (2004)

- Aerosols from cleaning products.

Ref: V. Yusá et al (2008)



Before Cleaning



After Cleaning

In-addition to this.....



# 1. Introduction

In this Information era, more particulate pollutants are added into the Office environment rapidly with the addition of

➤ **Computers**

Ref: **Ren et al.,(2006)**



➤ **Photocopiers**

Ref: **Lee et al (2007),**



➤ **Laser printers.**

**Kagi et al.,(2006), He et al., (2007), Tobias schripp et al., (2008), M.Wensing et al., (2008)**





# 1. Introduction

➤ **Laser printers have been classified as a high emission source of airborne particles due to**

- ✓ **regular printing activities.**
- ✓ **toner replacement.**
- ✓ **printer maintenance.**
- ✓ **Close proximity – higher chance of inhalation.**  
(Laser printers are commonly found on the office desk)
- ✓ **off gassing from printed circuit boards and fusion roller**

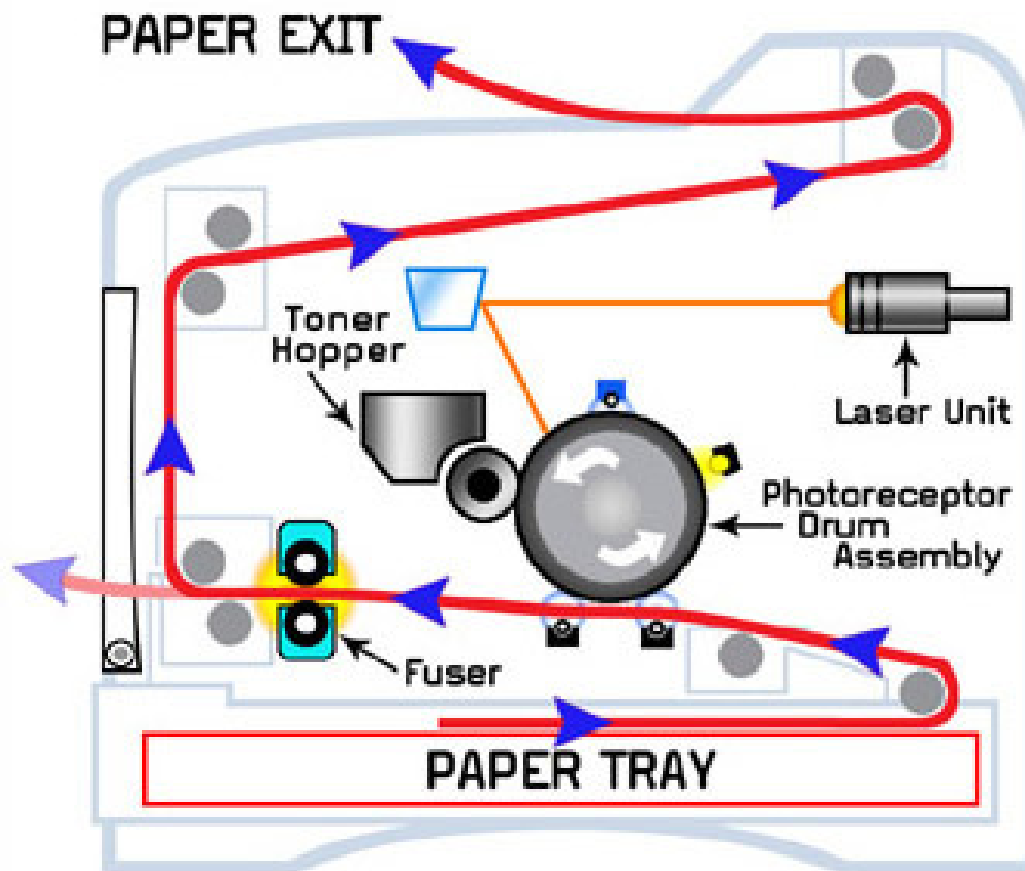


Ref: Kagi et al.,(2006), He et al., (2007), M.Wensing et al., (2008)



