Indoor Air Quality in Healthcare Units

Subjects: Public, Environmental & Occupational Health

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Indoor air quality (IAQ) in Healthcare Units is a complex and dynamic issue of utmost importance for patient safety and occupational health purposes, since healthcare providers, medical practitioners, staff and patients spend long hours in the facilities subject to their inherent air quality. IAQ is affected by outdoor air quality, indoor activities, indoor occupant density, ventilation practices, indoor intrinsic emissions (e.g., equipment/furniture/coatings).
The presence of vulnerable individuals and the characteristics of the ongoing activities highlight the importance of adequately managing IAQ in healthcare facilities. Headaches, fatigue, dryness and irritation of the eyes and skin are common complaints of healthcare professionals, which have often been associated with poor IAQ. In addition, hospitals operate on a full-time basis (24 h per day, seven days a week), with no idle time to recover from activities' emissions and consequent impact on IAQ.

indoor air quality | healthcare units | hospital | patient safety | occupational health and safety

1. Introduction

Air pollution is currently recognized as the single biggest environmental threat to human health [1]. In 2019, it was responsible for an estimated 6.7 million deaths globally, beside the cost in years of healthy life [1][2].

People spend 90% of their time in indoor environments [3], therefore maintaining adequate IAQ is essential to minimize negative health impacts.

In healthcare units, IAQ may be affected both by chemical and microbiological contaminants. Chemical contamination may be originated by cleaning, disinfectant and sterilizing products containing ethylene oxide, glutaraldehyde, formaldehyde and alcohols, as well as by the use of anesthetic gases and other chemical agents used in medical procedures [4][5]. Indoor biological contamination arises from the aerial dissemination of microbiological pathogens in the clinical environment, with the potential to cause nosocomial infections and work-related respiratory diseases [6]. Air temperature and relative humidity are frequently monitored in healthcare facilities due to the direct association of these parameters with microbial growth [4][7].

Studies focusing on IAQ in hospitals or other healthcare facilities are scarce when compared with IAQ studies in residential buildings, schools, or commercial buildings. In healthcare environments, many scholars support the assessment that less attention is given to the monitoring and analysis of chemical pollutants when compared with biological contamination studies [5]. There is also a recognized difficulty in conciliating strategies to address different indoor air pollutants occurring simultaneously [8]—recent concern has arisen regarding the formation of

secondary indoor pollutants from the reaction between primary pollutants and/or other compounds present indoors or introduced by ventilation [9]. There is an increasing research interest in the design and rehabilitation of healthcare infrastructures, given the influence of construction and finishing materials in IAQ [10][11].

The following sections describe results obtained through a systematic literature review focusing IAQ in healthcare units. Following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology [12], a total of 171 articles published in the period 2015–2020 were selected and analyzed.

Hospitals were the healthcare unit of major interest for the IAQ studies, being studied in 91% of the sampled papers. Other healthcare units, specifically focused in 17 papers, highlight the IAQ concern in primary care centers (53 %) and dental clinics (29 %). The most frequently analyzed locations are operating rooms, wards and intensive care units.

2. Textometric Analysis

Textual content analysis of the abstracts of the 171 sampled papers was performed using the IRaMuTeQ software [13]. The dendrogram of the clusters obtained with the IRaMuTeQ (**Figure 1**) shows four clusters created from branch divisions of studies from the sampled papers. One branch includes Clusters 1 to 3, whereas Cluster 4 belongs to a single branch. The numbers in each bar correspond to the percentage of words in the abstracts associated with each cluster.

Figure 1. Dendrogram of the clusters from the abstracts, with the corresponding percentage of the forms.

Factorial representation (**Figure 2**) allows us to show the interconnection of these four clusters in the form of a factorial plan. Clusters 2 and 3 are clearly interconnected, while cluster 4 stands out for being less interconnected with the others (**Figure 1** and **Figure 2**). The size of the words in **Figure 2** is related to the associated Chi-square value.

