Sustainable Cities and Society 70 (2021) 102942

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Indoor air quality improvement in COVID-19 pandemic: Review

Nehul Agarwal [a,b], Chandan Swaroop Meena [a,c,*], Binju P Raj [a,b], Lohit Saini [a,b], Ashok Kumar [a,c], N. Gopalakrishnan [a,c], Anuj Kumar [a,c], Nagesh Babu Balam [a,c], Tabish Alam [a,c], Nishant Raj Kapoor [a,c], Vivek Aggarwal [a,c]

[a] CSIR-Central Building Research Institute (CBRI), Roorkee, 247667, India
[b] School of Energy and Environment, Thapar Institute of Engineering and Technology, Patiala, 147001, India
[c] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, 201002, India

ARTICLE INFO

Keywords:
Indoor air quality
Air purifiers
Social distancing
Facemasks
Lockdown
Ventilation
HVAC

ABSTRACT

Introduction: The advent of COVID-19 has impinged millions of people. The increased concern of the virus spread in confined spaces due to meteorological factors has sequentially fostered the need to improve indoor air quality.
Objective: This paper aims to review control measures and preventive sustainable solutions for the future that can deliberately help in bringing down the impact of declined air quality and prevent future biological attacks from affecting the occupant's health.
Methodology: Anontology chart is constructed based on the set objectives and review of all the possible measures to improve the indoor air quality taking into account the affecting parameters has been done.
Observations: An integrated approach considering non-pharmaceutical and engineering control measures together for a healthy indoor environment should be contemplated rather than discretizing the available solutions. Maintaining social distance by reducing occupant density and implementing a modified ventilation system with advance filters for decontamination of viral load can help in sustaining healthy indoor air quality.
Conclusion: The review paper in the main, provides a brief overview of all the improvement techniques bearing in mind thermal comfort and safety of occupants and looks for a common ground for all the technologies based on literature survey and offers recommendation for a sustainable future.

1. Introduction

The rapid outbreak of peculiar global pandemic COVID-19 spawned by SARS-COV-2 made unprecedented impacts around the world leading to 2–3% increased fatality rate (Rodriguez-Morales et al., 2020). The highly infectious disease is transmitted by inhalation or contact with infected droplets causing mild to moderate respiratory illness further progressing to pneumonia, septic shock, acute respiratory distress syndrome, and cytokine release syndrome (Cdc.gov/coronavirus, 2020). The contagion of this virus and its response to the patients depends on various factors. Recently, scientific interest has been focused on determining the factors responsible for the increased spread of viruses and their fatality rate. The studies suggest people who have had medical problems like chronic respiratory disease, diabetes, cardiovascular disease, or even high blood pressure and cancer are expected to be at higher risk from coronavirus (Zheng, Ma, Zhang, & Xie, 2020). The socio-demographic factors like lack of basic amenities, or clustered slum areas, and density across public transportation, traveling time, the infrastructure condition also impact the increasing COVID-19 cases (Das et al., 2021; Li, Peng, He, Wang, & Feng, 2021; Ma, Li, & Zhang, 2020). Also, shreds of evidence are growing for the impact of climatic factors like temperature, humidity, airflow, air quality, solar irradiance, wind speed, rainfall on the seasonal spread of COVID-19 (Tzampoglou & Loukidis, 2020). Among all, poor air quality is a considerable factor that may increase the fatality rate in the socio-economic group already dealing with respiratory diseases and those having age above 60 years (Bashir et al., 2020). The main anthropogenic activities contributing to the deterioration of air quality include fossil fuel combustion from vehicles and power plants, industrial activities, and livestock farming. These activities induce certain emissions (PM_{10}, NO_2, $PM_{2.5}$, O_3, CO, and SO_2) that may turn noxious if it exceeds permissible limits and may accelerate the contagion of the virus. Moreover, these pollutants can be generated indoors due to cooking/frying, cleaning activities, paints, religious activities like incense burning, and workstations which affect the health of people residing indoors (Amoatey, Omidvarborna,

* Corresponding author.
E-mail address: chandan@cbri.res.in (C.S. Meena).

https://doi.org/10.1016/j.scs.2021.102942
Received 12 December 2020; Received in revised form 11 April 2021; Accepted 12 April 2021
Available online 15 April 2021

Nomenclature

ANN	Artificial Neural Networks
AQI	Air Quality Index
ARIMA	Autoregressive Integrated Moving Average
CADR	Clean Air Delivery Rate
CPCB	Central Pollution Control Board
CPR	Cardiopulmonary Resuscitation
EMD	Empirical Mode Decomposition
EPA	Environment Protection Agency
HVAC	Heating, Ventilation, and Air Conditioning
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
IMF	Intrinsic Mode Functions
MLR	Multiple Linear Regression
NAQI	New Air Quality Index
ORAQI	Oak Ridge Air Quality Index
PC	Principal Component
PCA	Principal Component Analysis
PM	Particulate Matter
PSI	Pollutant Standard Index
R-CNN	Region Based Convolutional Neural Networks
SARS-COV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SOP	Solid Oxygen Purifying
SPI	Soy Protein Isolate
SSD	Single Shot Detector
SVR	Support Vector Regressions
VOC	Volatile Organic Compounds
WHO	World Health Organization
YOLO	You Only Look Once

Baawain, & Al-Mamun, 2020; (Sean) Chang, Capuozzo, Okumus, and Cho, 2021). The positive association between $PM_{2.5}$ and COVID-19 cases, hospital admissions, and deaths has been demonstrated in various studies conducted in regions affected worst by pandemic (Cole, Ozgen, & Strobl, 2020; Coker et al., 2020; Wu, Nethery, Sabath, Braun, & Dominici, 2020). With regards to NO_2 concentration, a similar positive relationship with increasing COVID-19 is reported (Latif, Dominick, Hawari, Mohtar, & Othman, 2021; Ogen, 2020; Wang & Li, 2021). Taken together, the data provide evidence of the relevant role of air pollutants in the hike of COVID-19 cases. These emissions must be within the permissible limits and should be monitored on the daily basis to take some effective mitigation measures against the increasing pollution levels.

One such effective monitoring technique is the AQI which depicts the condition of air by comparing the concentration of gases in ambient air with the standards formed by the government (Beig, Ghude, & Deshpande, 2010). A typical AQI is an interpretive technique that transfers complex data of measured air pollutant concentration into a single number or a set of numbers to make the data more understandable. AQI is reviewed by different terminologies (Murena, 2004; Ott & Hunt, 1976; Ott & Thorn, 1976; Shenfeld, 1970; Thom & Ott, 1973) and calculated using numerous methodologies (Babcock & Nagda, 1972; Bishoi, Prakash, & Jain, 2009; Cannistraro & Ponterio, 2009; Kyrkilis, Chaloulakou, & Kassomenos, 2007; Sicard, Lesne, Alexandre, Mangin, & Collomp, 2011; van den Elshout, Léger, & Nussio, 2008) around the globe. Fuzzy aggregation (Mandal, Gorai, & Pathak, 2012), coupled PCA, and ANN (Kumar & Goyal, 2013), combined IoT and cloud computing technology (Jo, Jo, Kim, & Choi, 2020) are some of the recent development in the field of AQI forecasting. The statistical analysis (Ikram & Yan, 2017) evaluating the impact of AQI and its concentration levels on respiratory disease, genders, and age groups resulted that the higher the index level, the higher is the risk of having a respiratory disease in the aged group.

Many studies suggested COVID-19 may be airborne and is stable on aerosols for 3 h and can travel a long distance in the closed and open environment (van Doremalen et al., 2020; Santarpia et al., 2020; Wang & Du, 2020). As studied by (Liu et al., 2020), the peak concentration of coronavirus was found in two size ranges; one having an aerodynamic diameter of 0.25–1 μm, the second range of virus having a diameter greater than 2.5 μm which may travel indoor in hospital. WHO also considered airborne precautions for medical staff as the virus remains viable in aerosols for multiple hours depending on factors like heat and humidity (van Doremalen et al., 2020) and it can be transmitted up to a distance of 4 m in hospital wards (Guo et al., 2020). Also, as COVID-19 cases are exponentially increasing, making people stay indoors, it is necessary to provide a healthy indoor environment for occupants' safety and look forward to preventive measures for a better future.

