Modelling of the effect of indoor intermittent emissions produced by electronic cigarette users on exposure of bystanders.

Stéphane COLARD and Thomas VERRON

Introduction

Modelling of air indoor quality is widely used worldwide for the assessment of exposure. Such an approach presents a number of benefits:

- Provides rapid answers
- Far cheaper than experiments
- Flexible (easily adaptable to different situations)
- Enables the identification of the key factors of exposure
- Provide a support for training, awareness and understanding improvement
- Already used for elaborating guides on air quality under various likely scenarios
- Can be combined with risk assessment

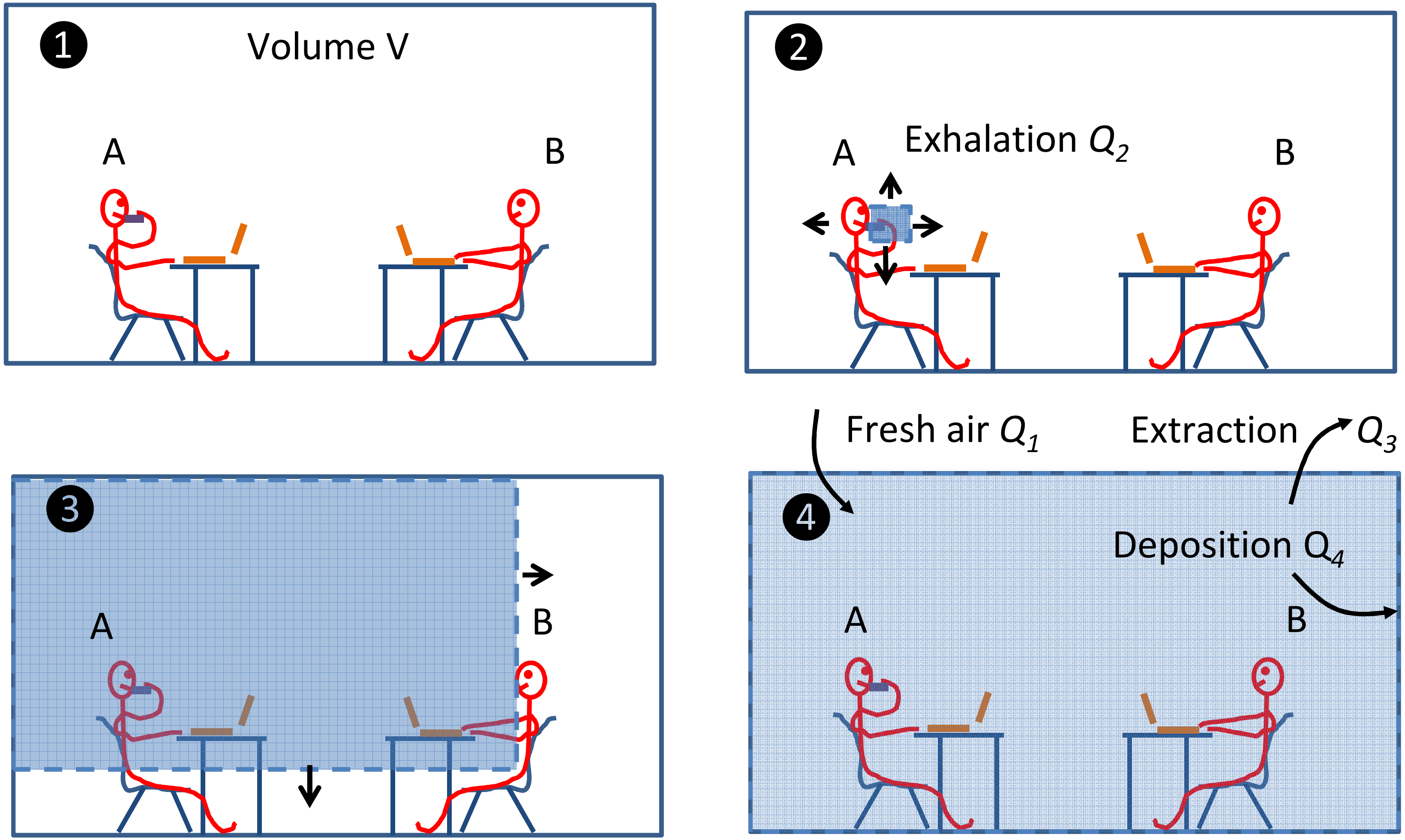
Introduction

The modelling approach is not a pure intellectual exercise based on mathematics !

