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SARS-CoV-2 indoor contamination: considerations on anti-COVID-19 management of ventilation systems, and finishing materials in healthcare facilities

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Abstract

Many of the devastating pandemics and outbreaks of last centuries have been caused by enveloped viruses. The recent pandemic of Coronavirus disease 2019 (COVID-19) has seriously endangered the global health system. In particular, hospitals have had to deal with a frequency in the emergency room and a request for beds for infectious diseases never faced in the last decades.
It is well-known that hospitals are environments with a high infectious risk. Environmental control of indoor air and surfaces becomes an important means of limiting the spread of SARS-CoV-2. In particular, to preserve an adequate indoor microbiological quality, an important non-pharmacological strategy is represented by Heating, Ventilation and Air Conditioning (HVAC) systems and finishing materials.
Starting from the SARS-CoV-2 transmission routes, the paper investigates the hospital risk analysis and management, the indoor air quality and determination of microbial load, surface management and strategies in cleaning activities, HVAC systems' management and filters' efficiency.
In conclusion, the paper suggests some strategies of interventions and best practices to be taken into considerations for the next steps in design and management.

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Introduction

Many of the devastating pandemics and outbreaks of the 21st centuries have been caused by hard viruses, among these the Severe Acute Respiratory Syndrome (SARS), the Middle Eastern Respiratory Syndrome (MERS), and the Ebola Hemorrhagic Fever (EHF). On 11^{th} March 2020, the World Health Organization (WHO) declared a pandemic of the "Coronavirus Disease 2019" (COVID-19), a kind of severe acute respiratory syndrome caused by a new Coronavirus (SARS-CoV-2), which first appeared in Wuhan, China, in late 2019 and was subsequently reported in other cities around the world.

The entire world population has been considered at risk of infection, although the most exposed subjects seem to be the elderly, because of their more delicate immune system and, as a contributory cause, because of their concomitant pathologies (1).

The COVID-19 pandemic has seriously endangered the global health system. In particular, hospitals had to deal with an unusually high frequency of patients in the emergency room and a request of beds for infectious diseases never faced in recent years. In addition, they had to adapt the space available to quickly open new hospital beds (2, 3).

The COVID-19 cases have saturated the Emergency Departments and, in particular, the Intensive Care Units (ICUs) worldwide, highlighting the organizational and structural difficulties of hospitals, the lack of flexibility and the low efficiency to manage such unexpected number of patients. In fact, during the emergency, many hospitals lacked enough space, advanced technologies and human resources to deal with this crisis (4). In order to face the first aspect, researchers and professionals, administrators and decision-makers gave rise to rapid conversion solutions for hotels, conference centers, even city parks into new hospital areas, revealing several criticisms due to distance of the new ICUs from the other hard functional units. Many strategies have therefore been designed "on site" with ad-hoc solutions of extremely different kind, according to the specific needs of the entire hospital, department or hospital ward.

Moreover, it is well-known that hospitals and healthcare spaces are environments with a high infection risk (5, 6) and they have an increase of awareness and concern regarding healthcare acquired infections (HAIs) and surgical site infections (SSIs), and, at the same time, a rise of control measures and capabilities to challenge infections. It is also evident that the protection from infectious risks is not limited only to patients, but also to the hospital staff and to the relatives of patients (who often assist bedridden patients, especially those who are most fragile and in need of daily care) (7). The complexity of infection risk control is also related to the several and diverse ways of transmission, such as direct and indirect contact, surfaces contamination, airborne contamination and air transport, etc., but deeply correlated.

At the beginning of the pandemic, several healthcare directors did not know the actions to be carried out, so much so that some healthcare facilities have stopped the engineering plants, others have transformed into negative pressure systems, others have done the sanitization of the entire air ducts, etc. without any specific guidelines. The main criticisms in fact have been related to ventilation systems because they represent a primary infectious disease control strategy, and the mechanical ventilation serves several functional areas with requirements and medical processes that cannot be met without special considerations and attention.

For these reasons, effective results in infection risk control require the use of combination of procedural and behavioral measures (e.g. personal hygiene, protective devices, methods of sanitizing surfaces, pharmacological prophylaxis tools, etc.)

and engineering solutions concerning buildings (e.g. hospital layouts, flows' differentiation, etc.) and plants (natural ventilation systems vs heating, ventilation and air conditioning - HVAC systems). In particular, the HVAC systems are aimed to control temperatures and humidity, related both to human body and immunological defense system capabilities and to survival and proliferation of bio-contaminants. Moreover, they are even more importantly able and intended to guarantee an adequate level of Indoor Air Quality (IAQ) through a combination of controlled air changes, pollutant dilution and removal, air filtration and cleaning, air flow and diffusion, room pressure control, etc.