The solution to this problem is twofold: one is by adopting non-pharmaceutical measures such as maintaining social distance in indoor spaces, hand washing, regular surface sanitization, implementing lockdown, wearing a facemask in a crowded place; second is to provide a proper ventilation rate (Atkinson et al., 2016) to reduce exposure to aerosols in confined areas either by natural, mechanical ventilation or by portable, wall-mounted or in-duct air cleaners.

Based on our analysis, it has been observed that parameters affecting IAQ, its solutions like non-pharmaceutical measures and engineering controls have been looked at separately by scientists, researchers, policy/decision-makers, which may often lead to limited solutions. So, this review article eyes on the parameters affecting IAQ and occupant's health along with a collaborative solution that can help to pave a better way for a sustainable solution.

2. Methodology

The purpose of this study is to review the factors related to degrading IAQ, its effect in pertaining COVID-19 condition, and to examine the effective IAQ improvement methods which can help in mitigating any bio-attack in the future. For satisfying the purpose of the review paper, a broad spectrum of sections related to IAQ and COVID-19 were explored to cover all the concerning aspects in the prevailing situation. For a better reach and understanding, we divided the research interest into different regimes of science such as biology, chemistry, engineering, information, physical and human resource development. Thus, precisely extracting the information majorly from the recent publications including peer-reviewed research articles, review papers, letter to the editor, dissertations, and books. The pre-determined search terms used were Indoor Air Quality, Coronavirus, COVID-19, lockdown, social distancing, air purifiers, Air Quality Index, AQI forecasting, Indoor air quality improvement, impact or effectiveness, ventilation, face masks. Multiple permutations and combinations of the keywords were used for amplifying the search results. The follow-up of this study contributed to an ontology chart represented in Fig. 1 which chronologically co-relates to the occupants' comfort during COVID-19 in a confined space with affecting parameters along with the possible and available preventive measures.

Among the classifications in the ontology chart, this paper essentially seeks to peep into firm IAQ improvement measures considering affecting factors, that can enhance the safety of the occupants within the confined area. Thereby, suggesting possible future measures that could be stepped in for a sustainable indoor environment preventing such situations in the future.

The paper is further structured in this approach: the first section reviews the impact of air quality parameters on COVID-19 and parameter assessment techniques, the second section reviews the IAQ

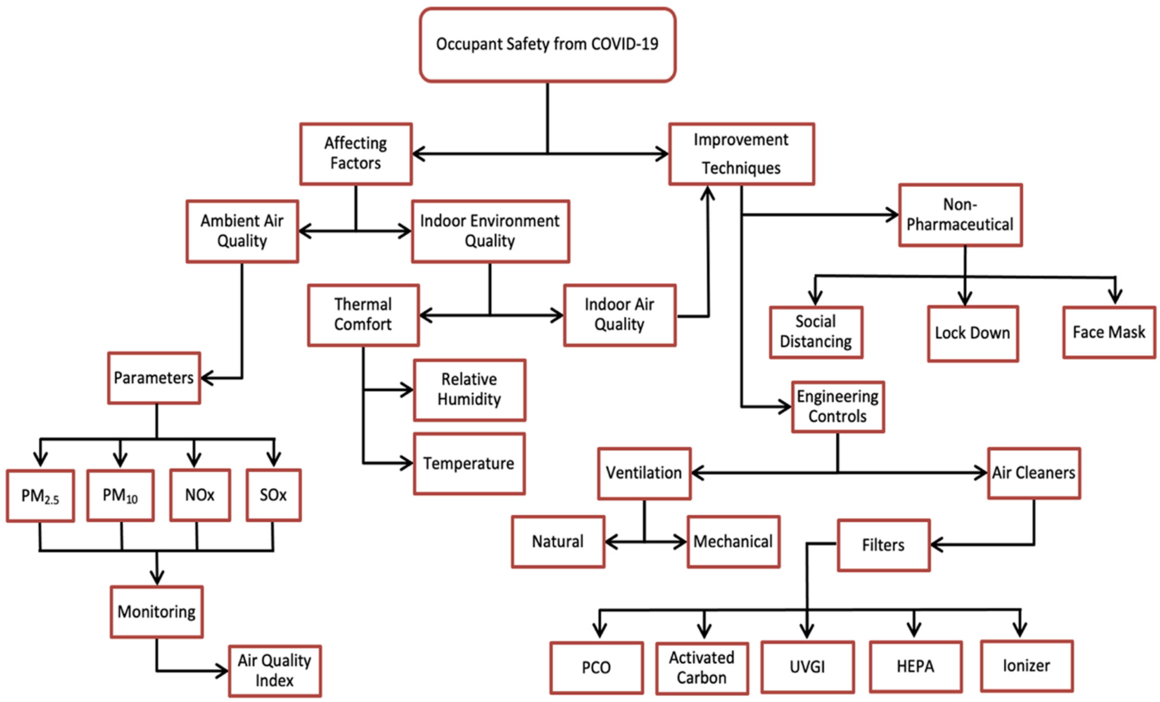

Fig. 1. The ontology chart.

improvement techniques useful for reducing potential airborne transmission, which includes non-pharmaceutical measures (social distancing, facemasks, and lockdown) and engineering controls (ventilation and air cleaners), the third section represents discussion, and the last section summarizes the key points and future outlook.

3. Impact of air quality on COVID-19

Clean air is beneficial for human health as it impacts the regular metabolism of our body. The risk of all-cause deaths, lung cancer, and other pulmonary pathologies elevated by continuous exposure to aerosols, PM, and nitrogen compounds (Heal, Kumar, & Harrison, 2012). According to the WHO statistics, 20% of all-cause deaths in Europe are due to environmental diseases (Beelen et al., 2014). Air quality has been degrading due to excessive emissions and this directly upshot the spread of COVID-19. According to the epidemiological study conducted in Italy, $PM_{2.5}$ magnifies SARs-COV-2 infectivity (Borro et al., 2020). The study revealed that 10−25 μg/m^3 increase in $PM_{2.5}$ concentration triples the infection rate and mortality case doubles. On a similar line, by using a negative binomial regression model with chemical transport modeling, represented in Eq. (1), an epidemiological assessment was conducted in 355 municipalities of the Netherlands to find the relationship between air quality and COVID-19 deaths (Cole et al., 2020).

$$C_i = \varnothing Pollution + \beta_1 D_i^{'} + \beta_2 P_i^{'} + \beta_3 E_i^{'} + \beta_3 S_i^{'} + \beta_4 L_i^{'} + \gamma_r + \varepsilon_i \tag{1}$$

Where, C is COVID-19 infected cases or personals hospitalized due to COVID-19, or the number of mortals from COVID-19 in municipality i. Pollution specifies annual concentrations of $PM_{2.5}$, NO_2, and SO_2averaged for the period 2015–2019. Vector $D^{'}$, P', E', S' and L' includes control variables capturing demography, social, and physical proximity, employment/education, spatial and health variables, respectively, for the year 2019 and β is the associated parameter. The term γ_r denotes province-level fixed effects for each province r. The modeling resulted that all three pollutants were in a positive association with the COVID-19 cases and concluded that a particular increase in 1 unit ($\mu g/m^3$) of $PM_{2.5}$ increases 9.4–15.1 COVID-19 cases, 2.9–4.4 hospital admissions, and 2.2–3.6 mortality cases. A similar study examining deaths due to COVID-19 in the US (Wu et al., 2020), reported that a 1 $\mu g/m^3$ increase in $PM_{2.5}$ is associated with an 8% hike in the COVID-19 mortality rate. Accordingly, a study conducted using negative binomial regression and spatial interpolation (kriging) data (Coker et al., 2020) in northern Italy accounted that 1 unit $\mu g/m^3$ increase in $PM_{2.5}$ relates to a 9% increase in COVID-19 mortality. The model is represented in Eq. (2) as:

$$Ex\ Deaths_i \sim NB(\mu_i,\ \theta) \tag{2}$$

$$\log(\mu_i) = \alpha + \beta PM_i + \delta^{'} X_i + \varepsilon_i \tag{3}$$

Where *Ex Deaths* refers to the average number of deaths in the same period of the previous 5 years, θ is the over dispersion parameter and μ_i is the municipality-specific expectation conditional on the value of the covariates which can be calculated using Eq. (3). Among the covariates, PM is the fine PM concentration in municipality i and $\beta$is the associated parameter, which is expected to be positive and statistically different from zero; X is a vector of control variables that adjusts for the potential confounding effects and includes the (log of) total population as the offset while ε_i is a normally distributed error term. The findings also deduce that the municipalities having a population of age group 65 and more or the ones nearby the airports were the cluster of contagion and had a high mortality rate. PM can also be produced from socio-cultural activities in the indoor environment like incense burning, which can act as a supporting medium for the rapid transmission of the virus. This can be exacerbated if proper ventilation is not provided in the buildings (Amoatey et al., 2020).

