



Indoor Environmental Quality in Operating Rooms and Human Behaviour

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HumanIC project has received funding from the European Union's Horizon Europe research and innovation program under the Marie Skłodowska-Curie (HORIZON-MSCA-2022-DN-01, project no 101119726)

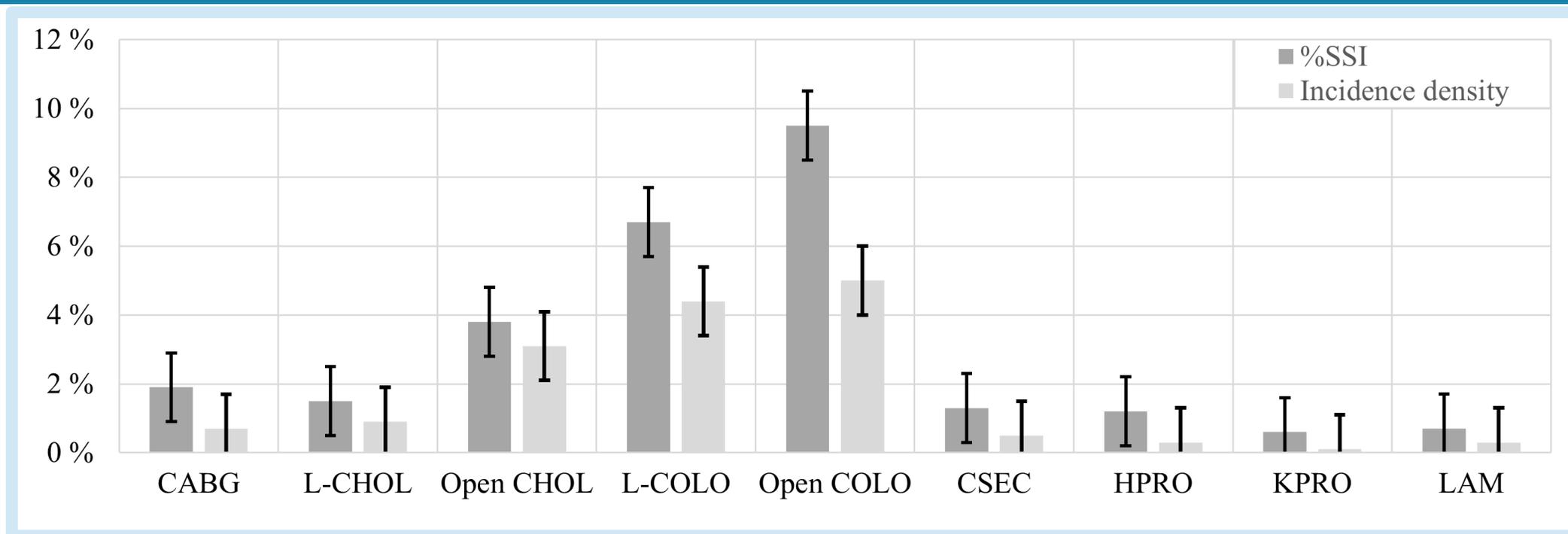


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0 Surgical Site Infections



Procedure-specific percentage and incidence density of in-hospital surgical site infections (SSI) in EU/EEA hospitals, 2018–2020



L: Laparoscopic, COLO: Colon; CSEC: Caesarean section, HPRO: Hip Prosthesis, KPRO: Knee Prosthesis, LAM: Laminectomy.

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1 Literature Review

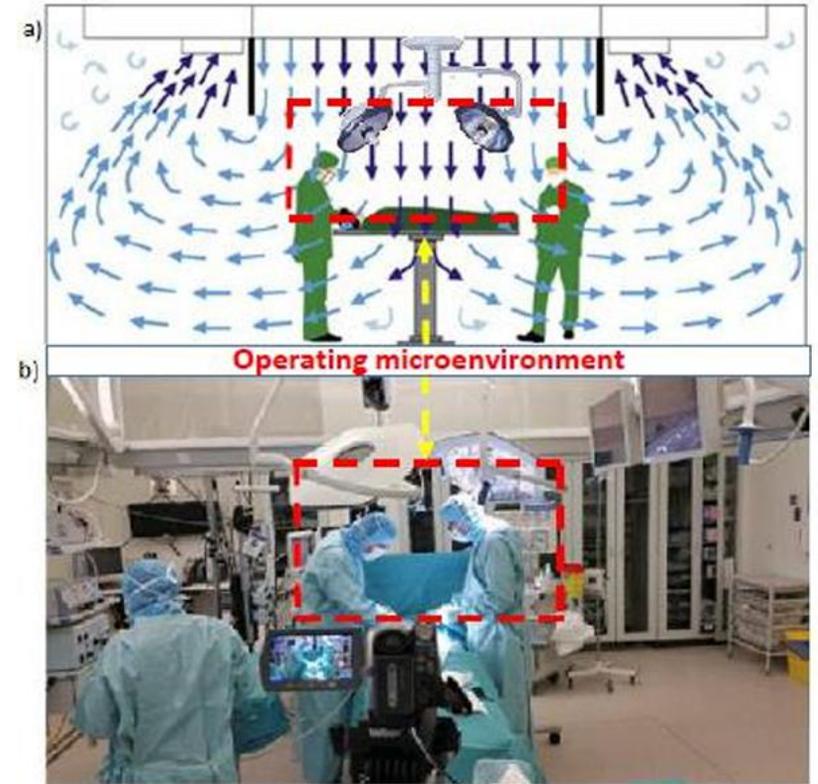


Ventilation System



Scrub suit: shirt and trousers with cuffs

- Critical zone immediately surrounding the surgical site and bounded by the patient, the surgical team, and the surgical lights. Air quality in this zone is critical for preventing SSIs caused by airborne microorganism contamination, while maintaining appropriate thermal conditions is essential to prevent intraoperative hypothermia, both of which are associated with adverse postoperative outcomes.