In fact the strategic role of HVAC systems, aimed to control IAQ and to prevent biological contaminants (bacteria, virusses, fungi) and other contaminants spread in hospital settings, have been widely investigated and demonstrated (8-10), but they remain a controversial issue among several disciplines (medicine, engineering, maintenance and management, etc.).

The aims of the paper are, starting from the COVID-19 experience, to analyze of the present and main issues related to COVID-19 and to argue some strategies and best practices regarding indoor air and mechanical ventilation in healthcare settings, and their HVAC systems operation, maintenance and cleaning activities.

Hospital risk analysis and management

The lack of a common and unitary strategy is not only to be found in the complexity of the emergency issue but also in the high complexity of healthcare infrastructures (4). In fact, starting from its dimensions, number of daily users and volumes of activities, the hospital is comparable to a city characterized by stratifications of service networks which are distributed inside and/or outside. In addition, the present state of conservation of the hospitals is very critical. It is estimated that several hospitals have exhausted their life cycle and more than half are not adequate for the new organizational models (11). This general state of obsolescence and rigidity has indeed further complicated the management of this particular pandemic.

During the COVID-19 emergency, healthcare facilities concentrated on various transversal strategies. These include the definition of buffer areas among the departments, the division between contaminated and non-contaminated areas, the transformation of high care spaces (already equipped with advanced engineering plants) - as surgery blocks - for postponed elective interventions, the creation of dressing and decontamination areas for healthcare workers, the construction of new volumes with prefabricated technologies with free surfaces well connected to the hard areas of the hospital and the re-functionalization of environments, seldom already prepared or more frequently to be equipped for emergencies (such as gyms, parking areas or conference centres), etc. (3, 4, 11).

The other fundamental aspect related to hospital settings is the transmission of the virus. The lack of scientifically validated data and protocols has forced each structure to develop specific solutions, sometimes based on models from previous epidemics caused by viruses such as SARS in 2003 and Ebola in 2013 or by bacteria, such as tuberculosis, etc., including the suspension of HVAC systems and windows opening, changes on systems from positive to negative pressures, etc.

Starting from the pandemic, it is clear that the application of rigid protocols for the control of infections, and a regular and adequate maintenance and cleaning procedures can be strategies for managing healthy spaces, especially during and after an emergency. In parallel, it is necessary to give rise to a risk matrix, depending on the functional units and the patient's susceptibility, which must involve specific directions for the HVAC system ruling the operation settings and scheduling the inspections and maintenance procedures, aimed to guarantee appropriately adequate levels of cleanliness and disinfection of the hospital settings. It is worthy to highlight that maintenance and cleaning of systems, if executed in improper ways, far from improving the medical processes, could determine an increase of contagion risks.

Indoor air quality and determination of microbial load

The airborne contaminants represent one of the main determinants of human health and can spread infections. However, the air itself and the ventilation of indoor spaces can perform the irreplaceable and positive function of removing contaminants from the environment and to maintain cleanliness and aseptic conditions. Conversely, the air and the movements induced by ventilation systems can carry contaminants to a great distance from the emitting sources, contributing to the spread of disease and creating cross-contamination between separate spaces (12, 13).

Therefore, every consideration on the positive role exerted by ventilation, and on the capacity and the ability of a specific system to provide for it, must necessarily start from the identification of the contamination sources. In the case of SARS-CoV-2, the source is an infected person, both symptomatic (e.g. in a dedicated hospital wards, or under investigation in the emergency room) or asymptomatic (potentially everywhere), such as patients with COVID-19 or asymptomatic subjects. It is therefore mainly an indoor source and it is necessary to dilute the concentration of the contaminant in indoor settings through the introduction of clean air from outdoors or cleaned by other technical means (14, 15). Quite obvious consequence is that patients and healthcare workers (HCWs) are at high risk in hospital settings, due to the presence and numbers of infected patients, and to the long duration and frequency of inevitable contacts with them.

For the characterization of the scenario and the risks, it is necessary to obtain quantitative measures on the presence of airborne contaminants, and the IAQ should be frequently checked (16), although it is not easy.

