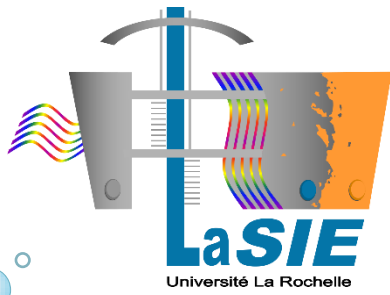


Barcelona - May, 7 2015



Optimal ventilation and filtering strategies for air quality in carriages

P. Blondeau, M. O. Abadie

University of La Rochelle, France

Open Day on Air quality in rail subway systems, CSIC



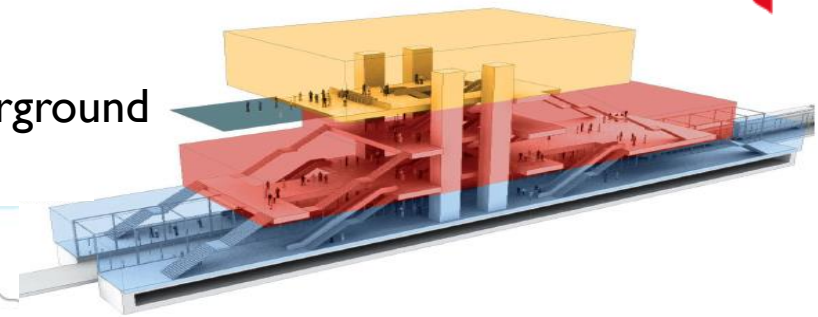
Expansion of the existing rail public transport network of Paris



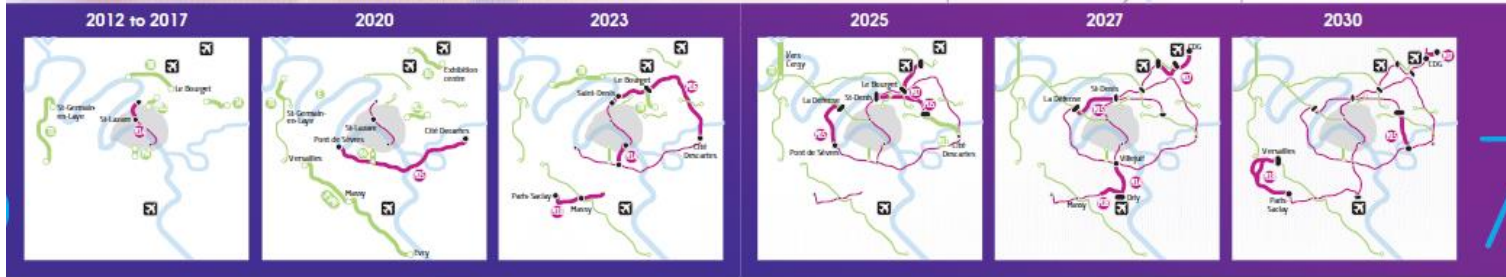
4 new lines and 2 expanded lines :

- + 70 km of high speed metro
 - + 30 km of metro
 - + 150 km of light rail
- } Underground

72 stations, 57 new



▲ SCHEDULED SERVICE LAUNCHES



Motivations of SGP for IAQ studies

- Construction and operation based on sustainable development principles
- French national plan on IAQ (2013): « Action S: undertake actions as a way to improve IAQ in subway systems »
 - ➔ Setup of mandatory monitoring of IAQ in subways

Objectives

- Identify air quality main issues and key parameters for IAQ

Literature review:



