

Overview of hospital regulations, compliance strategies related to energy, ventilation, other building systems, infection transmission

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Plan for today

- What do I do?

- Hospital infections
- Hospital regulations standards
- Possible approaches for OR design
- Simulation / visualization
- Summary and take home
- Discussion

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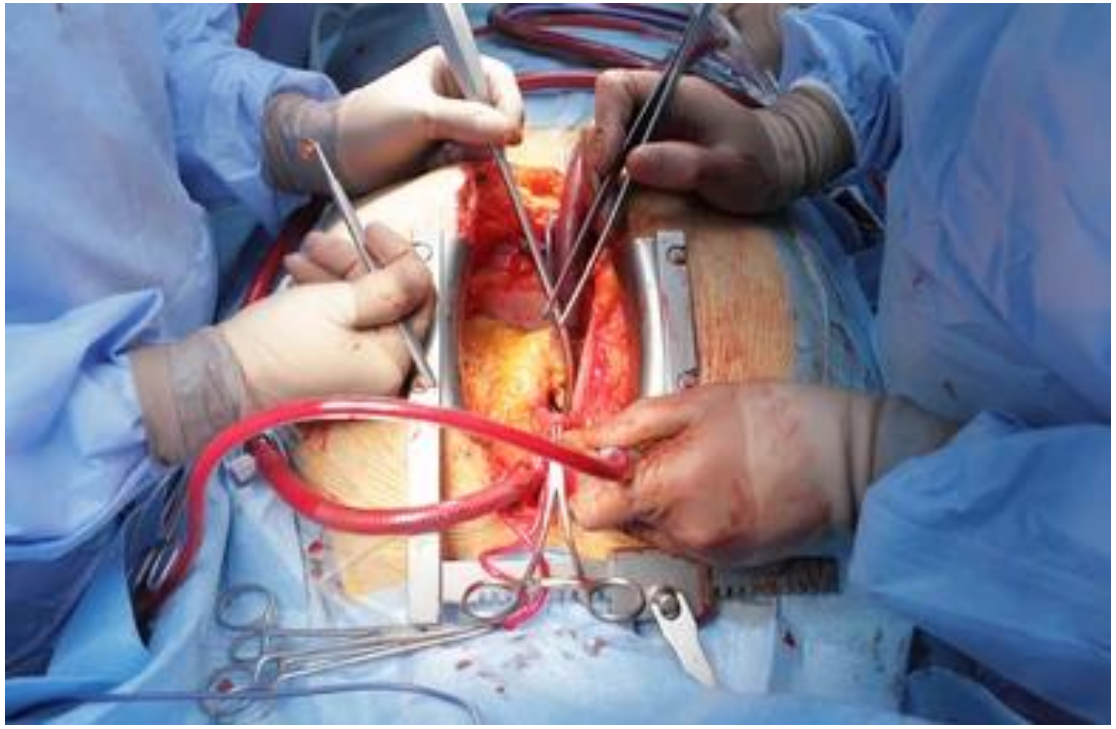
Interventions in structural heart disease

Improved LV monitoring

- During surgery



- In intensive care

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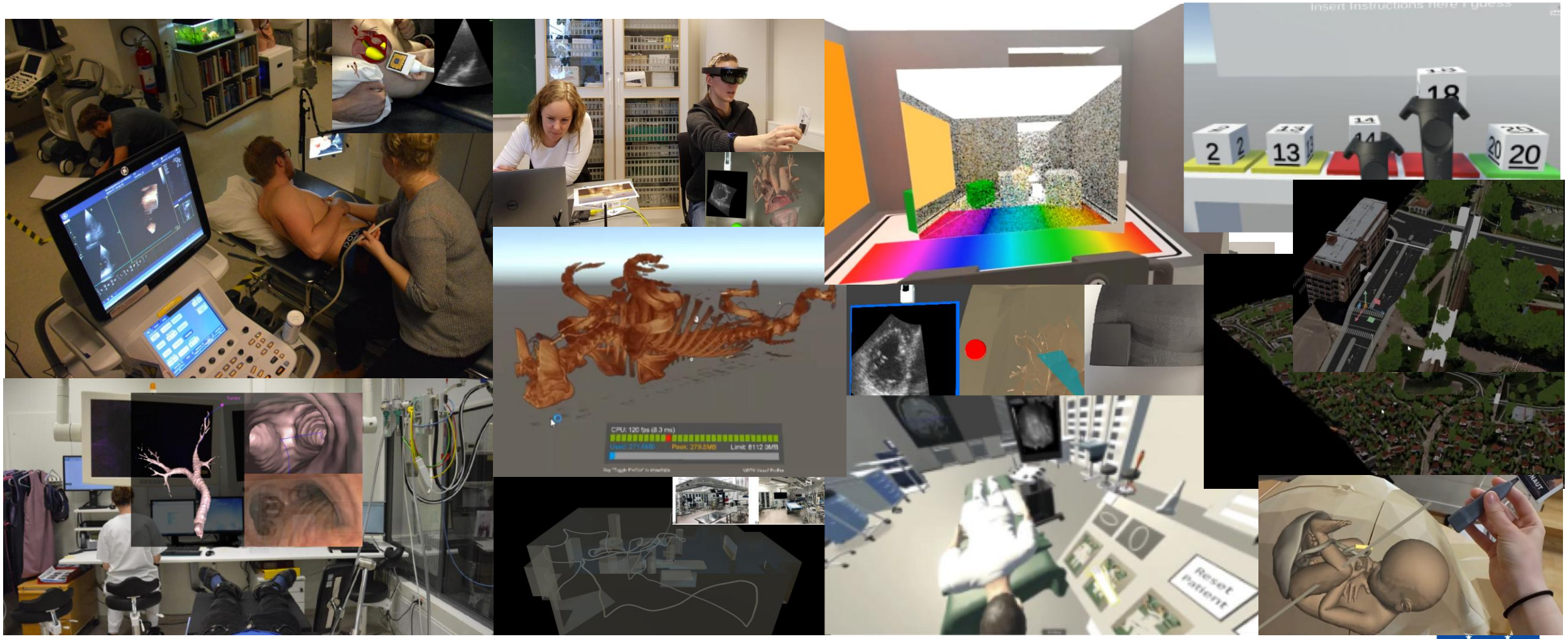
Practical XR applications



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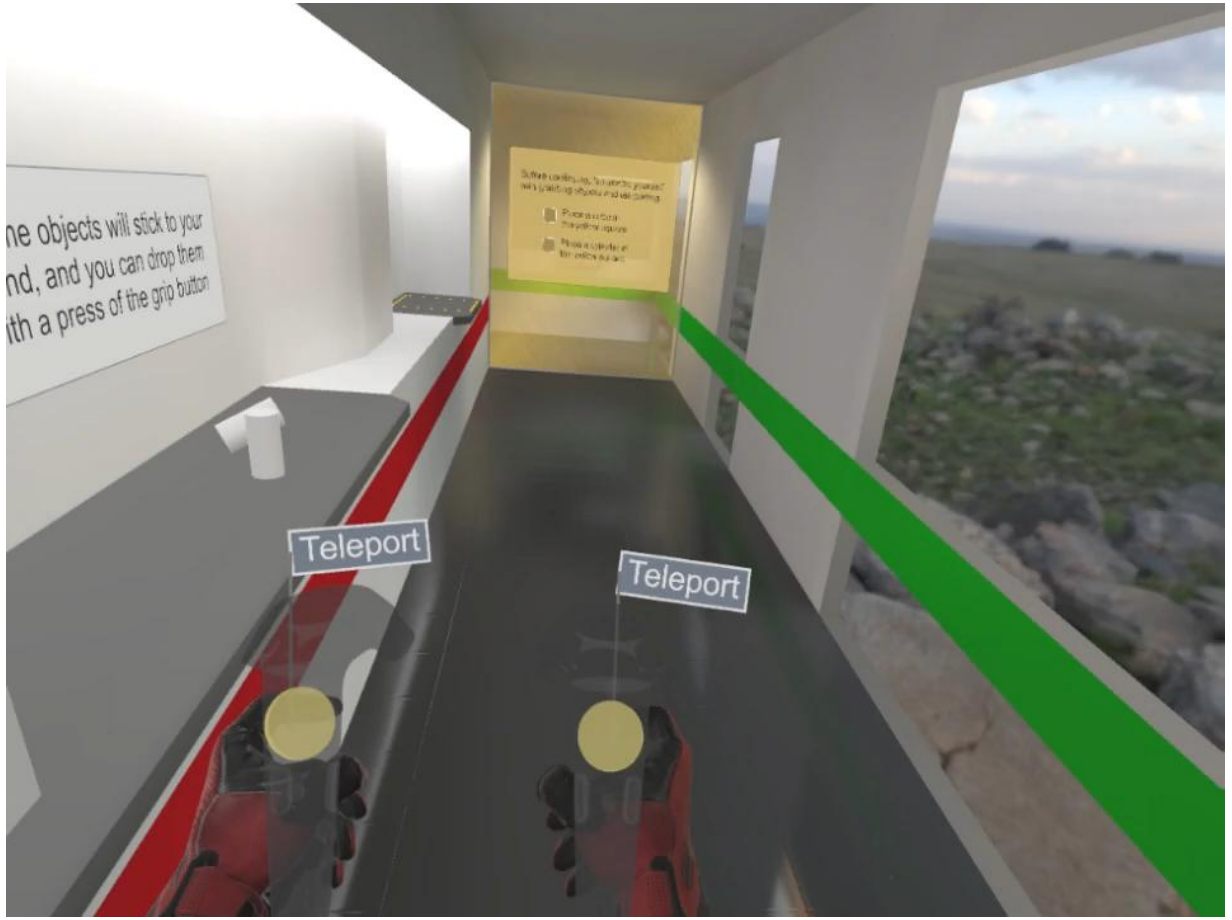
Serious games



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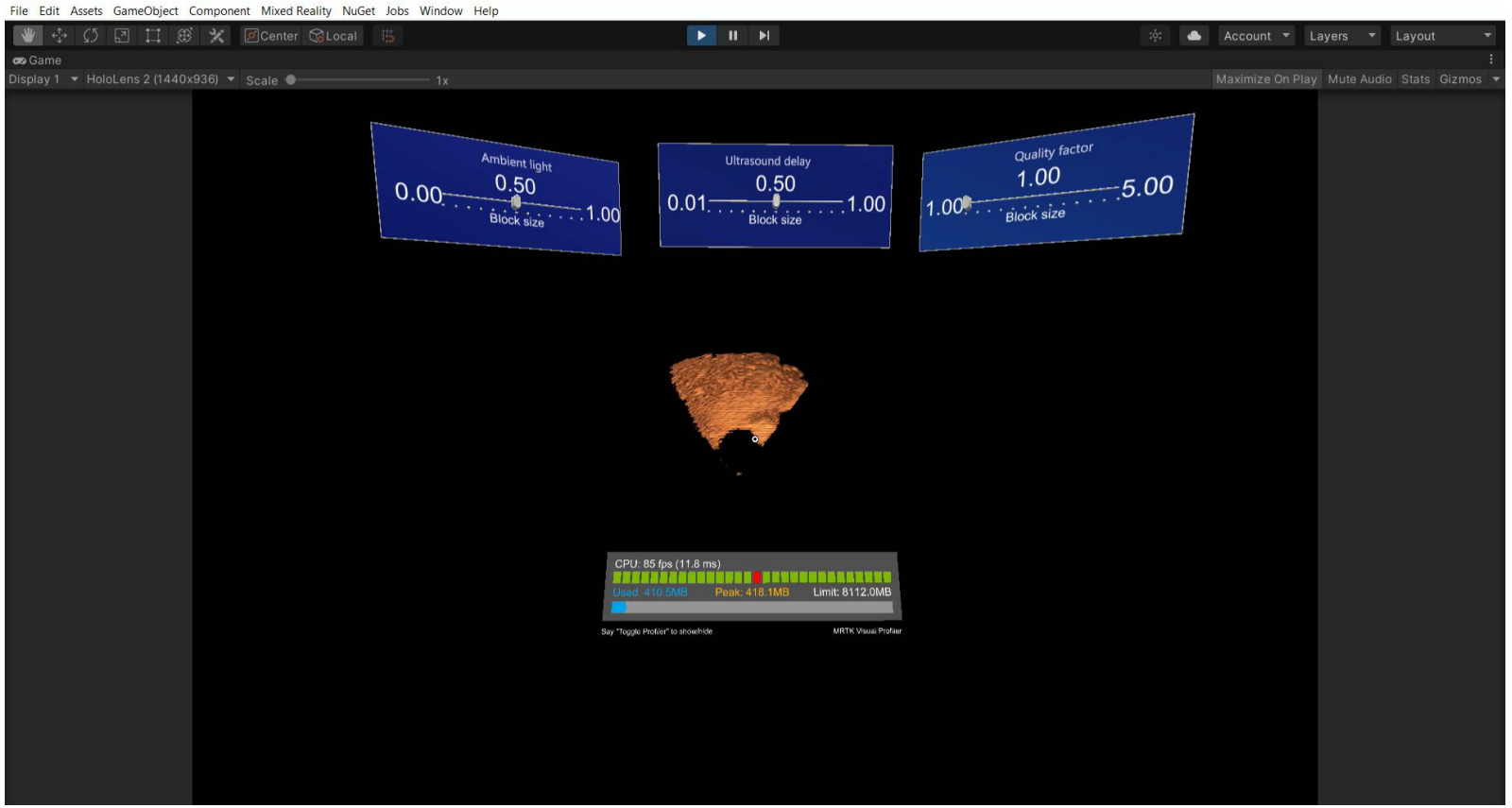
Surgical planning



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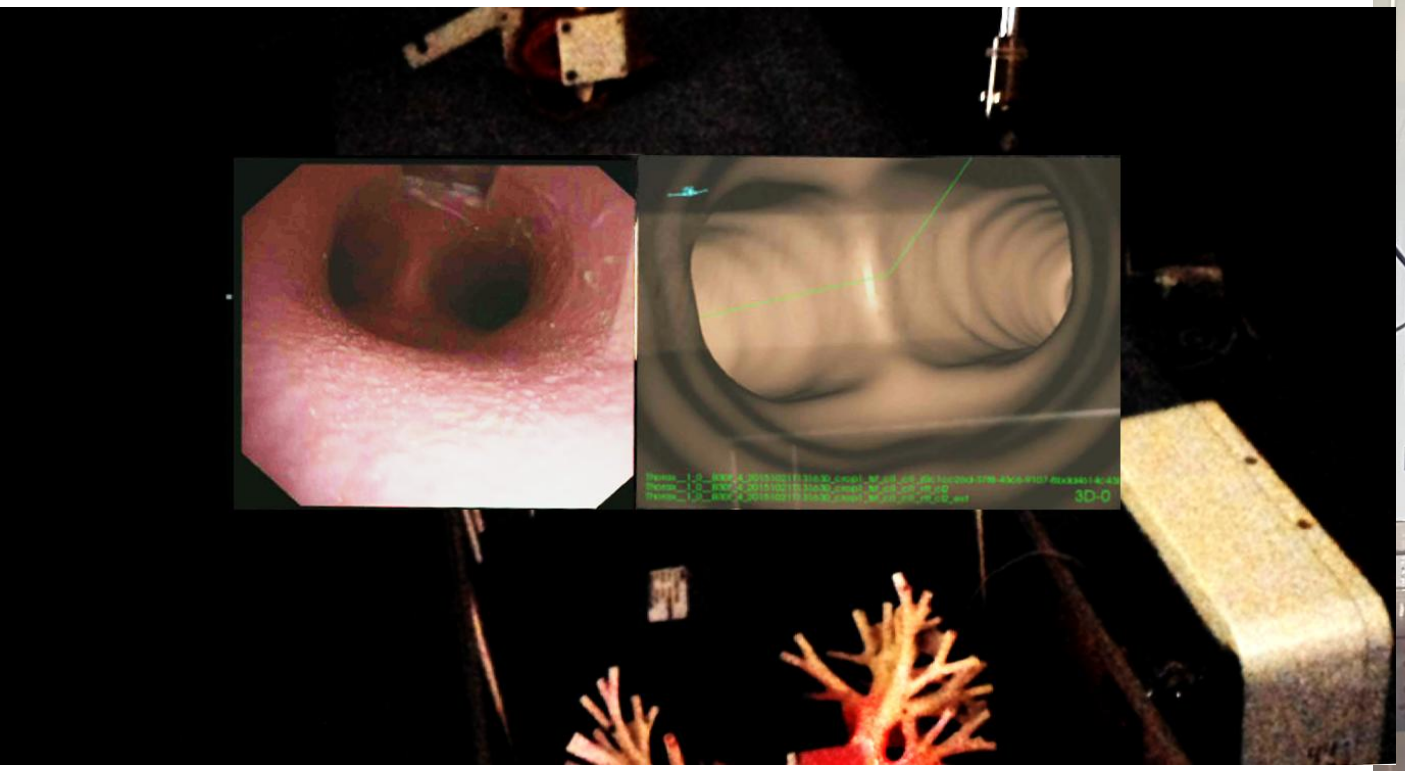
AR bronchoscopy