Both passive and active sampling methods, on both solid and liquid substrates, can be used to assess air quality and microbial load in a confined space (5, 17). It offers information on the presence and relevance of the sources of contamination and on the capacity of ventilation system to maintain acceptable levels for hospital staff and patients' health status and safety. The passive method allows to evaluate the microbial load capable to deposit onto the Petri plates and the results are expressed as Index of Microbial Air (IMA) (18). The active method collects a predetermined volume of air and captures the microorganisms onto an agar-based growth medium or into a liquid medium. In both cases the results are typically expressed as Colony Forming Units per cubic meter (CFU/m^3). The air sampling on agar substrates is used for bacteria and fungi isolation, while the sampling in liquid medium allows also the research of viral particles. This last method can employ different instruments, such as Coriolis® (Bertin Technologies, Montigny le Bretonneux, France). This investigation is based on a wet cyclonic technology, combined with a high air flow rate. The sample liquid output is compatible with molecular analysis of type on RT-PCR + DNA microarray hybridization for qualitative detection of the capture of nucleic acid from the SARS-CoV-2 particle, as well as other viral organisms present in the air of the surrounding environment.

The debate is on-going among the scientific community and the knowledge is growing on the use and results of cultural methods and molecular analysis and on the duration of survival of SARS-CoV-2 in the air and in contact with different materials. Some authors sustained that the virus remained viable in aerosols until three hours (19).

The use of particle sampling techniques with Optical Particle Counter (OPC) can also be considered to measure the concentration of total particulate matter (both non-viable and viable ones). The OPC particle counter measures all airborne particles and do not distinguish viable from non-viable particles. Particulate monitoring is normally done by a calibrated OPC, used to sample a defined volume of air. The OPC can measure the sizes and it gives results on differential and cumulative concentrations of particles (around 0.5 and 5.0 μm). Particle counts are recorded as the number of particles per volume of air sampled. It should be highlighted that OPC measurements are a quite consolidated and widely used tool and they give immediate results, allowing to check the air quality and performance of the HVAC system. The information resulting from the use of OPC and active microbial air sampler are complementary, due to the fact that OPC sampling allows to measure all the particles suspended in the air, and the microbial active sampling and cultural methods are able to assess the viable particle fraction and to characterize the different microbes.

The OPC sampling can be used in situ to measure the indoor air particles' concentration in a specific moment and position, resulting from all the concurring factors (i.e. the pollutant source strength, the dilution obtained with the ventilation and the effects of filtration and particle deposition). The measurement of OPC could be important to exclude ventilation as a source of contaminants and it is a widely used tool to quantitatively evaluate, monitor and control hospital ventilation. OPC measurements could be nevertheless misleading in relation to the present emergency and the specific virus, pertaining to the viable particle fraction, and that comparison of particle concentration among different indoor spaces and between indoor and outdoor air, is only a proxy giving us some comparative and useful indications for verifying ventilation effects.

Surface management

Although person-to-person transmission has been described both in hospital and residential settings (1), the spread of coronavirus should be considered connected with the dry surfaces contamination level. In fact, gravity effects and drag forces exerted by air flow favour the deposition and resuspension of viral droplets on surfaces. The hands of patients and HCWs, even if equipped with gloves, touching surfaces can be vehicle of contagion spread (20). In other studies, no air samples resulted positive, but one sample from an air exhaust outlet was positive indicating that virus particles may be displaced by air and deposited on surfaces (21, 22). Laboratory data show that the virus has a different survival based on the type of surface. Under controlled conditions, the virus has been detected for periods of less than three hours on paper, up to one day on wood and textiles, two days on glass, and for longer periods (3/4 days) on smooth surfaces such as steel and plastic, persisting up to 7 days on the fabric outside of the surgical masks (19, 23).

Currently the market offers different innovative surface and finishing materials intended to reduce the bacterial and viral load on the surfaces, also with eco-active materials and photocatalytic paints, even if there is not any complete and shared demonstration of their effect on the viral load (24). Starting from previous and ongoing experiences, to ensure effective management of emergencies, it is important to introduce finishing materials with high performance and degree of flexibility in the use and organization of spaces.