- Pollutant concentrations in metro areas

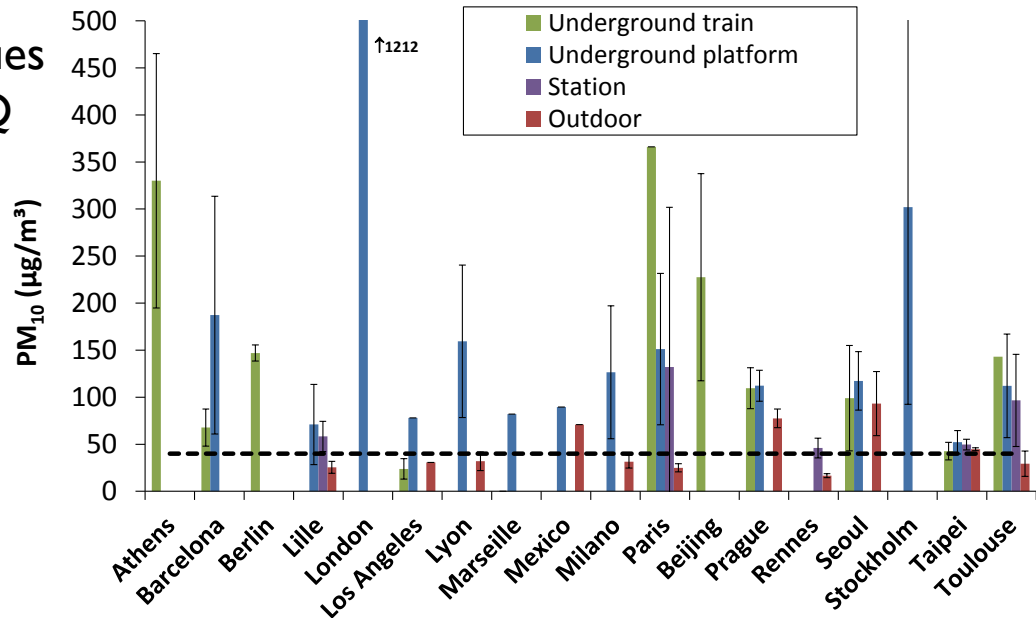


Target contaminants:
PM₁₀, PM_{2.5}, NO₂, benzene

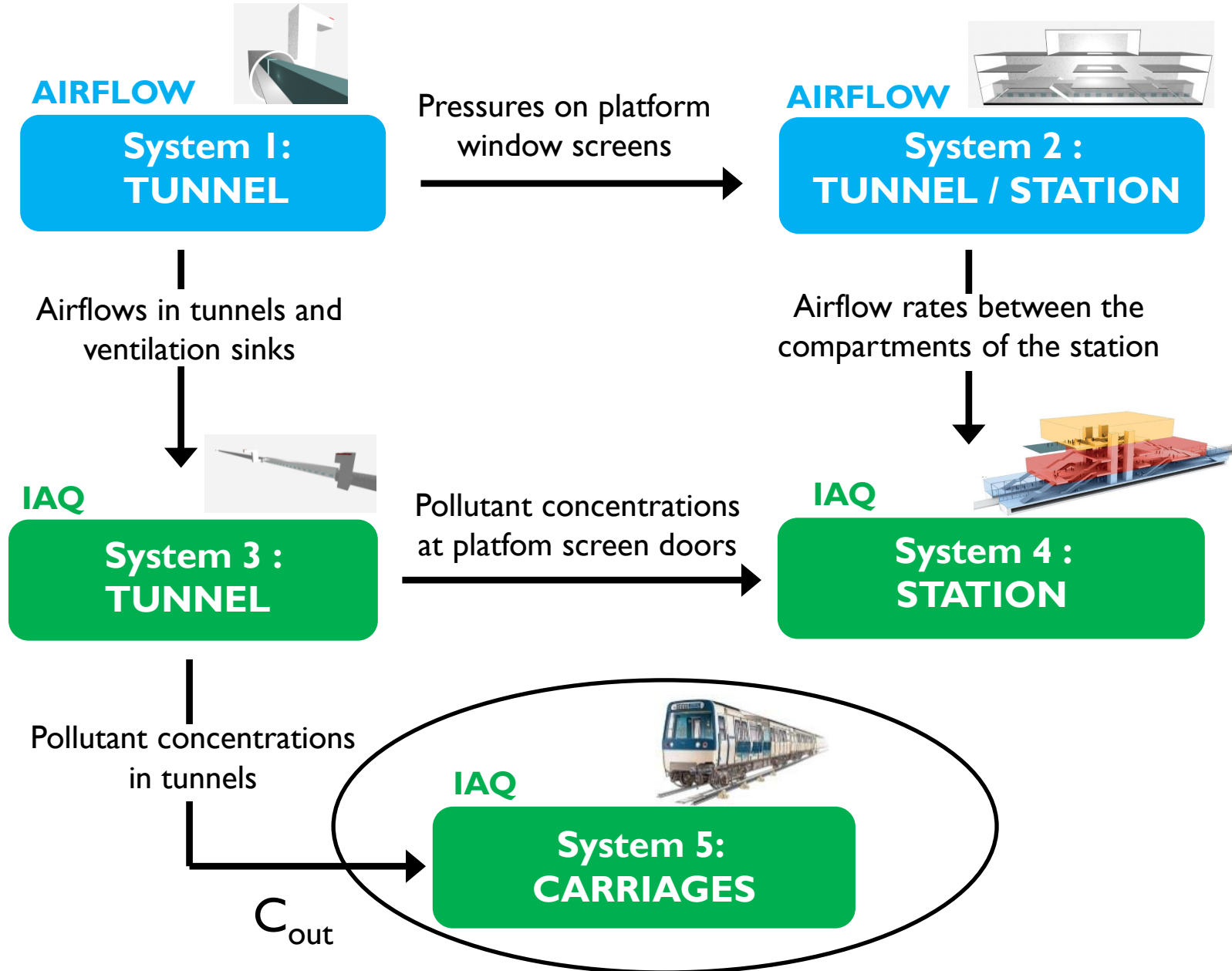
- Technical data : ventilation (stations/tunnels/carriages), tyre/steel wheels, braking system, platform equipments (e.g. window screens), ...

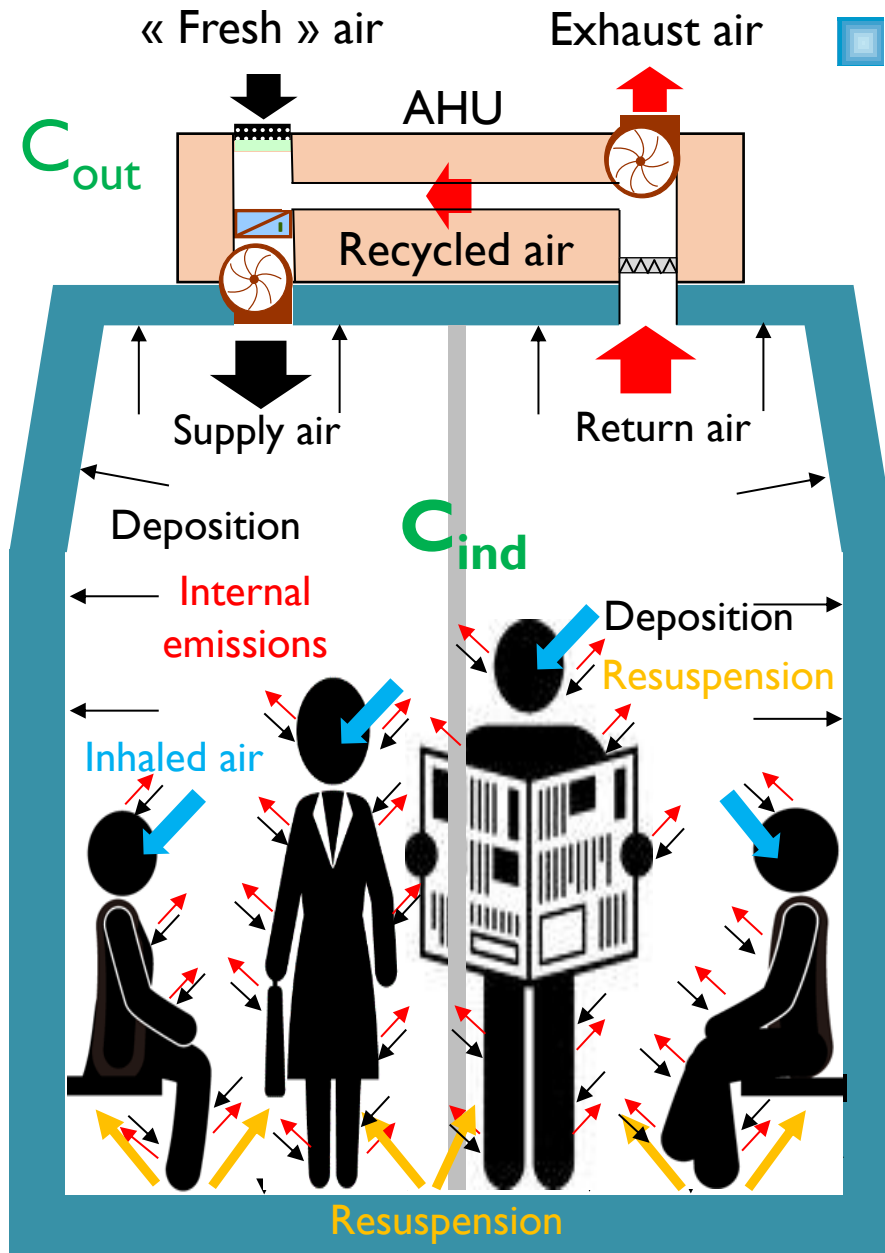
- Define design guidelines for acceptable air quality in the underground indoor spaces from airflow and air quality simulations

$$C_{\text{outdoor}} < C_{\text{station}} < C_{\text{platform}} < C_{\text{carriage}} \text{ (except Taipei)}$$



Modelling strategy





(1) $H = 1.65$ m, $W = 65$ kg, winter clothes

(2) $1.6 \cdot 10^6$ to $3 \cdot 10^6$ part/h/person, density = 1000 kg/m³

(3) 0.42 m³/h/person

Single zone model accounting for:

- Ventilation (including filters)
- Deposition onto surfaces
- Influence of passengers



- ✓ Volume reduction
- ✓ Particle emission
- ✓ Particle deposition on body
- ✓ Particle resuspension due to movements (body, floor)
- ✓ Particle sink by inhaled air

2 simulation tools :

- Design tool (steady-state)
- Exposure assesment (dynamic)

MP 05 train carriage:

$V = 73$ m³, Max. load: 162 persons

➤ $V_{\text{body}} = 11$ m³ (1)

