The Role of Ventilation in Indoor Spaces During the Covid-19 Pandemic: Comprehensive Analysis of ASHRAE Standard 62.1

Giovanni Francesco Giuzio – Università degli studi di Napoli Federico II, Italy – giovannifrancesco.giuzio@unina.it
Giovanni Barone – Università degli studi di Napoli Federico II, Italy – giovanni.barone@unina.it
Annamaria Buonomano – Università degli studi di Napoli Federico II, Italy – annamaria.buonomano@unina.it
Gianluca Del Papa – Università degli studi di Napoli Federico II, Italy – gianluca.delpapa@unina.it
Cesare Forzano – Università degli studi di Napoli Federico II, Italy – cesare.forzano@unina.it
Adolfo Palombo – Università degli studi di Napoli Federico II, Italy – adolfo.palombo@unina.it
Giuseppe Russo – Università degli studi di Napoli Federico II, Italy – giuseppe.russo9@unina.it

Abstract

The spread of COVID-19 has significantly increased attention focused on the air quality of indoor environments. All major international health organizations (e.g., World Health Organization, etc.) recognize the importance of ventilation in enclosed spaces in reducing pathogen concentrations and fighting the Corona virus, or future pandemics. In this context, the roadmap to ensure safer and healthier indoor environments, by also guaranteeing an adequate comfort level, involves the implementation of several measures leading to a not-negligible increase in buildings' energy consumption. Within this framework, the present paper aims to analyze the adequacy of the current Indoor Air Quality (IAQ) standards requirements, and to assess the impact of IAQ improving measures on end-use energy profiles to ensure occupants' comfort. Specifically, a dynamic simulation approach is adopted to estimate, for each building space typology defined by ASHRAE 62.1, both air contaminant concentration and zone energy consumption. Specifically, the risk to occupants of contracting the COVID-19 virus was assessed for different scenarios using a modified Wells-Riley model. The study confirms the urgent need for enhancing ventilation in enclosed spaces to exit the health emergency caused by COVID-19. In addition, the paper provides quantitative data on the resulting operating costs of HVAC systems.

1. Introduction

The diffusion of general pollutants, viruses, bio effluents, etc. in the indoor environment is kept under control by the ventilation system, whose key role is largely recognized and investigated in the scientific community (Emmerich et al., 2013; Risbeck et al. 2021; Shrubsole et al., 2019). Still, higher attention and interest has increased around this topic since the Covid-19 outbreak (Faulkner et al., 2021; Pan et al., 2021; Sun & Zhai, 2020; Zheng et al., 2021) and the vital need for reducing the infection risk (Agarwal et al., 2021; Li & Tang, 2021) by supplying outdoor air in adequate quantities (Guo et al., 2021; Sha et al., 2021). In this context, the aim of the present work is to analyze the existing connection between SARS-CoV-2 contagion risk and the fresh air rates per person, targeting a proposal of different solutions to reduce the contagion risk by also evaluating their energy impact to maintain adequate occupant comfort regarding indoor air quality and healthy conditions in indoor spaces (Castaldo et al., 2018).

Several studies in the literature investigate the risk of contagion of COVID-19 with increased mechanical ventilation in the indoor environment, such as classrooms (Schibuola & Tambani, 2021a; Xu et al., 2021), offices (Sha et al., 2021; Srivastava et al., 2021; Pavilonis et al., 2021), universities (Mokhtari & Jahangir, 2021), restaurants (Li et al., 2021), and hospitals (Li & Tang, 2021) etc. Among the works

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stating the usefulness of adopting increased outdoor air ventilation rates in reducing the Covid-19 contagion risk, it is very difficult to find works quantitatively assessing the related energy impact, with the only exception of works reported in Balocco & Leoncini (2020) and Schibuola & Tambani (2021b). This is a large gap, given the great influence of ventilation systems on building energy demands. In addition, there is a lack of manuscripts investigating the Covid-19 contagion risk in a comprehensive way by assessing the analysis for a large group of space types, whereas it is more common to find works focusing on a specific case study. Such a lack implies the impossibility of determining unique design criteria and defining guidelines.