Similarly, a positive relation is assessed between increasing NO_X concentration and COVID-19 cases. For instance, the study conducted in Italy (Ogen, 2020) reported that the areas having high NO_2 concentration with downward airflow (positive omega), were the ones having the highest fatality rate due to COVID-19 as no dispersion of air pollutants could take place, increasing respiratory problems, and inflammation. Moreover, NO_2 generates harmful pollutants as by-products such as nitric acid and ozone (Khoder, 2002).

Overall, these studies indicate that increasing the concentration of these pollutants degrades the air quality, consequently, casting doubt on the occupant's health within the confined space as people spend 90% of their time indoors which eventually is considered 4–5 times more polluted than the outdoors. Moreover, aerosols are the reason for COVID-19 to be more contagious within the confined space thus, increasing cases and fatality. For this very reason, assessment of the air quality becomes significant.

4. Air quality assessment

As the pollutants and the air flow in different manner and directions due to natural causes and atmospheric phenomena, it is bit complicated to model the concentration of the pollutant in a specific area (Kurt & Oktay, 2010). To express the magnitude of deteriorating air quality, AQI was formed and is often called by several names having some parametric modifications like the inclusion of $PM_{2.5}$ after the year 2009 and some toxic elements for accurate measurement of AQI, which are represented in Table 1. AQI is an information tool that helps the public acknowledge the air quality level of the surroundings daily. The EPA formed the PSI considering five major pollutants (PM_{10}, NO_2, O_3, CO, and SO_2) for air quality determination. A scale of 0–500 was divided into 5 equal parts and the highest value of the concentration of one of the five pollutants indicated PSI value. But many other pollutants like $PM_{2.5}$, whose exposure had a severe effect on human health, were not taken into account. Considering new sub-indices for 24-h $PM_{2.5}$ concentration, a sub-index of 8 -h average O_3 concentrations, and breakpoints for O_3, USEPA renamed PSI as AQI. The formulation of the AQI was done using Eq. (4).

$$I_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{Lo}) + I_{Lo} \quad (4)$$

Where, I_P = pollutant index value, P; C_P =the truncated pollutant concentration, P; BP_{Hi}= the breakpoint $\geq C_p$; BP_{Lo}= the breakpoint $\leq C_p$; I_{Hi} = the AQI value correspondent to BP_{Hi}, I_{Lo} = the AQI value correspondent to BP_{Lo}. Indices of each pollutant were calculated using the above equation, and then the maximum index value was indicated as AQI which can be represented in mathematical form as in Eq. (5).

$$AQI = Max\ (I_P) \quad (5)$$

The AQI is subdivided into six health concern levels according to the values. The AQI value from 0 to 50, 51–100, 101–150, 151–200, 201–300, 301–500 represents good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous air quality respectively.

Table 1
Air quality indices.

References	Year	Name of Index	Parameters included
(Ott & Hunt, 1976)	1976	Pollution Standard Index	PM_{10}, NO_2, O_3, CO, and SO_2
(Babcock & Nagda, 1972)	1972	Oak Ridge AQI	PM_{10}, NO_2, O_3, CO, and SO_2
(Murena, 2004)	2004	Air Pollution Index	PM_{10}, NO_2, O_3, CO, and SO_2
(USEPA, 2004)	1999	Air Quality Index	PM_{10}, NO_2, $PM_{2.5}$, O_3, CO, and SO_2
(Sowlat et al., 2011)	2011	Fuzzy AQI	PM_{10}, $PM_{2.5}$, O_3, SO_2, NO_2 and CO, benzene, toluene, ethylbenzene, xylene, and 1, 3-butadiene
(Kyrkilis et al., 2007)	2007	Aggregate AQI	PM_{10}, NO_2, O_3, CO, and SO_2
(van den Elshout et al., 2008)	2008	Common AQI	PM_{10}, O_3, NO_2 (main) and CO, SO_2(auxiliary)
(Bishoi et al., 2009)	2009	New AQI	PM_{10}, NO_2, $PM_{2.5}$, O_3, CO, and SO_2
(Sicard et al., 2011)	2011	Aggregate Risk Index	PM_{10}, NO_2, $PM_{2.5}$, O_3, and SO_2
(CPCB, 2014)	2014	National AQI	PM_{10}, NO_2, $PM_{2.5}$, O_3, CO, and SO_2
(Chelani et al., 2002)	2002	Air Quality Index	RSPM, SO_2, and NO_2

A comparison study using correlation- regression method between the revised AQI and PSI showed more correlation of revised AQI with PM_{10} than the correlation between PSI and $PM_{10,}$ indicating more accurate results by revised AQI than PSI (Cheng et al., 2007). Many studies demonstrated different techniques to assess the AQI for different locations that showed more accurate results than USEPA AQI. Chelani et al. Chelani, Chalapati Rao, Phadke, and Hasan (2002) assessed the air quality of Delhi, Calcutta, Mumbai, Nagpur, and Chennai by modifying the ORAQI according to the environmental factors of India. The ORAQI was made for 5 pollutants and is represented in Eq. (6).

$$ORAQI = 5.7 \times \left(\sum_{i=1}^{S} I_i\right)^{1.37} \quad (6)$$

Where I_i represents the ratio of the concentration of pollutant to the standard level of pollutant.

In India, as standards were stipulated for specific pollutants, SO_2, NO_2, and SPM, so the modified equation for different sectors like residential, commercial, and industrial and the standard values were obtained from the CPCB as represented in Eqs. (7) and (8).

The AQI on the 24 -hly basis for the residential area can be calculated by:

$$AQI_{(RSPM,SO_2,NO_2)} = 55.16 \times \left(\frac{RSPM}{STD} + \frac{SO_2}{STD} + \frac{NO_2}{STD}\right)^{0.901} \quad (7)$$

The 24- hourly AQI for commercial and industrial sectors can be calculated by:

$$AQI_{(RSPM,SO_2,NO_2)} = 24.48 \times \left(\frac{RSPM}{STD} + \frac{SO_2}{STD} + \frac{NO_2}{STD}\right)^{1.07} \quad (8)$$

Further, AQI was categorized indicating simply understandable information; if values were less than 30, air quality was considered good, moderate if lies between 30–49, poor if ranges between 50–79, bad for range 80–99, and dangerous if the value is greater than or equal to 100.

Using this method, Delhi came out to be the most polluted city out of five cities considered as the residential and commercial sectors were under the dangerous category. Calcutta and Mumbai attained second and third ranks respectively and Nagpur and Chennai were the comparatively least polluted cities.

4.1. Air quality forecasting

Sowlat, Gharibi, Yunesian, Tayefeh Mahmoudi, and Lotfi (2011) formed AQI applying fuzzy interference system, taking into consideration toxic pollutants such as toluene, benzene, xylene, ethylbenzene, and 1, 3-butadiene along with the criteria pollutants (PM_{10}, $NO_{2,}$ O_3, CO, and SO_2) and then assigned weighing factors to every pollutant according to the priority. The trapezoidal membership function was implemented to form fuzzy AQI; later results were compared with the USEPA AQI for the analysis. The result suggests that all the pollutants should be considered, and fuzzy logic is an apt tool for forecasting air quality.