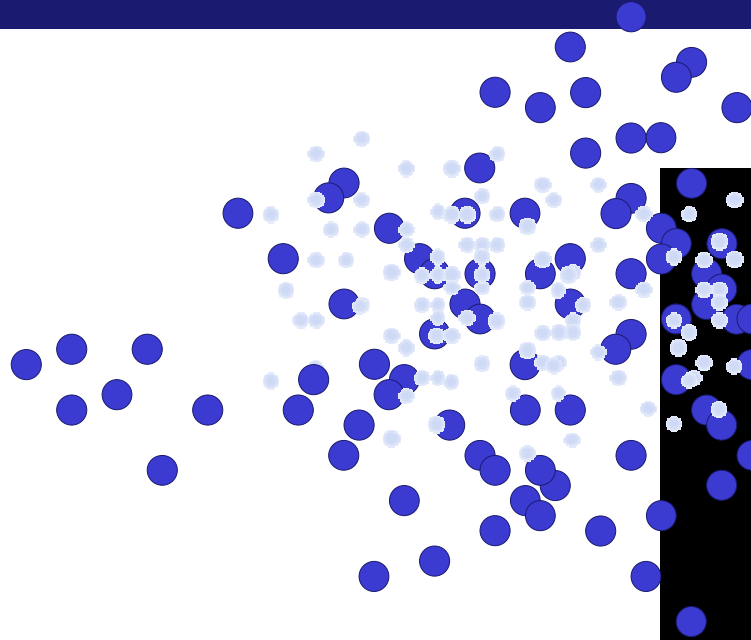
# 1. Introduction

## Stages in Laser printing





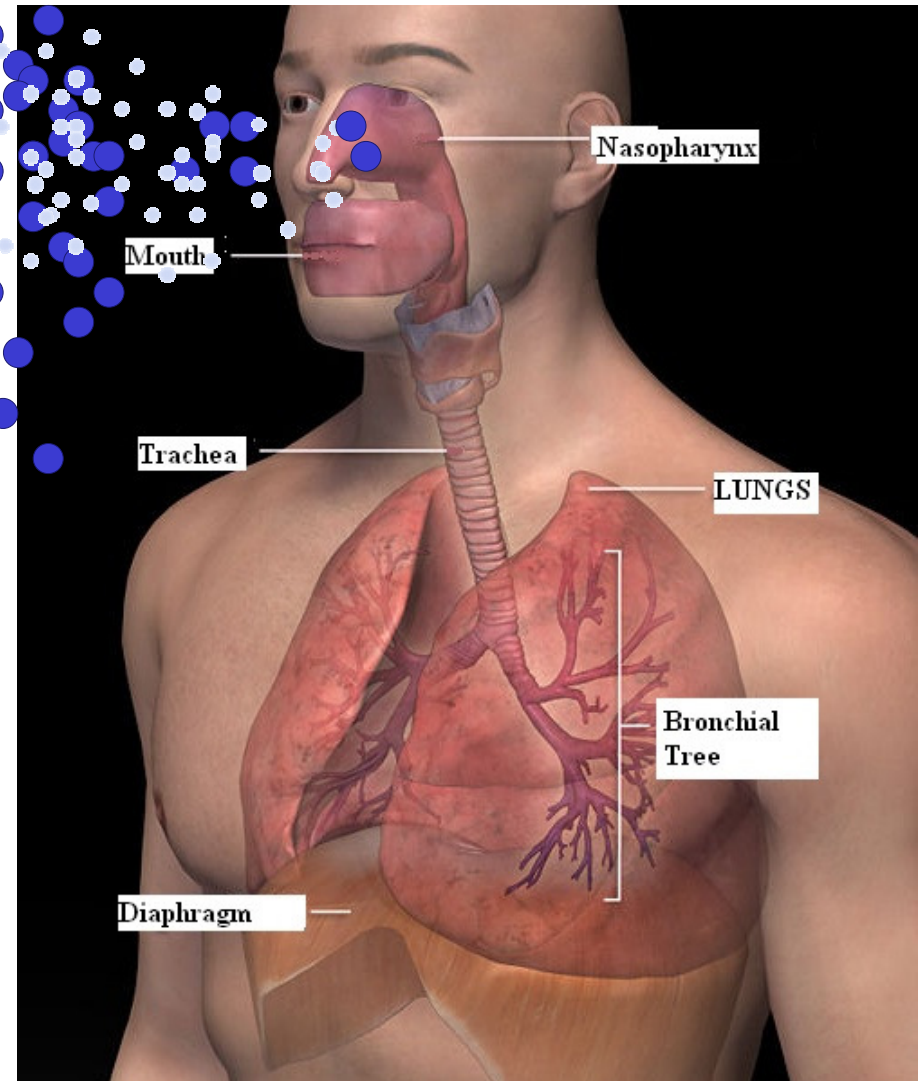
# 1. Introduction – Health Impacts



Ultra fine particles are more harmful than coarse particles because

**They remain airborne for a longer period of time and therefore have a higher chance of being inhaled.**

**They deposit more efficiently in deeper regions of the lung where removal from the body is slower.**





# 1. Introduction – Health Impacts

## Ultra fine particles can

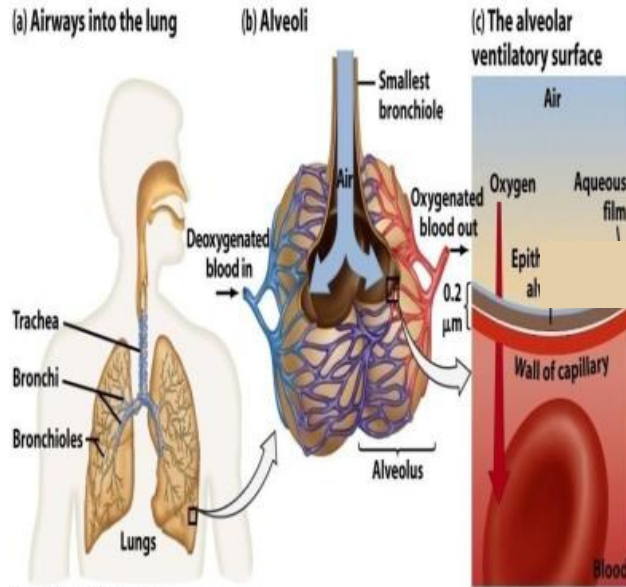


Figure 44-8 Biological Science, 2/e  
© 2005 Pearson Prentice Hall, Inc.

- have a higher surface area per unit mass.
- adsorb more chemical species on their surfaces, some of which are toxic.
- even get into the blood stream.
- have adverse effect depends on **physical** and **chemical properties** of particles

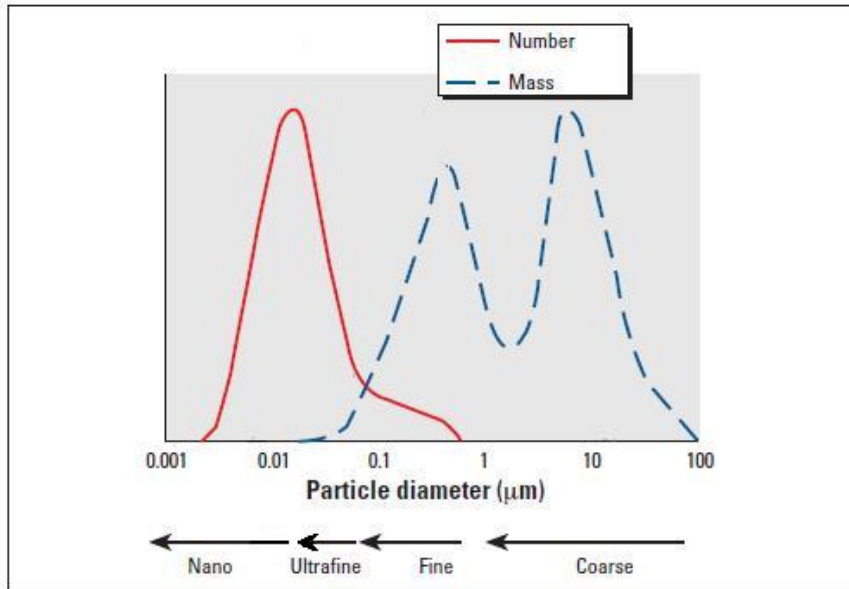
Clearance Mechanism	Site Cleaned	Rate of Cleaning
Cough	Trachea, bronchus	Instant
macrophages	Alveoli (air sacs)	24 hrs
lymphatics	Lung tissue	Months, years

Exposure	Health effects
Long term (Chronic effects)	Decreased Lung Function
	chronic Bronchitis
	Premature death
Short term (Acute effects)	Increased respiratory symptoms
	Cardiac arrhythmias (heartbeat irregularities)
	heart attacks
	Sensitive group like older adults and children are at high risk



# 1. Introduction

## Particulate measurement – Number or Mass



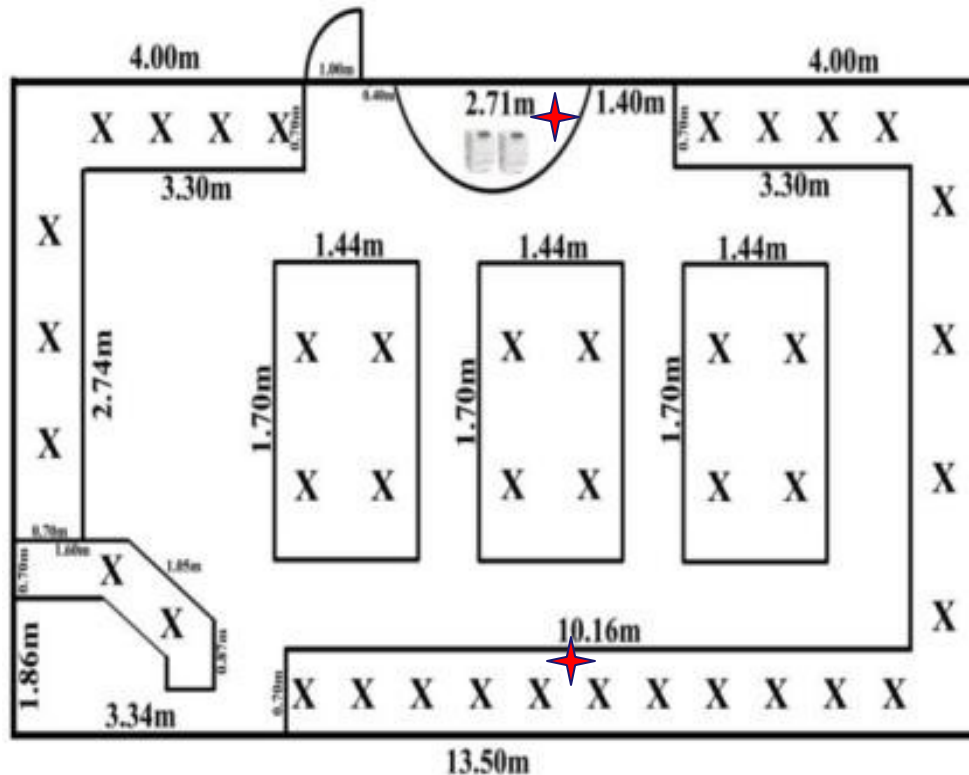
**1. Number concentration a better indicator for pollution level.**