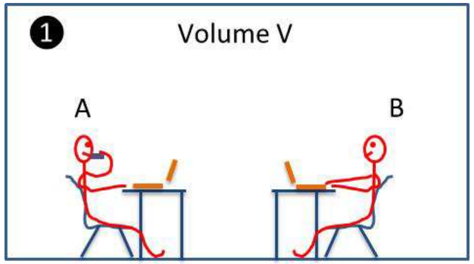
We speak about models based on general physical principles and real-life situations

- Quantities emitted, and emitter's positions
- Size of the room(s)
- Speed of propagation
- Ventilation
- …

The Scene and the Scenario



The Phases

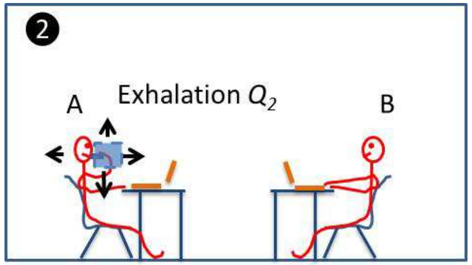


Puff inhalation
of E-cig user

$$M_{Inhaled}$$

Retention

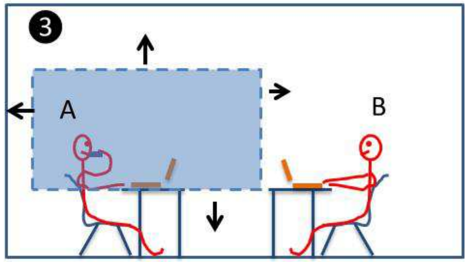
$$M_{Exhaled} = M_{Inhaled} \times (1 - Ret_{\%})$$



Exhalation

$$C(t=0) = \frac{M_{Exhaled}}{V_{Exhaled}}$$

Aerosol propagation

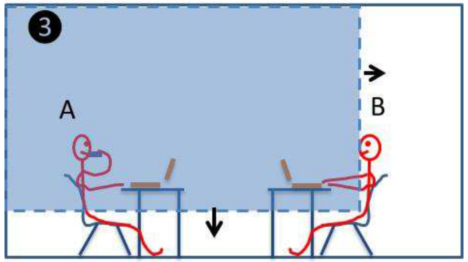


$$C(t) = \frac{M_{Exhaled}}{V_{Aerosol}(t)}$$

Dilution in air

The Phases

Start of the exposure of non-user

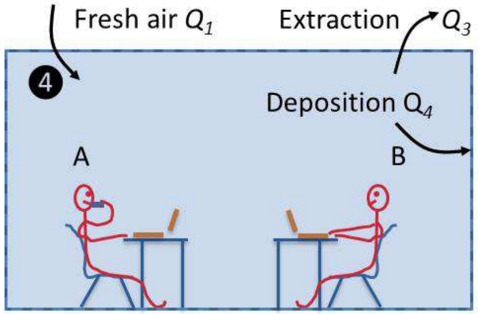


Dilution in air

$$C(t)=\frac{M_{Exhaled}}{V_{Aerosol}(t)}$$

Surface deposition

$$Q_4=S_{Dep}\times v_d$$



Indoor air renewal

$$Q_3=\frac{ACH\times V_{Room}}{60}\times(100-RRA)$$

$$C(t)=C(t_{Init})\times\exp\left[-\frac{Q_3+Q_4}{V_{Room}}\times(t-t_{Init})\right]$$

Dose by breathing during a certain period of time

$$M_{Tot\_Inhaled\_User}=\sum_{1}^{N_{Puff}}M_{Inhaled}+\int_0^t C_{User}(t)\times V_{Inhaled}.dt$$

$$M_{Tot\_Inhaled\_Bystander}=\int_0^t C_{Bystander}(t)\times V_{Inhaled}.dt$$

The Parameters

Phase	Parameter
Inhalation/Exhalation	• Quantity of aerosol constituent inhaled • Retention rate / Quantity exhaled • Puff frequency • Number of puffs in each successive puffing sessions
Aerosol propagation/dilution	• Source position (the user(s)) • Speed of propagation (possibly different in the 6 directions) • Volume of the room (length, width, height)
User/Bystander exposure	• Non-user(s) position
Air exchange/deposition	• Air exchange rate • Air recycling rate • Speed of deposition
Bystander dose	• Breathing pattern (volume of air inhaled per minute) • Time spent in the room

