A simple technique to improve pollutant reduction efficiency and mass removal by near-road vegetation barriers

MORAKINYO Tobi Eniolu and LAM Yun Fat

PhD Candidate,

School of Energy and Environment,

City University of Hong Kong , Hong Kong.

tobimorak@yahoo.com

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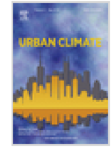
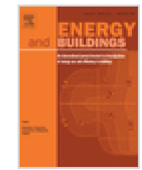


Comparing the effect of trees on thermal conditions of two typical urban buildings

Tobi Eniolu Morakinyo[a], Ahmed Adedoyin Balogun[a, 1], Olumuyiwa Bayode Adegun[b, 2]

Energy and Buildings

Volume 81, October 2014, Pages 305–315



Effect of tree-shading on energy demand of two similar buildings

Ahmed Adedoyin Balogun[a], Tobi Eniolu Morakinyo[a], Olumuyiwa Bayode Adegun[b]

Indoor and Built Environment

http://ibe.sagepub.com/

The effect of vegetation on indoor and outdoor thermal comfort conditions: Evidence from a microscale study of two similar urban buildings in Akure, Nigeria

Tobi Eniolu Morakinyo, Olumuyiwa Bayode Adegun and Ahmed Adedoyin Balogun

Indoor and Built Environment published online 8 December 2014
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OUTLINE

- Background of study
- State of the art
- Aim and specific objectives of study
- Description of methodology
- Results and discussion
- Conclusion

What is good air quality to you????

Higher Dispersion or Higher removal ???

Urban environment and pollution

	MAJOR SOURCES	HEALTH EFFECTS	ENVIRONMENTAL EFFECTS
SO_2	Industry	Respiratory and cardiovascular illness	Precursor to acid rain, which damages lakes, rivers, and trees; damage to cultural relics
NO_x	Vehicles; industry	Respiratory and cardiovascular illness	Nitrogen deposition leading to over-fertilization and eutrophication
PM	Vehicles; industry	Particles penetrate deep into lungs and can enter bloodstream	Visibility
CO	Vehicles	Headaches and fatigue, especially in people with weak cardiovascular health	
Lead	Vehicles (burning leaded gasoline)	Accumulates in bloodstream over time; damages nervous system	Fish/animal kills
Ozone	Formed from reaction of NO_x and VOCs	Respiratory illness	Reduced crop production and forest growth; smog precursor
VOCs	Vehicles; industrial processes	Eye and skin irritation; nausea; headaches; carcinogenic	Smog precursor

Earth day Network (retrieved 18 July,2015)

Methods of pollution control

–Control emissions
- •Catalytic converter
- •Replacing diesel engine vehicles
- •Regulations and legislation

–increasing dispersion
- •environmental condition
- •Urban geometry

–increasing deposition rates (Green infrastructures)
- •Surface characteristics

Green infrastructures and pollution

Typical examples of roadside VB

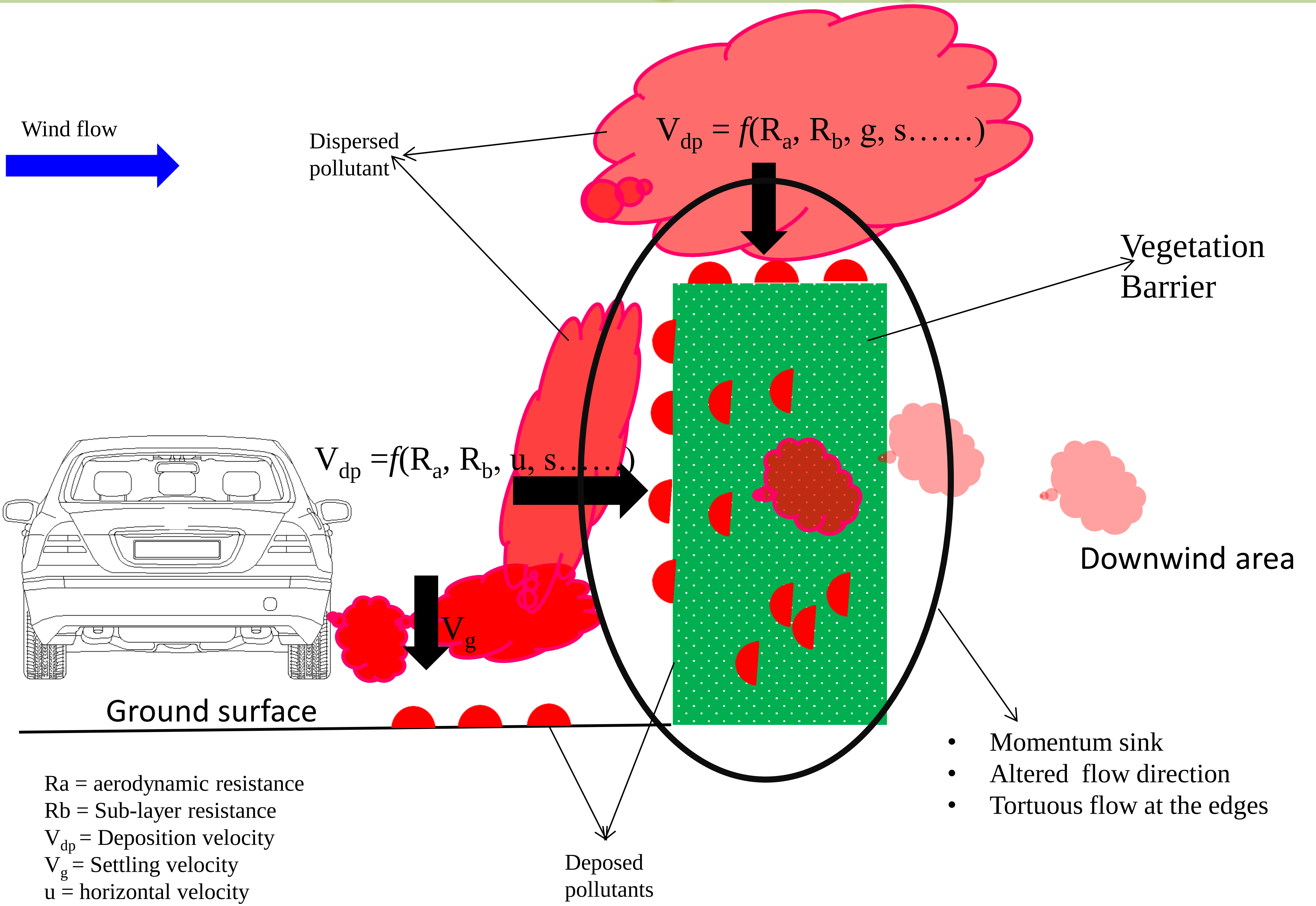
a

Source: Alkalaj and Thorsteinsson, 2014

b

Source: Hagler et.al.,2012

Interaction between vegetation and particulate



Ra = aerodynamic resistance
Rb = Sub-layer resistance
V_{dp} = Deposition velocity
V_g = Settling velocity
u = horizontal velocity
s= particle size

Urban vegetation and air quality: Discrepancies

Urban Vegetation Type	YES / Location	NO / Location	Method
Street trees		Rien and Eichordern , Gromke, 2011; Gromke and Ruck, 2012 ; Wania et al., 2012 and Vos et al.,2013/ Local scale /Street canyon	CFD modelling (Dispersion-related)
Urban forest (street trees +Urban park	Nowak et al., 2006;Bealey, et al., 2006; McDonald et. al., 2007; Tallis et. al., 2011/ City scale		Modelling /Field measurement (Deposition-related)
Green wall/roof	Tan and Sia, 2005 ; Rosenzweig et al., 2006 and Yang et al., 2008/ local scale		Field measurment (Deposition-related)
Vegetation Barrier	Steffens et al., 2012 ; Hagler et al., 2012 ; Brantley et al., 2014 ; Al-Dabbous and Kumar, 2014 / near-road Wania et al., 2012, Vos et al., 2013/street-canyon	Wania et al., 2012, Vos et al., 2013/ street-canyon	CFD modelling and Field measuremnt (Dispersion-related)

Research gap

Atmospheric Environment 105 (2015) 130–137

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ELSEVIER

Review

Review on urban vegetation and particle air pollution — Deposition and dispersion

Sara Janhäll

Swedish National Road and Transport Research Institute-VTI, Sweden

CrossMark

H I G H L I G H T S

- Combining deposition and dispersion helps designing urban vegetation related to air quality.
- The dilution of emissions with clean air from aloft is crucial; limit high urban vegetation.
- High concentrations of air pollutants increase deposition; vegetation should be close to the source.
- Air floating above, and not through, vegetation barriers is not filtered; decides barrier porosity.
- Differently designed vegetation catch different particle sizes.