Bishoi et al. (2009) proposed a NAQI based on factor analysis using the PCA technique. The PC can be calculated using Eq. (9).

$$P_i = \sum_{j=1}^{n} \frac{a_{ji}\ X_j}{\lambda_i} \quad (9)$$

where P_i is the ithPC; a_{ji} is the factor loading of the jth variable on the ith PC and λ_i is the eigenvalue associated with Pi. After obtaining the PCs, the NAQI is computed using the expression given in Eq. (10).

$$NAQI = \frac{\sum_{i=1}^{n}(P_i E_i)}{\sum_{i=1}^{n}(E_i)} \quad (10)$$

Where E_i is the initial eigenvalue ($\geq$1) for the 'percentage of variance'.

NAQI took into account the variances of concentrations of different pollutants which were useful for the determination of air quality. Though, it didn't provide any information about the impact of air quality on health but was still considered better than EPA AQI.

Noteworthy, nowadays hybrid statistical models are in use because of their high precision in predicting the air quality status. Some of the statistical models are MLR, ARIMA model, SVRs, ANNs, and hybrid models. These models alone are inefficient for air quality forecasting as experimentally verified by Kumar and Goyal (2011) in their study for assessing AQI for Delhi. Three statistical models, namely MLR, ARIMA, and a combination of both MLR and ARIMA were proposed by (Goyal, Chan, & Jaiswal, 2006) for determining interrelation in meteorological parameters and pollutants concentration and their efficiency in forecasting AQI in Hong Kong and Delhi. The analysis reported that the combination of both the models MLR-ARIMA was better in forecasting AQI than individual models and humidity, temperature, and wind speed were significant factors in determining the concentration of pollutants in Delhi whereas, in Hong Kong, humidity and wind speed were the significant ones. Zhu et al. (2017) proposed two hybrid models namely EMD-SVR-Hybrid and EMD-IMFs-Hybrid integrated with EMD and S-ARIMA, in the former model data pre-processing technique EMD shifts the original AQI data driving a group of smoother IMFs and noise series. The SVR forecasted the sum of the IMFs, and then, S-ARIMA revised the residual sequence. In the latter model, EMD-IMFs-Hybrid firstly forecasted the IMFs with statistical models and then models the residual data along with S-ARIMA. Similarly, a novel optimal-hybrid model based on Secondary Decomposition (SD), Sample Entropy (SE), Long Short-Term Memory (LSTM) Neural Network, and Least Squares Support Vector Machine optimized by Bat Algorithm (BA-LSSVM) named SD-SE-LSTM-BA-LSSVM was developed (Wu & Lin, 2019) for improvising AQI forecasting bearing the ability to capture the original AQI series characteristics and possess forecasting accuracy of AQI classes.

Such hybrid models need to be embraced at the government level as they possess high precision. Moreover, the toxic compounds should be taken into consideration while calculating AQI as exposure to a small dose of these compounds can be lethal.

5. Indoor air quality improvement

IAP has emerged as the leading risk factor contributing to poor health. The air quality inside households, offices, or other private and public buildings where people spend ample time signifies the health and well-being of people (Vijayan, Paramesh, Salvi, & Dalal, 2015). Hazardous emissions from construction materials of buildings and indoor equipment or due to combustion of fuels for cooking or heating can cause health problems. The existence of IAPs can foster drowsiness, sore throat, or acute respiratory problems which can be acknowledged as sick building syndrome. While investigating 60 Hong Kong residencies, it was found that particles of size less than 400 nm contributed most to the total particle mass (Chao, Wong, & Cheng, 2002). Moreover, particles within the 200 nm size range can efficiently perforate into building shells and will be airborne for a longer residential time due to low depositional velocities (Lai, 2002). Also, various studies reveal the deep penetration capability of the particles ranging below 400 nm into the human body causing damage to different organs (Heyder, 2004; Maher et al., 2016; Wick et al., 2010). On the top, adversity and the loss bought in by COVID-19 have enlightened the need for a wiser solution, to enfold a sustainable future.

IAQ can be improvised by using numerous techniques which include developing a green environment by plantation, adopting non-pharmaceutical measures, and implementing engineering controls as represented in Fig. 2 depicting all the methodologies that should be adopted for the betterment of occupants' health (Megahed & Ghoneim, 2020b; Rahmani & Mirmahaleh, 2021). Looking towards non-pharmaceutical measures, the current situation made the world familiar with the terms social distancing, quarantine, lockdown, and usage of facemasks. These primary measures have helped to control the peak of COVID-19 infection rates and mortalities. The use of facemasks has become ubiquitous around the world. The stringent lockdown and restrictions imposed on millions made a positive impact in reducing the infection rates. The engineering controls like providing proper ventilation or air filtration have been endorsed as a capable method of improvising IAQ. Indoor air filtration can be provided by whole house filtration through an HVAC system or by portable room air cleaners, or an integrated system. All the strategies useful in improving IAQ are discussed underneath.

5.1. Non-pharmaceutical measures

Wearing face masks, maintaining social distance, and implementing lockdown by government officials come under the category of non-pharmaceutical measures that can help in reducing the transmission rates. These three control strategies are discussed below throwing light on their association with transmission rates, benefits of adopting them, adverse effects on health and economy, and its efficiency with proper implementation.

5.1.1. Facemasks

The use of face masks has become new normal for society as it is

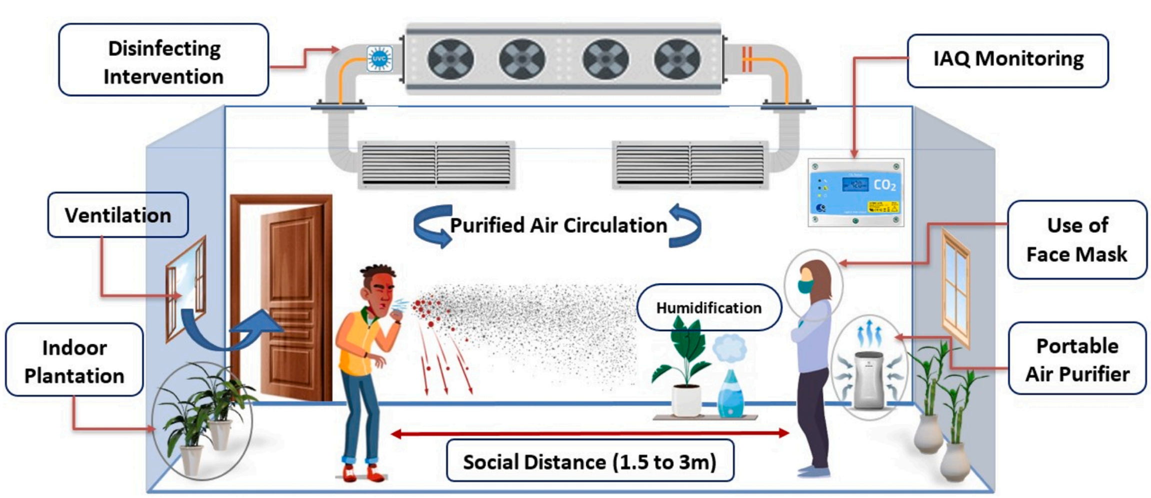

Fig. 2. IAQ improvement techniques.

considered to provide significant protection against SARS-CoV-2 transmission (Tan, Wang, Luo, & Hu, 2021). Moreover, its usage is mandated across the countries hit hardest by the virus. Wearing masks in public gatherings or crowded areas may help in restricting the contagion of disease from the infected individuals (Scerri & Grech, 2020). Its potential in controlling airborne transmission has been recognized by (Abboah-Offei et al., 2021) in a review article based on 58 case studies. An online cross-sectional survey performed in the USA reported control of SARS-CoV-2 transmission by mask-wearing even before the government made it mandatory (Rader et al., 2021). On a similar line, (Gondim, 2021) stated that the epidemic would have been controlled at the initial stage in Italy, Brazil, and the USA if at least 85–91% of the population had wear masks.

