Ventilation in Hospitals: Human-Centric Challenges in Sustainable Healthcare Buildings

Anna Bogdan, Vasco Vasconcelos, Rahmat Rizal, Muhammad Tayyab Waheed, Marcin Michalski

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Funded by the European Union

REHVA

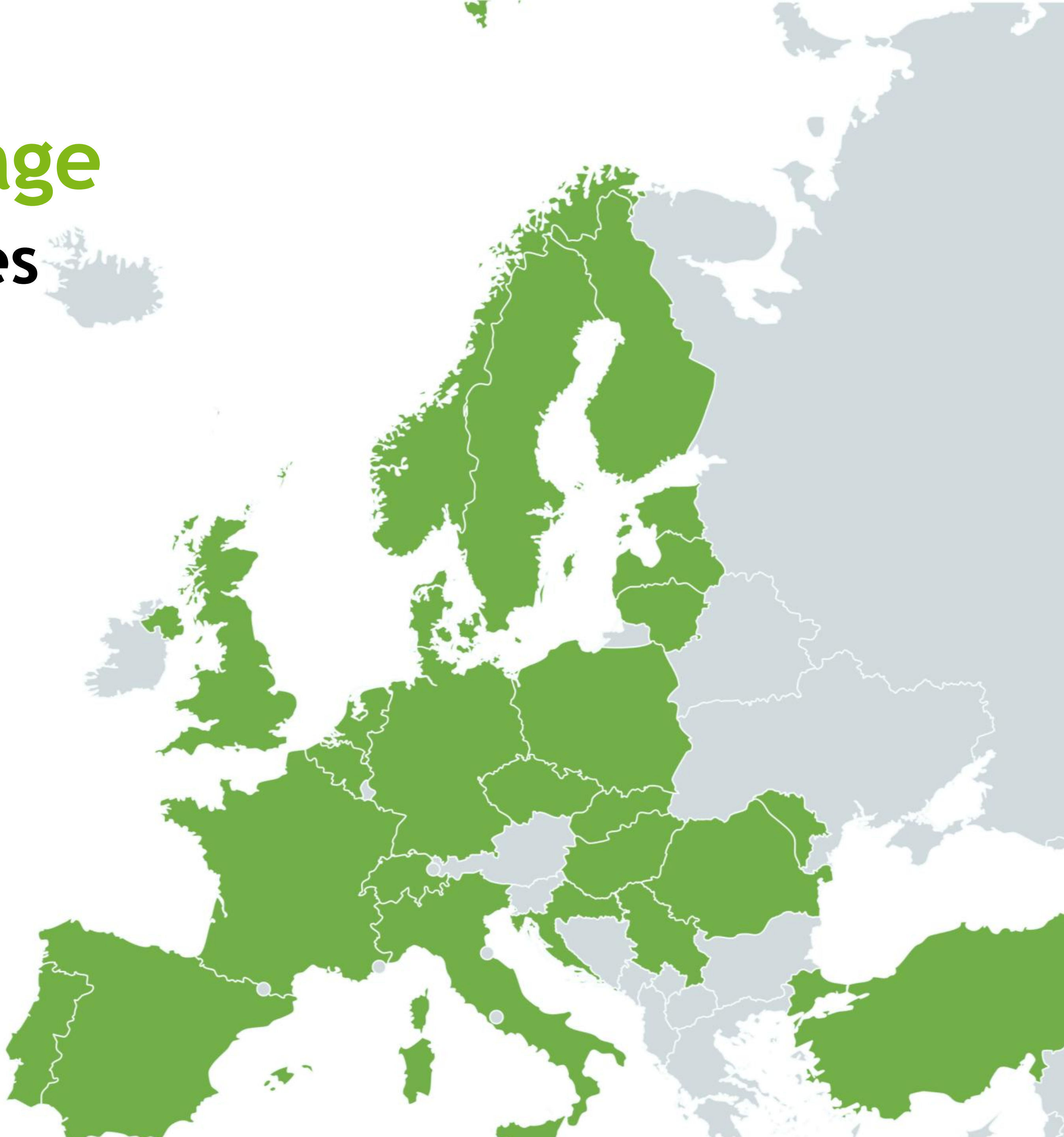
Federation of European Heating, Ventilation and Air Conditioning Associations

is a professional organisation founded in 1963 representing 120.000+ building services engineers from 24 countries

Geographical coverage

24 European countries

Belgium	Latvia	Slovakia
Czech Republic	Lithuania	Spain
Denmark	Moldavia	Sweden
Estonia	Netherlands	Switzerland
Finland	Norway	Turkey
France	Poland	United Kingdom
Germany	Portugal	
Hungary	Romania	
Italy	Serbia	



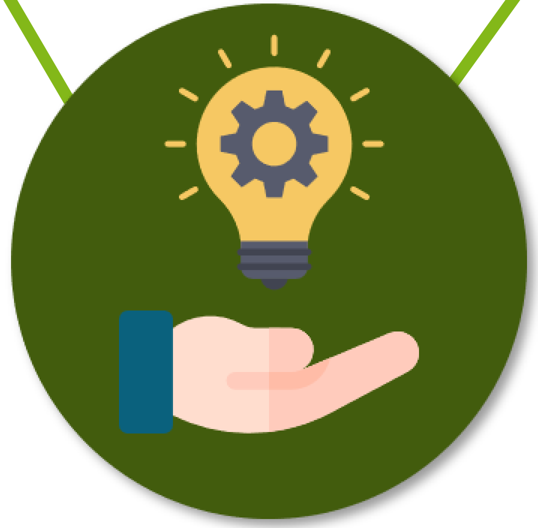
REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

Mission

REHVA's mission is to develop and disseminate economical, energy efficient, safe and healthy technology for mechanical services of building; to serve its members and the field of building engineering (heating, ventilation and air conditioning) by facilitating knowledge exchange, supporting the development of related EU policies and their national level implementation.