An uncommon material, but used for emergency camps, is the washable fabric. Its application could be extended to different healthcare settings for users' flows, and which, in case of need, can be easily washed and replaced to guarantee hygiene levels, or removed and moved to ensure spaces' resiliency (25). It is thus relevant to conduct microbiological a monitoring of the surfaces. This involves the use of synthetic fibre swabs pre-moistened with viral transport media that are brushed over the surfaces most likely to be contaminated, such as the floor, patient's bedside tables, armrests, computer keyboards and touch monitors. Then the swabs are subjected to molecular investigations through RT-PCR (26) or LAMP (loop-mediated isothermal amplification) technology, to find and possibly evaluate the viral load.

However, the absence of antibacterial and antiviral materials of surfaces can easily be overcome by careful, regular and constant cleaning activities. This fact underlines the importance of performing disinfection processes using different biocides such as hydrogen peroxide, alcohols, sodium hypochlorite or benzalkonium chloride, especially for sanitary disinfection (27, 28), remembering that a specific disinfectant is not usable and fit for all materials.

HVAC systems' management

Constant and progressive innovations in medicine and technology highlight the need to regularly re-evaluate the state of microclimatic parameters and air quality parameters affected by ventilation and air-conditioning systems (29). In fact, scientific evidence has shown that appropriate ventilation and air-conditioning is useful for the indoor environment quality (IEQ) and in preventing negative health effects and the spread of bacterial and viral infections (through the air filtration and the achievement of the adequate differential pressures among high risk environments) (9, 13).

HVAC systems used in healthcare settings should face a large set of configurations and adopted equipment (9). The differences can be due to multiple choices and factors:

- requirements due to diverse functional areas and medical processes;
- building age and architectural features;
- use of mechanical ventilation vs. natural ventilation;
- adoption of humidification and/or dehumidification control vs. free-running air humidifiers;
- national and local norms and rules, and/or adoption of voluntary technical standards;
- budget for the costs of construction and for the costs of operation and maintenance (O&M).

The primary and fundamental difference among and within the hospitals and among the different spaces, is the presence and functioning of mechanical ventilation. When it is not provided, the functions of HVAC equipment are limited to the cooling and/or heating of the confined environments; as a consequence, the indoor and outdoor airborne pollutant and air-humidity control are inconstant due to the irregular use of window openings (*airing*) and to large variations in wind and stack effects, also well-known as chimney effect, acting both on fixed and openable air flows through the building. Mechanical ventilation, when adopted, allows to set (constant or variable) fresh, outdoor, air flows rates (more is better) and the desired levels of humidification and/or dehumidification (9, 29). Moreover, mechanical ventilation adds four main possibilities and improvements:

• filtration and cleaning of outdoor air flows, air recirculation and supply air;

• air flow and room air diffusion allowing convenient transport and removal of airborne pathogens (e.g. Unidirectional Air Flows in operating rooms);

• pressure control for guaranteeing segregation between rooms and spaces (e.g. isolation rooms);

• ventilation energy savings due both to energy recovery from exhaust air and to better control of air changes (reduction of redundant heating & cooling dispersions).

Considering the COVID-19 and other infectious diseases, they are mainly transmitted by direct and indirect person-to-person contact and by large aerosol droplets travelling at close distance. However the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) declared in a recent position paper, "*airborne transmission of SARS-CoV-2 through the air is sufficiently likely that airborne exposure to the virus should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures*" (30). Emerging knowledge can be combined with analysis made and with results obtained from the SARS outbreak in 2003 and from other viruses transmission studies (12, 31). Correia et al. analyzed, referring to previous transmission and spreading of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox, SARS, etc. (32-34). In fact, as the Scientific Community highlights, ventilation represents one of the main infectious disease control strategies (35). HVAC systems can play a positive role in risk mitigation when mechanical ventilation is supplying clean air diluting the aerosol emitted by an infected person and when the outdoor air flow rates are increased following the "As Low As Reasonably Achievable" (ALARA) risk reduction approach (9). However, possible contributions for a better management of risk could be obtained through other interventions, such as effective filtration and air cleaning technologies, suitable air diffusion and movement, air pressure and room containment, air humidity control to limit evaporation and droplet size reduction.