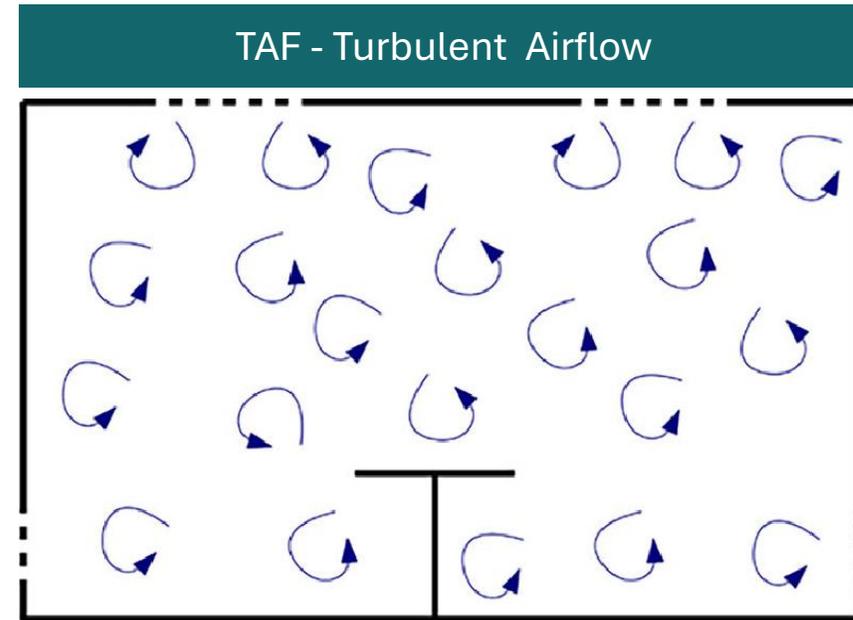
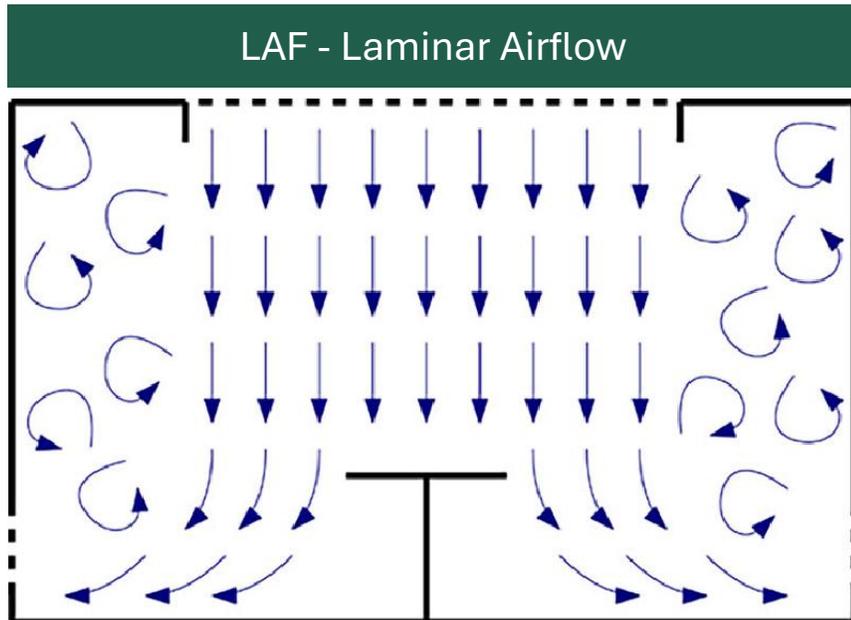


Aganovic, A., 2019. Airflow distribution for minimizing human exposure to airborne contaminants in healthcare facilities. NTNU: Trondheim, Norway.

1 Literature Review



A Ventilation System



Hofer, V., Hartmann, A., Rotheudt, H., Zielke, B. and Kriegel, M., 2022. Disturbance of a laminar air flow caused by differently shaped surgical lights. *International Journal of Ventilation*, 21(3), pp.213-228.