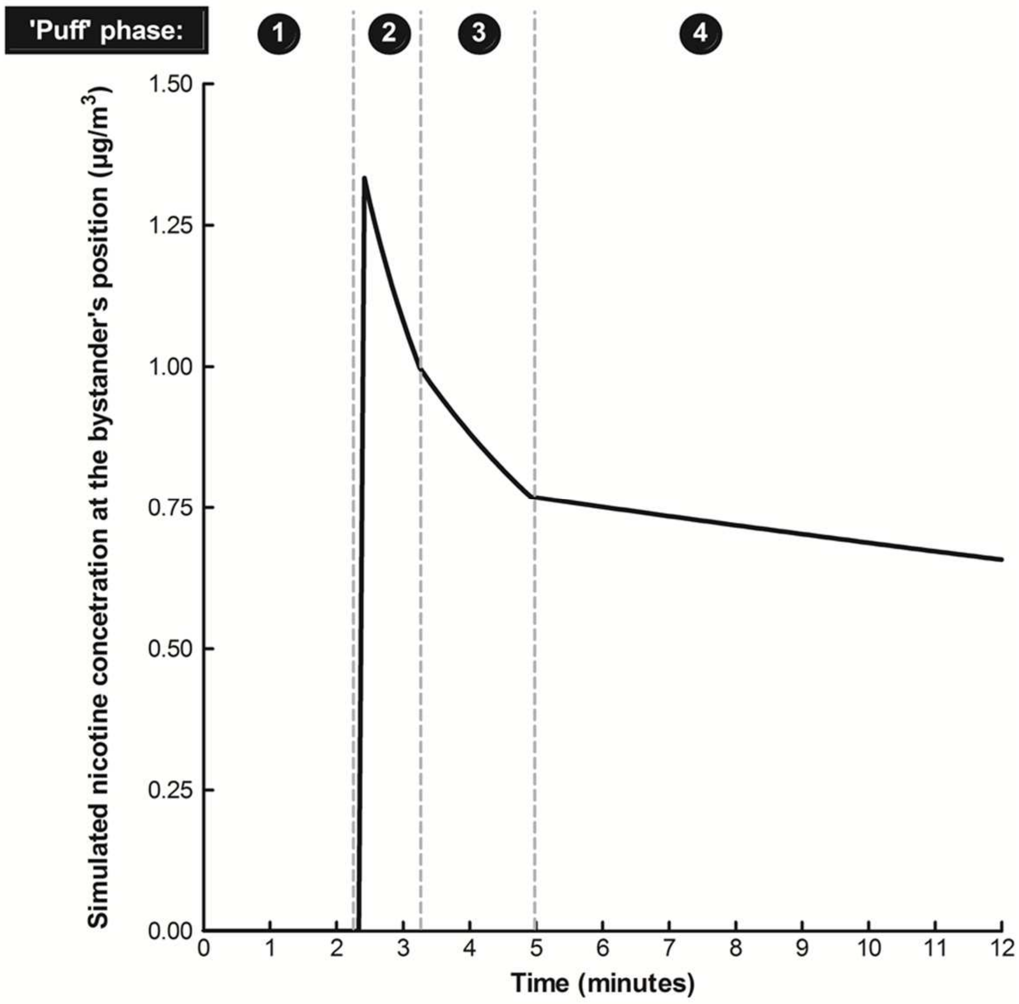
Phases of Exposure

❶ Exhalation / Propagation

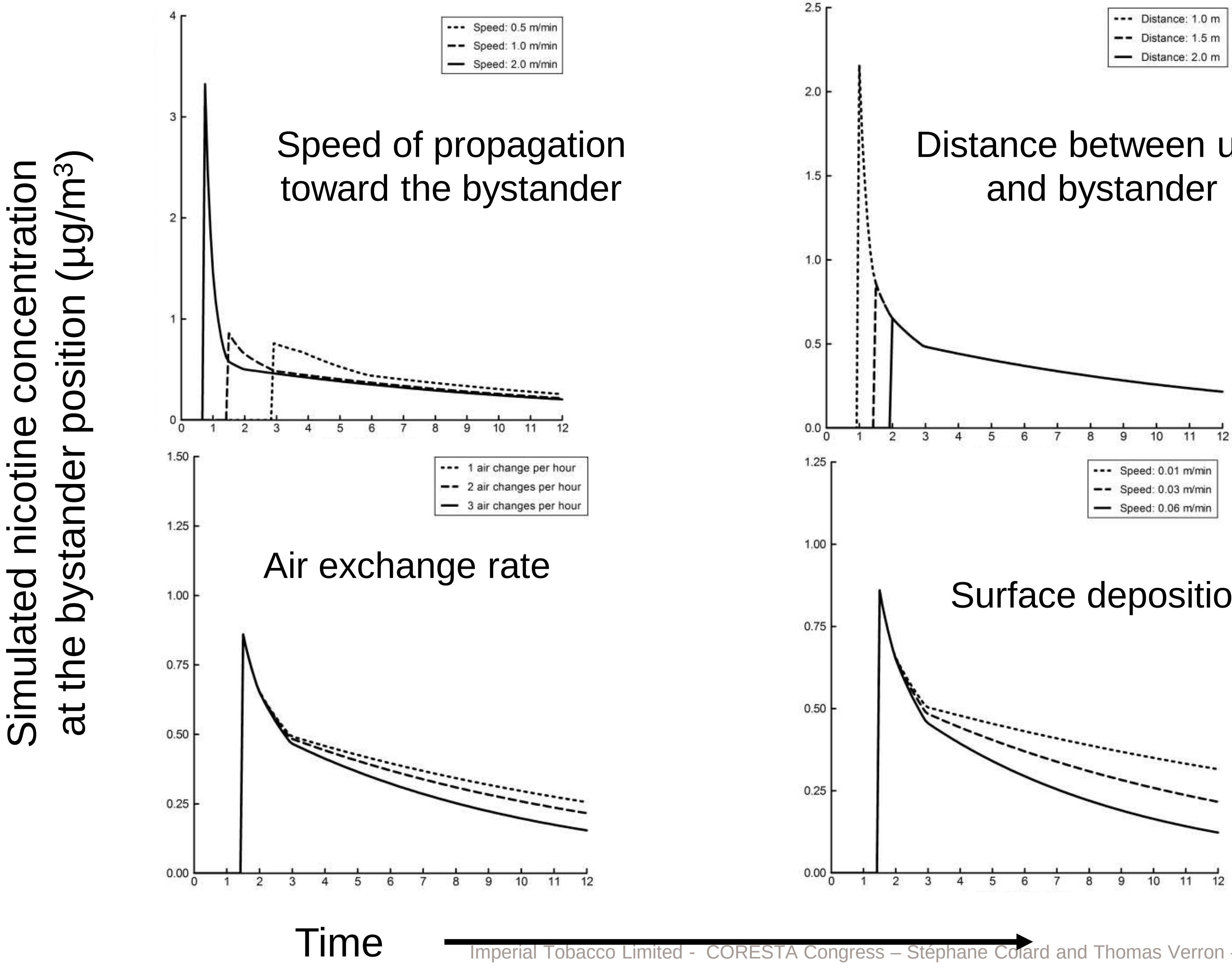
❷ Start of exposure / dilution

❸ Dilution, extraction and/or deposition

❹ Extraction and/or deposition



Effect of the parameters