XR teaching tools

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XR collaboration

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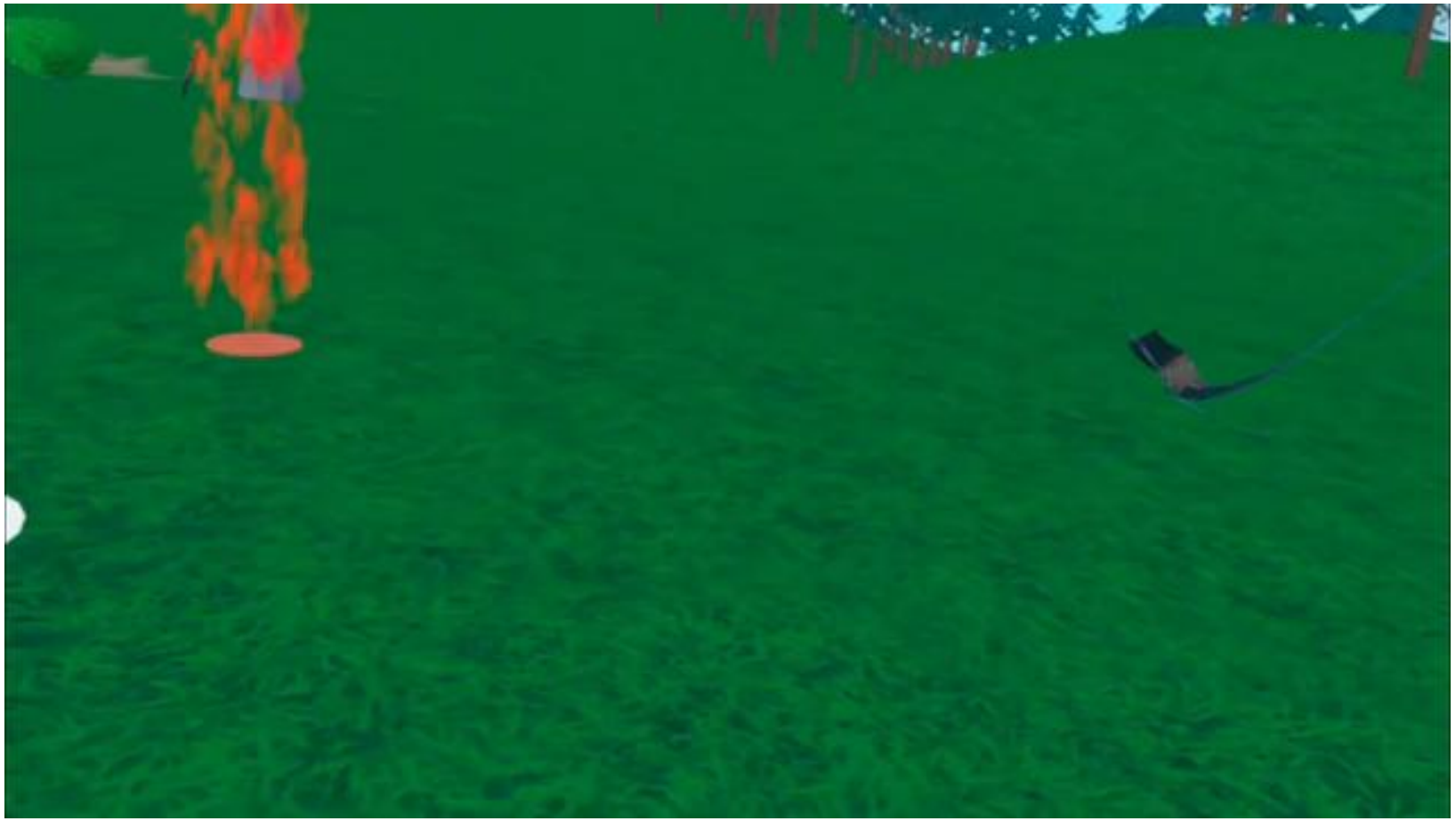
XR - NE VR MIND



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XR - Sleep paralysis

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Hospital infections

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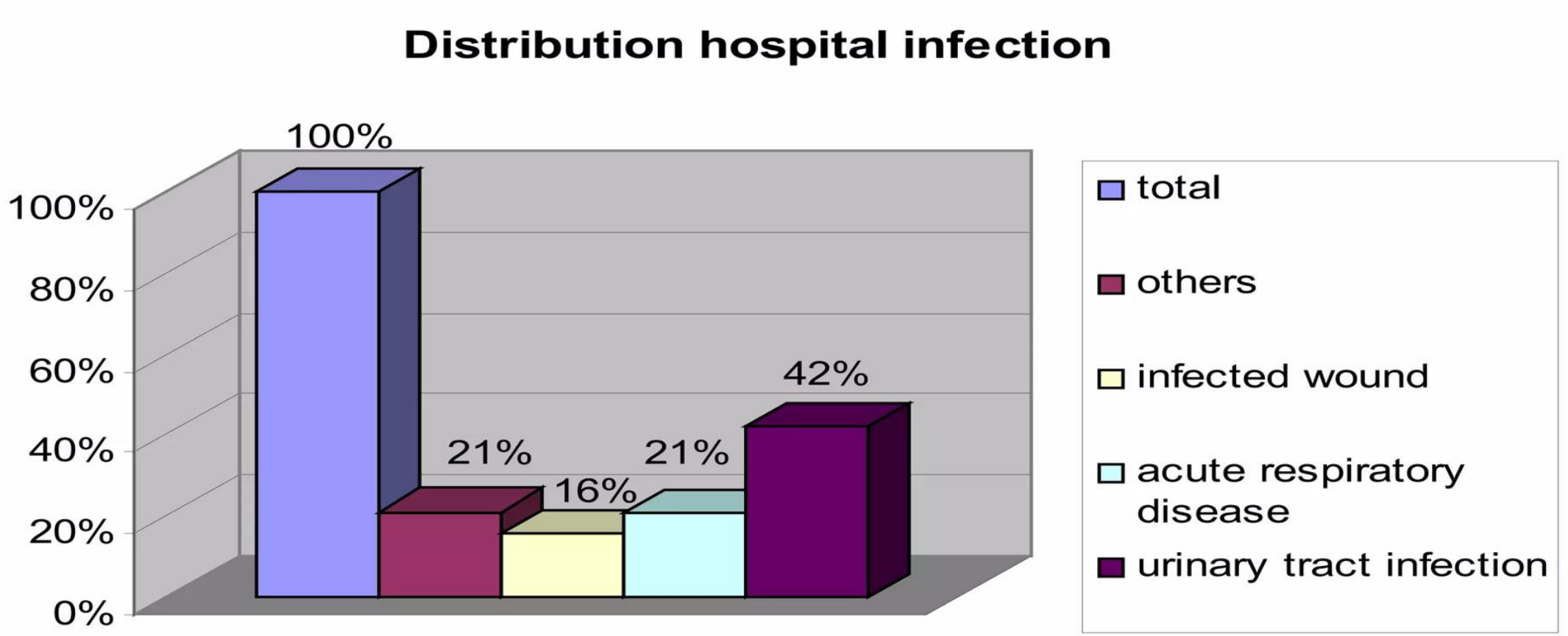
Hospital infections



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Why are they important?

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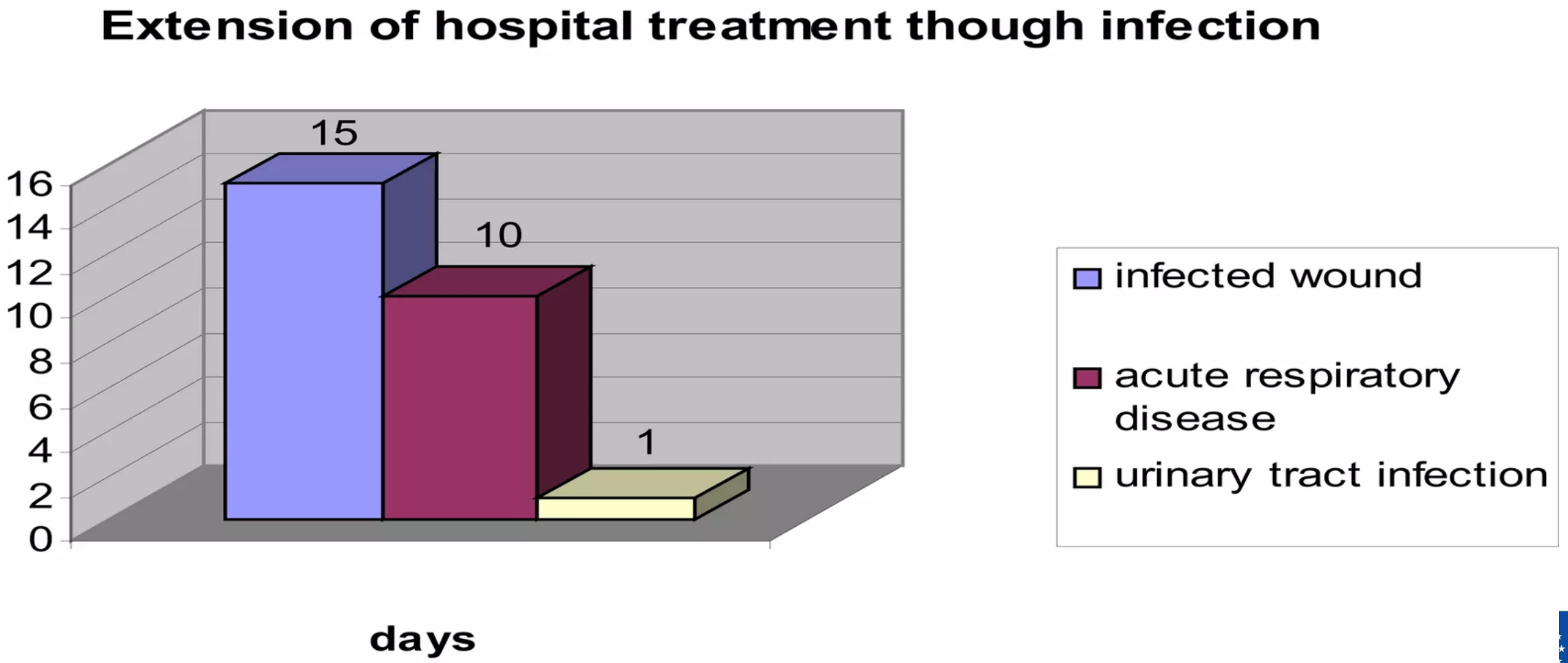
Patient discomfort



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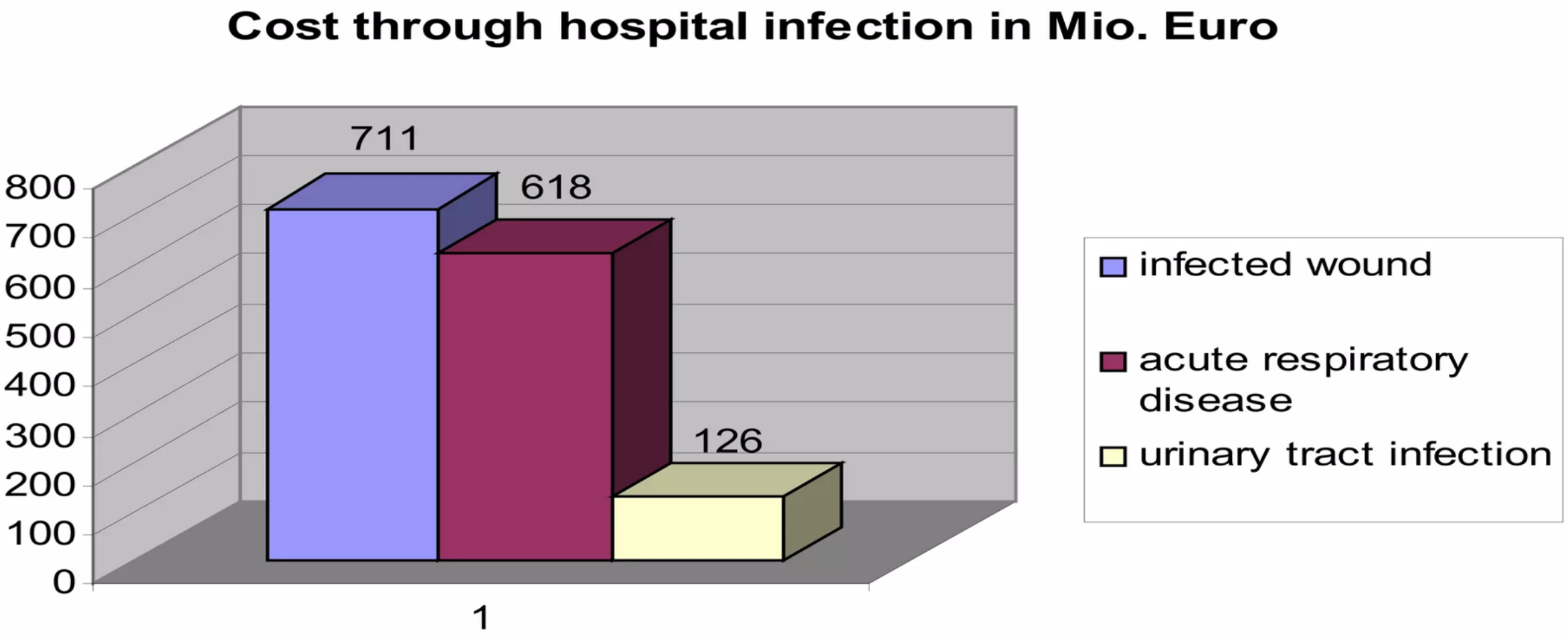
Hospital infections (for Germany)



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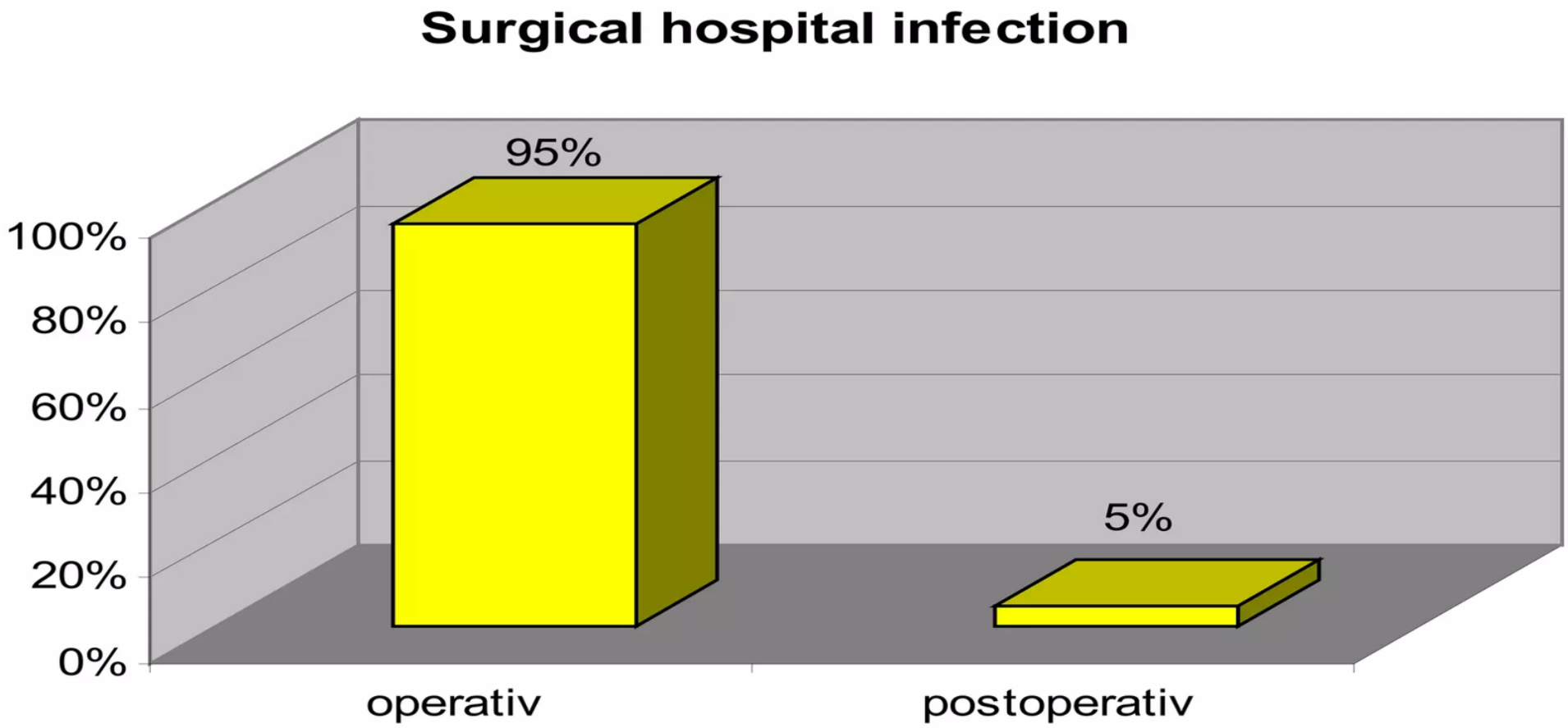
Why focus on the OR?