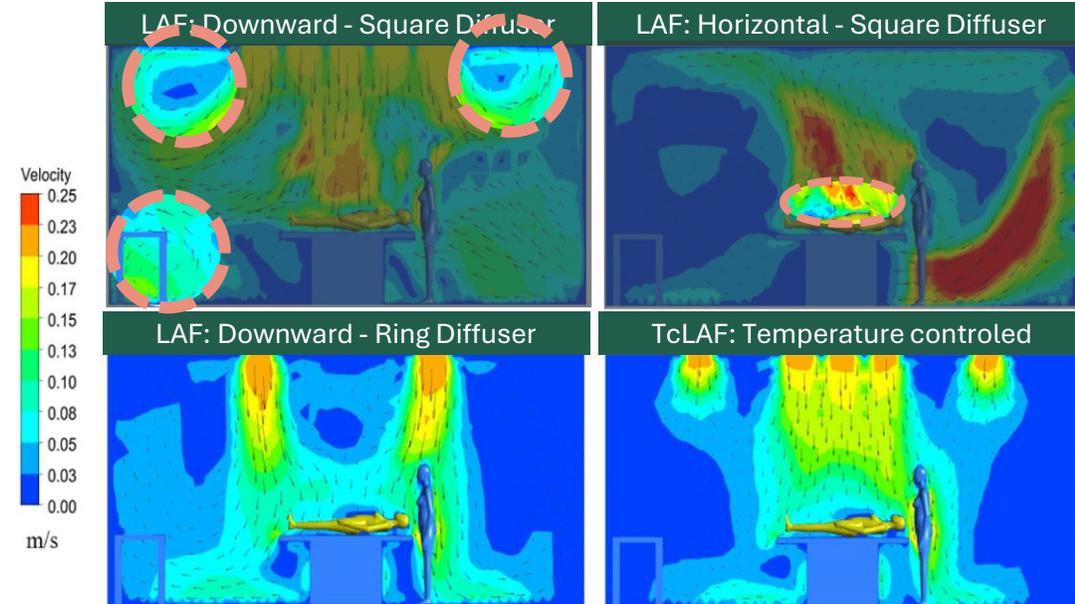
1 Literature Review



A Ventilation System Room Layout

| Ventilation system | | Room geometry | | Supply diffuser characteristics | | Exhaust grill characteristics | |
|--------------------|-----------------|--------------------|------------------------------|---------------------------------|------------------------------------|-------------------------------|-------------------------------------|
| | | Height [m] | Floor area [m ²] | Quantity | Area (per inlet) [m ²] | Quantity | Area (per outlet) [m ²] |
| TAF | No. of mentions | 7 | 7 | 6 | 5 | 7 | 4 |
| | % of mentions | 58.33 | 58.33 | 50 | 41.67 | 58.33 | 33.33 |
| | mean | 3.10 ± 0.18 | 51.53 ± 13.53 | 8.33 ± 7.84 | 0.26 ± 0.13 | 5.14 ± 2.61 | 0.17 ± 0.18 |
| LAF | No. of mentions | 11 | 10 | 11 | 10 | 9 | 6 |
| | % of mentions | 91.67 | 83.33 | 91.67 | 83.33 | 75.00 | 50.00 |
| | mean | 2.94 ± 0.26 | 39.72 ± 15.75 | 1.09 ± 0.30 | 6.11 ± 2.69 | 6.11 ± 2.32 | 0.25 ± 0.24 |

* The data presented in this table is currently under further development



Liu, Z., Yin, D., Hu, L., He, J. and Cao, G., 2022. Bacteria-carrying particles diffusion in the operating room due to the interaction between human thermal plume and ventilation systems: An experimental-numerical simulation study. Energy and Buildings, 270, p.112277.

1 Literature Review



Ventilation System

Environmental control parameters

$$\dot{V}_{total|in} = ACH \cdot V_{room} = \sum_{i=1}^{n|in} \dot{V}|_{in_i} \quad \dot{V}|_i = 3600 \cdot \bar{v}|_i \cdot A|_i \quad , \quad i = in, out$$

| Ventilation system | | Supply characteristics | | | | | Exhaust characteristics | | | Differential Pressure | |
|--------------------|-----------------|--------------------------|------------------|---------------------------------------|------------------------|-------------------------------|-------------------------|---------------------------|--------------------------------|-----------------------|------------------------|
| | | Kinematic properties | | | Hygrometric properties | | Kinematic properties | | Hygrometric properties | | |
| | | Volumetric Airflow Rate | Air Change Rate | Mean Air Velocity | Turbulence Intensity | Mean Air Dry Bulb Temperature | Relative Humidity | Volumetric Airflow Rate | Mean Air Dry Bulb Temperature | | Relative Humidity |
| | | $V_{total in} [m^3/(h)]$ | ACH [h^{-1}] | $v _{in} [m/s]$ (on each diffuser) | $TI _{in}$ | $T_{db,ha} _{in} [^{\circ}C]$ | $\phi_{ha} _{in} [%]$ | $V_{total out} [m^3/(h)]$ | $T_{db,ha} _{out} [^{\circ}C]$ | | $\phi_{ha} _{out} [%]$ |
| TAF | No. of mentions | 6 | 8 | 4 | 0 | 4 | 1 | 1 | 1 | 0 | 6 |
| | % of mentions | 50 | 66.67 | 33.33 | 0 | 33.33 | 8.33 | 8.33 | 8.33 | 0 | 50 |
| | mean | 4593.91 ± 3004.24 | 27.17 ± 15.42 | 1.02 ± 1.08 | --- | 21.76 ± 2.74 | 72.39 | 3481.75 | 24.00 | --- | 4593.91 ± 3004.24 |
| LAF | No. of mentions | 8 | 8 | 9 | 0 | 8 | 1 | 1 | 0 | 0 | 2 |
| | % of mentions | 66.67 | 66.67 | 75.00 | 0 | 66.67 | 8.33 | 8.33 | 0 | 0 | 16.67 |
| | mean | 5079.64 ± 2647.75 | 42.37 ± 14.23 | 0.27 ± 0.11 | --- | 19.45 ± 2.34 | 72.40 | 8067.20 | --- | --- | 6.25 ± 5.30 |