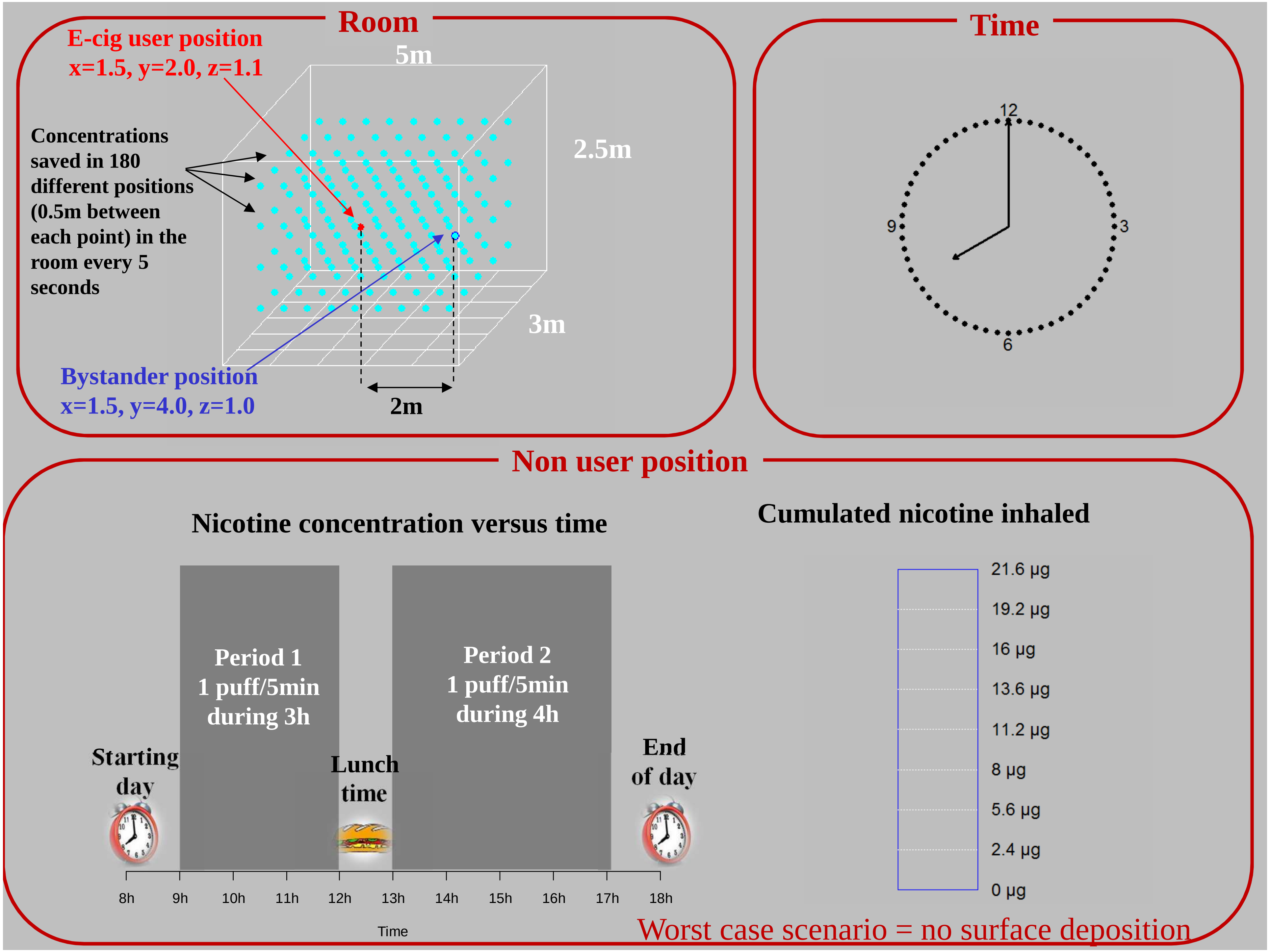
With Modelling We Can Write a Story

Two employees are working in a same office. One is an e-cigarette user and makes 1 puff every 5 min*. He inhales 0.06mg of Nicotine per puff and exhales 0.03mg (50% retention rate).

