AIVC International Workshop Climate Change and Resilient Ventilation
Madrid, Spain 21-22 April 2026

Personal exposure to exhaled contaminants using a personalized exhaust system integrated in a hospital bed

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Agenda

- Introduction
- Methodology
- Results
- Conclusions

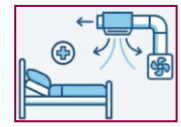
Introduction

Personal exposure to exhaled contaminants
Hospital rooms

Experimental Hospital Test Room

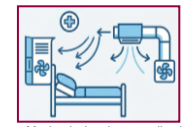
Ventilation
Natural, mechanical and personalized ventilation

Natural ventilation



Mechanical ventilation

Personalised ventilation



Mechanical and personalized ventilation

Mechanical and personalized ventilation

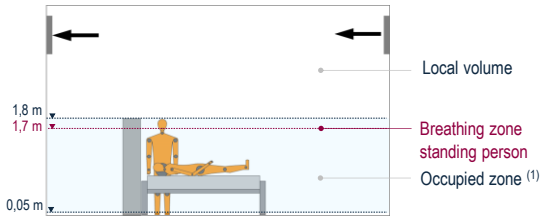
Objective

How effectively can a hospital-bed integrated personalized exhaust system reduce healthcare worker exposure to patient-exhaled contaminants under different room ventilation configurations?

Experimental methodology.

Occupied and breathing zone

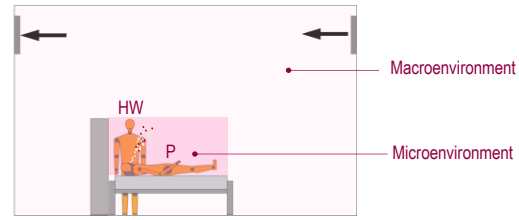
Analysis zones in a hospital room



(1) EN 16798-3:2025 Energy performance buildings - Ventilation for buildings - Part 3: For non-residential buildings.
(2) ISO 17772-1:2017. Energy performance buildings – IEQ - Part 1: Indoor environmental input parameters.

Macroenvironment and Microenvironment

Risk analysis to inhale exhaled contaminants



P: patient manikin, source of exhaled contaminants
HW: health worker manikin, target of inhaled contaminants

BTM: breathing thermal manikins:
- Breathing cycle 0.55 L of tidal volume; airflow rate 9.46 l/min.
- Respiration frequency 17.90 min-1 exhalation; 16.43 min-1 inhalation.
- Exhaled particles Di-Ethyl-Hexyl-Sebacat (DEHS) in the range 0.55–0.71 µm.
- Particles were seeded into the exhalation tube of P manikin.

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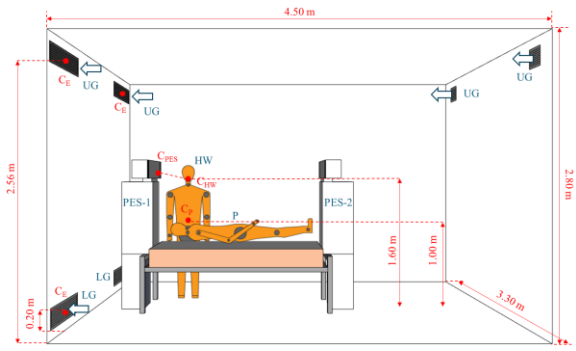
Experimental setup