* The data presented in this table is currently under further development

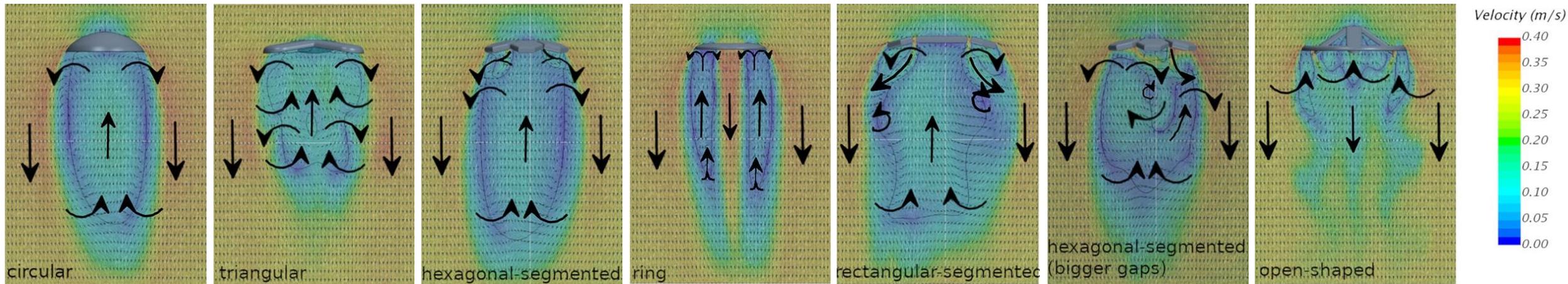


1 Literature Review



A Ventilation System

Surfaces



Hofer, V., Hartmann, A., Rotheudt, H., Zielke, B. and Kriegel, M., 2022. Disturbance of a laminar air flow caused by differently shaped surgical lights. *International Journal of Ventilation*, 21(3), pp.213-228.

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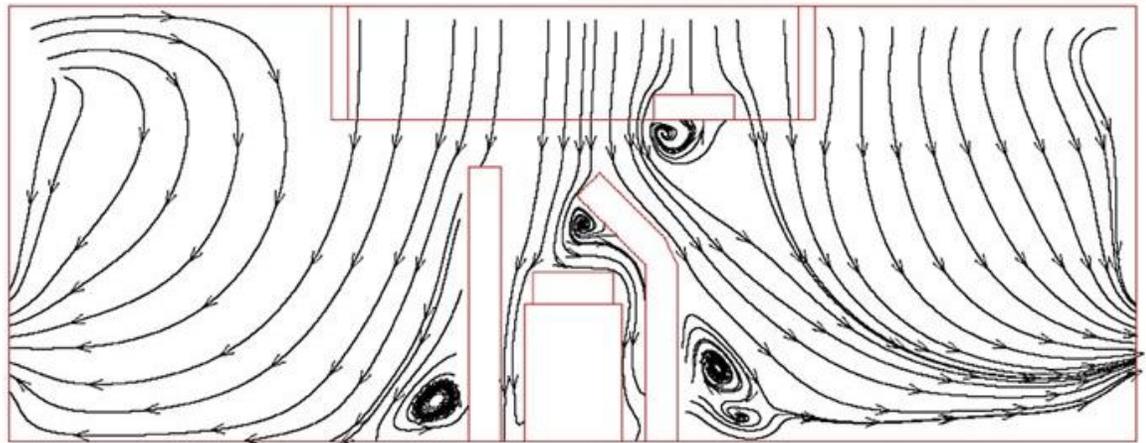
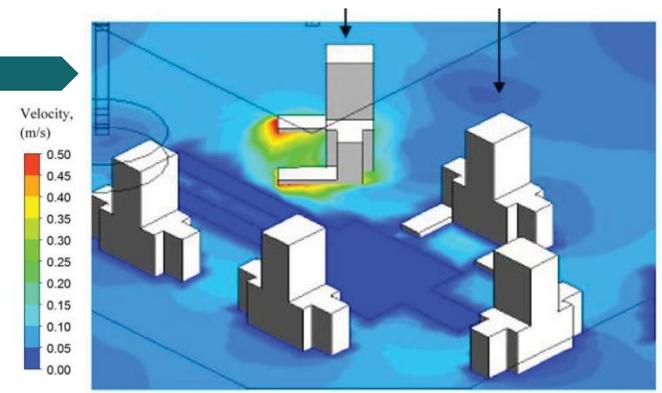
1 Literature Review