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Difficult problem

J. Hyg., Camb. (1984), **93**, 505–529
Printed in Great Britain

Infection and sepsis after operations for total hip or knee-joint replacement: influence of ultraclean air, prophylactic antibiotics and other factors

By O. M. LIDWELL*

Operating-room conditions		Without antibiotics: No. of operations	Without antibiotics: Septic No.	Without antibiotics: Septic %	With antibiotics: No. of operations	With antibiotics: Septic No.	With antibiotics: Septic %
Control	Observed	1161	39		2968	24	
	Calculated*		39·5	3·4		25·2	0·85
Ultraclean air: conventional clothing	Observed	516	8		1279	9	
	Calculated		8·8	1·7		5·4	0·42
Body exhaust or plastic isolator†	Observed	544	5		1584	1	
	Calculated		4·1	0·76		3·0	0·19

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The sterile space

Operating theatre staff in gowns, masks and rubber gloves, Gloucester 1909.
Wellcome Collection, CC-BY

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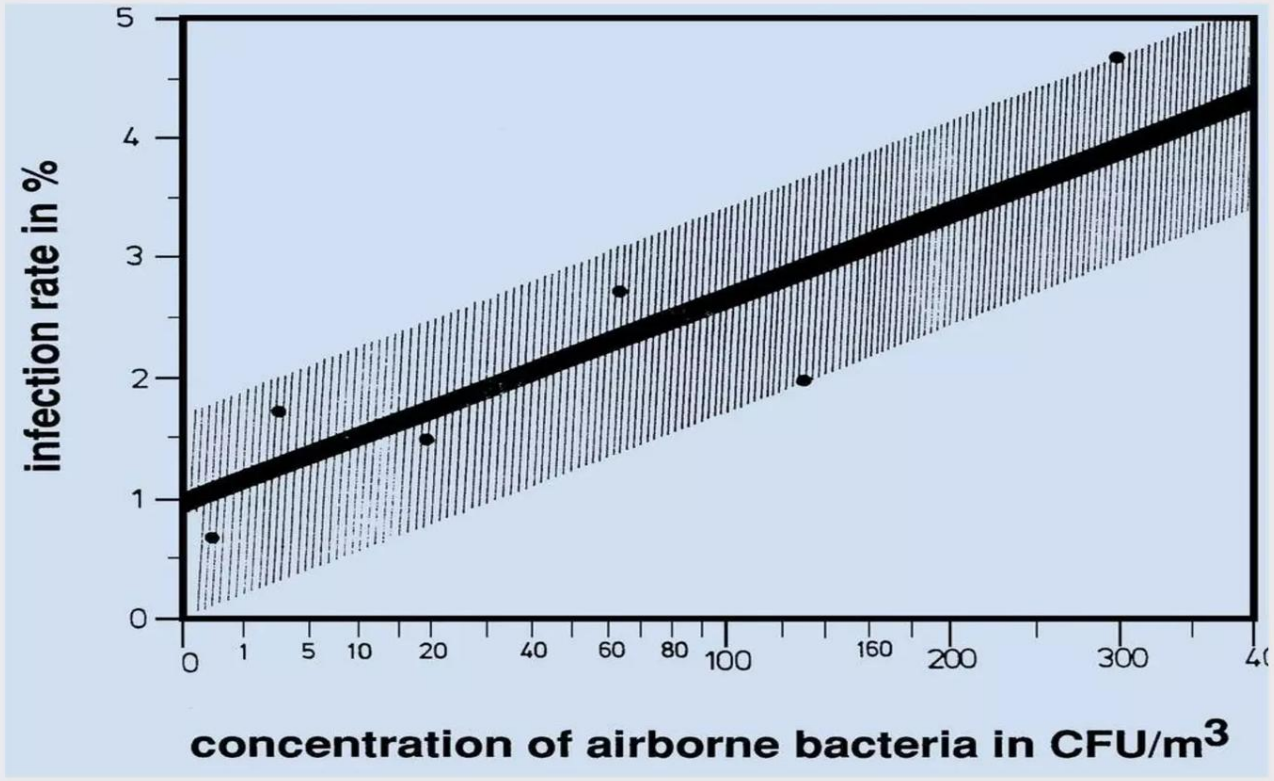
One way of looking at it:



- 7500 surgeries
- 19 Hospitals
- 5 ½ years
- Finished in 1980

Lidwell study, 3 countries over several years 1980s

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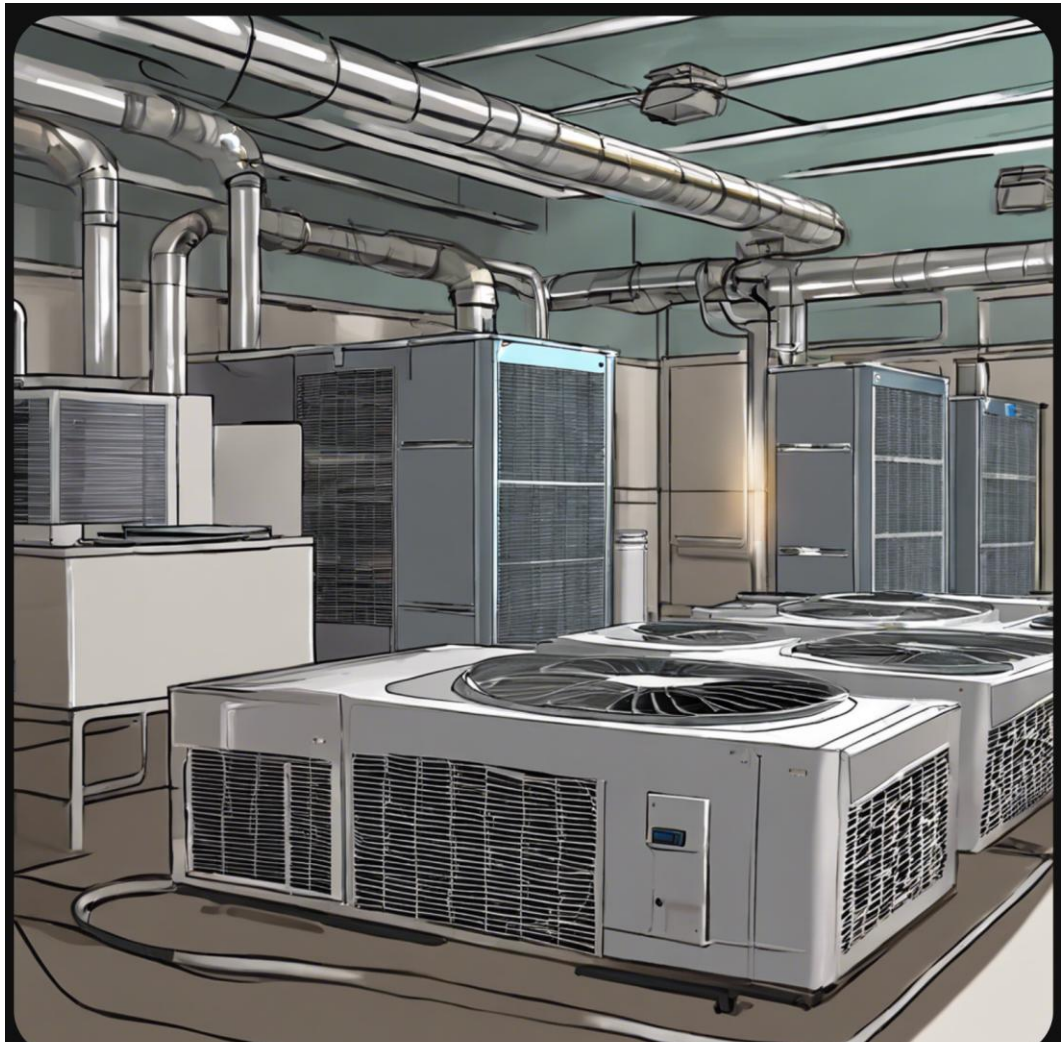
Operating theater what is important

1. **Ventilation**
2. **Filtration**
3. **Temperature and Humidity Control**
4. **Air Quality Monitoring**
5. **Zoning Systems**
6. **Exhaust Systems**



Energy usage

Benchmarking acute hospitals: Composite electricity targets based on departmental consumption intensities?

March 2016 · Energy and Buildings 118
DOI: 10.1016/j.enbuild.2016.02.052
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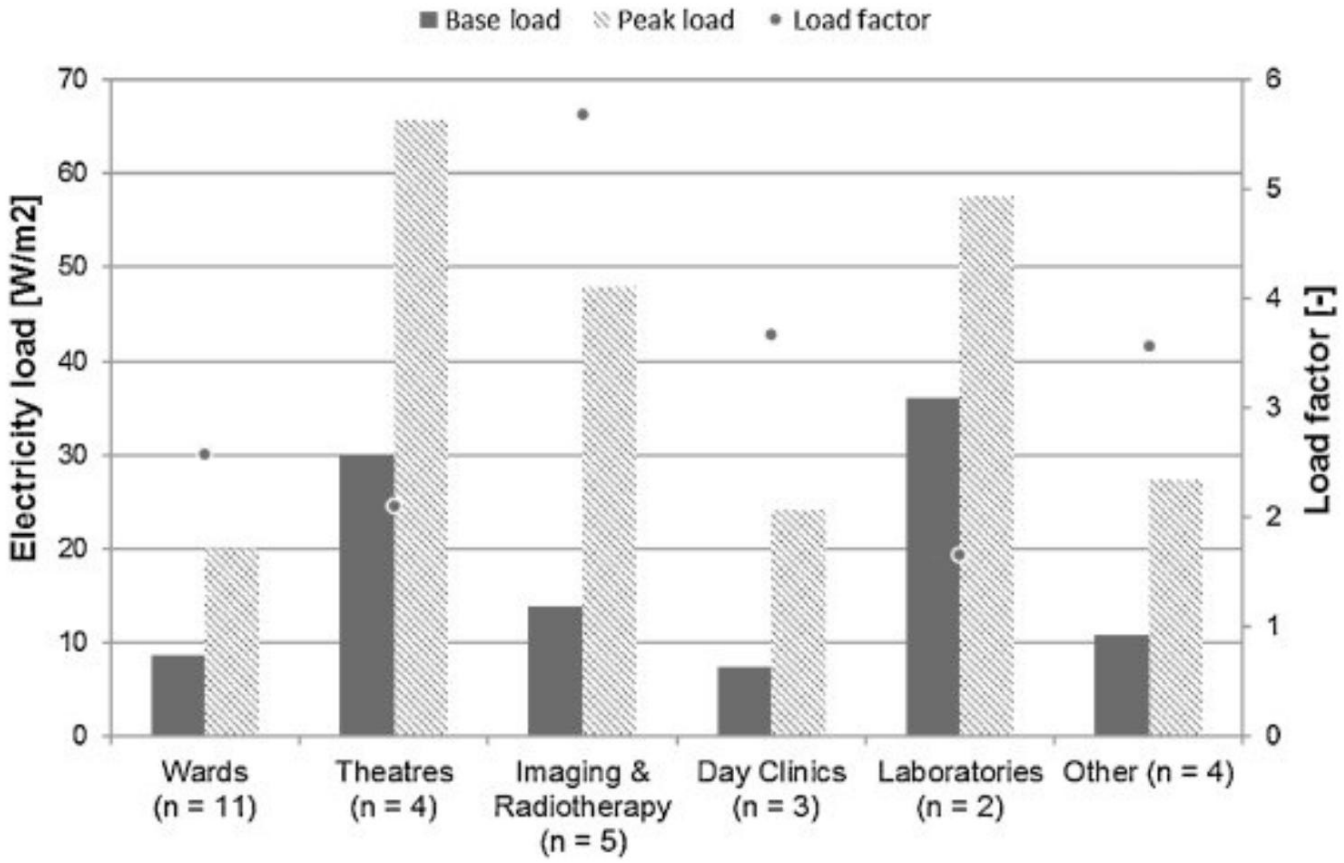
Paula Morgenstern · Maria Li · Rokia Raslan · Show all 5 authors · Andrew John Wright



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Clean rooms are they only medical?

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Main tasks

- Prevent air born infections during surgery / dilute airborne contamination
- Control air movement within the suite to limit transfer of airborn contaminants
- Manage thermal loads / space humidity
- Remove harmful gases
- Comfortable climate in the OR - > patient + clinicians

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But we

Name	Modified	Modified By	File size	Sharing
ASHRAE_170	January 24	Bogdan Anna	9 items	Shared
AFNOR SPEC S99-120.pdf	July 6, 2020	Bogdan Anna	2.76 MB	Shared
ANSI+ASHRAE+ASHE+170-2021 (1).pdf	October 2, 2024	Bogdan Anna	1.01 MB	Shared
ASHRAE-D-86529.pdf	June 8, 2020	Bogdan Anna	903 KB	Shared
CEN-TC156-WG18_N0442_prEN_xxxxx_...	June 8, 2020	Bogdan Anna	2.16 MB	Shared
DIN1946-4.pdf	June 15, 2020	Bogdan Anna	4.48 MB	Shared
HTM_03-01_Part_A.pdf	July 15, 2020	Bogdan Anna	2.67 MB	Shared
HTM_03-01_Part_B.pdf	May 24, 2020	Bogdan Anna	1.42 MB	Shared
NF S90-351.pdf	July 6, 2020	Bogdan Anna	1.34 MB	Shared
PN-EN-13098_2020-01E.pdf	June 8, 2020	Bogdan Anna	1.22 MB	Shared
PN-EN-16798-1_2019-06E_KOLOR.pdf	July 23, 2019	Bogdan Anna	3.66 MB	Shared
PN-EN-16798-3_2017-09E_KOLOR.pdf	October 9, 2018	Bogdan Anna	2.04 MB	Shared
PN-EN-ISO-14644-1_2016-03E.pdf	June 8, 2020	Bogdan Anna	1.42 MB	Shared
PN-EN-ISO-14644-2_2016-03E.pdf	June 8, 2020	Bogdan Anna	1.61 MB	Shared

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Relevant European Guidelines:

- National Guidelines and Standards for OR Ventilation
- Swedish Standard SIS-TS 39:2015
- Dutch standards – FMS:2022/WIP:2014/VCCN Guideline 7:2017
- German standard – DIN 1946-4:2018-09
- UK Guidelines - Health Technical Memorandum 03-01
- US standard – ANSI/ASHRAE/ASHE 170:2017

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Comparison

Room Class I(a)	German DIN Dec. 2008	ASHRAE 2007	English HTM 03-01 Since 2007
Size of Air Diffusor	3,2 x 3,2 m²	No information (laminar airflow "interest")	2,8 m x 2,8 m Rec 3,2 m x 3,2 m
Recirculation ?	Yes (1.200 m³/h) Fresh air	Yes (20 AC/hr) Fresh air 4 AC/hr	Yes (AC/hr 25, min.2700 m³/h fresh air)
Supply air velocity Total Air Volume	≥ 0,23 m/s, 8.800 m³/h	Not specified 2.000-2.700 m³/h depending on size of OT	0,38 m/s on 2 m height 11.900 m³/h
Overflow into adjoining rooms ?	Yes, no figure	Yes, with pressure monitoring	Yes, no figure (close to ceiling recommended)
Air Curtain	2,0 m above floor level	Not specified	2 m above floor level
Three stage supply air filtration	Min F5 + F9 + H13	2 Filters (8, 17) (2 could be HEPA filter)	G3 + min. F9 + min. H 10
Sound pressure level	≤ 48 dB (A)	Not specified	≤ 55 dB (A)
Acceptance Test	Rate of Turbulence Or Measurements by protection degree		Velocity/Validation

Ultra-clean ventilation

- Howorth Air Technology Ltd
- John Charnley
- Started in 1960

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Ultra-clean ventilation

- UCV – Ultra Clean Ventilation
- Laminar (Unidirectional) Air Systems
- Ultra Clean Operating Room
- Ultraclean Air Systems
- Clean Air Canopy
- Ultra Clean Canopy
- Cleanroom
- Charnley-Howorth System

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Where are UCVs Used?

