# AIR QUALITY IN SCHOOLS AND CHILDREN'S EXPOSURE TO PARTICULATE POLLUTION IN BARCELONA

*Ioar Rivas Lara*

*Doctoral Dissertation*
*5th November 2015*

PhD in Environmental Science and Technology

# Air quality in schools and children's exposure to particulate pollution in Barcelona

Barcelona, 5th November 2015


*Candidate:* Ioar Rivas Lara

*Supervisors:* Prof. Xavier Querol
Prof. Jordi Sunyer



Funding acknowledged to: erc European Research Council

# Contents

# INTRODUCTION

# THE BREATHE PROJECT

BREATHE Brain Air School investigation

Exposure assessment

Air quality in schools and children's exposure

Focusing on traffic related pollutants

+

Effects on the brain

Psycometrics, for the assessment of memory and attentiveness

Neuroimaging for structural changes in the brain

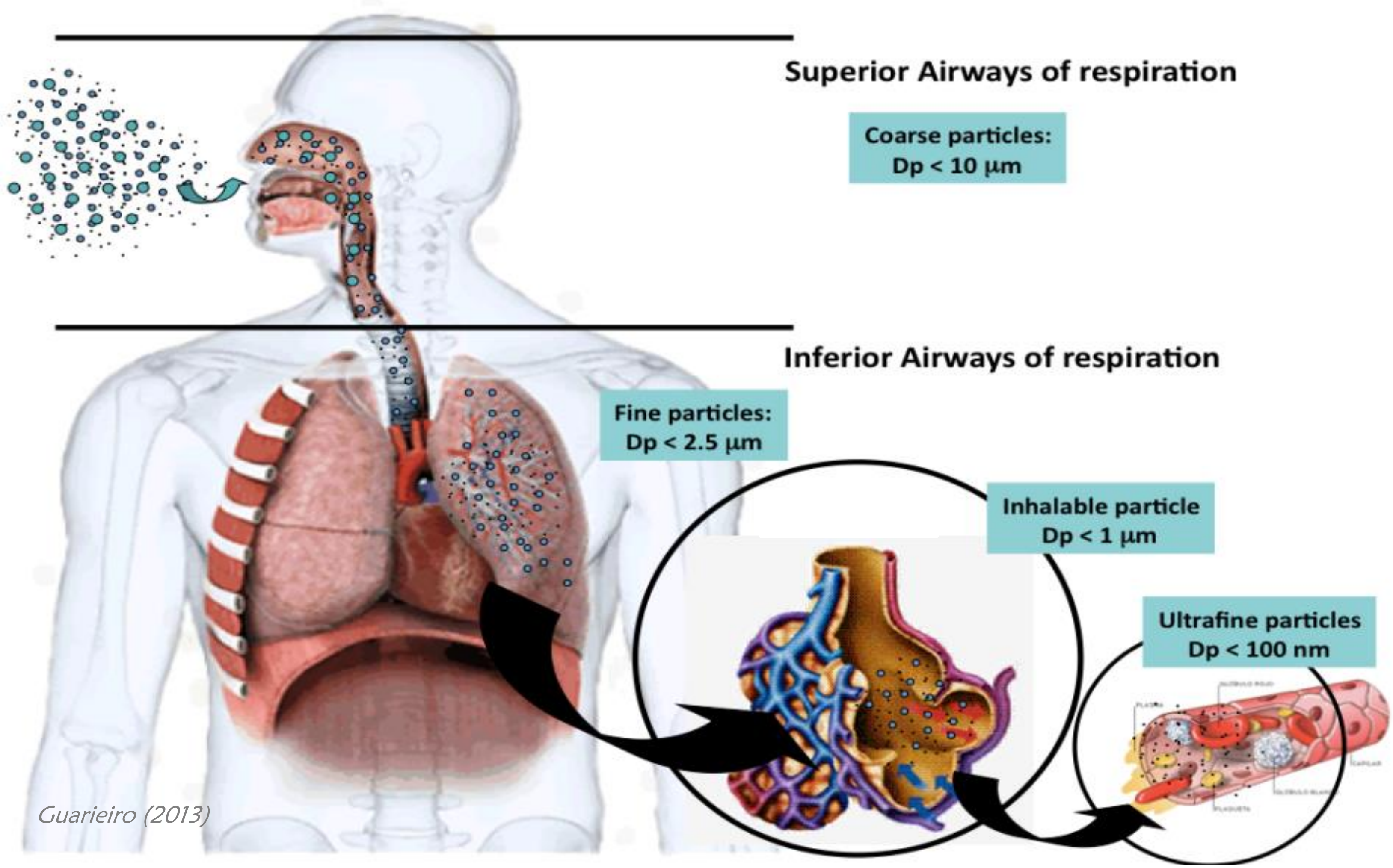
Genetics for gene-environment interactions

=

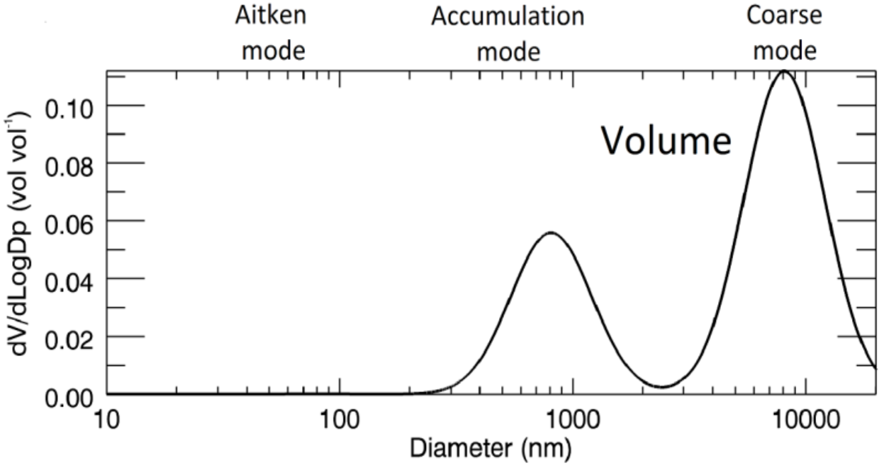
Effects of urban air pollution on neurodevelopment

European Research Council

# ADVERSE HEALTH EFFECTS



# ATMOSPHERIC AEROSOLS




*(Directive 2004/107/EC; Directive 2008/50/EC; RD 10/2011)*

| POLLUTANT | AVERAGING PERIOD | EUROPEAN LEGISLATION | WHO GUIDELINES |
|---|---|---|---|
| $PM_{10}$ | 24 h | 50 µg·m$^{-3}$ | |
| | 1 y | 40 µg·m$^{-3}$ | 20 µg·m$^{-3}$ |
| $PM_{2.5}$ | 1 y | 25 µg·m$^{-3}$ | 10 µg·m$^{-3}$ |

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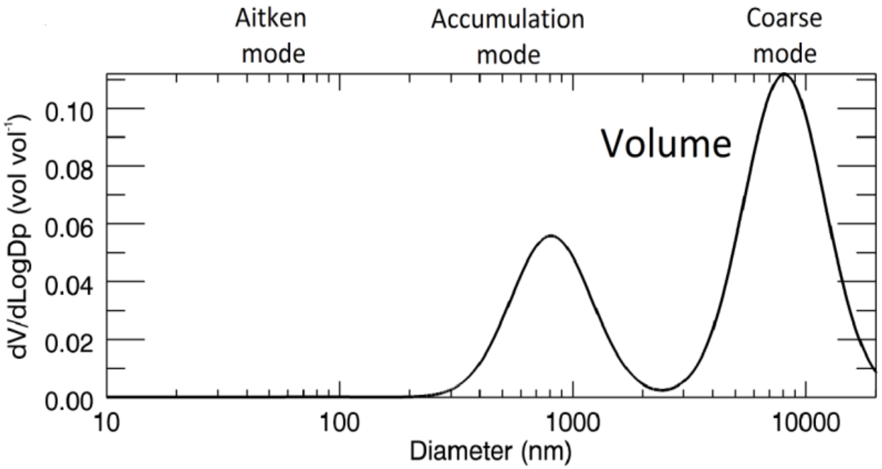


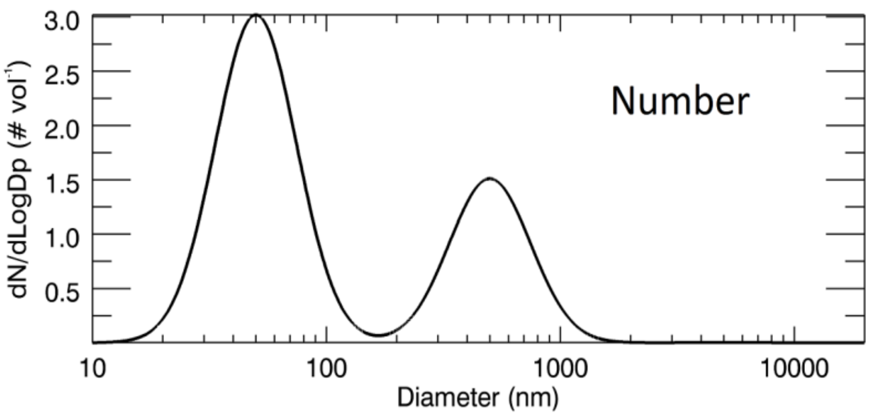


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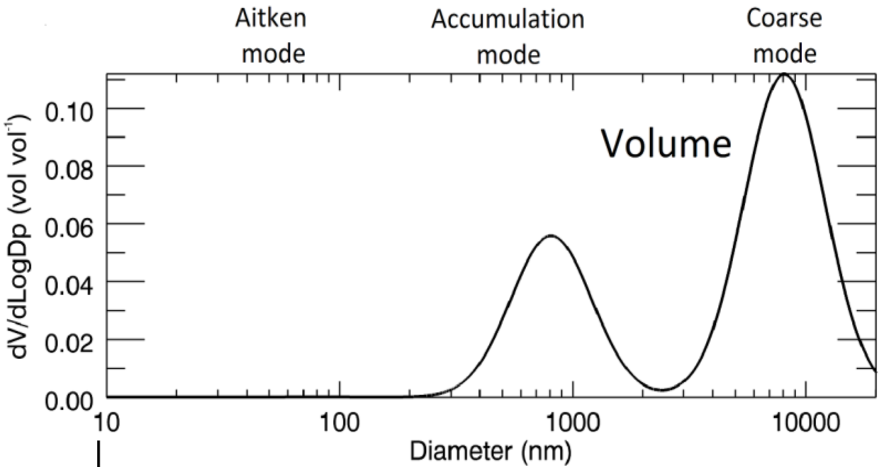


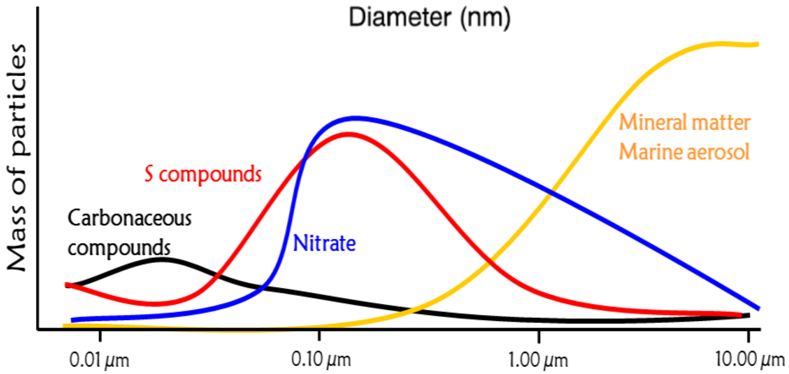


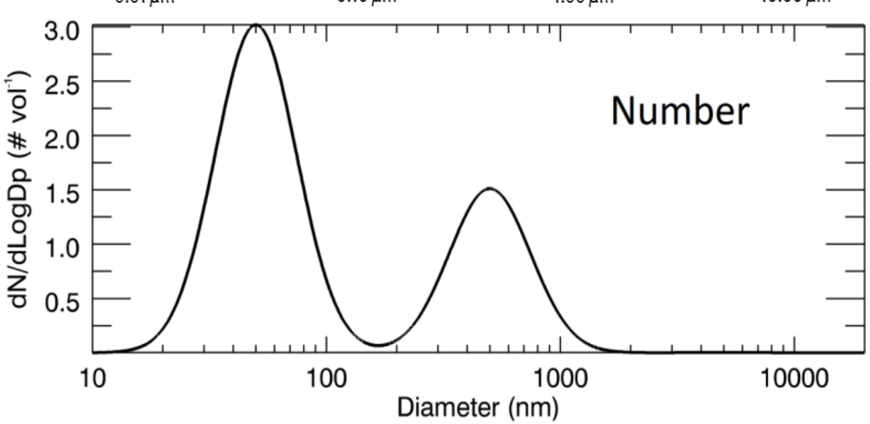


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| Lead (Pb) | 1 y | 0.5 µg·$m^{-3}$ | 0.5 µg·$m^{-3}$ |
| Arsenic (As) | 1 y | 6 ng·$m^{-3}$ | |
| Cadmium (cd) | 1 y | 5 ng·$m^{-3}$ | |
| Nickel (Ni) | 1 y | 20 ng·$m^{-3}$ | |

# TRACERS OF TRAFFIC EMISSIONS



## Black Carbon (BC)

Very fine particles (Ø<1μm)

>85% of concentration in Barcelona

*Minguillón et al., 2011*


Carrier of other substances from combustion sources, such as organic compounds

Not regulated

## Nitrogen dioxide ($NO_2$)

Gaseous compound

>50% of emissions in Barcelona

*Generalitat de Catalunya, 2015*

| POLLUTANT | AVERAGING PERIOD | EUROPEAN LEGISLATION |
|---|---|---|
| $NO_2$ | 1 h | 200 μg·m$^{-3}$ |
| | 1 y | 40 μg·m$^{-3}$ |

# AEROSOL CHEMICAL COMPOSITION



## Crustal-mineral

$Al_2O_3$, Mg, Ti, Fe, K, $SiO_2$, $CO_3^{2-}$, P, Ca

## Carbonaceous compounds

Organic Matter + Elemental carbon

## Secondary inorganic aerosols (SIA)

$NH_4^+$, $SO_4^{2-}$, $NO_3^-$

## Marine aerosols

$Na^+$, $Cl^-$

## Trace elements

As, Ba, Bi, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Ga, Gd, Ge, Hf, La, Li, Mn, Mo, Nd, Ni, Pb, Pr, Rb, Sb, Sc, Se, Sm, Sn, Sr, Ta, Th, Ti, Tl, U, V, W, Yb, Zn, Zr

## Outdoor sources (infiltration):

ambient concentrations, AER, penetration factors

1 2 3 4 5 6 7 8

# INDOOR AIR QUALITY

## Outdoor sources (infiltration):

ambient concentrations, AER, penetration factors

## Indoor sources:

Indoor sources and formation of new particles

room occupancy

↓

resuspension of coarser particles

# INDOOR AIR QUALITY

## Outdoor sources (infiltration):

ambient concentrations, AER, penetration factors

## Indoor sources:

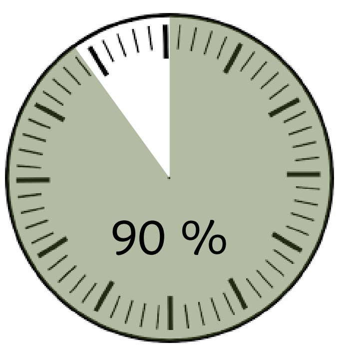
Indoor sources and formation of new particles

room occupancy

↓

resuspension of coarser particles

Time spent indoors:




Many different indoor facilities:

# INDOOR AIR QUALITY IN SCHOOLS

Crowded classrooms, occupied during long periods

Children are very active

# PREVIOUS STUDIES IN SCHOOLS

# PREVIOUS STUDIES IN SCHOOLS

$PM_{10}$ and $PM_{2.5}$ concentrations in different levels.
(Fromme et al., 2007)

Indoor and outdoor BC, $NO_2$, $PM_{2.5}$ and trace elements.
(Mólnar et al., 2007; Wichmann et al., 2010)

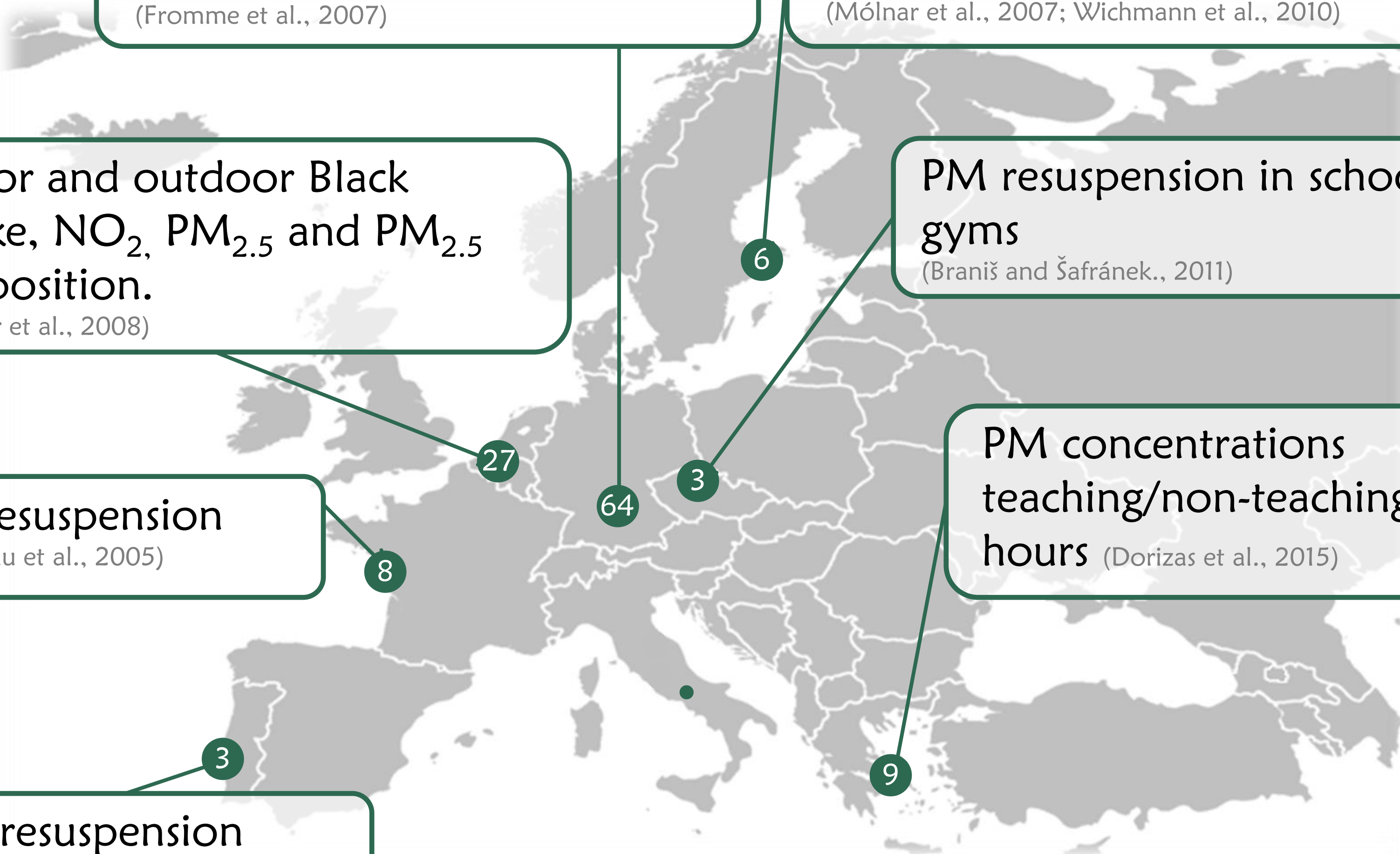
Indoor and outdoor Black Smoke, $NO_2$, $PM_{2.5}$ and $PM_{2.5}$ composition.
(Stranger et al., 2008)

PM resuspension in school gyms
(Braniš and Šafránek., 2011)

PM concentrations teaching/non-teaching hours (Dorizas et al., 2015)

PM resuspension
(Blondeau et al., 2005)

PM resuspension
(Almeida et al., 2011)



# PREVIOUS STUDIES IN SCHOOLS

$PM_{10}$ and $PM_{2.5}$ concentrations in different levels. Chalk – Ca.
(Fromme et al., 2007) (Fromme et al, 2008)

Indoor and outdoor BC, $NO_2$, $PM_{2.5}$ and trace elements.
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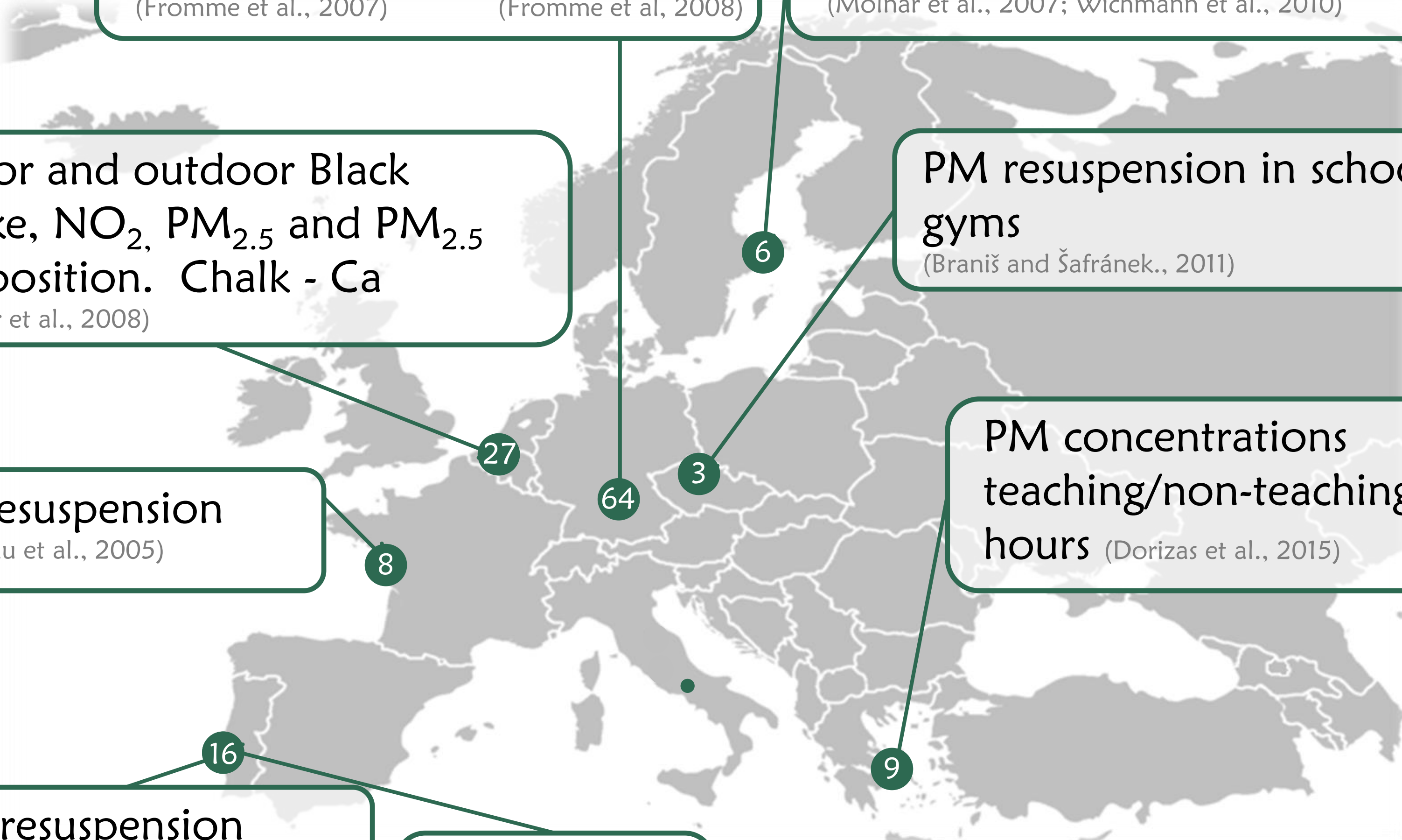


PM resuspension
(Almeida et al., 2011)

Chalk as the source of Ca
(Canha et al., 2014)

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(Braniš and Šafránek., 2011)

PM concentrations teaching/non-teaching hours (Dorizas et al., 2015)

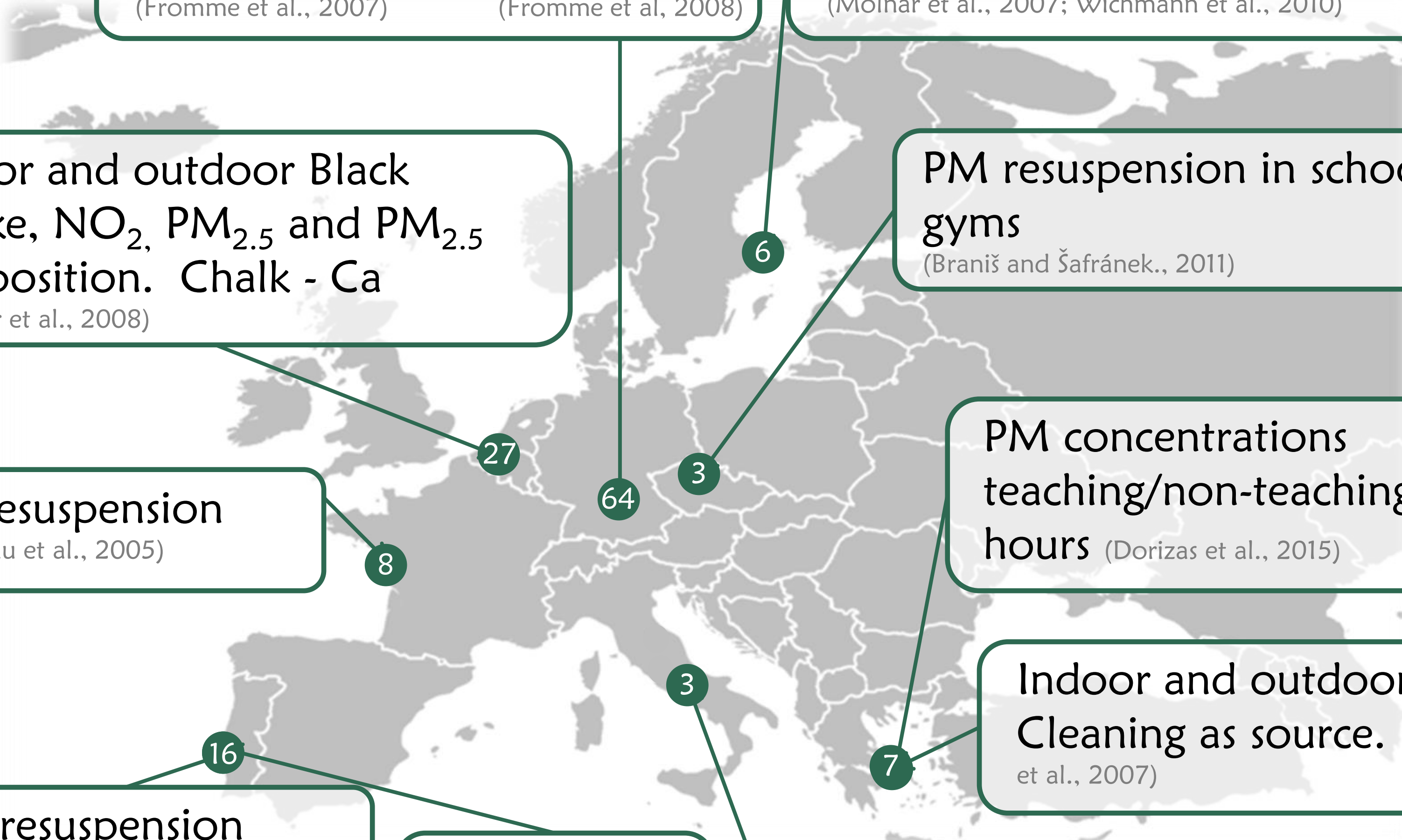
PM resuspension
(Blondeau et al., 2005)

Indoor and outdoor UFP. Cleaning as source. (Diapouli et al., 2007)

PM resuspension
(Almeida et al., 2011)

Chalk as the source of Ca
(Canha et al., 2014)

Indoor and outdoor BC and UFP. (Buonanno et al., 2013)



# GAPS IN CURRENT KNOWLEDGE

- Air quality in indoor and outdoor spaces in school has not been yet well characterised
- Inorganic chemical composition of PM and concentrations of UFP and BC at school facilities is very scarce and focused only in few PM components
- Processes and sources affecting PM levels and its composition
- Few studies about personal exposure.

# JUSTIFICATION

Sources and children's exposure to air pollutants at schools in Barcelona remains unknown and must be assessed in order to find potential harmful pollutants and find the necessary abatement strategies to reduce the exposure.