Experimental chamber

Hospital room setup; volume 41.58 m³



Breathing thermal manikins

BTM exhaled contaminants (DEHS 0.55-0.71 µm) through the nose

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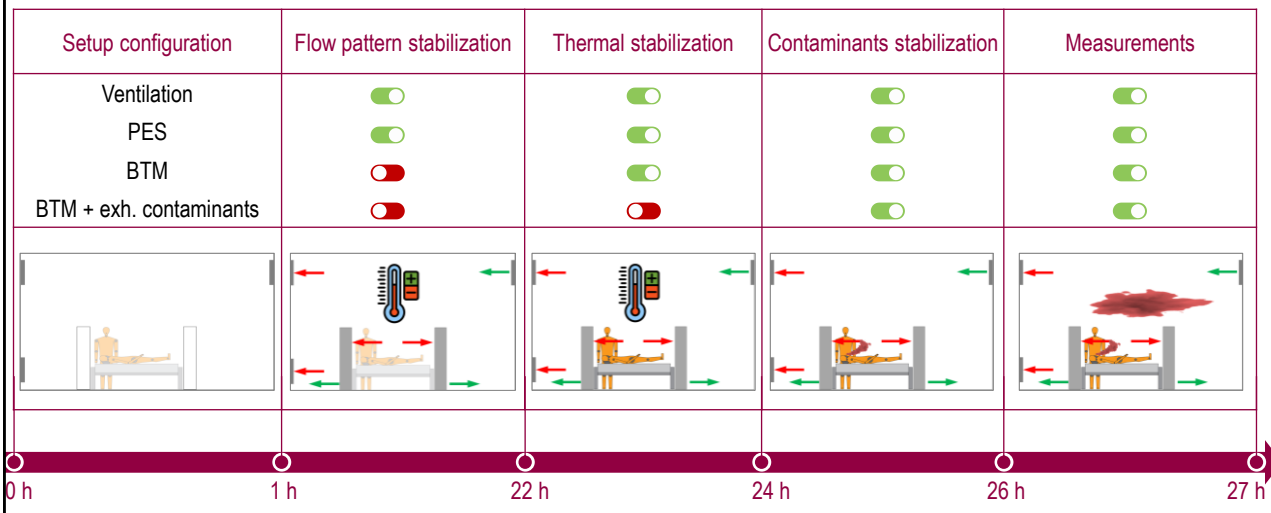
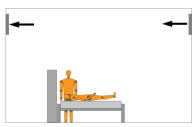
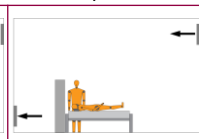
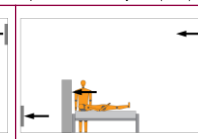
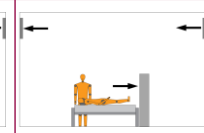
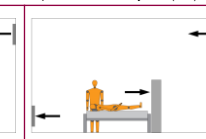
Experimental methodology. Test timeline



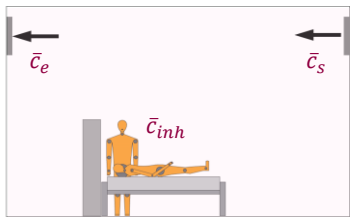
Experimental tests. 6 case studies

Only ventilation Case study a. Only general ventilation system		**Ventilation + PES1** Case study b. Ventilation system and personal exhaust system (head)		**Ventilation + PES2** Case study c. Ventilation system and personal exhaust system (foot)	
					
1a	2a	1b	2b	1c	2c
UG-UG	UG-LG	UG-UG+PES1	UG-LG+PES1	UG-UG+PES2	UG-LG+PES2
196 m^3/h (4.7 h^{-1})		98 m^3/h (2.35 h^{-1}) + 98 m^3/h (2.35 h^{-1})		98 m^3/h (2.35 h^{-1}) + 98 m^3/h (2.35 h^{-1})	

Experimental methodology. Personal exposure indices

Macroenvironment

Exposure to exhaled contaminants compared to the exhaust of the hospital room

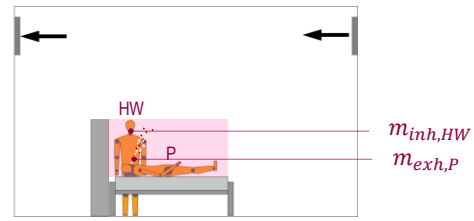


$$\varepsilon = \frac{\bar{c}_{inh} - \bar{c}_s}{\bar{c}_e - \bar{c}_s}$$

$$\varepsilon_r = \frac{\varepsilon_{test\ a} - \varepsilon_{test\ i}}{\varepsilon_{test\ a}} \cdot 100$$

Microenvironment

Intake fraction or ratio of inhaled particles of health worker to exhaled particles by patient



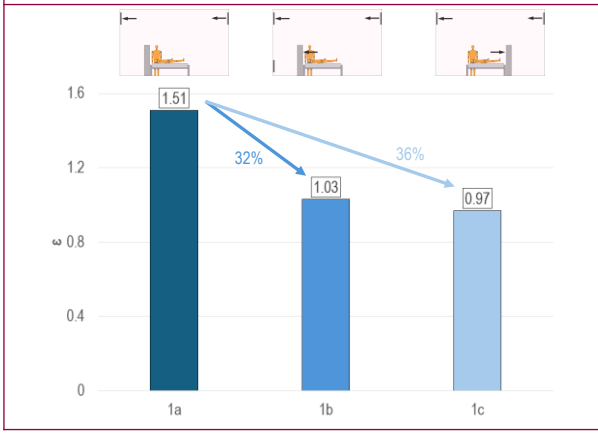
$$IF = \frac{m_{inh,HW}}{m_{exh,P}} = \frac{\int_{t_1}^{t_2} \dot{V}_{HW}(t) \cdot c_{HW}(t) \cdot dt}{\int_{t_1 0}^{t_2} \dot{V}_P(t) \cdot c_P(t) \cdot dt} \cdot 100$$