Face masks having different standards depending on thickness and permeability are designed for use in specific areas. The face masks range from homemade cloth masks to surgical masks, half-face masks, and filtering face piece respirators (N95 respirators). The surgical masks are affordable, one-time-use masks comprising of three layers, the outer two layers are made of polypropylene, and the middle layer from melt-blown fabric, having the ability to filter out large particles. N95 respirators are more effective than surgical masks as it is made of five layers having three melt-blown middle layers and also it covers the face properly, finding its application in health care centres. The homemade cloth masks used by the general public are usually made of cotton or nonwoven fiber that can capture droplets emitted while speaking, sneezing, or coughing (Abboah-Offei et al., 2021; Li et al., 2020). The different types of masks are shown in Table 2 representing its characteristics defining the filtration range based on the particle size, and on this ground, area of usage is specified, and further, the findings are analyzed.

Health care workers have been working day and night restlessly to serve humanity. The face masks worn by them as a piece of personal protective equipment for protection from infections can affect the efficacy of their work. A systematic review and meta-analysis conducted by (Li et al., 2020) concluded that the usage of face masks reduces the infection risk by 70% for health care workers. In a study conducted by (Serin & Caglar, 2020) including 48 participants for determining the CPR while wearing different ranges of masks, it was observed that face masks adversely affect the chest compression quality as wearing masks increases the pulse rate of rescuer leading to fatigue and degrading the quality of CPR. From the 5 rounds each for 2 min for chest compression of mannequins performed wearing different masks, it was found that surgical masks cause lesser rescuer fatigue than N95 and half-face masks.

Prolonged usage of face masks can cause various discomforts including headache, difficulty in breathing, skin irritation, sweating, fogging on glasses, dryness in the eyes (Ahmad et al., 2020; Boccardo, 2021; Li, Zhao, Li, & Song, 2021; Scheid, Lupien, Ford, & West, 2020; Serin & Caglar, 2020). According to an online survey of 3605 conducted by (Boccardo, 2021), the dry eye problem was observed in 18.3% of participants, specifically in women and the ones who wear glasses or use contact lenses. The individuals already dealing with ocular discomfort reported worsening of the condition due to the masks. But this study seemed to be incomplete as various factors like climatic conditions, usage timings, age, and clinical support were neglected.

Wearing face masks for a longer duration creates secondary complications especially in sensitive groups as airflow is restricted thereby, creating a high concentration of CO_2 in the body. The pH of the blood is regulated by CO_2 and its increased level can decrease the pH, making blood acidic which may cause various health hazards (Ahmad et al., 2020; Diaz Milian, Foley, Bauer, Martinez-Velez, & Castresana, 2019). CO_2 retention in the body also called hypercapnia can lead to confusion, headache, dizziness, depression and can even cause respiratory failure (Diaz Milian et al., 2019). Moreover, accumulation of humidity inside the masks can be observed due to restricted airflow, creating favorable conditions for the existence of the SARS-CoV-2 virus increasing the viral load. It can even be exacerbated if proper hygiene is not maintained especially in children and infants (Esposito & Principi, 2020). Restricted airflow is common while carrying out physical activities wearing masks which can cause hypoxia due to imbalanced carbon dioxide and oxygen exchange. This type of incident has been reported where young individuals died while jogging or exercising wearing masks due to collapsed lungs and cardiac arrest (C. Control Center of Disease, 2020).

Thus, after reviewing the above-mentioned articles, it is found that facemasks help in preventing the infection from suspected cases but only if used properly without touching the masks. It sometimes can create a false sense of security causing more infections, so it is recommended to follow other control preventive measures like social distancing or face shields rather than using face masks for the sensitive group specifically in indoor areas.

5.1.2. Lockdown

As a safety measure, the lockdown was imposed in the countries where the pandemic blow hit the hardest to reduce the transmission of the deadly virus, which majorly exerted influence on the lifestyle of billions and the world's economy. Where the world is facing the worst time, COVID-19 induced lockdown improved the air quality during its early phase. Many regions recorded a significant reduction in air and water pollution as all the transportation, industrial sectors were shut down. This became one of the few positive impacts of the strict restriction imposed on billions across the world. Globally, a 5% drop in air pollution was recorded (Saadat, Rawtani, & Hussain, 2020). In China, a 25% drop in air pollution was recorded. Vultaggio et al. observed a decrease of 50% and 45% in NO_2 and PM_{10} concentration respectively in Palermo (Italy) (Vultaggio, Varrica, & Alaimo, 2020). Similarly, in Europe, NO_2 emissions dropped in north Italy by 60%, Brazil by 54.3% (Latif et al., 2021), and in the UK by 45%. Moreover, due to the restricted movement of vehicles in lockdown, Malaysia observed a reduction in NO_2 by 55–72% (Wang & Li, 2021). Reduction in NO_2 and PM during the first phase of lockdown across various countries of the world (Berman & Ebisu, 2020; Kumari & Toshniwal, 2020; Pei, Han, Ma, Su, & Gong, 2020; Yadav et al., 2020) is represented in Fig. 3. A comparative study by (Mahato, Pal, & Ghosh, 2020) between the pre-lockdown period and during the lockdown, of air quality parameters in Delhi, represented a drastic improvement in air quality just after 4 days of implementation of lockdown contributing 50% improvement

Table 2
Types of masks and their properties.

Type of mask	Characteristics	Uses	Findings	Ref.
Surgical mask	Filter particles of size 3 μm with 95% efficiency.	Hospitals and the general public	Cost-friendly, single time usage, fluid-resistant, lower adverse health risk, useful while CPR	(Li, Zhao et al., 2021)
Filtering facepiece respirator(N95)	Filter outs 5–50 μm aerosols.	Majorly by health care workers	Face sealing property, reduced microplastic inhalation risk, increased CO_2 retention and humidity, eye dryness problem, not fit for a longer duration	(Ahmad et al., 2020; Boccardo, 2021; Serin & Caglar, 2020)
Half face mask (P3 filter)	Filters 80% of aerosols.	At the crowded, dusty place	Does not slip from the face, durable for 8 hours, increased fatigue during CPR	(Leung et al., 2020; Serin & Caglar, 2020)
Cloth mask	Prevents particles of diameter >200 nm.	Indoor usage by the general public	Affordable, reusable, loose-fitting, less effective against viruses, not fluid resistant	(Davies et al., 2013; Leung et al., 2020)

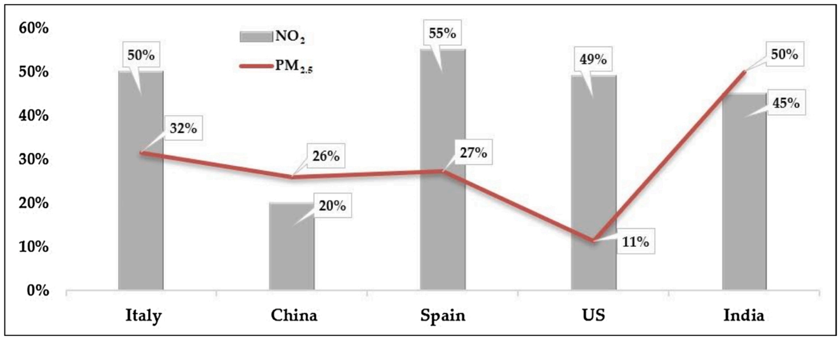

Fig. 3. Reduction in (a) NO_2 and (b) $PM_{2.5}$ concentration amid lockdown due to COVID-19.

from the past observing a decrease of about 60% and 39% in $PM_{2.5}$ and PM_{10} concentration respectively and suggesting for 2–3 days of lockdown every year once or twice as an alternative policy to control the air quality. Overall, the implementation of lockdown has decreased $PM_{2.5}$ emissions during the peak time in metropolitan cities (Kumar et al., 2020). But these shutdown measures plunged the global economy into severe contraction thereby saving the world from the worst recession, the lockdown was lifted. As a result of this, air quality started degrading again and this indirectly hiked the COVID-19 cases.