KEY ACTIVITIES

SUPPORTING INNOVATION



INVESTING IN REHVA TOOLS

STRENGHTENING REHVA NETWORK

EU POLICY MONITORING & ADVOCACY

SUPPORTING INNOVATION

TOWARDS HIGH IEQ & ENERGY PERFORMANCE & LOW-CARBON BUILT ENVIRONMENT

Supporting the collaboration of the HVAC sector with ICT & IoT, aiming at high IEQ

Interdisciplinaryy collaboration (social sciences, ICT, data science)

SMART BUILDINGS

Promoting advanced HVAC & building technologies

involvement in EU projects and initiatives

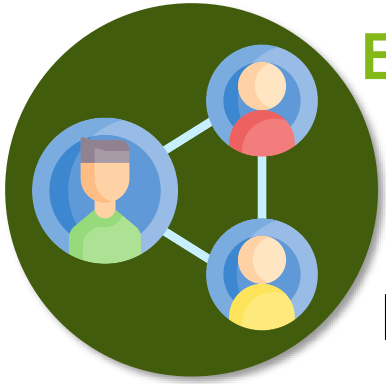
Promoting the integration of HVAC systems with energy production from RES

Promoting diffuse application of high energy efficient technologies and systems

Start connection with energy utilities and grid

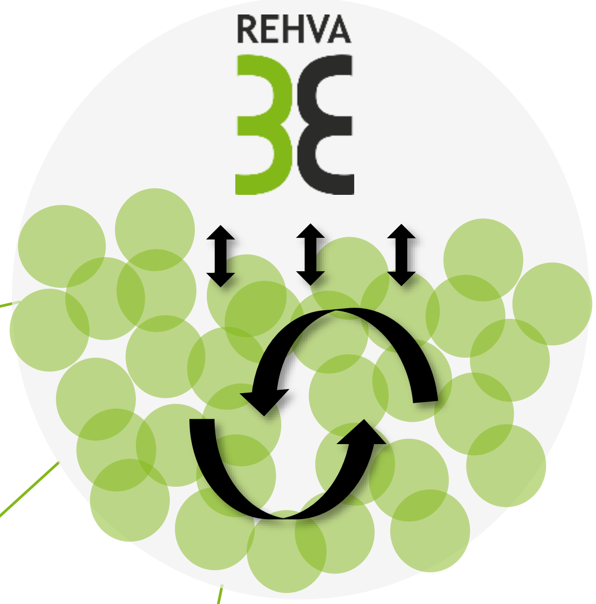
INVESTING IN REHVA TOOLS

TO PROMOTE KNOWLEDGE DISSEMINATION AND PROFESSIONAL DEVELOPMENT



ENHANCING REHVA REPUTATION AND VISIBILITY

STRENGHTENING THE REHVA NETWORK



EU LEVEL

Engagement in and support of EU policy developments and harmonised MSs implementation; EU-level associations and stakeholders

Advocacy actions & policy intelligence (EPBD, SRI, Ecodesign, EN standards)

WITHIN EUROPE

Networking and collaboration among and with REHVA members and supporters

- Membership collaboration
- EU projects
- Knowledge exchange, capacity building

BEYOND EUROPE

Collaboration and dissemination of EU HVAC culture at global level

- Global collaboration (IEQ-GA)
- Knowledge exchange & transfer

EU POLICY, ADVOCACY, SUPPORT OF NATIONAL IMPLEMENTATION

ADVOCATING FOR IEQ IN BUILDING AND ENERGY-RELATED EU POLICIES

- European Green Deal & Renovation wave
- Smart Readiness Indicator (Topical group C & SRI platform facilitated by REHVA, TRC)
- EPBD19a: feasibility study about the inspection of standalone ventilation systems
- Supporting the implementation of the revised EPBD (seminars, RJ articles, webinars)
- EPBD review & guidance documents to assist the Commission in the EPBD implementation phase
- Supporting the use and deployment of EPB standards in cooperation with the EPB Center

COMMUNICATION

REHVA website

News items
Events
REHVA Publications

REHVA emailing

REHVA Newsletter
EU Policy Newsletter
REHVA Journal Newsletter

Social media

Ventilation in Hospitals: Human-Centric Challenges in Sustainable Healthcare Buildings

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Hospital Ventilation in Europe: Current Challenges and Future Expectations

Anna Bogdan

Warsaw University of Technology

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Hospital Environments from Indoor Air Quality Perspective

Hospitals are among the most complex building types in terms of indoor environmental control. They consist of multiple functional zones with very different requirements related to air quality, cleanliness, temperature, and infection prevention.

Within a single hospital building, ventilation systems must simultaneously serve a wide range of spaces, including:

- patient wards and intensive care units
- isolation rooms used both for infectious patients and for highly vulnerable patients who must be protected from external contamination
- operating rooms with strict cleanliness and airflow requirements
- diagnostic rooms and treatment areas
- laboratories handling biological or chemical agents
- outpatient clinics and waiting areas

Each of these zones requires specific ventilation strategies, including different **airflow patterns, pressure regimes, air change rates, and filtration levels** to ensure both patient safety and proper environmental control.