What types of surgery are performed under Ultra Clean Ventilation Systems?

- Orthopaedics
- Ophthalmology
- Cardiothoracic Surgery
- Neurosurgery
- Transplant Surgery
- Endoscopy
- Plastic Surgery
- Various Day Surgeries
- Any invasive “Clean” Surgery

HumanIC

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Definition

- Ultra clean air = not more that 10 CFU/m^3 (0.3 CFU/ft^3)

- CFU = Colony-Forming Unit
- viable (living) bacterial or fungal cells

- UCV commonly used in orthopedic surgery

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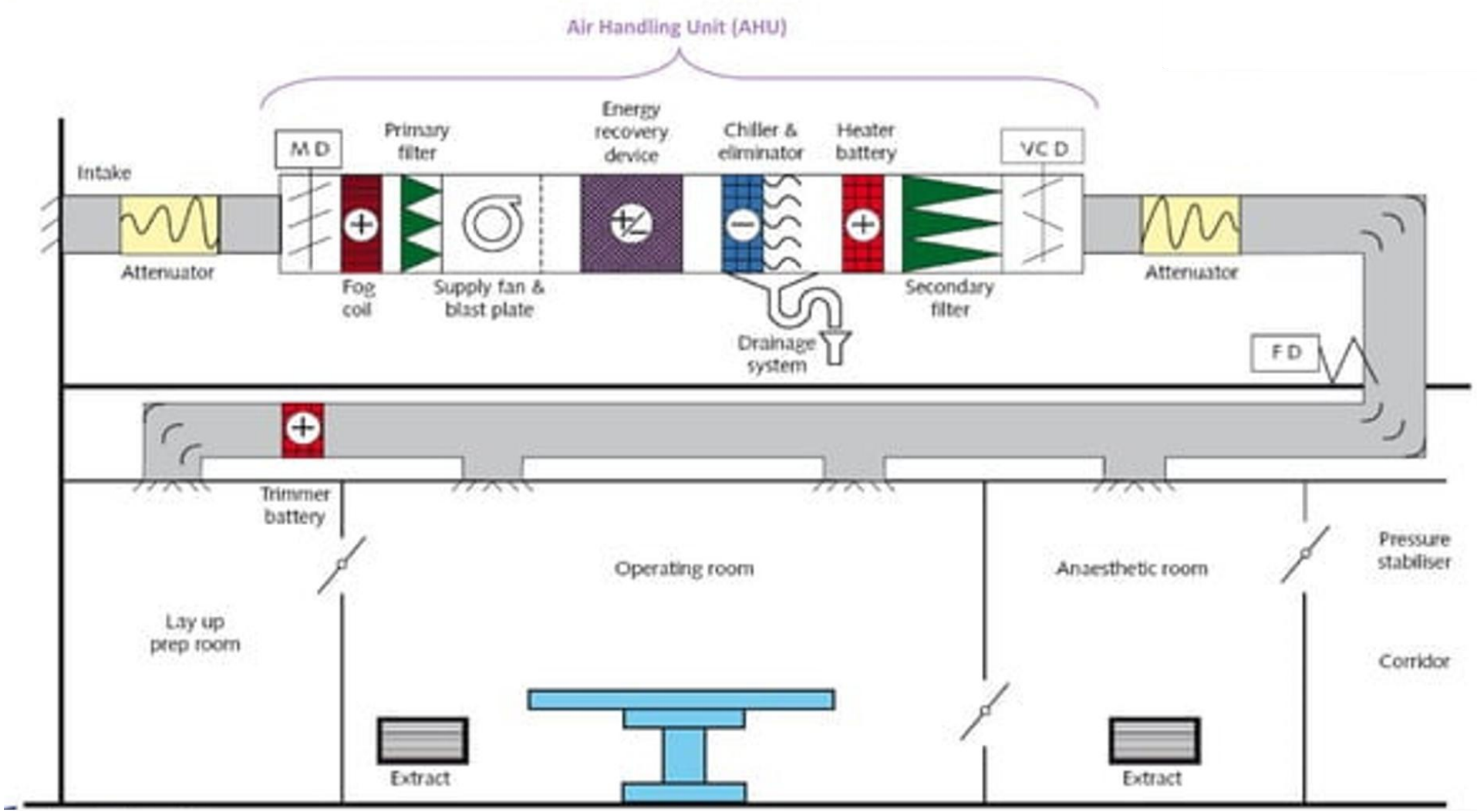
Typical OR ventilation system



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Types

- Nowadays only vertical systems (horizontal ones are outdated)
- Flow type:

Low Flow Systems

- Utilise main ventilation air with no additional fans
- Low number of air changes per hour, typically 15 – 30 ACH
- Downflow velocity typically low, i.e. less than 0.2 m/s (40 fpm)

High Flow Systems

- Supplement the main ventilation air supply with auxiliary fans
- High number of air changes per hour, typically >100 ACH
- Downflow velocity medium to high, i.e. 0.2 – 0.5 m/s (40 - 100 fpm)

Table 1
Characteristics of OR air distribution systems.

	Airflow disitribution concept	Location of supply	Location of exhaust	Air supply conditions as reported in field studies			Air supply conditions as defined by national guidelines		
				Velocity (m/s)	Air changes per hour (ACH)	Diffuser size (m2)	Velocity (m/s)	Air changes per hour (ACH)	Diffuser size (m2)
Turbulent Flow Air distribution (TFAD)	The concentration of airborne contaminants is diluted by mixing the supply air with the contaminated OR air	Ceiling or wall-mounted	Wall mounted near floor	–	11.5–23.8 [2] 12 [3] 15.5–21.3 [16] 50 [17] 5.3–27.6 [18]	–	N/A	≥20 [5, 11]	N/A
Vertical Laminar Airflow (vLAF)	The unidirectional airflow swipes away the contaminants over the operating microenvironment	Ceiling-mounted	Ceiling and/or wall mounted near floor	0.25–0.38 [19]	26-178 [3] 80.5 [16] 58 [17] 15.1–59.9 [18] 67 [19] 100 [20]	2.4 × 2.4–3.2 × 3.2 [2] 3.8 × 1.2–5.18 × 3.83 [3] 3.2 × 3.2 [16] 3.6 × 3.6 [19] 2.75 × 2.75 [20]	#N/A	≥20 [5,11)	≥3.0 × 3.0 [6] ≥ 3.2 × 3.2 [7] ≥ 8 [10] ≥ 9 [13]
Horizontal Laminar Airflow (hLAF)		Wall-mounted	Ceiling and/or wall mounted near floor						
Mobile Laminar Airflow (mLAF)		In the vicinity of the operating table	Ceiling and/or wall mounted near floor	0.5–0.7 [21]	8.4 [22]	0.5 × 0.4 [19] 0.69 × 0.7 [21]	N/A	N/A	N/A
Displacement Ventilation Airflow (DV)	Cool air is supplied at floor level and is moved up displacing the contaminated air from the operating microenvironment	Wall mounted near floor	Ceiling or wall mounted near ceiling	0.09–0.15 [19]	21 [19]	–	N/A	N/A	N/A
Temperature-Controlled Airflow (TAF)	Combination of LAF (cool laminar airflow breaking convective currents in the operating microenvironment) and TFW (warm air maintaining temperature gradient)	Both cool and warm air is supplied from the ceiling	Wall mounted near floor	>0.25 [20]	47 [20]	–	N/A	N/A	N/A

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OR temperature

Table 3
OR temperature suggested by different standards.

UNI 11425:2011 [107] (Italy)	Winter $\geq$ 20 °C, $\geq$40% RH | Summer $\leq$ 24 °C, $\leq$ 60% R
NF S 90 351 [108] (France and Belgium)	19–26 °C, 45–65% RH
ASHRAE, Std 170, 9/05 [5] (USA)	17–27 °C adjustable, 45–55% RH
DIN 1946-4 [7] (Germany)	19–26 °C adjustable, RH as per DIN 13779
SWKI 99-3F [109] (Switzerland)	18–24 °C adjustable, 30–50% RH
GB 50333-2013 [110] (China)	Level I clean OR temperatures 21–25 °C
GOST R 52 539/2006 [111] (Russia)	18–24 °C $\pm$ 1 °C, min value 30% RH with 22 °C

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Door openings

Table 4
OR door openings and their effect on SSI.

Authors (year)	Type of surgery	Ventilation type	Door opening frequency [Openings/h]	Monitoring contamination/SSI?	Association between door openings and contamination?	Association between door openings and SSI rate?
Bediako-Bowan et al. (2020) [154]	Abdominal	Mixing[c]	59.3[a]	SSI	–	Yes
Birgand et al. (2019) [155]	Cardiac/ orthopaedic	LAF/Mixing	20.2	Particles/CFU	Yes/Yes	–
DiBartola et al. (2019) [156]	Orthopaedic	Unknown	27.0–34.8[a]	–	–	–
Roth et al. (2019) [157]	Cardiac	LAF	32.4	SSI	–	Yes
Alsved et al. (2018) [20]	Orthopedic	LAF/Mixing/ TcAF	2.1–5.6	CFU	No	–
Hamilton et al. (2018) [158]	Total joint arthroplasty	LAF	19.2–21.6[a]	–	–	–
Perez et al. (2018) [159]	Orthopaedic/ general	LAF	12.6–36.6[a]	CFU	Yes	–
Teter et al. (2017) [160]	Plastic surgery	Unknown	13.4	Particles	Yes	–
Bohl et al. (2016) [161]	Neurosurgery	LAF	46.2	SSI	–	No
Mathijssen et al. (2016) [162]	Hip revision	Mixing	3.3[a]	CFU	Yes	–
Elliott et al. (2015) [163]	Cardiac/general	Unknown	33–54	–	–	–
Mears et al. (2015) [164]	Joint Arthroplasty	Mixing[b]	16.6–37.3[a]	SSI	–	Unclear
Smith et al. (2013) [165]	Orthopaedic	LAF	37.2[a]	CFU	Yes	–
Andersson et al. (2012) [166]	Orthopaedic	Displacement	12.5[a]	CFU	Yes	–
Crolla et al. (2012) [167]	Colorectal	Unknown	–	SSI	–	Yes
Panahi et al. (2012) [168]	Total joint arthroplasty	LAF	41.4[a]	–	–	–
Young and O'Regan (2010) [151]	Cardiac	Unknown	19.2	SSI	–	Yes
Stocks et al. (2010) [169]	Joint Arthroplasty	Mixing	33.6[a]	Particles/CFU	-/No	–
Lynch et al. (2009) [170]	Multiple	Unknown	19–50	–	–	–
Scaltriti et al. (2007) [171]	Orthopaedic/ urology/general	Mixing[b]	56.4[a]	Particles/CFU	No/Yes	–

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What solutions are available?

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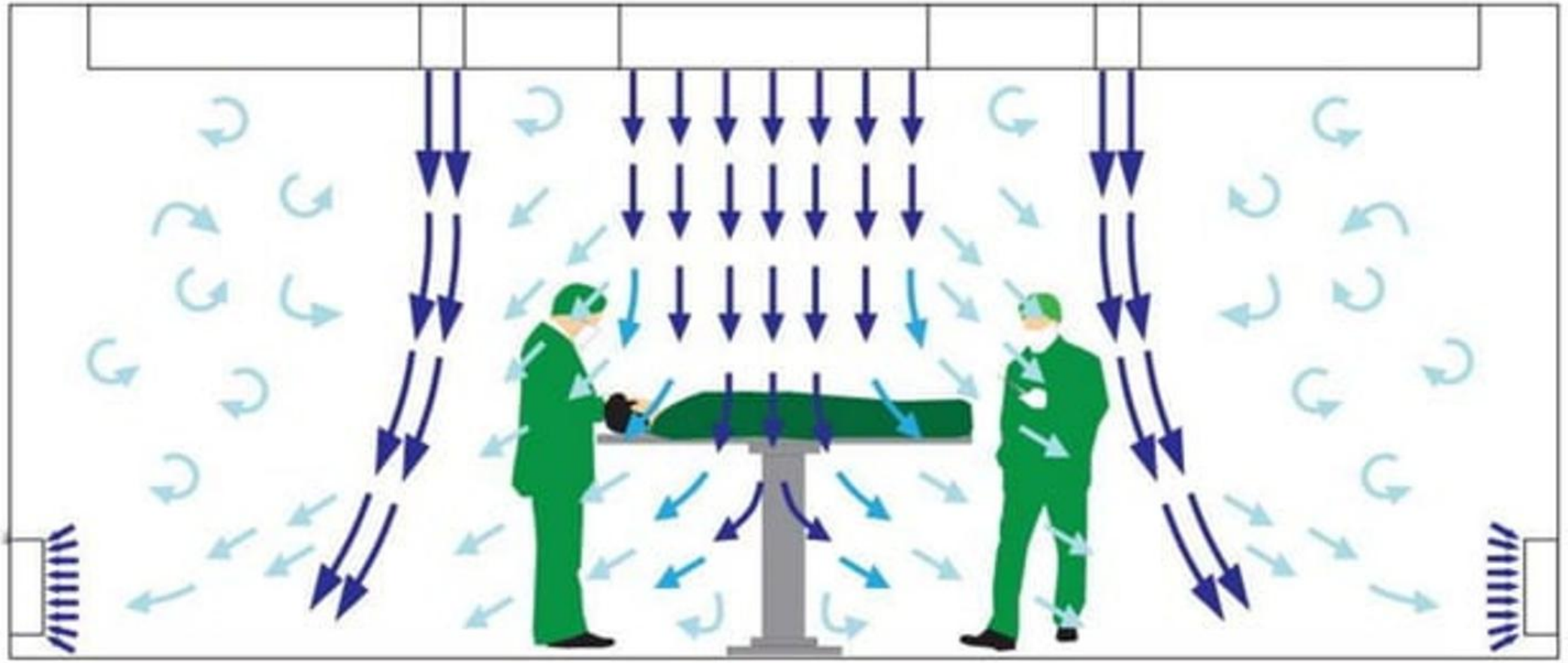
Air curtain UCV



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Air curtain UCV

- Standard systems use a central laminar air diffuser, surrounded by air curtain diffusers on 4 sides
- High velocity of the curtain causes entrainment
- Many systems are low flow thus dilution is limited
- Can be challenging to have high enough velocity in the center