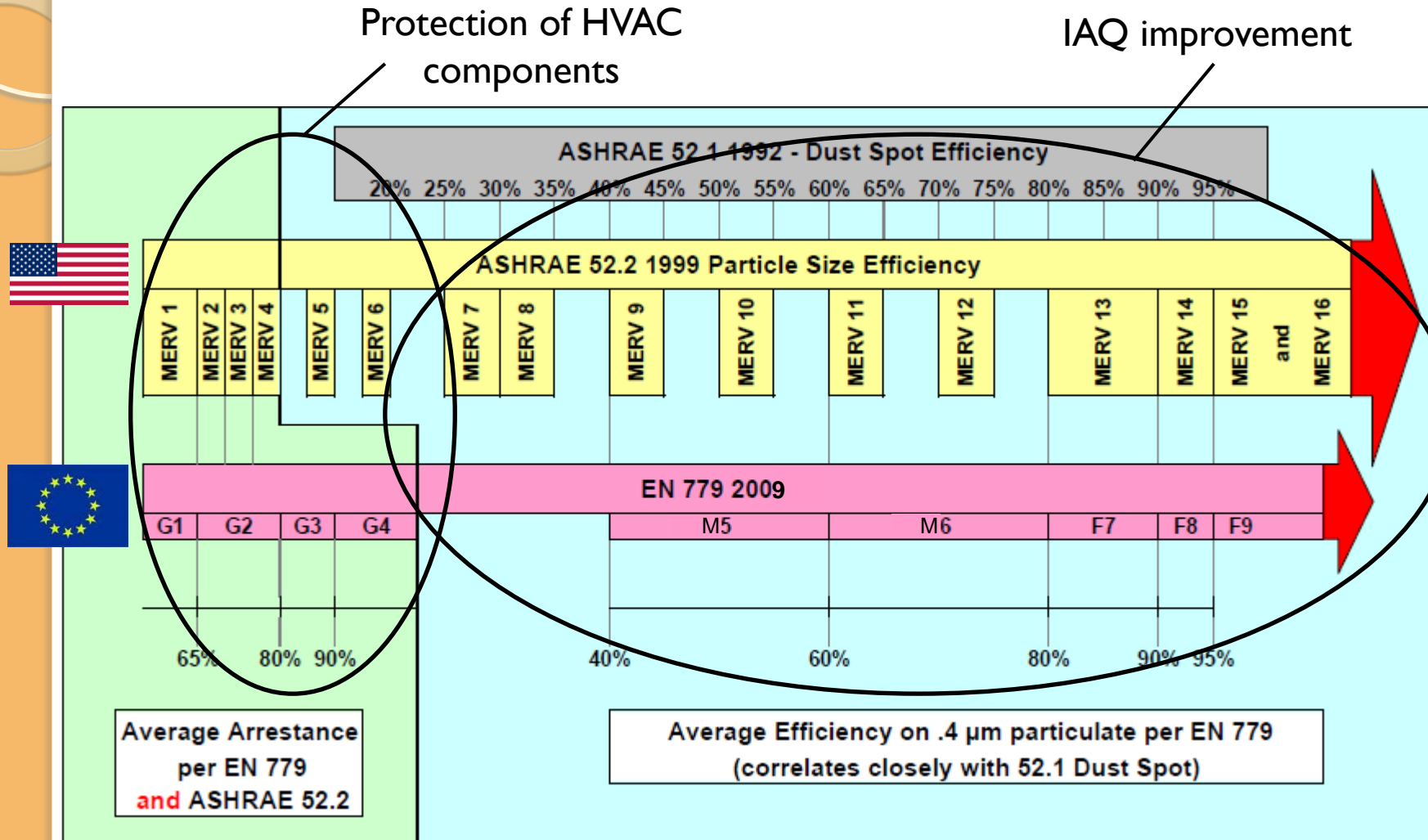
➤ $S_{\text{body}} = 340$ m² (1)

➤ PM10 emission rate = 100 mg/h (2)

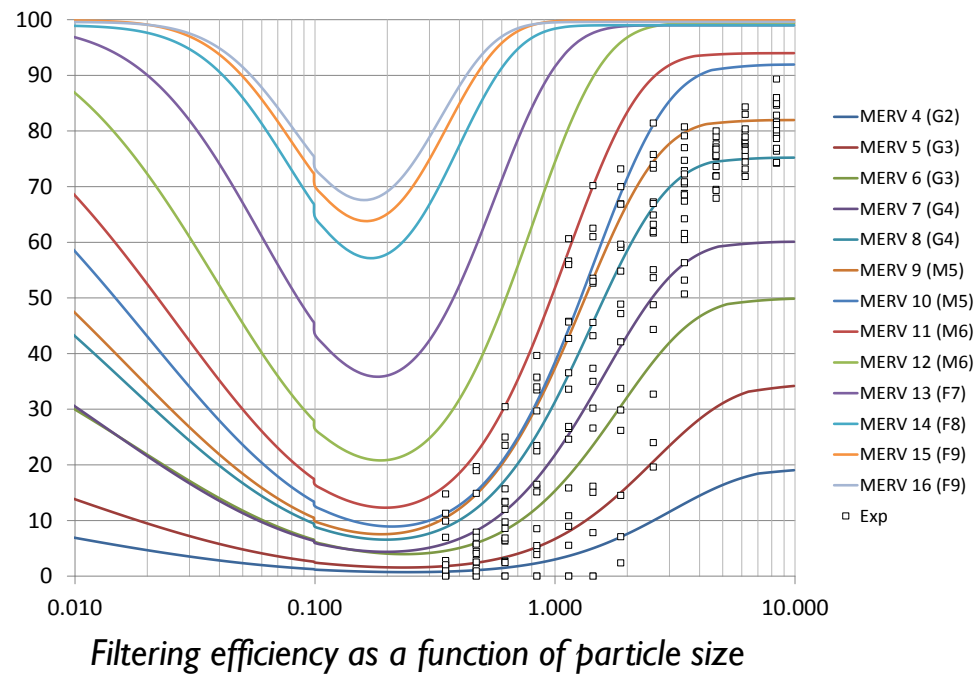
➤ Inhaled air flow rate = 68 m³/h (3)

Filter efficiencies for representative subway aerosol

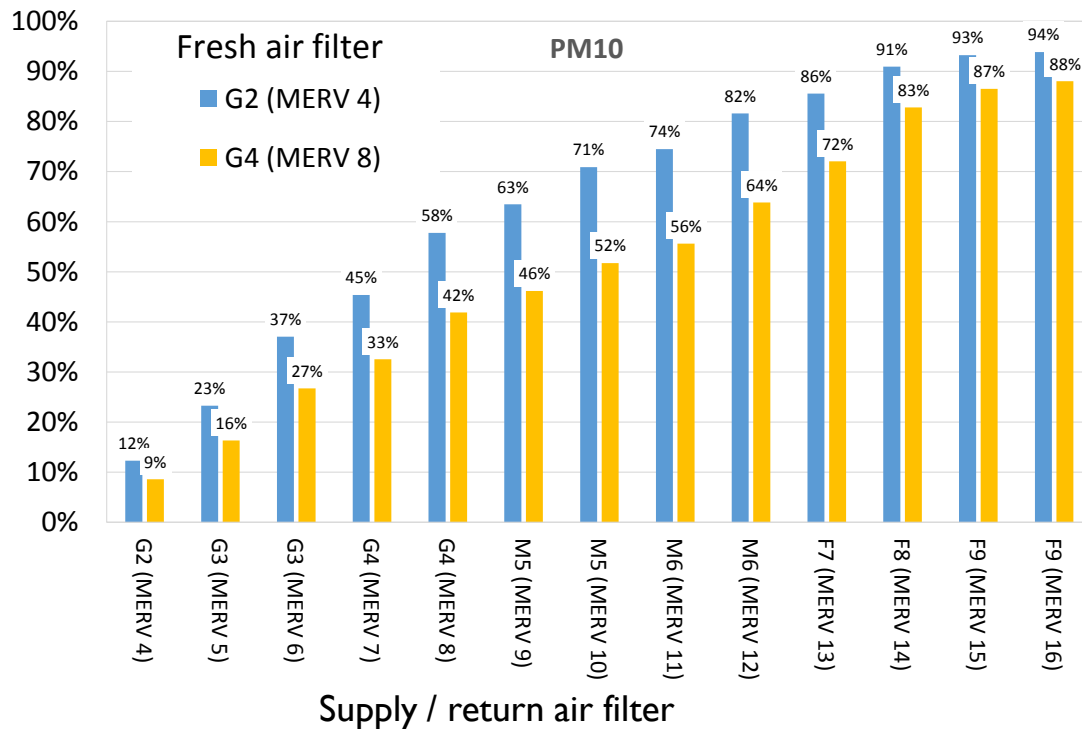
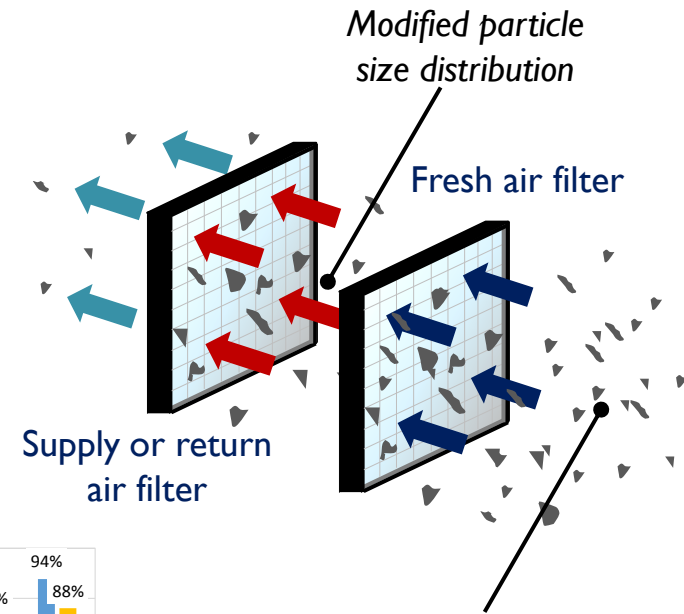
Ventilation filters are classified into 16 classes and 9 classes by international standards