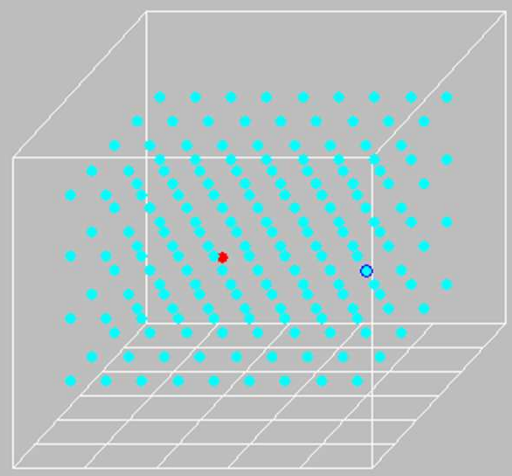
The room size is 15m^2 (3x5m) and the ceiling height is 2.5m. The air exchange rate is 50m^3/h (ACH=1.33). This generates movement of convection which makes an exhaled puff filling the room in 5 minutes.

The other employee is not an e-cigarette user. He seats at 2m from his colleague, he spends 7 hours per day with him with a lunch break of 1 hour, and he breathes 8 litres of air per minutes.

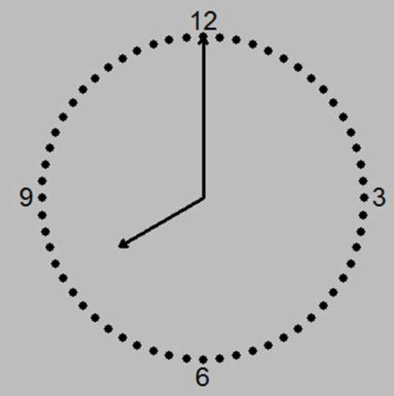
*Dautzenberg B., Dautzenberg M.D. (2014) La cigarette électronique est-elle fiable et efficace? *Presse Med*, http://dx.doi.org/10.1016/j.lpm.2014.03.015


Room
E-cig user position
x=1.5, y=2.0, z=1.1
5m
2.5m
3m
2m
Concentrations saved in 180 different positions (0.5m between each point) in the room every 5 seconds
Bystander position
x=1.5, y=4.0, z=1.0
Time
12
3
6
9
Non user position
Nicotine concentration versus time
Period 1
1 puff/5min
during 3h
Period 2
1 puff/5min
during 4h
Starting day
Lunch time
End of day
8h
9h
10h
11h
12h
13h
14h
15h
16h
17h
18h
Time
Cumulated nicotine inhaled
21.6 µg
19.2 µg
16 µg
13.6 µg
11.2 µg
8 µg
5.6 µg
2.4 µg
0 µg
Worst case scenario = no surface deposition