Urban vegetation and air quality: Discrepancies

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Street trees		Rien and Eichordern , Gromke, 2011; Gromke and Ruck, 2012 ; Wania et al., 2012 and Vos et al.,2013/ Local scale /Street canyon	CFD modelling (Dispersion-related)
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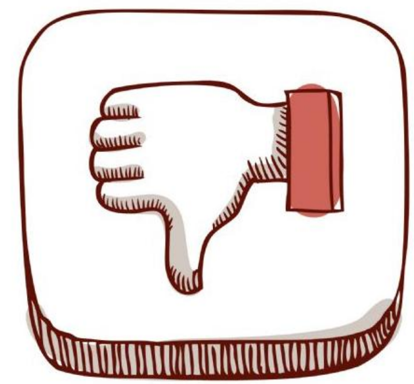
Assessment of air quality benefit of Vegetation Barrier using by combined dispersion and deposition methods

Dispersion and deposition related to vegetation in urban areas are both interesting and vivid research areas. This review suggests that these areas be further combined, as the environmental problem in which they interact, urban air quality, is crucial to human health and results are rapidly transferred into policy. Thus, results from one area must be modified with results from the other before action is taken in urban planning.

What is good air quality to you????

Higher Dispersion or Higher removal ???



OBJECTIVES OF STUDY

Objective

To assess of air quality benefit of Vegetation Barrier by combined dispersion and deposition methods.

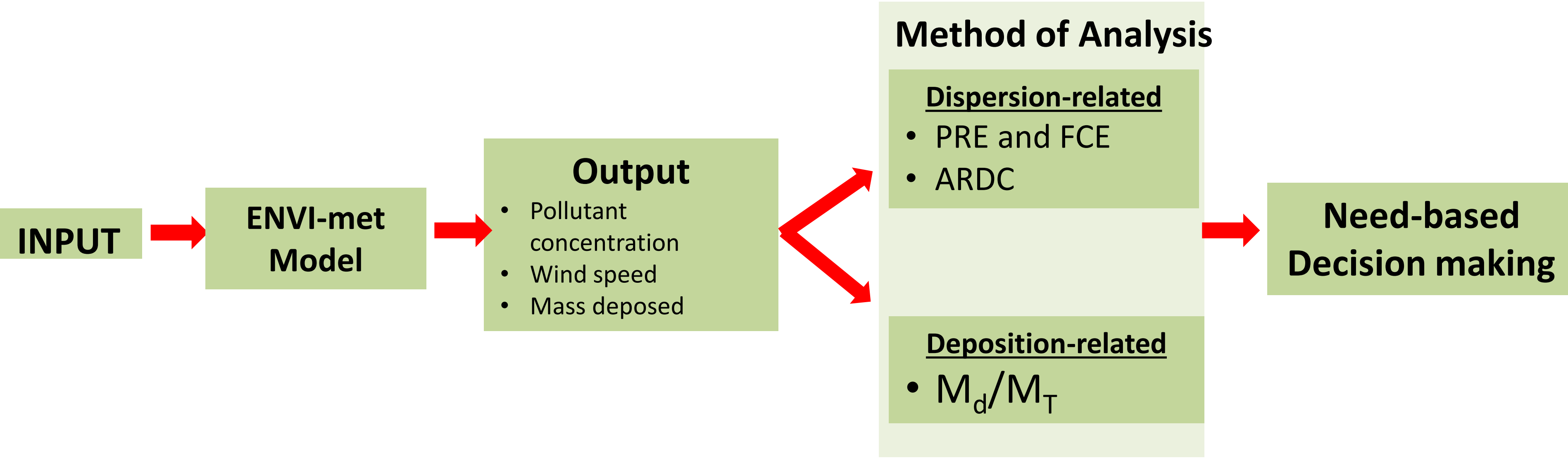
Research Questions

What is the optimum distance between VB and source region?

What is the optimum thickness of VB?

Can VB be beneficial to air quality from both dispersion and deposition standpoint???