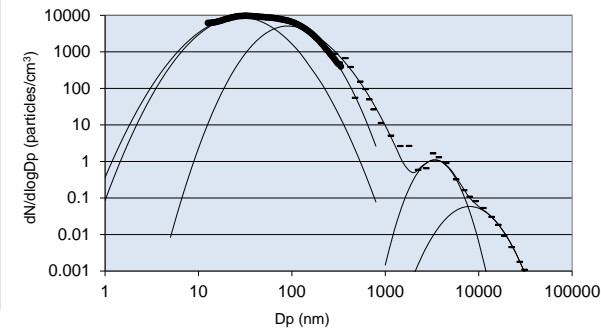
Filter class is determined based on the mean efficiency which is measured in standard test conditions using a specific aerosol → Not representative of the actual efficiency



Computation of the initial efficiency of filters as a function particle size



Particle size distribution of a typical subway aerosol (Midander et al, 2014)

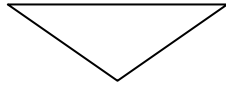


Deposition velocities on surfaces

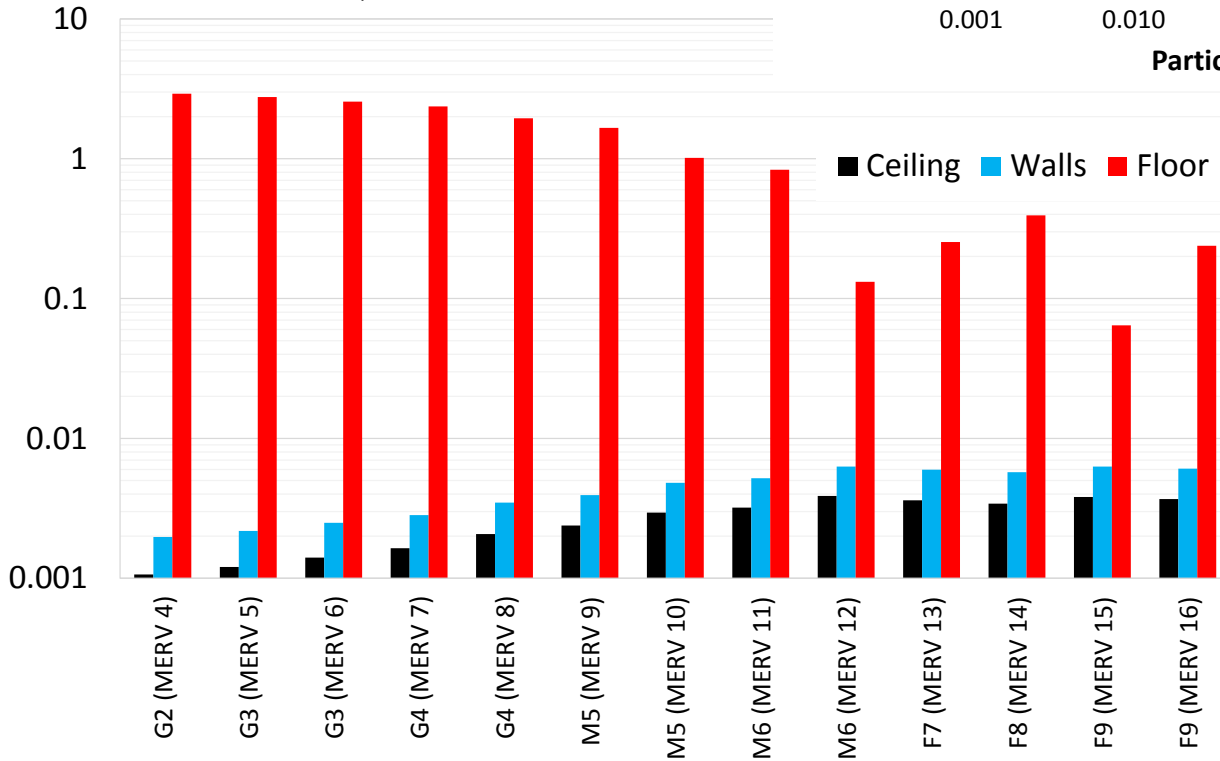
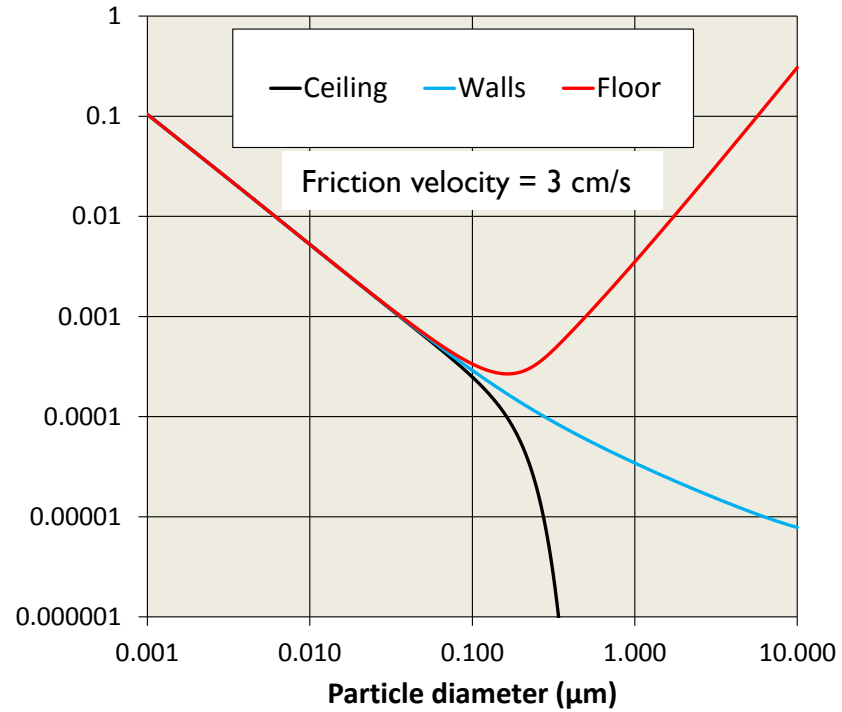
Deposition velocity of particles as a function of size (computed from Lai and Nazaroff model)

