Safety inside the Operating Room – an overview of the factors influencing a Healthy Surgical Microenvironment

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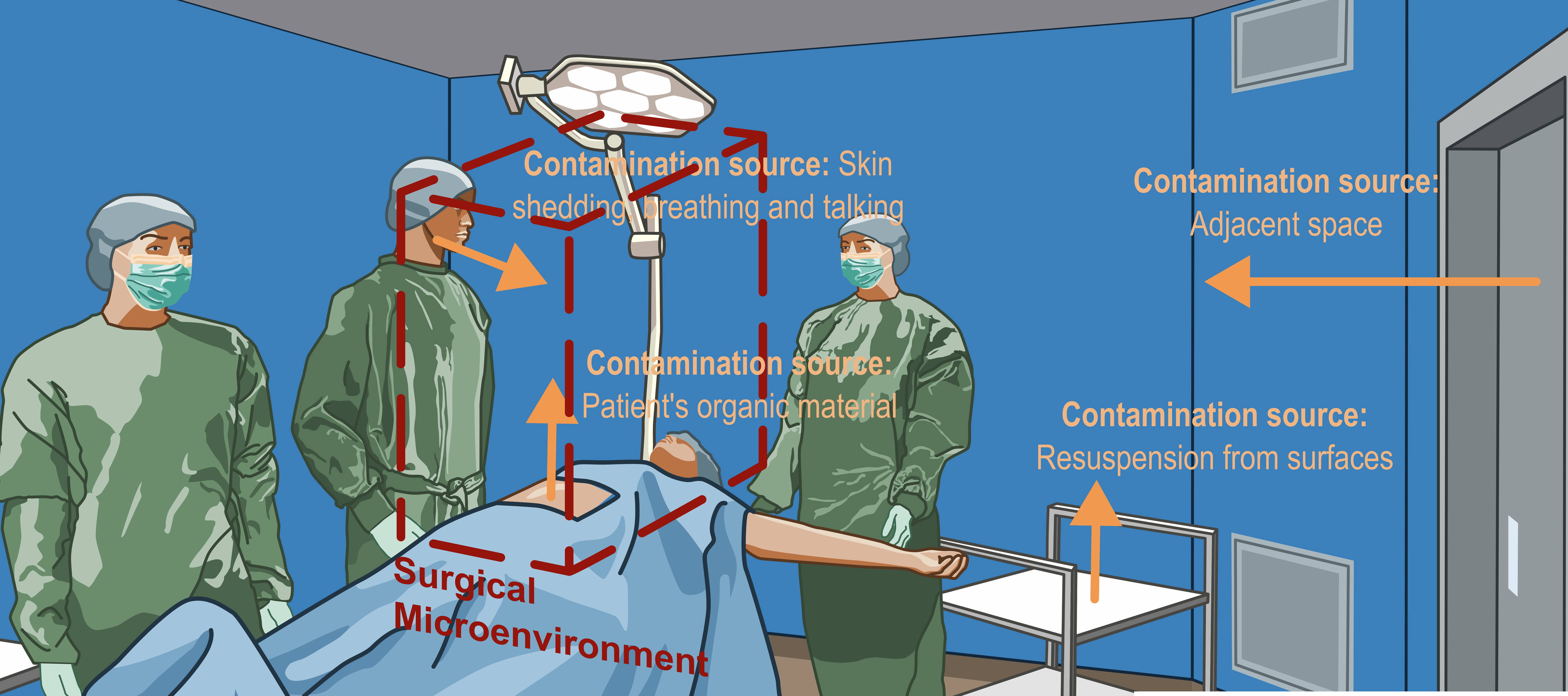
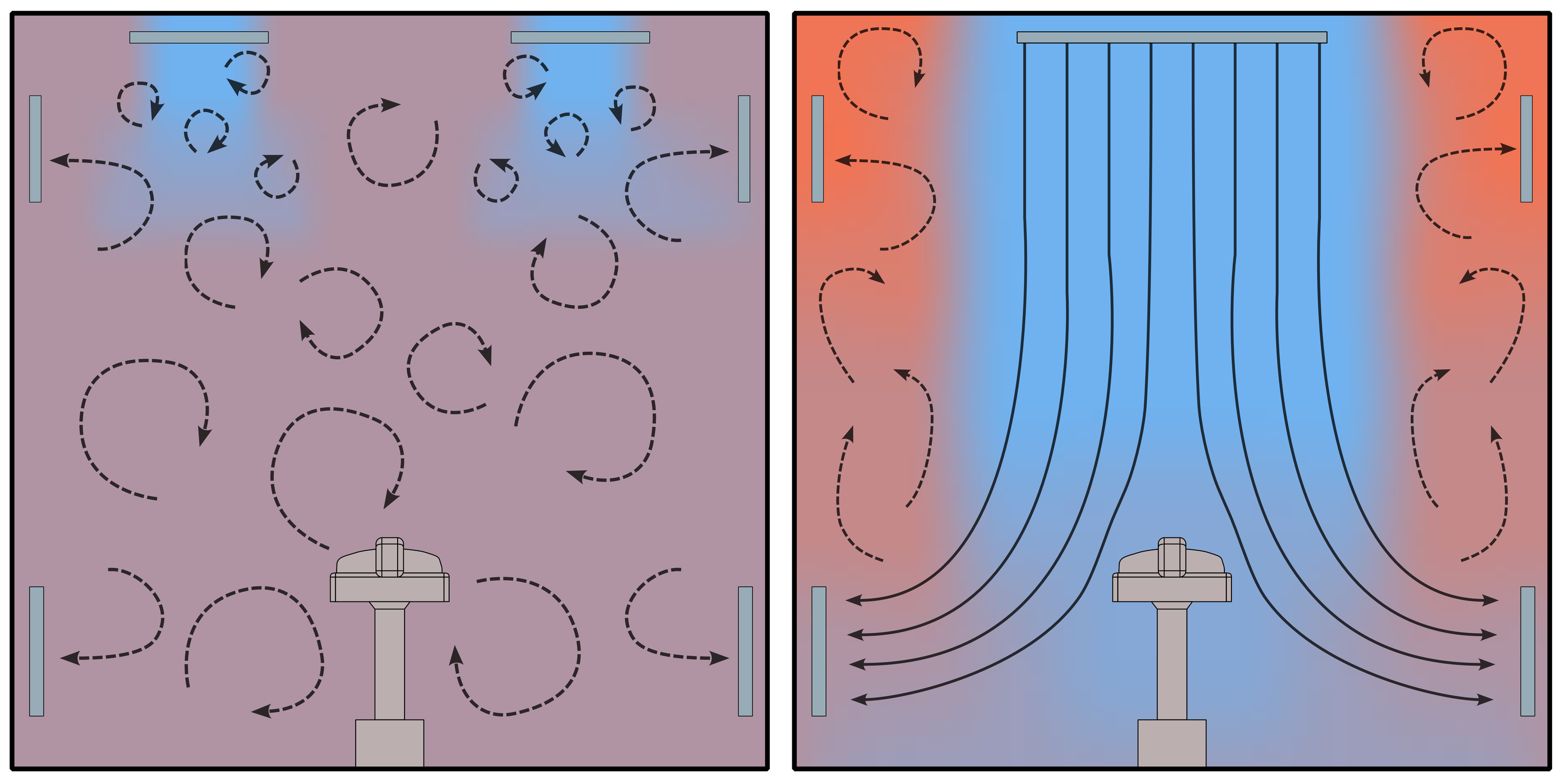
Ventilation system		Supply characteristics						Exhaust characteristics			Differential Pressure
		Kinematic properties				Hygrometric properties		Kinematic properties	Hygrometric properties		
		Volumetric Airflow Rate $V_{total}\|_{in}$ [m³/(h)]	Air Change Rate ACH [h⁻¹]	Mean Air Velocity $v\|_{in}$ [m/s] (on each diffuser)	Turbulence Intensity $TI\|_{in}$	Mean Air Dry Bulb Temperature $T_{db,ha}\|_{in}$ [°C]	Relative Humidity $\varphi_{ha}\|_{in}$ [%]	Volumetric Airflow Rate $V_{total}\|_{out}$ [m³/(h)]	Mean Air Dry Bulb Temperature $T_{db,ha}\|_{out}$ [°C]	Relative Humidity $\varphi_{ha}\|_{out}$ [%]	ΔP [Pa]
TAF	No. of mentions	10	14	4	0	5	1	2	3	1	4
	% of mentions	52.63157895	73.68	21.05	0	26.32	5.26	10.53	15.79	5.26	21.05263158
	mean	4403.64 ± 2560.77	26.04 ± 11.83	1.02 ± 1.08	---	21.41 ± 2.50	72.39	3390.88 ± 128.52	23.67 ± 0.58	40.00	7.68 ± 4.89
UDAF	No. of mentions	15	15	16	0	13	1	3	3	1	3
	% of mentions	75.00	75.00	80.00	0	65.00	5.00	15.00	15.00	5.00	15.00
	mean	6319.62 ± 3286.28	46.13 ± 21.28	0.27 ± 0.10	---	19.57 ± 1.80	72.40	4691.62 ± 2923.41	21.33 ± 0.58	28.00	12.50 ± 11.46