# OBJECTIVES

# OBJECTIVES

1 To characterise indoor and outdoor air quality at schools in Barcelona

2 To identify and quantify the main aerosol sources

3 To study the infiltration of ambient air pollutants to indoor air in schools

4 To determine children's exposure and dose to BC, and assess the agreement in BC concentrations between personal measurements and different fixed monitoring stations

# PUBLICATIONS

This thesis has been completed as a compilation of scientific publications:

1 **Rivas, I.**, Viana, M., Moreno, T., Pandolfi, M., Amato, F., Reche, C., Bouso, L., Àlvarez-Pedrerol, M., Alastuey, A., Sunyer, J., Querol, X., 2014. **Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain.** *Environment International* 69, 200–212

2 Amato, F., **Rivas, I.**, Viana, M., Moreno, T., Bouso, L., Reche, C., Alvarez-Pedrerol, M., Alastuey, A., Sunyer, J., Querol, X., 2014. **Sources of indoor and outdoor PM2.5 concentrations in primary schools.** *Science of the Total Environment* 490, 757–765

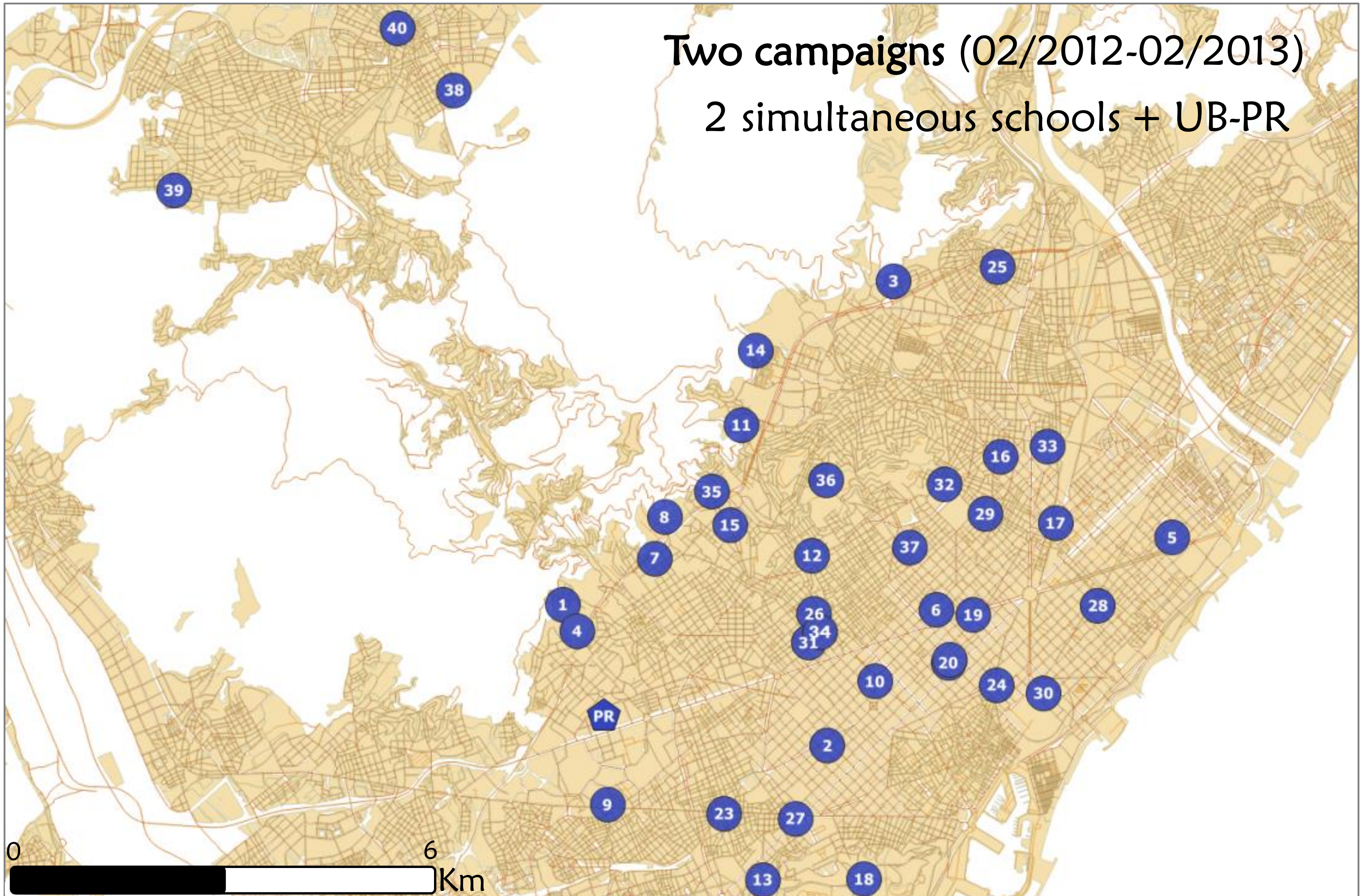
3 **Rivas, I.**, Viana, M., Moreno, T., Bouso, L., Pandolfi, M., Àlvarez-Pedrerol, M., Forns, J., Alastuey, A., Sunyer, J., Querol, X., 2015. **Outdoor infiltration and indoor contribution of UFP and BC, OC, secondary inorganic ions and metals in $PM_{2.5}$ in schools.** *Atmospheric Environment* 106, 129–138

4 **Rivas, I.**, Donaire-Gonzalez, D., Bouso, L., Esnaola, M., Pandolfi, M., de Castro, M., Viana, M., Àlvarez-Pedrerol, M., Nieuwenhuijsen, M., Alastuey, A., Sunyer, J., Querol, X. **Spatiotemporally resolved Black Carbon concentration, schoolchildren's exposure and dose in Barcelona.** *Indoor Air, in press*, 2015

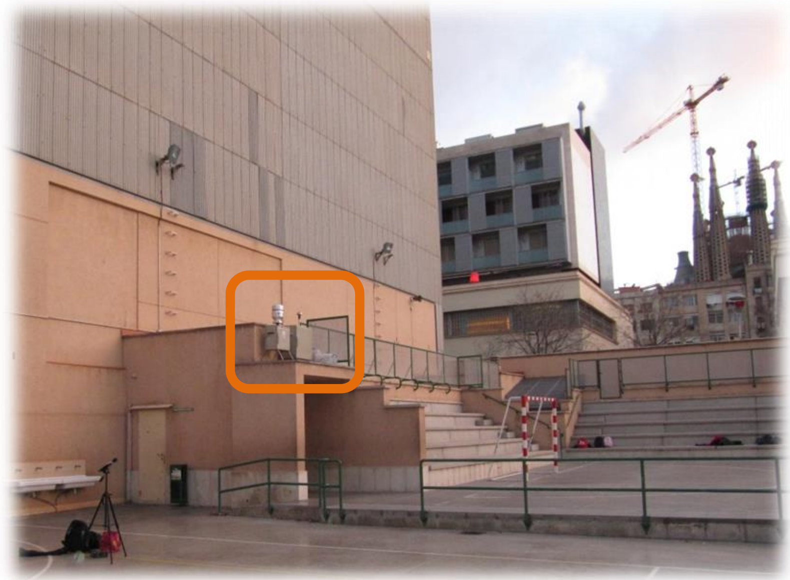
# METHODOLOGY

# LOCATION OF THE SCHOOLS

39 schools + Urban background station of Palau Reial (UB-PR)



# MONITORING STATIONS IN SCHOOLS



**Indoor environment:**
classroom with pupils 7-10 years old

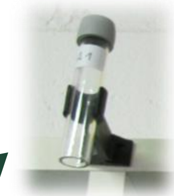
**Outdoor environment:**
school playground.

Sampling Monday to Friday

$PM_{2.5}$ filters sampled during schoolhours (9-17h)

# INSTRUMENTATION IN SCHOOLS

**MicroAeth AE51**
Online BC measurements
EBC=0.54·BC ($R^2$=0.88)



**Gradko**
$NO_2$ passive dosimeter

**DiSCmini**
Online:
-UFP (10-700 nm)
-Lung Deposited Surface Aera (LDSA)
-Mean particle size

**High-Volume sampler (MCV)**
8h gravimetric samples of $PM_{2.5}$

# INSTRUMENTATION IN UB-PR



**High-Volume sampler (DIGITEL)**
24h gravimetric samples of $PM_{2.5}$


**MAAP (model 5012)**
Online BC measurements


**GRIMM (model 1180)**
Online PM measurements


**WCPC (model 3785)**
Online UPF (5-1000 nm) measurement

**SIR (model S-5012)**
Online $NO_2$ measurements

**Gradko**
$NO_2$ passive dosimeter

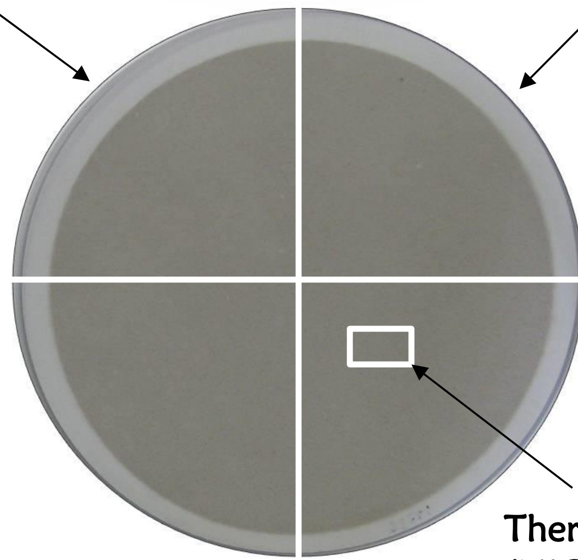

**NSAM (model 3550)**
Online LDSA measurement

# CHEMICAL CHARACTERISATION

**Acid digestion:**

**Major elements (ICP-AES):** Al, Fe, Ca, Na, Mg, S, P, Ba, Cr, Cu, Mn, Ni, Sr, Pb, Ti, V, Zn

**Trace elements (ICP-MS):** Li, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Cd, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Hf, W, Tl, Pb, Bi, Th, U



**Water leaching:**

**Chromatography (HPLC):** $NO_3^-$, $Cl^-$, $SO_4^{2-}$

**Selective electrode:** $NH_4^+$

**Thermal-optical method** (NIOSH Tº program): OC, EC

**Indirect determinations:**

$SiO_2 = 3 \cdot Al_2O_3$

$CO_3^{2-} = 1.5 \cdot Ca$

$OM = 1.6 \cdot OC$

**Σ CHEMISTRY = 85% of $PM_{2.5}$ mass**

*(Querol et al., 2001)*

# SOURCE APPORTIONMENT (PMF)

## For source identification and quantification:

Positive matrix factorisation $X_{measured} = (G \cdot F)_{model} + E_{model}$

| Measured concentration matrix | = | Source contribution matrix | x | Source profile matrix | + | Measured concentration not fitted by the model |
|---|---|---|---|---|---|---|
| n x m |  | n x p |  | p x m |  | n x m |
| $\mu g \cdot m^{-3}$ |  | $\mu g \cdot m^{-3}$ |  | $\mu g \cdot \mu g^{-1}$ |  | $\mu g \cdot m^{-3}$ |

i = 1,…, n samples

j = 1,…, m species

k =1,…, p sources (user specified)

Solved with Multilinear Engine 2 (ME2)

(Paatero and Tapper, 1994; Paatero, 1999)

# SEASONAL ADJUSTMENT



For removing the meteorological effect:

$$(C_i^j)_k^* = \frac{(C_i^j)_k}{\left(\frac{(C_i^{PR})_k}{\overline{C_i^{PR}}}\right)}$$

**Measured concentration** of the *ith* pollutant for the *kth* day at the *jth* school

**Measured concentration** of the *ith* pollutant for the *kth* day **at UB-PR**

**Adjusted concentration** of the *ith* pollutant for the *kth* day at the *jth* school

**Campaign average concentration** of the *ith* pollutant **at UB-PR**

i = 1, …, n pollutant

j = 1, …, 39 school

k = 1, …, m day

PR= at UB-PR

# FEATURES OF THE SCHOOLS

| School ID | Window material | Building construction year | Playground | Classroom orientation[1] | Playground location[2] | Classroom floor | Playground floor |
|---|---|---|---|---|---|---|---|
| **1** | PVC/Al | >1970 | paved | Interior | interior | 0-1st | 1st-2nd |
| **2** | Wood (SC1)<br>PVC/Al (SC2) | ≤1970 | paved | Interior | interior | 2nd | ground |
| **3** | wood | >1970 | paved | Playground | interior | 2nd | 1st-2nd |
| **4** | PVC/Al | ≤1970 | sand-filled | Playground | street | 2nd | ground |
| **5** | PVC/Al | >1970 | paved | directly street | street | 2nd | 3-5th |
| **6** | wood | ≤1970 | paved | Interior | street | 2nd | 1st-2nd |
| **7** | wood | ≤1970 | paved | Playground | street | 3-4th | 3-5th |
| **8** | PVC/Al | >1970 | paved | Playground | street | 2nd | 3-5th |
| **9** | PVC/Al | ≤1970 | paved | Playground | street | 3-4th | ground |
| **10** | wood | ≤1970 | paved | directly street | interior | 2nd | ground |
| **11** | PVC/Al | >1970 | paved | Interior | street | 0-1st | 1st-2nd |
| **12** | PVC/Al | >1970 | sand-filled | directly street | street | 0-1st | 1st-2nd |
| **13** | PVC/Al | >1970 | sand-filled | Interior | interior | 0-1st | ground |

# FEATURES OF THE SCHOOLS



| School ID | Window material | Building construction year |
|---|---|---|
| 1 | PVC/Al | >1970 |
| 2 | Wood (SC1) PVC/Al (SC2) | ≤1970 |
| 3 | wood | >1970 |
| 4 | PVC/Al | ≤1970 |
| 5 | PVC/Al | >1970 |
| 6 | wood | |
| 7 | wood | |
| 8 | PVC/Al | |
| 9 | PVC/Al | |
| 10 | wood | |
| 11 | PVC/Al | |
| 12 | PVC/Al | |
| 13 | PVC/Al | |

Al/PVC vs. Wood

# FEATURES OF THE SCHOOLS

| School ID | Window material | Building construction year | Playground | Classroom orientation[1] | Playground location[2] | Classroom floor | Playground floor |
|---|---|---|---|---|---|---|---|
| 1 | PVC/Al | >1970 | pave | [illegible] | [illegible] | [illegible] | d |
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| 3 | wood | >1970 | pave | [illegible] | [illegible] | [illegible] | d |
| 4 | PVC/Al | ≤1970 | sand-f | [illegible] | [illegible] | [illegible] | d |
| 5 | PVC/Al | >1970 | pave | [illegible] | [illegible] | [illegible] | [illegible] |
| 6 | wood | ≤1970 | pave | [illegible] | [illegible] | [illegible] | d |
| 7 | wood | ≤1970 | pave | [illegible] | [illegible] | [illegible] | [illegible] |
| 8 | PVC/Al | >1970 | pave | [illegible] | [illegible] | [illegible] | [illegible] |
| 9 | PVC/Al | ≤1970 | pave | [illegible] | [illegible] | [illegible] | d |
| 10 | wood | ≤1970 | pave | [illegible] | [illegible] | [illegible] | d |
| 11 | PVC/Al | >1970 | pave | [illegible] | [illegible] | [illegible] | d |
| 12 | PVC/Al | >1970 | sand-filled | directly street | street | 0-1st | 1st-2nd |
| 13 | PVC/Al | >1970 | sand-filled | Interior | interior | 0-1st | ground |

Before 1970 VS. In/After 1970

1 2 3 4 5 6 7 8

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| 8 | PVC/Al | | | | | | th |
| 9 | PVC/Al | | | | | | nd |
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| 13 | PVC/Al | >1970 | sand-filled | Interior | interior | 0-1st | ground |

| | Type of windows | |
|---|---|---|
| Building construction year | Al/PVC | Wood |
| ≤1970 | 13 (65%) | 7 (35%) |
| >1970 | 10 (53%) | 9 (47%) |

Pearson $\chi^2 = 0.61$
**$p=0.43$**

# FEATURES OF THE SCHOOLS

| School ID | Window material | Building construction year | Playground | Classroo... orientati... | [illegible] | [illegible] | ...nd |
|---|---|---|---|---|---|---|---|
| 1 | PVC/Al | >1970 | paved | Interio | [illegible] | [illegible] | [illegible] |
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| 3 | wood | >1970 | paved | Playgrou | [illegible] | [illegible] | [illegible] |
| 4 | PVC/Al | ≤1970 | sand-filled | Playgrou | [illegible] | [illegible] | [illegible] |
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| 6 | wood | ≤1970 | paved | Interior | street | 2nd | 1st-2nd |
| [illegible] | [illegible] | [illegible] | aved | Playgrou | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | aved | Playgrou | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | aved | Playgrou | [illegible] | [illegible] | [illegible] |
| 1 | [illegible] | [illegible] | aved | directly st | [illegible] | [illegible] | [illegible] |
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| 1 | [illegible] | [illegible] | -filled | directly st | [illegible] | [illegible] | [illegible] |
| 1 | [illegible] | [illegible] | -filled | Interio | [illegible] | [illegible] | [illegible] |



Paved vs. Sandy

# FEATURES OF THE SCHOOLS

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| 6 | wood | ≤1970 | paved | Interior | street | 2nd | 1st-2nd |
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# PERSONAL MEASUREMENTS


•**53 children** (7-10 years old) participated in personal monitoring of EBC during 48h

•Children carried a belt bag with a MicroAeth AE51 (inlet tube in the breathing zone)

•They filled in a time-activity diary reporting location and activity

**Microenvironments (ME) classification:**

- classroom
- School playground
- Home
- Commuting
- Other

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# LINEAR MIXED EFFECT MODEL

Linear regression model containing both **fixed** and **random** effects

Multiple measurements at the same schools are **not independent**

## INFILTRATION

*Indoor concentration* = $\beta_0 + \beta_1\,(\text{outdoor concentration})_{it} + \beta_2\,(\text{building age: } \leq 1970)_i + \beta_3\,(\text{type of windows: wood})_i + \beta_4\,(\text{type of playground: sand-filled} < 20\text{m})_i + u_i + \varepsilon_{it}$

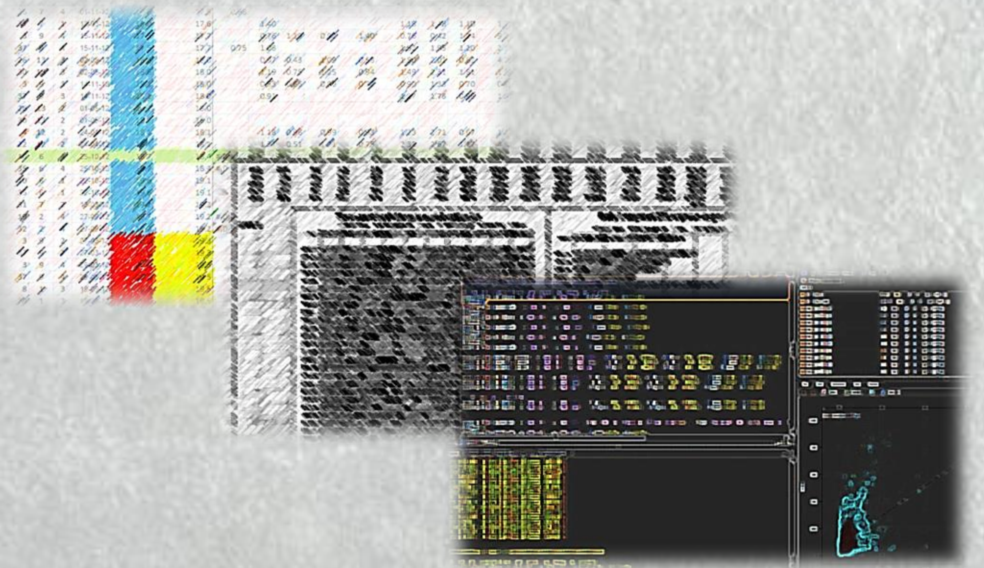
→ **Schools** as random effect

## PERSONAL MEASUREMENTS & FIXED STATIONS

*Personal EBC concentrations* = $\beta_0 + \beta_1\,(\text{BC concentrations from fixed station X})_{ict} + u_i + u_c + \varepsilon_{ict}$

→ **Schools and children** as random effect

# RESULTS AND DISCUSSION



# OBJECTIVE 1

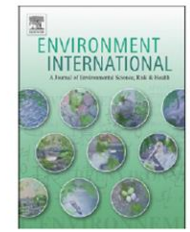
Environment International 69 (2014) 200–212

ELSEVIER

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint




## Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain

CrossMark

I. Rivas [a,b,d,e,f,*], M. Viana [b], T. Moreno [b], M. Pandolfi [b], F. Amato [b], C. Reche [b], L. Bouso [a,d,e], M. Àlvarez-Pedrerol [a,d,e], A. Alastuey [b], J. Sunyer [a,c,d,e], X. Querol [b]

# AVERAGE CONCENTRATIONS

| | INDOOR | | OUTDOOR | | UB-PR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| $NO_2$ ($\mu g \cdot m^{-3}$) | 30 | 13 | 47 | 19 | 41 | 20 |
| $PM_{2.5}$ ($\mu g \cdot m^{-3}$) | 37 | 16 | 29 | 24 | 17 | 8 |
| UFP ($\# \cdot cm^{-3}$) | 15625 | 6673 | 23614 | 9514 | 14665 | 6034 |
| EBC ($\mu g \cdot m^{-3}$) | 1.3 | 0.9 | 1.4 | 1.1 | 1.3 | 0.8 |

BREATHE schools are **representative** of the rest of schools in Barcelona

# AVERAGE CONCENTRATIONS

NO2 traffic stations:
≈ 62 $\mu g \cdot m^{-3}$

| | INDOOR | | OUTDOOR | | UB-PR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| $NO_2$ ($\mu g \cdot m^{-3}$) | 30 | 13 | 47 | 19 | 41 | 20 |
| $PM_{2.5}$ ($\mu g \cdot m^{-3}$) | 37 | 16 | 29 | 24 | 17 | 8 |
| UFP ($\# \cdot cm^{-3}$) | 15625 | 6673 | 23614 | 9514 | 14665 | 6034 |
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BREATHE schools are **representative** of the rest of schools in Barcelona

- **Mean level of $NO_2$ is intermediate between traffic and urban background sites**

# AVERAGE CONCENTRATIONS

| | INDOOR | | OUTDOOR | | UB-PR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| **$NO_2$** ($\mu g \cdot m^{-3}$) | 30 | 13 | 47 | 19 | 41 | 20 |
| **$PM_{2.5}$** ($\mu g \cdot m^{-3}$) | 37 | 16 | 29 | 24 | 17 | 8 |
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BREATHE schools are **representative** of the rest of schools in Barcelona

- **Mean level of $NO_2$ is intermediate between traffic and urban background sites**
- **High levels of $PM_{2.5}$ in schools → Local (school) emission of $PM_{2.5}$**

# AVERAGE CONCENTRATIONS

| | INDOOR | | OUTDOOR | | UB-PR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| $NO_2$ ($\mu g \cdot m^{-3}$) | 30 | 13 | 47 | 19 | 41 | 20 |
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BREATHE schools are **representative** of the rest of schools in Barcelona

- Mean level of $NO_2$ is intermediate between traffic and urban background sites
- High levels of $PM_{2.5}$ in schools → Local (school) emission of $PM_{2.5}$

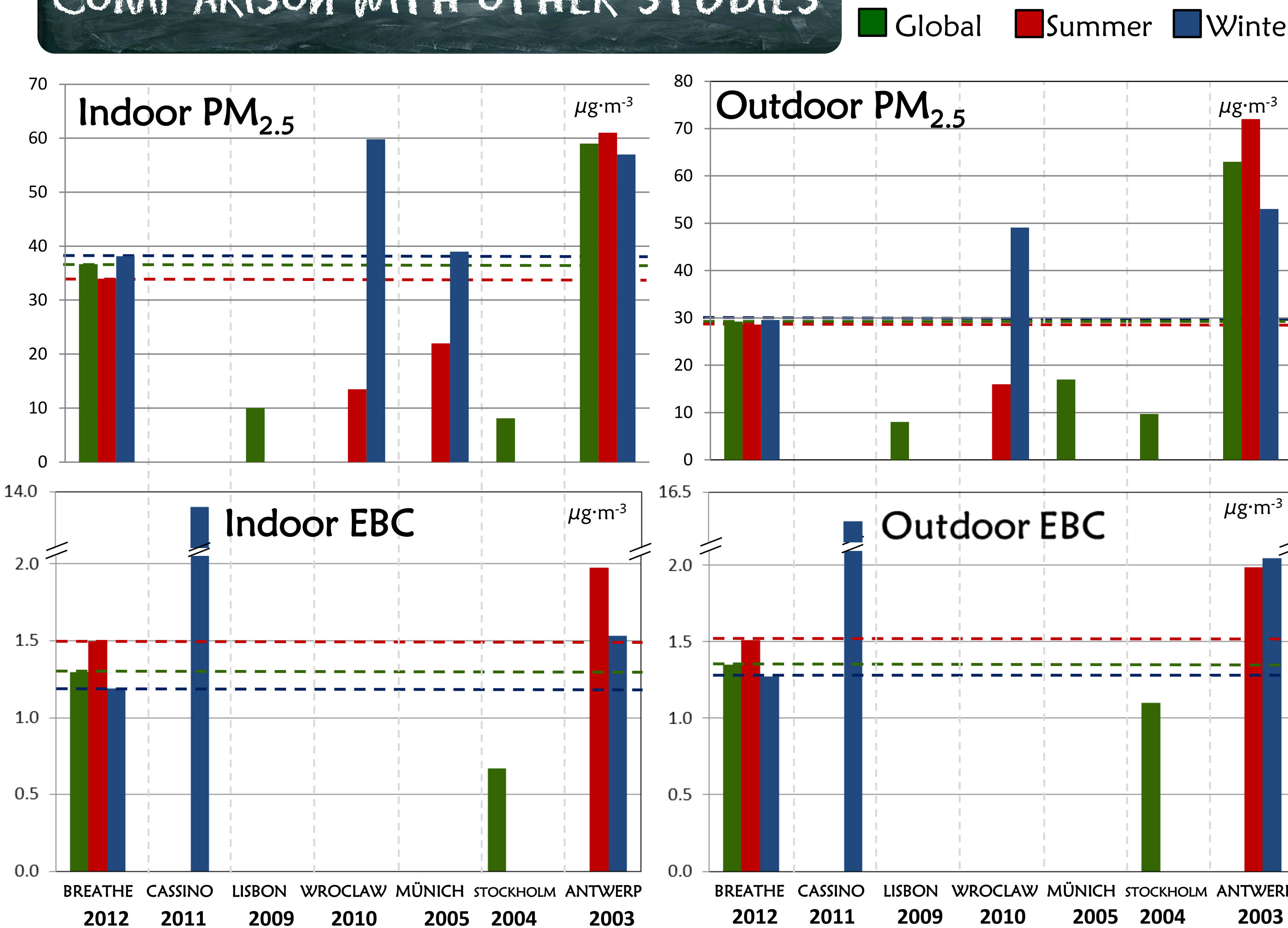
# AVERAGE CONCENTRATIONS

| | INDOOR | | OUTDOOR | | UB-PR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| $NO_2$ (μg·m$^{-3}$) | 30 | 13 | 47 | 19 | 41 | 20 |
| $PM_{2.5}$ (μg·m$^{-3}$) | 37 | 16 | 29 | 24 | 17 | 8 |
| UFP (#·cm$^{-3}$) | 15625 | 6673 | 23614 | 9514 | 14665 | 6034 |
| EBC (μg·m$^{-3}$) | 1.3 | 0.9 | 1.4 | 1.1 | 1.3 | 0.8 |

BREATHE schools are **representative** of the rest of schools in Barcelona

- Mean level of $NO_2$ is intermediate between traffic and urban background sites
- High levels of $PM_{2.5}$ in schools → Local (school) emission of $PM_{2.5}$

# COMPARISON WITH OTHER STUDIES

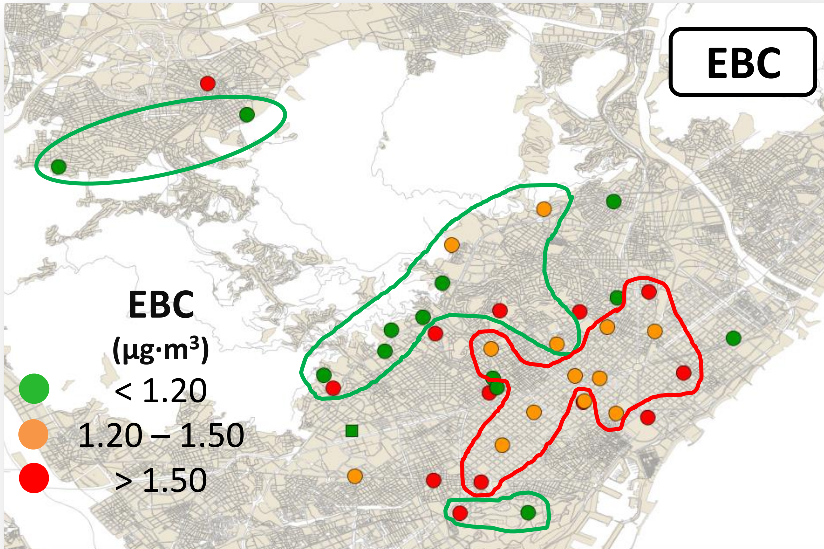


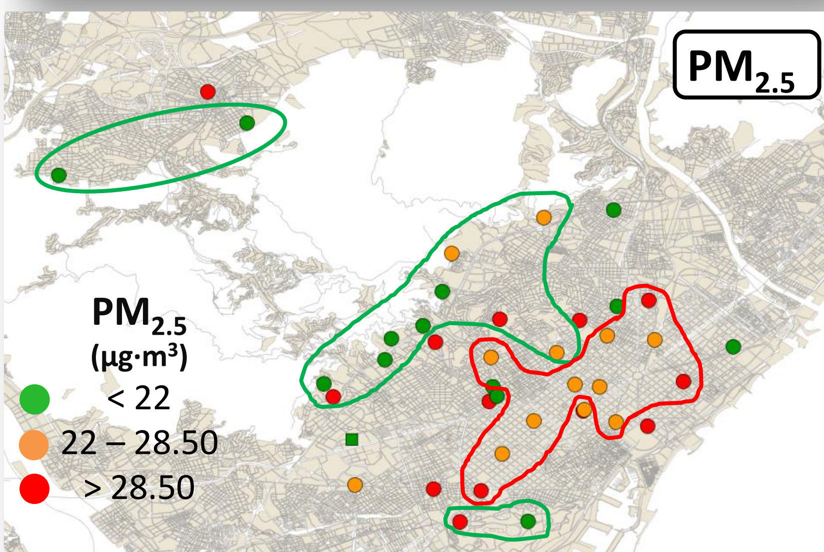
# SEASONAL ADJUSTMENT

○ BREATHE Schools
□ Reference Station

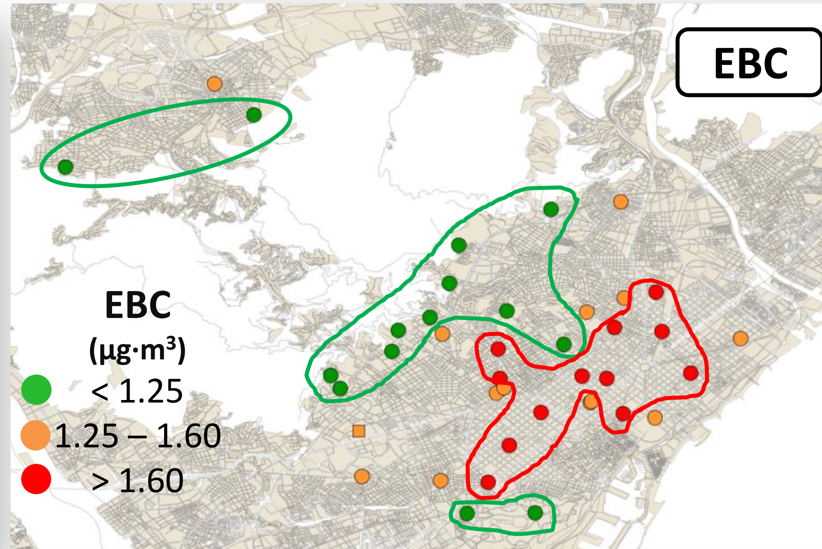
EBC perimeter
Low
High

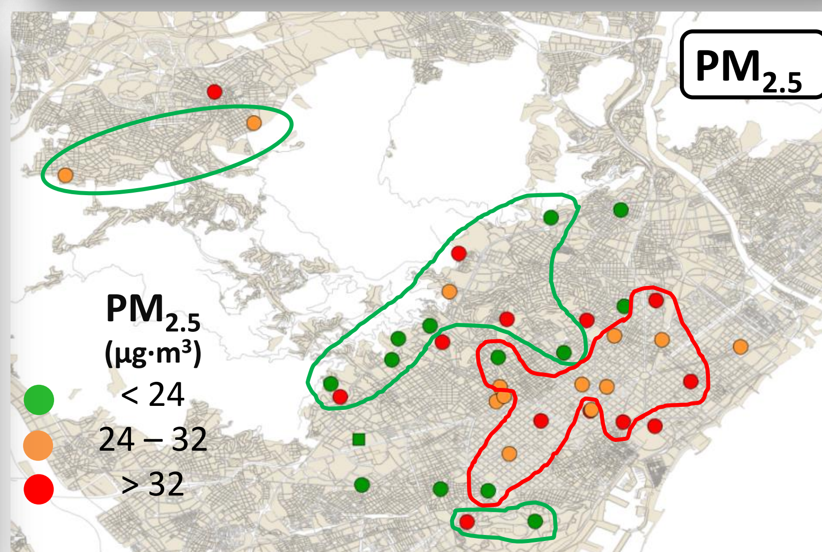
## NOT ADJUSTED




## ADJUSTED

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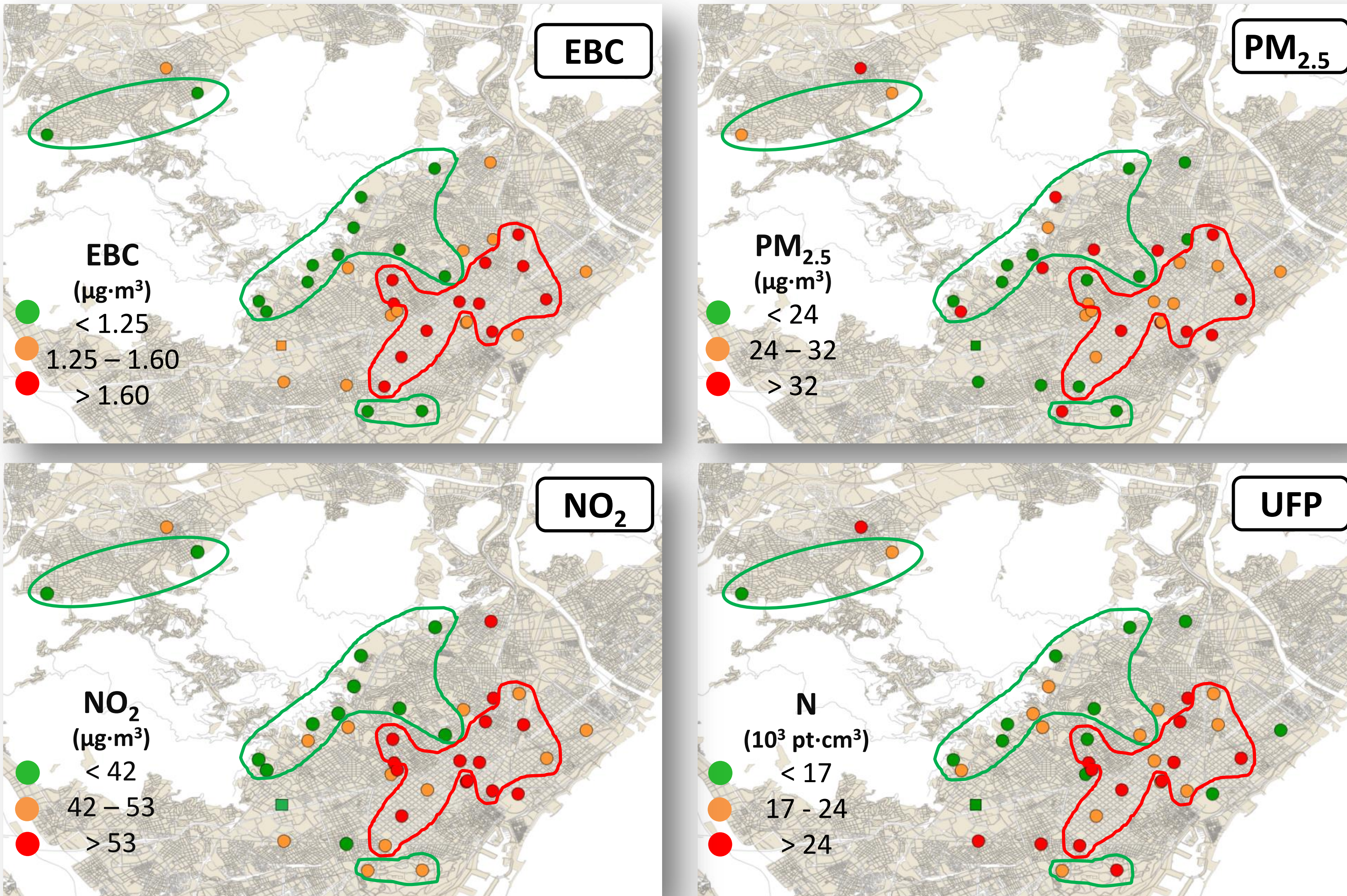
# SPATIAL VARIATION