**2. Particle size a better indicator for health risk assessment.**

Mass in ( $\mu\text{g}/\text{m}^3$ )	Particle Diameter in nm	Particle number ( $\text{cm}^{-3}$ )
10	5	153,000,000
10	20	2,400,000
10	250	1,200
10	5000	0.15



# 3. Experimental Setup



**X- computers**

**★ - PM Monitoring Locations**

**Commercial Printing center**

		Indoor characteristics	
Business Hours		0830H – 2100H	
Total internal volume m <sup>3</sup>		221.85	
Indoor temperature °C		24±2	
Relative humidity (%)		50±5	
Aircon Unit	Model	FXA50LV E	FXF80 LVE
	Quantity	3	2
	Air Flow rate (m <sup>3</sup> /min)	12	20
Air recirculation rate (h <sup>-1</sup> )		16 and 20.55	
Average number of pages printed		7000	



# Sampling instrumentation

## Physical Characterization

### Real-time monitoring



#### **Fast Mobility Particle Sizer (FMPS)**

Measures number concentration of 5 to 500 nm particles



#### **DustTrak Aerosol Monitor**

Measures mass concentration of PM<sub>2.5</sub>



#### **Aethalometer**

Measures black carbon concentration in ng / m<sup>3</sup>

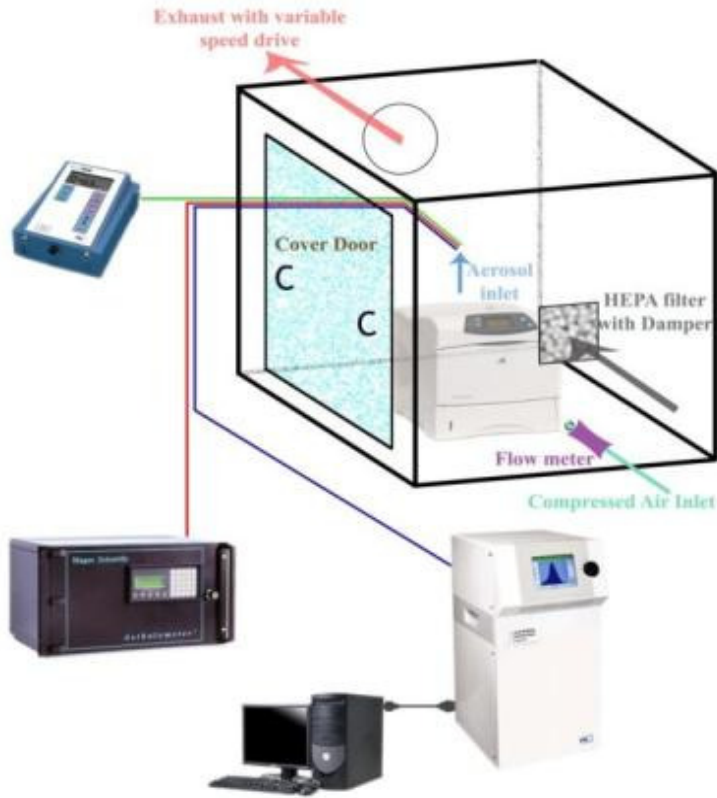


#### **Temperature . Humidity Logger**

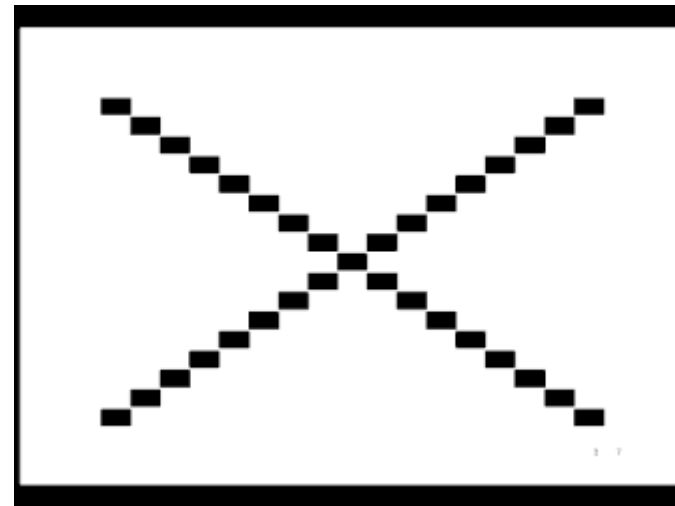
Measures temperature ° C and relative humidity % RH



# 3. Experimental Setup



	Chamber characteristics
	Mean
Total internal volume m <sup>3</sup>	one
temperature °C	24±2
Air humidity (%)	50±5
Air change rate (h <sup>-1</sup> )	0.3, 0.6 and 1



Printing done with Standard Monochrome printing format specified by ECMA - 328

Chamber study



## 4. Results and Discussion

### Number concentration during operating and non operating hours

All Days Average	<u>Number concentration during operating hours</u> (#/cm <sup>3</sup> )			
	Mean	Max	Min	SD
6nm - 50 nm	3.96E+03	1.29E+04	1.25E+03	2.26E+03
50nm - 100 nm	3.77E+03	7.74E+03	1.75E+03	1.26E+03
100nm - 500 nm	1.22E+03	2.32E+03	5.83E+02	3.88E+02
6 - 500 nm	1.02E+04	2.12E+04	5.11E+03	3.30E+03
All Days Average	<u>Number concentration during non-operating hours</u> (#/cm <sup>3</sup> )			
	Mean	Max	Min	SD
6nm - 50 nm	1.63E+03	3.18E+03	7.76E+02	6.02E+02
50nm - 100 nm	2.64E+03	4.41E+03	1.52E+03	7.92E+02
100nm - 500 nm	1.19E+03	2.04E+03	5.69E+02	4.35E+02
6 - 500 nm	5.45E+03	9.25E+03	3.18E+03	1.62E+03