Room

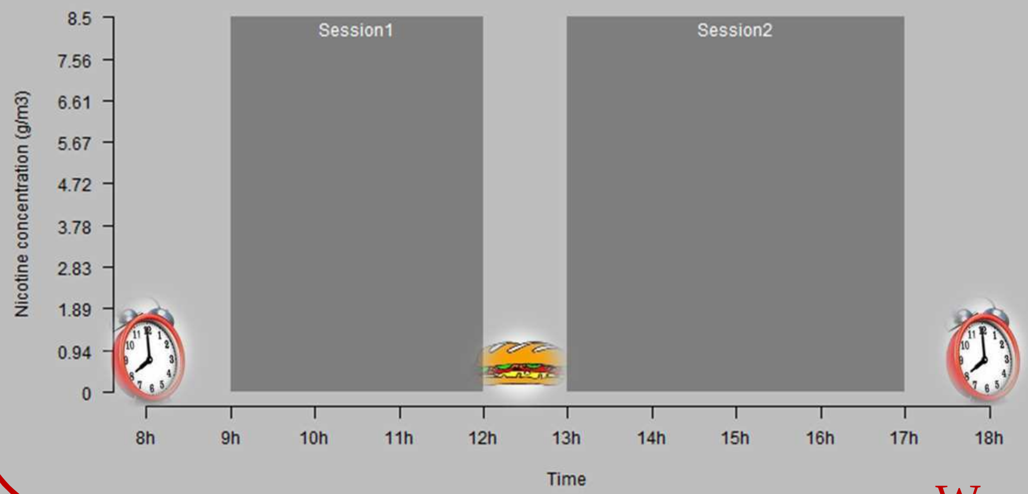


Time

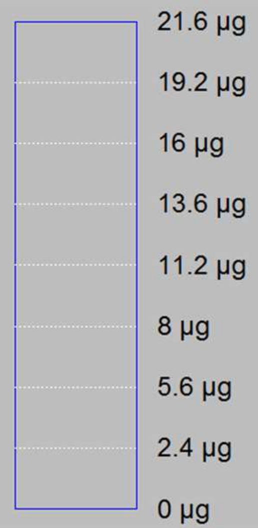


Non user position

Nicotine concentration versus time

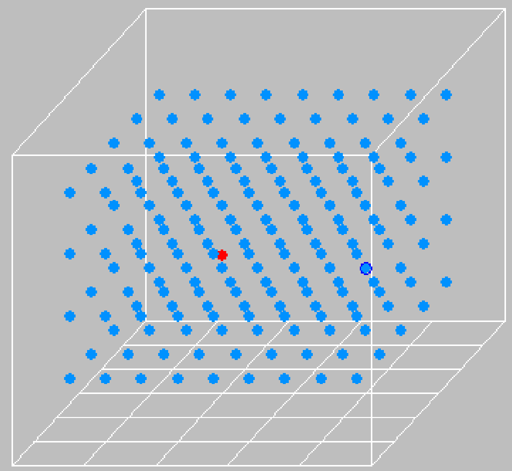


Cumulated nicotine inhaled

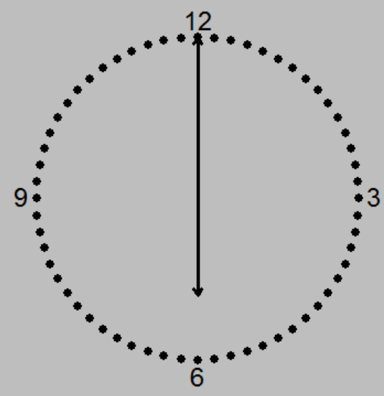


Worst case scenario = no surface deposition

Room

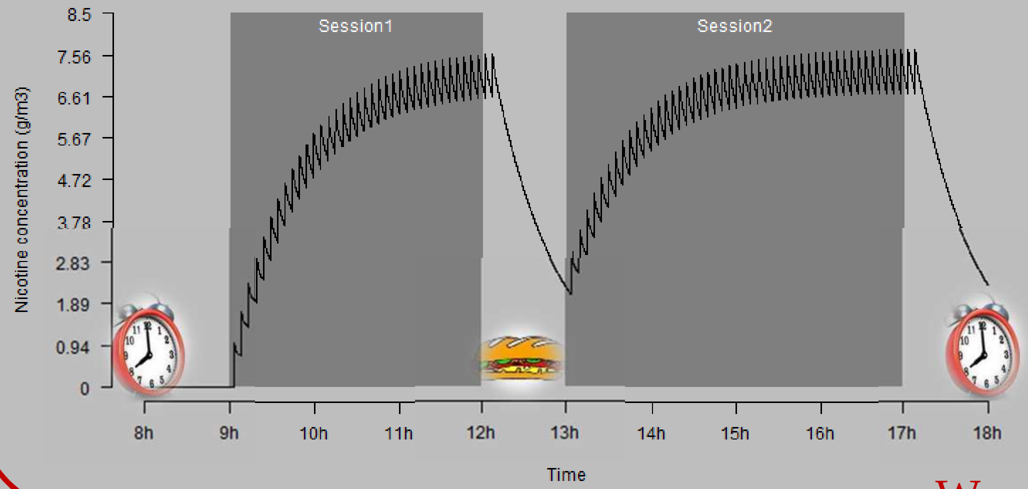


Time

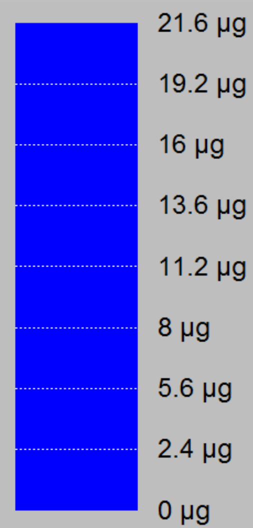


Non user position

Nicotine concentration versus time



Cumulated nicotine inhaled