BREATHE Schools
Reference Station

EBC perimeter
Low
High

## ADJUSTED - OUTDOOR



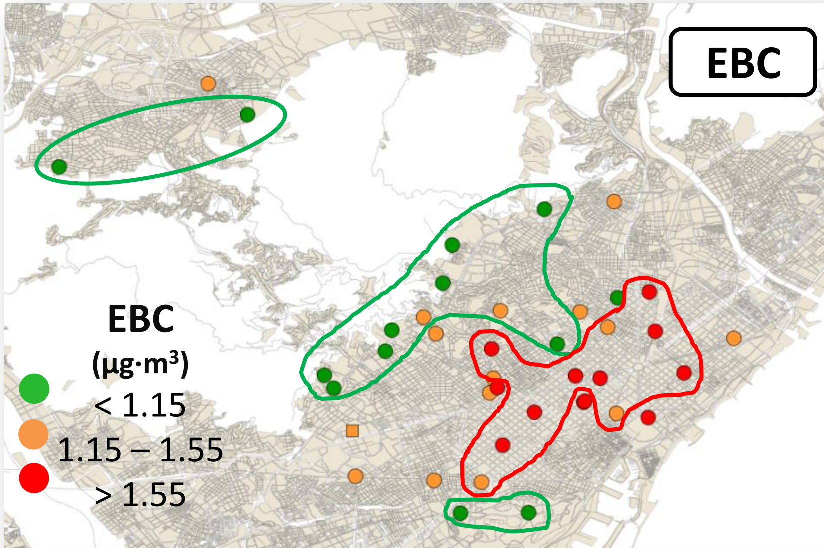
# SPATIAL VARIATION

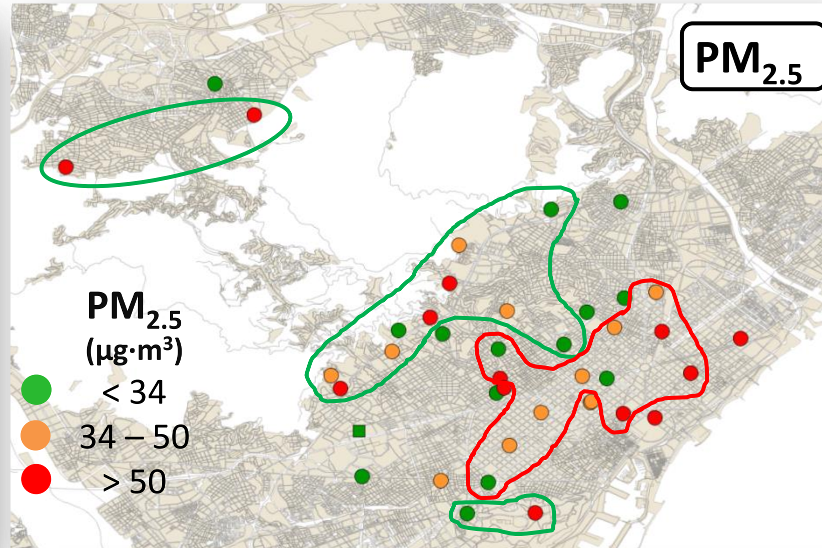
○ BREATHE Schools
□ Reference Station

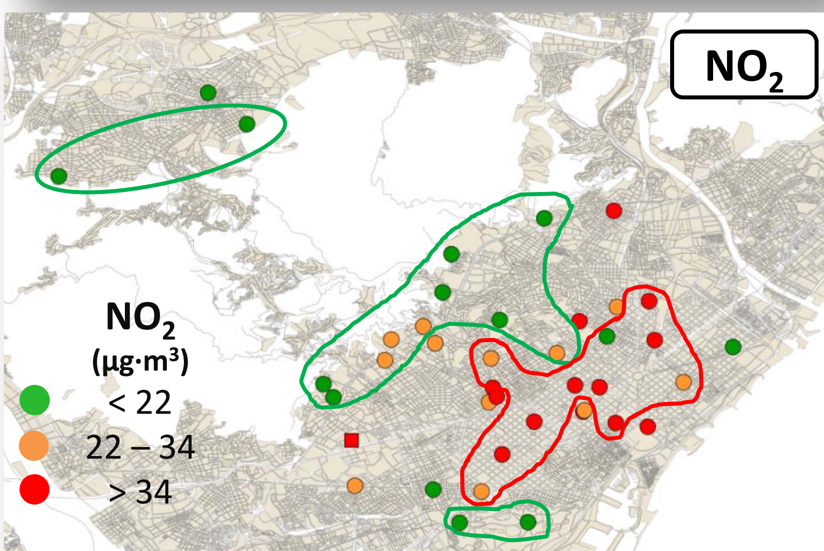
EBC perimeter
Low
High

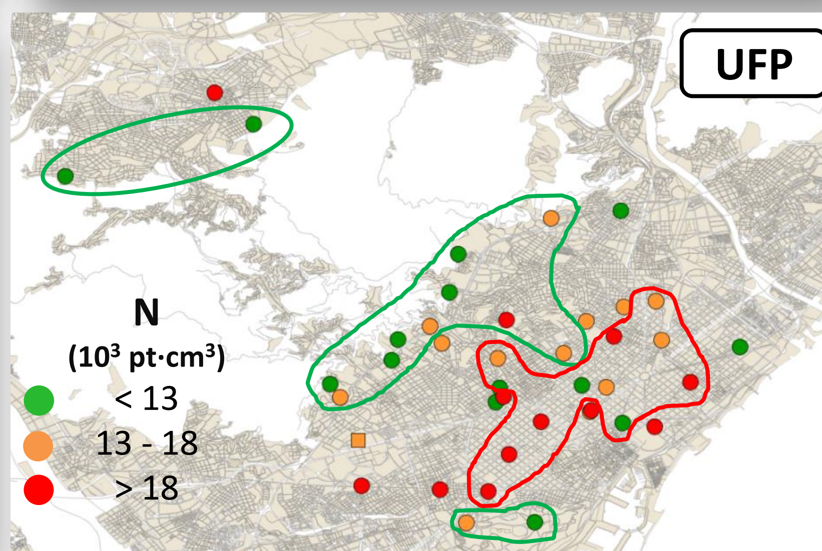


## ADJUSTED - INDOOR



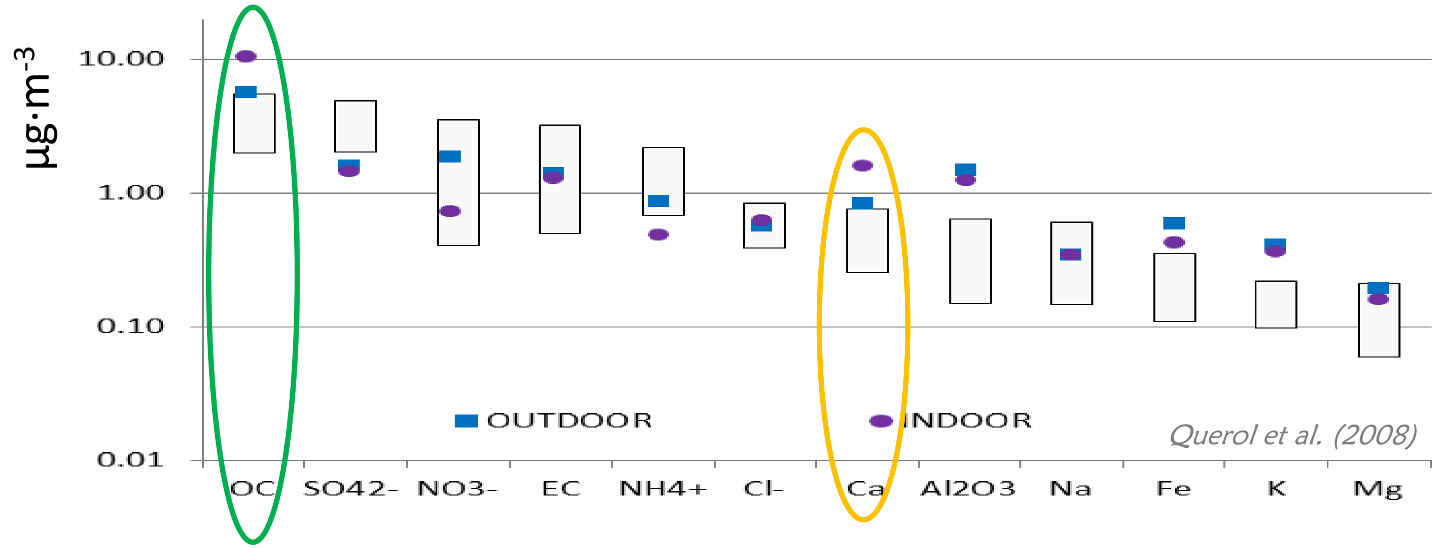



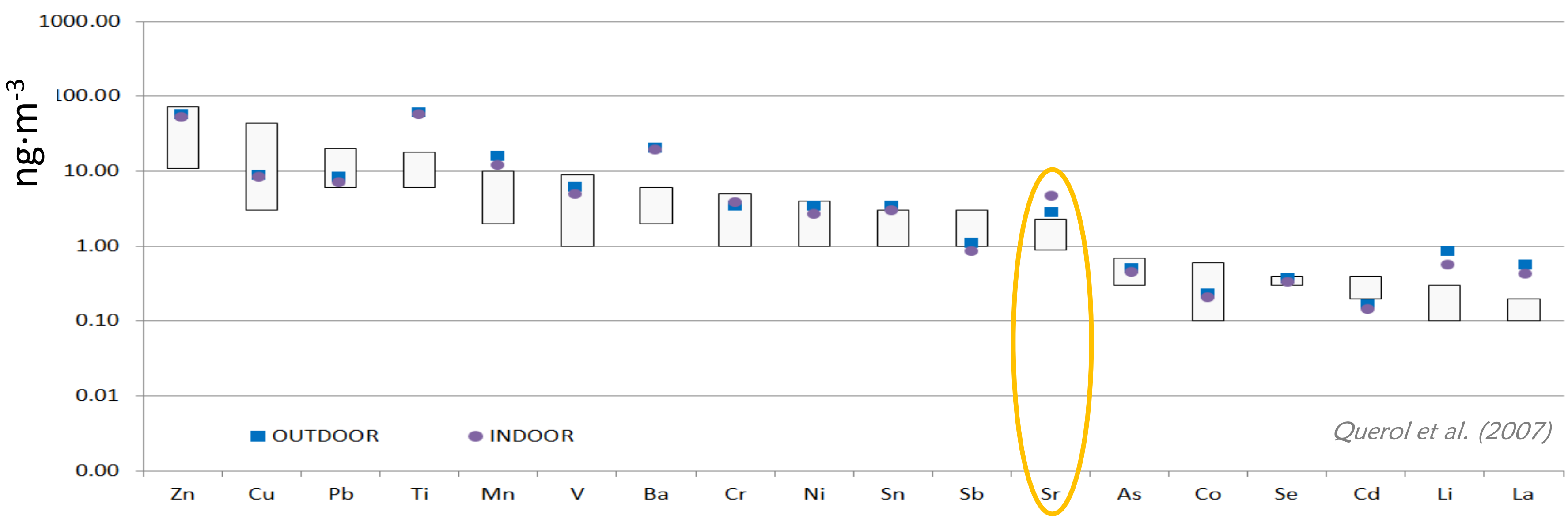



# PM2.5 CHEMICAL COMPONENTS

## $PM_{2.5}$ major and trace elements vs Spanish urban ambient air range

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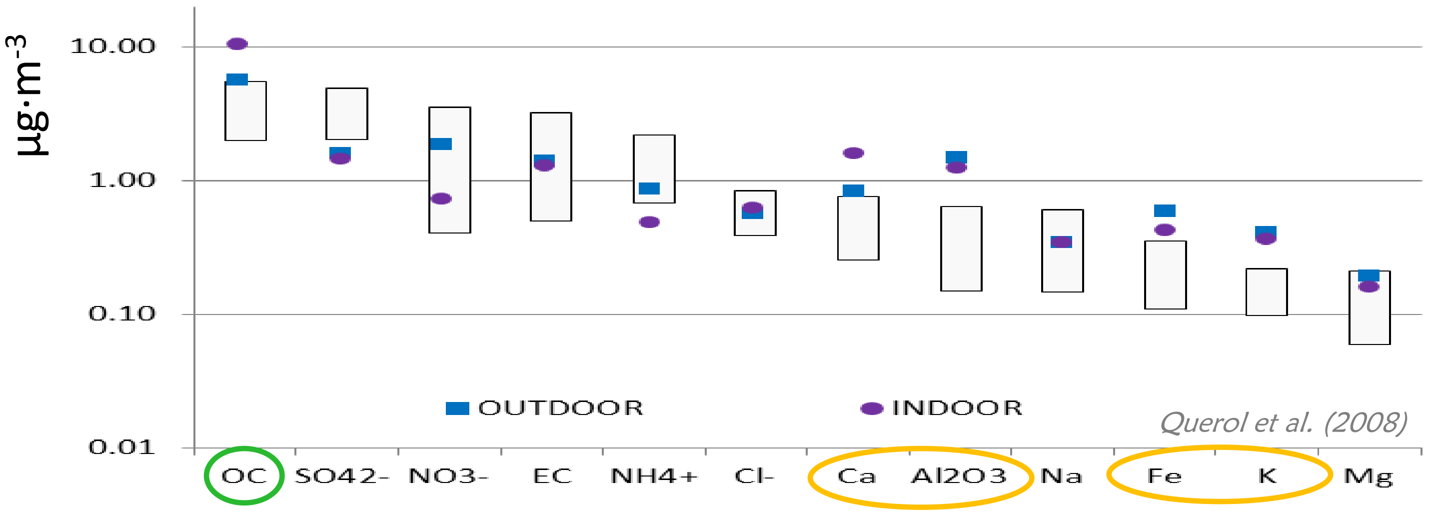
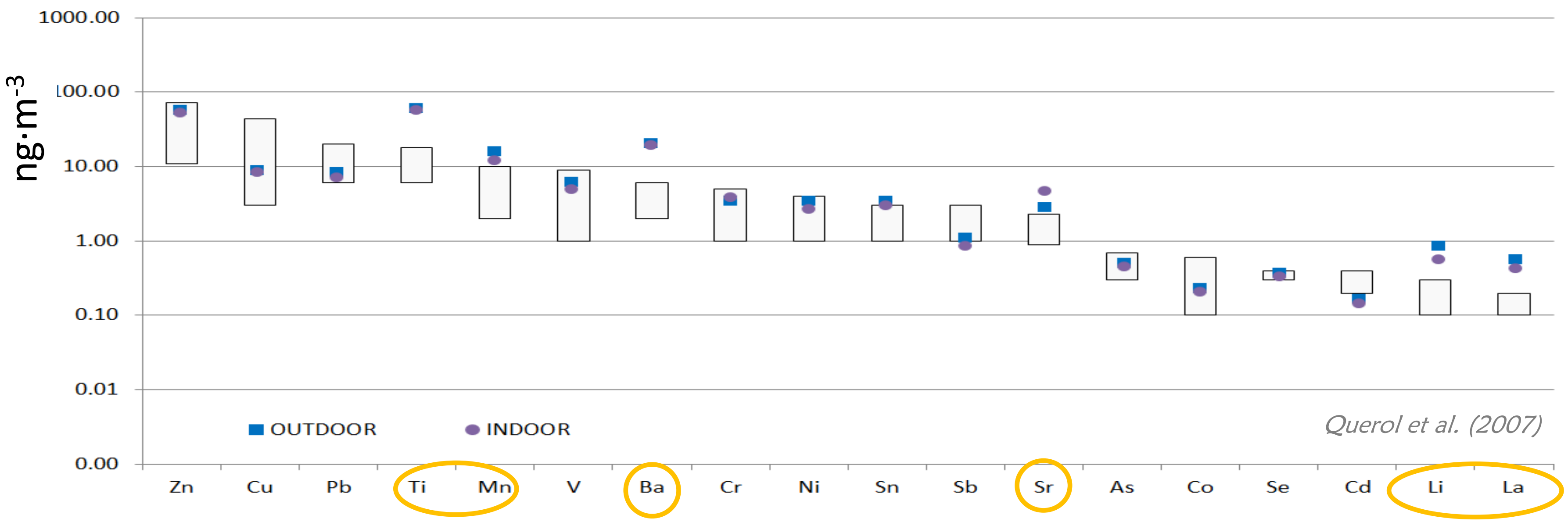
# $PM_{2.5}$ CHEMICAL COMPONENTS

## $PM_{2.5}$ major and trace elements vs Spanish urban ambient air range

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# OBJECTIVE 2

Science of the Total Environment 490 (2014) 757–765

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv


## Sources of indoor and outdoor PM2.5 concentrations in primary schools

F. Amato [a,*], I. Rivas [a,b,d,e,f], M. Viana [a], T. Moreno [a], L. Bouso [a,d,e], C. Reche [a], M. Àlvarez-Pedrerol [b,d,e], A. Alastuey [a], J. Sunyer [b,c,d,e], X. Querol [a]

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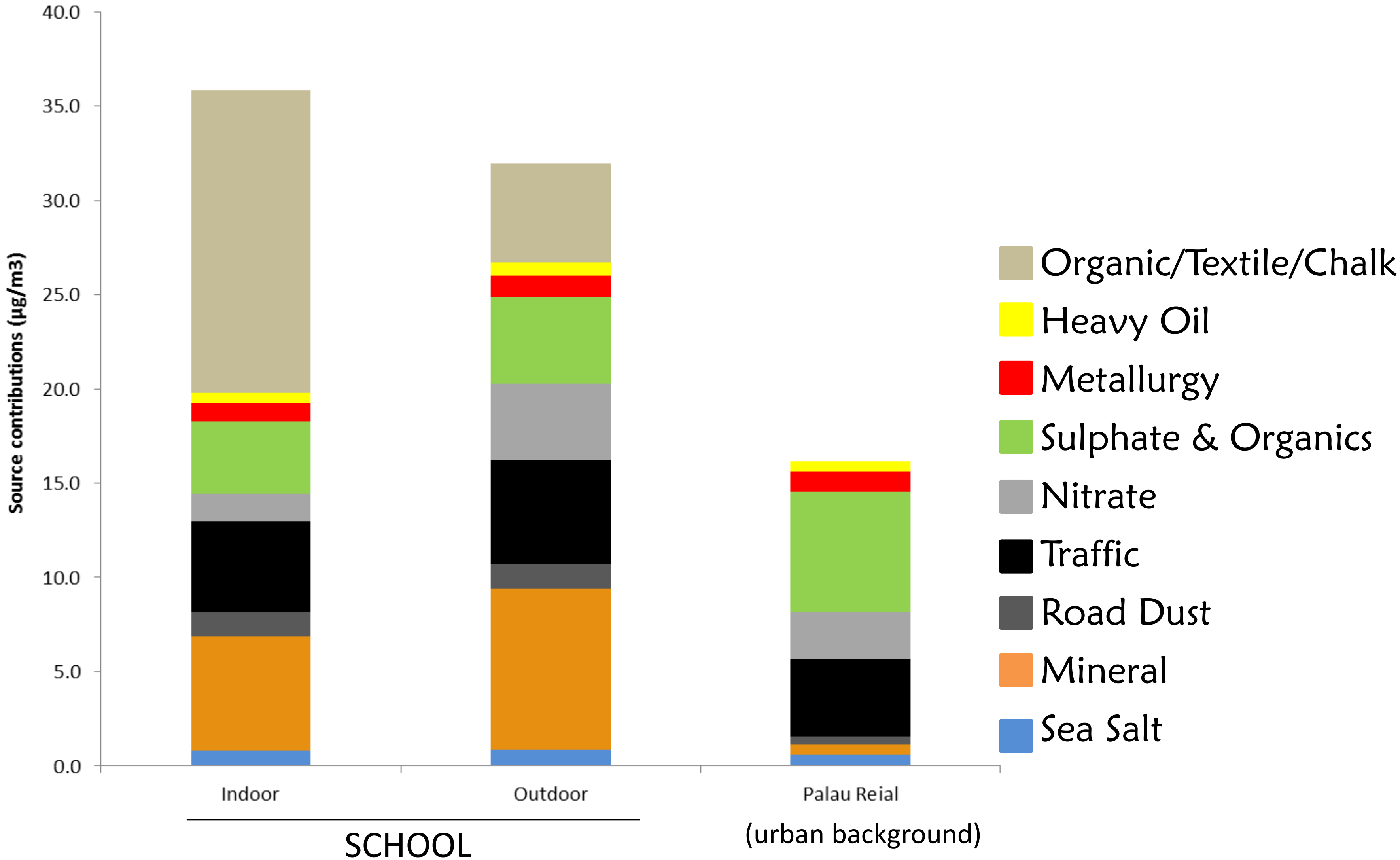
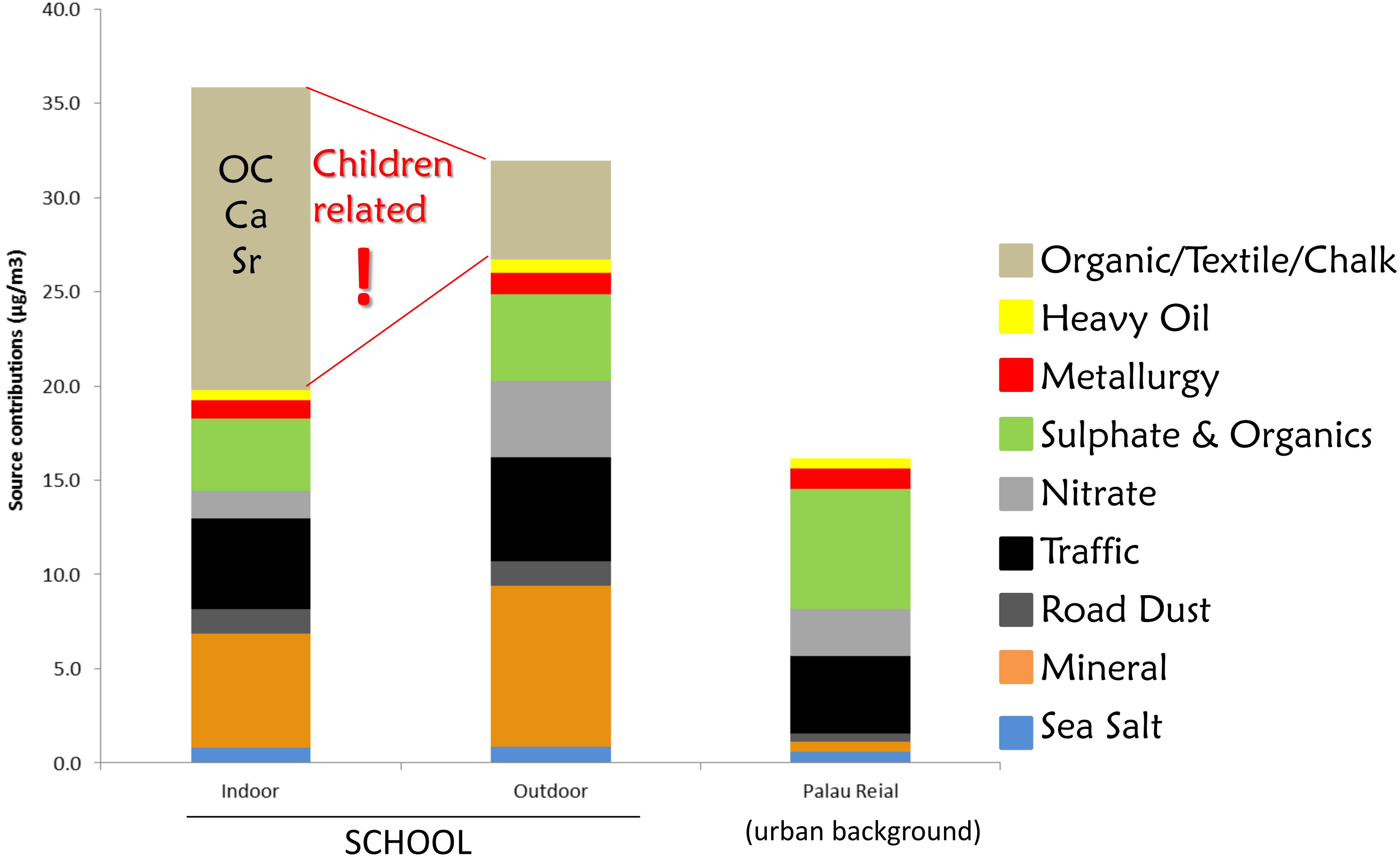
# PM$_{2.5}$ SOURCE APPORTIONMENT