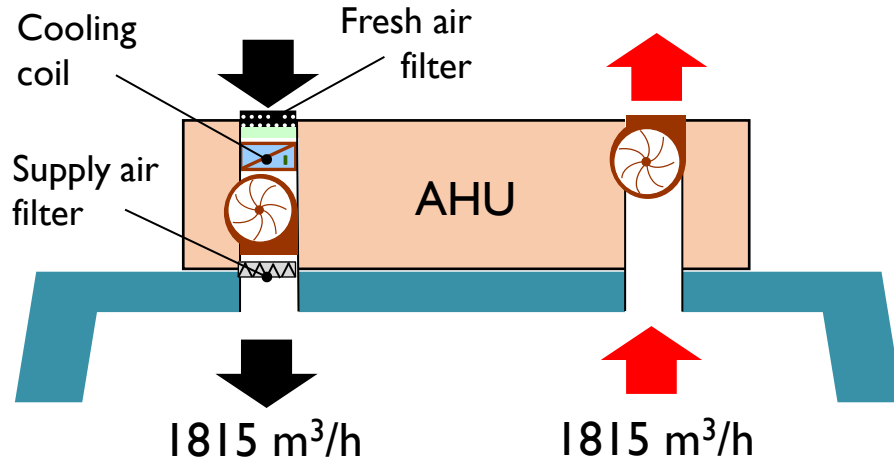


Deposition velocity of PM10 (m/h) as a function of fresh air filter



Deposition velocity (cm/s)



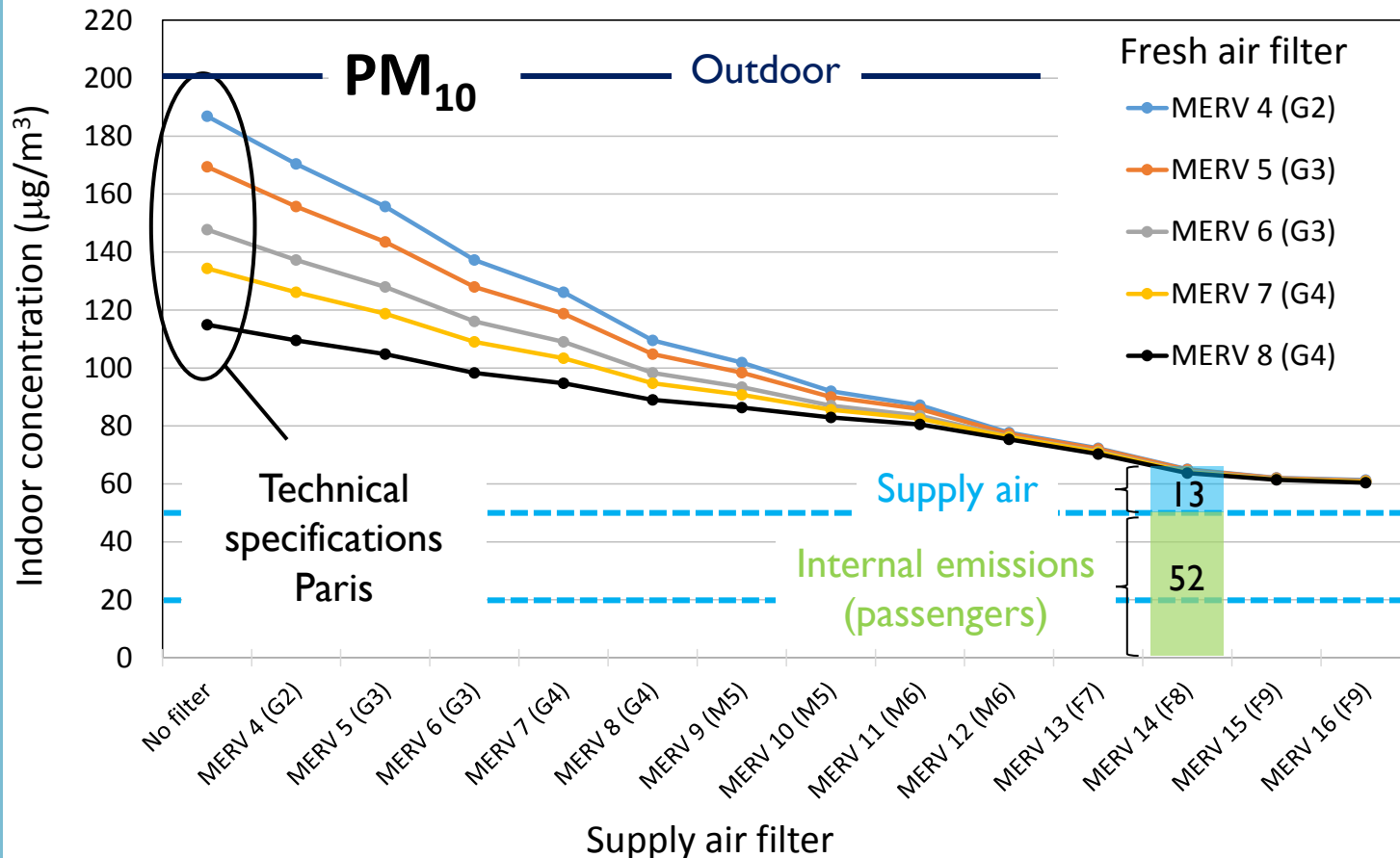


Train MP05, 1st configuration

Cooled air mechanical ventilation:
no recycled air, 11.5 kW cooling coil

Simulation conditions:

- 162 passengers (full load)
- Tunnel concentrations:
200 μg/m³ PM₁₀, 75 μg/m³ PM_{2.5}



World Health Organization

WHO guidelines (2005)