Methodology



PRE = Pollutant Reduction Efficiency

FCE= Filtration-Collection Efficiency

ARDC= Average Relative Difference in Concentration

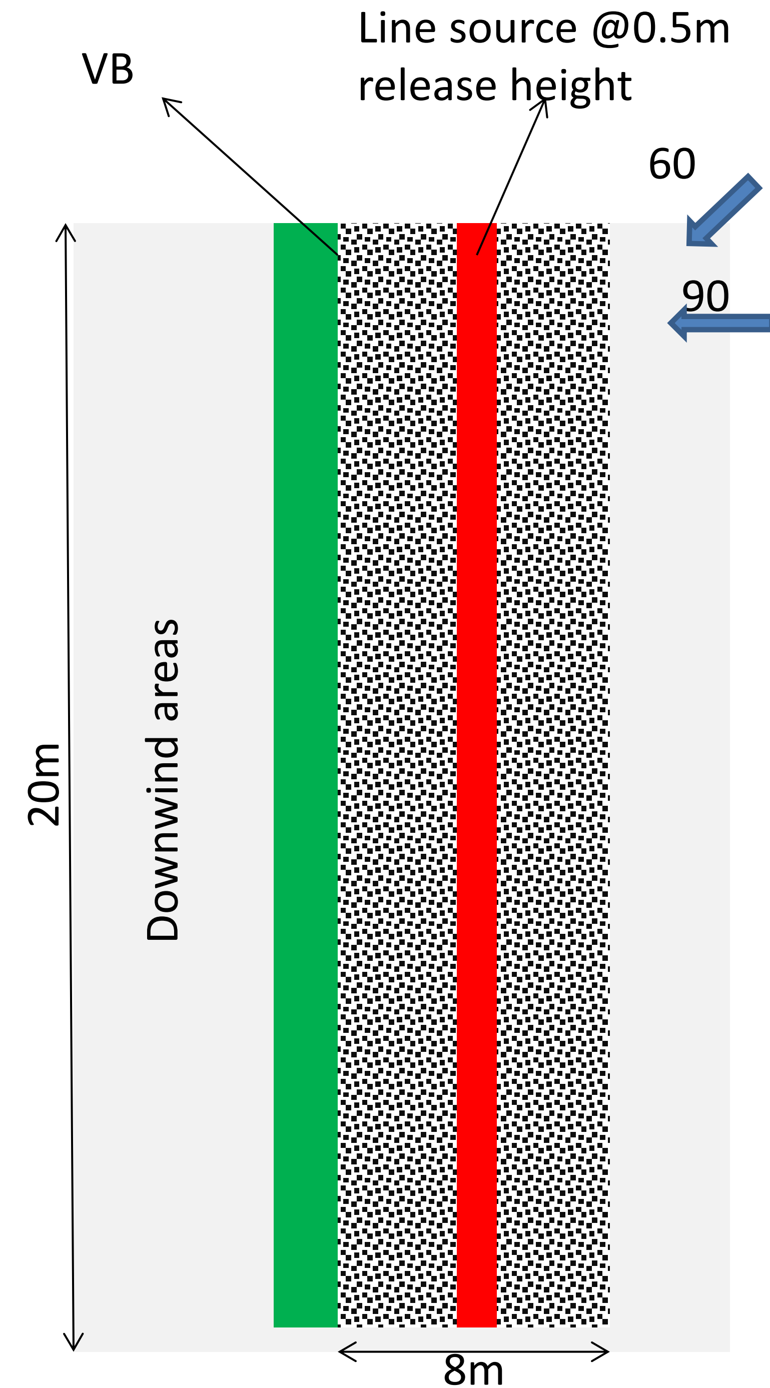
M_d = Mass deposed on the leaf surfaces

M_T = Total Mass available in the reference domain

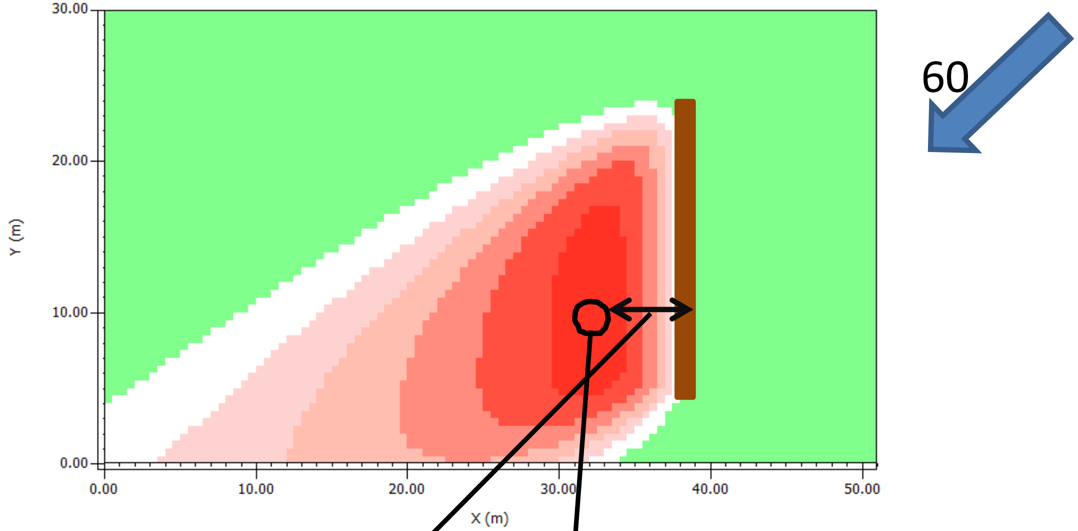
INPUT

Table 1: Overview of input and test parameters

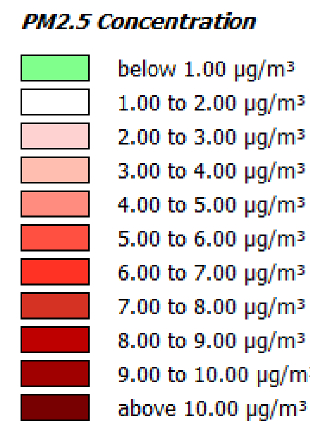
Parameter	Definition	Value
Meteorological conditions	Initial potential air temperature Relative Humidity at 2m Inflow direction Wind speed at 10m	29°C 80% 60° (Oblique), 90° (Perpendicular) 3m/s
Road layout	Length Width Carriage type	20m 8m Single (uni-directional)
Pollution source	Specie Source geometry Emission rate	2.5µm Line source at 0.5m 12.7µg/s/m
Vegetation barrier (VB)	Length Thickness and Height LAD Deposition velocity	20m varies per case (see Table 2) $2m^2/m^3$ 0.1cm/s



Introduction to ‘Distance to Maximum Concentration (DMC) ‘



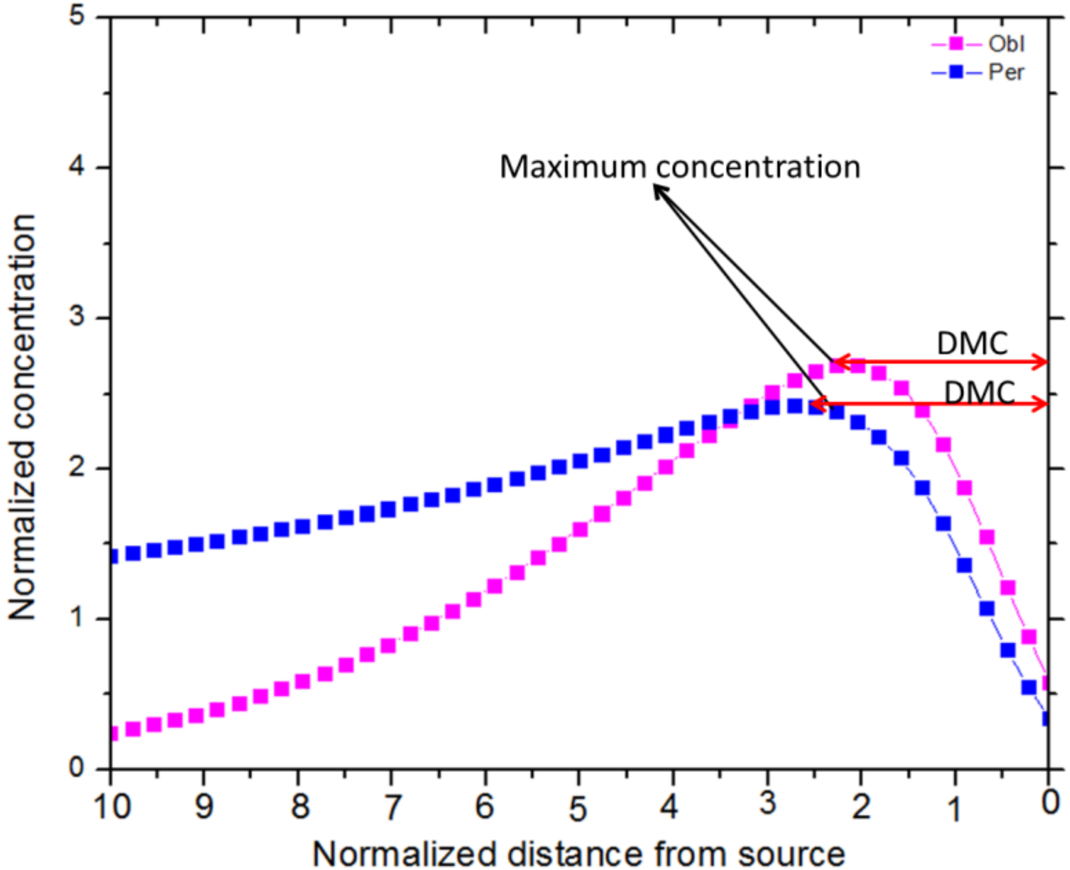
@1.4m (pedestrian height)