## Source contributions



# $PM_{2.5}$ SOURCE APPORTIONMENT

## Source contributions

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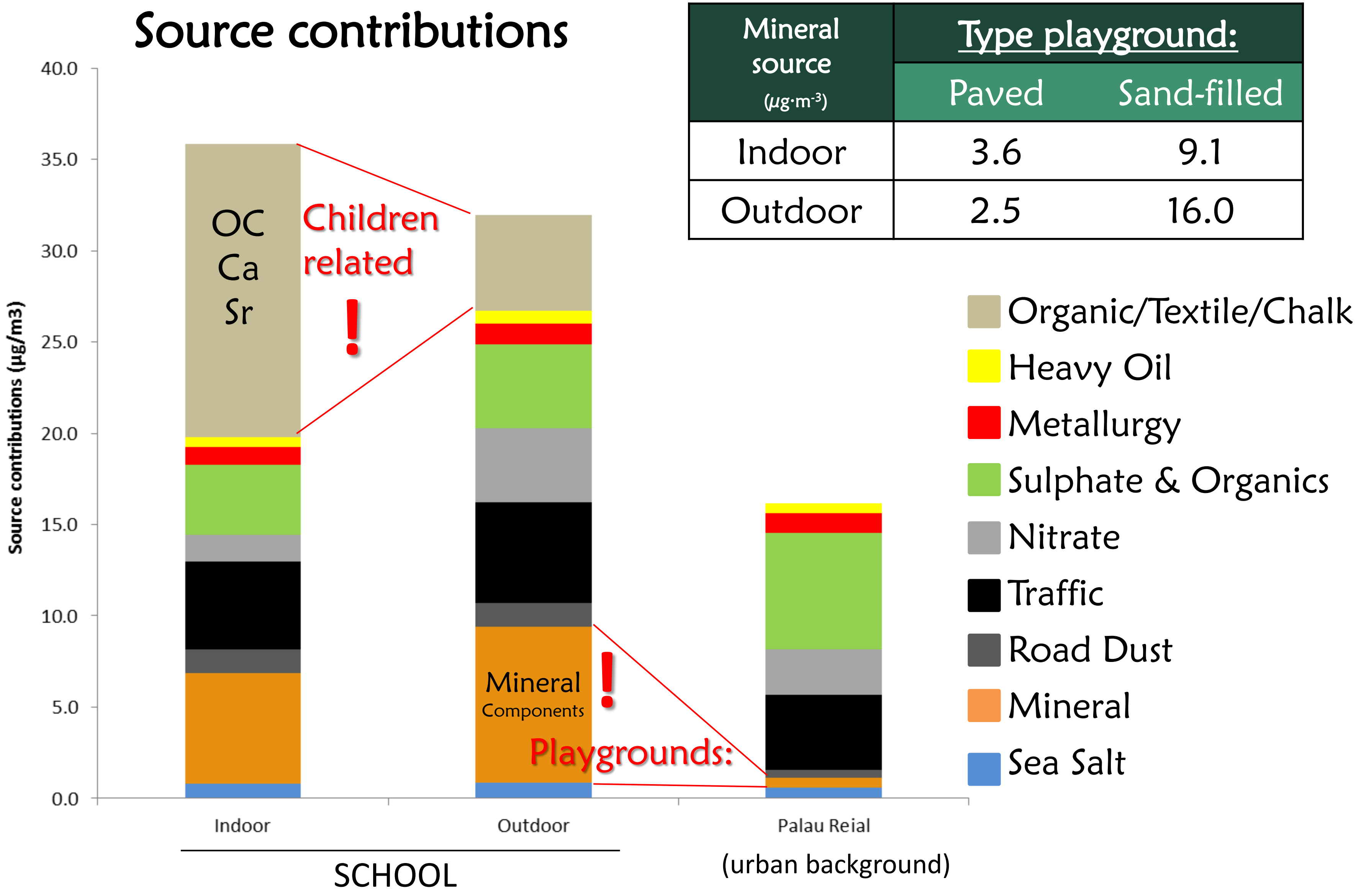
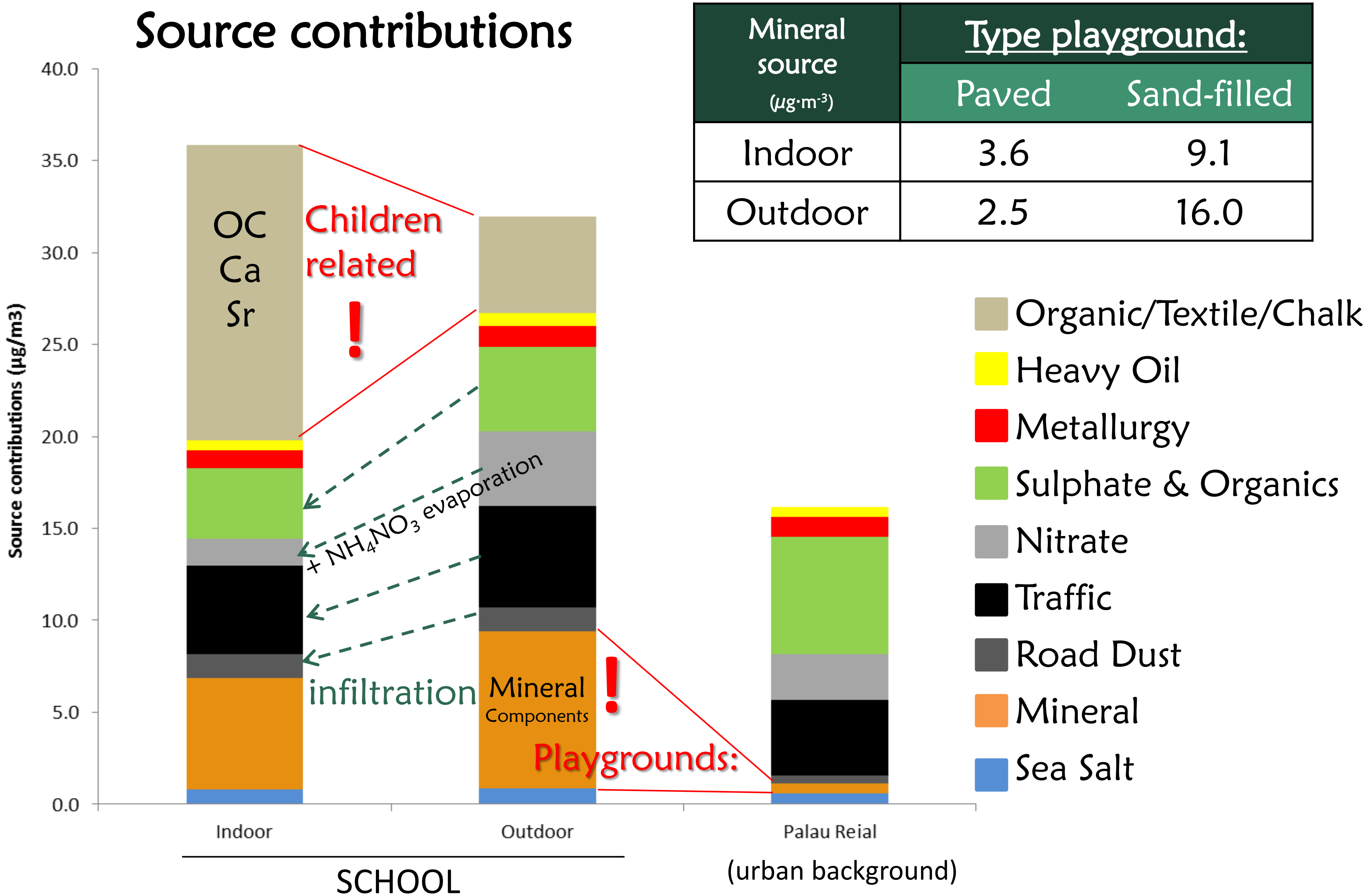
# $PM_{2.5}$ SOURCE APPORTIONMENT




| Mineral source ($\mu g \cdot m^{-3}$) | Type playground: | |
|---|---|---|
| | Paved | Sand-filled |
| Indoor | 3.6 | 9.1 |
| Outdoor | 2.5 | 16.0 |

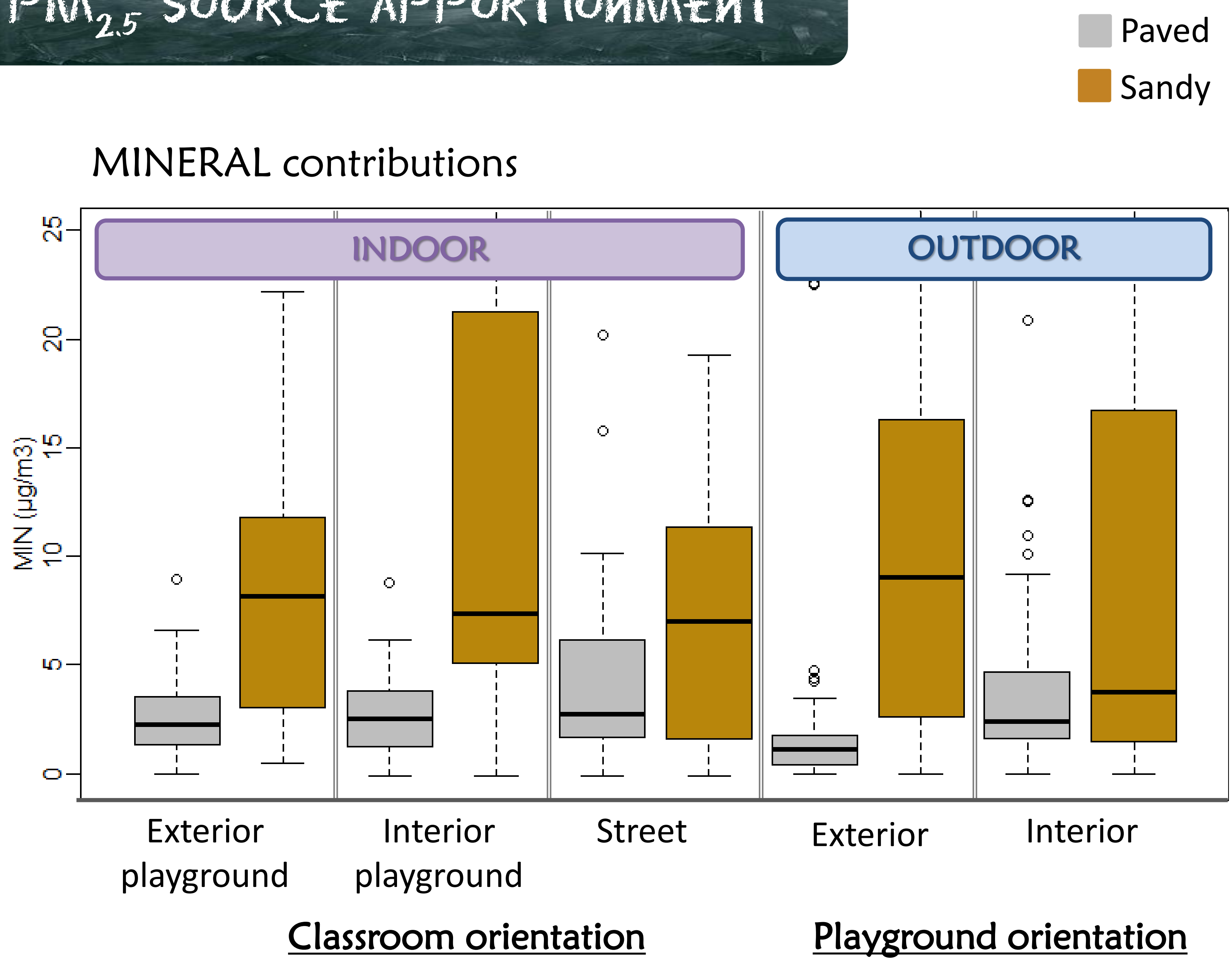
# PM$_{2.5}$ SOURCE APPORTIONMENT




| Mineral source ($\mu g \cdot m^{-3}$) | Type playground: | |
|---|---|---|
| | Paved | Sand-filled |
| Indoor | 3.6 | 9.1 |
| Outdoor | 2.5 | 16.0 |

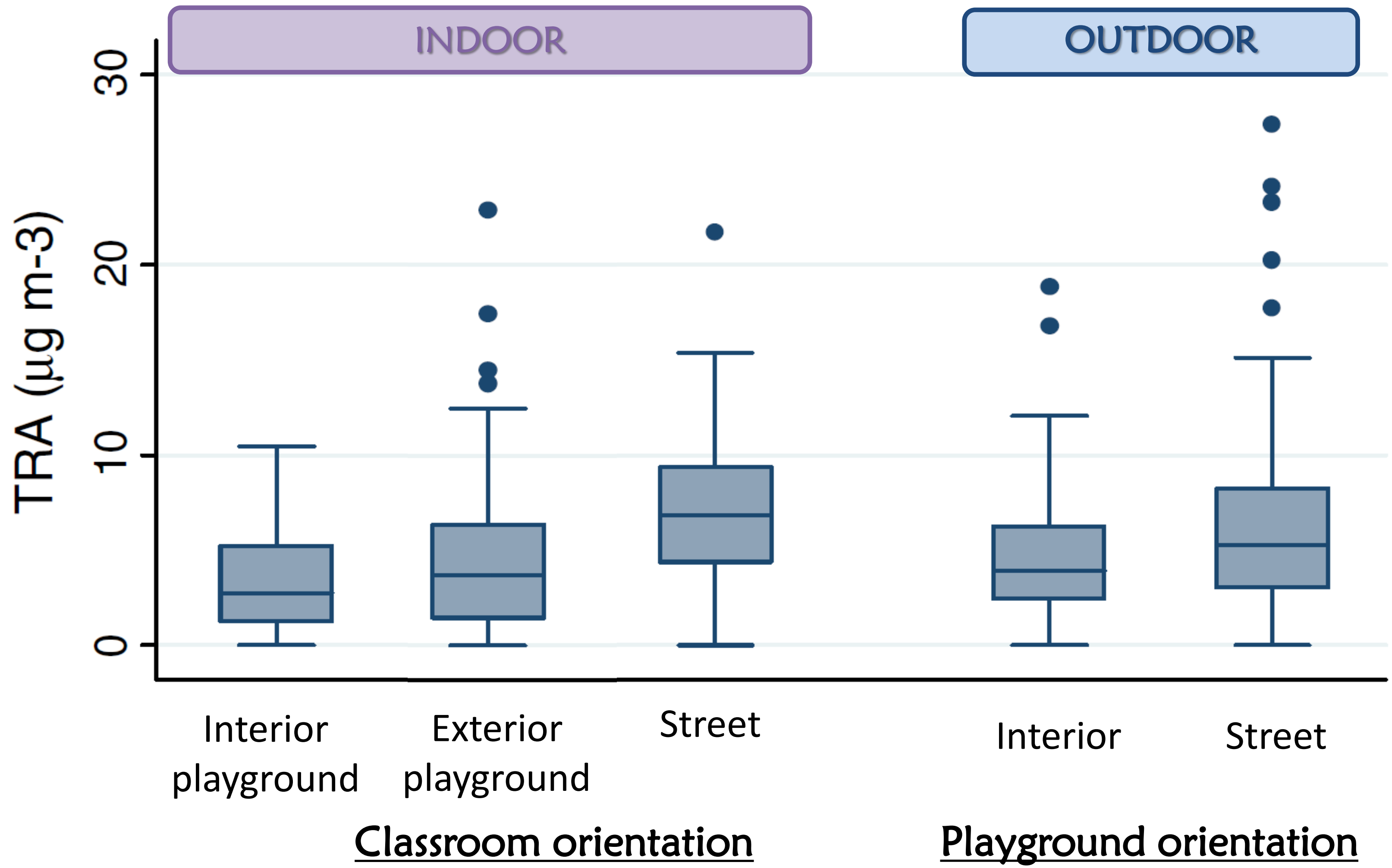
# PM$_{2.5}$ SOURCE APPORTIONMENT

MINERAL contributions



# PM$_{2.5}$ SOURCE APPORTIONMENT

TRAFFIC contributions (seasonally adjusted data)



# OBJECTIVE 3

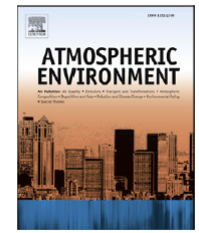
Atmospheric Environment 106 (2015) 129–138

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

ELSEVIER




## Outdoor infiltration and indoor contribution of UFP and BC, OC, secondary inorganic ions and metals in $PM_{2.5}$ in schools

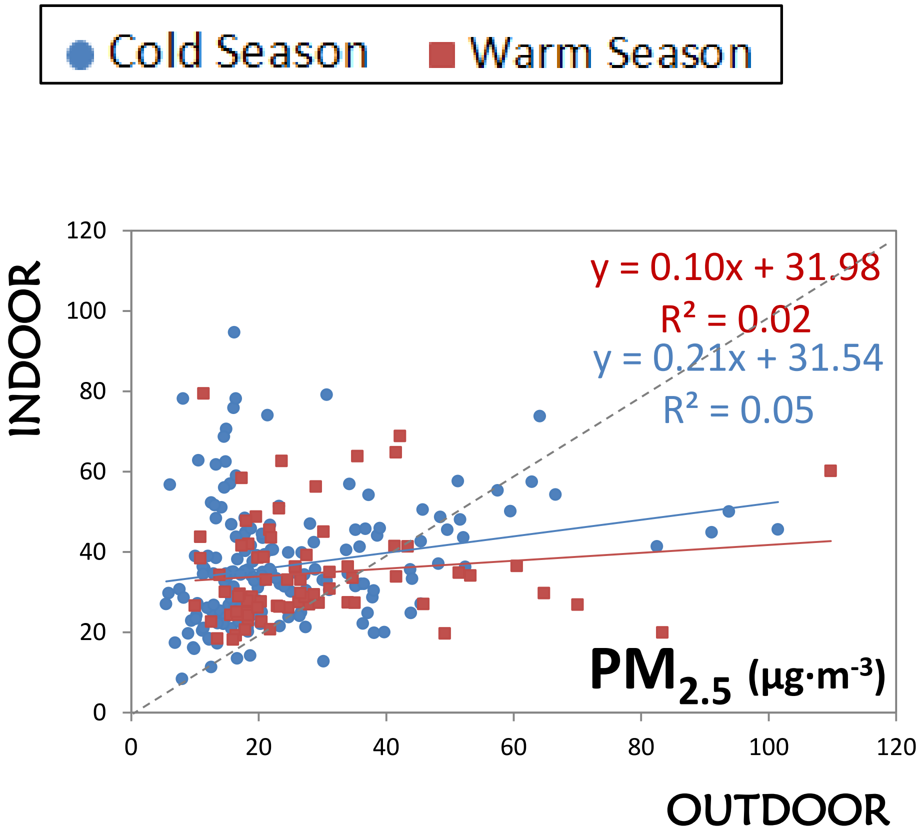
CrossMark

I. Rivas [a, b, d, e, f, *], M. Viana [a], T. Moreno [a], L. Bouso [b, d, e], M. Pandolfi [a], M. Alvarez-Pedrerol [b, d, e], J. Forns [b, d, e, g], A. Alastuey [a], J. Sunyer [b, c, d, e], X. Querol [a]

# INFILTRATION OF AIR POLLUTANTS

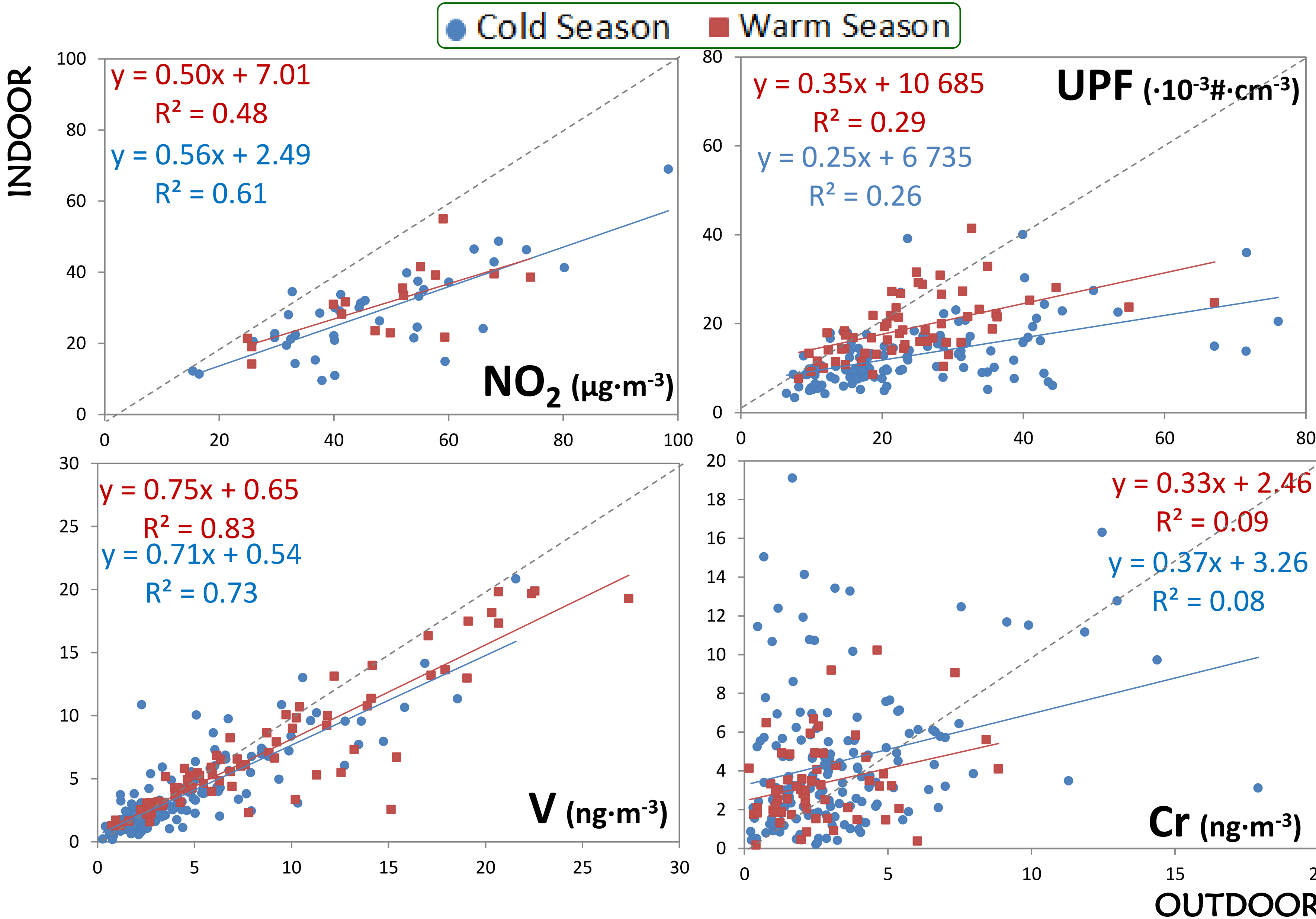
$$C_{in} = F_{inf} \cdot C_{out} + C_{ig}$$

Dockery and Spengler (1981).




Similar results for OC and Mineral components

# INFILTRATION OF AIR POLLUTANTS





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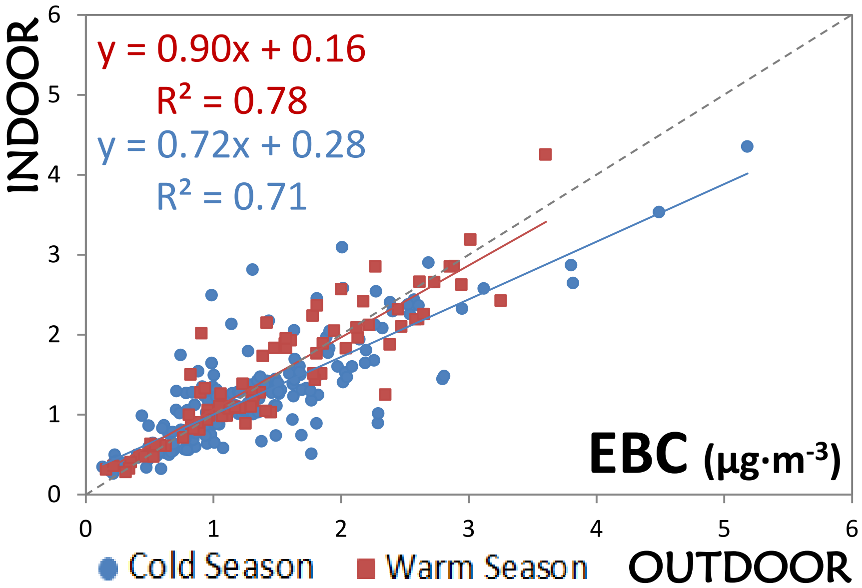
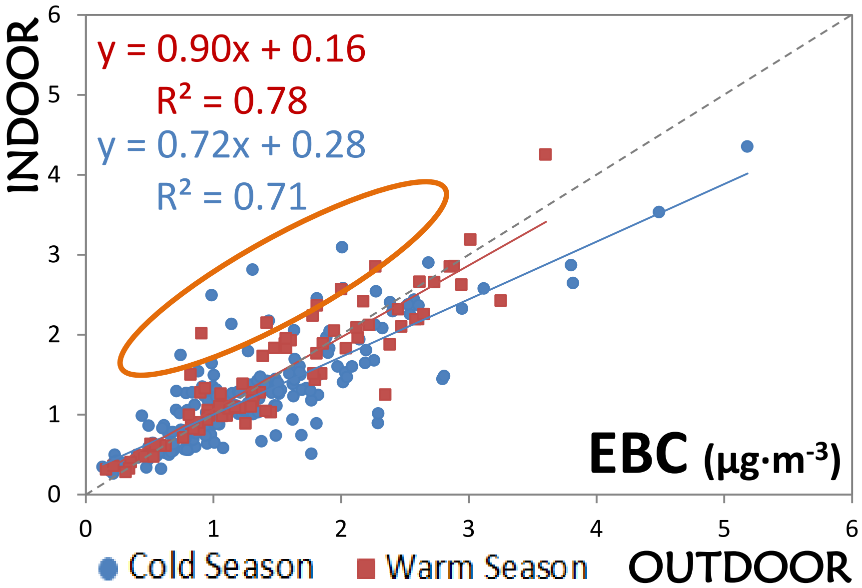
# INFILTRATION OF AIR POLLUTANTS




$$C_{in} = F_{inf} \cdot C_{out} + C_{ig}$$

*Dockery and Spengler (1981).*

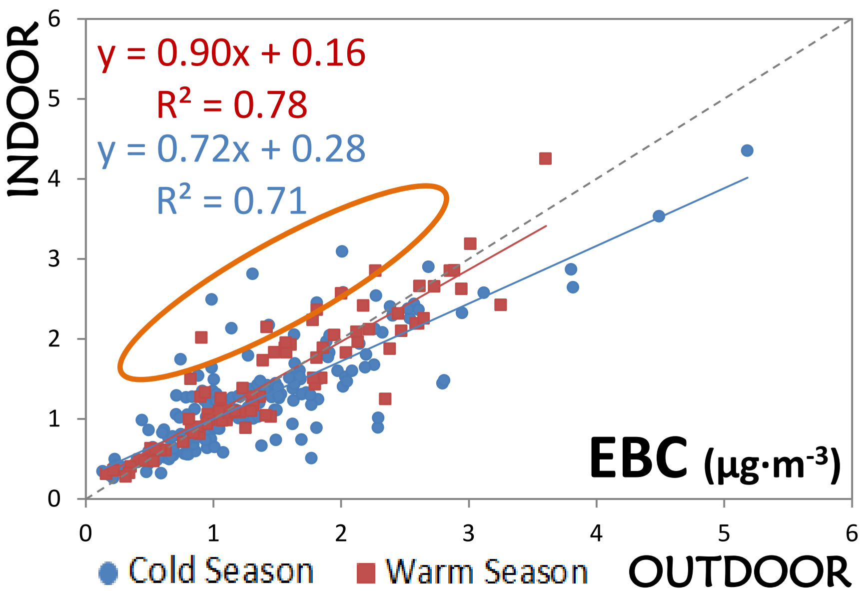
# INFILTRATION OF AIR POLLUTANTS




$$C_{in} = F_{inf} \cdot C_{out} + C_{ig}$$

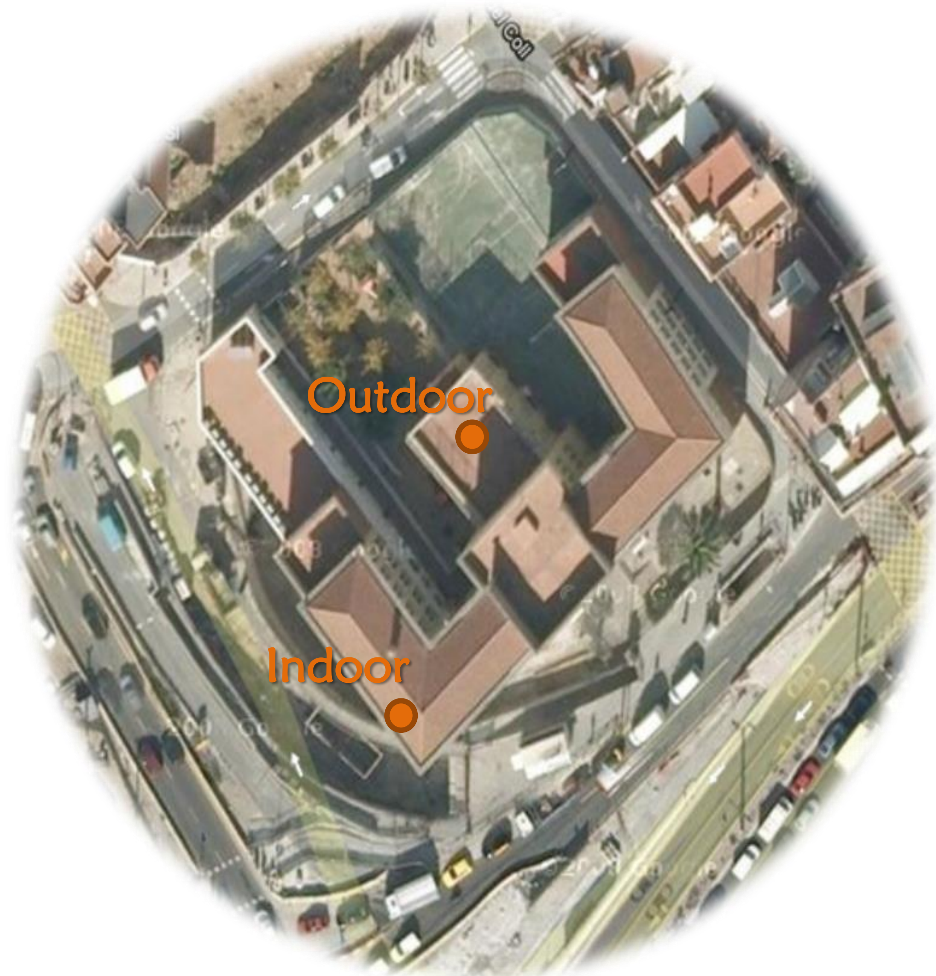
*Dockery and Spengler (1981).*

# INFILTRATION OF AIR POLLUTANTS




$$C_{in} = F_{inf} \cdot C_{out} + C_{ig}$$

*Dockery and Spengler (1981).*

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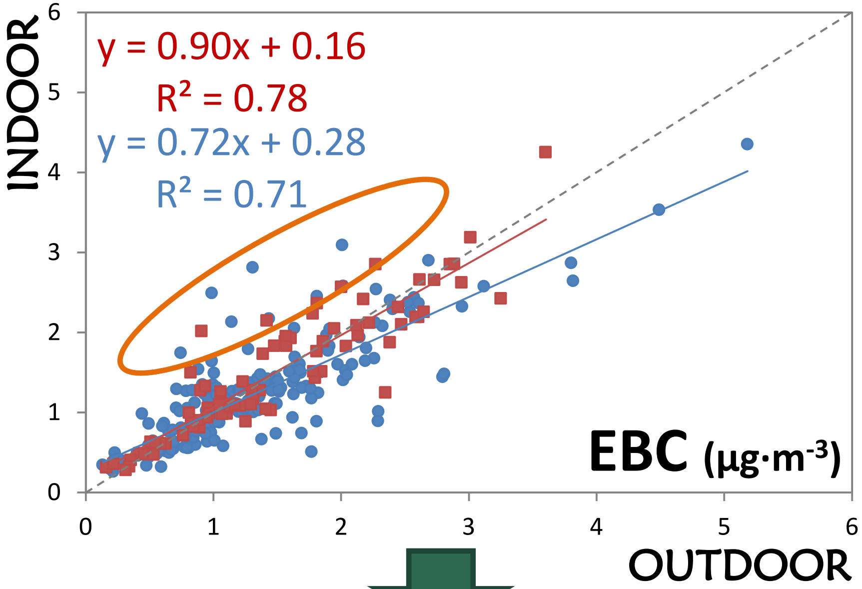
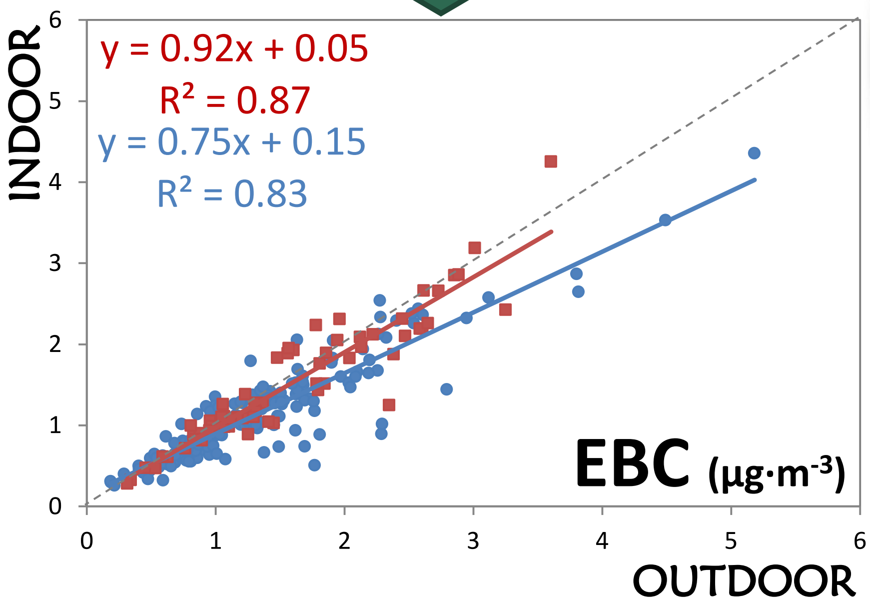
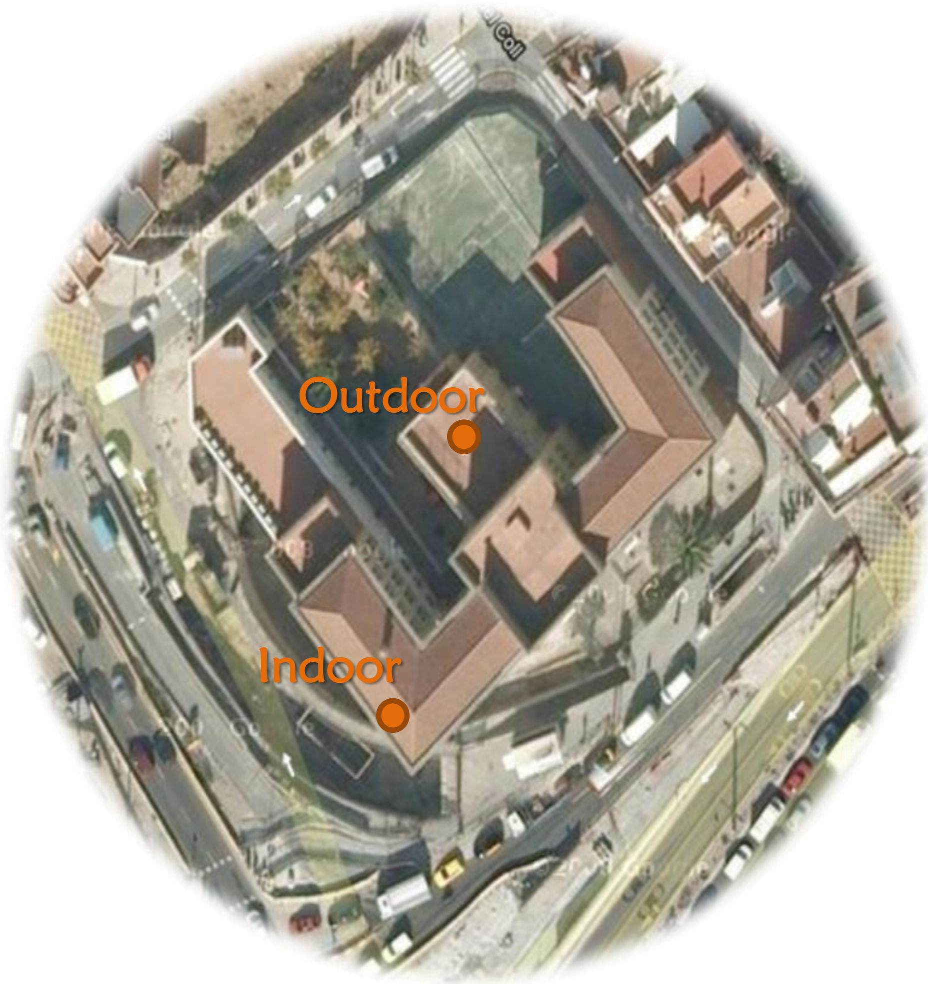
# INFILTRATION OF AIR POLLUTANTS