24-hour mean

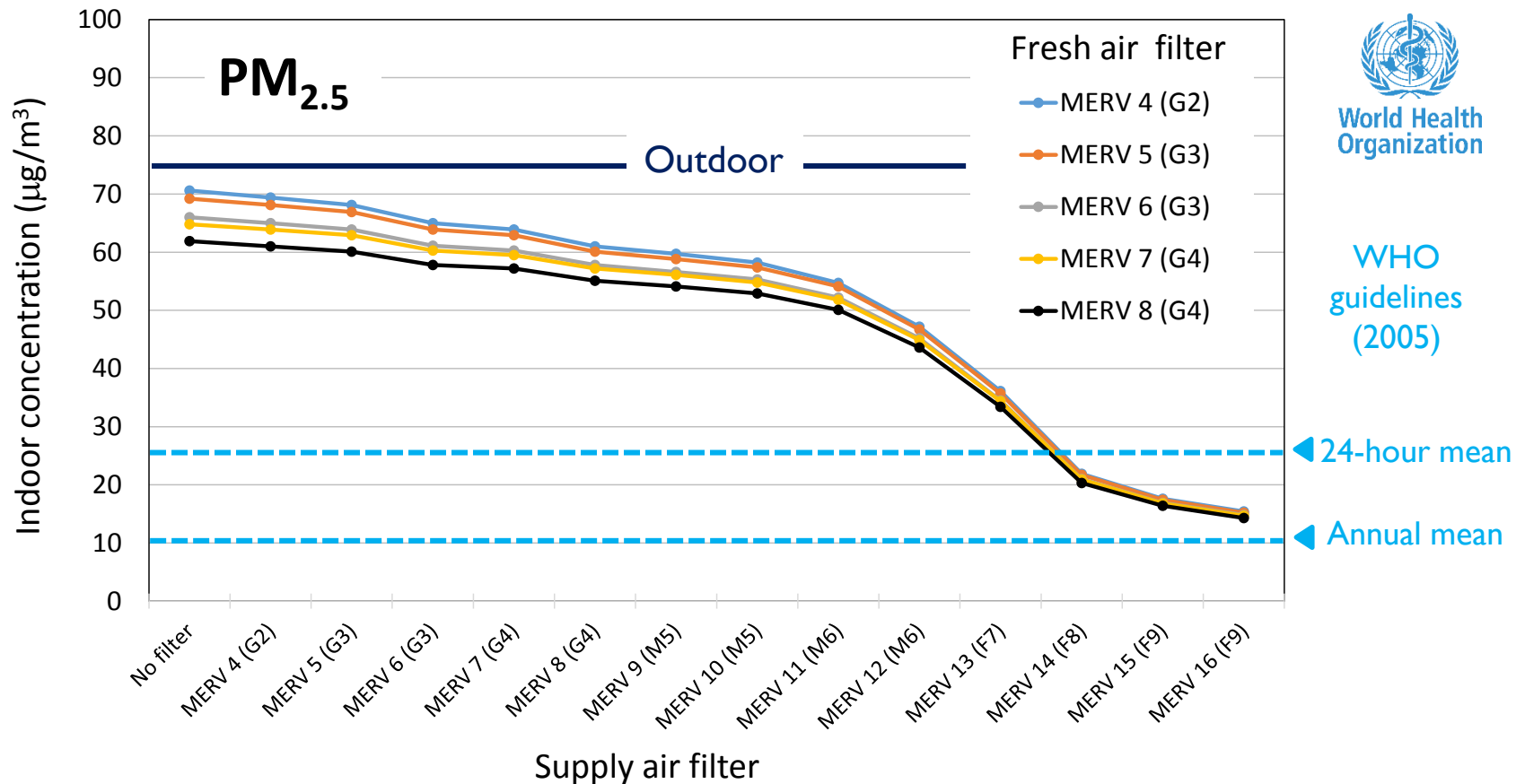
Annual mean

Train MP05, 1st configuration

Cooled air mechanical ventilation:
no recycled air, 11.5 kW cooling coil

Simulation conditions:

- 162 passengers (full load)
- Tunnel concentrations:
200 $\mu\text{g}/\text{m}^3$ PM_{10} , 75 $\mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$



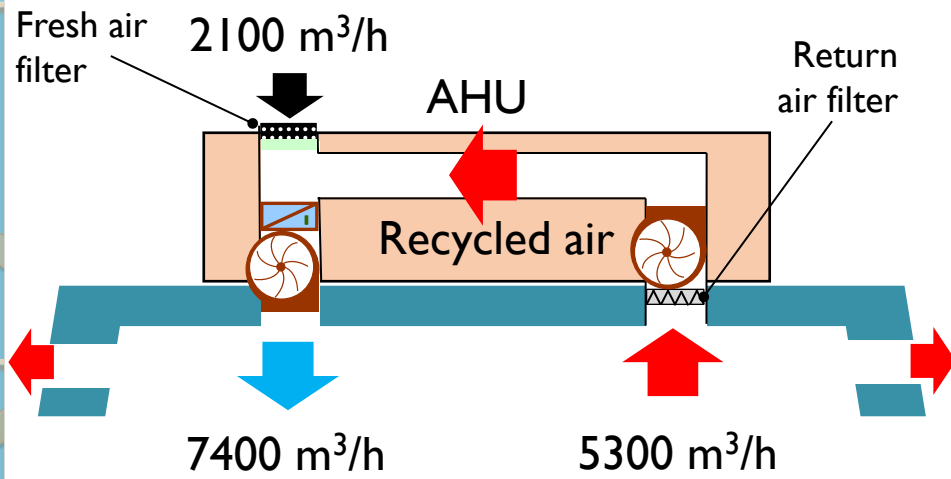
World Health Organization

WHO guidelines (2005)

24-hour mean

Annual mean

- Small influence of the fresh air filter on $\text{PM}_{2.5}$ concentrations
- Significant efficiency of filters from MERV 11 (M6)
- MERV 14 (F8) needed to meet the WHO guideline for 24-hour mean

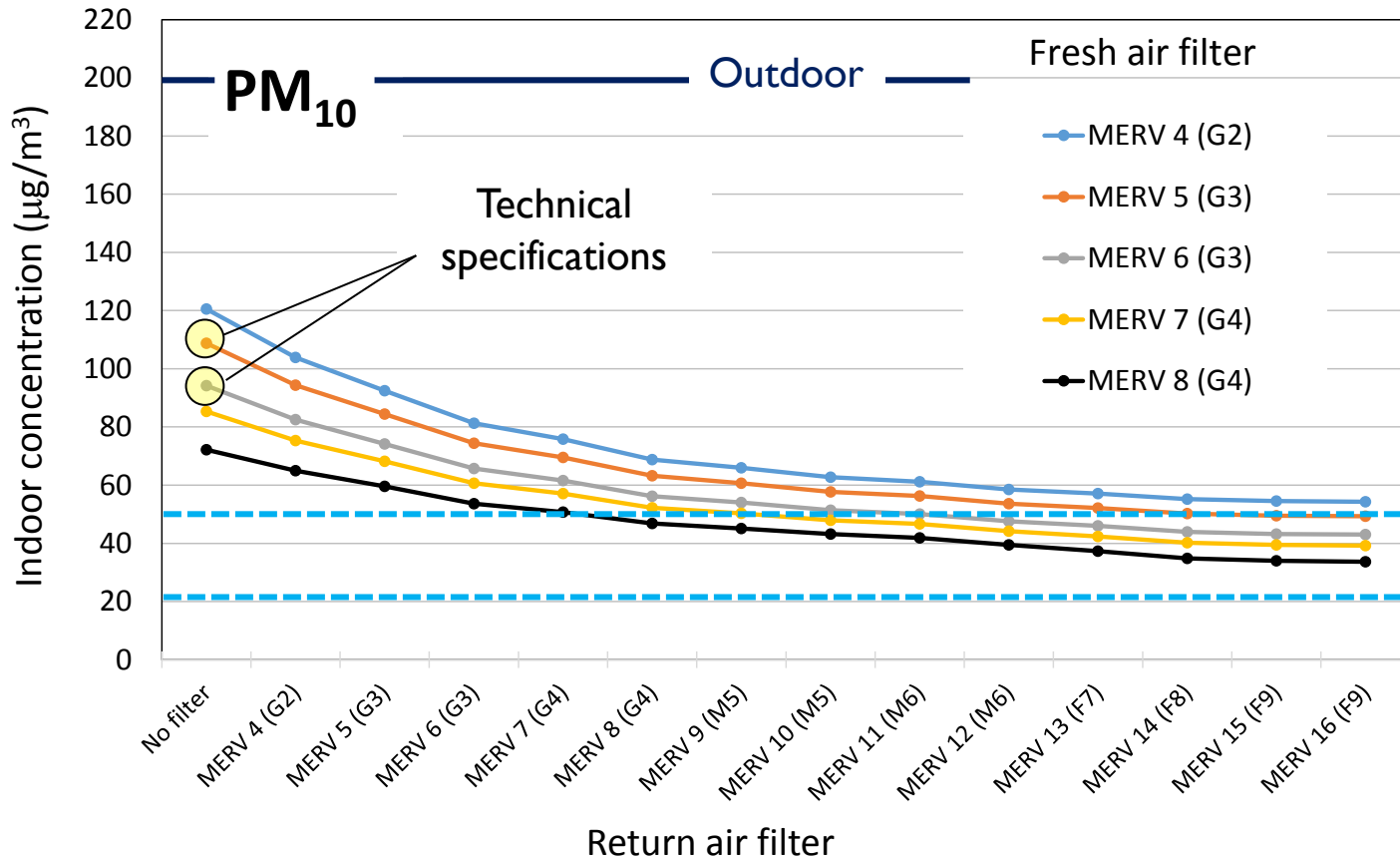


Train MP05, 2nd configuration

Air conditioning (recycled air)