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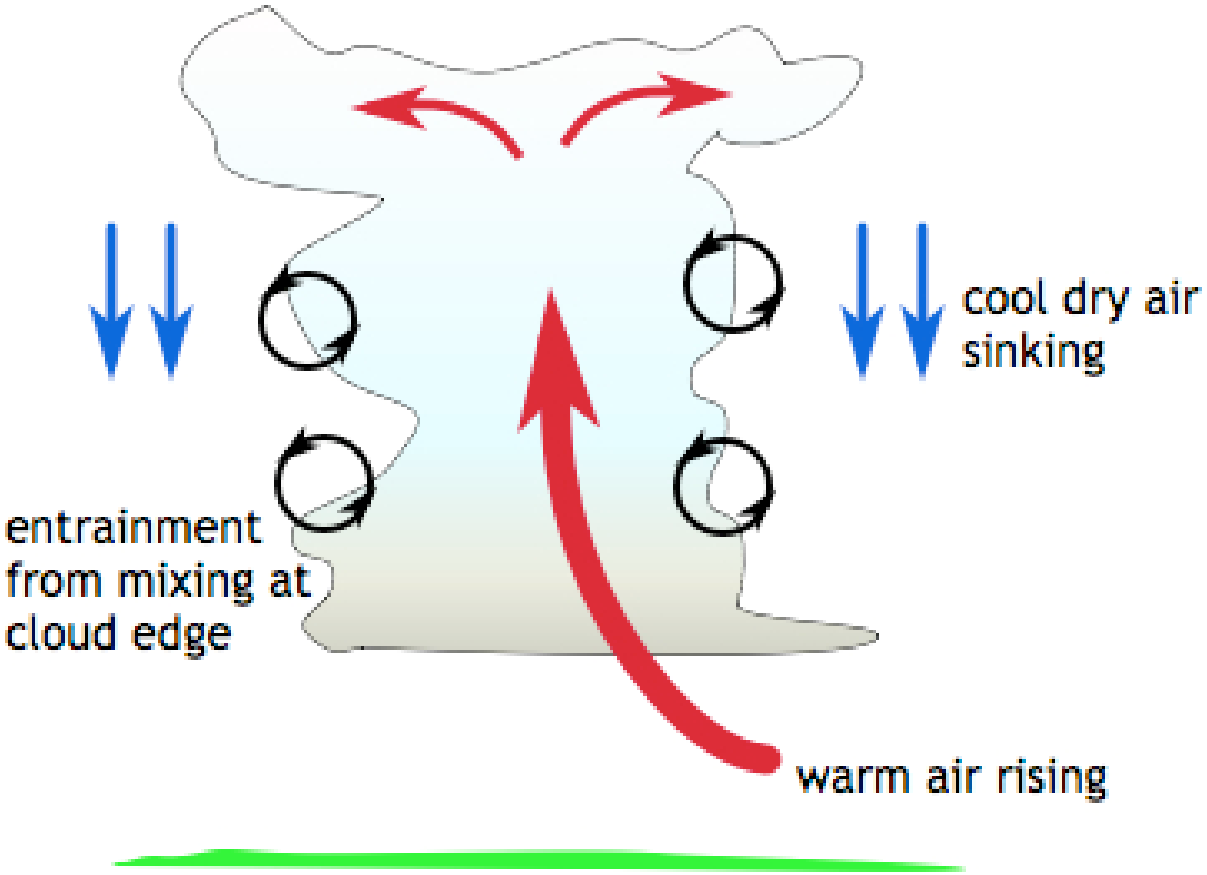
Side note: Entrainment



https://hogback.atmos.colostate.edu/cmmap/learn/clouds/howForm3.html

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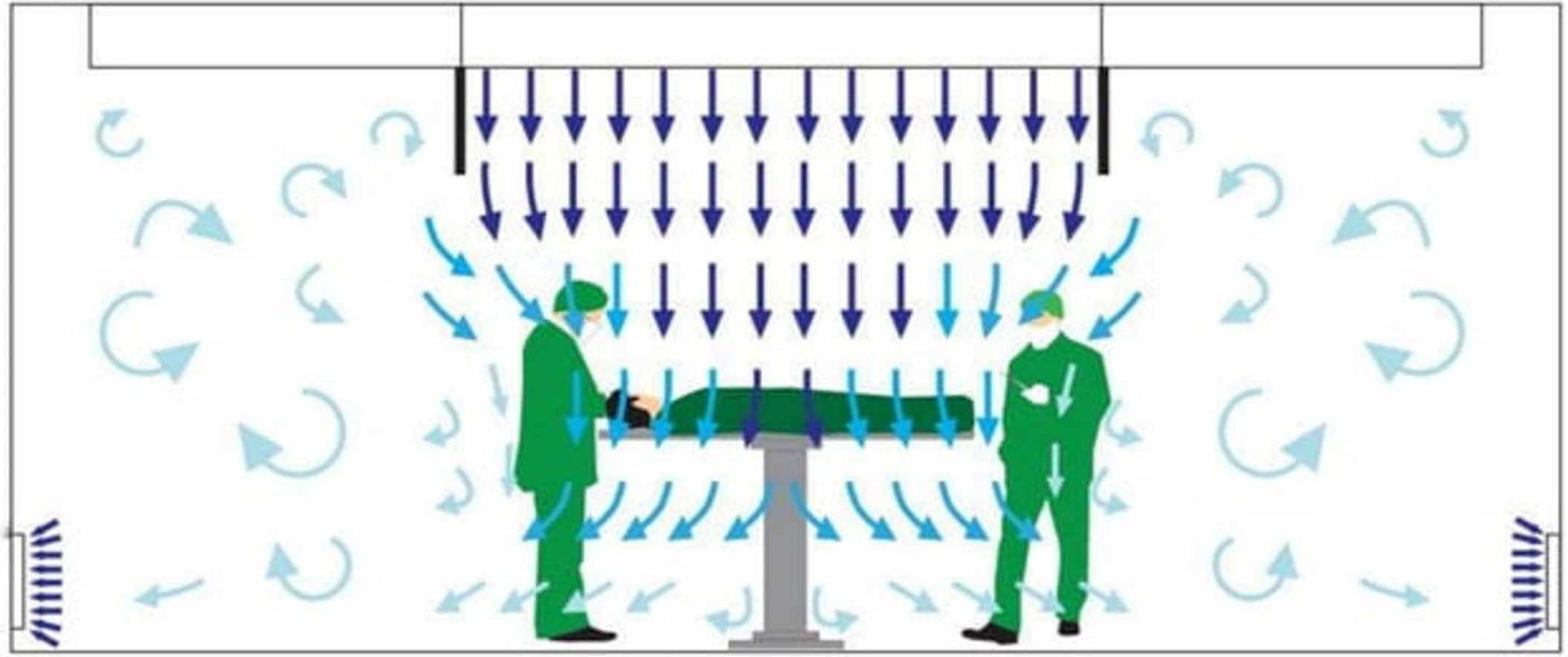
Partial wall UCV with low level returns



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Partial wall UCV with low level returns

- Provides good performance overall
  - Requires a large enough area
  - Requires adequate levels of flow
- Low flow or small area leads to entrainment and low-level dilution
- Come in various shapes and sizes
- Can increase maintenance costs -> additional service requirements
- More costly to install -> additional infrastructure

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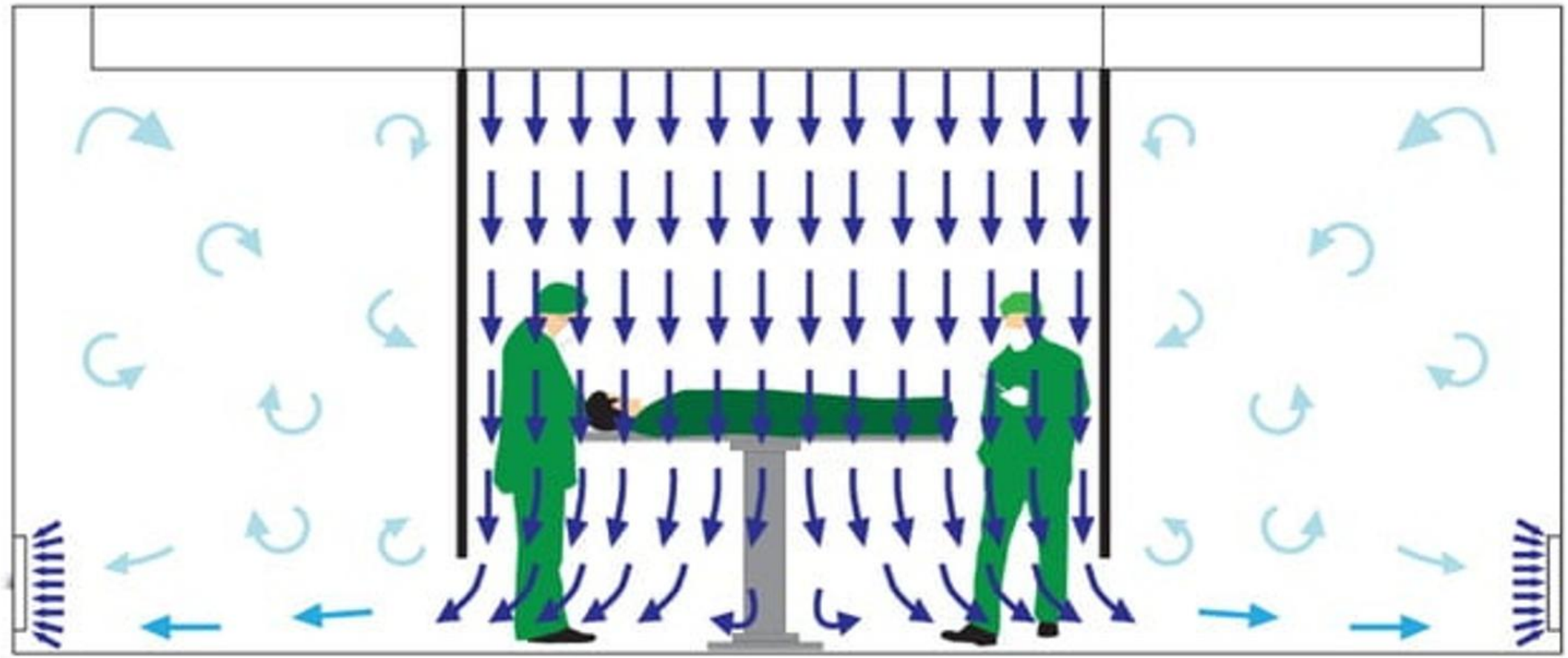
Partial wall UCV with low level returns

Fully enclosed UCV



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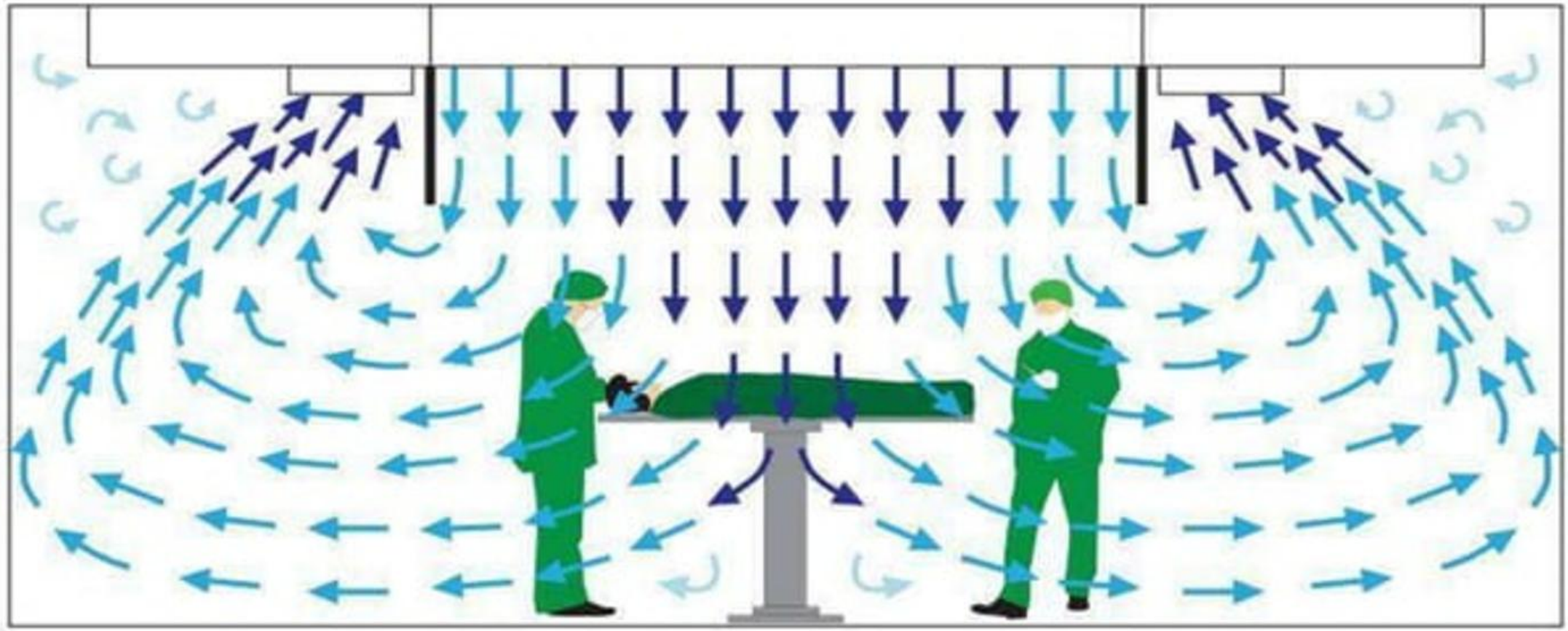
Fully enclosed UCV

- Excellent downflow
- Entrainment not an issue

- Lower CFU count at the wound site

- But extremely constricting for the staff and equipment usage

Partial wall style UCV



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Partial wall style UCV

- Very popular in UK
- Fully compliant HTM 03-01
- Different sizes available from 2.8x2.8m up to 3.5x3.5m
- Side screen prevents entrainment
- No requirement for low-flow recirculation
- Modular construction -> lower costs to install
- Steel perforated diffusers -> easy to clean

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Partial wall style UCV

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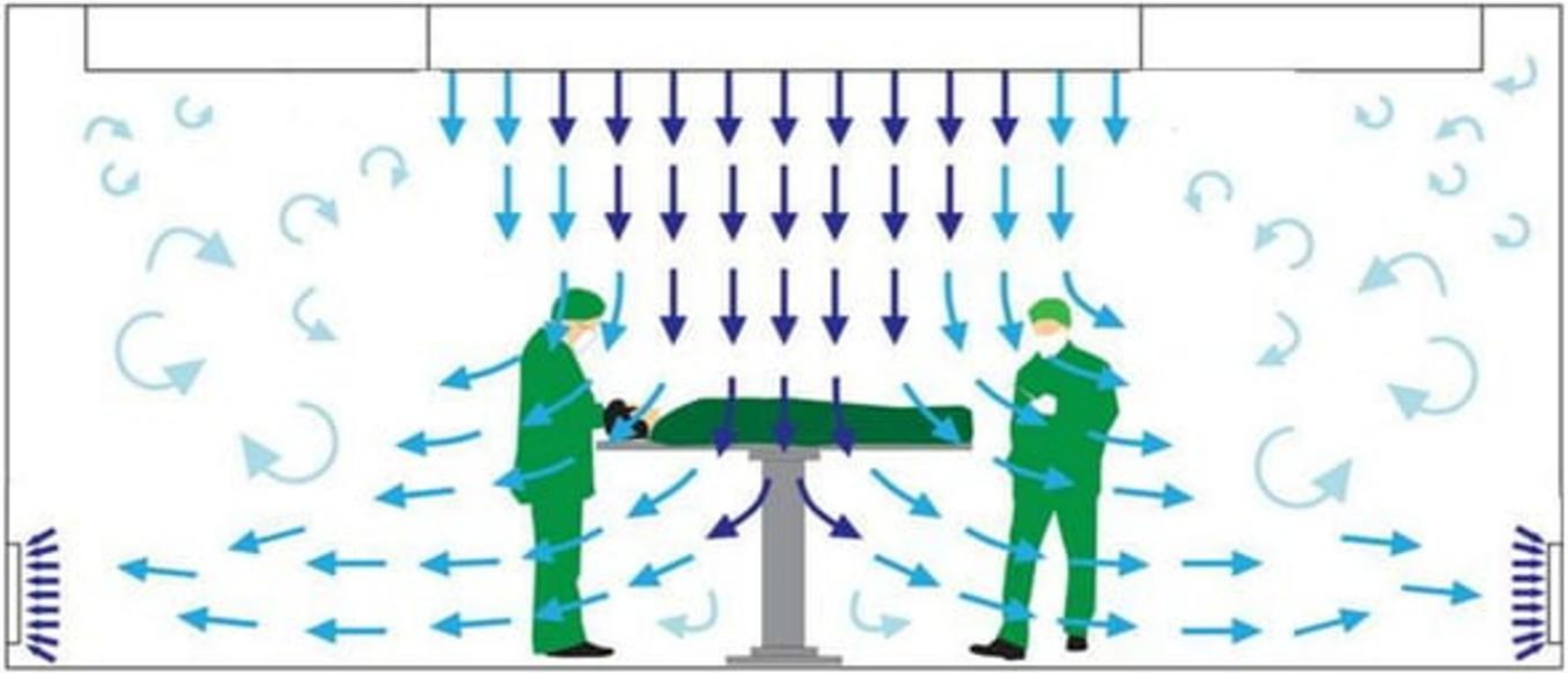
Screenless canopy – low level recirculation



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Screenless canopy – low level recirculation

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Screenless canopy – low level recirculation

- Popular in Europe, low velocity systems
- Usually at least 50% recirculation of supply air -> increased costs
- Very flexible since there are no screens
- Costly to install & maintain
  - Additional infrastructure
  - Additional service requirements