Worst case scenario = no surface deposition

Comparison Predictions / Measurements

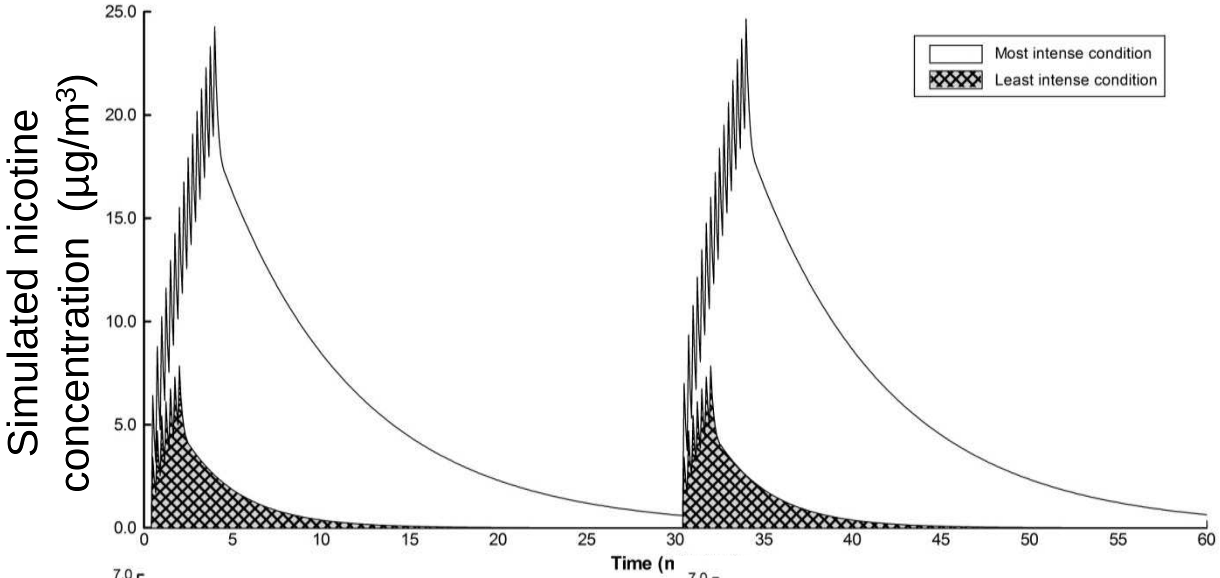
Imperial Tobacco

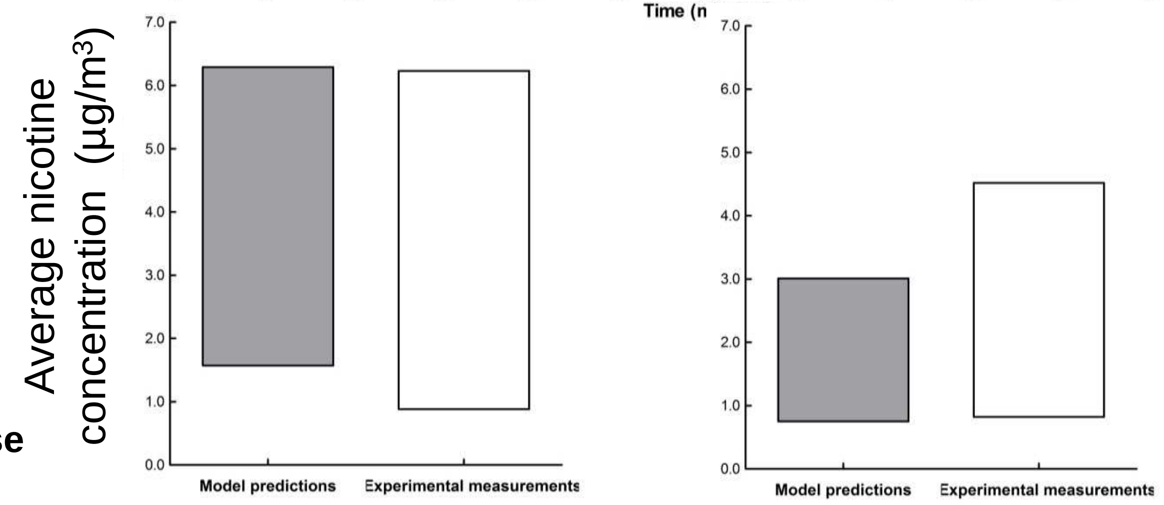
Czogala et al, 2014*

Puff N° per session	ACH (h^{-1})	Product
7	12.6	EC1
7	12.6	EC2
7	12.6	EC3
15	12.6	EC1
15	12.6	EC2
15	12.6	EC3
7	1.37	EC1
7	1.37	EC2
7	1.37	EC3
15	1.37	EC1
15	1.37	EC2
15	1.37	EC3

Speed of deposition assumed constant: 0.06m/min

Is deposition lower under intense ventilation conditions??