Maximum concentration

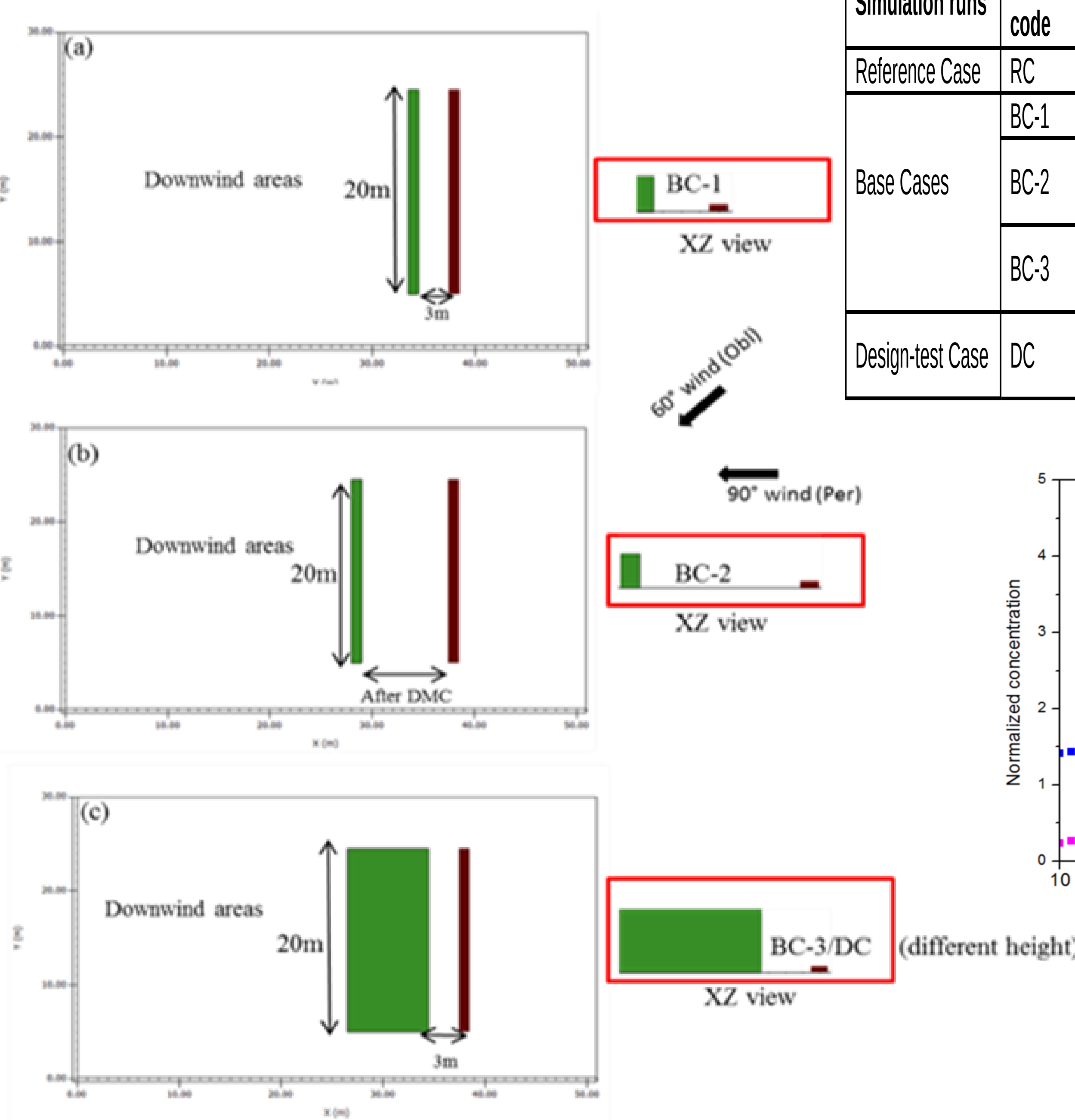
Distance between the source region and point of maximum concentration is referred **‘Distance to Maximum Concentration, DMC’**

Introduction to ‘Distance to Maximum Concentration (DMC) ‘

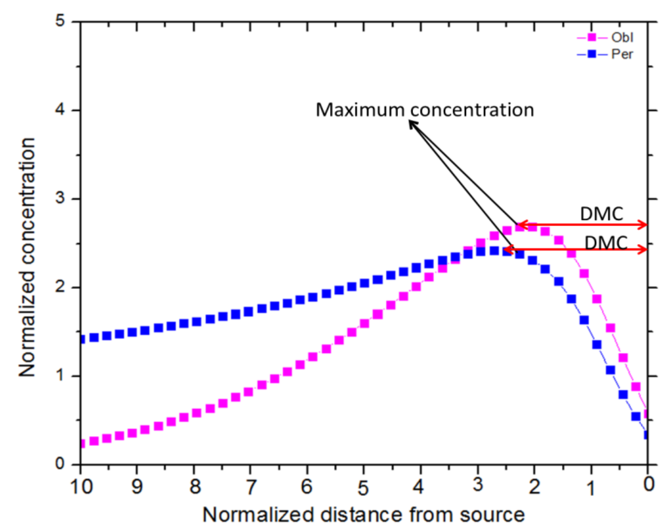


- **Existence of point of peak concentration and it varies with Wind speed and direction**
- **MC could be before or after a VB depending on its configuration.**

Simulation Experiments

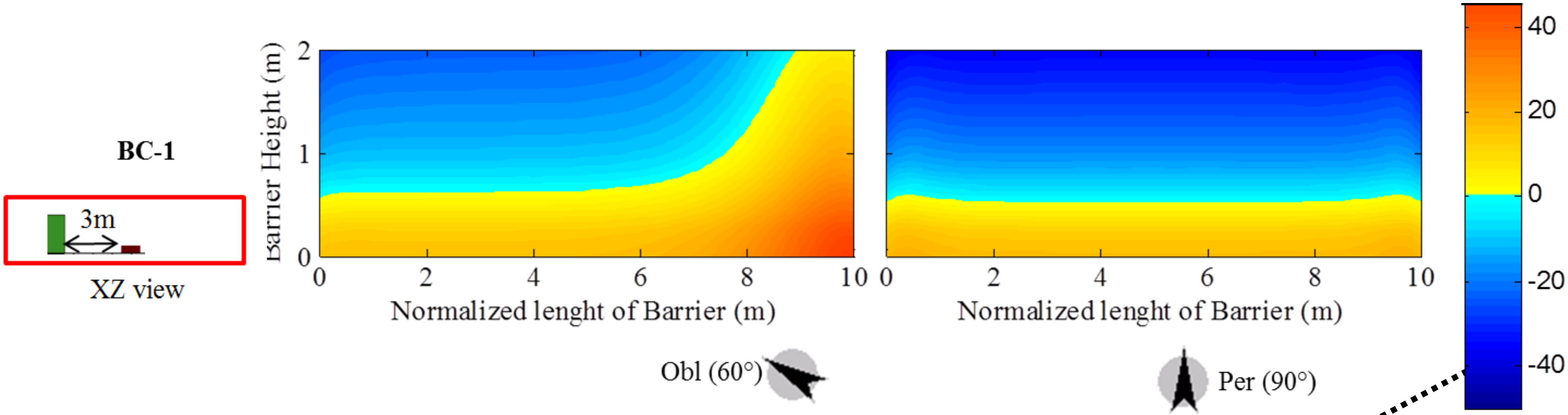


Simulation runs	Case code	H=2m,T=1m		Remarks
		Height (m)	Thickness (m)	
Reference Case	RC	-	-	
Base Cases	BC-1	H	T	VB positioned 3m from road
	BC-2	H	T	Placed after DMC of each wind direction
	BC-3	H	8T	Thickness was determined by DMC of each wind direction
Design-test Case	DC	1.5H	8T	Thickness was determined by DMC for varying wind direction



RESULTS and DISCUSSION

Spatial distribution of PRE across VB in BC-1



This is a Problem

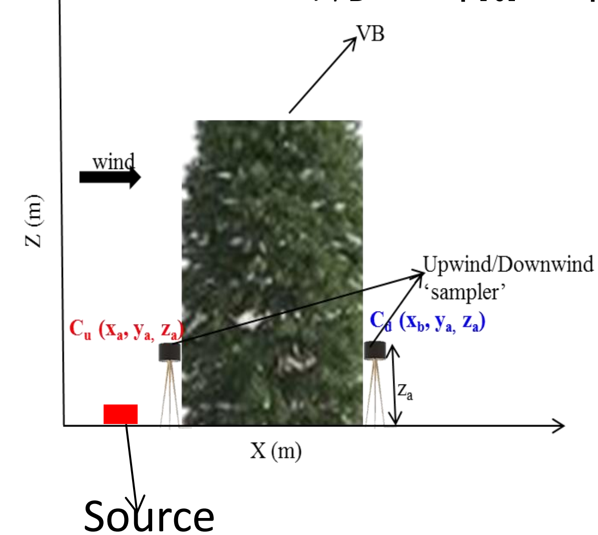
- **PRE across the entire length and height of a VB is not evenly distributed.**