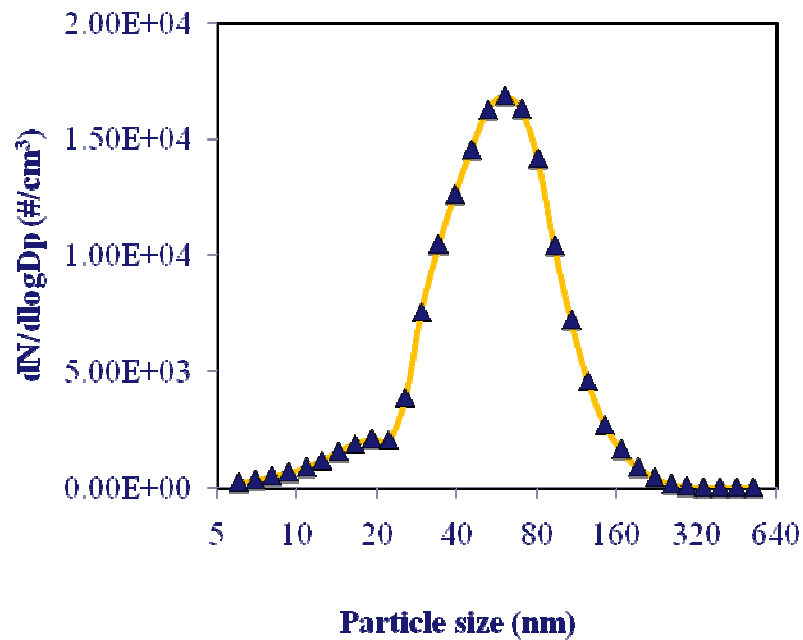
Commercial Printing center



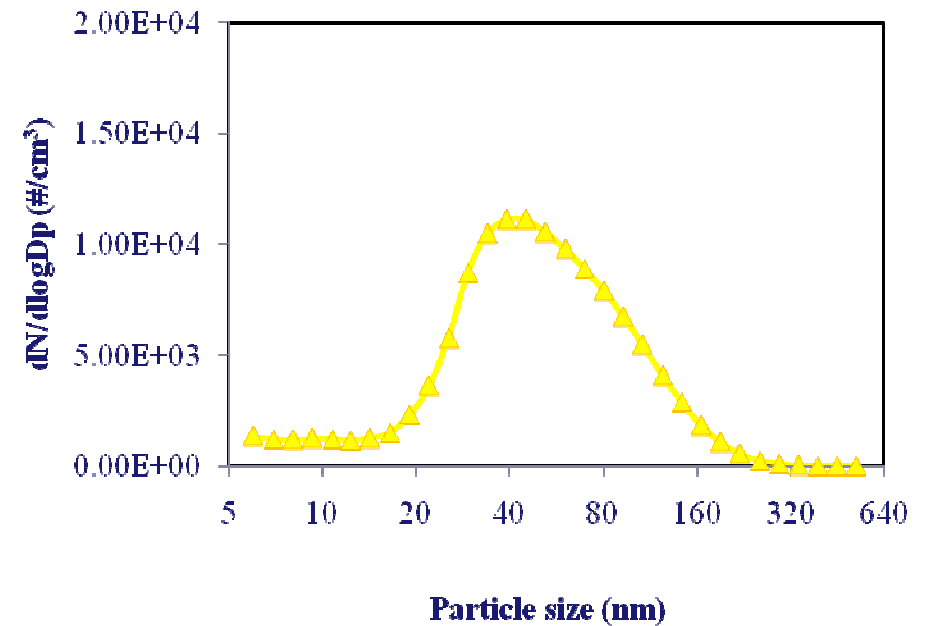
## 4. Results and Discussion

### Particle size distribution near and away from printer

Near the Printer



Away from Printer

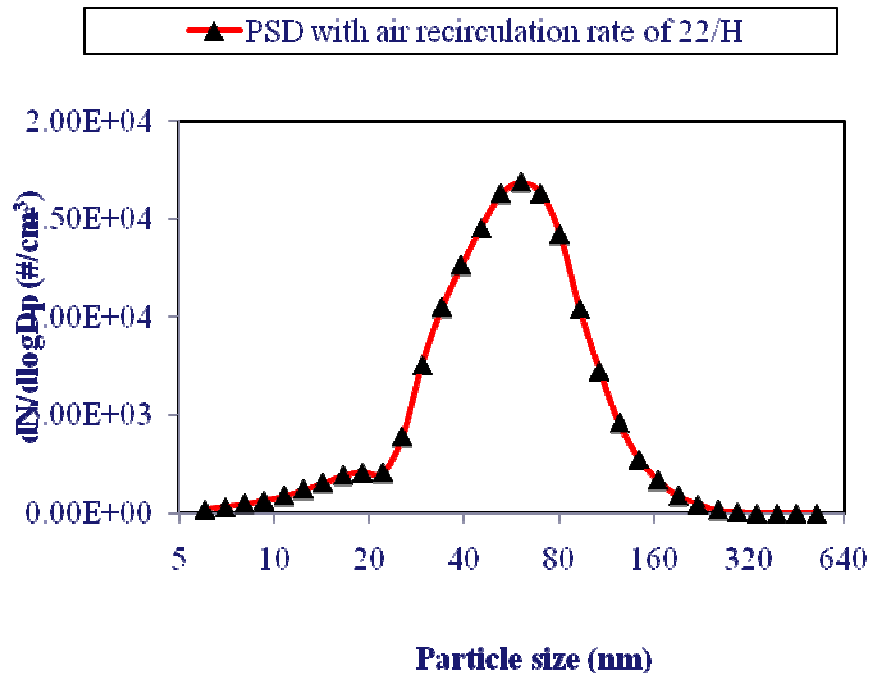


Commercial Printing center



## 4. Results and Discussion

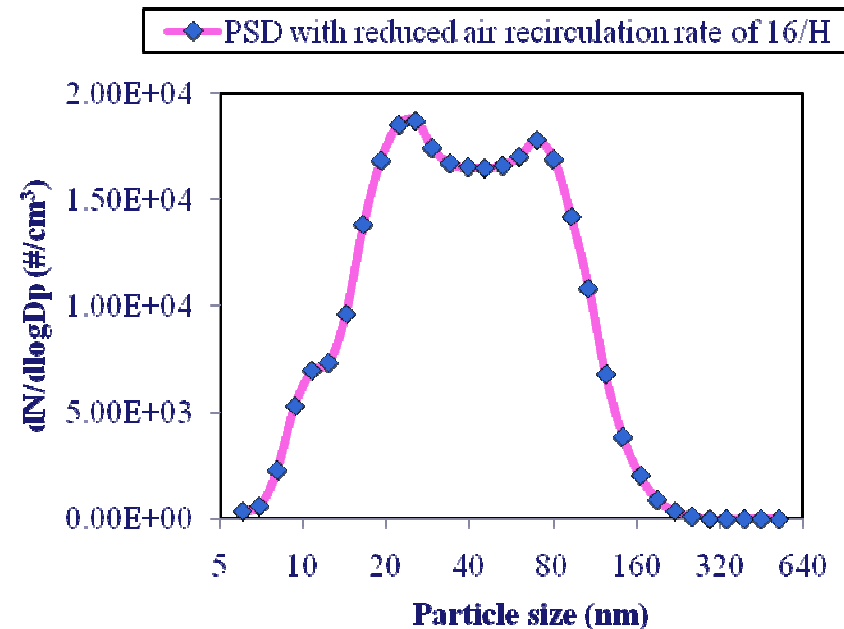
### Effect on ventilation rate on Particle size distribution



Location: Near printer

ACH : 2.2 h<sup>-1</sup>

Commercial Printing center



Location: Near printer

ACH : 1.6 h<sup>-1</sup>  
(reduced Ventilation)