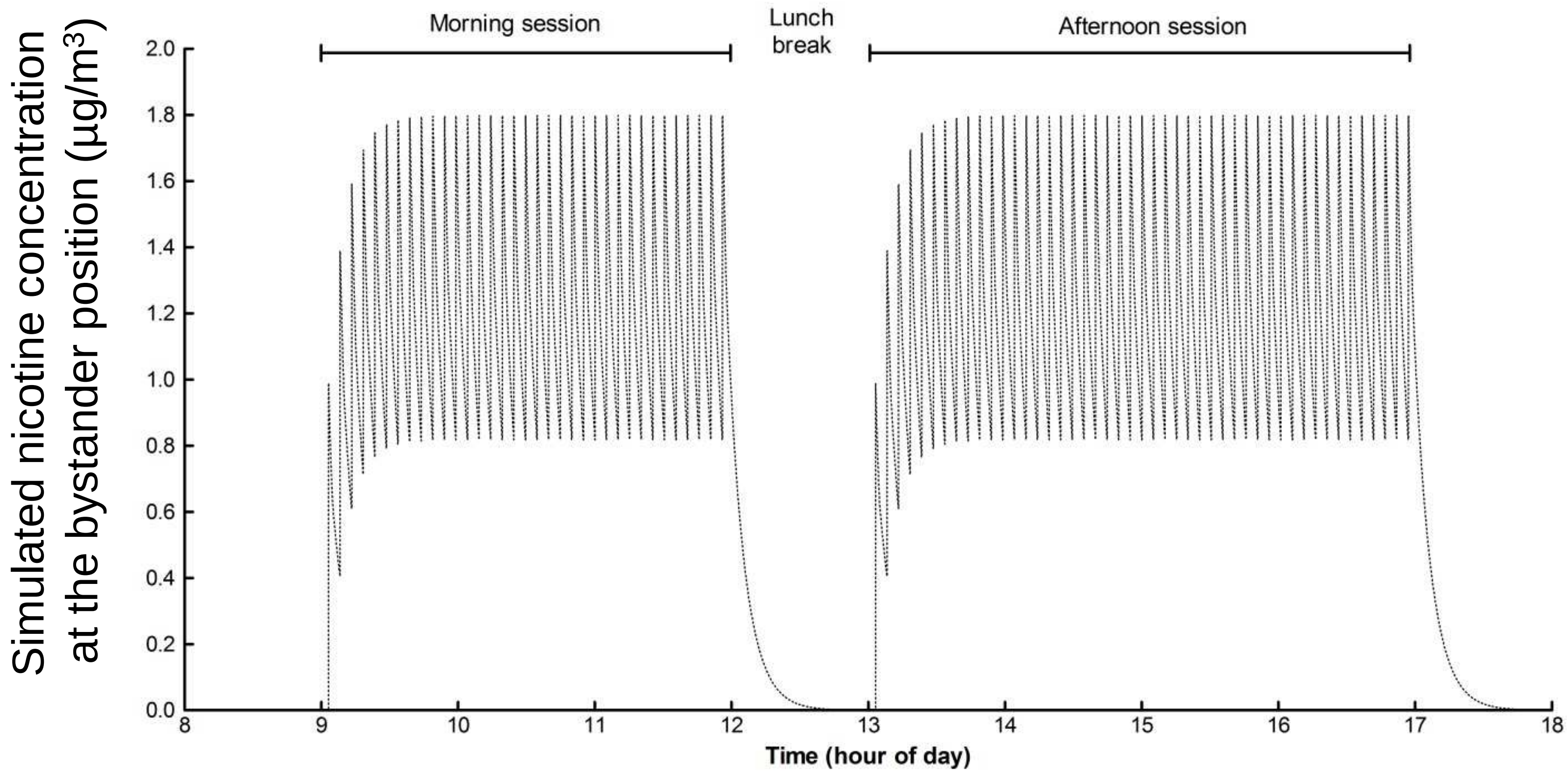




Low room ventilation   Intensive room ventilation

*Czogala, J., M.L. Goniewicz, B. Fidelus, W. Zielinska-Danch, M.J. Travers, and A. Sobczak. 2014. Secondhand exposure to vapors from electronic cigarettes. Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco. 16:655-662.

Profile of Exposure During a Working Day
(Previous scenario)



In the described conditions,

- The maximum Nicotine exposure over time is 1.8µg/m^3 (8h UK workplace exposure limit:500µg/m^3)
- The e-cigarette user has inhaled 6108µg of Nicotine; the bystander 1500 times less (i.e. 4µg)

The deposition velocity was supposed to be similar to the one derived from the Czogala experiment (0.06m/min)

The needs for further investigations

Phase	Study description
Inhalation/Exhalation	• Dynamic of the aerosol in the air pathways: condensation / evaporation / deposition • Range of retention rates • Typical vaping behaviours (puff volume, frequency …)
Aerosol propagation/dilution	• Dynamic of the aerosol in the air: condensation / evaporation / reaction • Typical speeds of propagation under air change regulatory conditions
User/Bystander exposure	• Exposure level of concern • Is-the distance between people a real issue?
Air exchange/Deposition	• Surface absorption/desorption dynamics versus environmental conditions (surface materials, air speed, air exchange…) • Surface chemical reactions?
Bystander dose	• Time of exposure • Breathing pattern • What's the level of concern?

Conclusions

- Modelling is cheap, fast and flexible
- A simple model reproducing the phases from e-cigarette user inhalation to bystander inhalation has been developed
- This model has shown its capacity to reproduce peak of exposure and to predict experimental measurements
- It is a powerful tool for assessing exposure in various conditions
- It can be a useful tool for informing public health decisions in the context of the current debates on vaping bans in public places

Modelling of the effect of indoor intermittent emissions produced by electronic cigarette users on exposure of bystanders.

Stéphane COLARD and Thomas VERRON

www.imperialtobaccoscience.com