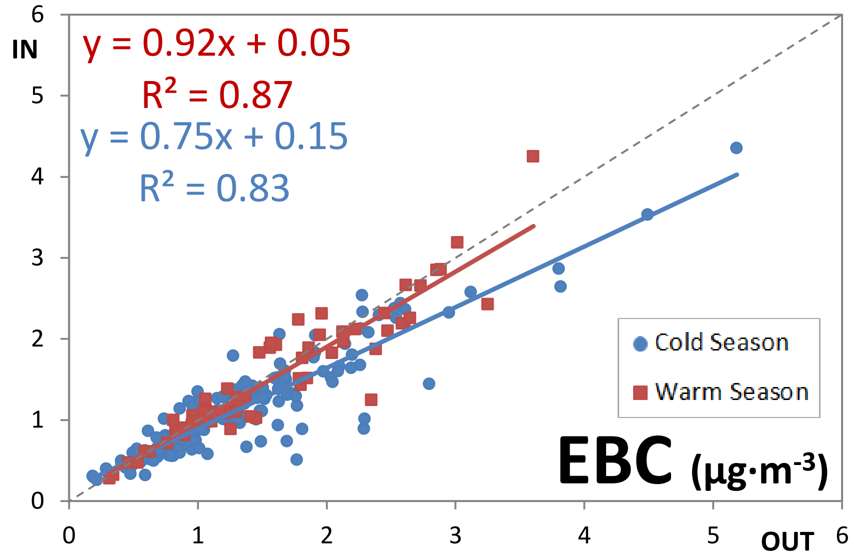

$$C_{in} = F_{inf} \cdot C_{out} + C_{ig}$$

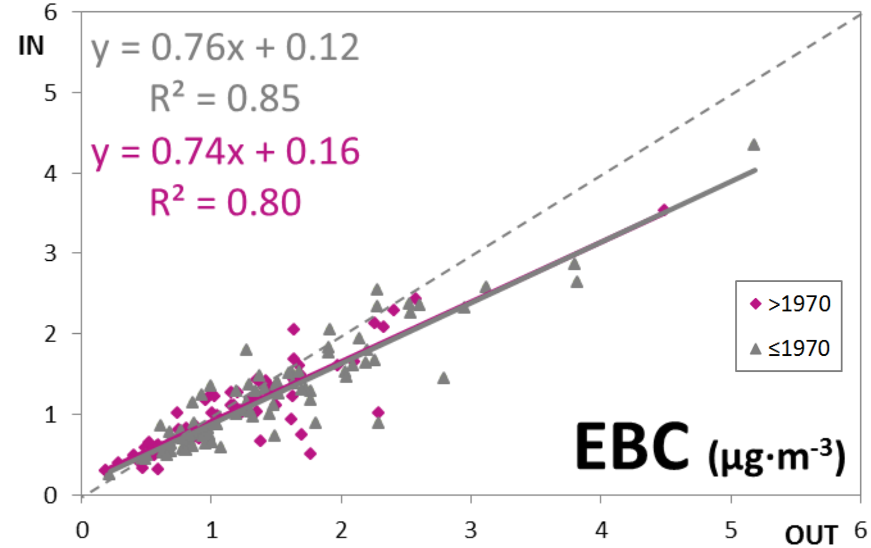
*Dockery and Spengler (1981).*

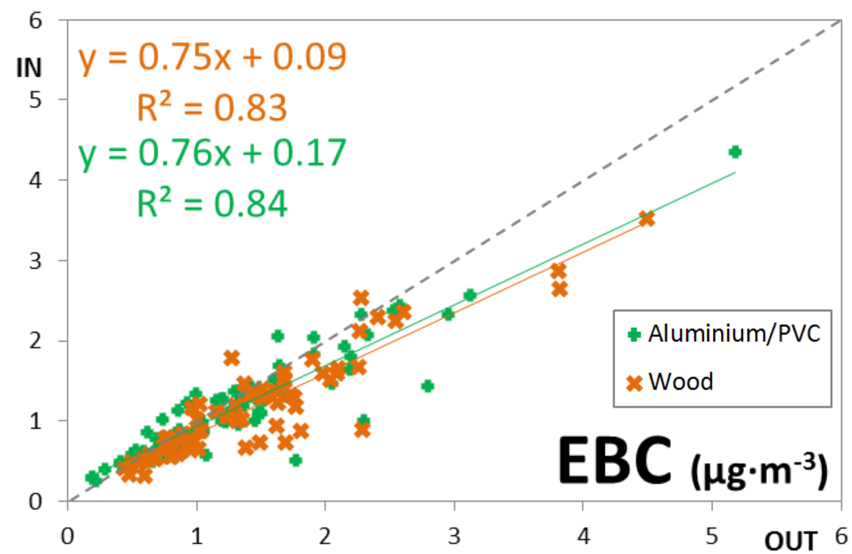


# INFILTRATION OF AIR POLLUTANTS

Cold season only




- **EBC** has the **maximum infiltration factor** of all the pollutants studied.
- Negligible indoor generation of EBC .

# FACTORS INFLUENCING INDOOR CONCENTRATIONS

Building age

**>1970 buildings:**

Fe +0.15 µg/m³

Cr +1.95 ng/m³

Co +0.09 ng/m³

Se +0.05 ng/m³

$$Y_{it} = \beta_0 + \beta_1\,(\text{outdoor concentration})_{it} + \beta_2\,(\text{building age: } \leq 1970)_i + \beta_3\,(\text{type of windows: wood})_i + \beta_4(\text{type of playground: sand-filled}<20\text{m})_i + u_i + \varepsilon_{it}$$

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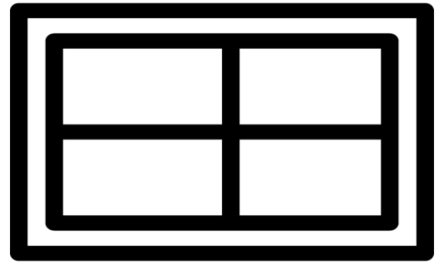
# FACTORS INFLUENCING INDOOR CONCENTRATIONS

Building age

**>1970 buildings:**

- Fe +0.15 μg/m$^3$
- Cr +1.95 ng/m$^3$
- Co +0.09 ng/m$^3$
- Se +0.05 ng/m$^3$



Type of window

**Al/PVC windows:**

- $PM_{2.5}$ +10.75 μg/m$^3$
- $NO_2$ -8.06 μg/m$^3$
- OC +2.25 μg/m$^3$
- Ca +1.01 μg/m$^3$
- Fe +0.23 μg/m$^3$
- As +0.09 ng/m$^3$

$$Y_{it} = \beta_0 + \beta_1 (\text{outdoor concentration})_{it} + \beta_2 (\text{building age: } \leq 1970)_i + \beta_3 (\text{type of windows: wood})_i + \beta_4 (\text{type of playground: sand-filled} < 20\text{m})_i + u_i + \varepsilon_{it}$$

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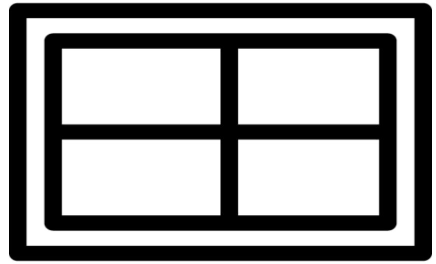
# FACTORS INFLUENCING INDOOR CONCENTRATIONS

## Building age

**>1970 buildings:**

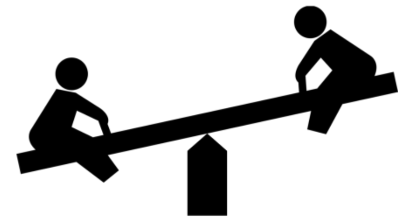
- Fe +0.15 µg/m$^3$
- Cr +1.95 ng/m$^3$
- Co +0.09 ng/m$^3$
- Se +0.05 ng/m$^3$



## Type of window

**Al/PVC windows:**

- $PM_{2.5}$ +10.75 µg/m$^3$
- $NO_2$ -8.06 µg/m$^3$
- OC +2.25 µg/m$^3$
- Ca +1.01 µg/m$^3$
- Fe +0.23 µg/m$^3$
- As +0.09 ng/m$^3$



## Type of playground

**Sandy playgrounds:**

- $PM_{2.5}$ +8.89 µg/m$^3$
- $Al_2O_3$ +1.07 µg/m$^3$
- Fe +0.47 µg/m$^3$
- V +1.04 ng/m$^3$
- As +0.11 ng/m$^3$

$$Y_{it} = \beta_0 + \beta_1 \text{(outdoor concentration)}_{it} + \beta_2 \text{(building age: ≤1970)}_i + \beta_3 \text{(type of windows: wood)}_i + \beta_4 \text{(type of playground: sand-filled<20m)}_i + u_i + \varepsilon_{it}$$

# OBJECTIVE 4

*Indoor Air 2015*
*wileyonlinelibrary.com/journal/ina*


INDOOR AIR
*doi:10.1111/ina.12214*

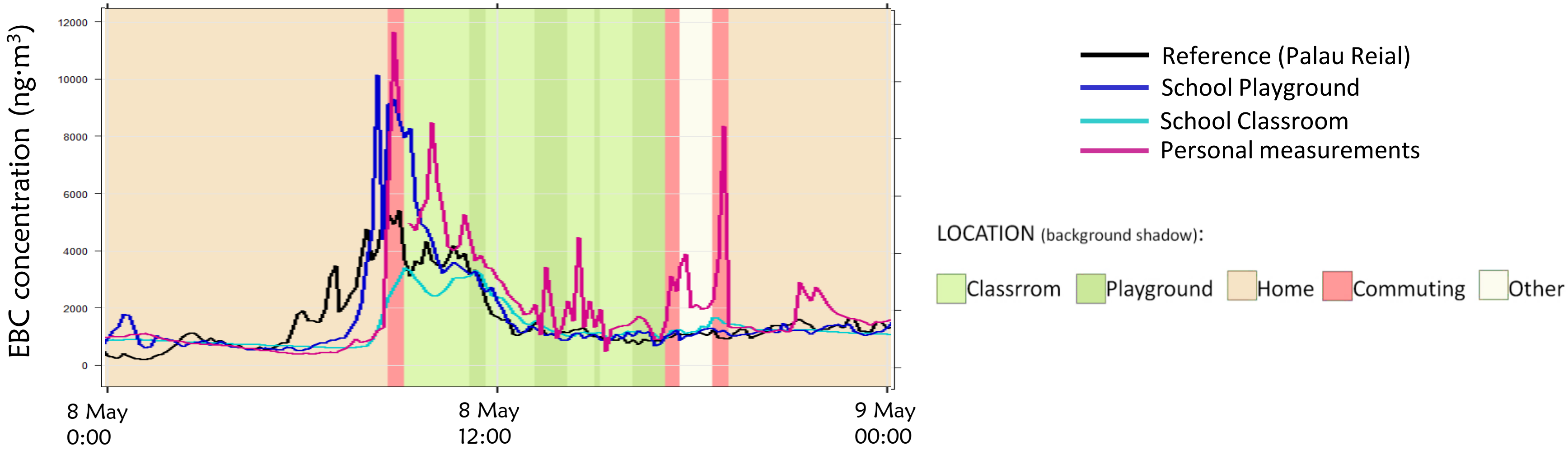
# Spatiotemporally resolved black carbon concentration, schoolchildren's exposure and dose in Barcelona

**Abstract** At city level, personal monitoring is the best way to assess people's exposure. However, it is usually estimated from a few monitoring stations. Our aim was to determine the exposure to black carbon (BC) and BC dose for 45 schoolchildren with portable microaethalometers and to evaluate the relationship between personal monitoring and fixed stations at schools (indoor and outdoor) and in an urban background (UB) site. Personal BC concentrations were 20% higher than in fixed stations at schools. Linear mixed-effect models showed low $R^2$ between personal measurements and fixed stations at

I. Rivas[1,2,3,4,5], D. Donaire-Gonzalez[2,3,4], L. Bouso[2,3,4], M. Esnaola[2,3,4], M.Pandolfi[1], M. de Castro[2,3,4], M. Viana[1], M. Àlvarez-Pedrerol[2,3,4], M. Nieuwenhuijsen[2,3,4], A. Alastuey[1], J. Sunyer[2,3,4,6], X. Querol[1]

# CHILDREN'S PERSONAL EXPOSURE

Commuting periods are clearly those with the highest EBC concentrations



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In the morning, children's commuting time co-ocurrs with traffic rush hours

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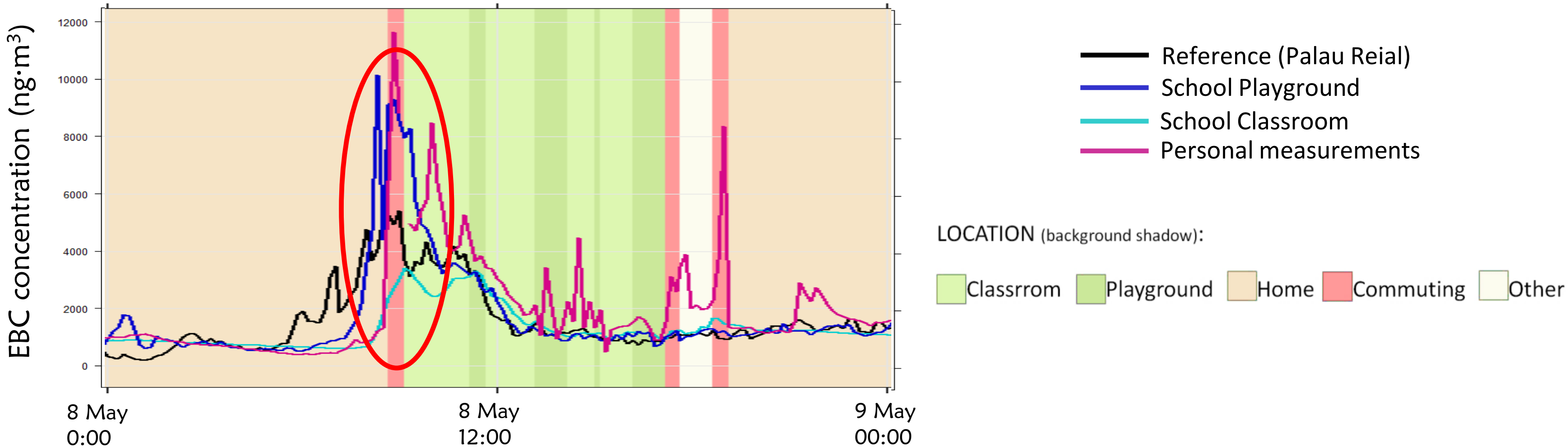


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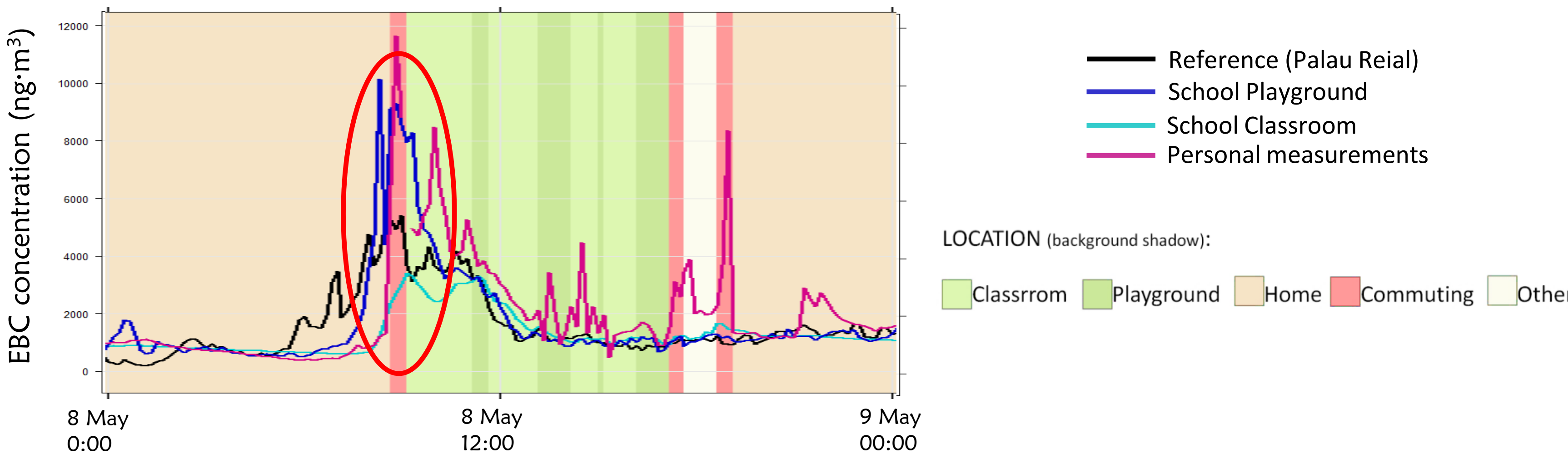


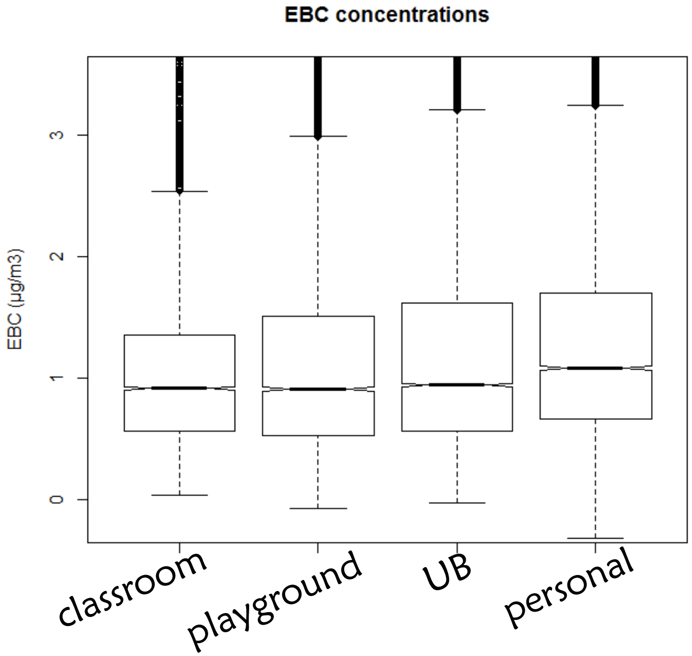


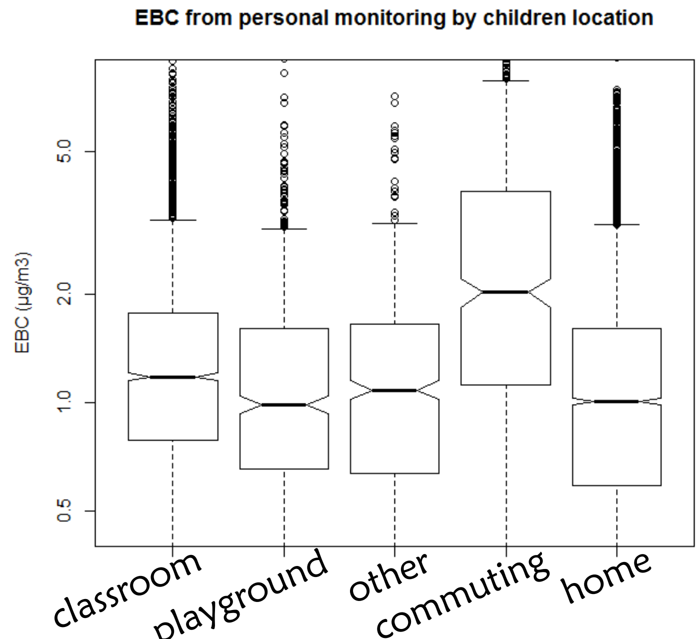

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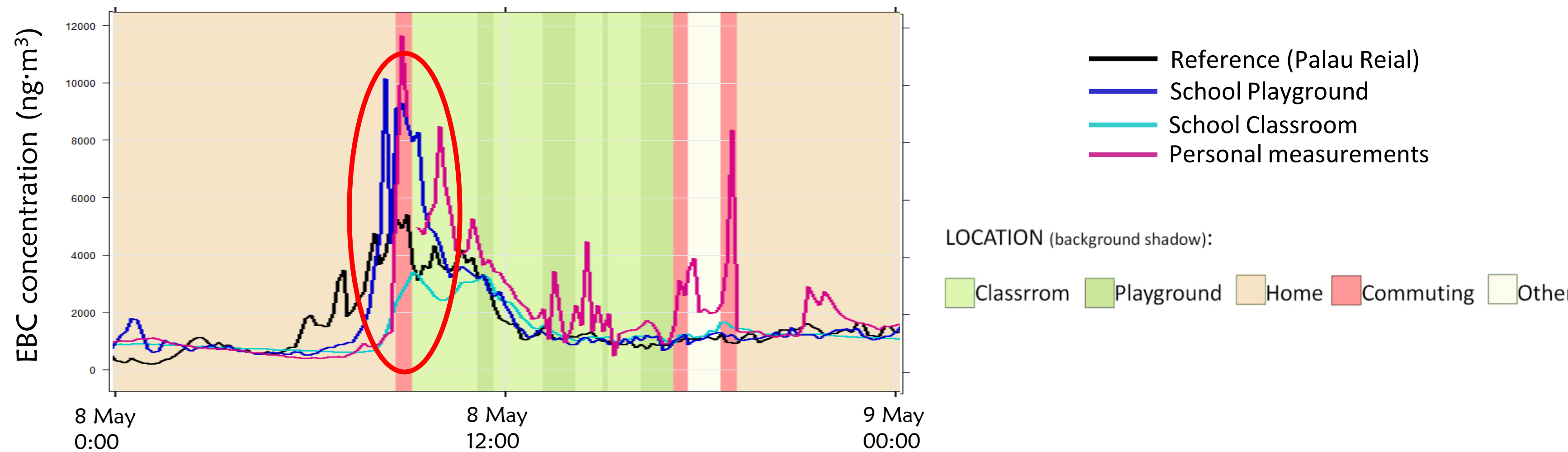


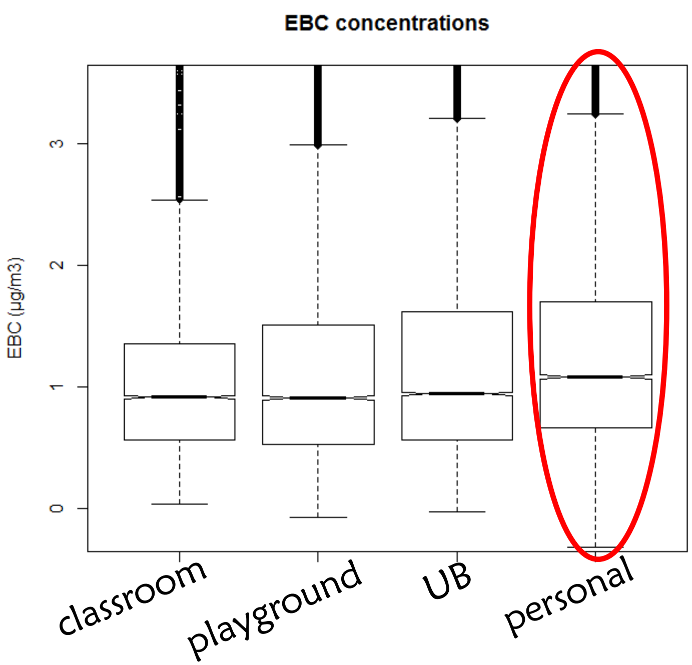


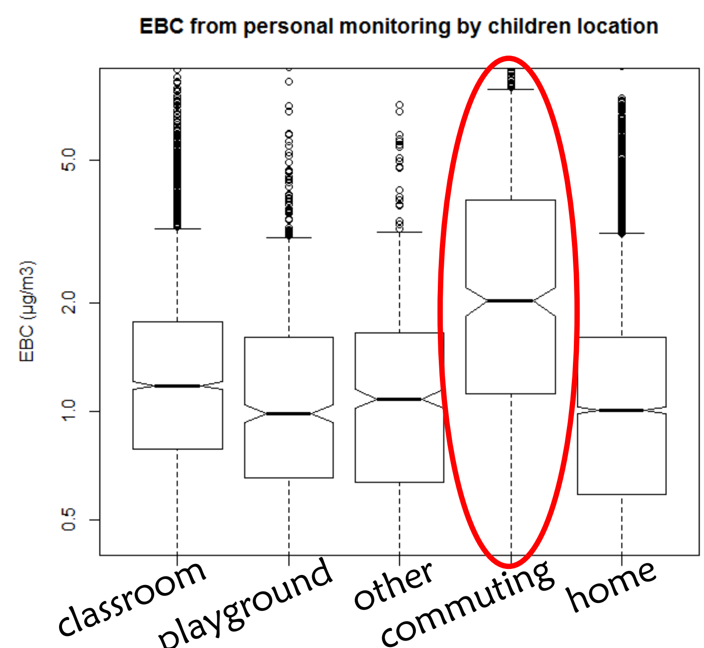


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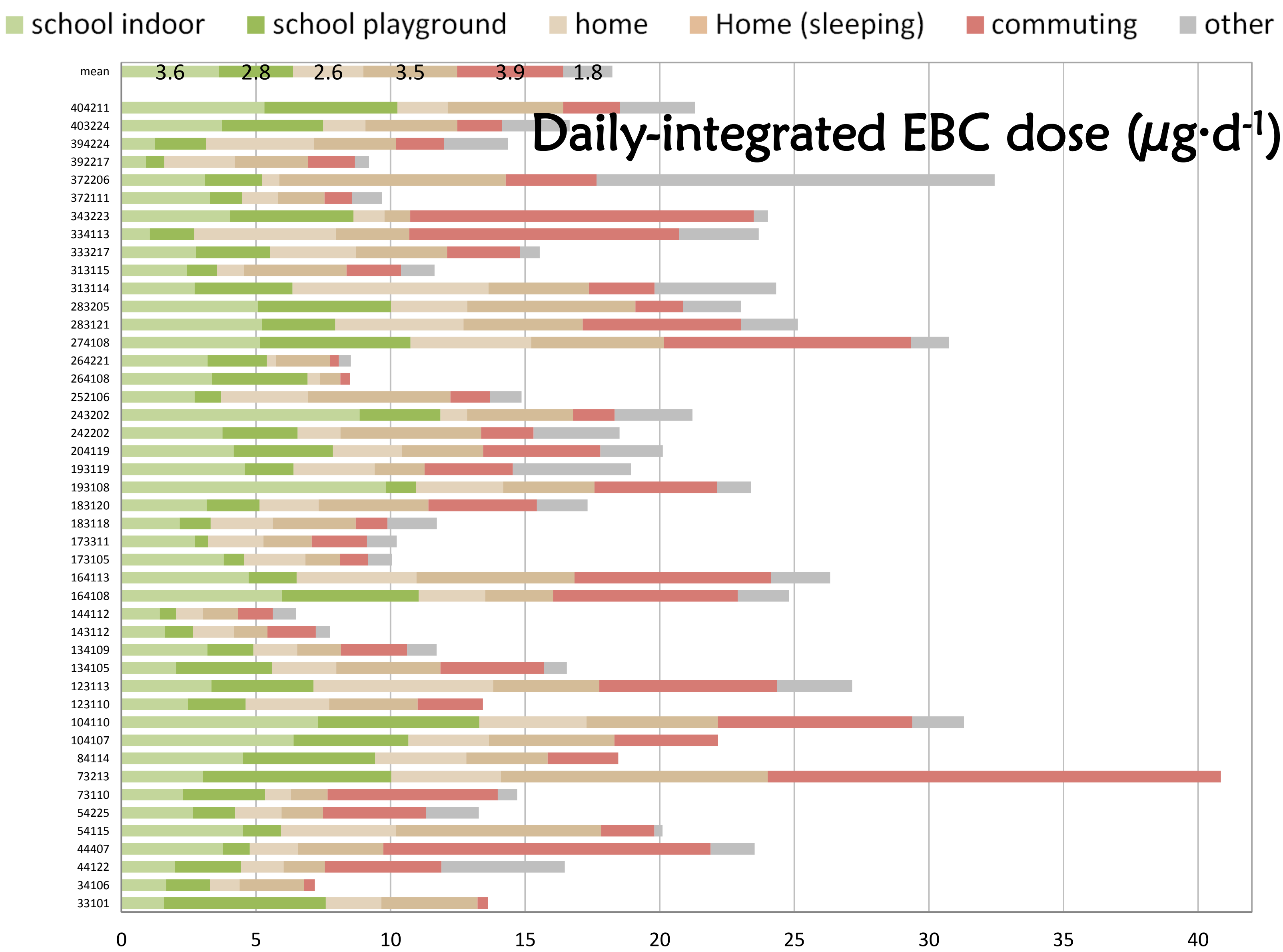