The aim of the present work is to fill the gap in knowledge identified above. Specifically, the Wells-Riley model (Miller et al., 2021; Riley et al., 1978), largely adopted in the literature to evaluate Covid-19 contagion risk, was implemented in a purpose - developed Matlab routine. By means of this tool, aiming at filling the lack of works examining a wide range of building types, all the building categories presented in the ANSI/ASHRAE Standard 62.1-2019 were studied by considering, for each space type, the related crowding indexes, the occupancy schedules, and the outdoor air ventilation rates suggested by the standard. By doing so, it was possible to assess Covid-19 contagion risk in the case of the presence of infected people for each of the investigated building typologies, as a function of diverse pivotal parameters (exposure time to virus, typology of the facial mask worn, etc.). To reduce the Covid-19 contagion risk associated with the investigated scenarios, and with the aim of providing useful insights and design criteria for ventilation system, higher outdoor air flow rates were tested by assessing their effect in terms of infection probability. Finally, by exploiting a dynamic simulation model, purposely developed by means of a Building Energy Modeling (BEM) approach, the energy implications of the proposed ventilation strategies were assessed. The mentioned analyses are presented in detail hereinafter.

2. Method and Mathematical Model

In the present paragraph, the method adopted to carry out the previously mentioned analyses is described. Specifically, in Fig. 1, a schematic diagram of the adopted workflow is presented. Specifically, to perform a parametric analysis of several building categories, a Matlab routine capable of both simulating energy performance of the examined room and assessing the probability of infection of the occupants was purposely developed. As shown in Fig. 1, the Matlab script is intended to manage either the inputs and outputs of the detailed simulation model of the building room or the infection risk calculation model.

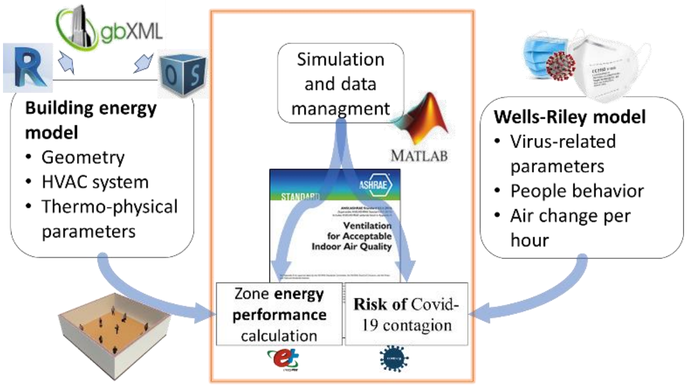

Fig. 1 - Schematic workflow of the methodology adopted (authors' illustration)

The building energy simulation relies on three different tools: Autodesk Revit, OpenStudio, and Energy Plus. Specifically, in Autodesk Revit, the building 3D model is developed in detail, by including building elements, as well as thermal zone data. The building model is then exported, by exploiting gbXML file, into OpenStudio suite, which is an energy-modeling software built on the EnergyPlus engine. At the same time, the assessment of Covid-19 contagion risk, for the same building and operating condition is also performed. This is conducted into a purposely developed Matlab subroutine, based on the Wells-Riley model. Both the energy consumption and Covid-19 contagion risk assessment methods will be described in detail in the following.

2.1 Building Energy Model

The energy model resulted in a well-mixed air single-zone building equipped with an ideal air loads systems capable of providing the exact thermal energy required to keep the temperature setpoints. An HVAC system like this also guarantees the minimum outdoor airflow rate (V_{bz}, breathing-zone ventilation), specified by means of Eq. (1), which depends on the number of people in the zone (N), the outdoor airflow rate per person (R_p), the net area of the zone (A_z), and the corresponding outdoor airflow rate required for unit of zone area (R_a).

$$V_{bz} = R_p \cdot N + R_a \cdot A_z \tag{1}$$

Furthermore, the influence of people, lighting and electrical equipment on the heat balance algorithm is accounted for by means of characteristic heat gain parameters, such as sensible and latent heat fraction per person ($g_{s,p}$ and $g_{l,p}$, $W/person$), lighting power load intensity (g_l, W/m^2) and electrical equipment power load intensity (g_{ee}, W/m^2). Appropriate schedules complete the model, taking into account the actual operating regime of the buildings under investigation. It is worth noticing that the ventilation rate necessary to ensure adequate IAQ is one of the key multi-physics factors that influences the occupants' comfort in indoor spaces; in this regard, complete multi-physics and multi-domain analysis aim at assessing thermo-hygrometric comfort, visual comfort, healthy conditions, and air quality.