Hospital Environments
from Indoor Air Quality Perspective

Key characteristics of hospital environments

- High occupant density – patients, medical staff, and visitors are present simultaneously
- Continuous operation (24/7) with constant movement of people and equipment
- Human activity strongly influences airflow patterns and contaminant transport
- Medical procedures can generate aerosols, increasing airborne infection risks
- Presence of vulnerable patients requiring enhanced environmental protection

Recent experiences during the COVID-19 pandemic highlighted the **critical role of ventilation systems** in limiting airborne transmission of pathogens and maintaining safe healthcare environments.

Hospital Environments from Thermal Environment Perspective

Ventilation systems in hospitals must respond to diverse
and often competing requirements across different functional spaces.

Thermal Environment Conditions from the Patient Perspective

- Reduced metabolic energy production (6–8 hours without food)
- Absence of behavioral thermoregulation (due to anesthesia)
- Suppressed shivering thermogenesis (caused by antiemetic medication)
- Impaired vasoconstriction and vasodilation mechanisms (effects of anesthetics and opioids)

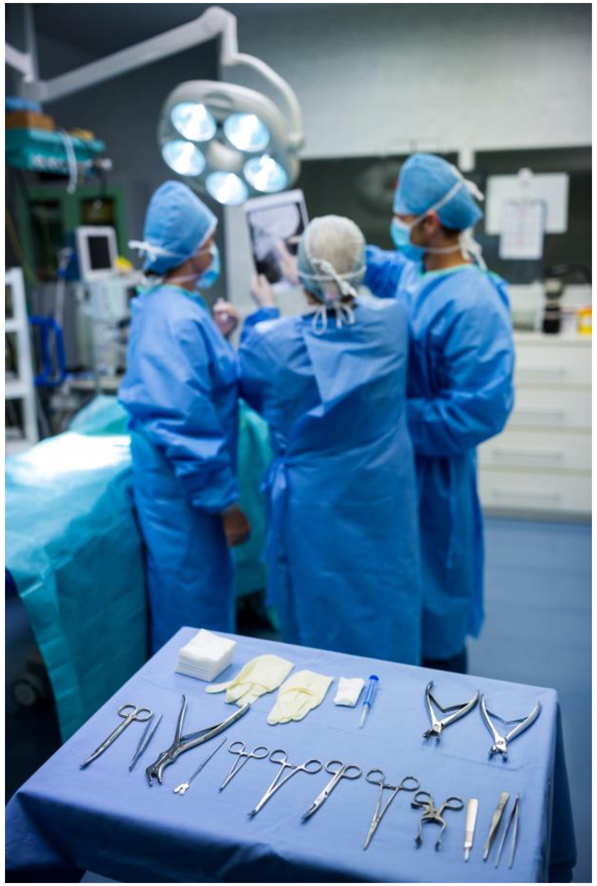
- Low air temperature
- High air velocity
- Low thermal insulation of clothing
- Low metabolic rate

Hospital Environments from Thermal Environment Perspective

Ventilation systems in hospitals must respond to diverse
and often competing requirements across different functional spaces.

Thermal Environment Conditions from the Staff Perspective

- High metabolic rate due to intensive physical activity during medical procedures
- High clothing insulation resulting from protective surgical garments and equipment
- Significant mental workload and cognitive stress during complex medical procedures



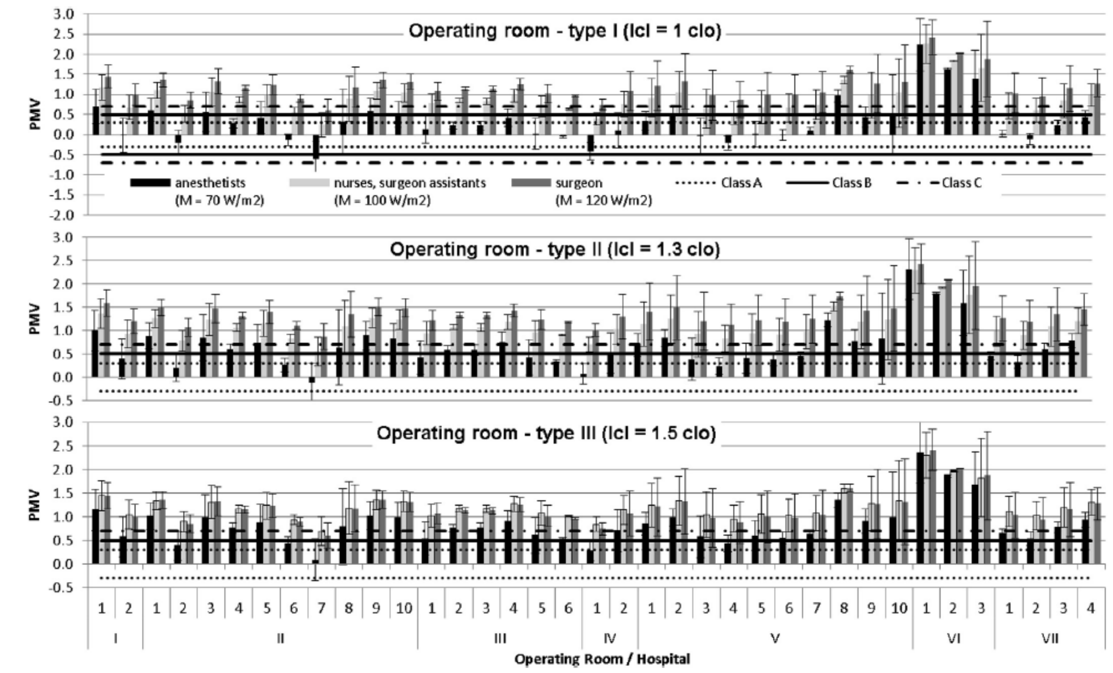


Fig. 3. Thermal comfort of medical staff in operating rooms – comparison of PMV indicators with the recommendations of the standard [29].