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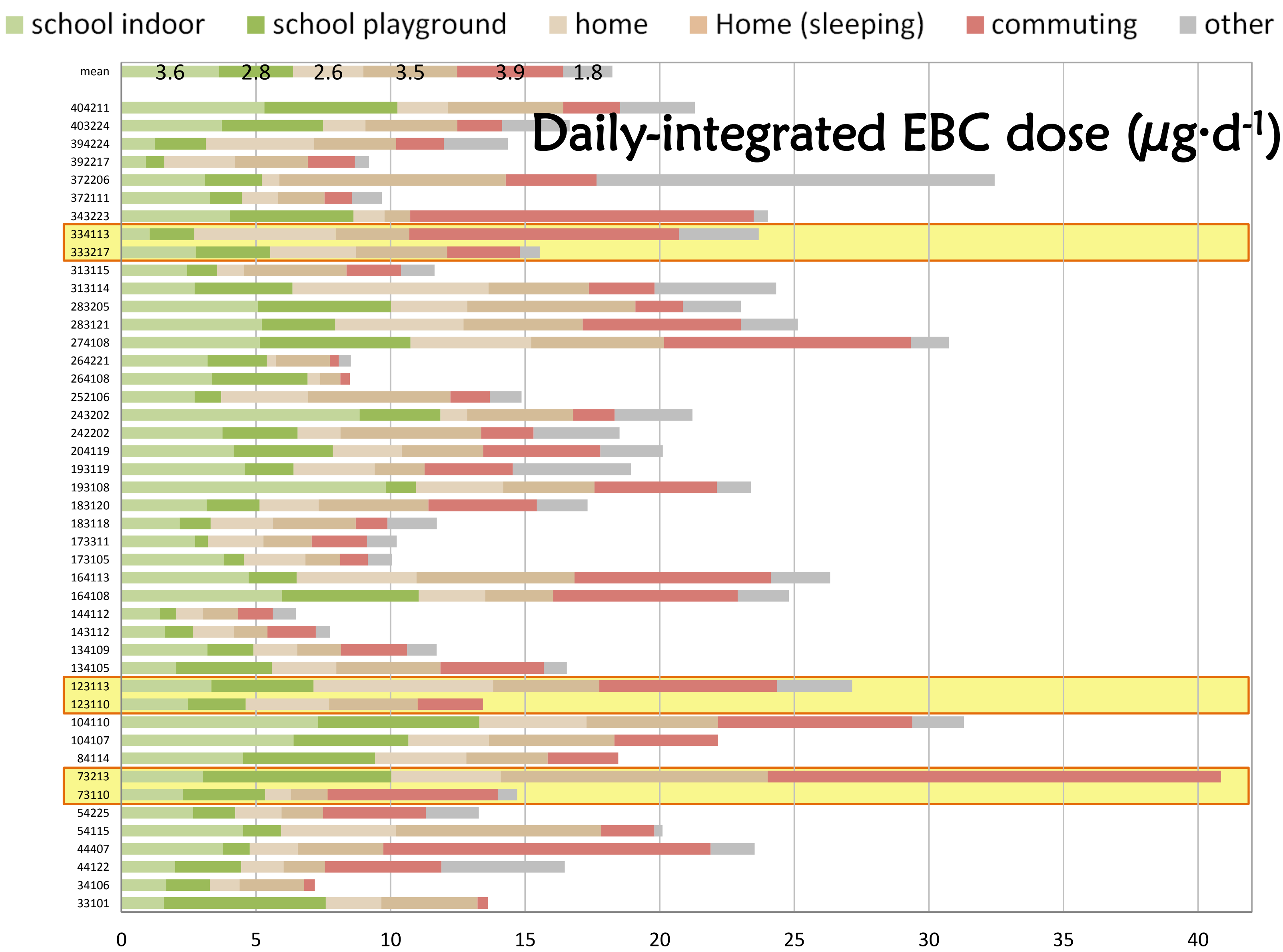

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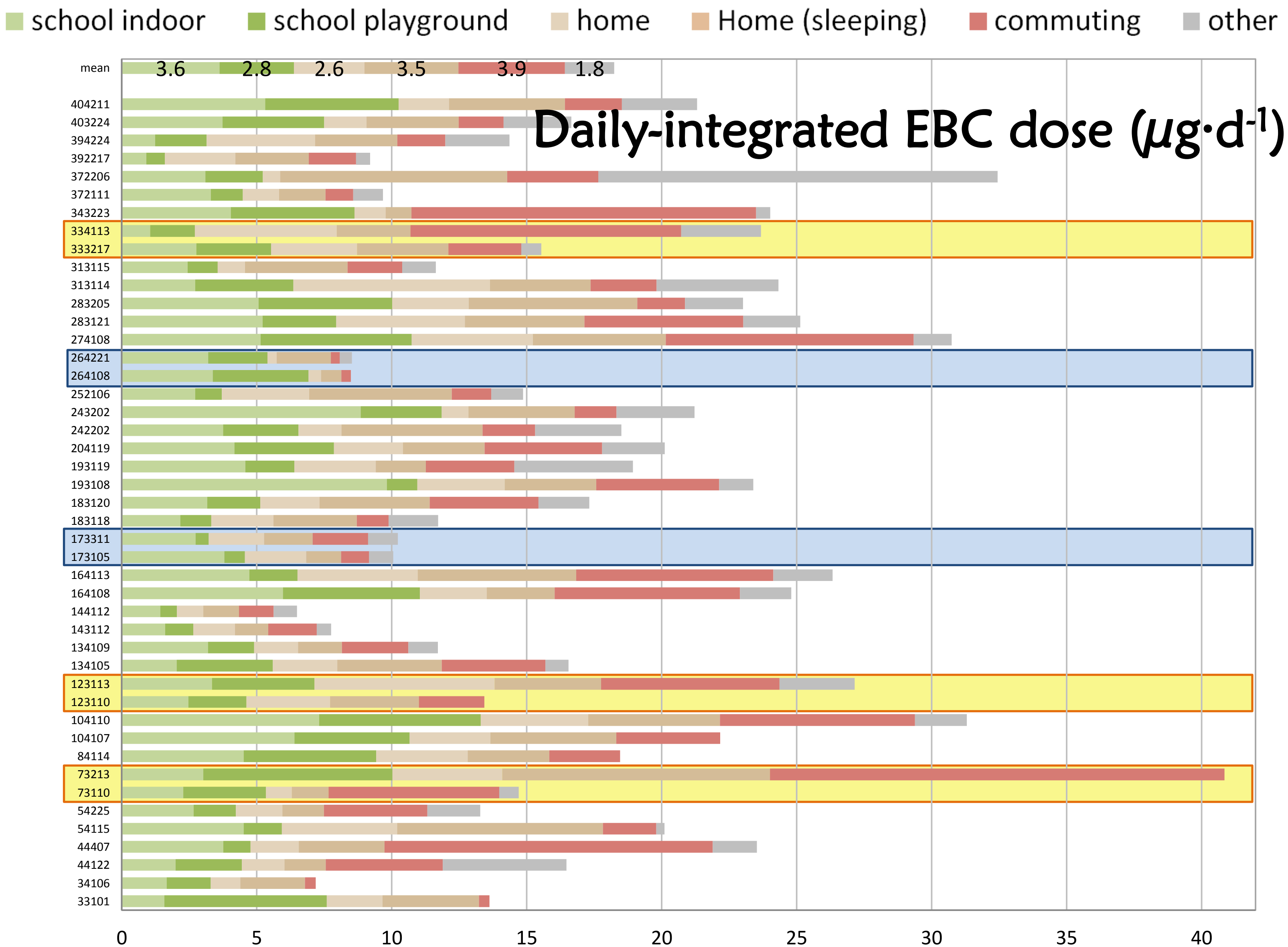

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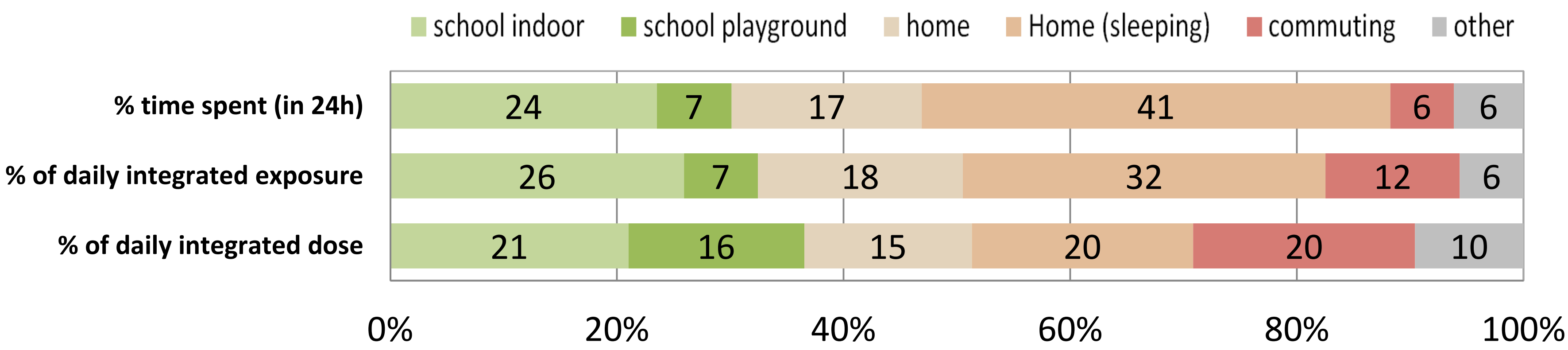

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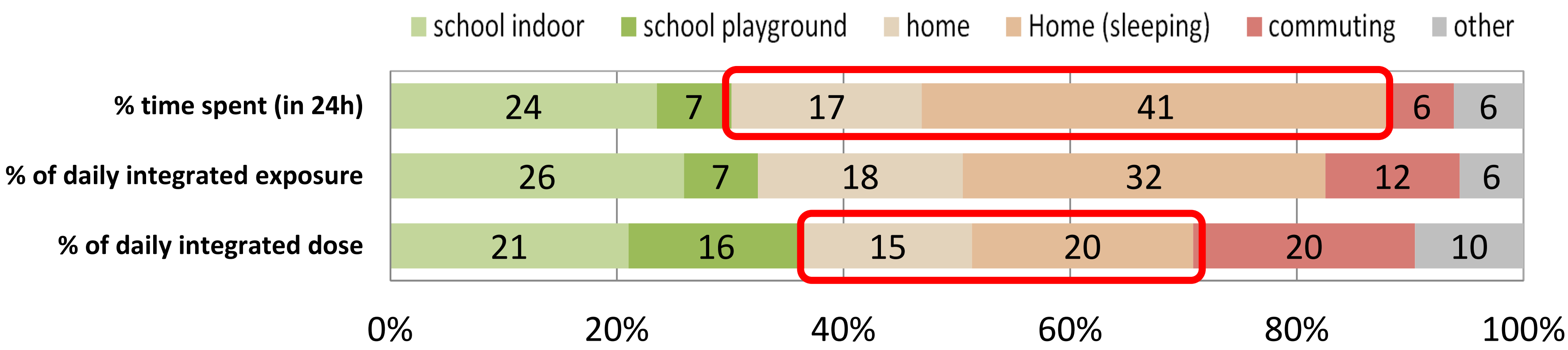

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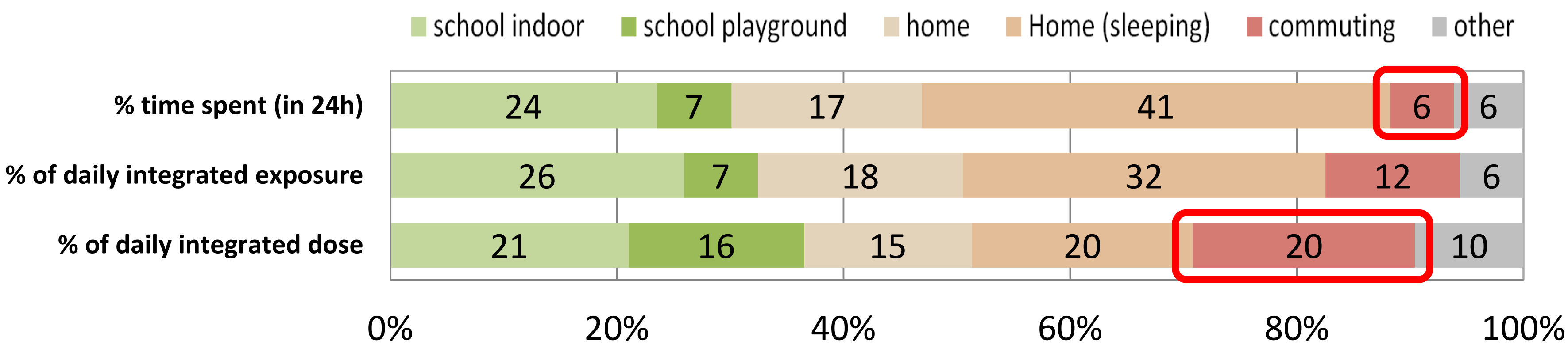


Commuting contributes to **20 %** of the integrated daily **dose** although it corresponds to the **6%** of the **time** of a day.

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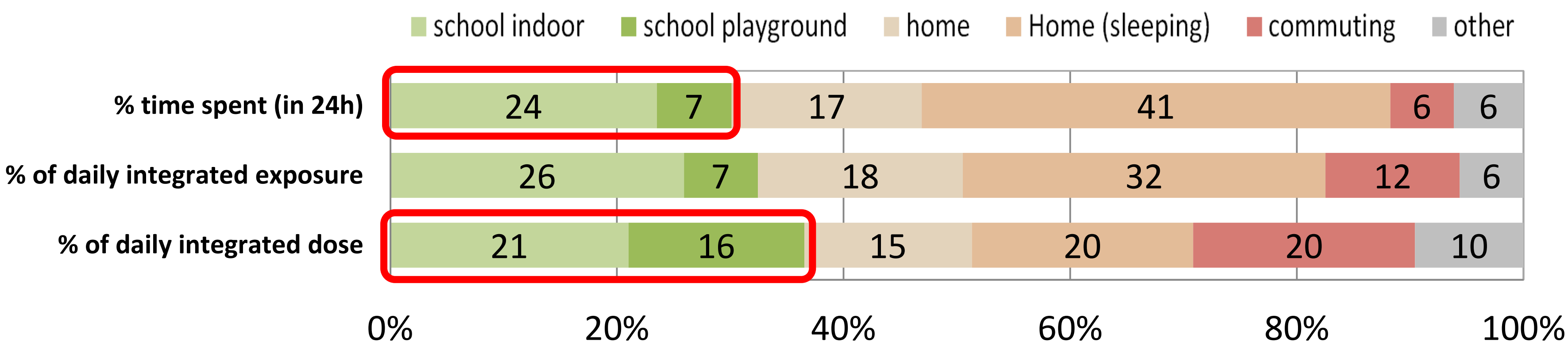
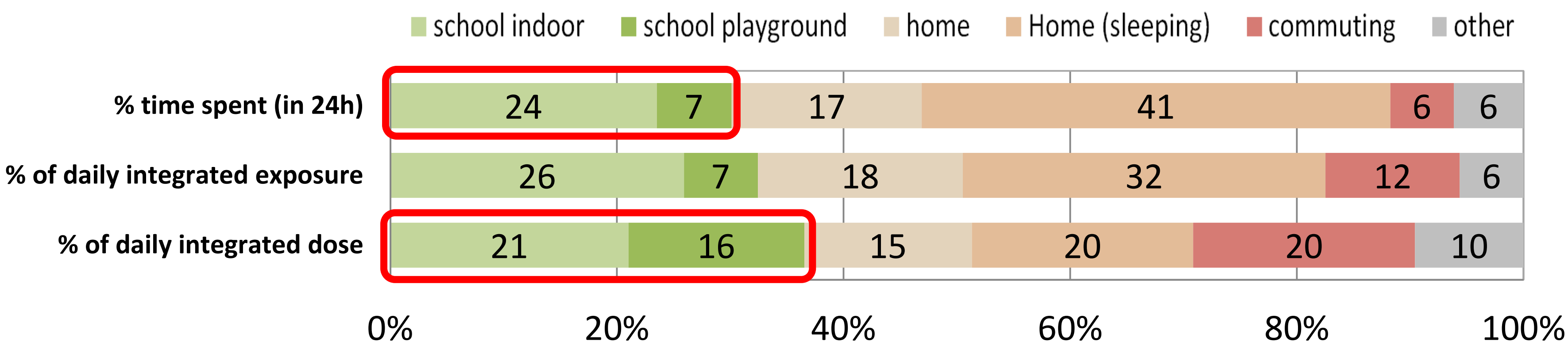



Commuting contributes to **20 %** of the integrated daily **dose** although it corresponds to the **5.6%** of the **time** of a day.

**School** contributes with the **37%** of the total dose of EBC

# CHILDREN'S PERSONAL EXPOSURE

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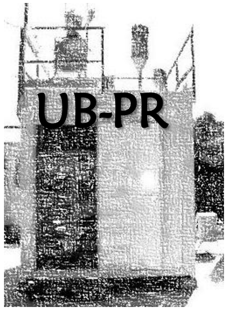
**School** contributes with the **37%** of the total dose of EBC

Policies for improving air quality can reduce the exposure of many children if focused on schools

# AGREEMENT BETWEEN FIXED STATIONS AND PERSONAL MEASUREMENTS

vs.




vs.


Playground/classroom:

| | vs. UB-PR | vs. School (Playground/classroom) |
|---|---|---|
| 24h | $R^2$: 0.18 | $R^2$: 0.26 / 0.28 |
| school | $R^2$: 0.45 | $R^2$: 0.75 / 0.79 |
| home | $R^2$: 0.43 | $R^2$: 0.47 / 0.48 |
| commuting | $R^2$: 0.30 | $R^2$: 0.26 – 0.28 |

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# AGREEMENT BETWEEN FIXED STATIONS AND PERSONAL MEASUREMENTS

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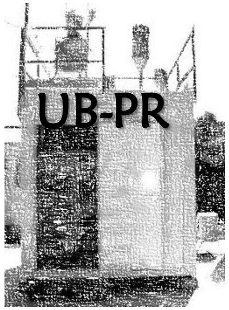


| | |
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vs. SCHOOL

Playground/classroom:

| | |
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# POLICY IMPLICATIONS

# POLICY IMPLICATIONS

- Future schools → Away from trafficked roads
- Pedestrian school pathways + use of public transport
- Replace sand periodically
- Cleaning activities in the afternoon
- Ventilation advised if the classroom is not facing to a major road

# FUTURE RESEARCH

- Effect of the **application of measures for air quality improvemen**t in schools
- **Specific indoor sources** of air pollutants in schools. Especially of UFP and trace metals
- Speciation of the **organic compounds**
- **Interaction of $O_3$ with VOCs** in indoor environments
- More studies involving **personal measurements in children**

# RELATED PUBLICATIONS

## Air quality and exposure assessment:

Atmospheric Environment 120 (2015) 417–426
Contents lists available at ScienceDirect
Atmospheric Environment
journal homepage: www.elsevier.com/locate/atmosenv

Real-time indoor and outdoor measurements of black carbon at primary schools

C. Reche, I. Rivas, M. Pandolfi, M. Viana, L. Bouso, M. Álvarez-Pedrerol, A. Alastuey, J. Sunyer, X. Querol

Road traffic and sandy playground influence on ambient pollutants in schools

M.C. Minguillón, I. Rivas, T. Moreno, A. Alastuey, O. Font, P. Córdoba, M. Álvarez-Pedrerol, J. Sunyer, X. Querol

The association between greenness and traffic-related air pollution at schools

Payam Dadvand, Ioar Rivas, Xavier Basagaña, Mar Alvarez-Pedrerol, Jason Su, Montserrat De Castro Pascual, Fulvio Amato, Michael Jerret, Xavier Querol, Jordi Sunyer, Mark J. Nieuwenhuijsen

Environmental Science & Technology

Variability in and Agreement between Modeled and Personal Continuously Measured Black Carbon Levels Using Novel Smartphone and Sensor Technologies

Mark J. Nieuwenhuijsen, David Donaire-Gonzalez, Ioar Rivas, Montserrat de Castro, Marta Cirach, Gerard Hoek, Edmund Seto, Michael Jerrett, and Jordi Sunyer

Partitioning of trace elements and metals between quasi-ultrafine, accumulation and coarse aerosols in indoor and outdoor air in schools

M. Viana, I. Rivas, X. Querol, A. Alastuey, M. Álvarez-Pedrerol, L. Bouso, C. Sioutas, J. Sunyer

Outdoor and indoor UFP in primary schools across Barcelona

C. Reche, M. Viana, I. Rivas, L. Bouso, M. Àlvarez-Pedrerol, A. Alastuey, J. Sunyer, X. Querol

Variations in school playground and classroom atmospheric particulate chemistry

Teresa Moreno, Ioar Rivas, Laura Bouso, Mar Viana, Tim Jones, Mar Àlvarez-Pedrerol, Andrés Alastuey, Jordi Sunyer, Xavier Querol

Indoor/outdoor relationships and mass closure of quasi-ultrafine, accumulation and coarse particles in Barcelona schools

M. Viana, I. Rivas, X. Querol, A. Alastuey, J. Sunyer, M. Álvarez-Pedrerol, L. Bouso, and C. Sioutas

BREATHE Brain Air School investigation

## Effects on neurodevelopment:

PLOS MEDICINE

RESEARCH ARTICLE

Association between Traffic-Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study

PNAS

Green spaces and cognitive development in primary schoolchildren

Payam Dadvand, Mark J. Nieuwenhuijsen, Mikel Esnaola, Joan Forns, Xavier Basagaña, Mar Alvarez-Pedrerol, Ioar Rivas, Mònica López-Vicente, Montserrat De Castro Pascual, Jason Su, Michael Jerrett, Xavier Querol, and Jordi Sunyer

ehp ENVIRONMENTAL HEALTH PERSPECTIVES

Traffic-Related Air Pollution, Noise at School, and Behavioral Problems in Barcelona Schoolchildren: A Cross-Sectional Study

Joan Forns, Payam Dadvand, Maria Foraster, Mar Alvarez-Pedrerol, Ioar Rivas, Mònica López-Vicente, Elisabet Suades-Gonzalez, Raquel Garcia-Esteban, Mikel Esnaola, Marta Cirach, James Grellier, Xavier Basagaña, Xavier Querol, Mònica Guxens, Mark J. Nieuwenhuijsen, and Jordi Sunyer

## Other projects:

Journal of Environmental Monitoring
Cite this: J. Environ. Monit., 2012, 14, 2718
PAPER

Within-city contrasts ... with nitrogen oxides

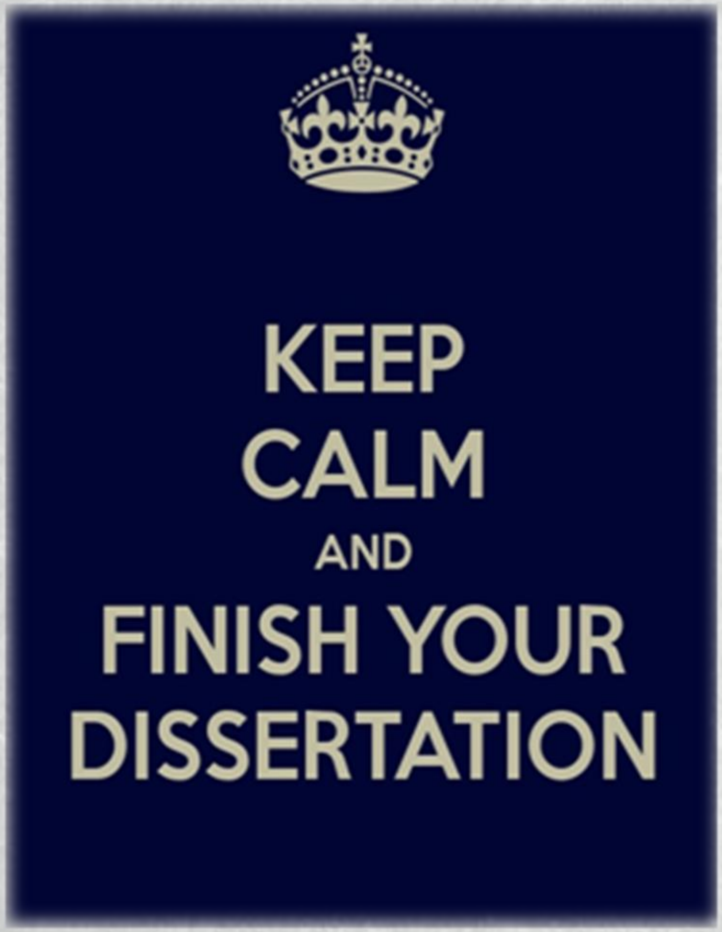
M. C. Minguillón, I. Rivas, ... and X. Querol

Environmental Research 142 (2015) 495–510
Contents lists available at ScienceDirect
Environmental Research

Urban air quality comparison for bus, tram, subway and pedestrian commutes in Barcelona

Teresa Moreno, Cristina Reche, Ioar Rivas, Maria Cruz Minguillón, Vânia Martins, Concepción Vargas, Giorgio Buonanno, Jesus Parga, Marco Pandolfi, Mariola Brines, Marina Ealo, Ana Sofia Fonseca, Fulvio Amato, Garay Sosa, Marta Capdevila, Eladio de Miguel, Xavier Querol, Wes Gibbons

# CONCLUSIONS



# CONCLUSIONS

- **Concentrations of air pollutants** in BREATHE schools were **between typical concentrations in urban background (UB-PR) and traffic stations** in Barcelona.
    - Increasing gradient towards city centre for **EBC, $NO_2$ and UFP concentrations.** The gradient was blurred **for $PM_{2.5}$ (local school sources)**.

- **7 outdoor** (traffic, sulphate & organics, nitrate, road dust, metallurgy, sea spray, and heavy oil) and **2 children's activity-related** (organic/textile/chalk and mineral) sources were responsible for the high $PM_{2.5}$ concentrations.
    - **Sand-filled playground** unusually increased **$PM_{2.5}$ mineral contributions** (breakdown of mineral particles because of children's activity).
    - **Indoor traffic contributions** were higher in classrooms with **windows oriented directly to the street** (importance of urban planning).

# CONCLUSIONS

- **High infiltration of outdoor air pollutants.** Concentrations of **traffic-related** pollutants were generally lower indoors, but very close to outdoor levels.
    - **No differences in infiltration** for many of the traffic related pollutants by **type of windows.**
    - **Cd and EBC** are the pollutants with the highest $F_{inf}$ in the cold season.
    - Some **trace metals** may have higher indoor levels in **newer buildings** due to specific indoor materials emissions.

# CONCLUSIONS

- **EBC** concentrations **higher in personal measurements** than fixed stations (school and UB-PR) owing to peak concentration events during **commuting time.**
  - **Good agreement** between **personal measurements** and **school fixed stations** while children where there, **lower with UB-PR** (distance to the station is important for assessing exposure).

- Children spent **82% of their time in indoor environments** (classroom and home), while receiving **56%** of their daily **dose of EBC** (important to characterise indoor environments).
  - The **contribution from schools** to the total daily **EBC dose was 37%**. Reducing traffic intensities around schools should be enhanced.

# ACKNOWLEDGEMENTS


Funding acknowledged to: erc European Research Council

SCHOOLS: Antoni Brusi, Baloo, Betània-Patmos, Centre d'estudis Montseny, Col·legi Shalom, Costa i Llobera, El Sagrer, Els Llorers, Escola Pia de Sarrià, Escola Pia Balmes, Escola concertada Ramon Llull, Escola Nostra Sra. de Lourdes, Escola Tècnica Professional del Clot, Ferran i Clua, Francesc Macià, Frederic Mistral, Infant Jesús, Joan Maragall, Jovellanos, La Llacuna del Poblenou, Lloret, Menéndez Pidal, Nuestra Señora del Rosario, Miralletes, Ramon Llull, Rius i Taulet, Pau Vila, Pere Vila, Pi d'en Xandri, Projecte, Prosperitat, Sant Ramon Nonat-Sagrat Cor, Santa Anna, Sant Gregori, Sagrat Cor Diputació, Tres Pins, Tomàs Moro, Torrent d'en Melis and Virolai.