5.1.3. Social distancing

Social distancing is an effective non-pharmaceutical measure to minimize the spread of deadly viruses by maintaining an appropriate distance from other individuals so that there is no physical contact between them (ECDC, 2020). Social distancing approaches can be categorized at communal and individual levels. Communal actions rope in closing or reducing access to educational institutions and offices, canceling public gatherings, prohibiting travel outside home other than essential activities or for front line workers, border control, and quarantining buildings. Individual actions include isolation, quarantine, and encouragement to keep physical distances between people (Vultaggio et al., 2020). This approach should be implemented and followed at both levels, majorly in crowded areas, marketplaces, or in public gatherings. If an infected or suspected person is home quarantined, then other housemates must maintain distance, protecting themselves from getting infected. Considering the threshold physical distance to be maintained to mitigate the transmission, a distance of at least 2 m or 6 ft is taken into account (Centers for Disease Control & Prevention, 2020; Guo, Qian et al., 2021; Megahed & Ghoneim, 2020a; Noorimotlagh, Jaafarzadeh, Martínez, & Mirzaee, 2021). While Sun abd Zhai (2020) projected a safe distance of 1.6–3 m (5.2–9.8 ft) for daily social activities.

If the social distancing measure was executed at the beginning of the pandemic, it would have reduced infection frequency leading to reduced daily new cases and delay of disease peak in a region (Qureshi, Suri, Chu, Suri, & Suri, 2020), thereby lowering the burden on medical workers and dropping death rates. And for effective social distancing at the communal level, it is studied that government policies and stringency play a pivotal role in its success (Wang, 2021).

Social distancing relates to numerous individual and environmental factors in indoor spaces. Individual factors such as demographic information (age, race, sex, income, education), mental health status play a significant role in implementing it (Hu, Roberts, Azevedo, & Milner, 2021). An online survey done to analyze the influential factors of social distancing, resulted that women abide by the rules three times more seriously than men as they are painted as homemakers and holds more responsibility for the family than men (Guo, Qin, Wang, & Yang, 2021). Inherent psychological behavior of individuals like altruism, sensitivity to public shaming can inflict social distancing (Cato et al., 2020). While, some of the dark traits like machiavellianism, narcissism, and psychopathy can intrude social distancing as people with these traits are more likely to attain personal gains having no concern for others (Triberti, Durosini, & Pravettoni, 2021).

Environmental factors like societies and inhabiting culture can influence social distancing. Crowding in indoor spaces can adversely impinge on social distancing and can increase transmission risk (Saadat et al., 2020). The reduced population density in offices and other public gatherings can be beneficial for maintaining social distance which will directly reduce the spread of infection. For predicting the impact of social distancing and ventilation on contagion risk, Sun and Zhai (2020) modified the Wells-Riley model by introducing two indices namely, social distancing probability P_d and ventilation effectiveness E_Z. Considering 50% occupancy density and 30 min exposure time, they found that infection risk reduced by 18.8–28.2% in the transportation sector, 9.1% in a high-speed train, 9.6% in the office, and 28.6–40.6% in building spaces. Social distancing can also help in reducing the required ventilation rate in confined spaces (Hu et al., 2021).

Social distancing can be maintained and tracked upon for determining its effectiveness using information communication technologies like IoT, big data, and various other deep learning models (Saxena et al., 2020). Three deep learning-based models, fast R-CNN, YOLO, and SSD were (Shorfuzzaman, Hossain, & Alhamid, 2021) tested for real-time object detection and tracking the individuals in crowded areas for monitoring of efficient social distancing. If detected with any violation, the crowd is warned with an audio-visual non-intrusive alarm. From the three models, YOLO proved to be the best model owing to its balanced map score and speed. On a similar note (Ahmed, Ahmad, Rodrigues, Jeon, & Din, 2021), used the YOLOv3 object recognition paradigm with transfer learning methodology for overhead perspective social distance tracking. The ones found breaching the norms or violating threshold distance were further tracked using a centroid tracking algorithm. Also, this study confirms the results of the previous study (Shorfuzzaman et al., 2021), as it also compares other deep learning models, obtaining the same results.

Social distancing abiding can be challenging at various levels and can cause negative impacts on the economy and mental health. Canceling mass gatherings, quarantining and isolation can conflict with ethical and religious principles. Moreover, it is hard to maintain a safe distance every time as people have to go outside for health care or food and it is not always possible to work from home. Social distancing can be challenging for the ones living in crowded areas, sharing apartments, or having more family members in small houses (Fu & Zhai, 2021). With the closure of schools and workplaces, people have to work in online mode which causes trouble due to internet trafficking. Social distancing also negatively relates to mental health (Cao et al., 2020). It has been studied in an online survey of 118 participants that social distancing grounds negative impact on mental health having symptoms of anxiety, stress, insomnia, and depression (Marroquín, Vine, & Morgan, 2020).

Based on the research articles reviewed above, it can be observed that social distancing can reduce the infection rate in indoor spaces if implemented accurately by either reducing the occupancy density at workplaces or by work from home. For maintaining this measure indoors, the government can play a key role by providing some incentives to daily wage workers and small-scale business holders, which can encourage them to make their safety priority rather than the earnings. Also, they can penalize the individuals for making them abide by the rules and conduct extensive monitoring. Social media can also help society by encouraging and influencing them to follow safety guidelines and organizing webinars on different online platforms related to mental health. Some of the key points of analysis of reviewed articles are described in Table 3 representing the results of the reviewed articles according to their objectives and our views and findings from these articles.

5.2. Engineering controls

The protective measures like social distancing, lockdown, or wearing masks are only effective till authorities are stringent towards it. Once, the restrictions are relaxed, a hike in the COVID-19 cases can be observed. Moreover, these measures do not provide a permanent solution for the future. This pandemic alerts engineers to search for a better control strategy that can be further useful in preventing bio-attacks. Two such control strategies recognized to help in improving residents' health and protecting them from infection spread are adequate ventilation and air purification. These two control measures are further discussed showcasing their application and effectiveness.

5.2.1. Ventilation

Since people spend 80–90% of their time in confined indoor spaces, dilution of the contaminants inside the space should be the prime consideration to reduce exposure risk and maintain a healthy environment. One such engineering control technique for maintaining IAQ is ventilation. Ventilation dilutes the air contaminants in confined spaces by indoor-outdoor air exchange (Morawska et al., 2020). Ventilation can be provided either naturally using windows, louvers, vents, or mechanically through an HVAC system. An adequate ventilation rate is necessary for reducing the infection risk in confined spaces such as offices, residential areas, public buildings like malls, restaurants, museums, and public vehicles (Jiang et al., 2009). A high ventilation rate doesn't give assurance of eliminating the viral load, but it can dilute the contaminants that reduce the viral concentration to a great extent. The ventilation rate of 288 m^3/hr/person is suggested by WHO for healthcare settings which can be achieved either by natural or mechanical ventilation (Atkinson et al., 2016). But the dependence of natural ventilation on climatic factors makes it less viable, also this is not possible in offices as most of the glass façade buildings have fixed glazing and hence, it is preferable to install a mechanical system.

HVAC is primarily used for controlling the probability of increasing infections. But if the system is not implemented properly, it can worsen the situation and can itself become the source of transmission or outspread of virus-laden aerosols as already noticed in past SARS epidemic. Generally, the HVAC system recirculates the air as bringing fresh air will consume more energy, so the recirculation can also be a source of an increased rate of infection. According to ASHRAE, REHVA guidelines, recirculation of air should be prohibited in the indoor environment in the current situation especially for centralized conditioning systems (V. & A.C. The Federation of European Heating, 2020). The HVAC system can also deter the situation if low temperature and relative humidity are maintained. Some studies suggested maintaining negative pressure and high relative humidity in intensive care units of hospitals using adequate mechanical ventilation rate as the SARS-CoV-2 virus was detected majorly in ICU (Ge et al., 2020; Jin et al., 2021). The study has shown that high temperature and relative humidity can reduce the infection risk as these conditions can make the virus less active (Ahlawat, Wiedensohler, & Mishra, 2020). Analogous to this, (Antony Aroul Raj, Velraj, & Haghighat, 2020) studied the impact of the dry environment on infection risk indoors considering different climatic conditions. It stated that when surrounding air has lower relative humidity and temperature, naturally or in conditioned space, than the body temperature, the droplet size gets reduced due to combined mass and heat transfer. The reduced droplet cannot be filtered out by the respiratory tract as the mucus membrane also dries up. But in hot and humid conditions, the mucus membrane will be wet which humidifies and dilutes droplet nuclei, thus making the virus less active. The required ventilation rate for diluting the contaminants can be reduced by maintaining a physical distance. If occupancy density reduces to 25% for the first 30 min in the office, ventilation rate drops by more than 4/5, and by 40% in the public bus (Sun & Zhai, 2020). ASHRAE also suggested increasing the outdoor air ventilation by lowering the population

Table 3
Analysis of social distancing measure.