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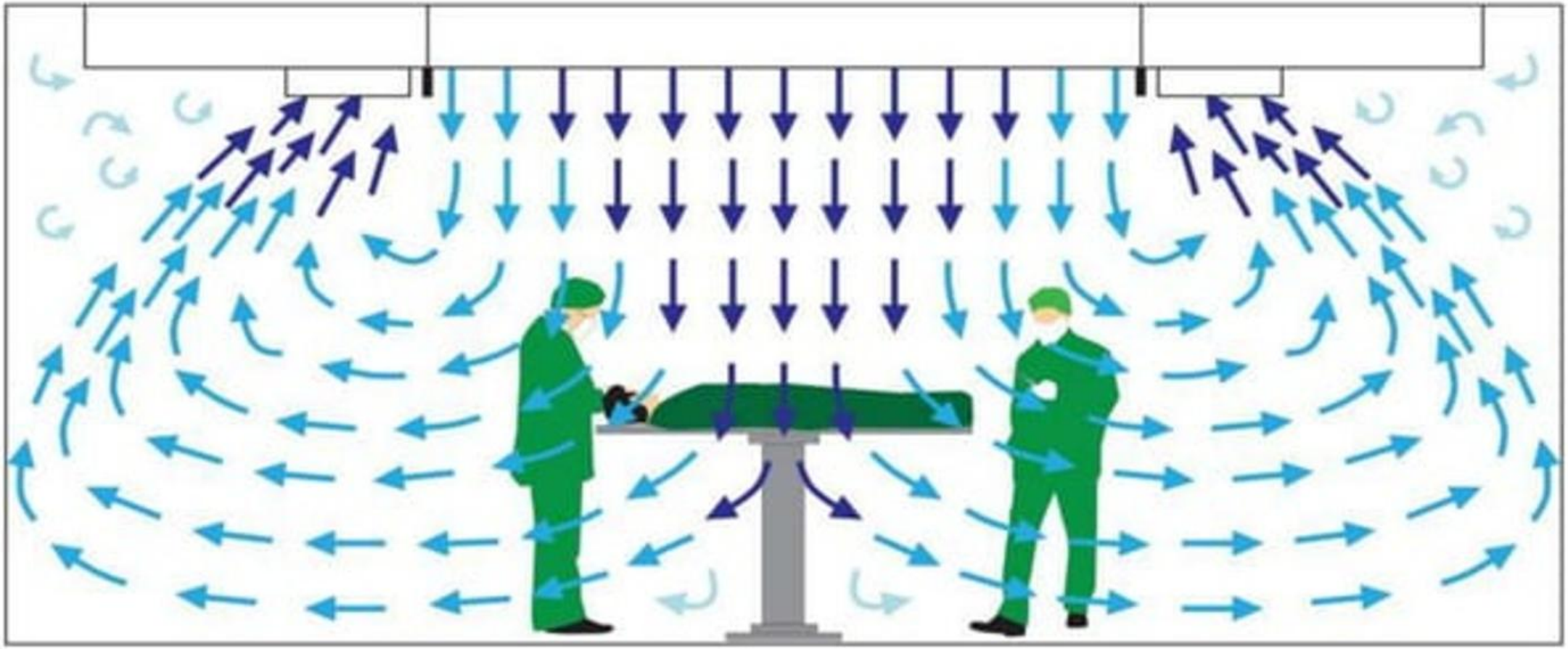
Screenless canopy – integrated recirculation



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Screenless canopy – integrated recirculation

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Screenless canopy – integrated recirculation

- Compliant with HTM 03-01, UK designed and manufactured
- Standard UCV technology
  - Low maintenance costs
- Fully integrated system
  - No need for recirculation ducts, additional fans or cooling coils
- Flexible, no side screens

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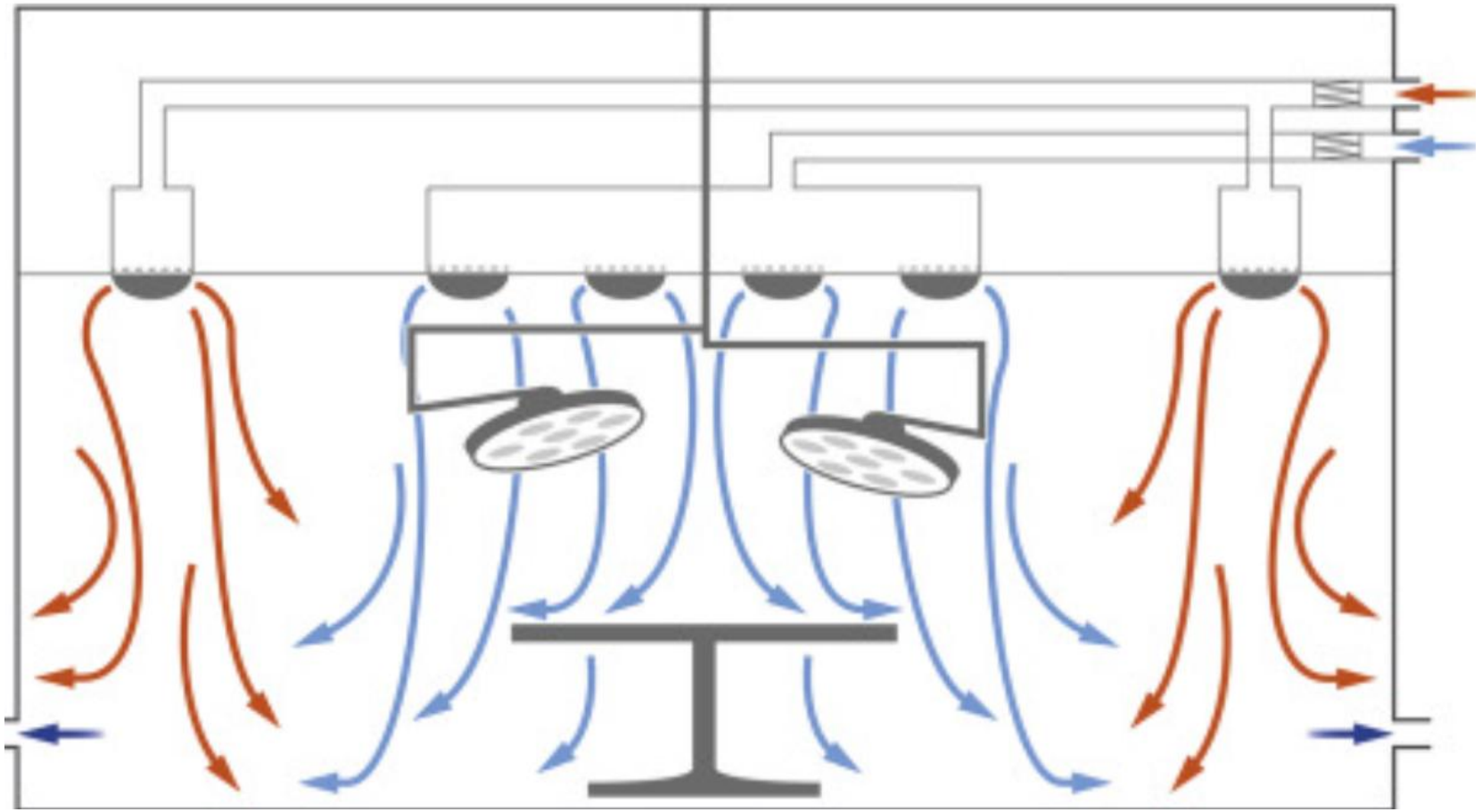
Temperature-controlled airflow systems



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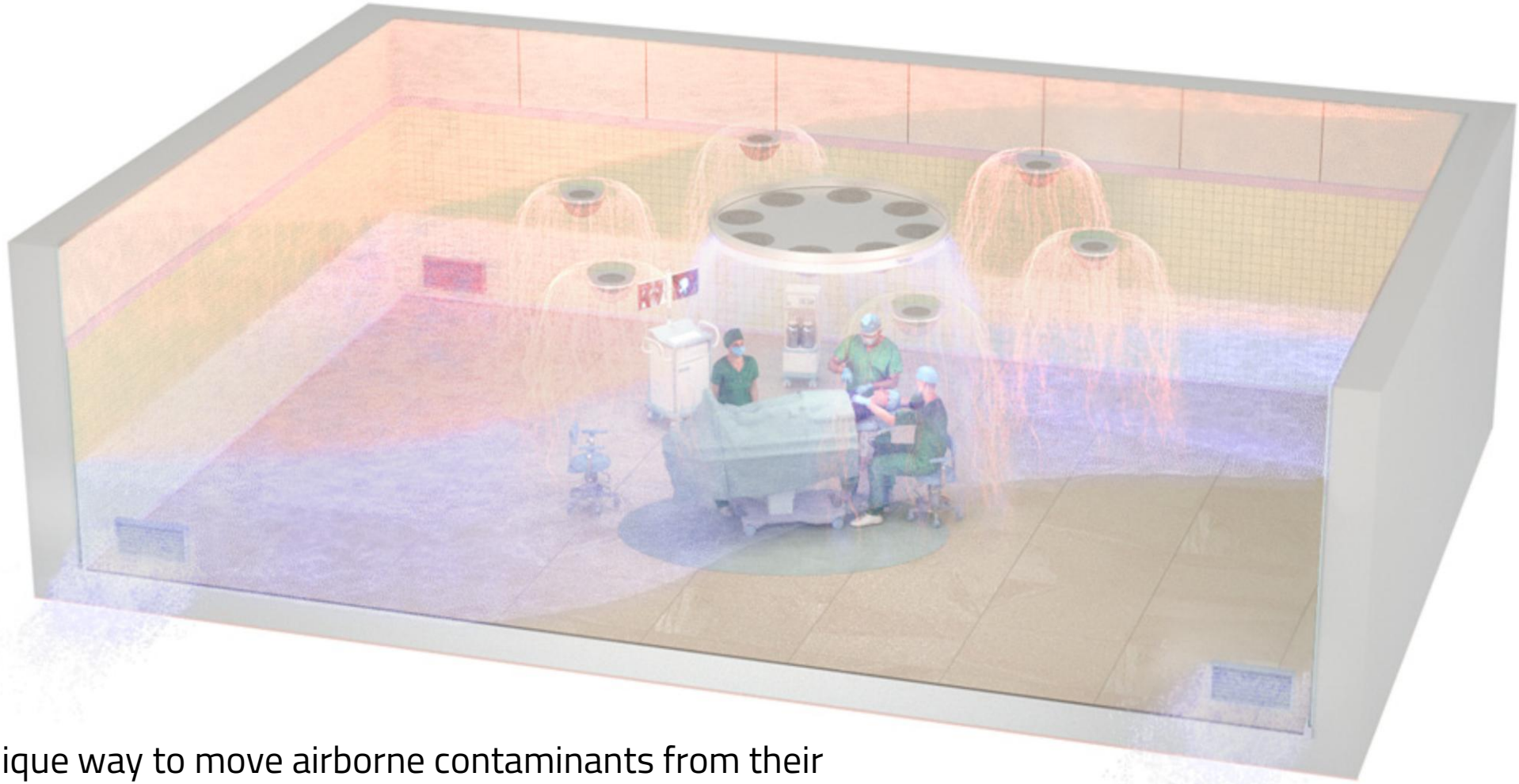
Avidicare - Temperature-controlled AirFlow (TcAF)



TcAF is a unique way to move airborne contaminants from their source to somewhere where they do no harm with very high ventilation efficiency.

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Opragon 8, Avidicare

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Opragon 8, Avidicare

- Low-turbulence airflow is 1.5-2C cooler than the room temperature
- Cooler air generates a gravitational effect
  - Consistent downward airflow
  - Comfortable thermal environment
- Smaller footprint in the ceiling
- Contamination displaced towards the periphery
- Low turbulence in both central and peripheral areas

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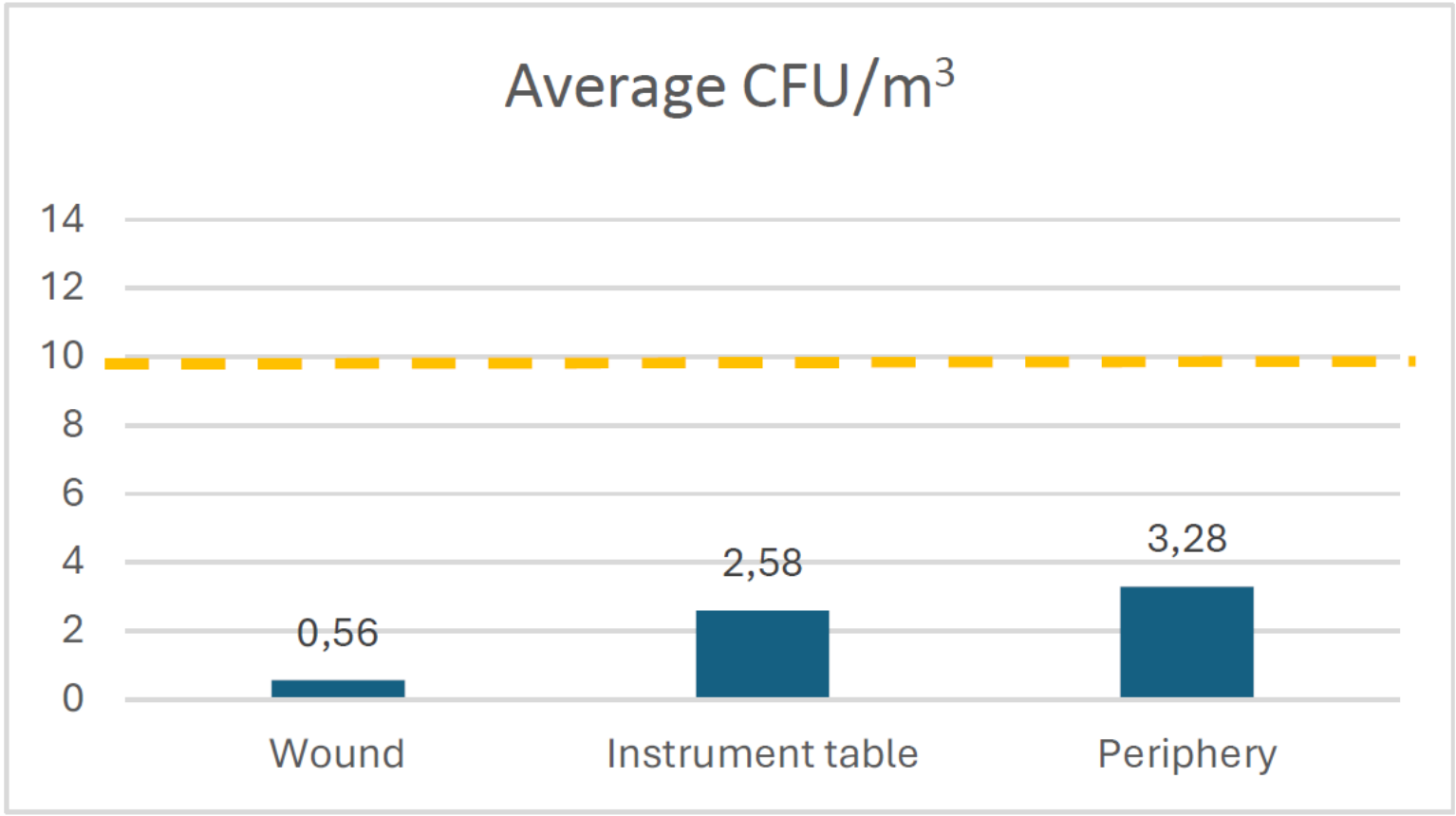
Opragon 8, Avidicare