# AIR QUALITY IN SCHOOLS AND CHILDREN'S EXPOSURE TO PARTICULATE POLLUTION IN BARCELONA

*Ioar Rivas Lara*

*Thank you for your attention*

# OUTDOOR AIR QUALITY

Sources:





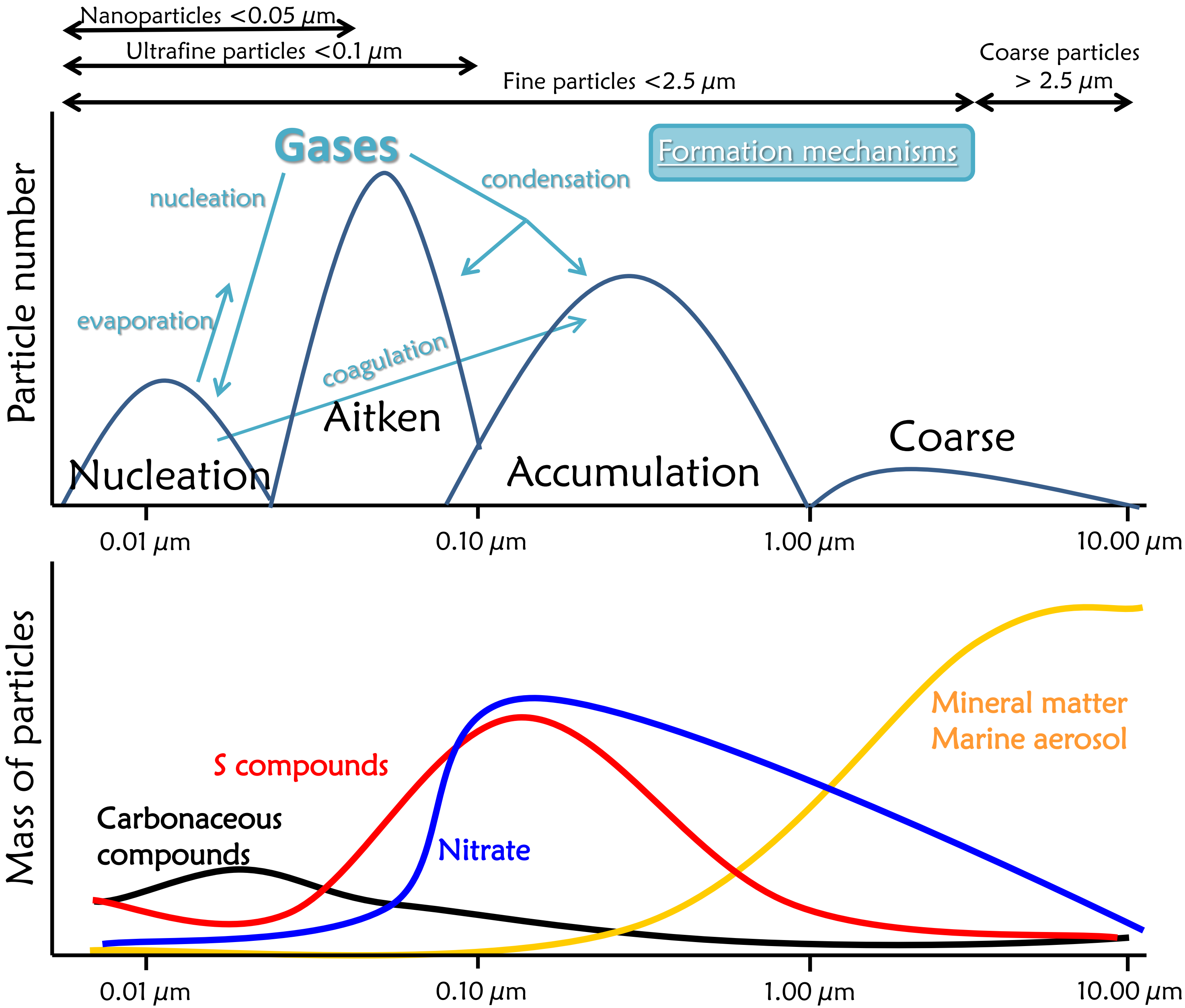
Legislation and guidelines:

| POLLUTANT | AVERAGING PERIOD | EUROPEAN LEGISLATION | | | WHO GUIDELINES |
|---|---|---|---|---|---|
| | | LEGAL NATURE | CONCENTRATION | PERMITTED EXCEEDANCES/YEAR | |
| $PM_{10}$ | 24 h | Limit value entered into force 1/01/2005 | 50 $\mu g \cdot m^{-3}$ | 35 (or percentile 90.4) | |
| | 1 y | Limit value entered into force 1/01/2005 | 40 $\mu g \cdot m^{-3}$ | - | 20 $\mu g \cdot m^{-3}$ |
| $PM_{2.5}$ | 1 y | Target value entered into force 1/01/2010. Limit value enters into force 1/01/2015 | 25 $\mu g \cdot m^{-3}$ | - | 10 $\mu g \cdot m^{-3}$ |
| Nitrogen dioxide ($NO_2$) | 1 h | Limit value entered into force 1/01/2010 | 200 $\mu g \cdot m^{-3}$ | 18 | 200 $\mu g \cdot m^{-3}$ |
| | 1 y | Limit value entered into force 1/01/2010 | 40 $\mu g \cdot m^{-3}$ | - | 40 $\mu g \cdot m^{-3}$ |
| Lead (Pb) | 1 y | Limit value entered into force 1/01/2005 | 0.5 $\mu g \cdot m^{-3}$ | - | 0.5 $\mu g \cdot m^{-3}$ |
| Arsenic (As) | 1 y | Target value entered into force 1/01/2012 | 6 $ng \cdot m^{-3}$ | - | |
| Cadmium (cd) | 1 y | Target value entered into force 1/01/2012 | 5 $ng \cdot m^{-3}$ | - | |
| Nickel (Ni) | 1 y | Target value entered into force 1/01/2012 | 20 $ng \cdot m^{-3}$ | - | |

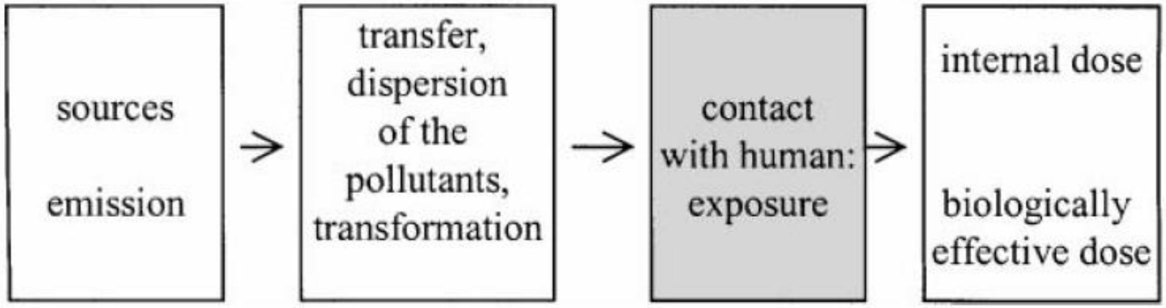
*(Directive 2004/107/EC; Directive 2008/50/EC; RD 10/2011)*

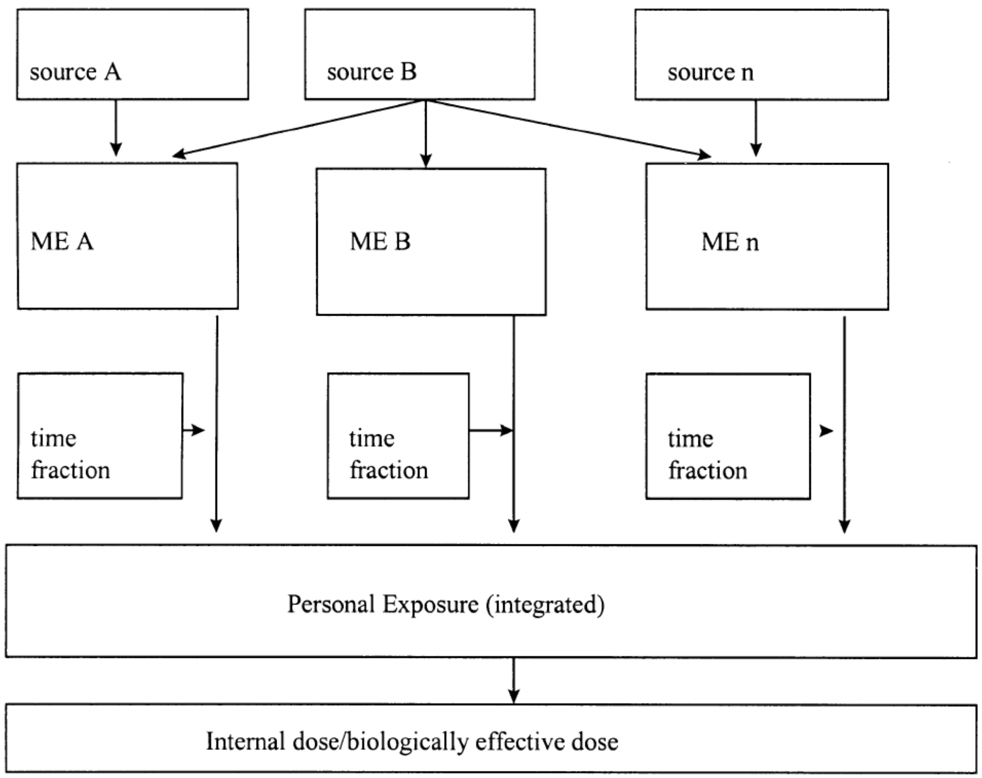
*(WHO,2000; 2005)*

# ATMOSPHERIC AEROSOLS



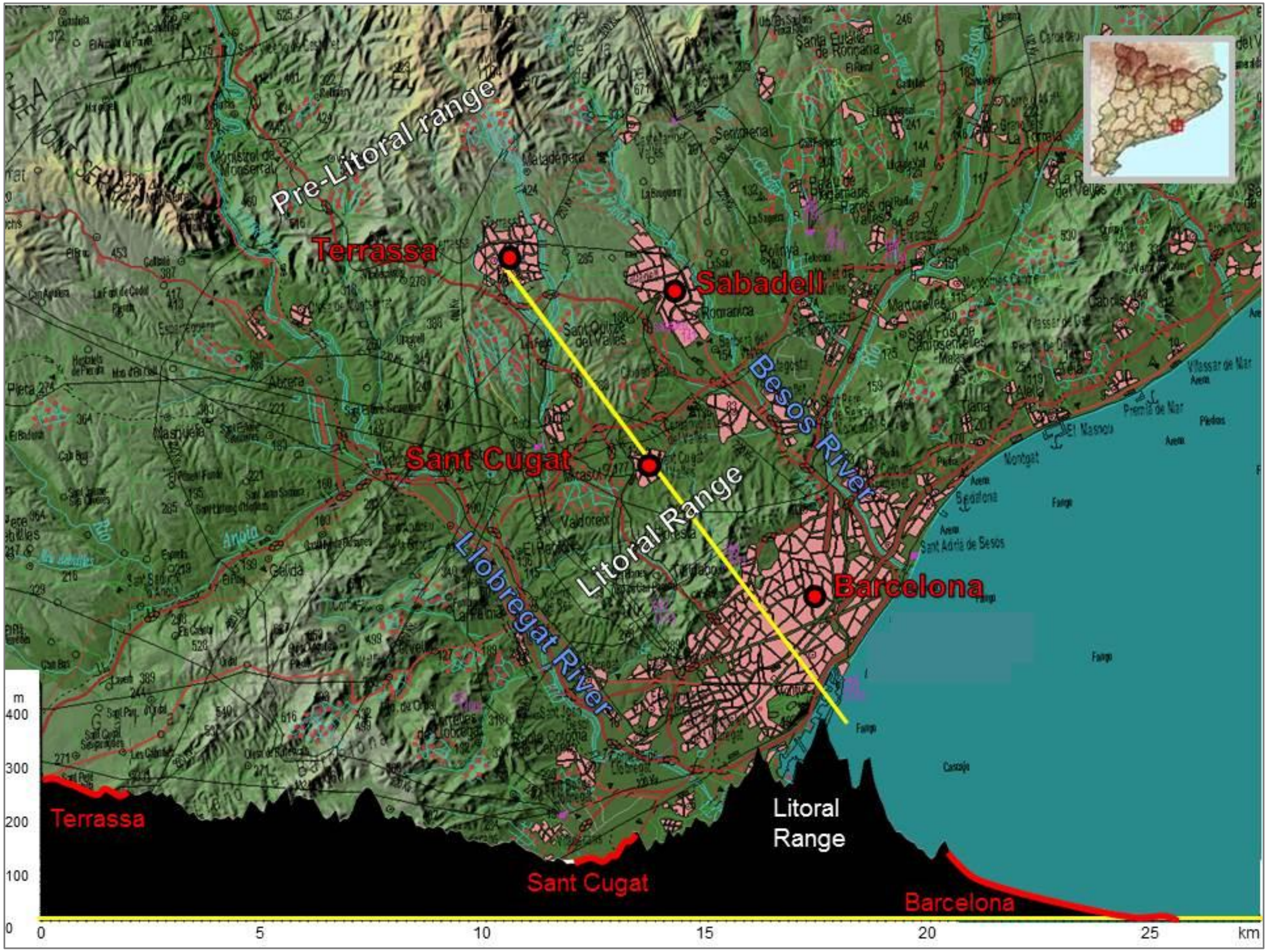
# PERSONAL EXPOSURE AND DOSE




(Monn et al., 2001)

# STUDY AREA



Pre-Litoral range
Terrassa
Sabadell
Sant Cugat
Besos River
Litoral Range
Llobregat River
Barcelona
m
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300
200
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Terrassa
Sant Cugat
Litoral
Range
Barcelona
0
5
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15
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25
km

# SAMPLING SITES

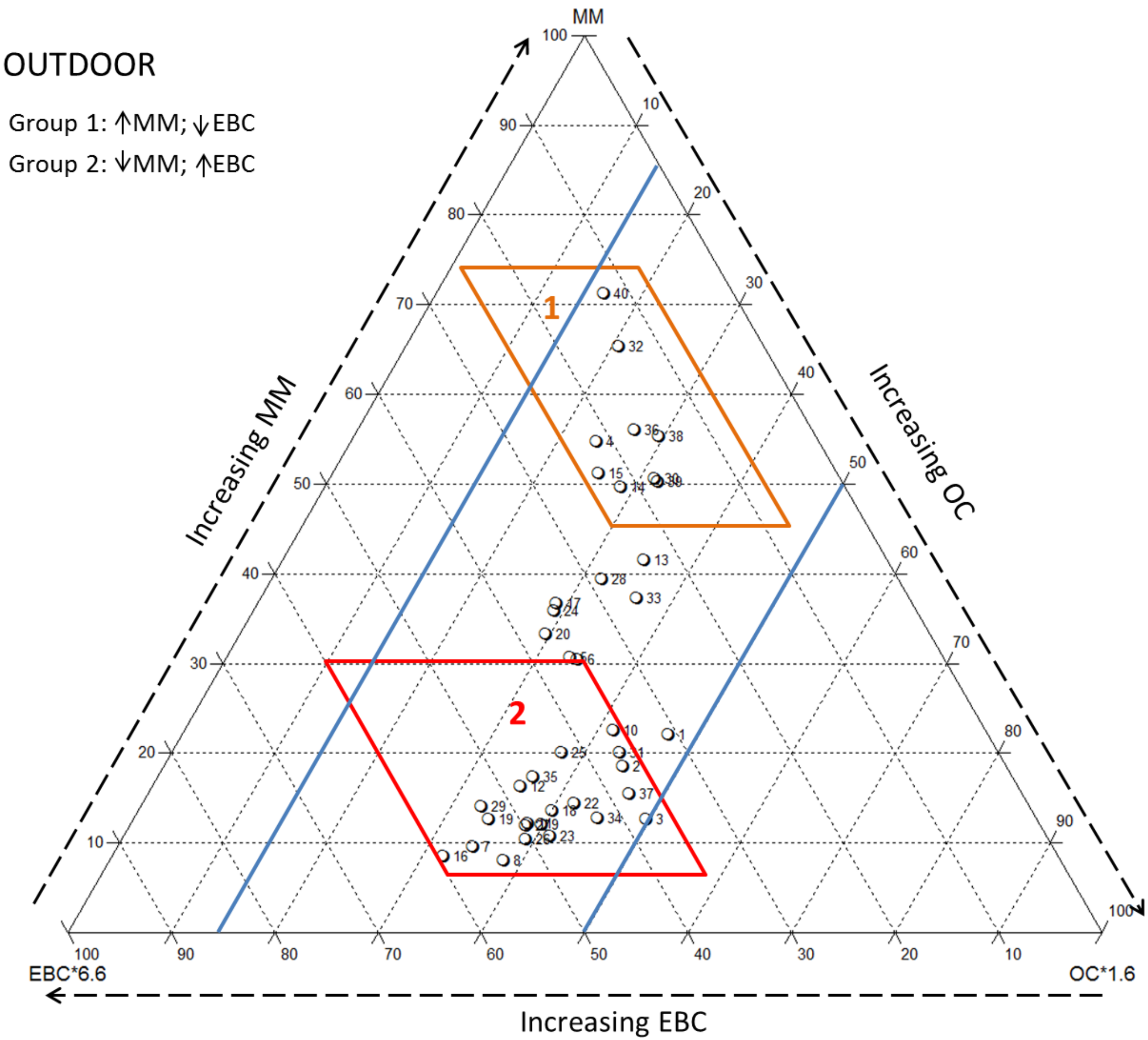

# SANDY VS. PAVED PLAYGROUND

# $PM_{2.5}$ CHEMICAL COMPONENTS

OUTDOOR

Group 1: ↑MM; ↓EBC

Group 2: ↓MM; ↑EBC

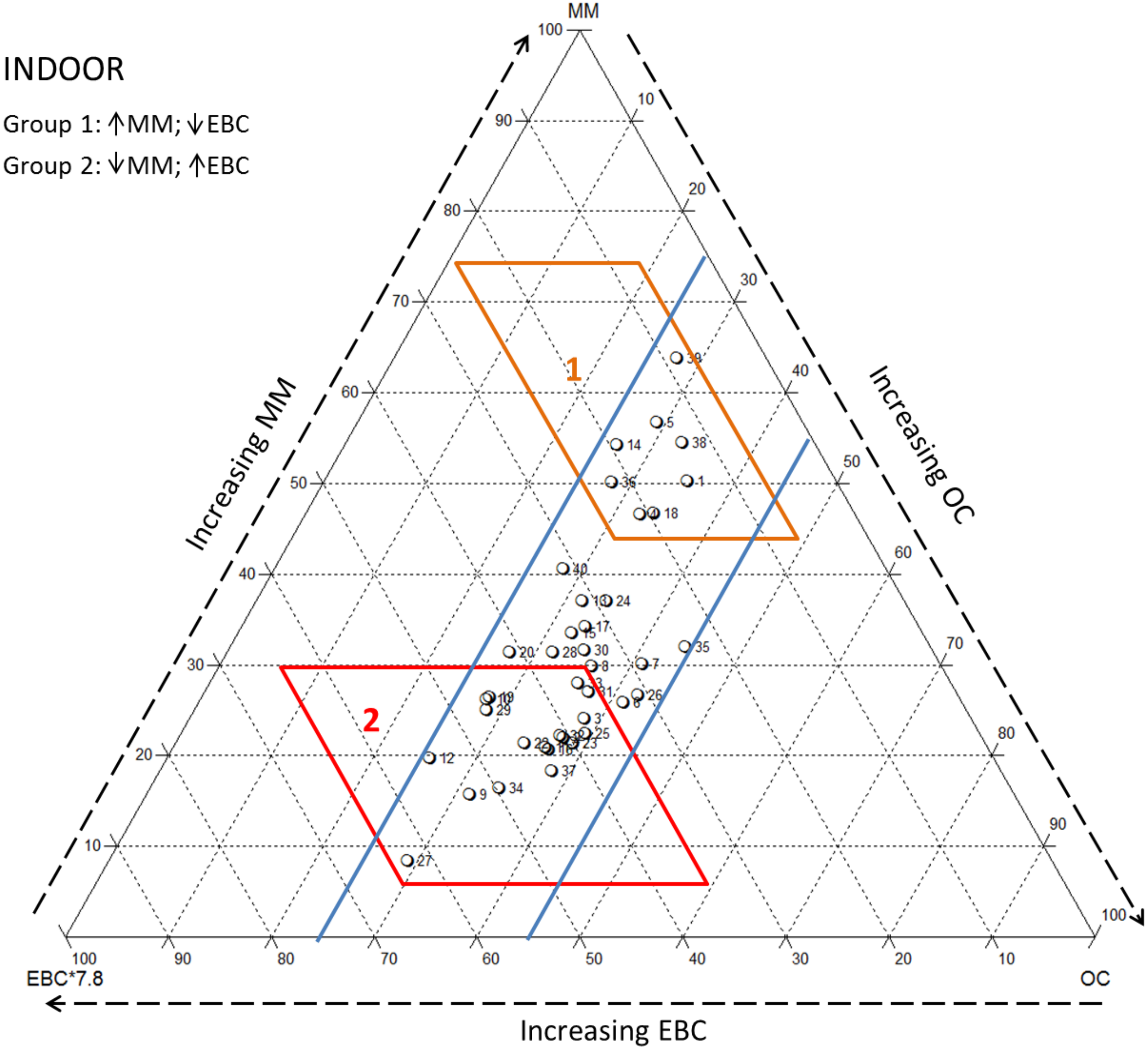


# PM$_{2.5}$ CHEMICAL COMPONENTS

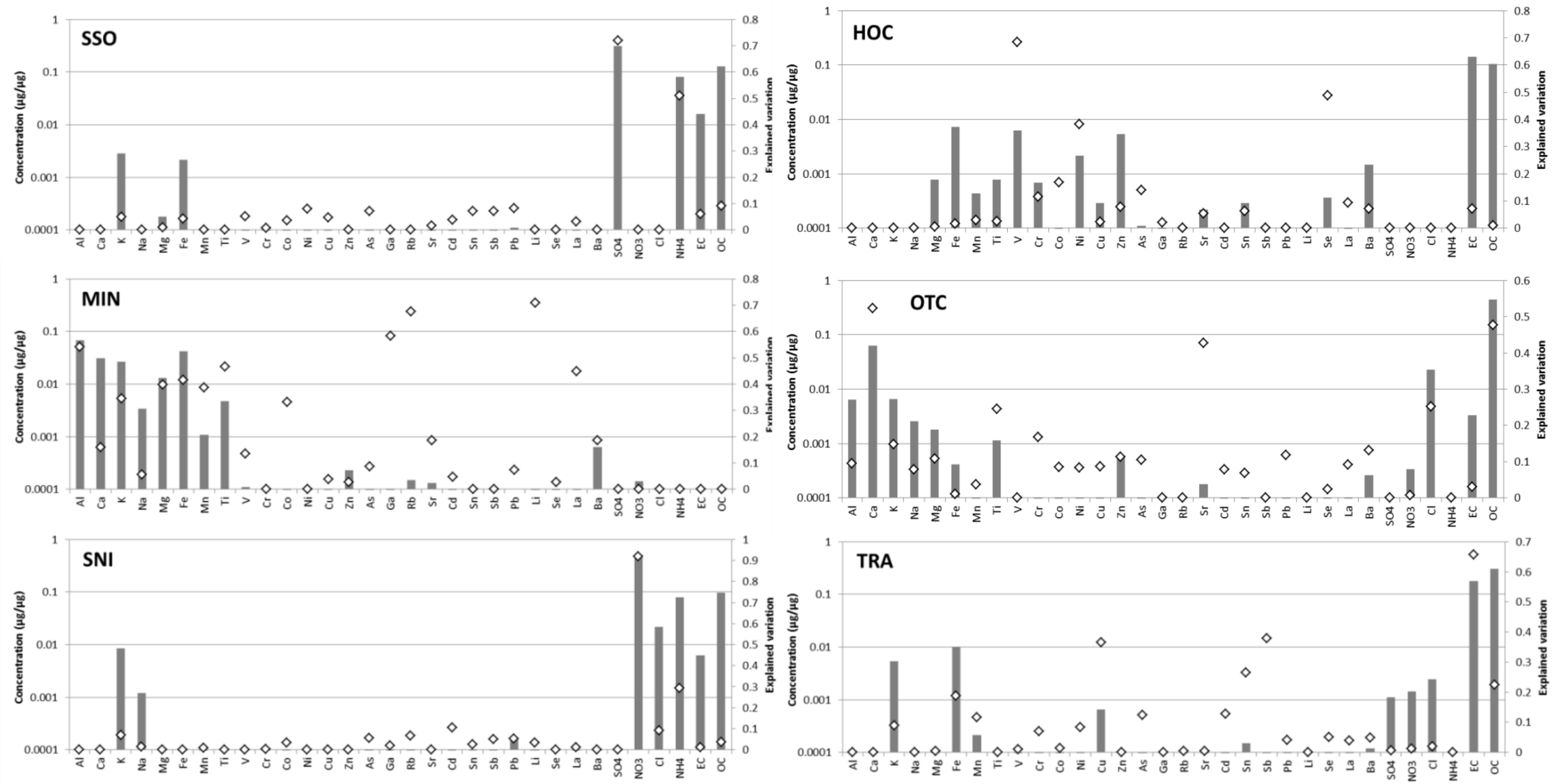
INDOOR

Group 1: ↑MM; ↓EBC

Group 2: ↓MM; ↑EBC



# $PM_{2.5}$ SOURCE APPORTIONMENT



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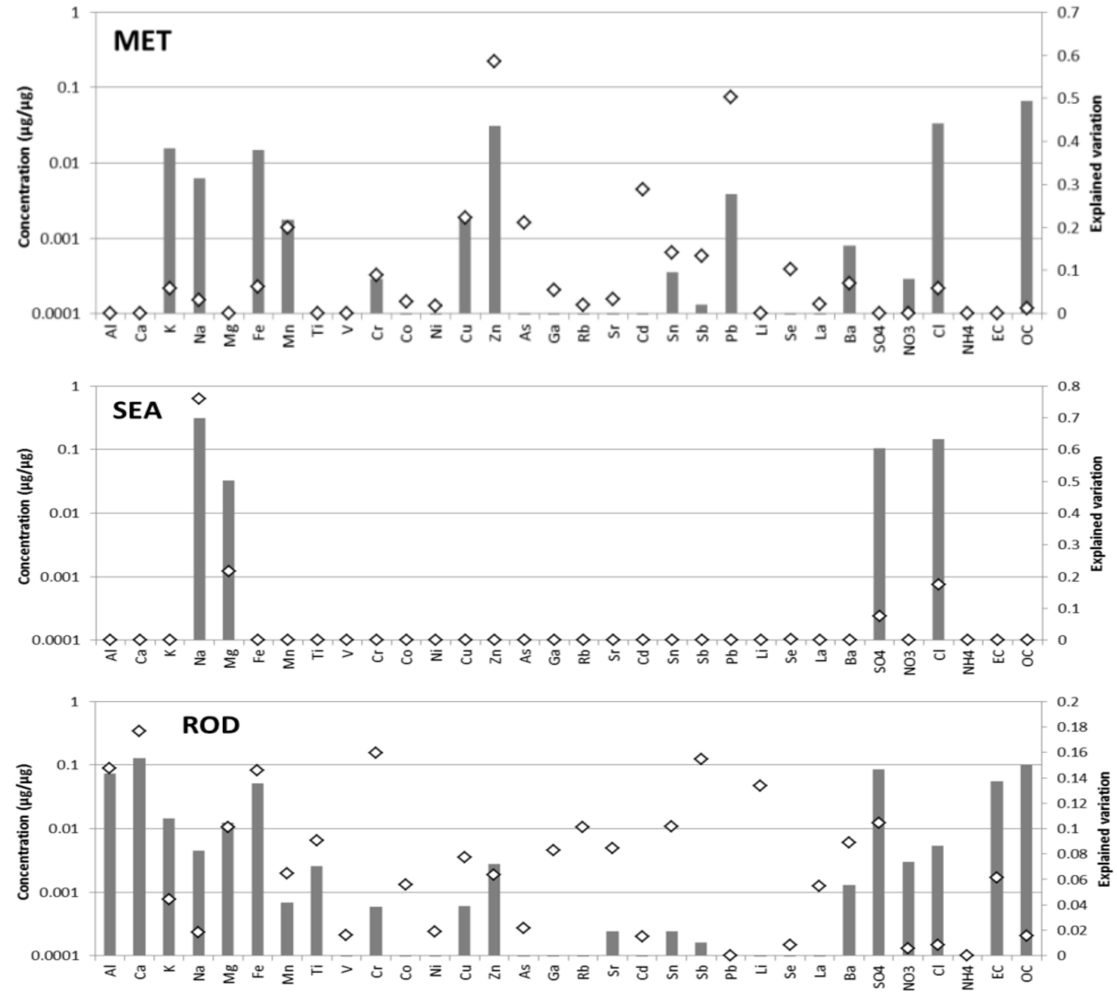
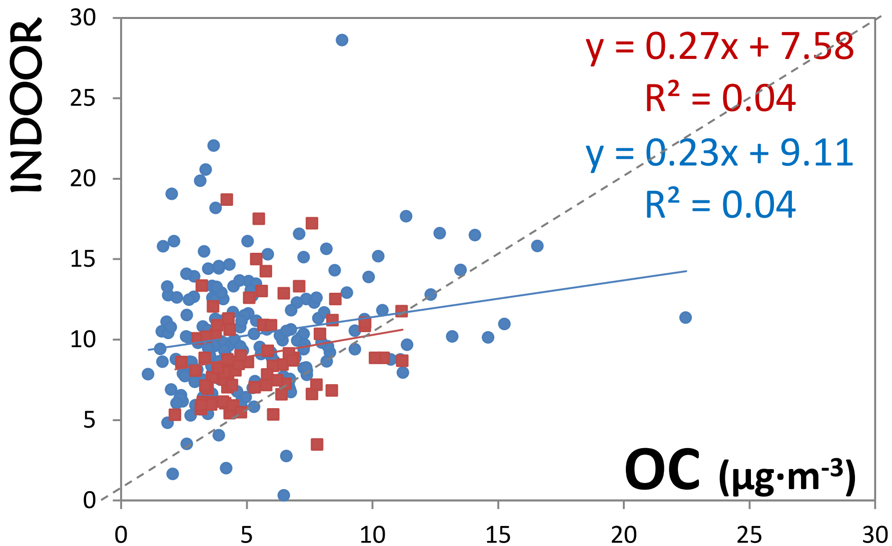
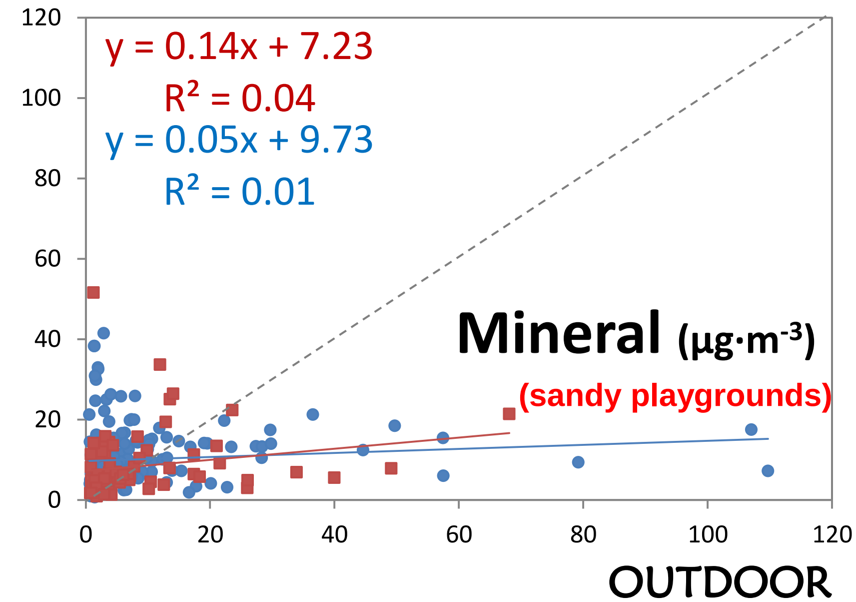
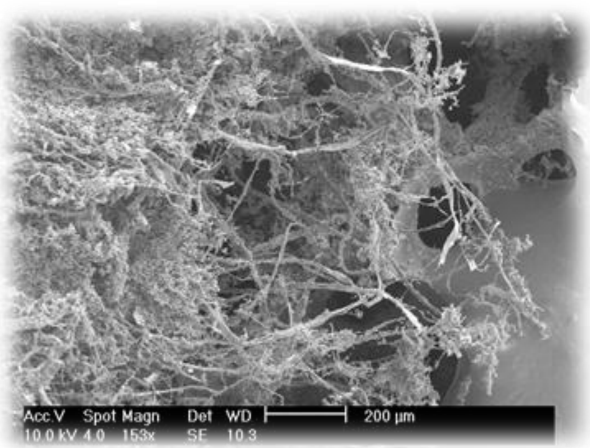