- **This result partially opposes previous studies** *(Tiwary et al., 2006; Tiwary et al., 2008; Islam et al. 2012; Alkalaj and Thorsteinsson, 2014 Al-Dabbous and Kumar, 2014 and Brantley et.al, 2014)* **who reported only positive PRE**

- A negative PRE suggests $C_d >> C_u$ due over-powering aerodynamic effect of VB over its reduction capacity (Vos et al., 2013). This pattern can also be observed if the VB is highly porous (Hagler et.al.,2012).

$$PRE, \phi_{VB} = u(H,L)\left(1 - \frac{C_d}{C_u}\right) \times 100\%$$

$$FCE, \quad \gamma_{VB} = [\phi_{ref} - \phi_{VB}]$$



Techniques to avoid negative PRE

- Increase LAD of VB ? NO

  Reason :

  > Air passing above, and not through, vegetation is not filtered; barriers should be high enough and porous enough to let the air through, but solid enough to allow the air to pass close to the surface. **(Janhall, 2015)**

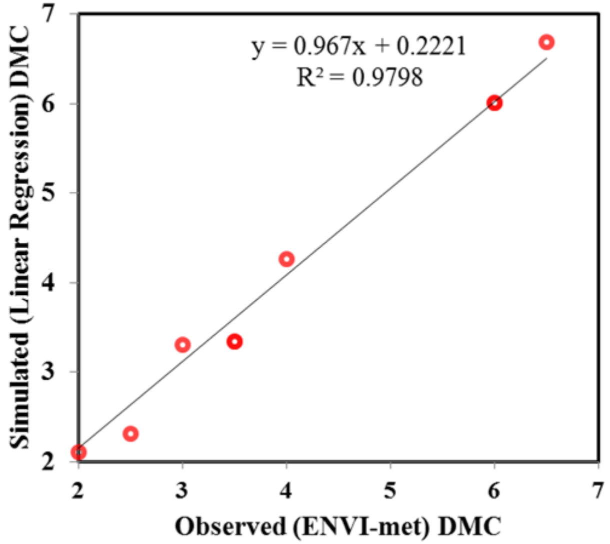
  Recommended value of $2m^2/m^3$ by Wania et.al 2012 and Vos et.al 2013 was used

- My proposed techniques:

  - Place VB after **DMC**
  - Increase the thickness of VB to cover entire **DMC**

$$DMC = -1.45 \frac{U}{Cos(\beta)} + 3.02U + 1.98$$

(U) is wind speed at 10m height
(β) is the angle between the actual wind direction and the wind direction that is normal to the road

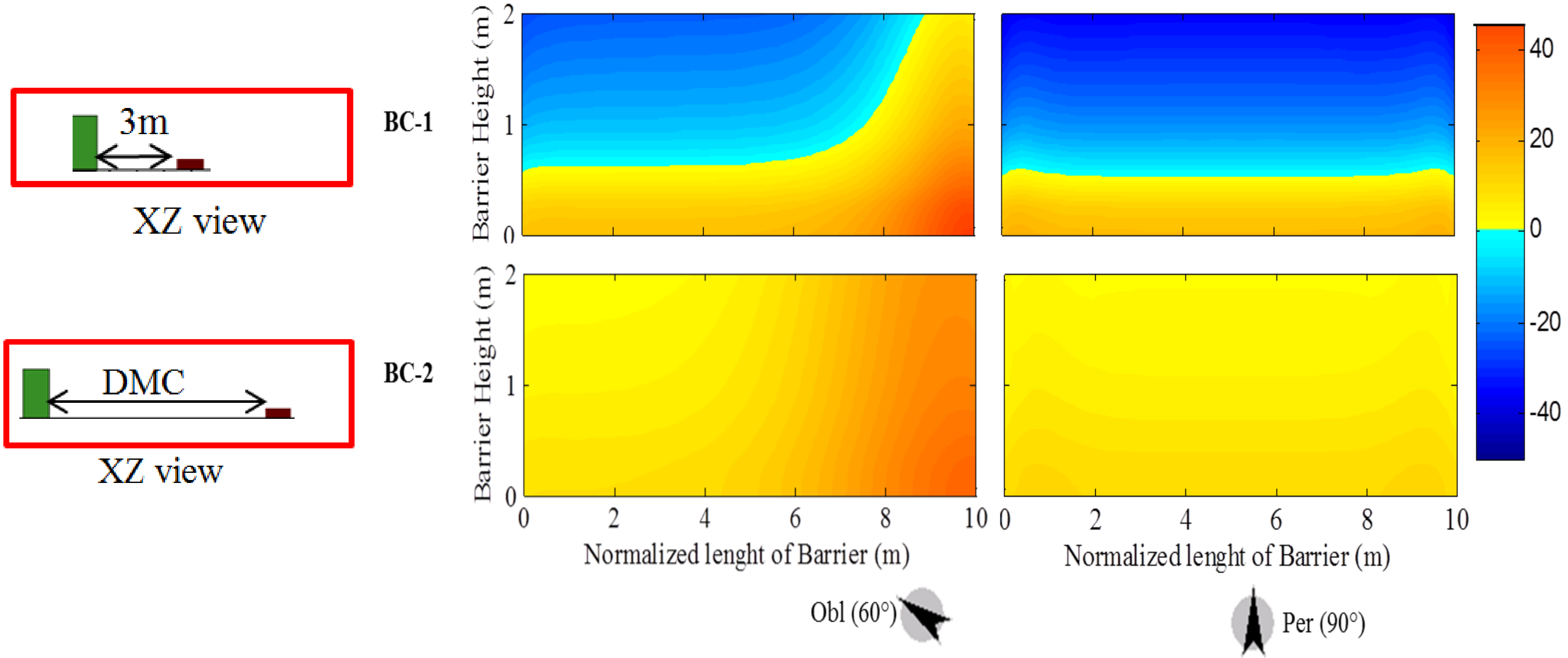


The simple linear model is useful to determine

- ✓ optimum distance from source to place VB for overall positive PRE
- ✓ optimum thickness for VB for maximizing deposition