Simulation conditions:

- 162 passengers
- Tunnel concentrations:
200 $\mu\text{g}/\text{m}^3$ PM_{10} , 75 $\mu\text{g}/\text{m}^3$ $\text{PM}_{2.5}$



World Health Organization

WHO guidelines (2005)

◀ 24-hour mean

◀ Annual mean

Operating conditions as the optimum between IAQ and energy

Normalized IAQ index

$$C_{norm} = \frac{C_{max} - C}{C_{max} - C_{min}}$$

$$0 < C_{norm} < 1^{(*)}$$

Normalized energy index

Fan power (W):

$$E = \frac{q_v (\Delta P_{ducts} + \Delta P_{filter})}{\eta_{fan}}$$

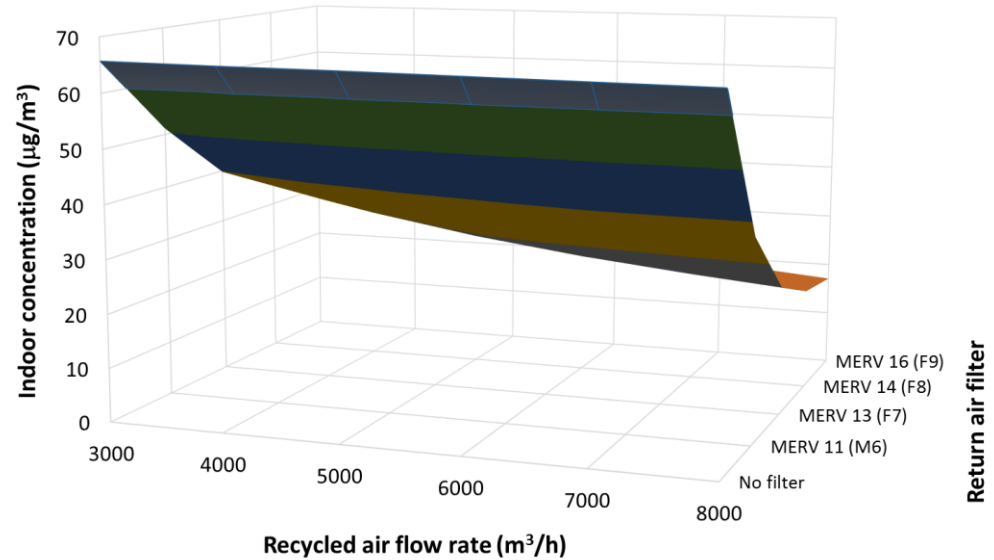
$$\Delta P_{filter} = \frac{\Delta P_{init.} + \Delta P_{final}}{2} \text{ (Pa)}$$

$$E_{norm} = \frac{E - E_{min}}{E_{max} - E_{min}}$$

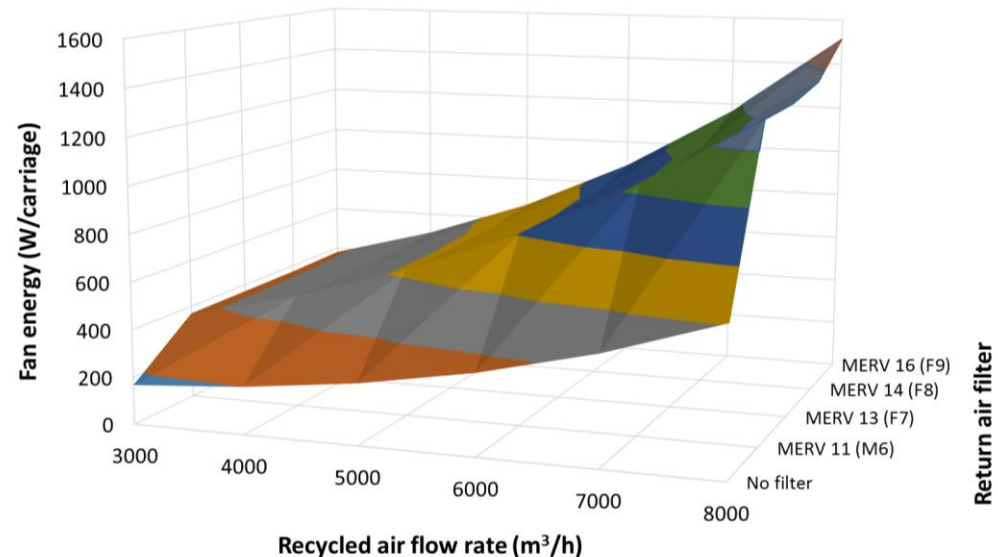
$$0^{(*)} < E_{norm} < 1$$

(*) best performance

PM_{2.5} concentration – Fresh air filter = MERV 6 (G3)



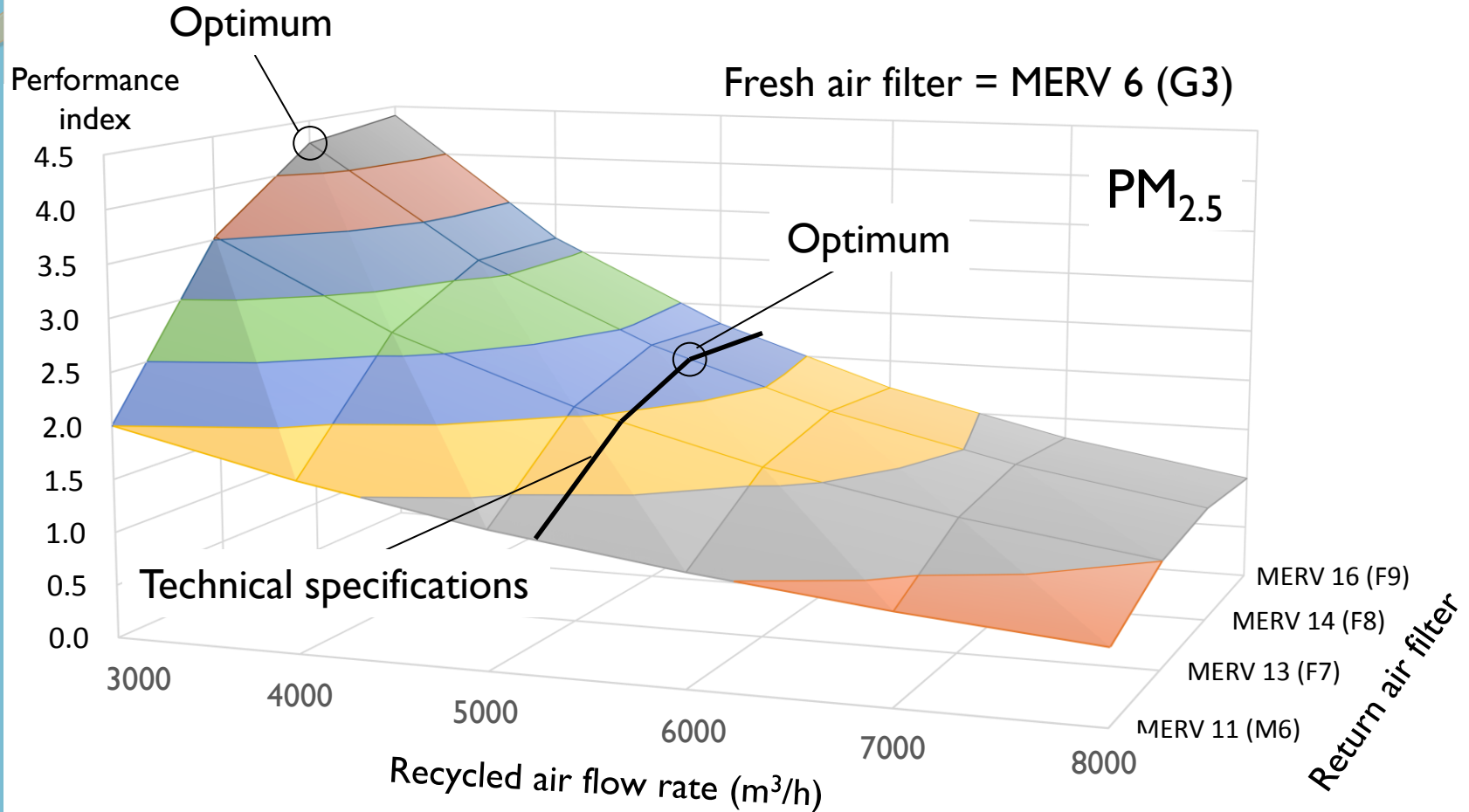
Fan energy – Fresh air filter = MERV 6 (G3)