Ventilation system		Supply diffuser characteristics		Exhaust grill characteristics	
		Quantity	Area, [m²/diffuser]	Quantity	Area, [m²/grille]
TAF	No. of mentions	8	5	9	4
	% of mentions	42.11	26.32	47.37	21.05
	mean	9.75 ± 8.91	0.26 ± 0.13	4.89 ± 2.32	0.17 ± 0.18
UDAF	No. of mentions	18	16	15	10
	% of mentions	90.00	80.00	75.00	50.00
	mean	1.28 ± 0.96	6.86 ± 2.63	5.49 ± 2.95	0.26 ± 0.24

Guideline	Supply Volumetric Airflow Rate, $V_{total}\|_{in}$ [m³/h]	Air Change Rate, ACH [h⁻¹]	Mean Air Dry Bulb Temperature, $T_{db,ha}\|_{out}$ [°C]	Relative Humidity, $\varphi_{ha}\|_{out}$ [%]
Portugal: ET 06/2008	≥ 600 or 100 m³/(h·person)	≥ 5	[17 ; 27]	[30 ; 60]
United Kingdom: Health Technical Memorandum 03-01: Specialised ventilation for healthcare premises	10 L/(s·person) Notes: ▪At least 20% of fresh air when recirculated air exists.	≥ 22	20 (summer) 22 (winter)	[35; 60]
Nordic: R³ Nordic Guideline for Hospital Ventilation	≥ 990	n.r.	[18 ; 26]	< 60 (at 21 °C)
Germany: DIN 1946-4: Ventilation and air conditioning – Part 4: Ventilation in buildings and rooms of health care	For TAF: ≥ 60 m³/(h·m²|operating area) For UDAF: ≥ 900 m³/(h·m²|supply diffuser area) Notes: ▪At least 1200 m³/h of fresh air.	For TAF: ≥ 20 For UDAF: n.r.	[19 ; 26]	[30; 65]
Spain: UNE 100713	≥ 2400 Notes: ▪At least 1200 m³/h of fresh air when recirculated air exists.	≥ 20	[22 ; 26]	[45; 55]
United States: ASHRAE 170-2021: Ventilation of Health Care Facilities	n.r.	≥ 20 Notes: ▪At least 4 ACH of fresh air	[20 ; 24]	[20 ; 60]

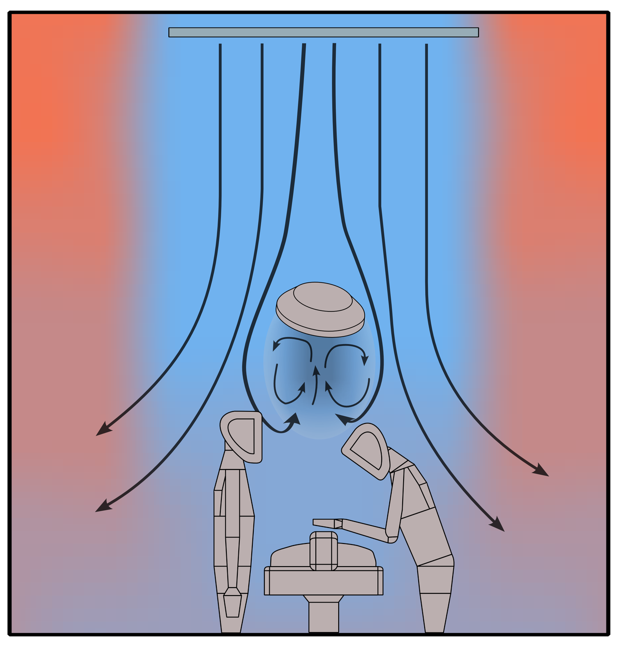




Turbulent Airflow (TAF)