Techniques to avoid negative PRE

Proposed Technique 1: Place VB after DMC

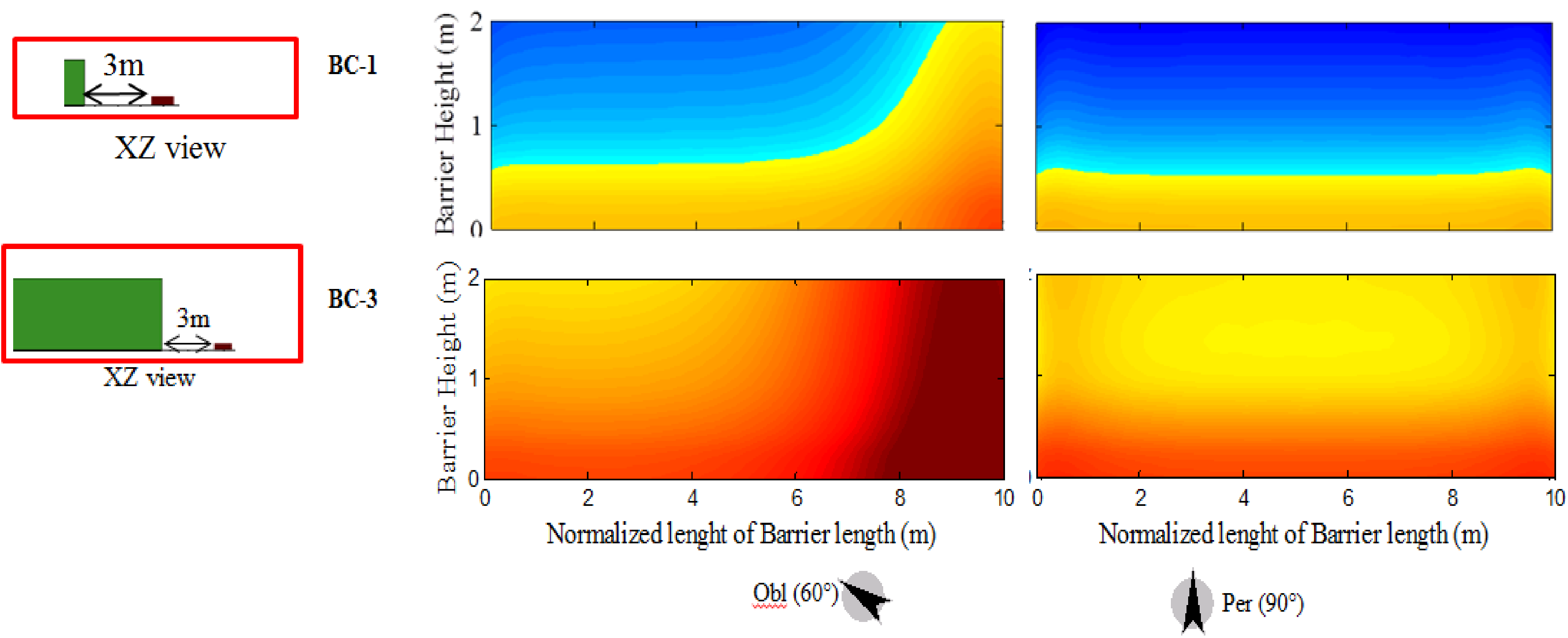


<u>Lessson</u>

Siting of Playground, sitting –out area , foot and cycling path right after a VB of certain configurat
is not always beneficial .

Techniques to avoid negative PRE

Proposed Technique 2: Increase the thickness of VB to cover entire **DMC**



Dual application

- Optimized PRE (dispersion-related)
- Determine optimum thickness of VB per prevailing wind direction : Maximized deposition (mass removal)

Summary : PRE and FCE

- PRE and FCE increases with increasing distance from source
- It is a function of upstream concentration and not total mass in the domain
- This finding suggests VB erected for dispersion-related benefit for target area e.g. playing ground, Sitting-out areas, footpath should be positioned ~2m after DMC (determined by prevailing wind condition)
- **This is against deposition theory:**

$S = V_d.LAD.C$

Dispersion and Deposition related assessment of air quality benefit of VB

Design-test Case

Design-criteria from previous studies summarized by Janhall,2015

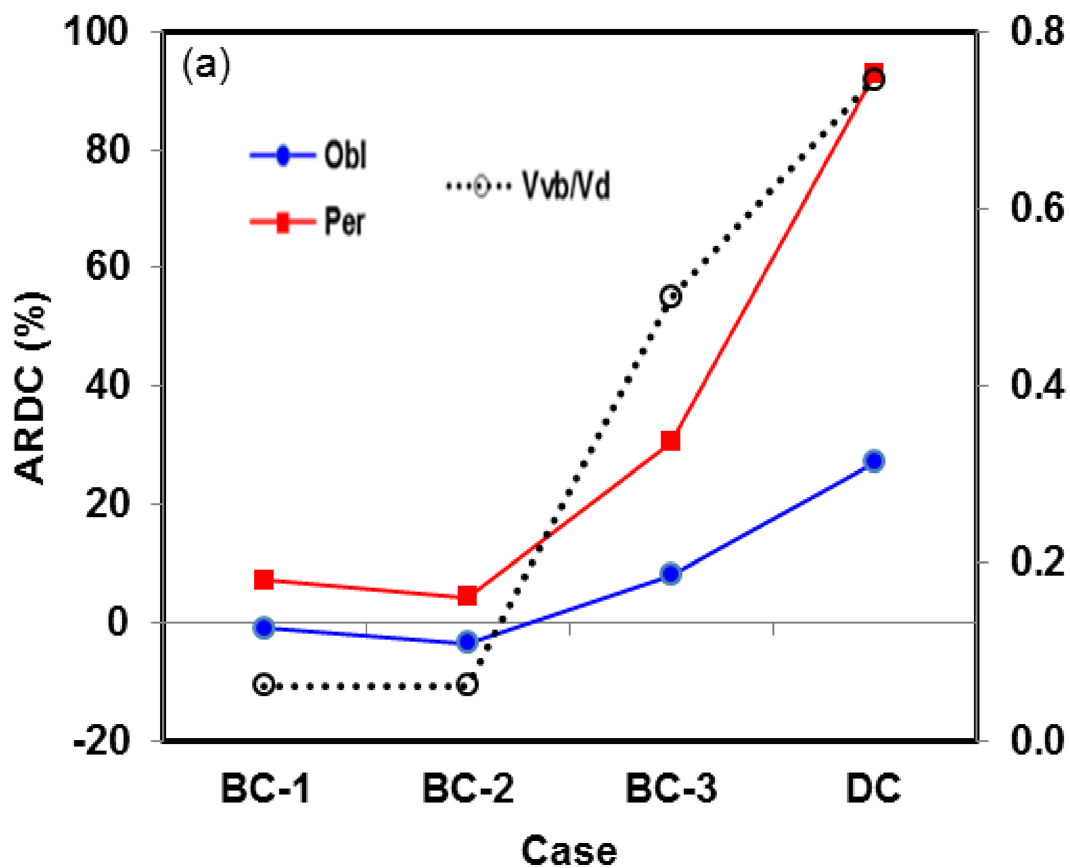
1. VB was positioned close to the road (source) , in this study 3m from the center line of the road.

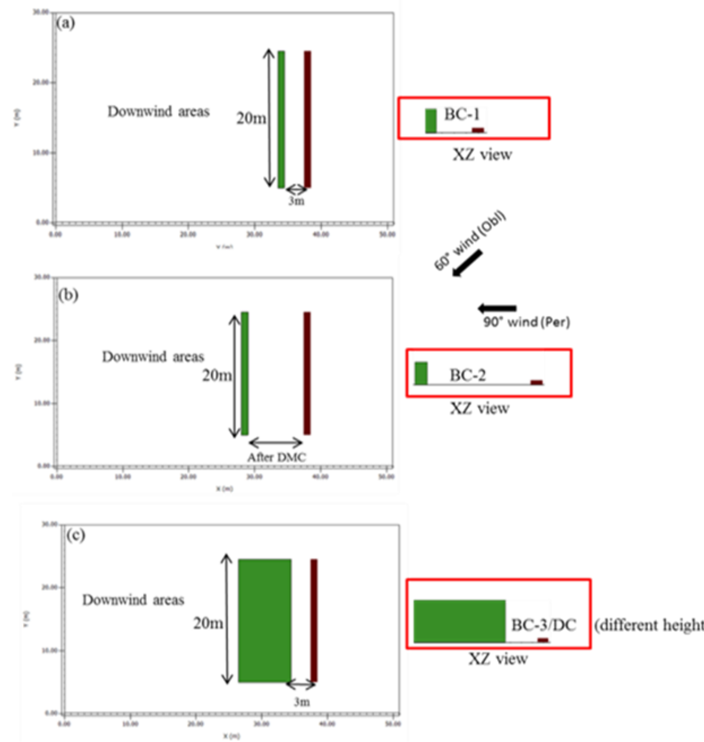
2. VB should be porous enough to allow penetration/filtration and high surface area for maximum deposition. LAD $2m^2/m^3$ was applied

3. optimum height of VB should be enough to capture the full plume height.

4. Optimum thickness should be enough to cover entire DMC (Our proposed technique)

Combined assessment of air quality benefit of VB





$$ARDC = \frac{1}{Area}\sum\left[\frac{C_{VB} - C_{ref}}{C_{ref}} \times 100\right]$$

The lower the better.