Filters for HVAC systems

Particle filters can halt contaminants and remove them from the filtered air flow. Filter efficiency (particles' fraction to be halted) varies with particle size and air flow rate. Filters are selected according to their efficiency-class certified by standard tests. There is a broad distinction between filters for general ventilation and very-high and ultra-high efficiency filters (EPA - Efficient Particulate Air, HEPA – High Efficiency Particulate Air, and ULPA - Ultra-Low Penetration Air) used in clean-room technology, in the pharmaceutical industry and in demanding applications of ventilation and air-conditioning (9, 29). In order to guarantee to the users a measure of protection from airborne pollutants and from bio-aerosol (0.3 – 1 micron), filters for supply air systems as a minimum should be PM_1 rated (according to ISO 16890), F7 rated with reference to the EN 779 (general ventilation), which is approximately equivalent to a MERV (Minimum Efficiency Reporting Value)-13 filter (36). More effective filters and HEPA/ULPA ones are available and they can amplify the filtration effect. In case of existing systems, a careful assessment should be done on the reduced airflow impacts from their higher-pressure drop, which can lead to difficulty with the filter seal and/or to loss of desired room pressure differentials (9).

Starting from the pandemic, the role of filters become strategic and differentiated for each healthcare setting and activity to be carried out.

The ability of HEPA filters, used in medium and high care areas of the hospital (ICUs, surgery block, etc.), to halt the COVID-19 virus, is very high. By definition, an HEPA filter is at least 99.97% effective for 0.1 - 0.3 micron particles in standard tests and it is not less but more effective for both smaller and bigger ones. Starting from some recommendations from CDC, HEPA filtration have been considered enough efficient for limiting the spread of COVID-19 (37).

Using HEPA filtration successfully in HVAC, the filters must be engineered into the HVAC installation and air handling unit (AHU). In general, it is requested that the filters must have a tight fit and proper sealing, since air leakage at perimeter could greatly limit their performance. Other air cleaning technologies (e.g. Ultraviolet Germicidal Irradiation UVGI, etc. (9)) are used and can be effective for inactivating viruses and other germs. Currently several experimental studies are still in progress to develop new air cleaning devices with demonstrated effectiveness in reducing the viral concentrations in air flows (e.g. in ducts, in AHUs, etc.) or directly in the indoor spaces. Their inactivation effectiveness for the type of virus or the type of bacteria and the existence of chemical or physical side effects affecting health should be specifically assessed.

Strategies of interventions and best practices

Among the effective activities, starting from best practices suggested by some institutions (AICAAR (13), ISS (12), ASHRAE (30), CDC (38) and REHVA (39)) and applied in last period, it is suggested to take into consideration some retrofit intervention.

Negative air pressure in new isolation units, i.e. to transform existing ordinary inpatient wards into areas for infectious patients. It means to increase the exhaust air flow rate in order to maintain the spaces at negative pressure with respect to the outdoor and to other departments/spaces for the non-infected (13).

Filtration of exhaust air, i.e. if the exhaust air from hospital wards and/or infectious areas can recirculate in the hospital (e.g. by air intakes and/or openable windows) or contaminate the outdoor environment, absolute filters should be introduced in the expulsion duct before the exhaust fan (13).

Cross-contamination and recirculation air flow. In order to prevent cross-contamination between separate rooms and spaces, in case they share the ventilation system and there is the air partial recirculation, it is recommended to close the recirculation path (13).

Terminals cleaning. Droplets can be located on all exposed and touchable surfaces; therefore it is necessary to provide the same disinfection procedures (adequate disinfectant, qualified personnel, well-defined procedures) (12-13), used for furniture, medical equipment, etc. (13).

Leakage test after absolute filters replacement. In order to avoid leakages of contaminated air, after each filter replacement and periodically, a leakage test according to ISO 14644 should be performed in order to verify that no damage to filter occurred during installation and that no leaks are originated by bad seals at the perimeter (13).

Use of room air purifiers units with HEPA filtration. Self-standing or ceiling mounted air purifier units are based on coupling of a fan and an HEPA filter; the unit can bring and filter the air in the room reducing local airborne viral concentration and effectively responding to the need of each specific area (9).

The ASHRAE highlighted the introduction of a filter in the upstream of the air-conditioning system in the hospital areas with patients at lower risk of contracting an airborne infection, and additional two or more filters in areas with high vulnerable patients, located in the upstream and downstream of the air-conditioning equipment. In any case, the trends should require the introduction of high–efficiency filters in hard functional areas (ICUs, surgery block, etc.) (40), with the addition of highly efficient particle filtration of the central ventilation systems to reduce the airborne load of infectious particles. This control strategy can reduce the transport of infectious agents within individual areas and among the hospital wards with the same ventilation system (41, 42). Efficient filtration units (either ceiling mounted or portable, floor-standing) reduce local airborne loads and may respond to the need of each specific area (9).