Hospital Environments from Thermal Environment Perspective

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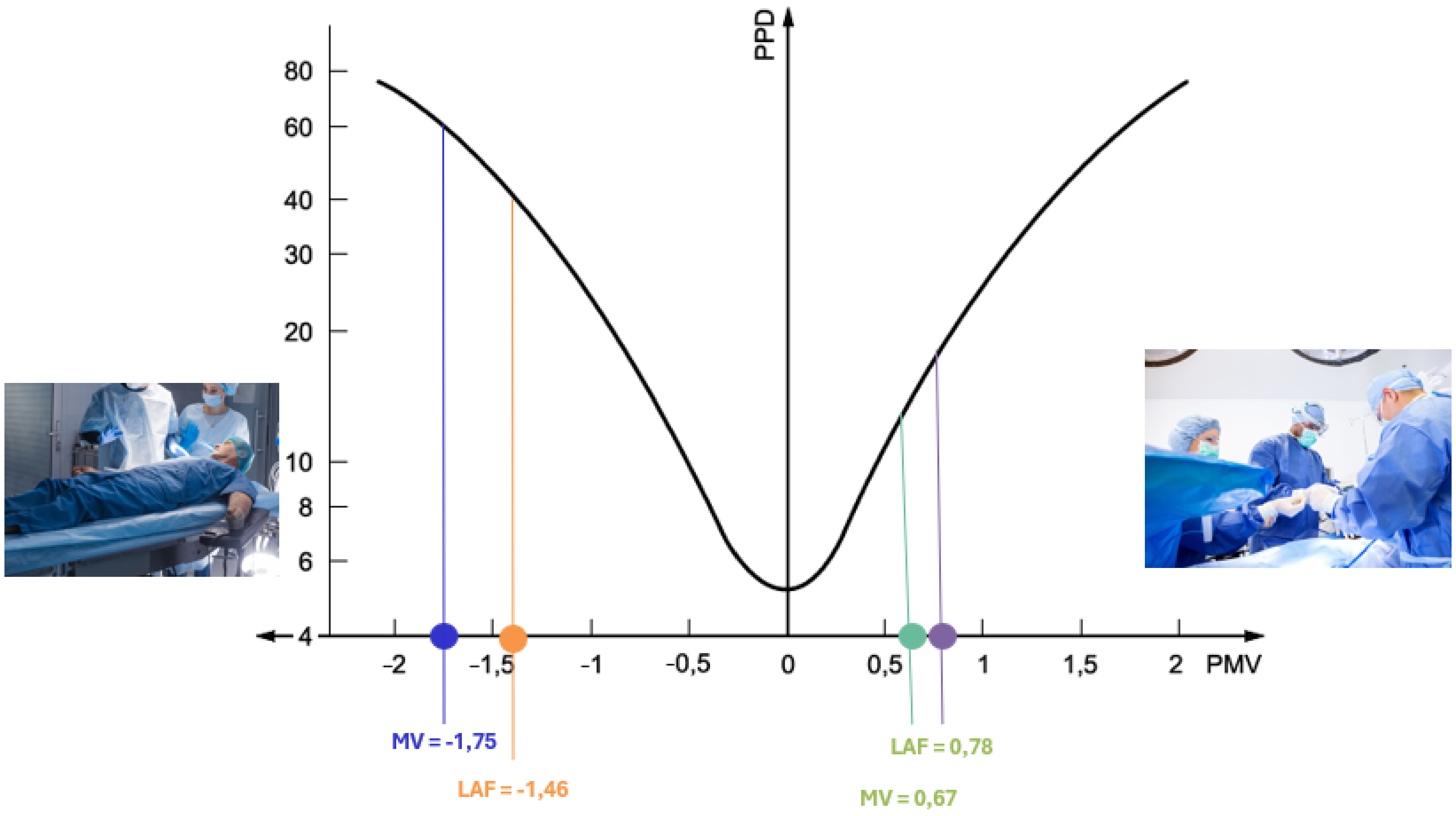
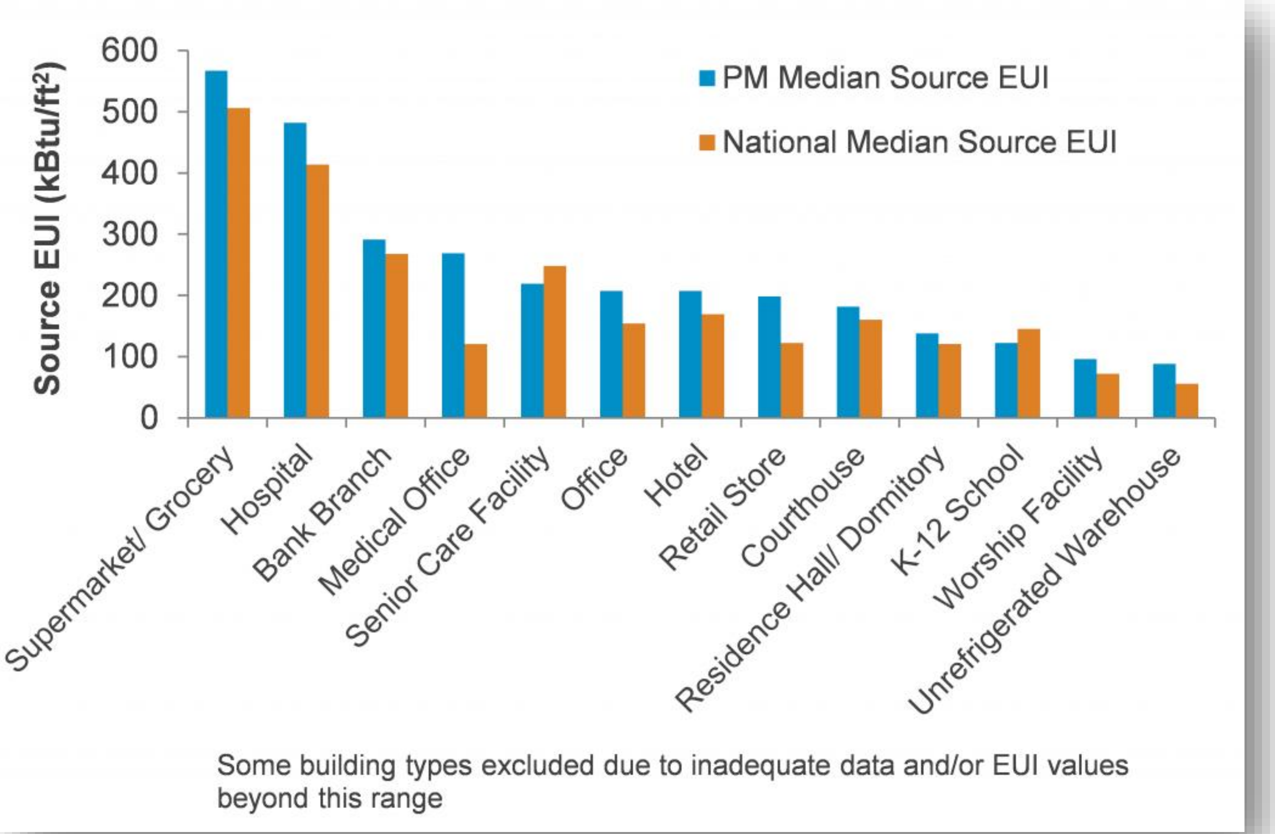