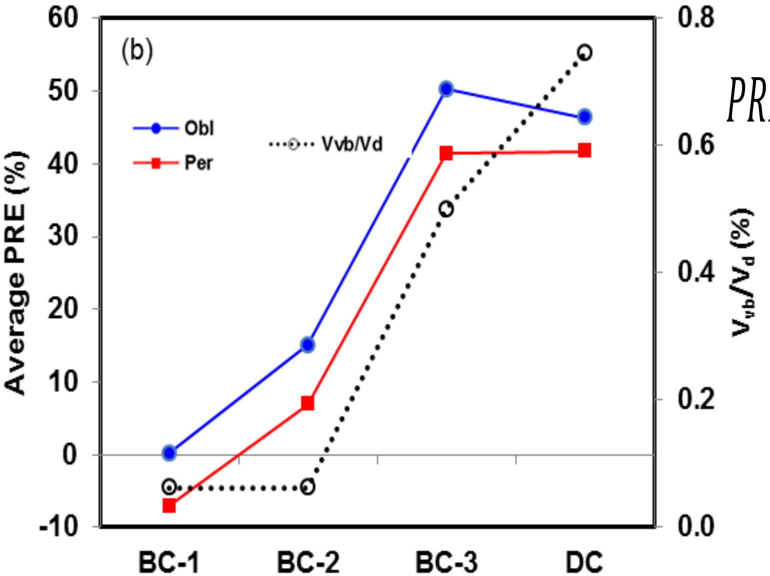
In BC-1 and BC-2

- V_{VB}/V_D = 0.06 – 0.12%
- ARDC = -4.20 – 7%

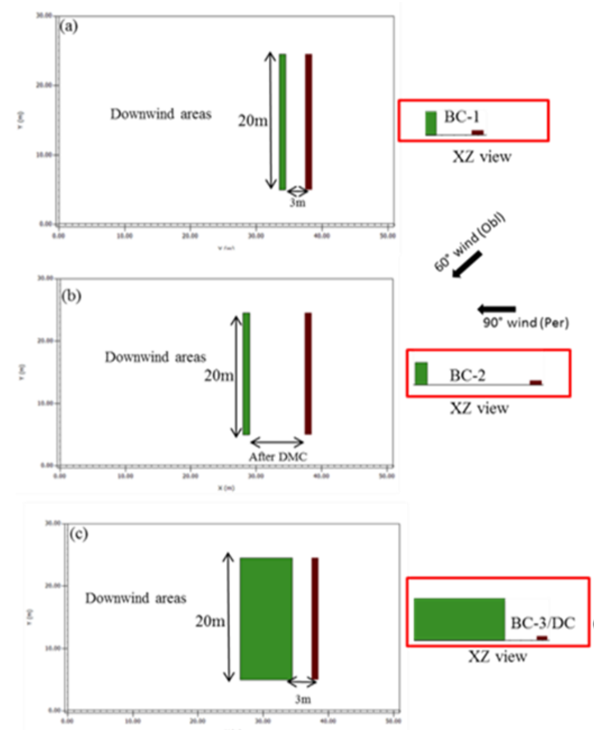
In BC-3 and DC

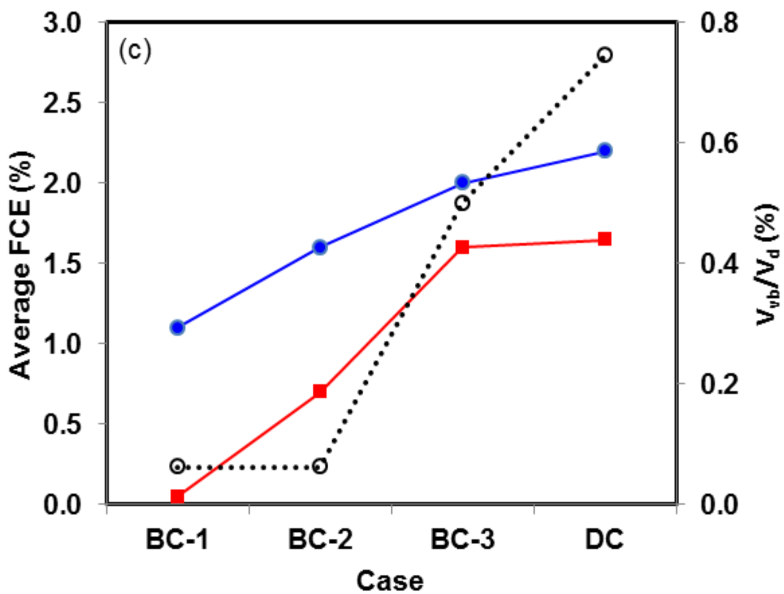
- V_{VB}/V_D = 0.45 – 0.77%
- ARDC = 3.7– 92 %