Performance index

$$I = \frac{C_{norm}}{E_{norm}}$$

⇒ $0 < I < \infty$ (best performance)



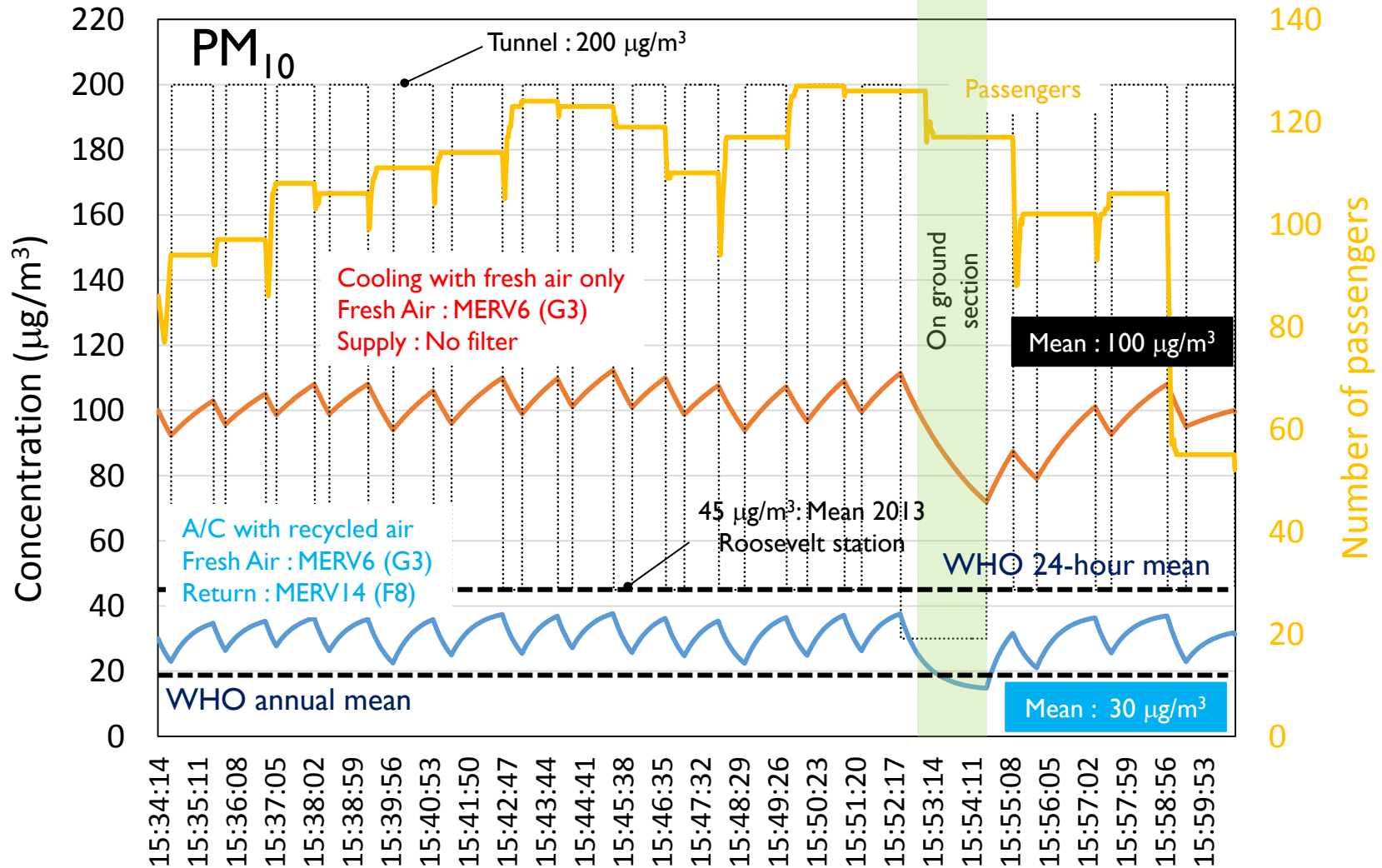
Fan efficiency : $\eta_{fan} = 0.54$

 Paris


1



Train : MP05





■ Easy to use models / friendly environment

- ✓ System owner or subway operator ⇒ Technical specifications in the frame of call for tenders
- ✓ Engineers and designers ⇒ Optimal ventilation / air conditioning strategies
- ✓ Health authorities ⇒ Assessment of exposure

■ Possible developments

- Modeling the increase of filter efficiency with particle load
 - Modeling the influence of airflow rate upon filter efficiency
- } Model improvement
- Improve accuracy of the energy index from information about cross sectional areas of air outlets / return duct in metro trains
 - Additional criteria for optimization : filter lifetimes, replacement costs, ...

Acknowledgements

Thanks to Klara Midander and Karine Elihn (Stockholm), Costas Sioutas and Winnie Kam (Los Angeles), Yu-Hsiang Cheng (Taipei)

■ Particle concentrations and size distribution in subways

K. Midander, K. Elihn, A. Wallén, L. Belova, A-K. Borg Karlsson, I. Odnevall Wallinder (2012) Characterisation of nano- and micron-sized airborne and collected subway particles, a multi-analytical approach. *Science of the Total Environment* 427–428 (2012) 390–400

■ Filter efficiency as a function of particle size

Kowalski W, Bahnfleth W. (2002) MERV filter models for aerobiological applications. *Air Media*, Summer Issue, pp. 13-17.

■ Deposition velocities of particles onto surfaces

Lai ACK, Nazaroff W. (2000) Modeling indoor particle deposition from turbulent flow onto smooth surfaces. *Journal of Aerosol Science*, 4, pp. 463-476

■ Human emissions of particles

S. Bhangar, R. I. Adams, W. Pasut, J.A. Huffman, E.A. Arens, J.W. Taylor, T. D. Bruns, W.W. Nazaroff (2015) Chamber bioaerosol study: human emissions of size-resolved fluorescent biological aerosol particles. *Indoor Air* (published online Mars 2015)

■ Particle resuspension from clothes

A. Mc Donagh and M.A. Byrne (2014) A study of the size distribution of aerosol particles resuspended from clothing surfaces. *Journal of Aerosol Science* 75(2014), 94–103

■ Particle resuspension from the floor

Z. Mana (2014) Etude de la remise en suspension de particules due à la marche d'un opérateur. Thèse de doctorat de l'Université Paris Sud