2.2 Modified Wells-Riley Model

In order to assess the Covid-19 contagion risk, the Wells-Riley model (Miller et al., 2021; Peng & Jimenez, 2021; Peng et al., 2022; Riley et al., 1978) was adopted. This model is based on a standard aerosol Wells-Riley infection model, opportunely modified to consider the hypothesis of well mixed air volume. Following this model, the Covid-19 infection probability P can be expressed as:

$$P = 1 - e^{-n} \tag{2}$$

where n represents the inhaled "quanta", which is the concentration of infectious doses of the virus which are inhaled by a person. Note that a quanta is defined as the dose necessary to cause an infection in 63 % of the persons susceptible. The Covid-19 infection probability expressed by Eq. (2) is valid under certain hypothesis: i) the quanta emission rate from the infectious individual is constant, ii) no prior quanta are in the investigated environment, iii) the quanta aerosol is evenly distributed in the environment, iv) close-proximity infection is neglected. The number of quanta inhaled by a person is calculated as follow:

$$n = q_c \cdot b_r \cdot D \cdot (1 - \eta_{wm} \cdot \eta_{in}) \tag{3}$$

where η_{in} is the mean filtration efficiency of the face mask for inhalation, η_{wm} is the percentage of people wearing a facemask, D is the exposure time to the virus, b_r is the breathing rate, and q_c is the average quanta concentrations.

3. Case Study

The Wells-Riley model was adopted to investigate the effectiveness, in relation to Covid-19 contagion risk, of the ventilation rates proposed by ANSI/ASHRAE Standard 62.1-2019. To perform this analysis, a generic room (Fig. 2) characterized by a walkable area of 100 m^2 (10 m x 10 m), with a height of 3 m, for a total volume of 300 m^3, was considered. It is worth noticing that the investigated room was assumed as to be located in the core of a generic building. Consequently, all the walls were modeled as adiabatic. Note that such a hypothesis was made to provide results that were as little case-specific as possible, and take into account the sole effect of ventilation and internal heat gains on energy performance.

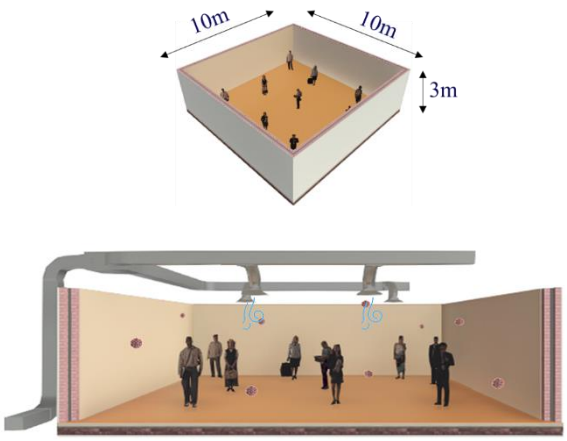

Fig. 2 – Investigated room

The investigated room was considered as alternatively belonging to all the 109 occupancy categories reported in the ANSI/ASHRAE Standard 62.1-2019, by taking into account the related outdoor air rates and occupancy density values. The 109 space typologies were grouped following the ANSI/ASHRAE Standard 62.1-2019, into 11 categories. The minimum and maximum outdoor air rates and occupancy density occurring within the group are reported in Table 1.
Note that the values reported in Table 1 represent the range limits of each building category group. However, each of the 109 spaces presented in the ANSI/ASHRAE Standard 62.1-2019 were simulated individually. For further details, please refer to the standard (ASHRAE, 2019). For each of the considered spaces, the Covid-19 contagion risk resulting from the adoption of the outdoor air ventilation rates suggested by the standard (calculated by means of Eq. 1) was assessed.

Table 1 – Outdoor ventilation rates, and occupant density for all the investigated categories

Occupancy Category	People Outdoor Air Rate *[L/s person]*		Area Outdoor Air Rate *[L/s person]*		Occupant Density *[persons/100m2]*	
	min	*max*	*min*	*max*	*min*	*max*
Animal Facilities	5	5	0.6	0.9	20	20
Correctional Facilities	2.5	3.8	0.3	0.6	15	50
Educational Facilities	2.5	5	0.3	0.9	10	100
Food and Beverage	2.5	3.8	0.3	0.9	2	100
Hotels, Motels, Resorts	2.5	3.8	0.3	0.6	10	120
Miscellaneous Spaces	2	5	0	0.9	0	100
Office Buildings	2.5	2.5	0.6	0.12	2	60
Outpatient Health Care	2.5	10	0.3	2.4	5	50
Public Assembly	2.5	3.8	0.3	0.6	10	150
Retail	3.8	10	0.3	2.4	7	150
Sports, Entertainment	3.8	10	0.3	2.4	7	150

The quanta exhalation rates, namely ER, used to evaluate the infection risk were gathered from the reference (Schibuola & Tambani, 2021a). Furthermore, in order to investigate diverse scenarios, five pivotal parameters were supposed to be variable as follows: i) three different Covid-19 variants were alternatively considered. The variant choice affects the quanta emission rate by means of a correction factor Q_{var}. Specifically, the three investigated variants are: original variant (Q_{var} = 1), Delta (Q_{var} = 2); and Omicron (Q_{var} = 2.5) (Burki, 2022; Campbell et al., 2021); ii) three different exposure times (D) were considered: 1 hour, 2 hours, 6 hours; iii) three different face mask scenarios, affecting inhalation and exhalation efficiency: no mask scenario, all people wearing chirurgical masks scenario, and all people wearing FFP2 masks scenario.