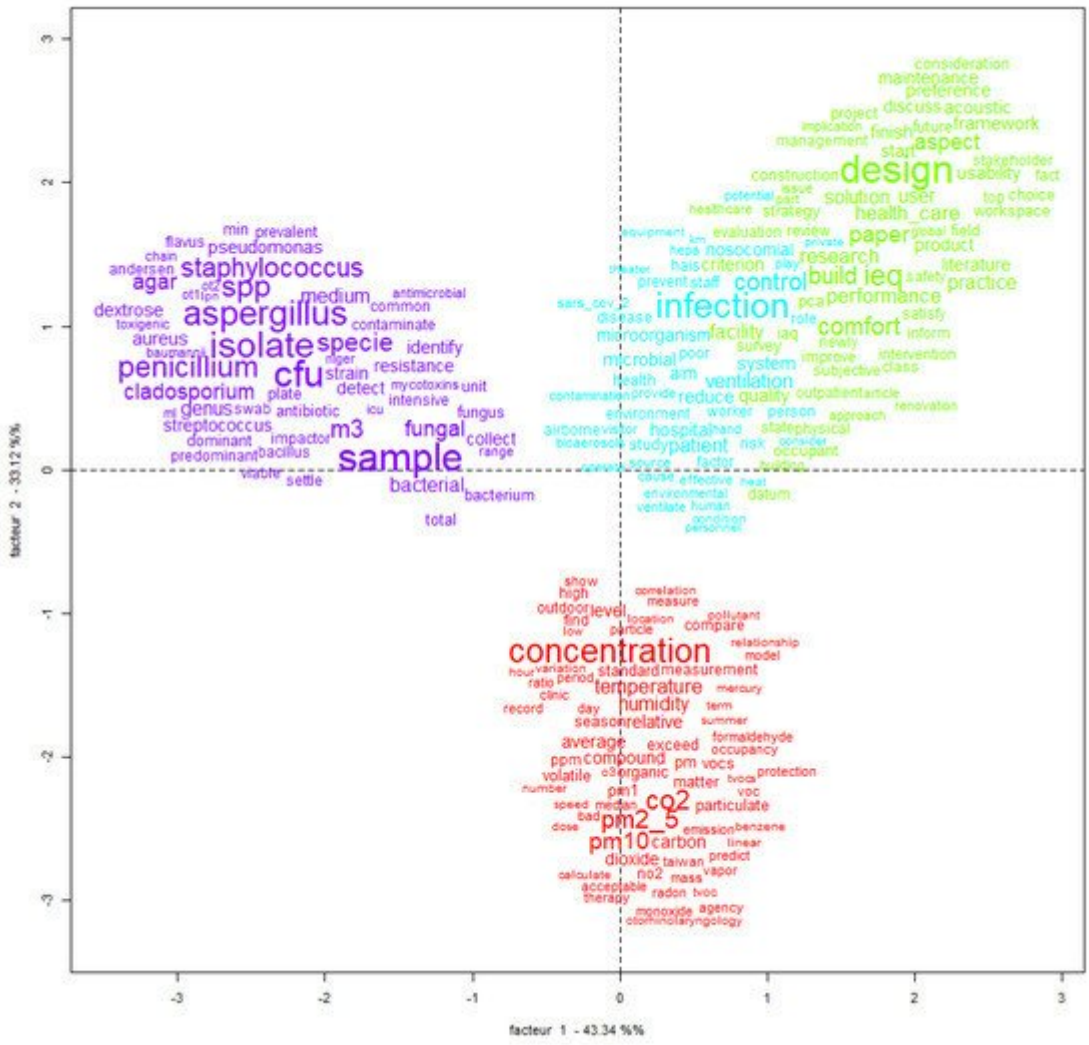

Figure 2. Representation of the factorial analysis.

The analysis of the semantic fields in each cluster identified in the dendrogram suggests the following categorization of the studies developed in the sample papers:

- Cluster 1 is related to studies focusing on physicochemical parameters. The most impacted words (higher Chi-squared values) are: concentration (120.2), CO_2 (89.6), PM2.5 (79.6), PM10 (64.7), temperature (53.2) and humidity (49.7). The analysis of the studies categorized in this cluster highlights the following issues: outdoor pollution sources should be addressed when evaluating indoor air quality [14], as should meteorological conditions [15]; isolated parameters—Radon gas [15] and CO_2 [7]—could be used to assess health risks in healthcare facilities; mercury vapors and VOCs in dental clinics are important issues which are still underexplored [16]; particles and VOCs released through surgical smoke in operating rooms are a concern for IAQ [17]; anatomopathological activities are associated with the significant release of organic contaminants to indoor air [18].

- Cluster 2 is related to the design and management of infrastructures. The most impacted words (higher Chi-squared values) are: design (153.9), *IEQ* (100.8), comfort (75.1) and build (73.2). The importance of design characteristics for adequate IAQ assurance is well established [19]. Nevertheless, there are still improvement

opportunities regarding the choices of products and construction materials [11][20], as well as of daily activities' products [19]; special attention needs to be given to engineering procedures and maintenance activities [10][21].