Study references	Main objective	Study design	Key findings	Analysis
(Guo, Qian et al., 2021)	Determine the effectiveness of social distancing	Numerical modeling	20-40% reduction in infection rate by halving the occupancy density. Determined safe distance of 1.6–3 m and transmission distance up to 8.2 m.	Maintaining a proper physical distance of up to 3 m reduces the risk of infection and also decreases the required ventilation rate.
(Qureshi et al., 2020)	Effect of early mandated social distancing	Observational study	Execution of social distancing at an early stage can reduce the number of daily new cases and total cases.	Early implementation of community-level actions can control the transmission rate.
(Guo, Qin et al., 2021)	Determined factors influencing social distancing in China	Survey	Women implied social distancing more seriously. Social media turned down psychological distress and influenced to follow social distancing while depression impeded.	Gender-sensitive promotions of social distancing should be done, and social media can be a useful means to influence society and motivate them to follow the norms.
(Cato et al., 2020)	Determined the factors that can reduce the economic cost of social distancing	Economic theory and empirical survey	Altruism, public shaming, and legal enforcement can be optimal solutions for reducing economic costs.	Voluntary actions and legal sanctions by policymakers can help control the infection rate.
(Triberti et al., 2021)	Correlation in personal behavior and social distancing	Online survey	Machiavellianism, narcissism, and psychopathy-like traits negatively correlate with social distancing.	Dark traits of personal can weaker the implementation of social distancing.
(Wang, 2021)	Assessment of cultural and government policies impact on social distancing	Numerical analysis	Government policies have more impact on the effective implementation than the culture of society.	Stringent government policies can play a key role in the success of social distancing.
(Marroquín et al., 2020)	Determined mental health during the lockdown	Online survey	Social distancing resulted in increased cases of depression and generalized anxiety disorders.	Social distancing may have negative mental health impacts.
(Shorfuzzaman et al., 2021)	Monitoring and tracking social distance violations	Experimental	Deep learning based YOLOv3 model monitors and tracks down the individuals breaching the norms with an efficiency of 92–95%.	Big data models can help improve the efficiency of social distancing implementation.
(Ahmed et al., 2021)	Real-time social distancing monitoring	Experimental	YOLO performed the best from faster R-CNN and SSD due to its balanced map score and speed. Also, alarms the crowd if any violation is detected.	Real-time monitoring works well in a crowded place but at the same time can question an individual's privacy.

in buildings. It is also recommended that the system must be run at maximum outside airflow for 2 h before and after the building is occupied (Schoen, 2020).

So, it can be concluded that we have to find a middle ground for appropriate mechanical ventilation rate where high temperature and relative humidity can be maintained without negotiating with thermal comfort.

5.2.2. Air purifiers

Air purifiers can be a pathway to enhance IAQ as they can inactivate the germicides as well as remove the pollutants with high efficiency. Air purifiers can capture a substantial amount of airborne dust particles and airborne allergens (Sublett, 2011). For instance, experimental studies conducted by (Park, Park, & Seo, 2020; Yoda et al., 2020) under everyday life conditions stated that the air purifiers were effective in reducing indoor PM concentration depending on the user location and the subject characteristics. The study done by (Chen et al., 2010; Zhang et al., 2019) signified that the usage of air purifiers limited the exposure of aerosols and droplets on healthcare workers in dental clinics significantly. Moreover, air purifiers can limit the exposure of the airborne virus to ones living with SARS-CoV-2 infected patients, or suspected cases being quarantined at home, thus reducing the risk of household contagion (Zhao, Liu, & Chen, 2020).

Air purifiers with disinfection capability can be marked as more effective filter than the normal ones to fight the deadly virus (Liu et al., 2017). Although the installation cost of these filters would be high and will comparatively use more energy, but looking towards the current scenario, cost and energy can be considered as a secondary thought and of less concern. Many commercial air purifiers having high efficiency to approximately 99% to remove the pollutants present in the surroundings, are available these days giving back fresh and pollutant-free air and thus improving IAQ. Some of the filters useful for improving IAQ are discussed in the next section.

a Activated carbon

The presence of harmful VOCs in households can cause serious health disorders. For improvement of IAQ, carbon-based filters are being implemented for several years and have proved their efficiency in adsorbing NO_2 and VOCs. Activated carbons are characterized as amorphous carbonaceous materials owing to a large surface area and porosity. Activated carbon can be obtained from chemical and physical activation of any carbonaceous precursor. These are cost-efficient adsorbents and have chemical, thermal, and mechanical stability (Molina-Sabio & Rodríguez-Reinoso, 2004). Carbon filters can be generated from shells of coconut, almond, and pecan, and in the form of activated charcoal, bamboo charcoal, granular activated carbon, or activated carbon fiber. Based on the carbon base used, pollutants can be removed using different techniques like oxidation, regeneration, catalysis, reverse reactor process. The review of all the carbon-based filters resulted that the bamboo-based activated carbon has the highest adsorption efficiency and the activated carbon fiber has the best effective surface than the others (Mondal & Saha, 2019). Activated carbon can also be obtained from agricultural waste products rather than from fossil fuels (Nowicki, Pietrzak, & Wachowska, 2009). On this note, Bader, Sager, Schneiderwind, and Ouederni (2019) successfully prepared foam and granular activated carbons from olive stone grains collected from olive oil factories through chemical and physical activation for adsorbing NO_2. Results from the adsorption tests indicated higher adsorption capacity of NO_2 by CO_2-activated carbon than KOH-activated carbon thus inferring that meso-microporous carbon activated with a strongly basic group is best suitable for adsorbing NO_2. However, activated carbons cannot completely remove contaminants as it is difficult to reach equilibrium in the adsorption process.

b HEPA (High-Efficiency Particulate Air) Filters

HEPA filters have been in the market for a decade and are considered valuable tool in protecting personal and equipment over the years. HEPA filters are standardized as the filters that must be able to remove particles greater than or equal to 0.3 μm by 99.97% efficiency. These are made up of borosilicate microfibers and laid down in form of pleated sheets (Dey, Choudhary, & Ghosh, 2017). In this, particles are physically captured by forcing air through the HEPA filter using four key mechanisms namely diffusion, interception, inertial impaction, and sieving. The smallest particles are filtered by diffusion and larger ones are more effectively removed by inertial impaction, interception, and sieving mechanism (Yang, 2012). HEPA can remove the aerosols of size range 0.25–1 μm with an efficiency of 95% and approximately 100% for particles greater than 2.5 μm. HEPA filters have a good CADR (median $361 m^3/h$) and consume low electric power per CADR ($0.15 W/m^3/h$) (Zhao et al., 2020). Liao, Ye, Pillarisetti, and Clasen (2019) analyzed the reduction in air pollution exposure by indoor air filter using CONTAM software for the simulations inferring that the all-day use of HEPA filters can reduce the $PM_{2.5}$ personal exposure by 31–72% for smoker-absent scenarios, 38–78% for smoker-present scenarios and 8–37% reduction in the mortality rate linked to IAP.