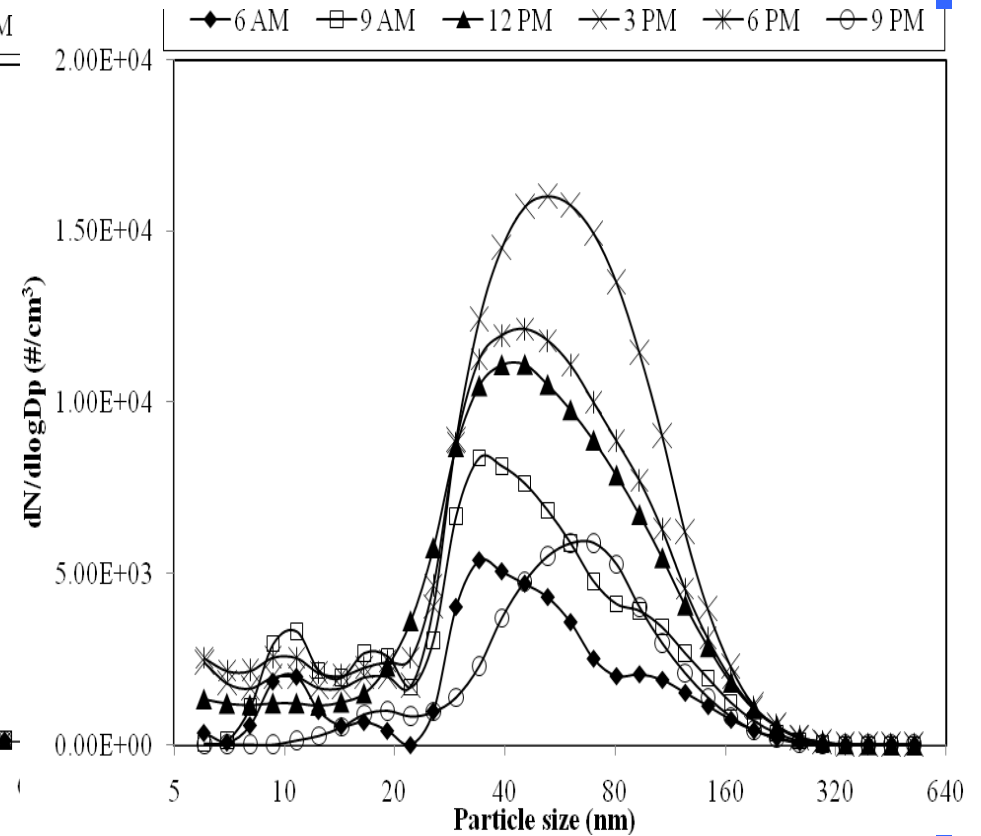
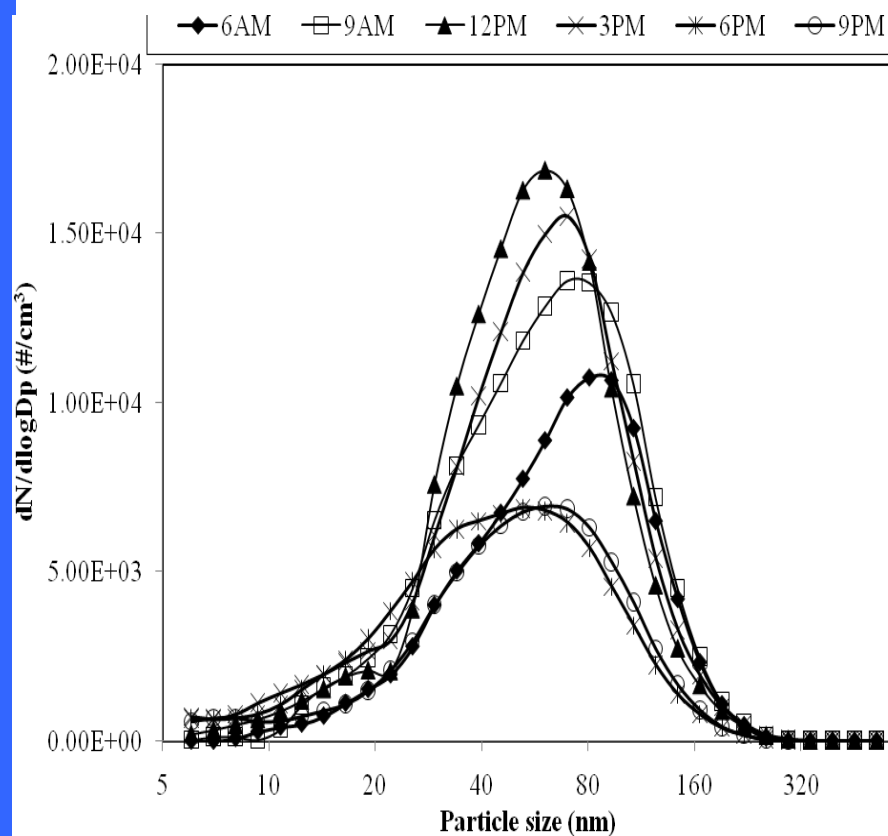


# 4. Results and Discussion

## Particle size distribution near and away from printer

Near the Printer

Away from Printer





# 4. Results and Discussion

## VOCs analysis

VOCs measurements were made peak printing and idling mode.

Description	In this Study in printing center		Chamber study by Lee et al	
	Idling mode	Peak printing period	Idling mode	Peak printing period
	Average Mass ( $\mu\text{g}/\text{m}^3$ )	Average Mass ( $\mu\text{g}/\text{m}^3$ )	Average Mass ( $\mu\text{g}/\text{m}^3$ )	Average Mass ( $\mu\text{g}/\text{m}^3$ )
Freon 12	2.8	2.7	0.5	0.64
Methyl Chloride	0.07	0.06	0.57	0.77
Freon 114	0.12	0.12	n.d.	n.d.
1,3-Butadiene (B)	<b>0.15</b>	<b>0.19</b>	n.d.	n.d.
Freon11	1.41	1.39	0.27	0.27
methylene chloride	<b>2.46</b>	<b>5.57</b>	0.4	0.52
Freon 113	0.62	0.61	n.d.	n.d.
Chloroform	0.18	0.19	1.02	1.24
Benzene (B/E/MS)	<b>1.35</b>	<b>2.84</b>	0.55	0.81
carbon tetra chloride	0.56	0.56	n.d.	n.d.
Trichloro ethene	0.07	0.06	n.d.	n.d.
Ethylbenzene (B)	<b>7.39</b>	<b>10.84</b>	<b>1.72</b>	<b>2.5</b>
m-xylene (MS)	<b>2.58</b>	<b>4.08</b>	<b>1.19</b>	<b>1.62</b>
p-Xylene (MS)	<b>2.16</b>	<b>4.09</b>	<b>1.3</b>	<b>1.82</b>
o-Xylene (B)	<b>3.3</b>	<b>5.71</b>	<b>0.93</b>	<b>2.13</b>
Styrene (B)	<b>4.18</b>	<b>4.44</b>	<b>3.35</b>	<b>4.23</b>

**Commercial Printing center**



## 4. Results and Discussion

### VOCs analysis (BTEXs)

#### Preliminary Health risk Assessment of BTEXS Compounds

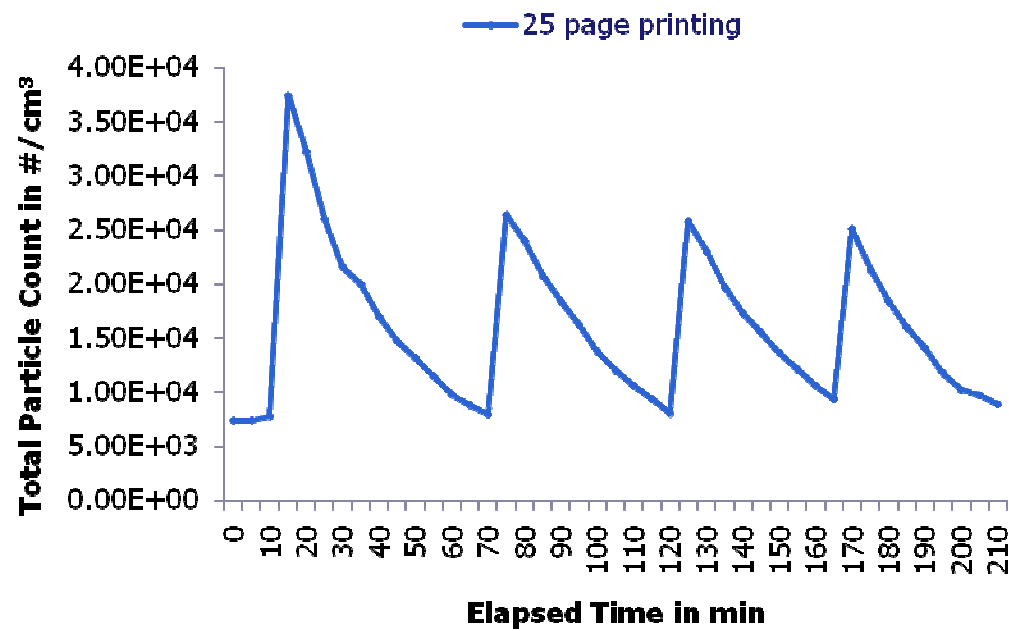
Description	Inhalation intake (mg/kg-day)	Carcinogenic Slope factor (mg/kg-day) <sup>-1</sup>	Cancer risk factor (PPM)	US (OSHA) std IN PPM	ACGIH std IN PPM
Benzene (B/E/MS)	<b>1.93E-04</b>	<b>0.1</b>	<b>19</b>	<b>1</b>	<b>0.5</b>
Toluene (B/E)	2.06E-03			200	50
Ethylbenzene (B)	5.23E-04	8.70E-03	4.55	100	100
m-xylene (MS)	2.21E-04			100	100
Styrene (B)	3.22E-04			100	-