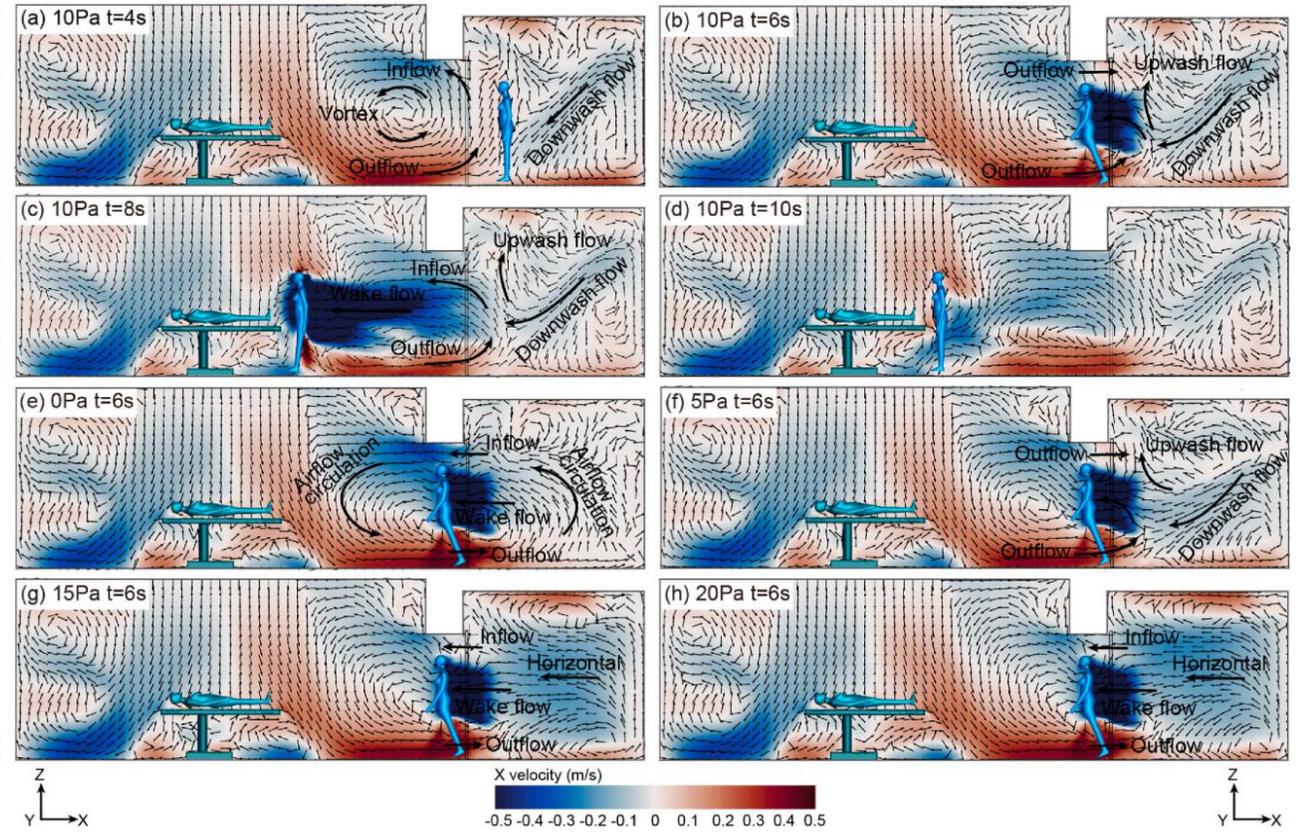
A Ventilation System

Human behaviour

Kamar, H.M., Wong, K.Y. and Kamsah, N., 2020. The effects of medical staff turning movements on airflow distribution and particle concentration in an operating room. *Journal of Building Performance Simulation*, 13(6), pp.684-706.



Chow, T.T. and Wang, J., 2012. Dynamic simulation on impact of surgeon bending movement on bacteria-carrying particles distribution in operating theatre. *Building and environment*, 57, pp.68-80.



Liu, H., Liu, Z., He, J., Hu, C. and Rong, R., 2024. Interfacial exchange of airflow and bacteria-carrying particles induced by door opening and foot traffic in an operating room. *Building and Environment*, 262, p.111812.



1 Literature Review



B Clothing System



Bogdan, A., Sudol-Szopińska, I. and Szopiński, T., 2011. Assessment of textiles for use in operating theatres with respect to the thermal comfort of surgeons. *Fibres & Textiles in Eastern Europe*, 19(2), pp.65-9.

Scrub suit: shirt and trousers with cuffs

- Microbial concentration is lower in cotton–polyester scrubs than in cotton scrubs.
- Microbial concentration is reduced when the shirt is tucked into the trousers, which in turn are tucked into the footwear and are combined with scuffs.

Surgical mask

- Despite reducing microbial concentration directly in front of the mouth, surgical masks merely redirect exhaled airflow and respiratory airborne particles, and do not reduce overall microbial counts in the operating room, making it unclear if they reduce surgical site infection rates.

Body exhaust gown

- Contradicting results regarding the effectiveness of the body exhaust system have shown better performance in reducing surgical site infection and microbial concentration next to the wound than standard head coverings.

Head covering: skull cap, or bouffant hat, or hood

- No clear result regarding the effectiveness of head covering in containing microbial fallout from the hair, scalp, and ears.
- In LAF-equipped rooms, the use of head covering gear reduces microbial concentration.

Gloves

- Surgical Site Infections are reduced with the wearing of gloves.
- No clear result regarding whether double-gloving has better performance in reducing surgical site infection than single-gloving.
- Multiple layers reduce the perforation in the inner glove.