Conclusions

Enhanced ventilation may be a key element in limiting the spread of the SARS-CoV-2 virus, until effective vaccines are available to reduce the risk of infection and limit the ongoing pandemic. If the ventilation system is properly designed and kept clean to preserve the correct pressure among the functional units, it can be effective in removing airborne infectious agents. For guaranteeing an adequate functioning and an accurate management and maintenance, these procedures should be carefully selected and applied in order to avoid risks for the users and possible contamination of the equipment and hospital settings.

Decision makers should take in consideration the costs, both direct and indirect, related to the reduction of the healthcare activities, since there is a probability of an increase of infections, paradoxically after the maintenance and cleaning of the systems, where such activities have not taken due account of the features and obsolescence of the healthcare structures.

In the light of the pandemic, this is also reflected on the level of skills and training preparation of the technical services that must manage and apply these activities.

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Riassunto

Contaminazione indoor da SARS-CoV-2: considerazioni sulla gestione anti-COVID-19 dei sistemi di ventilazione e dei materiali di finitura nelle strutture sanitarie

Molte delle devastanti pandemie ed epidemie degli ultimi secoli sono state causate da virus “rivestiti”. La recente pandemia da SARS-CoV-2 ha seriamente messo in pericolo il sistema sanitario globale. In particolare, gli ospedali hanno dovuto fare i conti con una frequenza al pronto soccorso e una richiesta di posti letto per malattie infettive e terapia intensiva mai affrontata negli ultimi decenni.

È noto che gli ospedali sono ambienti ad alto rischio infettivo. Il controllo ambientale dell’aria interna e delle superfici diventa uno strumento importante per limitare la diffusione di SARS-CoV-2. In particolare, per preservare un’adeguata qualità microbiologica indoor, un’importante strategia non farmacologica è rappresentata dai sistemi HVAC e dai materiali di finitura.

Partendo dalle vie di trasmissione SARS-CoV-2, il documento indaga l’analisi e la gestione del rischio ospedaliero, la qualità dell’aria interna e la determinazione della carica microbica, la gestione delle superfici e le strategie nelle attività di pulizia, la gestione dei sistemi HVAC e l’efficienza dei filtri.

In conclusione, il documento suggerisce diverse strategie di intervento e buone pratiche da prendere in considerazione per le fasi successive di progettazione e manutenzione.

References

1. Chan JF, Yuan S, Kok KH, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person

transmission: a study of a family cluster. Lancet 2020. doi: 10.1016/S0140-6736(20)30154-9.