Hospital Environments from Energy Efficiency Perspective

Hospitals are among the most energy-intensive building types. On average, a hospital complex consumes around 2.5 times more energy than a typical public or commercial building. Depending on the country, HVAC systems account for approximately 30% to 70% of a hospital's total energy consumption.

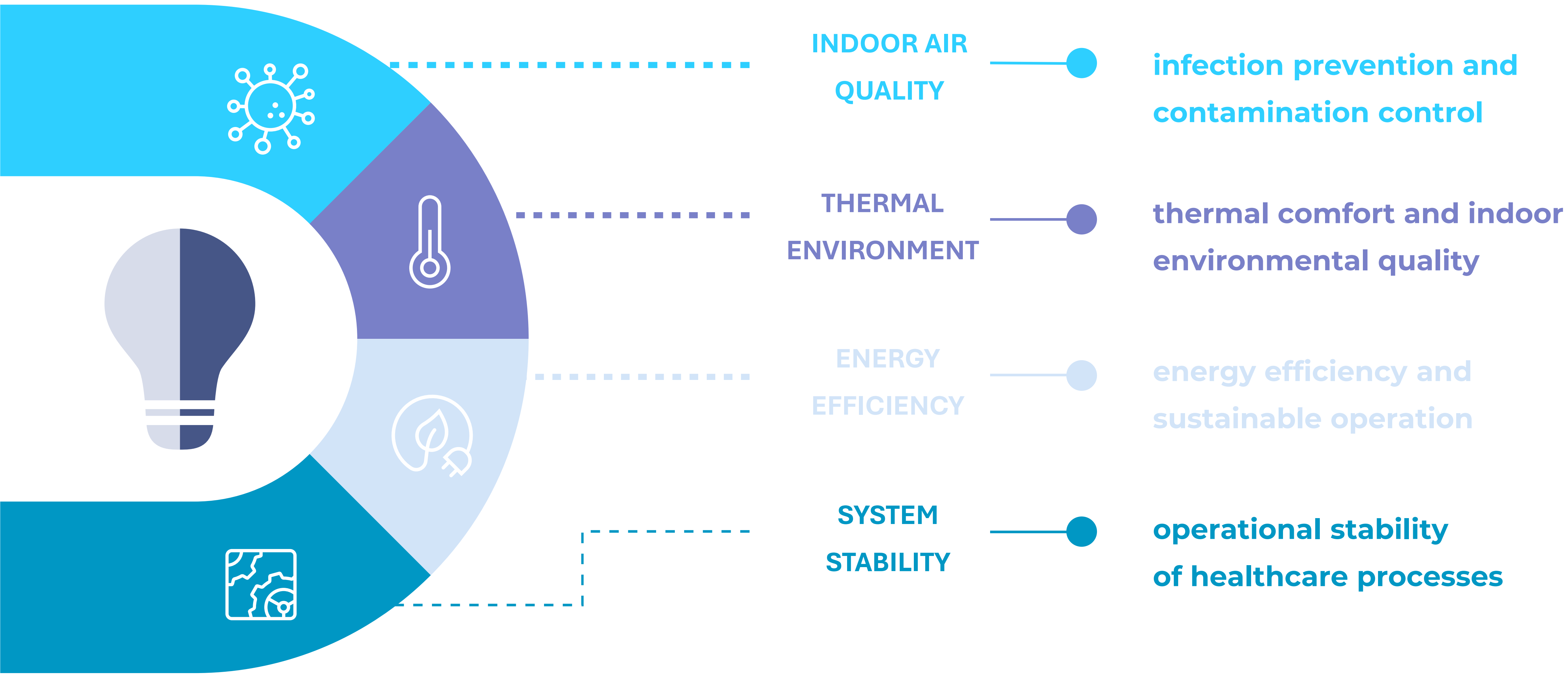
Country	Annual Energy Intensity (kWh/m^2)
Greece [29]	-
Hospitals, health centers, and clinics, 1980	235
Hospitals, health centers, and clinics, 2001	233
Hospitals, health centers, and clinics, 2010 (projected)	236
Scotland: small health buildings, 2001 [29]	310
Poland [29]	-
University hospital, heat/hot water only, 2005–2008	268
Provincial hospital, heat/hot water only, 2005–2008	327
Malaysia: public hospital, 2008 [29]	234
Spain: [29]	-
Hospital, total energy use,~2005	494
Hospital, electricity only, ~2005	169
Thailand: an average of 79 hospitals, electricity only, 1996–2006 [29]	149
Bulgaria [27]	656.5
Estonia [27]	147.8
France [27]	228.2
Germany [27]	317.2
Netherlands [27]	237.8
Sweden [27]	230.6
UK [27]	516.2