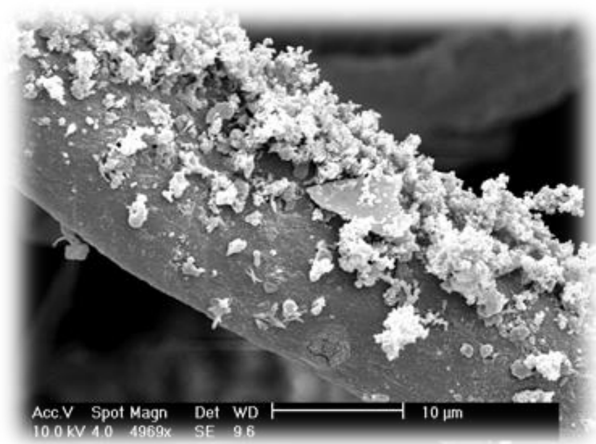
# INFILTRATION OF AIR POLLUTANTS

● Cold Season ■ Warm Season



# FACTORS INFLUENCING INDOOR CONCENTRATIONS

| | Building construction year: ≤1970 (Ref: >1970) | | Type of window: wood (Ref: Al/PVC) | | Playground: sand-filled <20m (Ref: Paved) | |
|---|---|---|---|---|---|---|
| | Coeff $(ng \cdot m^{-3})$ | % indoor median+ | Coeff $(ng \cdot m^{-3})$ | % indoor median+ | Coeff $(ng \cdot m^{-3})$ | % indoor median+ |
| Li | -0.27* | -73.19 | -0.37* | -10.24 | 0.65** | 179.33 |
| Ti | -15.85 | -36.93 | -27.19* | -63.35 | 53.00** | 123.49 |
| Sb¤ | -0.15 | -19.63 | -0.08 | -10.34 | 0.22 | 28.52 |
| V | 0.01 | 0.36 | -0.68* | -27.63 | 1.04* | 41.96 |
| Ni | 0.02 | 0.85 | 0.06 | 2.91 | 0.12 | 6.01 |
| Cr | -1.95* | -56.94 | -1.25 | -36.28 | 0.87 | 25.49 |
| Mn | -3.93 | -43.75 | -6.25** | -69.59 | 10.10** | 112.41 |
| Co | -0.09* | -62.41 | -0.10* | -66.23 | 0.09 | 63.38 |
| Cu¤ | -0.10 | -1.33 | -0.66 | -9.15 | 0.00 | 0.03 |
| Sn¤ | -0.36 | -16.98 | 0.05 | 2.39 | -0.05 | -2.42 |
| Zn | -6.22 | -13.93 | -7.32 | -16.40 | 3.13 | 7.01 |
| As | -0.02 | -6.54 | -0.09* | -25.29 | 0.11* | 30.44 |
| Se | -0.05* | -18.99 | 0.02 | 6.61 | -0.03 | -12.84 |
| Cd | 0.01 | 4.79 | 0.01 | 4.84 | -0.02 | -15.60 |
| Pb | -0.16 | -2.57 | -0.86 | -13.73 | 1.18 | 18.75 |

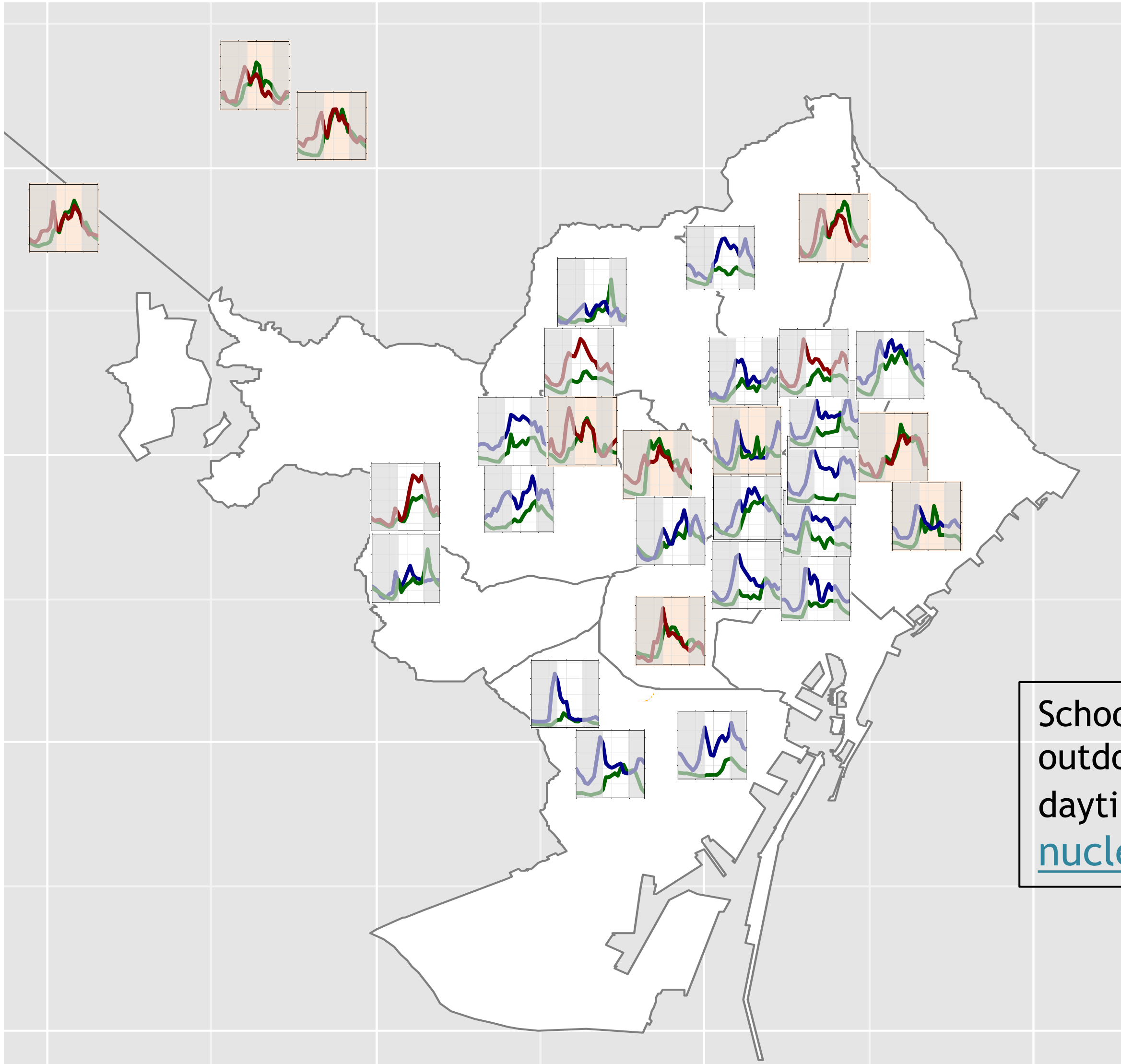
¤ Schools having I/O ratios above 1.2 for traffic-related pollutants have not been considered.

* Statistically significant at p-value ≤0.05.

** Statistically significant at p-value ≤0.01.

+ Median of the indoor concentrations during the cold period.

# ULTRAFINE PARTICLES



**Daily cyles from 0 to 23h**

Particles/cm$^3$ **Indoor**

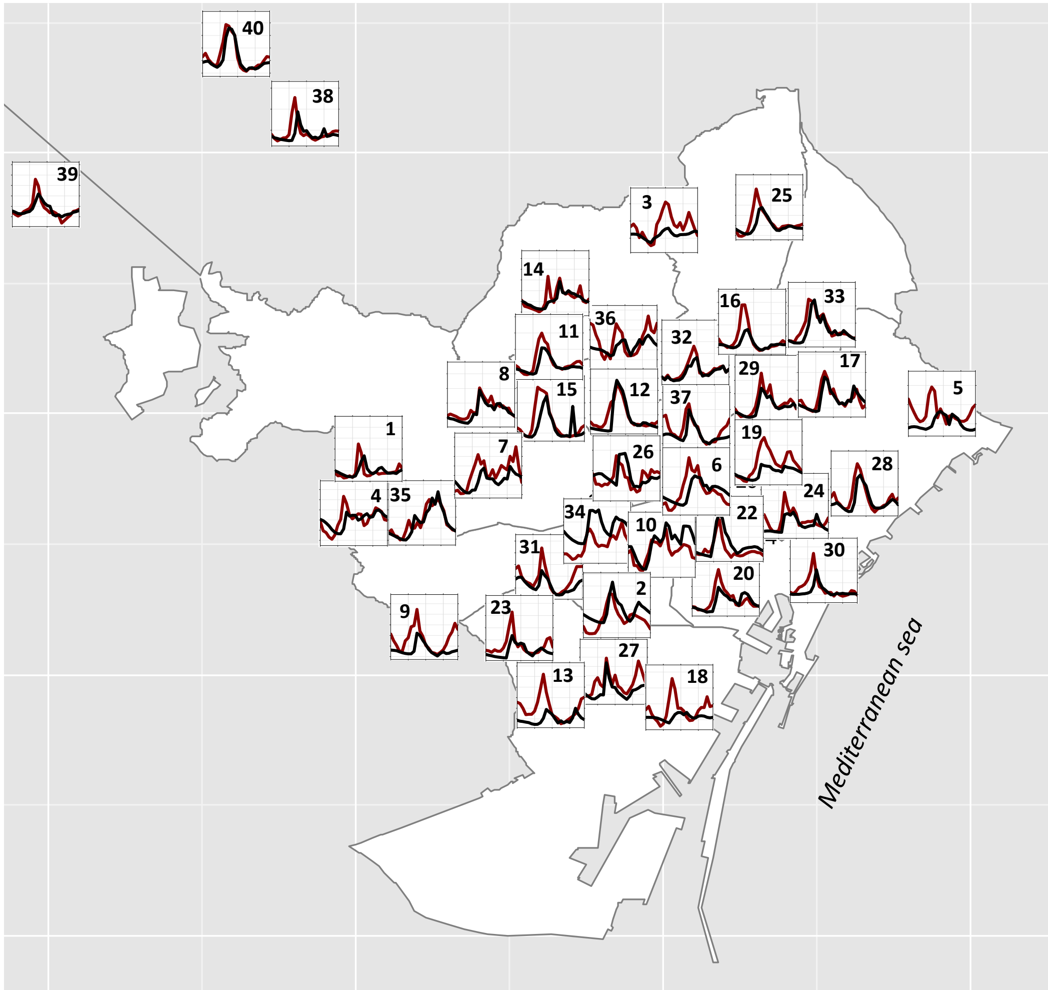
Particles/cm$^3$ **Outdoor** when outdoor temperature **<20ºC**

Particles/cm$^3$ **Outdoor** when outdoor temperature **>20ºC**

Schools with higher indoor than outdoor UFP levels during daytime: Both road traffic and nucleation processes

Schools with higher indoor than outdoor UFP levels during daytime: surfaces-$O_3$ reactions/ cooking

# BLACK CARBON



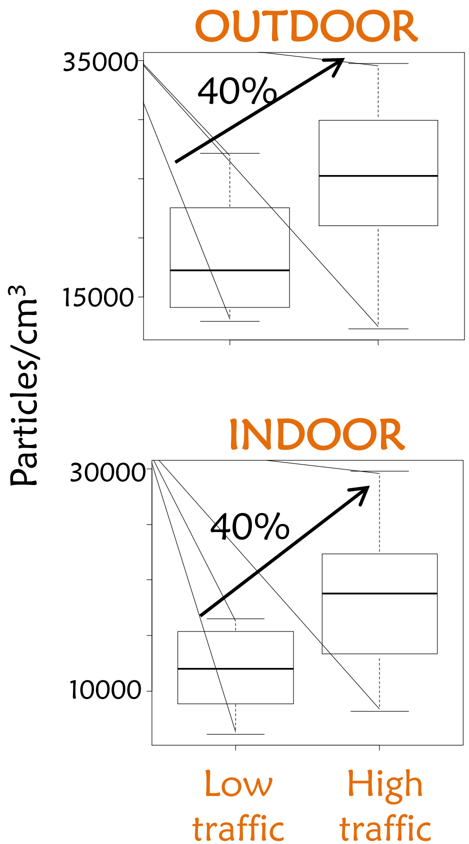

**Daily cyles from 0 to 23h**

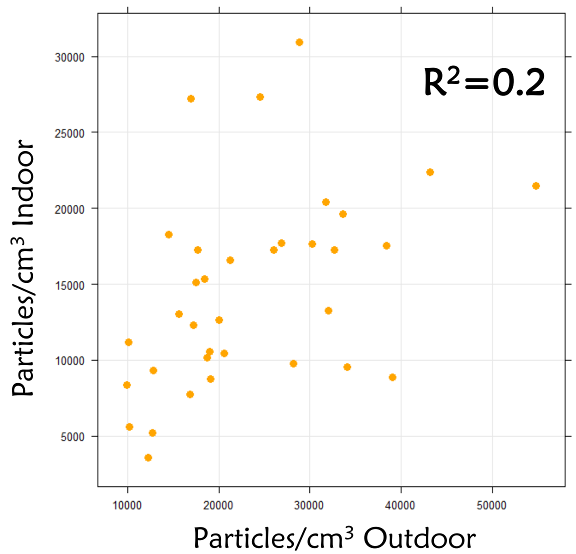
EBC **Indoor**

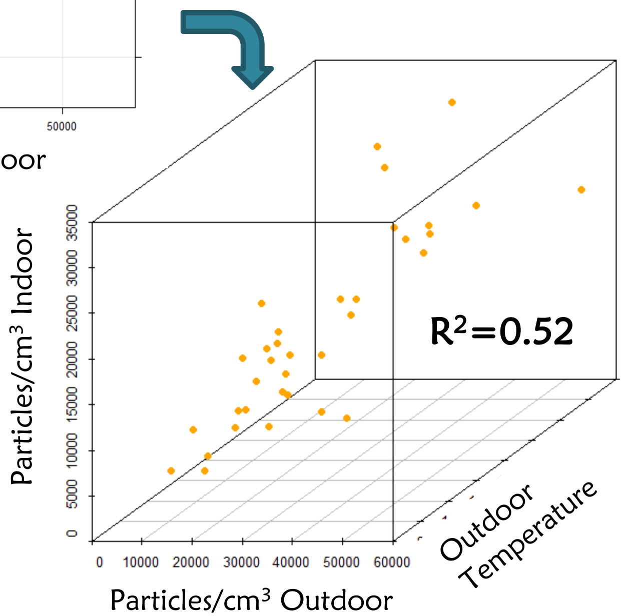
EBC **Outdoor**

Schools with higher indoor than outdoor BC levels: Indoor sampling location was relatively closer to heavy traffic

# ULTRAFINE PARTICLES



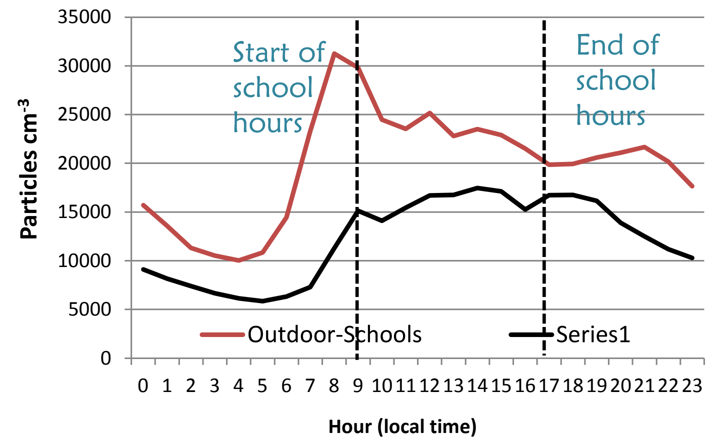



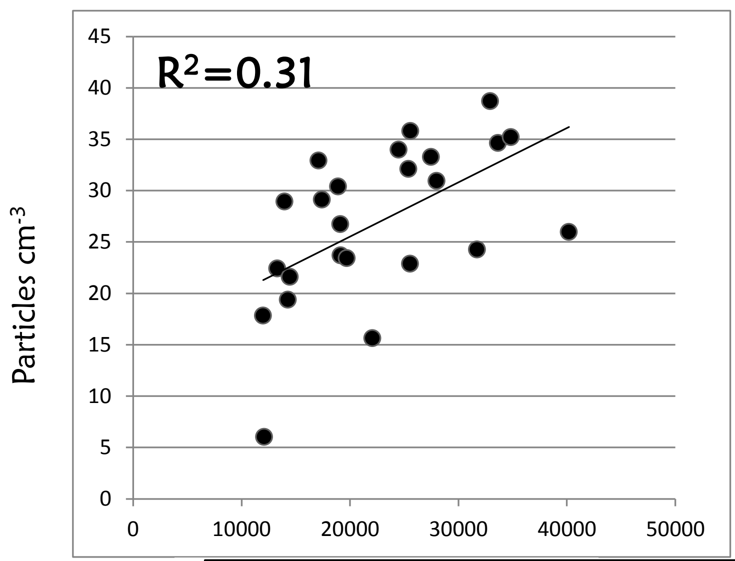

Ultrafine particles (UFP) levels by 40% higher at schools nearer to heavy traffic: impact on children's exposure of urban planning decisions

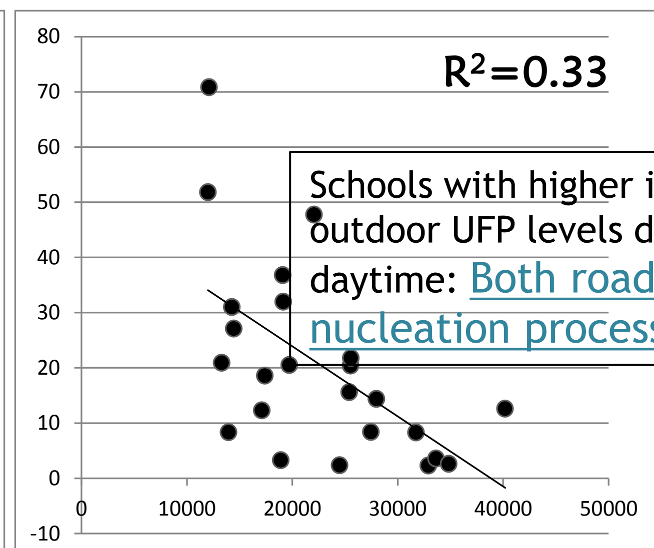
Indoor exposures were partly attributable to outdoor sources, especially under natural ventilation

# In & outdoor

Parallelism between mean indoor and outdoor daily cycles (more differences than for BC)



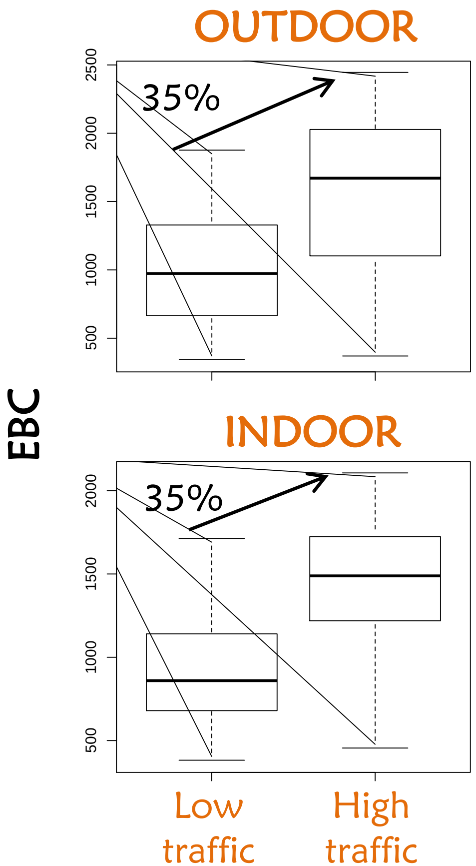



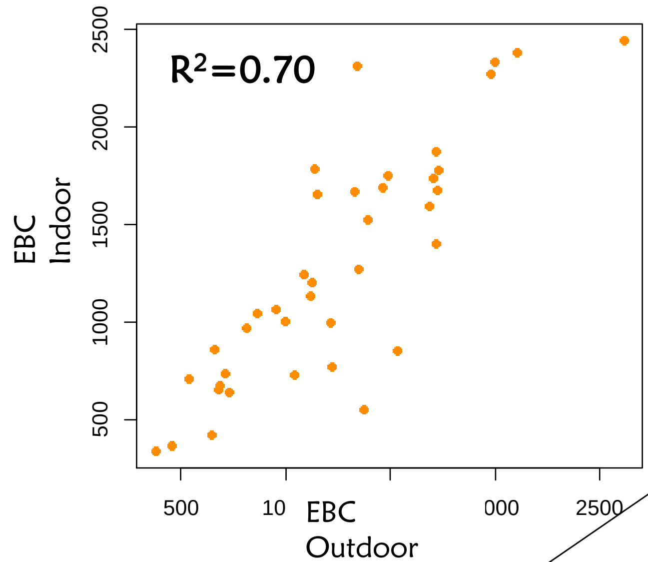

Schools with higher indoor than outdoor UFP levels during daytime: Both road traffic and nucleation processes

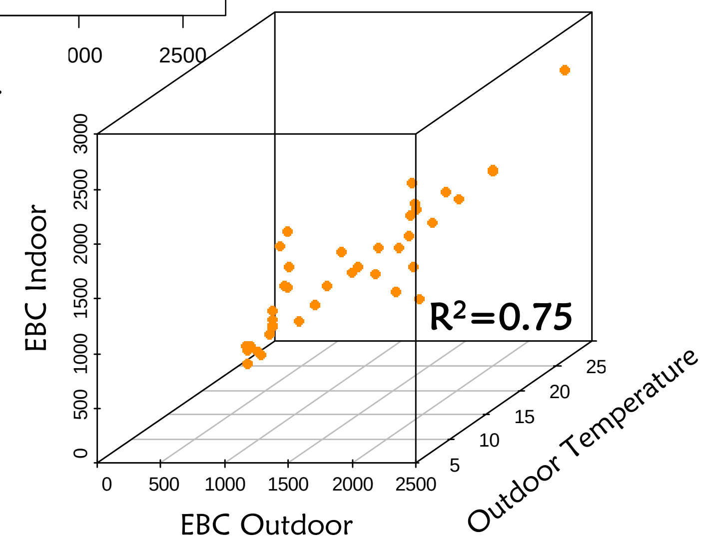
Schools with higher indoor than outdoor UFP levels during daytime: surfaces-$O_3$ reactions/ cooking

# BLACK CARBON




BC levels by 35% higher at schools nearer to heavy traffic: impact on children's exposure of urban planning decisions



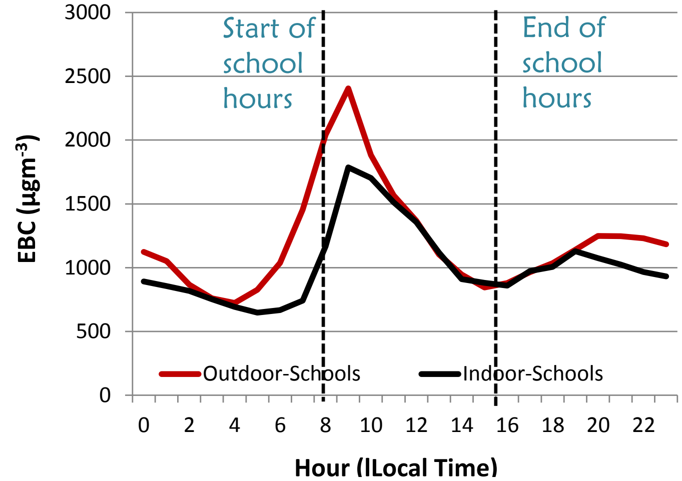




Indoor exposures attributable to outdoor sources

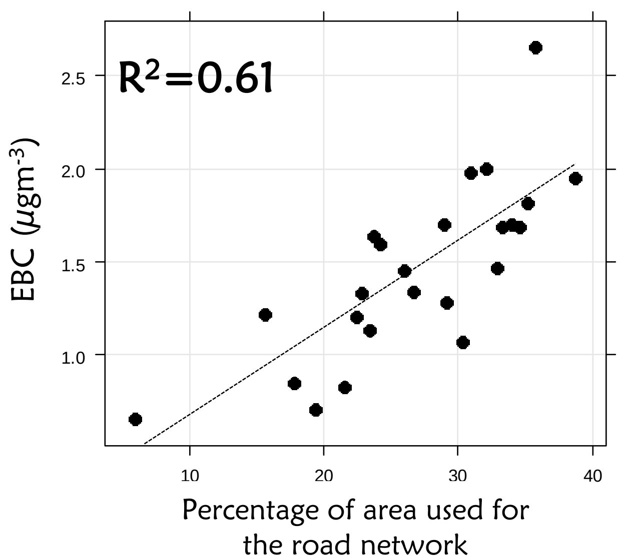
# BLACK CARBON

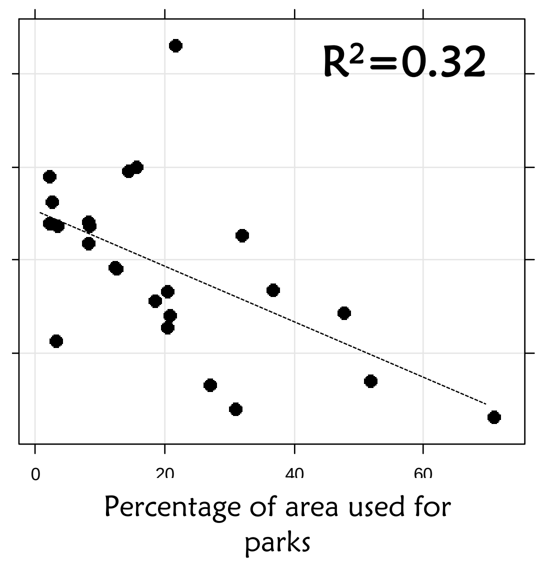
## In & outdoor

Parallelism between mean indoor and outdoor daily cycles. Peaks of exposure inside the classrooms determined by outdoor concentrations




A main contribution of road traffic emissions on indoor and outdoor Elemental Black Carbon (EBC) levels was evidenced




High correlation between average EBC levels at different districts of the city of Barcelona and the percentage of surface area used for the **road network**

# AGREEMENT BETWEEN FIXED

| Fixed-effect predictor (μg·m$^{-3}$) | All seasons RC | All seasons intercept (μg·m$^{-3}$) | All seasons $R^2$ | Cold Season RC | Cold Season intercept (μg·m$^{-3}$) | Cold Season $R^2$ | Warm Season RC | Warm Season intercept (μg·m$^{-3}$) | Warm Season $R^2$ |
|---|---|---|---|---|---|---|---|---|---|
| **<u>All day</u>** | | | | | | | | | |
| EBC classroom fixed | 0.95* | 0.4* | 0.28 | 0.85* | 0.5* | 0.17 | 1.00* | 0.3* | 0.52 |
| EBC playground fixed | 0.65* | 0.6* | 0.26 | 0.53* | 0.7* | 0.15 | 0.72* | 0.5* | 0.50 |
| EBC UB fixed | | | | | | | | | |
| Unadjusted | 0.39* | 0.9* | 0.18 | 0.28* | 0.9* | 0.14 | 0.49* | 0.9* | 0.29 |
| Adjusted$^+$ | 0.39* | 0.9* | 0.18 | 0.28* | 1.2* | 0.14 | 0.49* | 0.3 | 0.29 |
| **<u>Classroom time</u>** | | | | | | | | | |
| EBC classroom fixed | 0.94* | 0.3* | 0.79 | 0.81* | 0.4* | 0.68 | 0.99* | 0.2 | 0.79 |
| EBC playground fixed | 0.73* | 0.5* | 0.72 | 0.46* | 0.7* | 0.57 | 0.80* | 0.5* | 0.73 |
| EBC UB fixed | 0.49* | 0.9* | 0.45 | 0.11* | 1.1* | 0.41 | 0.61* | 1.0* | 0.40 |
| **<u>Playground time</u>** | | | | | | | | | |
| EBC classroom fixed | 1.00* | 0.1 | 0.73 | 0.87* | 0.2* | 0.49 | 0.99* | 0.1 | 0.87 |
| EBC playground fixed | 1.02* | 0.1 | 0.75 | 0.87* | 0.2* | 0.48 | 1.01* | 0.1 | 0.89 |
| EBC UB fixed | 0.53* | 0.8* | 0.45 | 0.18* | 0.9* | 0.31 | 0.64* | 0.9* | 0.47 |
| **<u>Home time</u>** | | | | | | | | | |
| EBC classroom fixed | 1.00* | 0.3* | 0.48 | 0.92* | 0.4* | 0.46 | 1.09* | 0.2 | 0.41 |
| EBC playground fixed | 0.48* | 0.7* | 0.47 | 0.50* | 0.7* | 0.46 | 0.49* | 0.7* | 0.40 |
| EBC UB fixed | 0.31* | 0.9* | 0.43 | 0.38* | 0.7* | 0.46 | 0.34* | 0.9* | 0.34 |
| **<u>Commuting time</u>** | | | | | | | | | |
| EBC classroom fixed | 0.93* | 1.9* | 0.30 | 0.63 | 2.3* | 0.29 | 1.12* | 1.0* | 0.43 |
| EBC playground fixed | 0.76* | 2.0* | 0.32 | 0.43 | 2.5* | 0.29 | 0.85* | 1.3* | 0.55 |
| EBC UB fixed | 0.53* | 2.2* | 0.30 | 0.18 | 2.7* | 0.29 | 0.65* | 1.5* | 0.41 |
| **<u>Other time</u>** | | | | | | | | | |
| EBC classroom fixed | -0.01 | 1.6* | 0.37 | -0.19 | 2.2* | 0.38 | 0.13 | 1.1* | 0.18 |
| EBC playground fixed | 0.00 | 1.5* | 0.37 | 0.11 | 1.9* | 0.37 | 0.14 | 1.1* | 0.18 |
| EBC UB fixed | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

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