Gown

- No clear result regarding whether reusable gowns have better performance in reducing surgical site infection than single-use gowns.

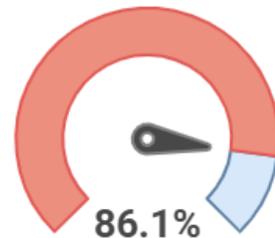


1 Literature Review

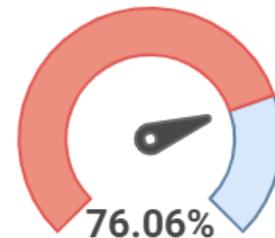


B Clothing System Thermal comfort

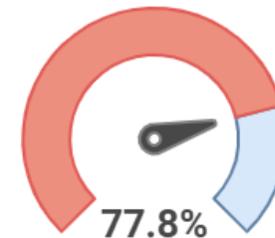
Confort assessment within the surgery team



Surgeons Perceive Thermal Environment as Uncomfortable



Surgeons Prefer Cooler Operating Room Conditions



Respondents Perceive Garments as Damp or Wet

Made with Napkin

Survey conducted by:

Ćwiklińska, D., Bogdan, A. and Szyłak-Szydłowski, M., 2022. Survey on factors influencing surgeons' sensation in Polish operating theatres. *Building and Environment*, 214, p.108929.



1 Literature Review



B Clothing System Thermal comfort

| Components | Usage | Fabric material: | Fabric structure | Weight | Penetration | Thermal insulation, I_{cl} [clo] |
|-----------------------------|---------------------------------------|--|--|------------------------|--|---|
| Scrub suit | Reusable | 69 % cotton, 30 % polyester, 1 % carbon fibre | Plain weave with 47 threads/cm warp and 26 threads/cm weft | 150 g/m ² | Microbial penetration - dry \leq 300 CFU | n. r. |
| | Single-use | Inner layer: 70 % viscose, 30 % polyester | n. r. | 30 g/m ² | Microbial penetration - dry \leq 100 CFU | n. r. |
| | | Outer layer: Spunbond Meltblown Spunbond Polypropylene | Tri-laminate non-woven fabric with top layer of spunbond polypropylene, a middle layer of meltblown polypropylene and a bottom layer of spunbond polypropylene | 35 g/m ² | | |
| | Reusable | 98 % olefin, 2 % carbon fibre | n. r. | 125 g/m ² | n. r. | n. r. |
| Reusable | n. r. % polyester, n. r. % coal fibre | n. r. | n. r. | n. r. | n. r. | parallel - 0.794 clo; series - 0.994 clo |
| Gown | Reusable | Front and sleeves: liquid-proof fabric of higher resistance; Remainder of gown: n.r. % polyester, n.r. % carbon fibre | n. r. | 300 g | n. r. | parallel - 0.974 clo; series - 1.303 clo |
| | Reusable | Front and sleeves: PTFE (polytetrafluoroethylene); Remainder of gown: n.r. % polyester, n.r. % carbon fibre | Front and sleeves: laminated membrane; Remainder of gown: n. r. | n. r. | n. r. | parallel - 1.032 clo; series - 1.406 clo |
| | Single-use | n.r. % cotton, n. r. % of other material | n. r. | n. r. | n. r. (not complied with Standard No. EN 13795:2011 due to lack of resistance to microbial penetration) | parallel - 1.071 clo; series - 1.490 clo |
| Surgical mask | Reusable | 100 % Cotton | Three-layer knit with 45 threads per inch | 111.5 g/m ² | 98.9 % for particles with 100 nm of diameter | n. r. |
| | Single-use | n.r. % polypropylene | non-woven | 53.9 g/m ² | 98.5 % for particles with 100 nm of diameter | n. r. |
| Head covering: hood | Reusable | 98 % olefin, 2 % carbon fibre | n. r. | 125 g/m ² | n. r. | n. r. |
| Footwear: knee-length boots | Reusable | 98 % olefin, 2 % carbon fibre | n. r. | 125 g/m ² | n. r. | n. r. |

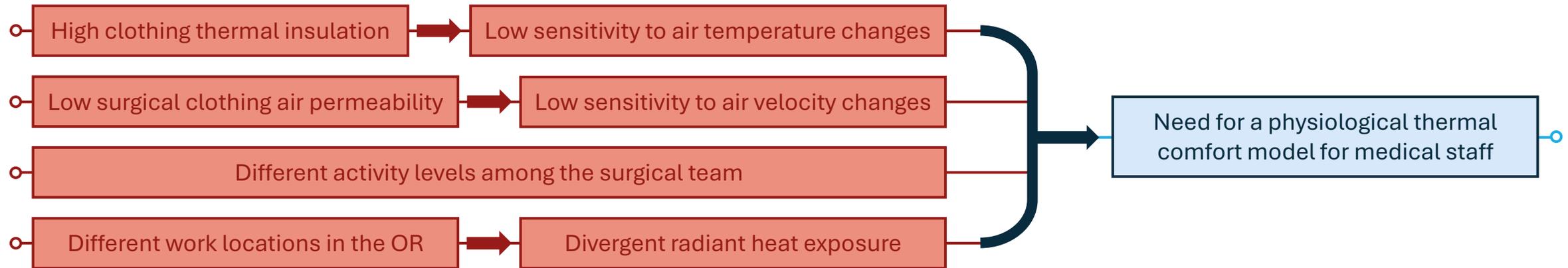
* The data presented in this table is currently under further development