3.1 Proposed Solutions

The previously described case study, adopting the outdoor ventilation rates suggested by the ANSI/ASHRAE Standard 62.1-2019, was considered as Reference System (RS). To reduce Covid-19 contagion risk, the convenience of using increased outdoor air ventilation rates was investigated. Specifically, ventilation rates augmented three and ten times (Proposed System 1 – PS1, and Proposed System 2 – PS2, respectively) higher than those suggested by the standard were considered and tested. These values, which might seem quite high compared to those adopted in the case of RS, were selected in accordance with the data found in the existing literature, referenced in the literature review section. It should be considered that, as expected, the proposed outdoor rates will imply a substantial increase of the energy consumption for space heating and cooling due to the augmented ventilation loads. For this reason, both PS1 and PS2 systems were also tested by additionally considering a sensible heat recovery device equipped to reduce the ventilation load. The selected sensible heat recovery device is a commercial device with an average heat recovery efficiency equal to 75 %, and nominal pressure drops ranging from 100 to 300 Pa (depending on the elaborated airflow rate). Table 2 lists all the investigated systems.

Table 2 – Investigated case studies

System	Outdoor Ventilation Rates	Heat Recovery
RS	ANSI/ASHRAE Standard 62.1-2019	No
PS1	Ventilation x3	No
PS1.1	Ventilation x3	Yes
PS2	Ventilation x10	No
PS2.1	Ventilation x10	Yes

3.2 Energy Analysis

To assess the energy consumption associated with the selected ventilation strategies (both RS and proposed systems), the ANSI/ASHRAE Standard 90.1-2016 was taken into account for the following data: i) occupancy scheduling; ii) lighting load density and scheduling; iii) machinery load density and scheduling; iv) indoor air setpoints. Specifically, each of the investigated occupancy category spaces (see Table 1) was simulated by considering the corresponding values of the above-reported parameters. Concerning the HVAC system, the considered room space heating and cooling is ensured by an air source HPC (heat pump/chiller), sized on the maximum load, with a variable COP (Barone et al., 2016 and 2020).The energy consumption resulting from the conducted analysis is affected substantially by the climate zone, due to the different outdoor air temperature (it is worth noticing that the room is placed in the core of a conditioned building, so no transmission load is considered). Thus, aiming at assessing the energy impact of the proposed ventilation strategies for diverse climates, three different European weather zones were considered as representative of hot, mild, and cold weather (see Table 3).

Table 3 - Investigated weather zones

Climate	HDD	CDD	ISR
	[K d]		[kWh/(m²y)]
Almeria	763	982	1664
Rome	1475	730	1529
Berlin	3394	262	1001

4. Result and Discussion

In this paragraph, the results of the analyses carried out are provided. Specifically, the Covid-19 results will be presented first, then the energy implications will be discussed.

4.1 Covid-19 Analysis

In this section, the results of the Covid-19 analysis, in term of contagion probability, are presented. Specifically, in Fig. 3, the Covid-19 contagion risk is reported for all the occupancy categories investigated, in the case of two different face mask scenarios (no mask, on the left, surgical mask on the right), and in the case of three different exposure times (one hour in blue, two hours in red, and six hours in yellow). Note that the FFP2 mask results are not presented, since in this case the resulting Covid-19 contagion risk was already remarkably low. Numerical results obtained (probability of infection) are reported as boxplots in Fig. 3. Specifically, the distribution of the set of data, the minimum and maximum values (whiskers), as well as the 1st and 3rd quartiles (boxes), and the median are depicted for each of the occupancy category groups.