- Cluster 3 is related to the environmental control of healthcare facilities. The most impacted words (higher Chi-squared values) are: infection (130.6), control (73.7), patient (53.2), ventilation (51.5), system (42.3) and hospital (42.2). These studies reveal great concern regarding air quality in operating rooms' air flow environment [22]. The importance of adequate particle filtration systems is also highlighted in several studies [17][23]. The influence of ventilation on the prevalence of hospital infections has also been studied [23], including studies on SARS-CoV-2 infection [21]. Cleaning procedures also have an important role in the control of microbiological loads [21]. Regular monitoring of indoor environmental conditions is essential to assess the efficiency of environmental control practices [19].

- Cluster 4 is related to studies focusing on microbiological contamination. The most impacted words (higher Chi-squared values) are: sample (151.8), CFU (146.1), isolate (131.2), aspergillus (126.3), penicillium (101.1) and staphylococcus (87.2). Relevance is given to the identification of microorganisms with antibiotic resistance [24], and to the detected presence of mycotoxins in HVAC filters [25]. The importance of controlling airborne particles in intensive care units is highlighted, due to the patient's compromised immune system [24]. The influence of the outdoor environment on indoor microbiological contamination is established [20], as well as the importance of adequate indoor temperature and relative humidity control to reduce microbiological loads [7].

Studies were found with no significant association with only one cluster. Articles frequently focus on environmental control measures considering both physicochemical and microbiological contaminants [24]. Ventilation management and control is of the utmost importance to reduce microbiological and physicochemical contamination in healthcare facilities [7][21][22][23].

3. Contributions per Country

In the period under analysis (2015–2020), 37 different countries conducted studies focusing on IAQ in healthcare facilities. The lead in these research studies was taken by Iran and China, with 35 (20%) and 27 (16%) of the 171 sampled papers, respectively (**Figure 3**).

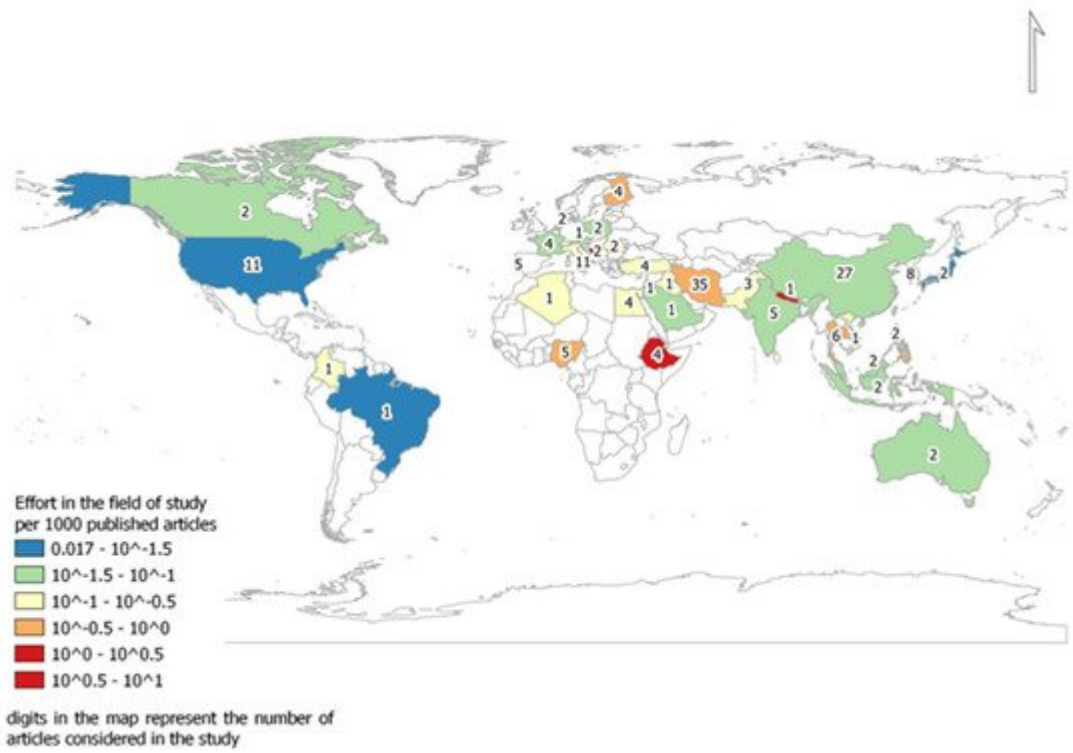

Figure 3. Number of selected papers per country and research effort in this field of studies.