Bawaneh, K., Ghazi Nezami, F., Rasheduzzaman, M., & Deken, B. (2019). Energy Consumption Analysis and Characterization of Healthcare Facilities in the United States. Energies, 12(19), 3775. https://doi.org/10.3390/en12193775

EnergyStar: https://www.energystar.gov/buildings/tools-and-resources/portfolio-manager-technical-reference-us-national-energy-use

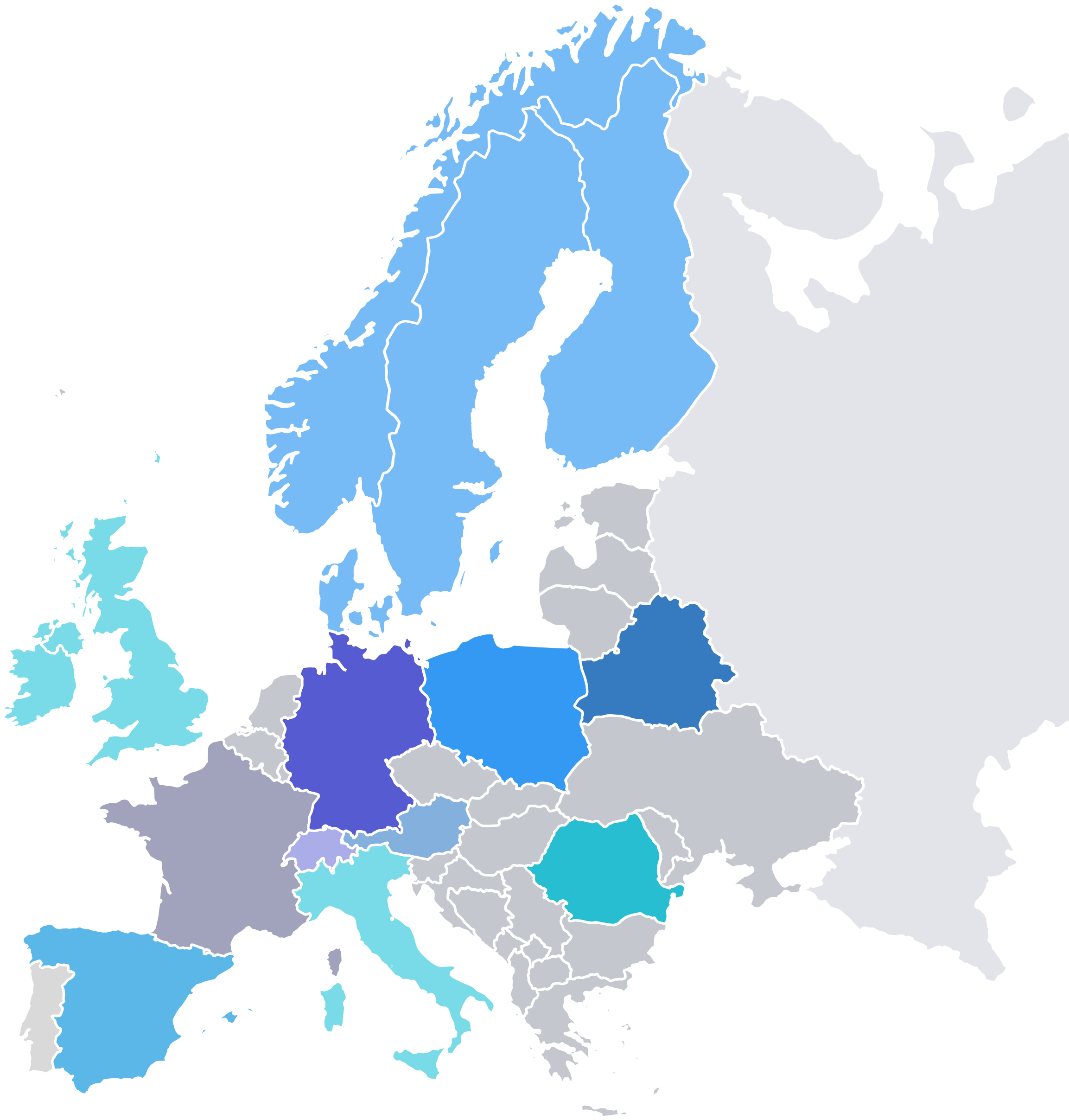
Key Challenges in Hospital Ventilation



Key Challenges in Hospital Ventilation

High regulatory diversity across European countries

- hospital ventilation is regulated through different national standards and technical guidelines
- additional requirements are defined in national healthcare regulations and building codes
- as a result, design criteria, ventilation rates, and system configurations may differ significantly between countries