NUS Printing center



## 4. Results and Discussion

Number concentration with respect to 25 Pages printed



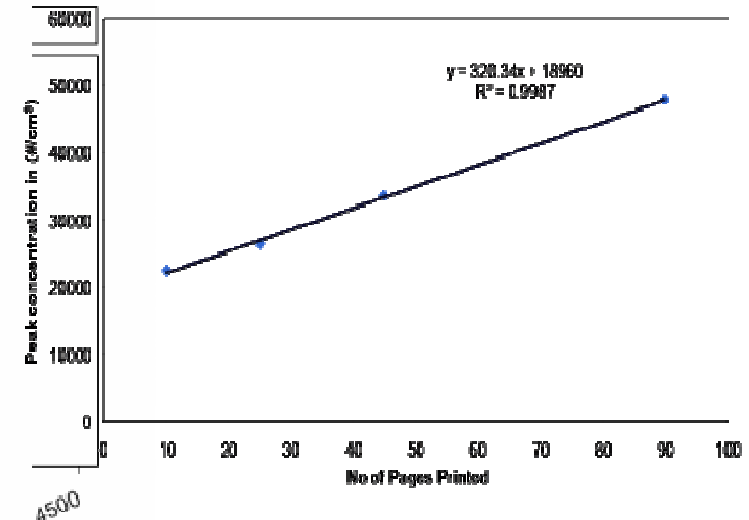
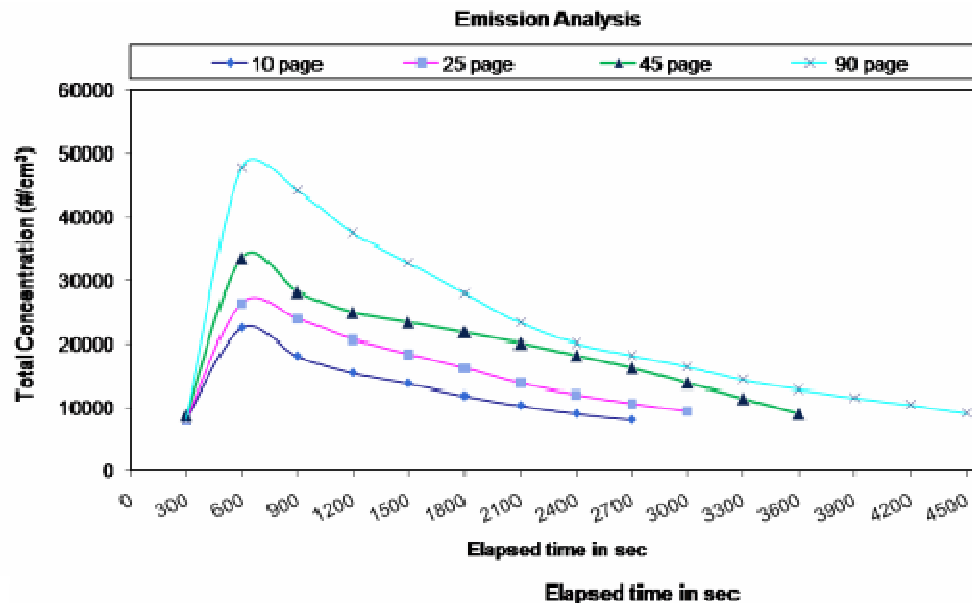
ACH : 0.6 h<sup>-1</sup>

Chamber study



## 4. Results and Discussion

### Effect on Number concentration with respect to number of Pages printed



ACH : 0.6 h<sup>-1</sup>

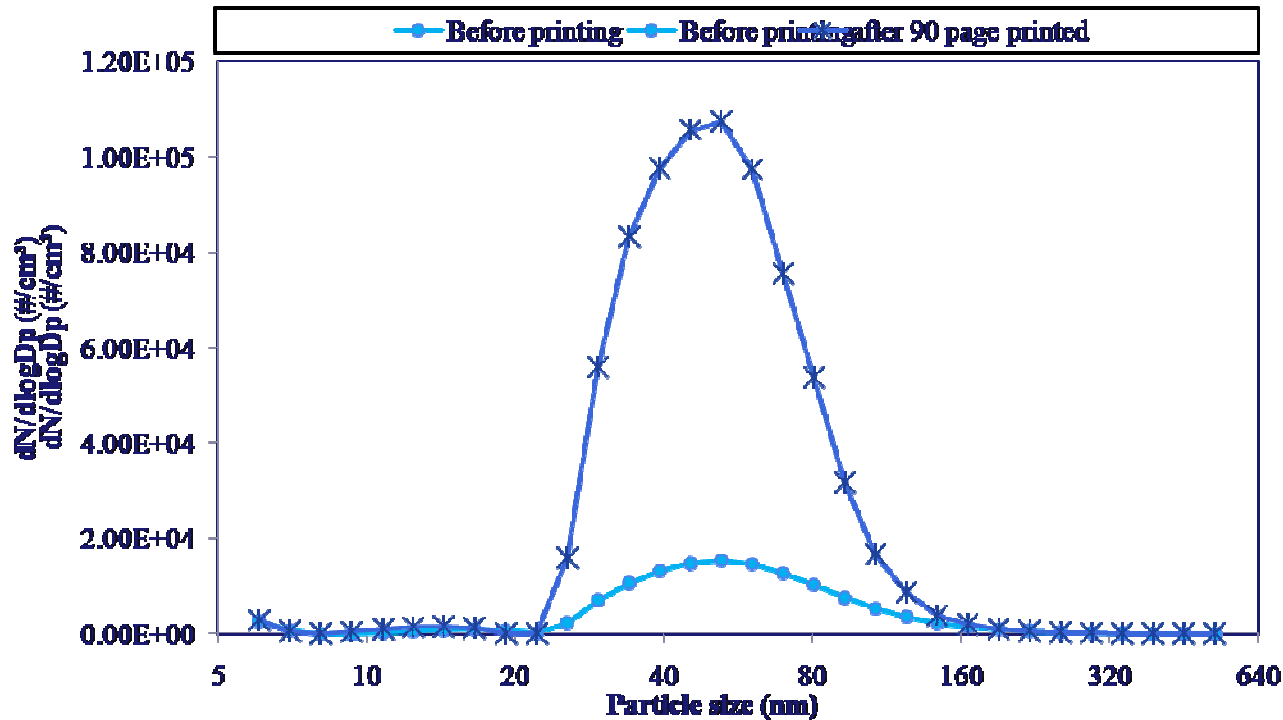
As number of pages increased the total particle count increased linearly