1 Literature Review



B Clothing System Thermal comfort

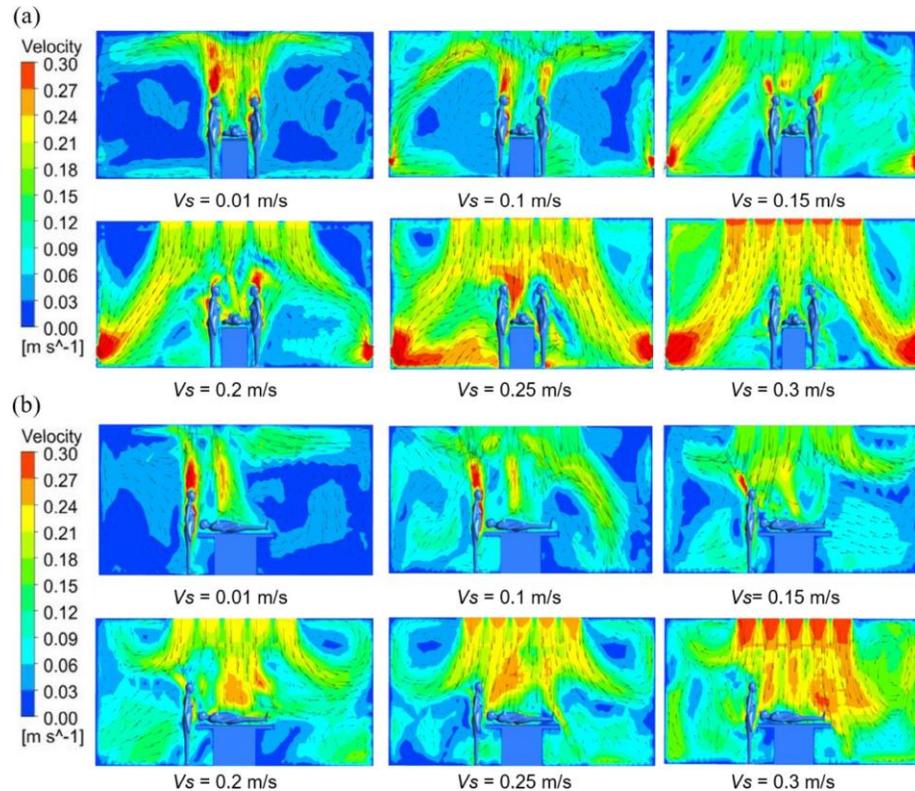


1 Literature Review

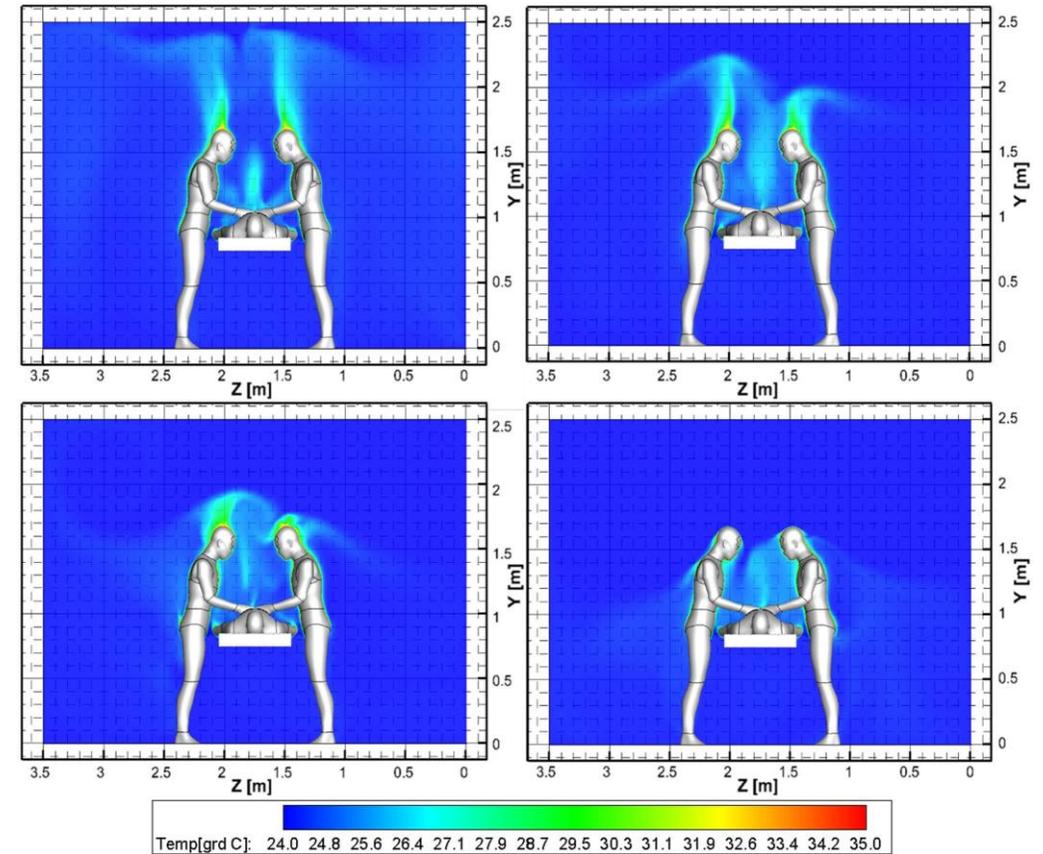


B Clothing System

Convective flows



Liu, Z., Yin, D., Niu, Y., Cao, G., Liu, H. and Wang, L., 2022. Effect of human thermal plume and ventilation interaction on bacteria-carrying particles diffusion in operating room microenvironment. *Energy and Buildings*, 254, p.111573.



Tacutu, L., Bode, F., Năstase, I., Croitoru, C. and Dogeanu, A., 2022. Experimental and numerical study on the thermal plumes of a standing and lying human in an operating room. *Science and Technology for the Built Environment*, 28(1), pp.2-20.



Literature Review



Standards | Guidelines

| Standard/design guideline of interest | Supply characteristics | | | | | | Exhaust characteristics | | | | Pressure | Overall room | Overall biological |
|---|--|---|--|---------------------------------|--|------------------------------------|--|---|-------------------------------------|--|----------|--|--|
| | Kinematic properties | | | Hygrometric properties | | | Kinematic properties | | Hygrometric properties | | | kinematic | properties |
| | Volumetric Airflow Rate, $V_{total,in}$ [m ³ /(h)] | Air Change Rate, ACH [h ⁻¹] | Mean Air Velocity, v_{in} [m/s] | Turbulence Intensity, TI_{in} | Mean Air Dry Bulb Temperature, $T_{db,ha,in}$ [°C] | Relative Humidity, ϕ_{in} [%] | Volumetric Airflow Rate, V_{out} [m ³ /(h)] | Mean Air Dry Bulb Temperature, $T_{db,ha,out}$ [°C] | Relative Humidity, ϕ_{out} [%] | Specific Humidity, $W_{ha,out}$ [g./kg _{da}] | | Air Velocity v_{ex} [m/s] | Airborne microbiological concentration [CFU/m ³] |
| Guideline - Poland: Design guidelines for hospitals | - | - | LAF: [0.4 ; 0.5] MTAF: [0.15 ; 0.25] | - | - | - | - | [22 ; 25] | 55 ± 5 | - | - | - | |
| Technical specification/guideline - Portugal: Technical Specifications for HVAC Installations in Hospital Buildings – ET 06/2008 | - | - | - | - | - | - | - | [17 ; 27] | [30 ; 60] | - | - | - | |
| Standard – United States (widely adopted internationally): ASHRAE 170 (2008, 2013, 2021). Ventilation of Health Care Facilities | 51 (outdoor air requirements for acceptable indoor air quality per person, regardless of the ventilation system) | - | LAF: [0.13 ; 0.18] | - | - | - | - | [20 ; 24] | [20 ; 60] | - | - | - | |