The relative effort of each country in publishing scientific papers in this area of expertise was evaluated by calculating the ratio between the number of sampled papers in this study and the total number of technical journal papers published by each country, reported by the World Bank [26].

Surprisingly, a higher GDP does not mean research interest in the subject—the countries with higher GDP showed little publication effort in this field during the period of study (**Figure 3**). On the other hand, countries like Bosnia and Herzegovina, Ethiopia, and Nepal show the highest publication effort in the topic (number of published articles per 1000 publications).

4. Parameters under Study

The parameters that were measured in the 145 papers with experimental data are shown in **Figure 4**. The most frequently reported parameters are related to environmental quality—temperature (T) and relative humidity (RH)—and with microbiologic contamination—bacteria and fungi load. Measurements of the concentration of carbon dioxide (CO_2) and particulate matter (PM) were also frequently reported. In what concerns chemical contaminations, the most frequently monitored compounds were total volatile organic compounds (TVOCs), carbon monoxide (CO), benzene, toluene, ethylbenzene and xylene (BTEX), and formaldehyde. Other parameters that were measured in at least one of the sampled papers were ammonia and nitrogen oxide, anesthetic gases, limonene, mercury vapor, n-hexane and styrene, polycyclic aromatic compounds (PAH), trichloroethylene and tetrachloroethylene, and phthalates. Ultrafine particles and black carbon, which have recently been considered a

priority research target by the World Health Organization (WHO) [1], were focused on in only three of the sampled articles.

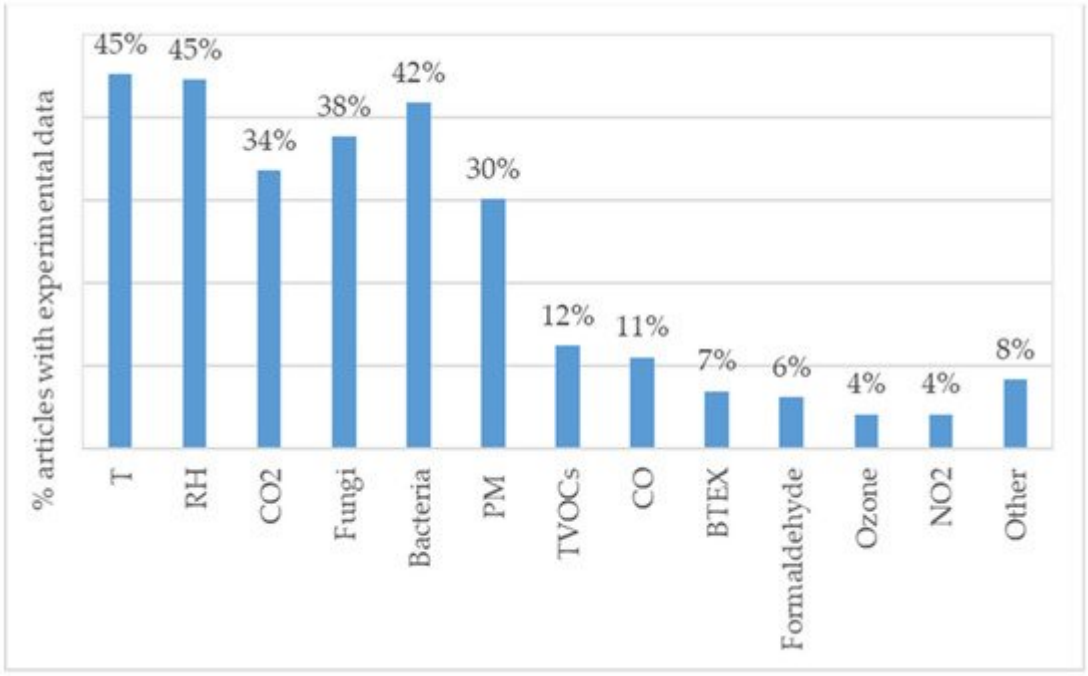

Figure 12. Parameters with reported results in the sampled papers with experimental data.

Situations of non-compliance with the WHO guidelines for indoor air quality are frequently reported, evidencing the need for further research investments leading to improvements in this area.

There are research opportunities for studies focusing on other important pollutants (e.g., ultrafine particles and PAH compounds). Moreover, research gaps exist regarding the formation of secondary pollutants from interactions between chemical contaminants, including those from outdoor air, and risk assessments on the synergistic interactions between chemical contaminants and microbiological loads.