- ✓ DIN 1946-4 Ventilation and air conditioning – Part 4: Ventilation in buildings and rooms of health care
- ✓ ANSI/ASHRAE/ASHE Standard 170-2021 Ventilation of Health Care Facilities
- ✓ R3Nordic Guideline for Hospital Ventilation
- ✓ DIN 1946-4 Ventilation and air conditioning – Part 4: Ventilation in buildings and rooms of health care
- ✓ DIN SPEC 94676:2018-07 Ventilation in hospitals – Coherent hierarchic structure and common terms and definitions for a standard related to ventilation in hospitals
- ✓ PAS 5748:2014 Specification for the planning, application, measurement and review of cleanliness services in hospitals
- ✓ HTM 01-03 Heating and Ventilation Systems, Specialised Ventilation for Healthcare Premises, Part A: Design and Validation; Department of Health and Social Care: London, UK, 2007
- ✓ CEN/TS 16244:2018. 2018 . „Ventilation in hospitals – Coherent hierarchic structure and common terms and definitions for a standard related to ventilation in hospitals."
- ✓ AFNOR SPEC S99-120 April 2019: Global French best practice guide for hospital construction and operation – Guide de bonnes pratiques de construction et exploitation hospitalières françaises à l'international
- ✓ UNE 100713:2005 Air conditioning in hospitals

From System-Centric to Human-Centric Ventilation

Traditional approach

- design based primarily on fixed air change rates (ACH) defined in standards and guidelines
- focus on room-level environmental conditions rather than the microenvironment around patients and staff
- static design assumptions regarding occupancy, activity levels, and internal loads
- limited consideration of human behavior and movement affecting airflow patterns
- ventilation systems typically operate at constant or predefined airflow rates regardless of real-time demand
- energy performance evaluated under standard design conditions, often using nominal airflow rates and typical operating scenarios rather than real operational variability
- limited integration of real-time monitoring, adaptive control, or user interaction

Ventilation performance and energy use are typically assessed under **idealized and static conditions**, which may differ significantly from real hospital operation.

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Human-centric approach

- focus on the micro-environment in the immediate vicinity of patients and healthcare staff, especially within the breathing zone
- consideration of patients, healthcare staff, and their activities as active elements shaping airflow, exposure, and contaminant transport
- ventilation strategies that respond to human presence, activity patterns, and actual demand rather than relying only on fixed design assumptions
- integration of infection risk reduction, thermal comfort, air quality, and energy performance into one coordinated framework
- use of real-time monitoring, sensing, and adaptive control to better match ventilation performance to current conditions
- support for a more flexible, responsive, and resilient operation of hospital ventilation systems in dynamic healthcare environments

Ventilation performance and energy use are typically assessed under **idealized and static conditions**, which may differ significantly from real hospital operation.

The human-centric approach shifts the focus from designing ventilation for rooms as static spaces to **designing it for people, their exposure, and their real interactions with the indoor environment.**