2. Capolongo S, Rebecchi A, Buffoli, M, et al. COVID-19 and Cities: from Urban Health strategies to the pandemic challenge. A Decalogue of Public Health opportunities. Acta Biomedica. 2020; **91**(2):13-22. doi: 10.23750/abm.v91i2.9615.
3. Astley P, Capolongo S, Gola M, Tartaglia A. Operative and design adaptability in healthcare facilities. Technè 2015; **9**: 162-70. doi: 10.13128/Techne-16118.
4. Capolongo S, Cocina GG,Gola M, Peretti G, Pollo R. Horizontality and verticality in architectures for health. Technè 2019; **17**: 152-60. doi: 10.13128/Techne-24028.
5. Montagna MT, De Giglio O, Cristina ML, et al. Evaluation of Legionella Air Contamination in Healthcare Facilities by Different Sampling Methods: An Italian Multicenter Study. Int J Environ Res Public Health 2017; **14**(7): 670. doi: 10.3390/ijerph14070670.
6. Caggiano G, Napoli C, Coretti C, et al. Mold contamination in a controlled hospital environment: a 3-year surveillance in southern Italy. BMC Infect Dis 2014; **14**: 595. doi: 10.1186/s12879-014-0595-z.
7. Brambilla A, Rebecchi A, Capolongo S. Evidence Based Hospital Design. A literature review of the recent publications about the EBD impact of built environment on hospital occupants' and organizational outcomes. Ann Ig 2019; **31**(2): 165-80. doi: 10.7416/ai.2019.2269.
8. Sehulster L, Chinn RY. Guidelines for environmental infection control in health-care facilities. Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC). MMWR Recomm Rep 2003, **52**(RR-10): 1-42.
9. Joppolo CM, Romano F. HVAC System Design in Health Care Facilities and Control of Aerosol Contaminants: Issues, Tools and Experiments. In: Capolongo S, Settimo G, Gola M, Eds. Indoor Air Quality in Healthcare Facilities. New York: Springer Public Health, 2017: 83-94. doi: 10.1007/978-3-319-49160-8_8.
10. D'Amico A, Montagna MT, Caggiano G, et al. Observational study on hospital building heritage and microbiological air quality in the orthopedic operating theatre: the IM.PA.C.T. Project. Ann Ig 2019; **31**(5): 482-95. doi:10.7416/ai.2019.2309.
11. Capolongo S, Gola M, Brambilla A, Morganti A, Mosca EI, Barach P. COVID-19 and Healthcare Facilities. A Decalogue of Design Strategies for Resilient Hospitals. Acta Biomedica 2020; **91**: 50-60. doi: 10.23750/abm.v91i9-S.10117.
12. Settimo G, Bertinato L, Bonadonna, L, D'Ancona, P, Santarsiero, A, Soggiu, ME. Indicazioni ad interim per la prevenzione e gestione degli ambienti indoor in relazione alla trasmissione dell'infezione da virus SARS-CoV-2. Roma: Istituto Superiore di Sanità, 2020 (Rapporto ISS COVID-19 n. 5/2020, Rev.). Available on: https://www.iss.it/documents/20126/0/Rapporto+ISS+COVID-19+n.+5_2020+REV.pdf/2d27068f-6306-94ea-47e8-0539f0119b91?t=1588146889381. [Last accessed: 2020, Sep 9].
13. Associazione Italiana Condizionamento dell'Aria, Riscaldamento e Refrigerazione (AICAAR). Protocollo per la riduzione del rischio da diffusione del SARS-CoV-2 mediante gli impianti di climatizzazione e ventilazione in ambienti sanitari. Rome: AICAAR, 2020.
14. Gola M, Settimo G, Capolongo S. Indoor Air Quality in Inpatient Environments: A Systematic Review on Factors that Influence Chemical Pollution in Inpatient Wards. J Healthc Eng 2019; 8358306. doi: 10.1155/2019/8358306.
15. Śmiełowska M, Marć M, Zabiegała B. Indoor air quality in public utility environments—A review. Environ Sci Pollut Res 2017; **24**: 11166-76. doi: 10.1007/s11356-017-8567-7.
16. Gola M, Settimo G, Capolongo S. Indoor air in healing environments: Monitoring chemical pollution in inpatient rooms. Facilities 2019; **37**(9/10): 600-23. doi: 10.1108/F-01-2018-0008.
17. Montagna MT, Rutigliano S, Trerotoli, P, et al. Evaluation of Air Contamination in Orthopaedic Operating Theatres in Hospitals in Southern Italy: The IMPACT Project. Int J Environ Res Public Health. 2019; **16**(19): 3581. doi: 10.3390/ijerph16193581.
18. Pasquarella C, Pitzurra O, Savino A. The index of microbial air contamination. J Hosp Infect 2000; **46**(4): 241-56. doi: 10.1053/jhin.2000.0820.
19. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. N Engl J Med 2020; **382**(16): 1564-7. doi: 10.1056/NEJMc2004973.
20. Casini B, Tuvo B, Cristina ML, et al. Evaluation of an ultraviolet C (UVC) light-emitting

device for disinfection of high touch surfaces in hospital critical areas. Int J Environ Res Public Health 2019; **16**(19): 3572. doi: 10.3390/ijerph16193572.