It is well established that the design of facilities, the choice of adequate materials for construction and renovation, and the adequacy of management procedures towards IAQ improvement should be based on scientific research and data analysis. Therefore, these topics are promising lines of research that may lead to improvements in the indoor air quality in healthcare facilities, with potentially relevant impacts on patient safety and occupational health.

References

1. World Heath Organization. WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide; World Heath Organization: Geneva, Switzerland, 2021; pp. ISBN 9789240034228.

2. Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Under-5 Mortality and Adult Mortality 1950–2019; Institute for Health Metrics and Evaluation (IHME) : Seatle, USA, 2020; pp. 1.
3. World Health Organization. Combined or Multiple Exposure to Health Stressors in Indoor Built Environments: An Evidence-BasedReview Prepared for the WHO Training Workshop “Multiple Environmental Exposures and Risks”: 16–18 October 2013, Bonn, Germany;World Health Organization, Regional Office for Europe: Copenhagen, Denmark, 2013.
4. Estelle Baurès; Olivier Blanchard; Fabien Mercier; Emilie Surget; Pierre LE Cann; Alexandre Rivier; Jean-Pierre Gangneux; Arnaud Florentin; Indoor air quality in two French hospitals: Measurement of chemical and microbiological contaminants. *Science of The Total Environment* **2018**, *642*, 168-179, 10.1016/j.scitotenv.2018.06.047.
5. Marco Gola; Gaetano Settimo; Stefano Capolongo; Indoor Air Quality in Inpatient Environments: A Systematic Review on Factors that Influence Chemical Pollution in Inpatient Wards. *Journal of Healthcare Engineering* **2019**, *2019*, 1-20, 10.1155/2019/8358306.
6. Clive B Beggs; Luke Knibbs; Graham Johnson; Lidia Morawska; Environmental contamination and hospital-acquired infection: factors that are easily overlooked. *Indoor Air* **2014**, *25*, 462-474, 10.1111/ina.12170.
7. Ana Fonseca; Isabel Abreu; Maria João Guerreiro; Cristina Abreu; Ricardo Silva; Nelson Barros; Indoor Air Quality and Sustainability Management—Case Study in Three Portuguese Healthcare Units. *Sustainability* **2018**, *11*, 101, 10.3390/su11010101.
8. Sarah H. Widder; Liv Haselbach; Relationship among Concentrations of Indoor Air Contaminants, Their Sources, and Different Mitigation Strategies on Indoor Air Quality. *Sustainability* **2017**, *9*, 1149, 10.3390/su9071149.
9. Magdalena Kruza; Alastair Lewis; G. C. Morrison; N. Carslaw; Impact of surface ozone interactions on indoor air chemistry: A modeling study. *Indoor Air* **2017**, *27*, 1001-1011, 10.1111/ina.12381.
10. Mauro Cannistraro; Ernesto Bernardo; Monitoring of the indoor microclimate in hospital environments a case study the Papardo hospital in Messina. *International Journal of Heat and Technology* **2017**, *35*, 456-465, 10.18280/ijht.35Sp0162.
11. Manish K. Dixit; Shashank Singh; Sarel Lavy; Wei Yan; Floor finish selection in health-care facilities: a systematic literature review. *Facilities* **2019**, *37*, 897-918, 10.1108/f-03-2018-0042.
12. Matthew J. Page; Joanne E. McKenzie; Patrick M. Bossuyt; Isabelle Boutron; Tammy C. Hoffmann; Cynthia D. Mulrow; Larissa Shamseer; Jennifer M. Tetzlaff; Elie A. Akl; Sue E. Brennan; et al.Roger ChouJulie GlanvilleJeremy M. GrimshawAsbjørn HróbjartssonManoj M. LaluTianjing LiElizabeth W. LoderEvan Mayo-WilsonSteve McDonaldLuke A. McGuinnessLesley

A. StewartJames ThomasAndrea C. TriccoVivian A. WelchPenny WhitingDavid Moher The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *International Journal of Surgery* **2021**, *88*, 105906, 10.1016/j.ijsu.2021.105906.