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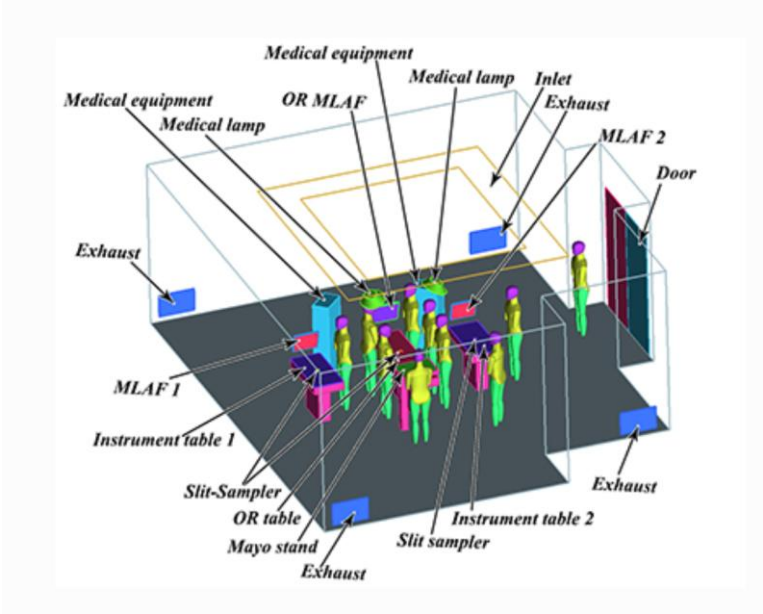
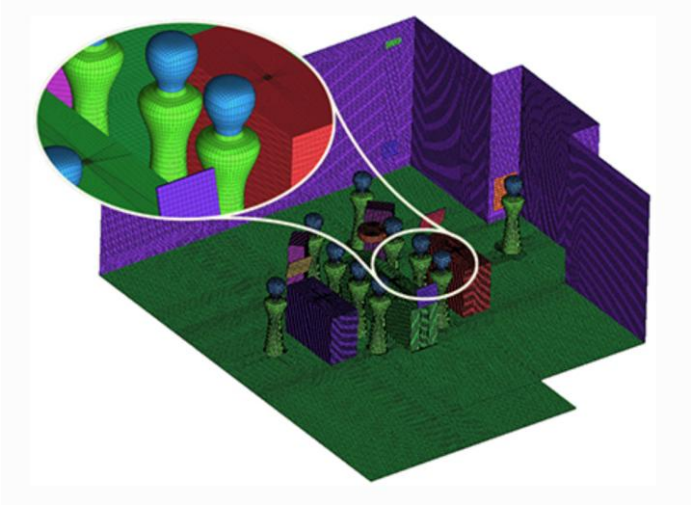
Simulate air flow in the OR

- Use CFD (Computational fluid dynamics) to simulate a given scenario
- Optimize for thermal comfort and / or contaminant transmission
- What is needed





https://www.byv.kth.se/en/avd/byggteknik-och-desig/2.4084/design-of-hospital-operating-room-ventilation-using-computational-fluid-dynamics-1.27399

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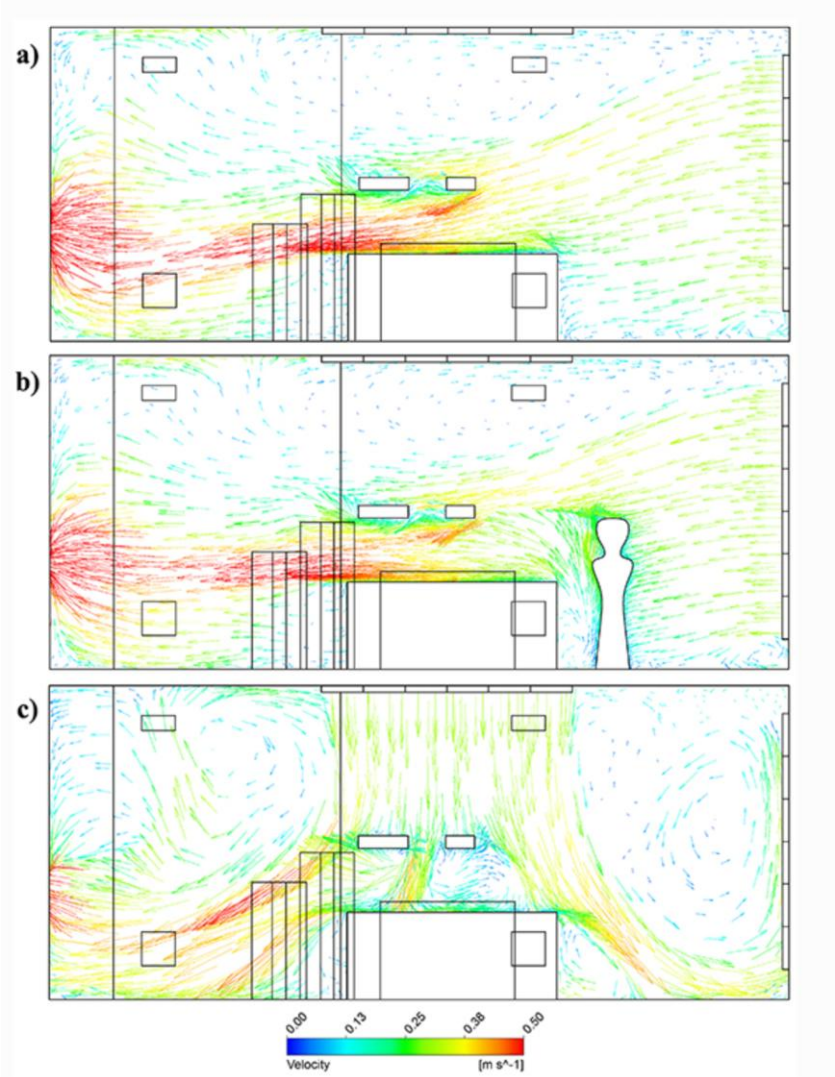
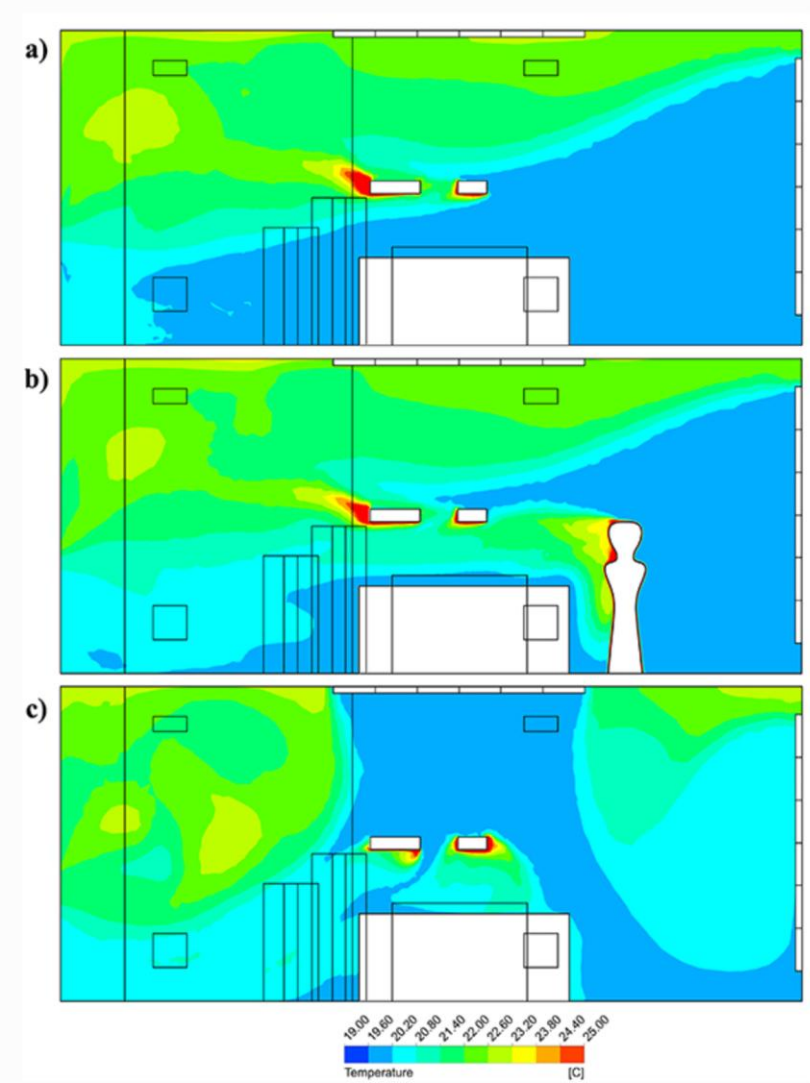
Simulation output





Sasan Sadrizadeh
https://www.byv.kth.se/en/avd/byggteknik-och-desig/2.4084/design-of-hospital-operating-room-ventilation-using-computational-fluid-dynamics-1.27399

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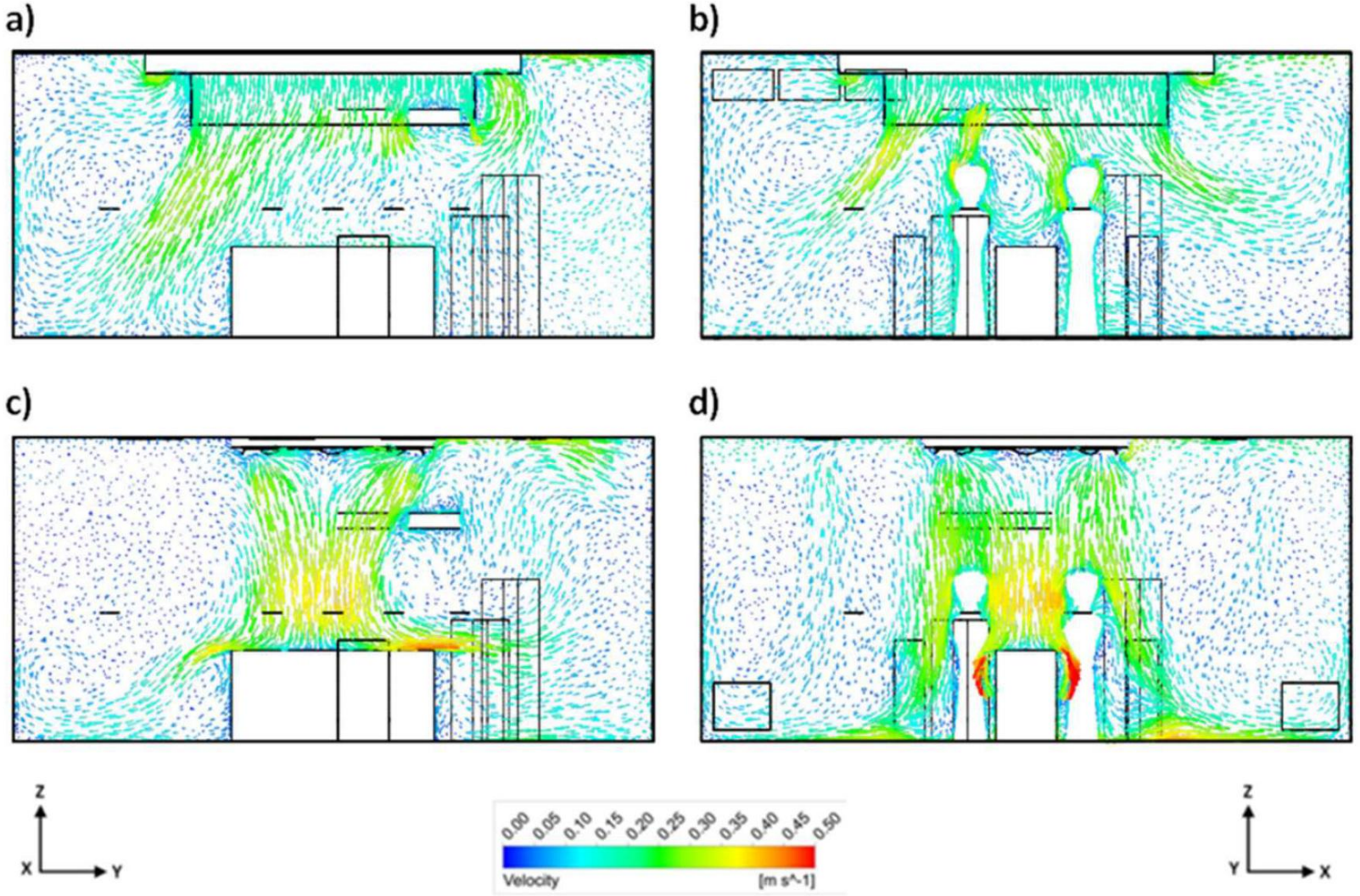
Compare UDAF (a, b) vs. TcAF (c,d)



Wang et al 2019

Can we visualize airflow?

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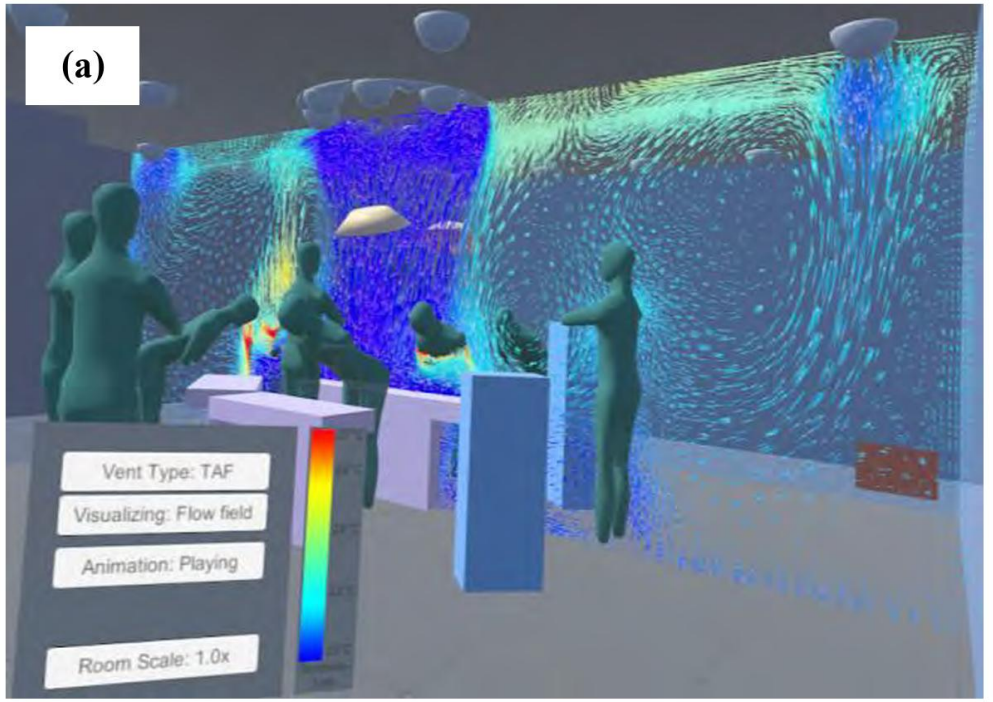
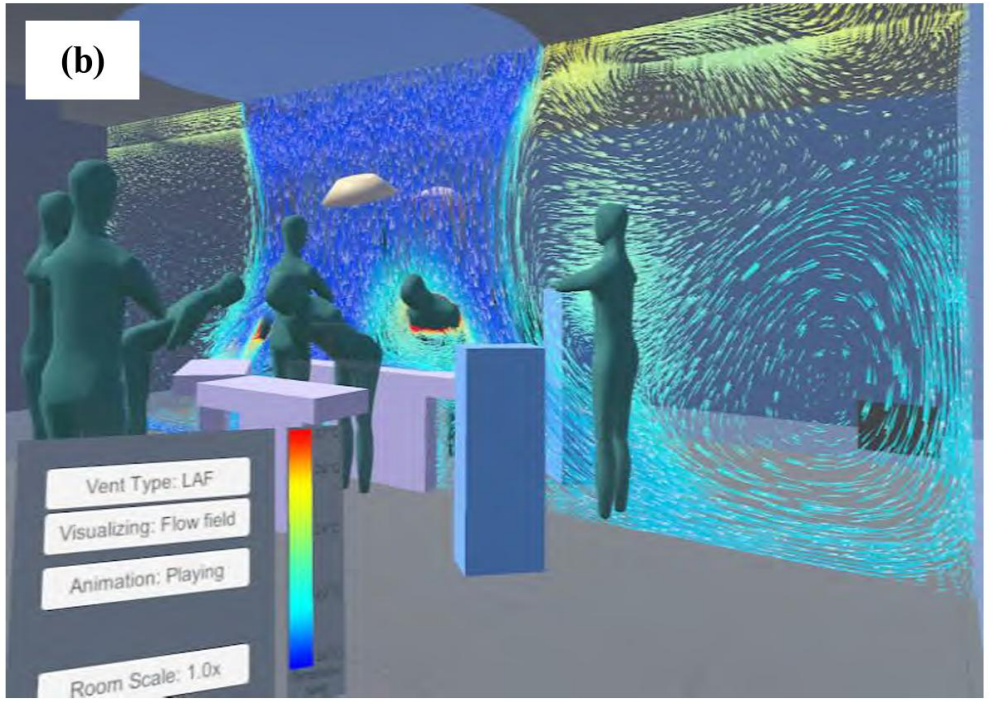
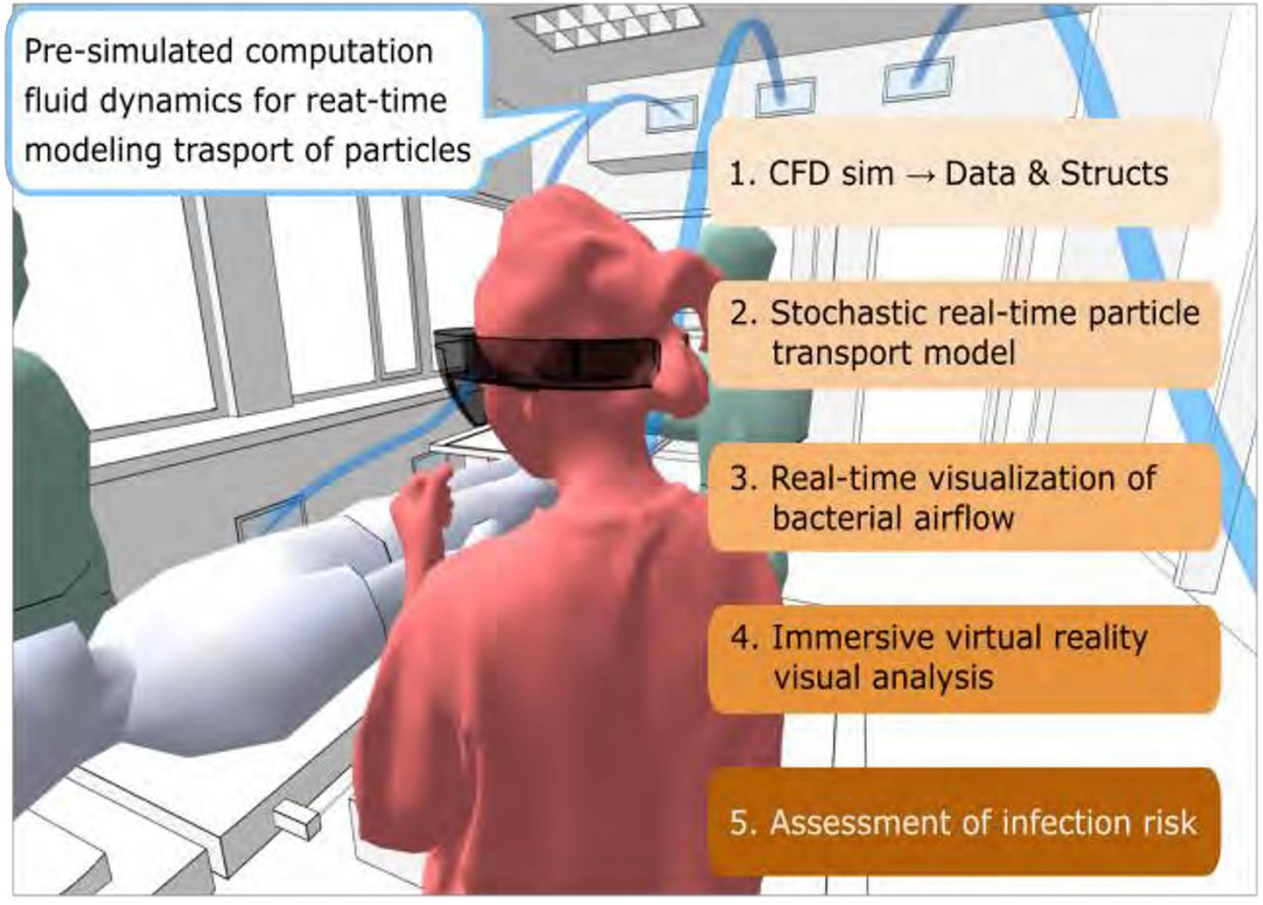
VR visualization