| Technical report – Europe: FprCEN/TR 16244:2011. Ventilation for hospitals | - | - | LAF: ≥ 0.25 (measured 0.3 m below the supply diffuser) | - | [20 ; 24] | - | - | - | [6.5 ; 11.5] | - | - | LAF: • local: [0.23 ; 0.45] MTAF: • local: < 0.19 (during summer season) | |
| Standard – Germany: DIN 1946-4:2008. Ventilation and air conditioning – Part 4: VAC systems in buildings and rooms used in the health care sector | - | - | ≤ 0.23 | - | [19 ; 26] $T_{db,ha,in} < T_{db,ha,out}$ | - | - | [19 ; 26] | - | - | - | LAF: • average: [0.23 ; 0.25] (measured 1.2 m above floor level) MTAF: • local: < 0.19 (during summer season) | |
| Standard – Worldwide: ISO 7730:2005. Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria | - | - | - | - | - | - | - | - | [30 ; 70] | - | - | - | |
| Technical memorandum/guideline – United Kingdom: Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises | - | - | - | - | - | - | - | - | - | - | - | LAF: • local: < 10 | |
| Technical specification – Sweden: SIS-TS 39:2015. Microbiological cleanliness in the operating room - Preventing airborne contamination - Guidance and fundamental requirements | - | - | - | - | - | - | - | - | - | - | - | • local: < 10 (regardless of the ventilation system) | |
| Technical handbook – United States (widely used internationally): ASHRAE Applications Handbook (HVAC Applications) | - | - | [1.3 ; 1.8] | - | - | - | - | [17 ; 27] | [45 ; 60] | - | - | - | |
| Guideline – United States: AIA Guidelines for Design and Construction of Hospitals and Health Care Facilities | - | - | - | - | - | - | - | [20 ; 23] | [45 ; 55] | - | - | - | |
| Standard – China: GB 50333-2013. Architectural technical code for hospital clean operating department | - | - | - | - | - | - | - | - | - | - | - | LAF: • local: - • average: [0.20 ; 0.25] (measured in the surgical area) | |

* The data presented in this table is currently under further development





Thank you!

The presentation will be made public on the:
Future hospitals - Open Resource Training Platform

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