The infection probability, in case of people not wearing a mask and for an exposure time of one hour, almost always turns out to be higher than 1 % (considered in the literature as a “safe” value), while remaining quite close to it. Higher risk occurs in the case of 2 hours, with infection probability rising to 4 %. Finally, the highest infection probability in the case of no masks worn is obtained for 6 hours of exposure time, with contagion risk values rising to 12-14 %

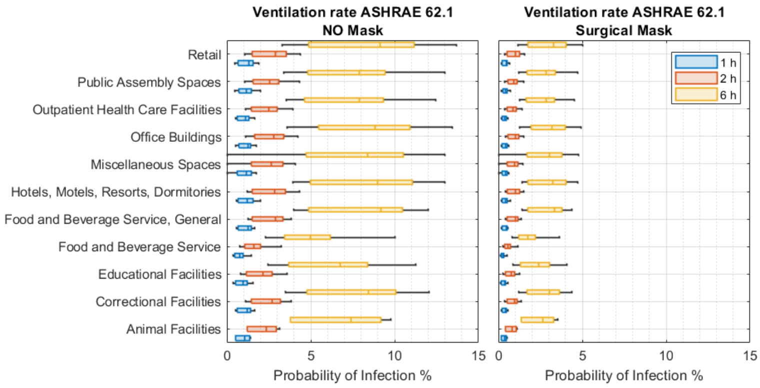

Fig. 3 – Covid-19 infection probability for all the investigated case studies (standard ventilation)

By using surgical masks (right-hand diagram in Fig. 3, it is possible to notice that, in the case of both 1 hour and 2 hours of exposure time, the infection probability is almost always below the 1 % value. Nevertheless, in the case of 6 hours, the risk is still higher than the threshold value. The reported results show that the ventilation rates suggested by the ANSI/ASHRAE Standard 62.1-2019 are adequate to control the Covid-19 contagion risk only in the case of all the occupants wearing an FFP2 mask, whereas a higher risk occurs in the case of surgical masks, and no mask worn. To reduce the estimated contagion risk, the ventilation rates suggested by the standard were augmented 3 times, and the related contagion risk results are shown in Fig. 4. Here, it is possible to notice that, in the case of the no mask scenario, the contagion risk in the case of 1 hour exposure time is almost always below 1 %, ensuring occupant safety. Also, the contagion risks relative to 2 hours of attendance time drop. However, many cases return infection probabilities still higher than the safe threshold. The contagion risk connected to six hours exposure time is also reduced regarding the standard ventilation base case. Still, very high values are reached. A different situation occurs in the case of surgical masks worn. In this case, both 1 hour and 2 hours' exposure time return contagion risks lower than 1 %, whereas the 6-hour case returns a contagion risk higher than the safe threshold, but remarkably reduced compared with the base case.

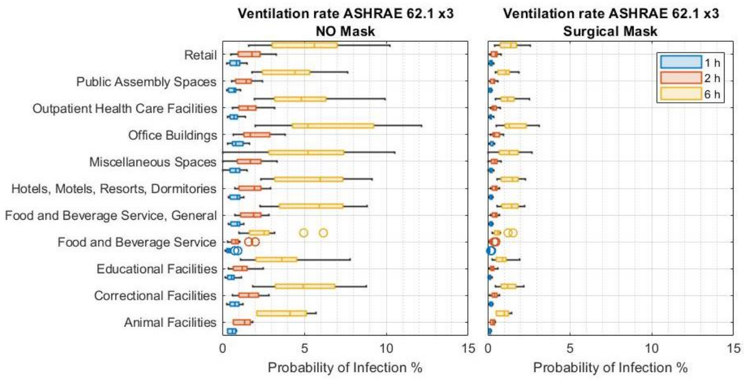

Fig. 4 – Covid-19 infection probability for all the investigated case studies (x3 ventilation)

In order to further reduce the contagion risk, ten-times-increased standard ventilation was also tested, and the related results are reported in Fig. 5. Here, it is possible to notice that, in the case of surgical mask worn, the contagion risk probability is lower than the threshold value for almost all the investigated scenarios and exposure times. On the contrary, in the case of no masks worn, one and two-hours residency time turns out to be still safe.

It is worth noticing that the absolute values shown in the previously reported figures are subject to uncertainty. This is mainly due to the adopted number of quanta, whose value is still under discussion in the scientific community. For this reason, relative results are also presented.

Specifically, the average relative contagion risk reduction, for all the mask configurations and exposure time, is presented in Fig. 6. From the figure it is possible to notice that, beside the absolute contagion risk value, the contagion risk percentage reduction ranges from 30 to 50 % in the case of x3 ventilation, and from 65 to 80 % in the case of x10 ventilation. Such results help in understanding the great effect that outdoor ventilation rates have on Covid-19 contagion risk reduction.