Future Hospital Ventilation: Toward Human-Centric and Adaptive Systems

Human–centric ventilation

focus on the micro-environment around patients and staff

consideration of human behavior and activity

Human–airflow interaction

humans as sources of heat, bioaerosols, CO_2 and particles

growing use of experiments, CFD and airflow visualization

Smart and adaptive systems

real-time monitoring and infection risk assessment

adaptive control strategies supported by sensors and data

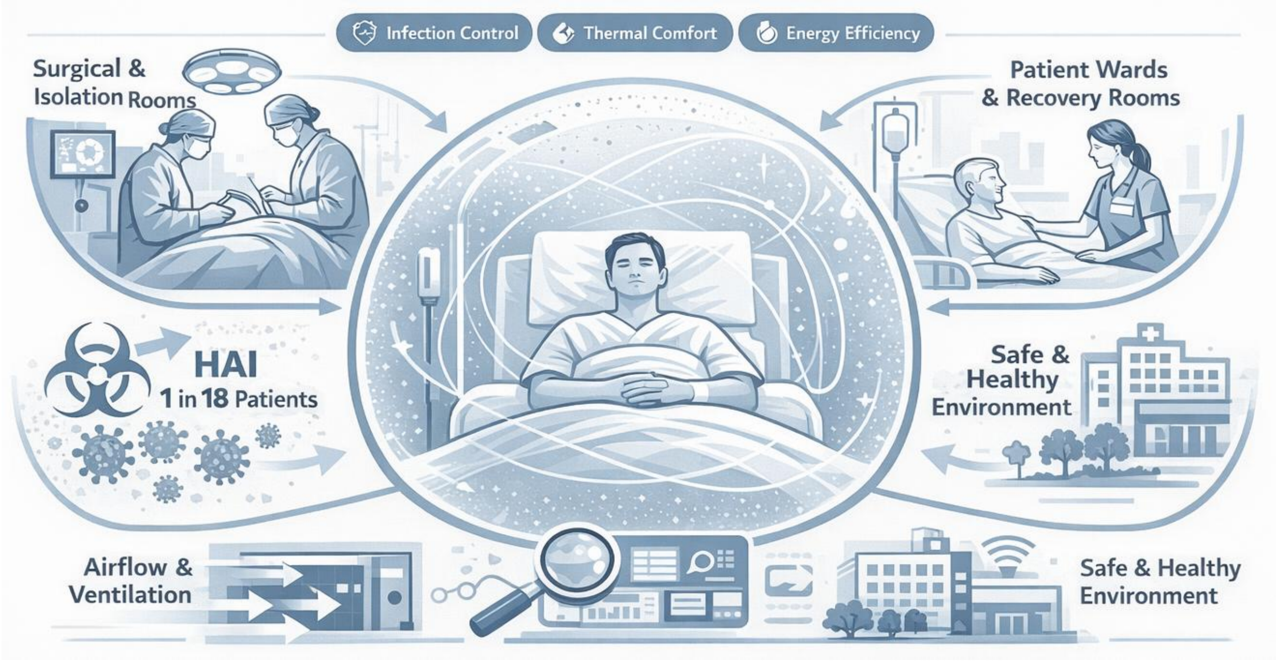
Integrated and sustainable hospitals

integration of HVAC, monitoring and energy management

future hospitals: safe, energy-efficient and intelligent

Research Directions in Europe

Human - Centric Indoor Climate for Healthcare Facilities



The HumanIC network aims to build a new approach to hospital environmental design through the concept of a human-centric indoor climate. Rather than the traditional approach of focusing solely on the building and its ventilation/heating systems, the network will develop new approaches to integrate the multi-dynamic interaction between contamination sources and airflow distribution systems with the clinical, patient and energy requirements of the hospital environment.

We will create and disseminate fundamental and applied science to improve the knowledge base and innovate new technologies for designing and operating hospital ventilation and thermal systems for reducing infection risk by at least 30%, meanwhile satisfying requirements of thermal comfort and safety, increasing energy efficiency 10%.

** infection risk understood as the content of particles in the air in healthcare facilities,*

*** the thermal comfort of the medical team members and patients,*

**** energy consumption for the operation of the air conditioning system in the building*

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Research Directions in Europe

Human - Centric Indoor Climate for Healthcare Facilities

- DC1: Characterization of source intensity and emission behaviour of airborne infectious pathogens from hospital staff
- DC2: Characterizing distribution of airborne microbial pollutants due to human activities in hospital environments
- DC5: Adaptable ventilation and optimal control methods to guarantee optimal indoor climate in energy efficient manner
- DC6: Airflow and contaminant visualization with real-time CFD simulation for the hospital operating rooms
- DC7: Augmented reality framework for visualizing airborne infectious pathogens in the operating room during surgery
- DC8: Low-order modelling and compressed sensing for real-time flow modelling in operating rooms
- DC9: Enabling instantaneous measurements of Aspergillus spores in healthcare air
- DC10: Continuous Monitoring of Airborne Pathogens in health care facilities
- DC11: Modelling dispersion of microorganisms due to healthcare activities

- DC3: Analysis of thermal micro-environment generated by the surgical team members in operating rooms with both laminar airflow and mixing ventilation
- DC4: Airflow distribution and heat/mass transfer in the surgical site microenvironment in operating rooms
- DC5: Adaptable ventilation and optimal control methods to guarantee optimal indoor climate in energy efficient manner

- DC5: Adaptable ventilation and optimal control methods to guarantee optimal indoor climate in energy efficient manner
- DC10: Continuous Monitoring of Airborne Pathogens in health care facilities

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Research Directions in Europe

Human - Centric Indoor Climate for Healthcare Facilities

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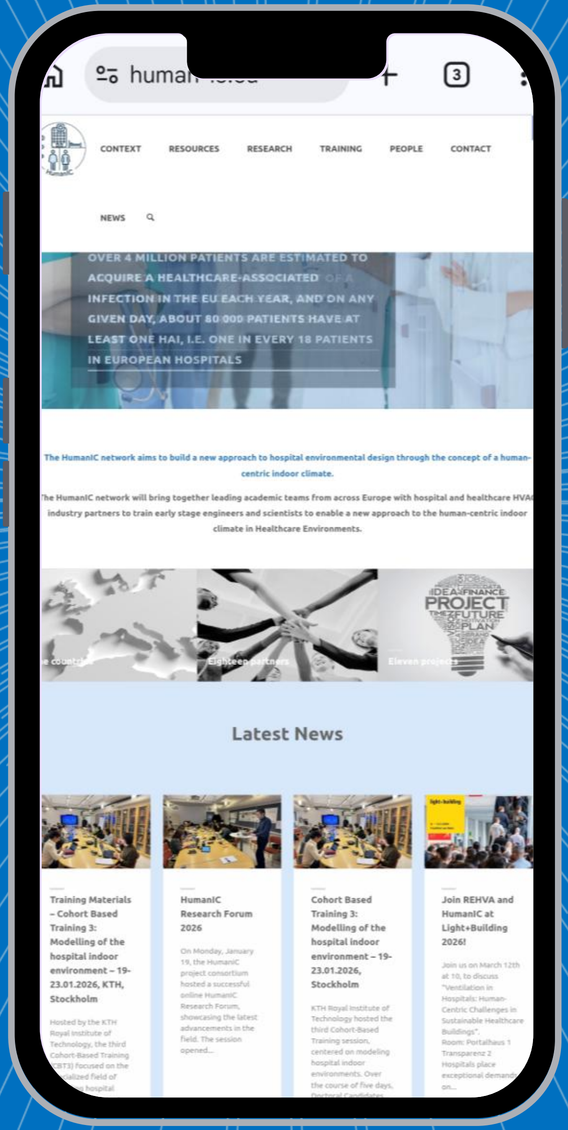

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