Chamber study



# 4. Results and Discussion

Comparison on Particle size distribution before and after printing



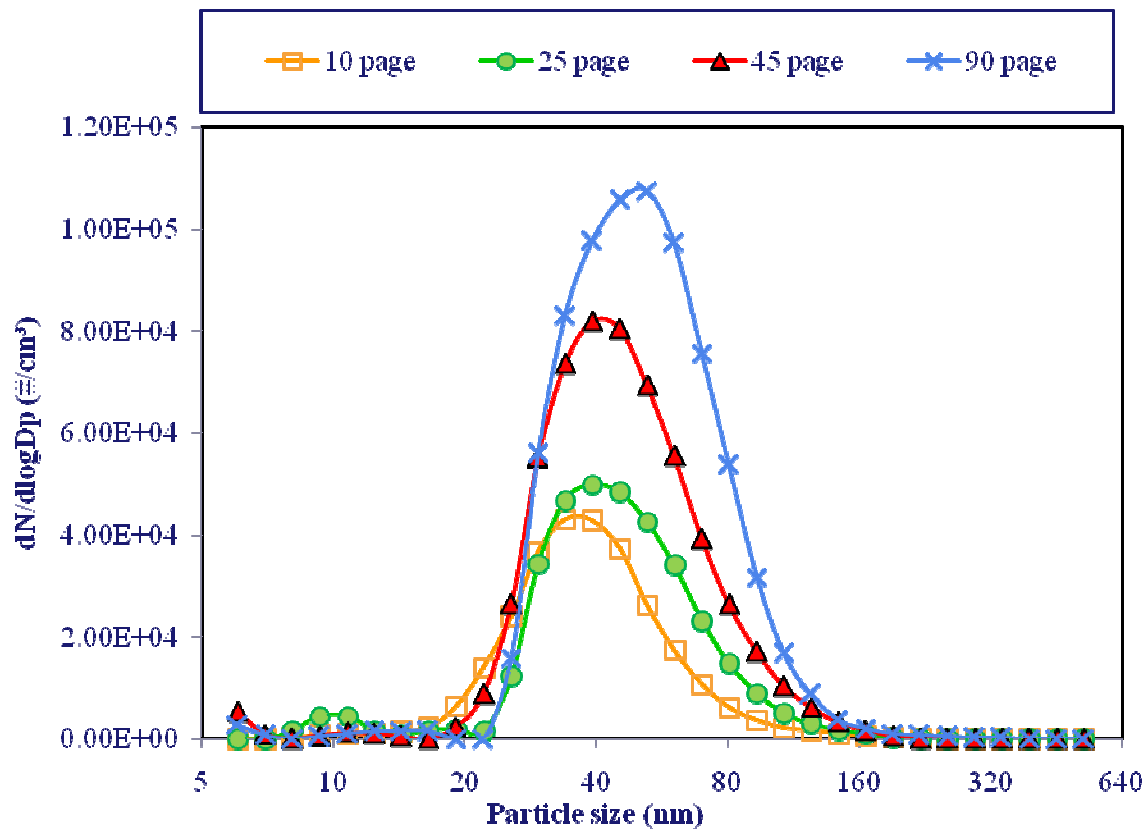
Particle count increased by 6 fold in the size range of 25-100nm by printing 90 pages

Chamber study



## 4. Results and Discussion

Variation in Particle size distribution with respect to number of pages printed



Chamber study

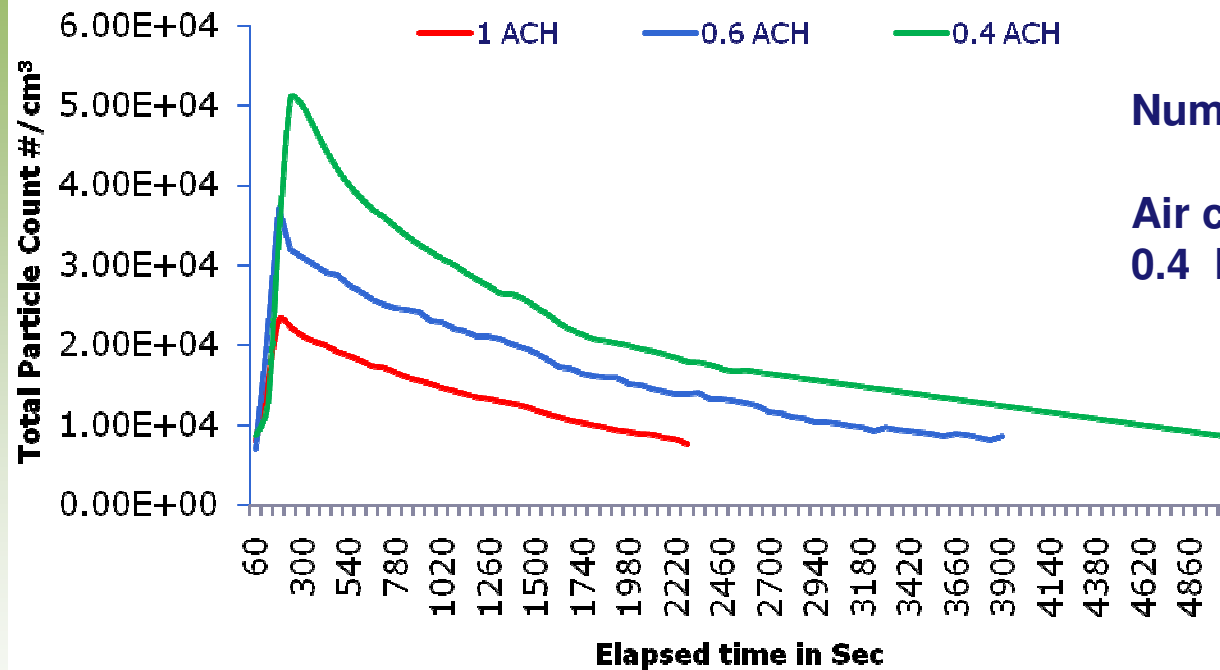
5/27/2010

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# 4. Results and Discussion

## Effect on Number concentration with respect to Ventilation rate.



Number of pages printed: 45

Air change rate (ACH) : 1, 0.6, 0.4 hr<sup>-1</sup>

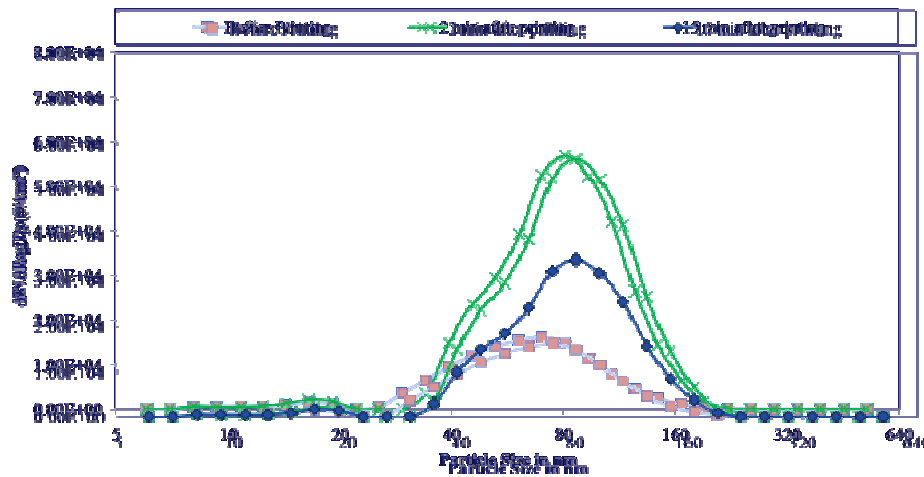
Air change rate	Residence Time (min)
0.4	83
0.6	64
1	37