Combined assessment of air quality benefit of VB



$$PRE, \phi_{VB} = u(H,L)\left(1 - \frac{C_d}{C_u}\right) \times 100\%$$

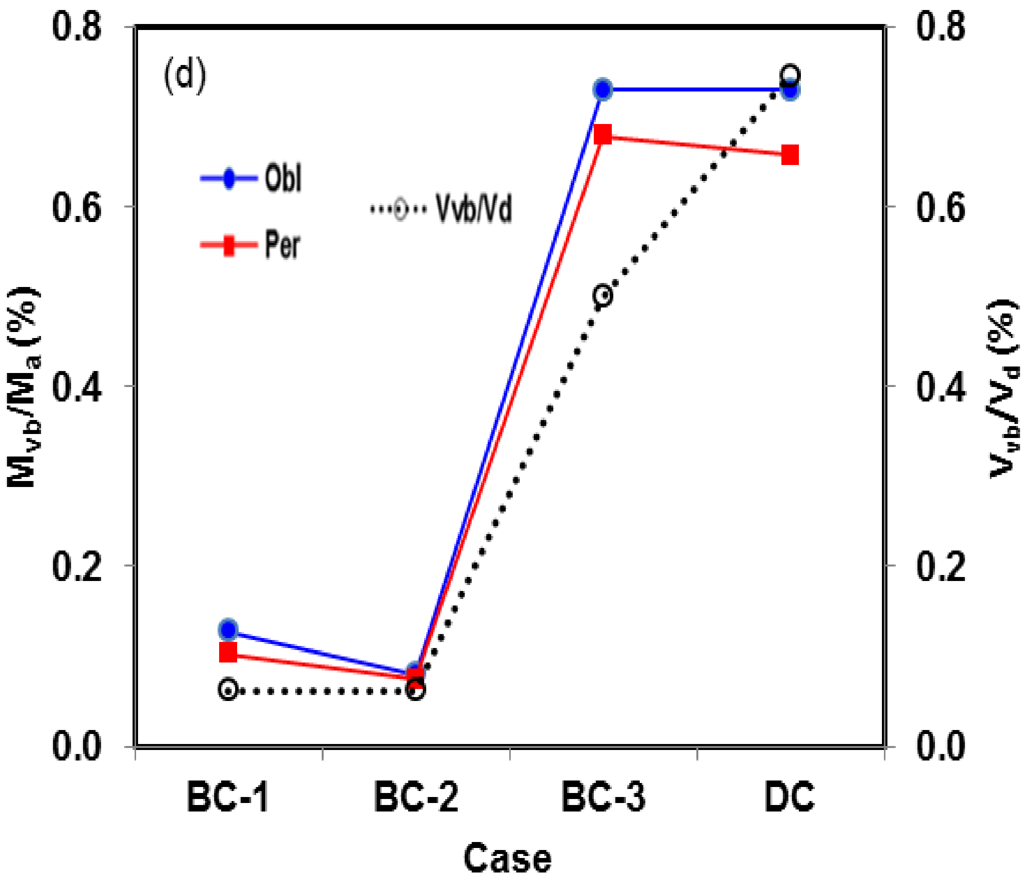


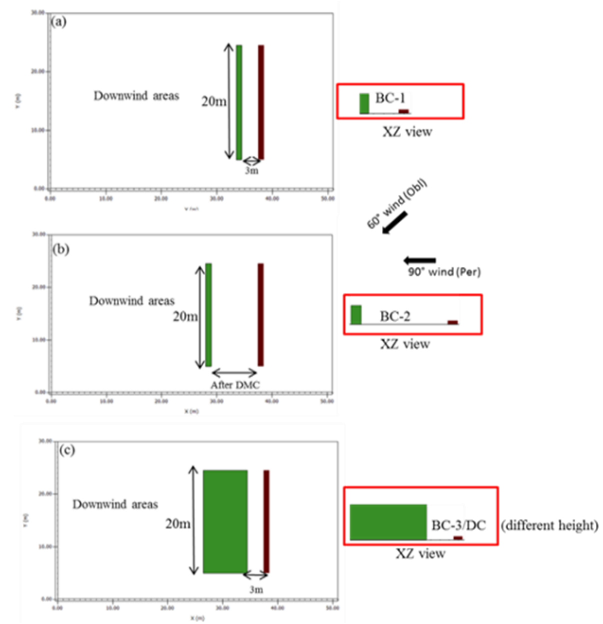


$$FCE, \quad \gamma_{VB} = [\phi_{ref} - \phi_{VB}]$$

PRE and FCE increases with distance from source and volume of VB

Combined assessment of air quality benefit of VB





$$\frac{M_d}{M_T} = \text{mass removal}$$

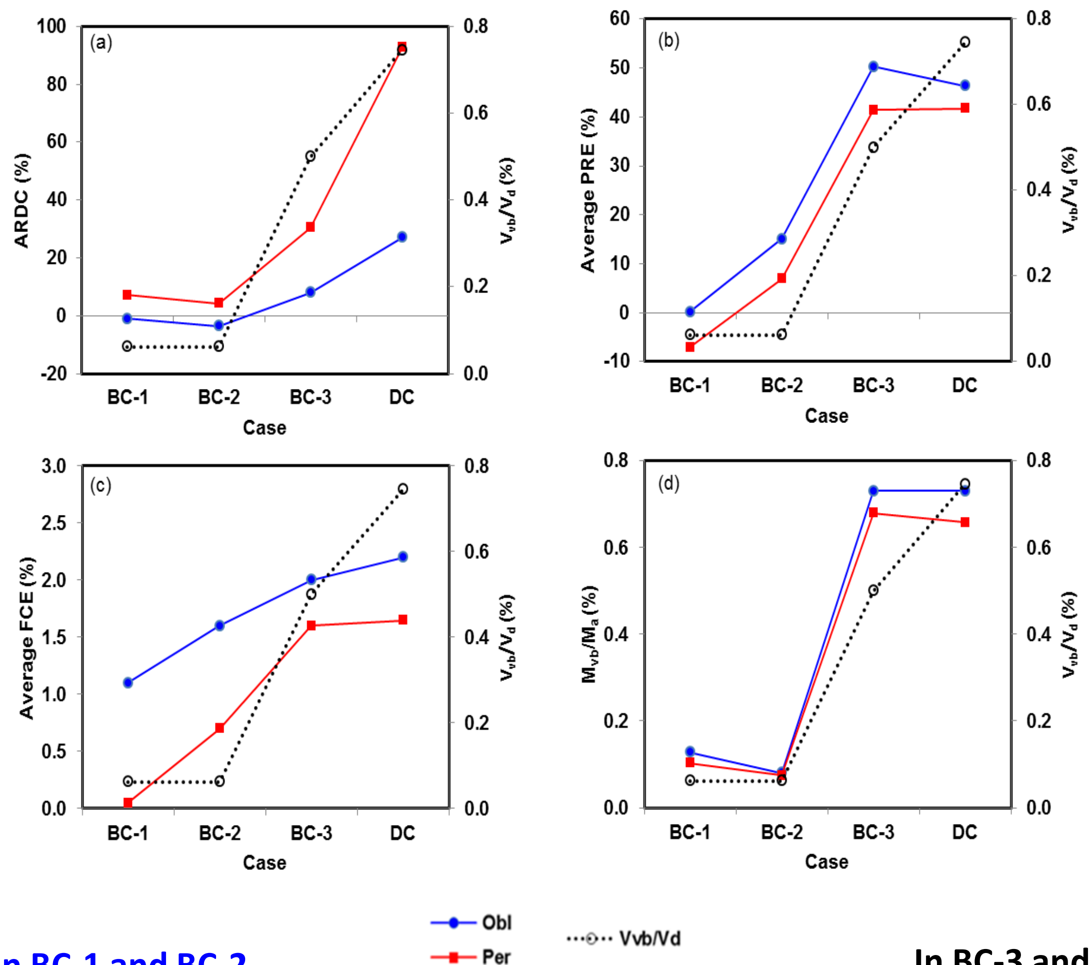
In BC-1 and BC-2

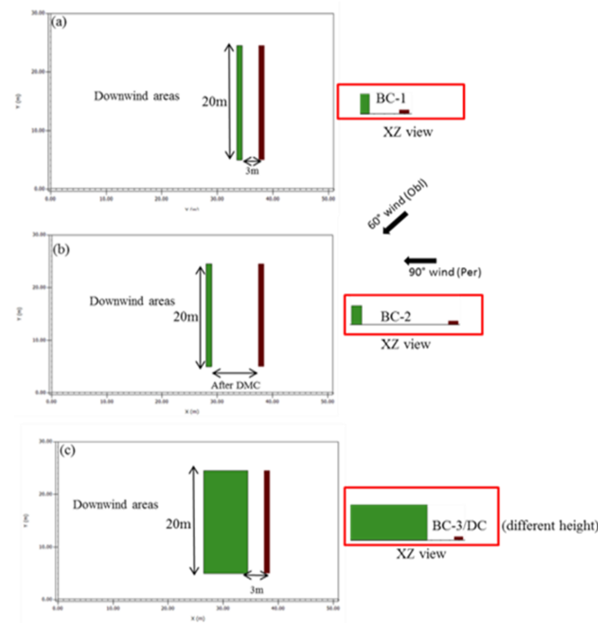
- $V_{VB}/V_D = 0.06 - 0.12\%$
- $M_d/M_T = 0.07 - 0.2\%$

In BC-3 and DC

- $V_{VB}/V_D = 0.45 - 0.77\%$
- $M_d/M_T = 0.5 - 0.8\%$

Combined assessment of air quality benefit of VB





In BC-1 and BC-2

- V_{VB}/V_D = 0.06 – 0.12%
- ARDC = -4.20 – 7%
- M_d/M_T = 0.07 – 0.2%
- higher dispersion but lower deposition

In BC-3 and DC

- V_{VB}/V_D = 0.45 – 0.77%
- ARDC = 3.7– 92 %
- M_d/M_T = 0.5 – 0.8%
- higher deposition but lower dispersion

PRE and FCE increases with distance from source and volume of VB

Summary ,conclusion and recommendation

- This study has employed a numerical micro-scale model, ENVI-met and other analytical techniques to investigate and compare dispersion and deposition related benefit of near-road VB.
- With the dispersion-related analysis, negative PRE is possible if the VB is not thick enough or if placed before DMC.
- The newly proposed concept of DMC is useful for determining the appropriate position (from source) and optimum thickness of VB
- Overall, inverse relationship between dispersion and deposition benefits of VB for near-road air quality improvement
- Choice ,placement and Design of road-side VB should be need-based(Higher dispersion or deposition)

What is good air quality to you????

Higher Dispersion or Higher removal ???

Make a need-based choice

Acknowledgement

- The work described in this paper was jointly supported by the Guy Carpenter Asia- Pacific Climate Impact Centre, City University of Hong Kong (Project No. 9360126) and a postgraduate studentship from City University of Hong Kong.
- Prof. Michael Bruse and his group (ENVI-met)

Questions and Comments?

MORAKINYO Tobi Eniolu

PhD Candidate,

School of Energy and Environment,

City University of Hong Kong , Hong Kong.

tobimorak@yahoo.com, tmorakiny2-c@my.cityu.edu.hk