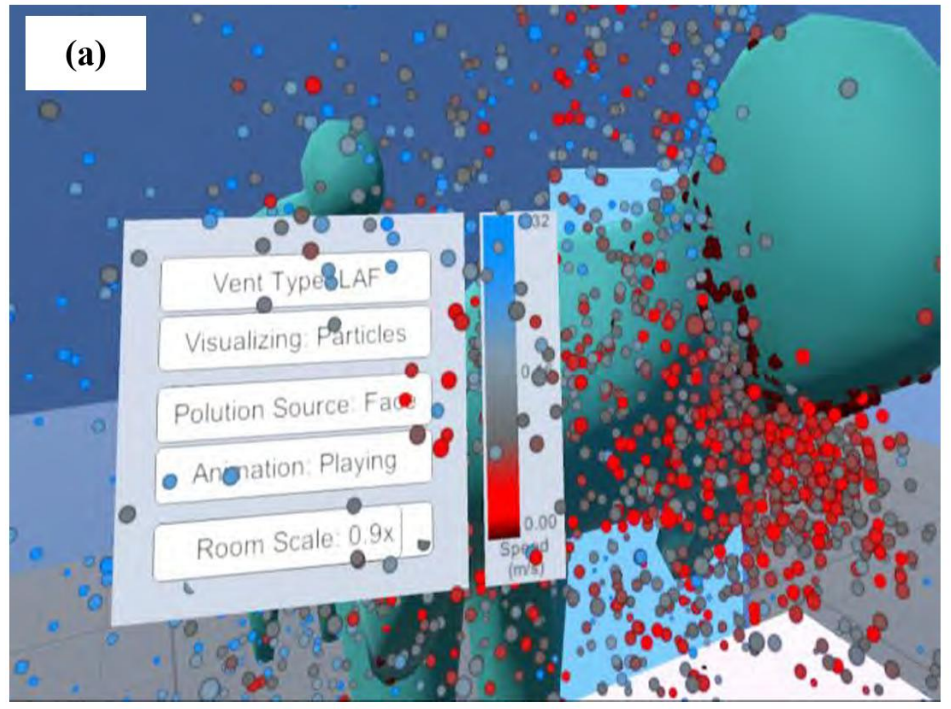


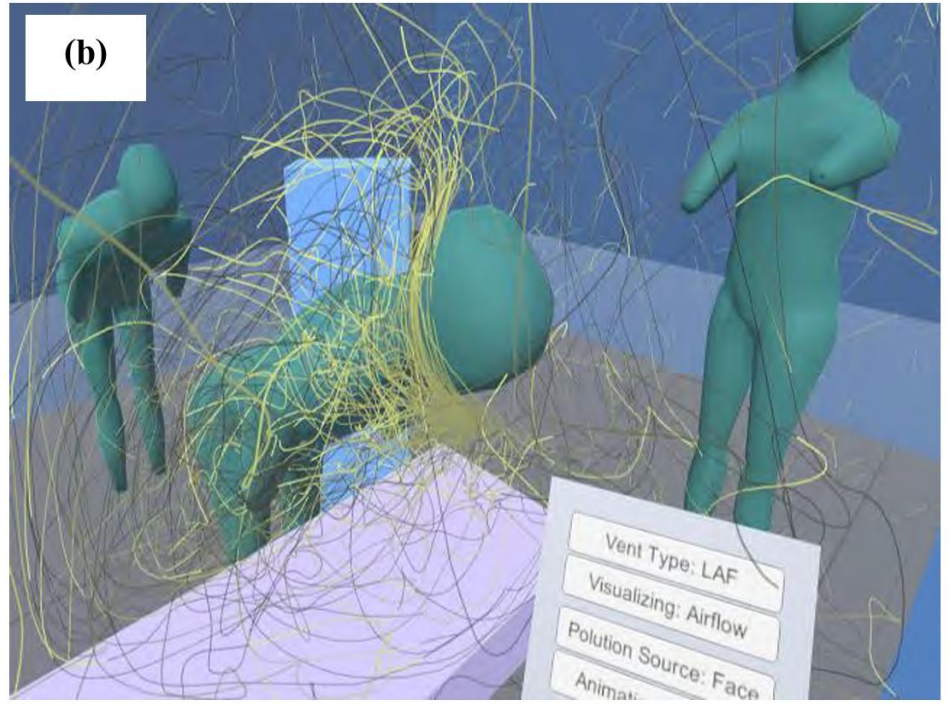
Sadeghian et al. 2021

VR visualization

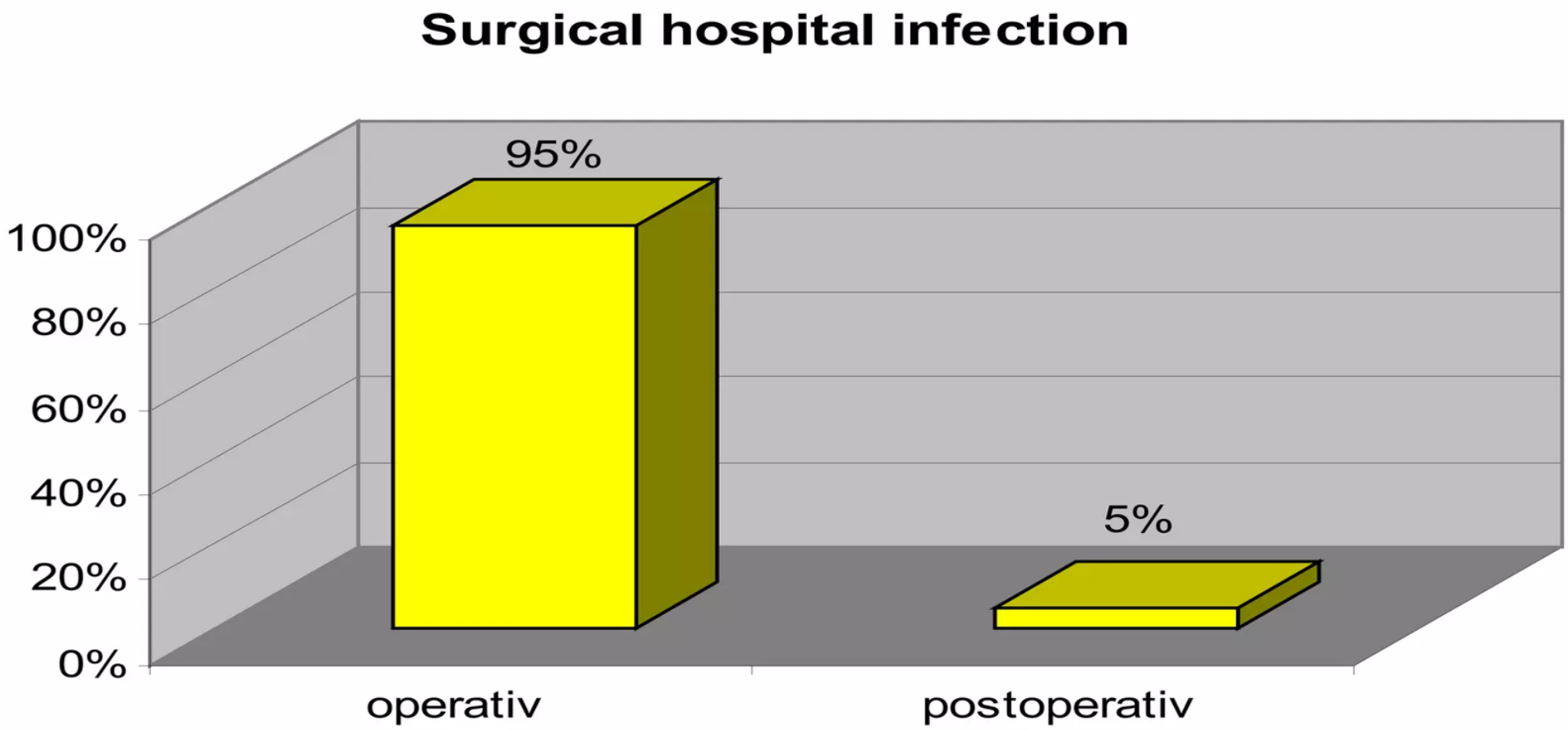


Sadeghian et al. 2021





Take home message: focus on the OR!



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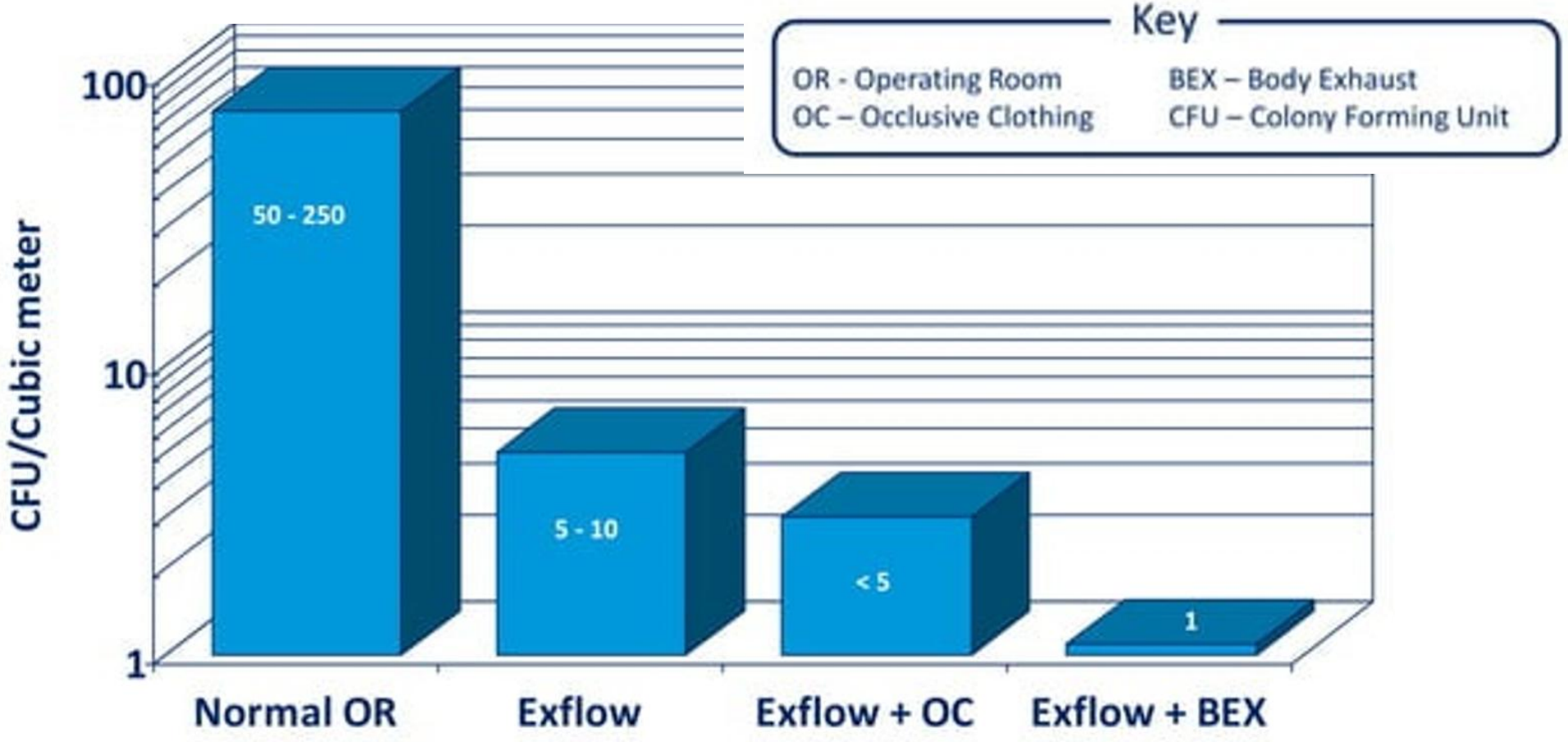
More than just room design!



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Health care ventilation aspects:

- Design considerations
  - Space
  - Energy
  - Maintenance
- Ventilation type
  - Laminar
  - Dilution
  - Displacement
- Design principles
  - Airflow pattern (direction usually vertical)
  - Air filtration
  - Ventilation rates
  - Temperature and humidity control
- Look at the entire lifecycle of the system

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In the investment justified?

- Just looking at the numbers:
  - Initial investment UCV: 100,000-200,000 USD
  - Maintenance: 3,500-7,000 USD / year
- One OR/ year:
  - 1000 surgeries / year
  - 1-2% infection rate
  - Cost of one SSI 20,000 USD
  - Cost of SSI / year: 200,000-400,000 USD
- One OR / 20 years
  - 4-8 million USD SSI related -> 200,000 investment is justifiable!
  - And many patients will thank you!

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Discussion / reflection

- How important is standardization for your project?
- Which standard is most relevant?
- How can it help improve the design an operating room?
- How about the life cycle of the OR?
- What about other rooms? ICU? Patient rooms?

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Resources

Hospital ventilation

- https://www.slideshare.net/slideshow/ultra-clean-ventilation-for-operating-theatres-236360687/236360687
- https://www.slideshare.net/slideshow/international-standards-in-comparison/8919020

White paper Avidicare

- https://www.avidicare.com/opragon/

Standards folder

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