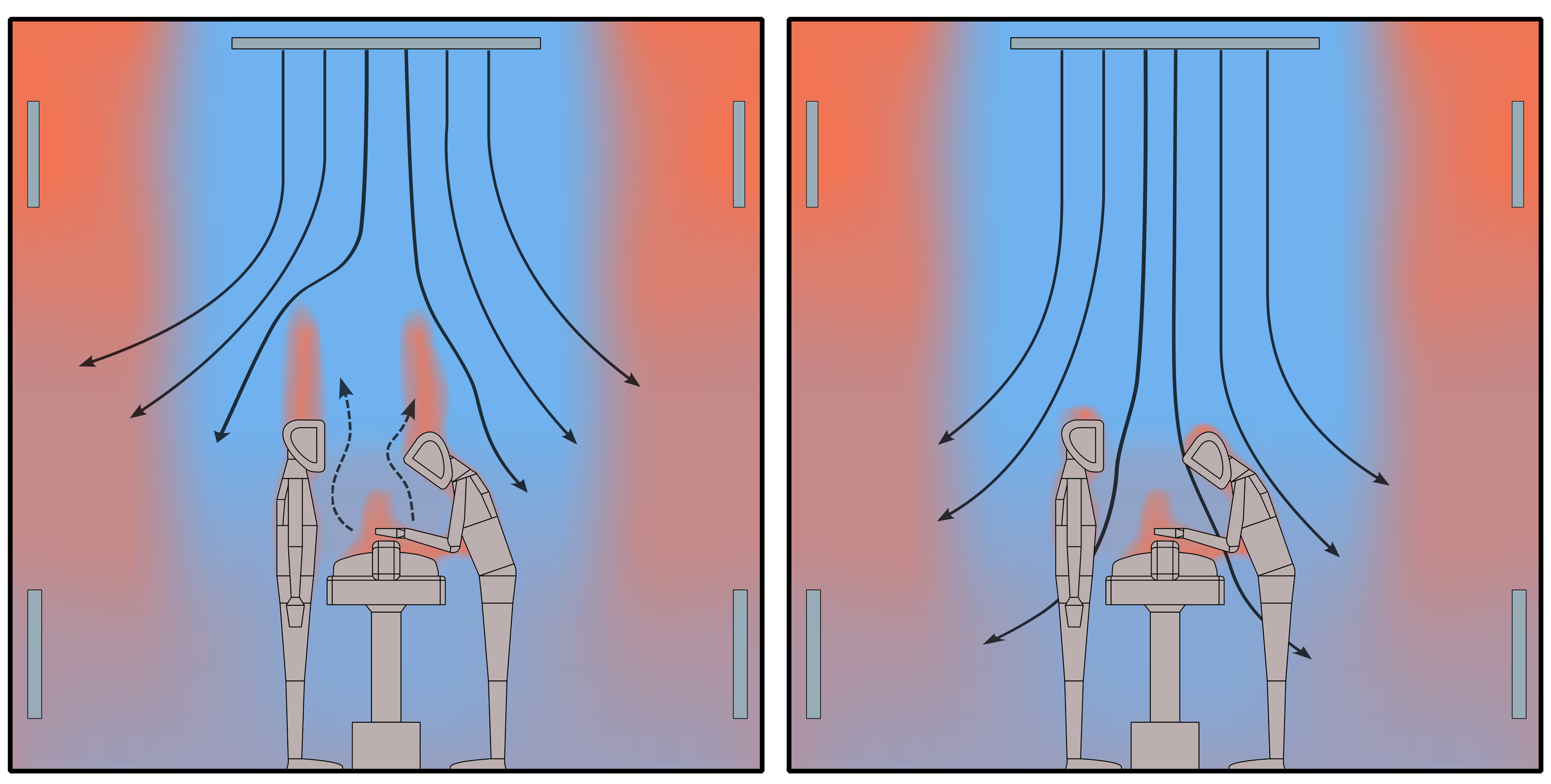
Unidirectional Downward Airflow (UDAF)

TAF (Turbulent Airflow) ventilation operates according to the contaminant dilution principle, supplying clean air at relatively high velocity to promote room-wide mixing and reduce airborne contaminant concentrations. In contrast, UDAF (Unidirectional Downward Airflow) ventilation delivers a downward parallel airflow over the operating table, creating a protected clean zone that continuously displaces airborne particles away from the surgical site.



Surgical lamp

Surgical lamps can significantly influence airflow patterns within the operating room by acting as physical obstructions to the ventilation airflow. As clean air passes around the lamp structure, flow separation and recirculation zones may develop downstream, creating a turbulent wake that can entrain and retain airborne infected particles within the surgical microenvironment. This phenomena increases their residence time within this zone and consequently elevates the probability of such particles reaching the patient's open wound.