$$IF_r = \frac{IF_{test\ a} - IF_{test\ i}}{IF_{test\ a}} \cdot 100$$

Experimental results. UG-UG + PES-1/PES-2

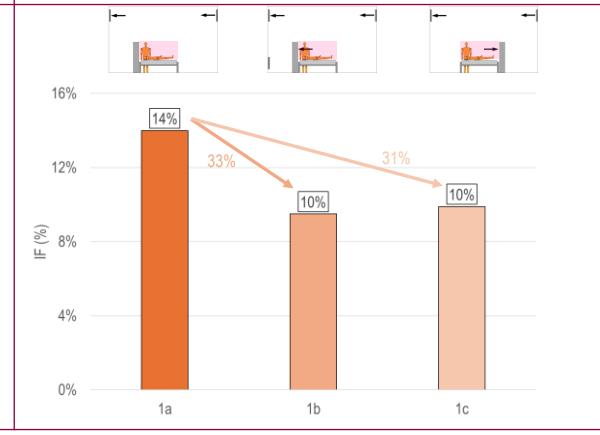
Exposure to exhaled contaminants

Upper-upper grille and PES ventilation

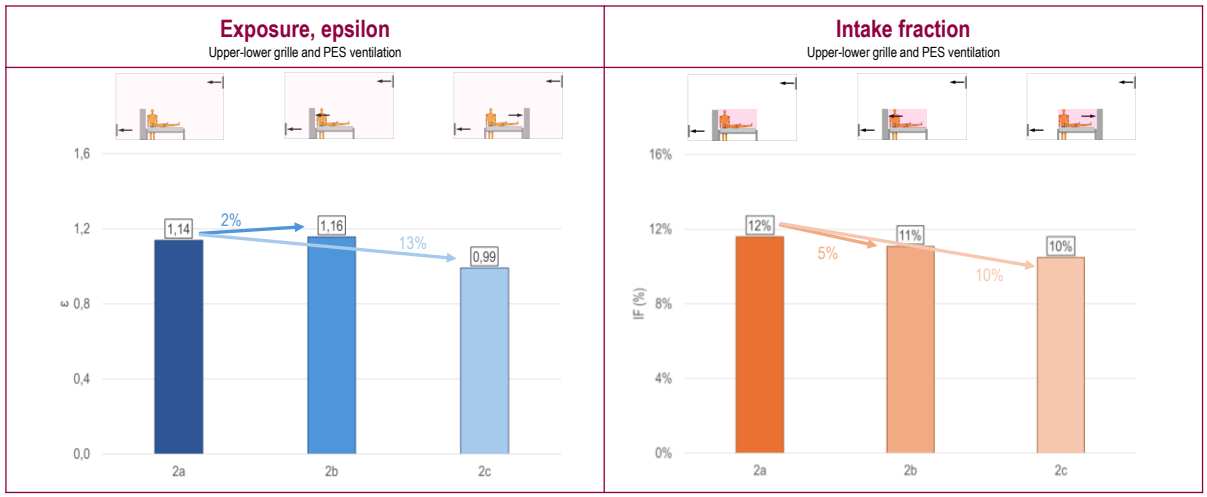


Intake fraction

Upper-upper grille and PES ventilation



Experimental results. UG-LG + PES-1/PES-2



Scientific conclusions

- General ventilation: the UG-LG configuration, with lower exhaust, improves microenvironment clearance and reduces healthcare worker exposure.
- PES macroenvironment impact (ε):
  - under poor mixing (UG-UG), the PES consistently reduces exposure by >30% regardless of whether it is installed at the head or foot of the bed;
  - under well-mixed conditions (UG-LG), its effect is smaller and is maximized only when installed at the foot of the bed.
- PES microenvironment impact (IF):
  - under UG-UG, the PES consistently reduces healthcare worker exposure by 31–33%;
  - under UG-LG its effect is smaller, achieving only 5–10% reduction.

Practical conclusions

- Optimal configuration: positioning the PES at the foot of the bed is the most robust strategy, as it captures the nose-exhaled plume earlier and more stably before it disperses into the room or the worker's breathing zone.
- Bed-integrated local exhaust strengthens general ventilation by improving near-field protection, making it a promising strategy for resilient hospital ventilation.

Acknowledgments

The authors acknowledge the financial support received from the Spanish Ministry of Science, Innovation and Universities to the National R&D project BIORISK with reference RTI2018-094703-B-I00, entitled "**Bioaerosols in hospital environments. Control and evaluation of the infection risk**". This project is financed by the European Regional Development Fund (ERDF).

Thanks for your attention!

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