21. Cheng VCC, Wong SC, Chen JHK, et al. Escalating infection control response to the rapidly evolving epidemiology of the Coronavirus disease 2019 (COVID-19) due to SARS-CoV-2 in Hong Kong. Infect Control Hosp Epidemiol 2020; 1-24. doi: 10.1017/ice.2020.58.
22. Ong SWX, Tan YK, Chia PY, et al. Air, Surface Environmental, and Personal Protective Equipment Contamination by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) From a Symptomatic Patient. JAMA 2020; **323**(16): 1610-12. doi: 10.1001/jama.2020.3227.
23. Chin A, Chu J, Perera M, et al. Stability of SARS-CoV-2 in different environmental conditions. Lancet Microbe 2020**.** doi: 10.1101/2020.03.15.20036673.
24. Bianchi CL, Sacchi B, Capelli S, et al. Micro-sized TiO_2 as photoactive catalyst coated on industrial porcelain grès tiles to photodegrade drugs in water. Environ Sci Pollut Res 2018; **25**(21): 20348-53. doi: 10.1007/s11356-017-9066-6.
25. Zanelli A, Campioli A, Monticelli C, Viscuso S, Giabardo G. Novel Textile-Based Solutions of Emergency Shelters: Case Studies and Field Tests of S(P)EEDKITS Project. In: Aste N, Della Torre S, Talamo C, Adhikari R, Rossi C, Eds. Innovative Models for Sustainable Development in Emerging African Countries. Cham: Springer, Research for Development, 2020. doi:10.1007/978-3-030-33323-2_10.
26. Guo ZD, Wang ZY, Zhang SF, et al. Aerosol and surface distribution of severe acute respiratory syndrome coronavirus 2 in hospital wards, Wuhan, China, 2020. Emerg Infect Dis 2020; **26**(7). doi: 10.3201/eid2607.200885.
27. Otter JA, Donskey C, Yezli S, Douthwaite S, Goldenberg SD, Weber DJ. Transmission of SARS and MERS coronaviruses andinfluenza virus in healthcare settings: the possible role of dry surface contamination. J Hosp Infect 2016; **92**(3): 235e50. doi: 10.1016/j.jhin.2015.08.027.
28. Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. J Hosp Infect 2020; **104**(3): 246-51. doi: 10.1016/j.jhin.2020.01.022.
29. Moscato U, Borghini A, Teleman AA. HVAC Management in Health Facilities. In: Capolongo S, Settimo G, Gola M, Eds. Indoor Air Quality in Healthcare Facilities. New York: Springer Public Health, 2017: 95-106. doi:10.1007/978-3-319-49160-8_9.
30. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Position Document on Infectious Aerosols. ASHRAE, 2020. Available on: https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf [Last accessed: 2020, Sep 8].
31. Mkhatshwa T, Mummert A. Modeling super-spreading events for infectious diseases: Case study SARS. IAENG Int J Appl Math 2011; **41**(2): 82–88.
32. Li Y, Leun GM, Tang JW, et al. Role of ventilation in airborne transmission of infectious agents in the built environment? A multidisciplinary systematic review. Indoor Air 2007; **17**(1): 2-18. doi:10.1111/j.1600-0668.2006.00445.x.
33. Shiu EYC, Leung NHL, Cowling BJ. Controversy around airborne versus droplet transmission of respiratory viruses. Curr Opin Infect Dis 2019; **32**(4): 372-9. doi:10.1097/QCO.0000000000000563.
34. Correia G, Rodrigues L, Gameiro da Silva M, Gonçalves T. Airborne route and bad use of ventilation systems as non-negligible factors in SARS-CoV-2 transmission. Med Hypotheses 2020; **141**: 109781. doi:10.1016/j.mehy.2020.109781.
35. Centers for Disease Control and Prevention (CDC). Guidelines for Preventing the Transmission of Mycobacterium Tuberculosis in Health-Care Settings. MMWR Recomm Rep 2005; **54**(RR17): 1-141.
36. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size. Standard 52.2, 2017.
37. Centers for Disease Control and Prevention (CDC). Interim Infection Prevention and Control Recommendations for Healthcare Personnel During the Coronavirus Disease 2019 (COVID-19). 2019. Pandemic. Available on: https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html [Last accessed: 2020, Sep 8].
38. Centers for Disease Control and Prevention (CDC). Guidelines for environmental infection control in health-care facilities: recommenda-

tions of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) (2003). Updated in 2017. Available on: https://www.cdc.gov/infectioncontrol/guidelines/environmental [Last accessed: 2020, Sep 8].
39. Kurnitski J, Boerstra A, Franchimon F, et al. Federation of European Heating, Ventilation and Air Conditioning Association (REHVA). COVID-19 guidance document, 2020. How to operate and use building services in order to prevent the spread of the COVID-19. REHVA, 2020: 1-6.
40. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ASHRAE Standards. Health care facilities. In: ASHRAE. Heating, Ventilating, and Air-Conditioning applications. Atlanta: ASHRAE Handbook, 1995.
41. Morawska L, Tang, JW, Bahnfleth W, et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Internat 2020; **142**: 105832. doi: 10.1016/j.envint.2020.105832.
42. Rezaei N, Jafari M, Nazari A, et al. A novel methodology and new concept of SARS-CoV-2 elimination in heating and ventilating air conditioning systems using waste heat recovery. AIP Adv 2020; **10**(8): 085308. doi: 10.1063/5.0021575.

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