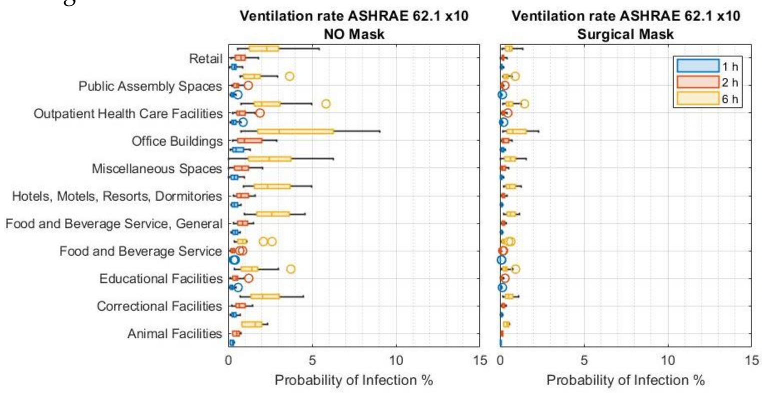

Fig. 5 – Covid-19 infection probability for all the investigated case studies (x10 ventilation)

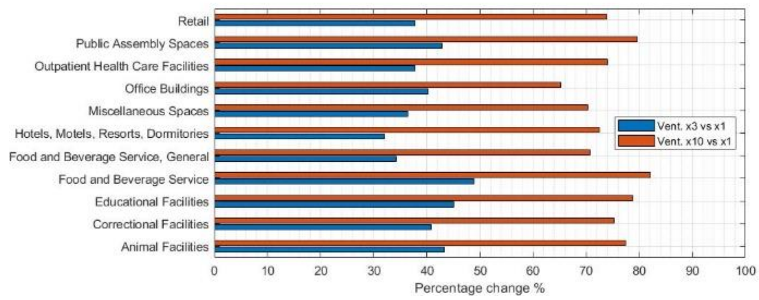

Fig. 6 – Average relative contagion risk reduction for all the face mask configurations

The higher ventilation rates proposed also entail a much higher dilution of indoor pollutants and lower level of carbon dioxide within the spaces. The indoor air quality significantly improves, so that the required comfort level by the occupants can be fully satisfied with the proposed ventilation rates (ASHRAE 62.1 x3 and ASHRAE 62.1 x10) as demonstrated by Fig. 7. The figure refers to an auditorium seating area with high occupancy (about 150 people). With the current standard (ASHRAE 62.1),the CO_2 concentration rises to 1800 ppm, leading to a discomfort level perceived by the occupants due to poor air. In contrast, both the proposed ventilation rates adopted to reduce the Covid contagion risk keep the CO_2 concentration within the acceptable range suggested by OHSA (Occupation Health & Safety Administration) for well ventilated indoor spaces.

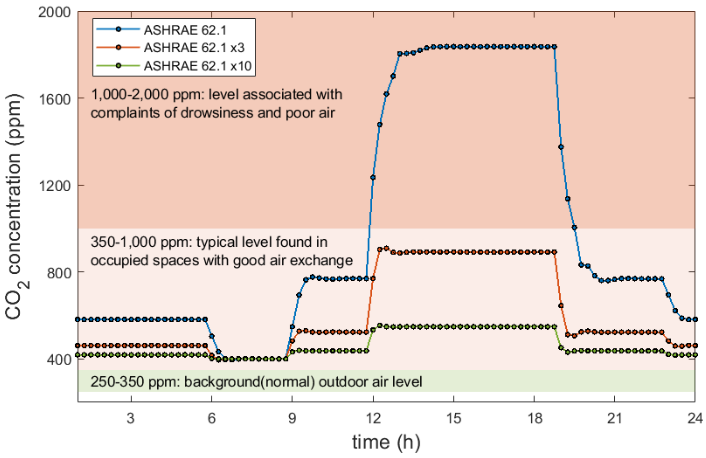

Fig. 7 – CO_2 concentration in the auditorium space and related comfort range for occupants

4.2 Energy Analysis

The previously described ventilation strategies, while reducing Covid-19 contagion risk, also increase the energy consumption of the building for space heating and cooling due to the augmented ventilation load. Furthermore, more air treated leads to higher handling costs. As an example of this increase, the space heating thermal energy demand for representative space typologies (selected from each category) are presented in Fig. 8 in the case of the building located in Berlin. From the figure, as expected, it is possible to notice that the adoption of x3 (PS1) and x10 (PS2) ventilation flow rates (red and light blue bars) always implies a remarkably higher energy demand compared with the RS scenario (blue bar). Different results are, on the other hand, achieved in the case of adoption of Heat Recovery (HR) device (orange – PS1.1 - and green – PS2.1 - bars in Fig. 8). Here, it is possible to notice that the energy demand increase is remarkably lower than those occurring without the HR adoption. It worth noticing that, in some cases, the PS1.1 energy demand (orange bars) is comparable with the RS one (blue bars).