Plume driven flow

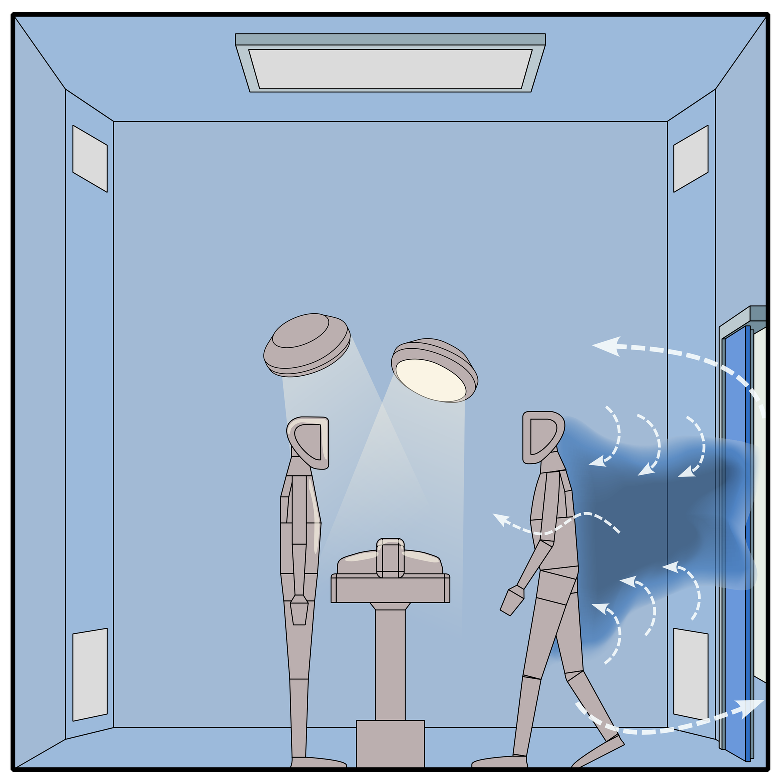
Ventilation driven flow

Airflow within the surgical microenvironment results from the competition between human thermal plumes and ventilation-induced airflow. Standing surgeons generate strong upward thermal plumes, with velocities up to 0.4 m/s, whereas the patient's plume is weaker and more fragmented. At low supply velocities, airflow is plume-driven and dominated by buoyancy effects; at higher velocities, ventilation-driven flow prevails, suppressing thermal plumes and establishing a stable downward clean-air layer over the surgical field.

Components	Usage	Fabric Material	Microbial Penetration -dry	Thermal insulation, I_{cl} [clo]
Scrub suit	Reusable	69 % cotton, 30 % polyester, 1 % carbon fibre.	≤ 300 CFU	n. r.
	Single-use	Inner layer: 70 % viscose, 30 % polyester; Outer layer: Spunbond Meltblown Spunbond Polypropylene.	≤ 100 CFU	n. r.
Gown	Reusable	Front and sleeves: liquid-proof fabric of higher resistance.	n. r.	parallel - 0.974; series - 1.303
	Reusable	Front and sleeves: PTFE (polytetrafluorothylene).	n. r.	parallel - 1.032; series - 1.406

Thermal comfort

Maintaining thermal comfort in the operating room is challenging because different members of the surgical team experience markedly different thermal conditions. Surgical clothing is designed primarily for infection control and therefore typically exhibits low air permeability and high thermal insulation, restricting convective and evaporative heat loss from the body. These effects are particularly pronounced for surgeons, who generally have higher metabolic rates due to prolonged standing, physical activity, and procedural demands. In addition, surgeons are directly exposed to radiant heat emitted by surgical lamps, further increasing their thermal load. Conversely, anaesthesiologists are usually less active and located outside the surgical field, receiving lower radiant heat gains and often experiencing sensations of cold. Consequently, identical environmental conditions can produce substantially different thermal perceptions among operating-room staff.



Door opening and walking motion

Door opening temporarily eliminates the positive pressure differential between the operating room and adjacent spaces, allowing airborne contaminants to enter through bidirectional airflow exchange at the doorway. Human movement further aggravates this effect, as walking generates a turbulent wake that entrains and transports contaminants into the room. These transient disturbances can compromise ventilation performance and increase contamination levels near the surgical field.

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