Chamber study



# 4. Results and Discussion

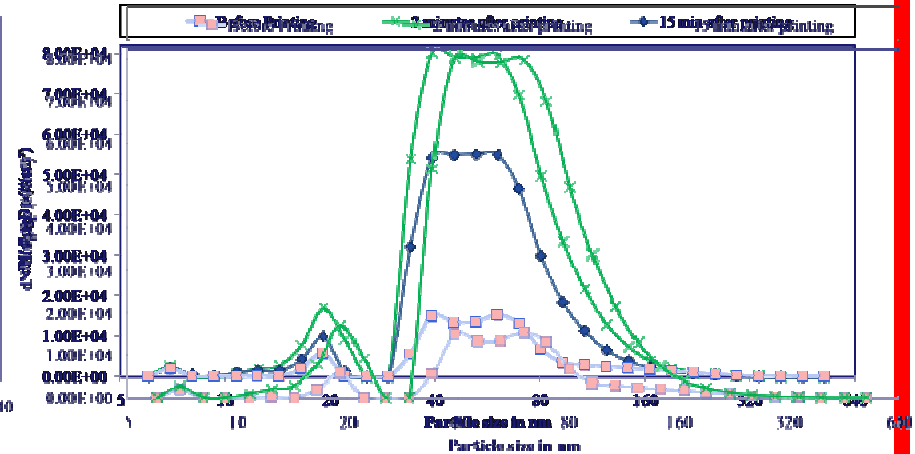
## Effect on ventilation rate on Particle size distribution



Number of pages printed: 45

Air change rate (ACH) : 1 hr<sup>-1</sup>  
(ACH is as per ECMA standard 328)

Chamber study



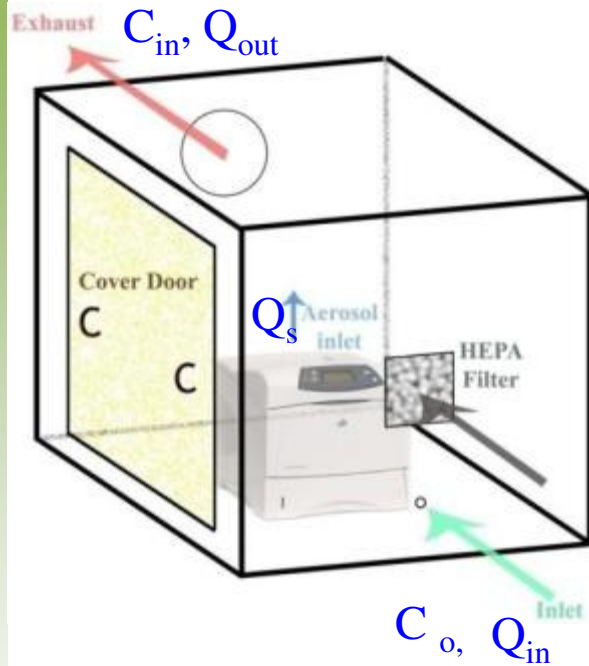
Number of pages printed: 45

Air change rate (ACH) : 0.4 hr<sup>-1</sup>  
(ACH is as lower than ECMA standard 328)



# 4. Results and Discussion

## Modeling work on Emission rate from laser printer



$$\left( \frac{dC_{in}}{dt} \right) = \frac{(Q_{in} C_o - Q_{out} C_{in})}{V} + \frac{Q_s}{V} - \lambda C_{in} \quad \text{---(1)}$$

Where

$Q_{in}$  is inflow rate;  $Q_{out}$  is out flow rate;

$C_{in}$  is # conc inside the chamber;  $C_o$  is # conc of inlet compressed air,

$V$  is Volume of chamber

$\lambda$  is total decay rate which includes air exchange, deposition and coagulation rate

$Q_s$  is the emission rate

$t$  is time.

Eqn (1) can be rewritten as

$$\frac{dC_{in}}{dt} = P \alpha C_o + \frac{Q_s}{V} - \lambda C_{in} \quad \text{---(2)}$$

Where

$P$  is penetration efficiency;

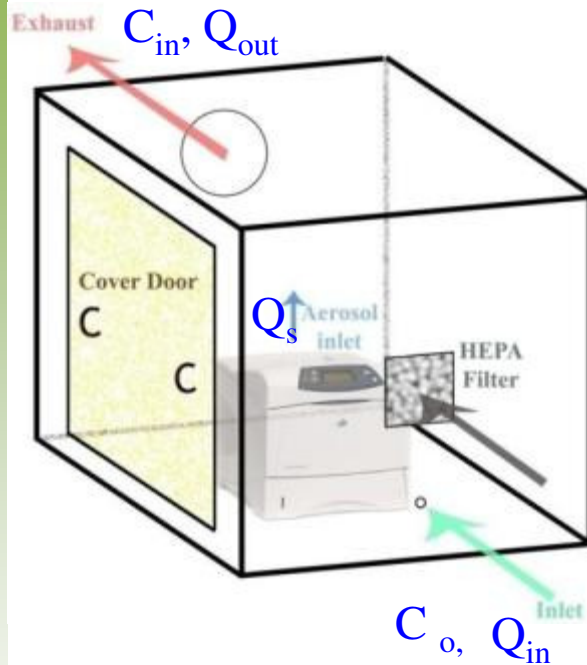
$\alpha$  is air exchange rate;

**Chamber study**



# 4. Results and Discussion

## Modeling work on Emission rate from laser printer



Assumptions made

1. Prior to printing the system attains a steady state.  $C_{in} = C_{background}$

$$P\alpha = \lambda C_{in} / C_o = P\alpha = \lambda C_{background} / C_o$$

Eqn (2) can be rewritten as

$$\left(\frac{dC_{in}}{dt}\right) = P\alpha C_o + \frac{Q_s}{V} - \lambda C_{in} = \lambda(C_{background} - C_{in}) + \frac{Q_s}{V} \quad \text{---(3)}$$

From Eqn (3), upon integrating

$$Q_s = V \left[ \frac{(C_{peak} - C_{background})}{\Delta t} - \lambda(C_{background} - \bar{C}_{in}) \right] \quad \text{---(4)}$$

2. After completion of printing, No emission takes place  $Q_s = 0$

$$\left(\frac{dC_{in}}{dt}\right) = \lambda(C_{background} - C_{in}) \quad \text{---(5)}$$

Upon Integrating Eqn (5)

$$\ln \left[ \frac{(C_{peak} - C_{background})}{(C - C_{background})} \right] = -\lambda t \quad \text{---(6)}$$

Chamber study



## 4. Results and Discussion

### Validation of Modeling work on Emission rate from Laser printer

- The emission rates were determined for 45 pages printing under three different air exchange rate such as 0.36, 0.6 and 1 per hour.

Air Flow Rate (L/min)	Air exchange rate per hour	Estimated emission Rate (min <sup>-1</sup> )
6	0.36	1.17E+09
10	0.6	1.14E+09
17	1.0	1.16E+09

- model predictions are good as the emission rates are printer specific and do not depend on the air exchange rates.

### Chamber study



## 5. Conclusion

- ❖ Number concentration increased 2-6 times during printing compared to background concentration.
- ❖ In both chamber and printing center a bimodal size distribution is observed with peaks around 20nm and 70 nm with reduced ventilation rate.
- ❖ The emission rate was  $1.1 \text{ E}+09 \text{ min}^{-1}$  for 45 paged printed .
- ❖ preliminary cancer health risk assessment for Benzene has exceeded the US (OSHA) standard which indicates the need of detailed study on the printer emission characteristics.



# Q & A

Thank You