Similar outcomes can be detected in the case of the thermal energy demand for space cooling, as shown in Fig. 9, where the results in the case of the building located in Almeria are presented. Nevertheless, by analyzing Fig. 9, it is possible to notice that, in the case of x3 ventilation, lower energy demands for space cooling are obtained also without HR (PS1 - orange bars). Such an occurrence is due to the free cooling effect played, in some cases, by the augmented flow rate. The same effect is not noticeable in the case of x10 ventilation (PS2 – light blue bars), since the positive effects connected with the free cooling are overwhelmed by the negative ones occurring in the other hours. However, it worth noticing that the overall weight of cooling need increase is remarkably lower than that of heating (the y-axis scale of Fig. 9 is different to that of Fig. 8). In addition, also the benefits of the HR are lower due to lower temperature difference between the outdoor air and the zone temperature during the summer season.

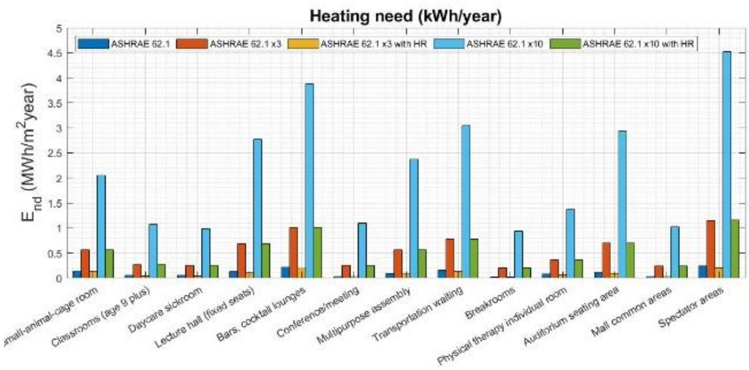

Fig. 8 – Space heating needs for all the case studies investigated for the building located in Berlin

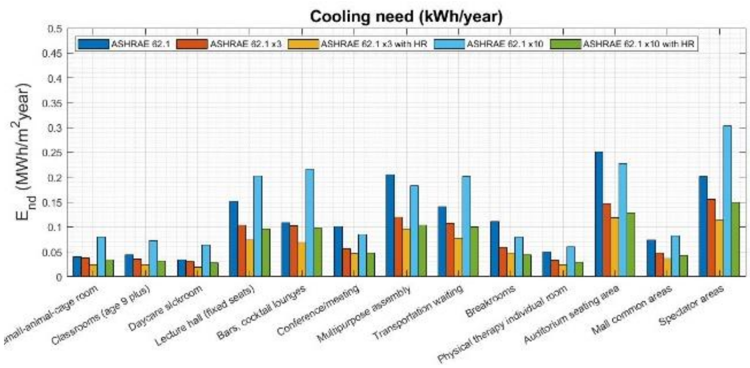

Fig. 9 – Space cooling needs for all the case studies investigated for the building located in Almeria

The thermal energy demand variations presented in Fig. 8 and Fig. 9 imply a variation of the considered room electricity consumption. Specifically, in Fig. 10, the distribution of electricity consumption is presented for all the investigated case studies. It is worth noticing that, differently to Fig. 8 and Fig. 9, which report only the influence of the diverse ventilation strategies on the space heating and cooling thermal energy demand, the electricity results presented in Fig. 10 also take the electricity consumption of the fans into account. Referring to the median values of the set of data in Fig. 10, as expected, the adoption of PS1 (red boxes) and PS2 (purple boxes) systems always presents higher electricity demand vs the RS (blue boxes).

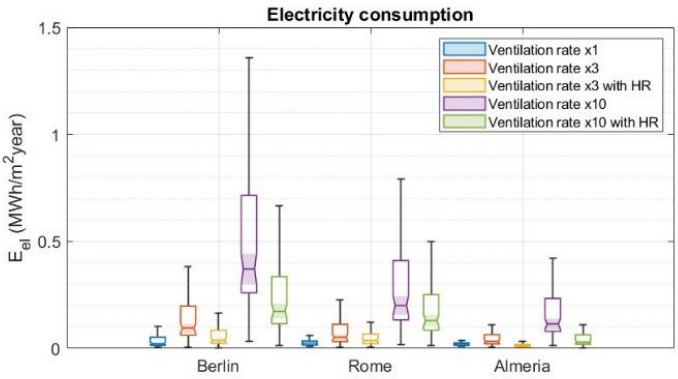

Fig. 10 – Electricity needs for all the case studies investigated

The benefits achieved during the cooling season, due to the free cooling effect, as shown in Fig. 9, are, in fact, counterbalanced by the highest consumption during the heating season. Lower electricity consumption increases are, on the other hand, detected in the case of adoption of PS1.1 (yellow bars) and PS2.1 (green bars). These reductions are smaller in magnitude with respect to those shown in the case of Fig. 7 and Fig. 8, due to the higher consumption of the fans connected to the HR adoption (higher duct system pressure drops).