13. IRaMuTeQ Software . iramuteq. Retrieved 2022-1-17
14. Ashraf Chamseddine; Ibrahim Alameddine; M. Hatzopoulou; M. El-Fadel; Seasonal variation of air quality in hospitals with indoor–outdoor correlations. *Building and Environment* **2018**, *148*, 689-700, 10.1016/j.buildenv.2018.11.034.
15. Kazemi, K. V; Mansouri, N.; Moattar, F.; Khezri, S.M.; Characterization of indoor/outdoor PM10, PM2.5, PM1 and radon concentrations in Imam Khomeini hospital. *Bulgarian Chemical Communications* **2016**, *48*, 345–350.
16. Afolabi Oyapero; Adolphous Odofin Loto; Adenike Ololade Awotile; A Olugbenga Adenuga-Taiwo; Lillian Lami Enone; Ifeoma Nkiruka Menakaya; Managing amalgam phase down: An evaluation of mercury vapor levels in a dental center in Lagos, Nigeria. *Journal of Dental Research and Review* **2017**, *4*, 4-8, 10.4103/jdrr.jdrr_20_17.
17. Mark H. Ereth; Donald H. Hess; Abigail Driscoll; Mark Hernandez; Frank Stamatatos; Particle control reduces fine and ultrafine particles greater than HEPA filtration in live operating rooms and kills biologic warfare surrogate. *American Journal of Infection Control* **2020**, *48*, 777-780, 10.1016/j.ajic.2019.11.017.
18. Massimo Cipolla; Alberto Izzotti; Filippo Ansaldi; Paolo Durando; Maria Teresa Piccardo; Volatile Organic Compounds in Anatomical Pathology Wards: Comparative and Qualitative Assessment of Indoor Airborne Pollution. *International Journal of Environmental Research and Public Health* **2017**, *14*, 609, 10.3390/ijerph14060609.
19. Marco Gola; Gaetano Settimo; Stefano Capolongo; Chemical Pollution in Healing Spaces: The Decalogue of the Best Practices for Adequate Indoor Air Quality in Inpatient Rooms. *International Journal of Environmental Research and Public Health* **2019**, *16*, 4388, 10.3390/ijerph16224388.
20. So Fujiyoshi; Daisuke Tanaka; Fumito Maruyama; Transmission of Airborne Bacteria across Built Environments and Its Measurement Standards: A Review. *Frontiers in Microbiology* **2017**, *8*, 2336-2336, 10.3389/fmicb.2017.02336.
21. Gola, M.; Caggiano, G.; De Giglio, O.; Napoli, C.; Diella, G.; Carlucci, M.; Carpagnano, L.F.; D'Alessandro, D.; Joppolo, C.M.; Capolongo, S.; et al.et al. SARS-CoV-2 indoor contamination: considerations on anti-COVID-19 management of ventilation systems, and finishing materials in healthcare facilities. *Annali di igiene : medicina preventiva e di comunita* **2020**, *33(4)*, 381-392, 10.7416/ai.2020.2396.
22. Ling Fu Shaw; Ian Horng Chen; Chii Shya Chen; Hui Hsin Wu; Li Shing Lai; Yin Yin Chen; Fu Der Wang; Factors influencing microbial colonies in the air of operating rooms. *BMC Infectious*

Diseases **2018**, *18*, 1-8, 10.1186/s12879-017-2928-1.

23. Rebecca E. Stockwell; Emma L. Ballard; Peter O'Rourke; Luke D. Knibbs; Lidia Morawska; Scott C. Bell; Indoor hospital air and the impact of ventilation on bioaerosols: a systematic review. *Journal of Hospital Infection* **2019**, *103*, 175-184, 10.1016/j.jhin.2019.06.016.
24. Wendy Beatriz Morgado-Gamero; Martha Mendoza Hernandez; Margarita Castillo Ramirez; Jhorma Medina-Altahona; Stephanie De La Hoz; Heidy Posso Mendoza; Alexander Parody; Elba C. Teixeira; Dayana Milena Agudelo-Castañeda; Antibiotic Resistance of Airborne Viable Bacteria and Size Distribution in Neonatal Intensive Care Units. *International Journal of Environmental Research and Public Health* **2019**, *16*, 3340, 10.3390/ijerph16183340.
25. Carla Viegas; Beatriz Almeida; Ana Monteiro; Liliana Aranha Caetano; Elisabete Carolino; Anita Quintal Gomes; Magdalena Twarużek; Robert Kosicki; Geneviéve Marchand; Susana Viegas; et al. Bioburden in health care centers: Is the compliance with Portuguese legislation enough to prevent and control infection?. *Building and Environment* **2019**, *160*, 106226, 10.1016/j.buildenv.2019.106226.
26. The World Bank . Scientific and technical journal articles. Retrieved 2022-1-19