5. Conclusions

In the present manuscript, the effectiveness of the ventilation rates proposed by the current ANSI/ASHRAE Standard 62.1-2019 in dealing with the Covid-19 contagion risk is investigated. To carry out this analysis, the Wells-Riley model (Riley, et al., 1978), largely adopted in the literature to evaluate the Covid-19 contagion risk, was implemented in a purpose -developed MATLAB routine. By means of this tool, all the building categories presented in the ANSI/ASHRAE Standard 62.1-2019, applied to a purpose -conceived case study, were studied by considering, for each space type, the related crowding indexes, the occupancy schedules, and the outdoor air ventilation rates suggested by the standard. By doing so, it was possible to assess the Covid-19 contagion risk in the case of the presence of infected people in the room for each of the investigated building typologies, as a function of diverse pivotal parameters (exposure time to virus, typology of the facial mask worn, etc.). Aiming at reducing the Covid-19 contagion risk associated with the scenarios investigated, and with the aim of providing useful insights and design criteria for ventilation systems, higher outdoor air flow rates were tested by assessing their effect in terms of infection probability. Finally, by exploiting a dynamic simulation model, purposely developed by means of a Building Energy Modeling (BEM) approach, the energy implications of the proposed ventilation strategies were assessed. From the analyses carried out, the key considerations are:

- The ventilation rates values proposed in the current ANSI/ASHRAE Standard 62.1-2019 are not capable of ensuring a safe indoor environment in the case of no face mask worn. Specifically, an infection risk probability higher than 1 % (value considered as safe) is almost always reached by the analysis conducted, regardless of the considered exposure time. The same is true for surgical mask adoption, which gives lower infection risk probability, but is very often still higher than the safe threshold.
- The current standard adoption returns a very low contagion risk probability only in the case of all occupants wearing a FFP2 mask.
- The adoption of higher ventilation rates (x3 and x10) always returns interesting infection risk reductions, ranging from between 30 to 50 % and 65 to 80 %, respectively. Nevertheless, x3 ventilation is viable only for an exposure time to the virus of 1 hour, whereas in the case of 2 and 6 hours, the resulting contagion risk is always higher than 1 %.
- Ten times augmented ventilation vs. ANSI/ASHRAE Standard 62.1-2019 values reduces the contagion risk below 1 % for both 1- and 2-hour exposure times, whereas 6 hours is often still too high.

- By increasing ventilation, it is possible to reduce the Covid-19 risk to under 1 %, without wearing face masks only for 1- and 2- hour attendance times, whereas, in the case of 6 hours, this is not possible. Consequently, in the case of certain space types characterized by long occupancy times (e.g., classrooms), further solutions should be adopted.
- From the energy point of view, the proposed ventilation strategies return remarkable electricity demand increases. In this framework, x3 ventilation proves to be the best trade-off solution.
- The adoption of a heat recovery device allows for a remarkable reduction of the energy impact of the proposed ventilation strategies, making both x3 and x10 ventilations more feasible than the same solutions without the HR.

From the results obtained, it is possible to conclude that the existing normative does not provide an adequate amount of outdoor air to ensure a low Covid-19 contagion risk in enclosed spaces for the wellbeing and comfort of occupants. In this framework, the augmentation of the outdoor air flowrate is proven to be a good solution to adopt. Nonetheless, such an action is highly energy- consuming, requiring the adoption of heat recovery devices. Otherwise, it would be unviable from an energy and economic point of view.

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Nomenclature

A_z	Net area of the zone
BEM	Building Energy Modeling
b_r	Breathing rate
D	Exposure time to the virus
ER	Quanta emission Rate
g_{ee}	Electrical equipment power load
g_l	Lighting power load intensity
$g_{l,p}$	Latent heat gain per person
$g_{s,p}$	Sensible heat gain per person
n	Inhaled quanta
N	Number of people in the room
P	Infection Probability
PS	Proposed System
q_c	Average quanta concentration
R_a	Outdoor airflow rate per area
R_p	Outdoor airflow rate per person
RS	Reference System
V	Room Volume
V_{bz}	Breathing-zone ventilation
V_{out}	Outdoor air ventilation flow rate

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