HEPA filters lack self-cleaning or disinfecting properties, resulting in the possibility of transmission of activated pathogens through the air during disposal or replacement of filter (Miaskiewicz-Peska & Lebkowska, 2012). An experimental study examining the efficiency of HEPA purifiers resulted in the fact that particles having 200−250 nm size range were least efficiently removed though this size range has the highest concentration in the ambient air (Lowther et al., 2020). The outcome concluded that the ambient air particles can be removed efficiently and at a similar rate or greater than the Association of home appliance manufacturers' standard particle size, but HEPA air purifiers are not beneficial for removing particles of size 200−250 nm range.

c Germicidal UV radiation

Ultraviolet radiation is one of the best methods for killing viable microorganisms be it bacteria, fungus, or virus as these radiations can directly damage its DNA. UV-C band having wavelength 200−280 nm is considered as the best suitable band for germicidal effect than UV-A and UV-B band. Three times higher radiation dose is required for the inactivation of bacterial spores than for polio and rotaviruses (Chang et al., 1985). Kierat et al. designed a sterilizer for deactivating the pathogens present on the face masks or any surface using the UV germicidal disinfection (UVGI) method (Kierat et al., 2020).According to the chamber design, a mask can be sterilized on average within 15 min giving a radiation dose of $1 J/cm^2$ three times without destroying the filtration properties. But non-transparent stiffening on the facemask was observed which inhibited the penetration of radiation to the next layers. One approach to solve this problem involves the use of an additional sterilization method. Based on the solution suggested, a study involved iodine use along with UV radiation for bacterial and fungal spore inactivation on AHU, as many spores residing on the filters of AHU can form colonies (Nakpan, Yermakov, Indugula, Reponen, & Grinshpun, 2019). Out of the three interventions, simultaneous application UV + Iodine, two sequential applications, UV followed by iodine (UV, Iodine) and Iodine followed by UV (Iodine, UV); (UV, Iodine) was considered the best method for killing the germicides as UV effectively damaged the coating layers of bacteria/fungus and iodine efficiently penetrated for complete DNA damage, thus inactivating bacteria. Flat filters were better than deep-bed filters as the type of filter and combined treatment implemented significantly impacts the inactivation of spores.

d Ionization air purifier

Ionization air purifiers are competent to bring down the concentration of contaminants, odors, airborne pathogens, and VOCs present in indoor air. Ionizers emit negatively charged ions using high dc voltage through corona discharge. The airborne particles are then electrically charged by emitted ions, which either repel, agglomerate or deposit on the surfaces by gravitation or static electrification, thereby purifying the air (Grabarczyk, 2001).

Ionic air purifiers can be either stationary or wearable devices. The study examining wearable ionizers (Grinshpun et al., 2001) discovered 80% removal efficiency of particles after 30 min and 100% after 1.5 h in a 2 m^3 chamber. Stationary ionic air purifiers in a 2.6 m^3 chamber demonstrated 100% removal efficiency of PM having a size between 0.3 and 3.0 µm within 10−12 min (Grinshpun et al., 2005). One of the studies (Shiue, Hu, & Tu, 2011) quantifying the relative impact of air mixing, distance, and height on removal efficiency of ionizer showed that air mixing enhances removal efficiency up to 90% for the particles having a size less than 0.1 µm and more than 0.5 µm and decreases up to 65–90% for particles of size 0.2–0.4 µm. The particle removal efficiency decreases as the horizontal distance increases and is maximum at a height above 60 cm. But the higher ionization rate can also charge the surfaces and can create an adverse impact on human health. Accordingly, a double-blind, crossover study (Dong et al., 2019) examining the effect of ionization air purifiers on the cardio-respiratory health of students aged 11–14 in a school showed that IAQ improved to a great extent but the high levels of negative air ions can harm cardiac autonomic function. Collectively, the results suggest, implementing unipolar ionic air purifiers in confined spaces having a high surface-to-volume ratio can efficiently reduce aerosol exposure.

e PCO (Photo-Catalytic Oxidation)

PCO is one of the promising energy-efficient air purification techniques that break down a wide range of pollutants into non-toxic by-products like CO_2 and H_2O. PCO owes properties like combined treatment of diverse pollutant mixture, easy operation and maintenance, and complete reaction, which can improve IAQ (Zhao & Yang, 2003). Photocatalysts used for oxidation can be pure or doped metal oxide semiconductors like TiO_2, ZnO, CdS, etc (Hoffmann, Martin, Choi, & Bahnemann, 1995). Among all, titanium dioxide (TiO_2) is the most widely used material owing to its high photocatalytic activity, non-toxicity, stability, and relatively low price. TiO_2 film has higher photocatalytic activity than commercial TiO_2 powder (Huang et al., 1999). Porous silica can also be used to support TiO_2, mainly for indoor air purification, so that the intermediates formed during the reaction can be adsorbed and are eliminated (Obuchi, Sakamoto, Nakano, & Shiraishi, 1999). UV lights with a wavelength of 300−370 nm are used as a light source, as they possess a dramatic effect on the degradation of reactants. The rate of reaction also depends on the configuration of reactors. Reactor having large volume and low-pressure drop is highly recommended. There are three reactor designs namely, honeycomb monolith reactor, fluidized bed reactor, and annular reactor. The Honeycomb monolith reactor is used for automobile exhaust emission control and NO_x reduction in power plant gases. It poses a low-pressure drop and a high surface area to volume ratio. The fluidized bed reactor can treat high gas feed rates and low-pressure drops. They can make efficient contact with UV photons, solid catalysts, and gaseous reactants. Two concentric cylinders forming an annular region by a certain gap makes an annular reactor. They exhibit high gas flow velocity because the cross-sectional area of the cylinder is small. The reaction rate of PCO depends on the efficiency of the reaction which is highly influenced by light intensity, contaminant concentration, oxygen concentration, humidity, and flow rate (Zhao & Yang, 2003). VUV-PCO consisting of PCO unit, nanoporous TiO_2 film, and an ozone removal unit having Mn-Fe catalyst and a radial fan to remove the TVOC concentration in a sealed room was constructed by (Xu, Zheng, & Zhang, 2018) which on operating resulted that VUV-PCO works efficiently in removing total VOCs mainly formaldehyde, toluene, and ketones. The VUV-PCO air purifier can remove benzene homologs with high efficiency. Further, it also reduces the concentration of ozone which is produced as a by-product and itself regenerates Mn-Fe catalyst up to a significant and permissible level.

f Recent innovations

Some of the recent technologies include biomaterials like soybean which are cost-effective and biodegradable. SPI is the best protein of all three forms derived from soybean due to its high protein content (90%) and its low cost (Roy, Mishra, Jain, & Solanki, 2018). Due to dipole attractions and electrostatic force of attraction, SPI can attract PM particles. SPI combines with Bacterial Cellulose (BC) synthesized during fermentation of gluconacetobacterxylinus possessing a 3D nano-network that helps to filter PM particles physically. Removal efficiency for $PM_{2.5}$ and PM_{10} can be in the range of 99.4% and 99.95% respectively by using SPI and BC in an appropriate ratio.

Another recent filter is the SOP filter, having the potential to filter, inactivate aerosolized viruses, and self-disinfect (Versoza, Heo, Ko, Kim, & Park, 2020). SOP filters can be implemented in face masks and HVAC systems to limit the transmission of airborne and aerosolized viruses. SOP filters are highly enriched oxygen-generating neutralizing compounds, which convert the air pollutants into oxygen. Hydrogen peroxide is one of the by-products of SOP filters which can disable or kill bacteria and viruses due to its instability.

Liu et al. (2015) researched polyacrylonitrile filters composed of nano-polymer material working on the principle of particle adhesion for curbing $PM_{2.5}$ pollutants. The filter being translucent can be installed on the windows as it is the part of the house that remains unutilized technically. Moreover, it allows natural light to enter the room with additional benefits of good optical transparency, lightweight, low resistance to airflow, and high filtering efficiency. More than 95% efficiency can be achieved for $PM_{2.5}$ filtration varying according to the surface chemistry of production of the polymer filter as well as the transparency to be achieved.

The analysis done for all the filtration techniques depicting their specifications, field of application, and the key findings from the reviewed articles are represented in Table 4. It is observed that activated carbon is the conventional method used for purification and it works on the principle of adsorption. HEPA filters are the most common filters used as they promise to remove $PM_{2.5}$ pollutants with a percentage of 99.97% but are expensive. UV filters can kill the germicidal pollutants and can find their application in residential sectors, but these filters are to be coupled with some other pre-filter for the removal of dirt or larger size particles. In current times, UV is in high demand as it has the capability of self-disinfecting and can kill the virus from its DNA. The latest emerging filter is PCO using TiO_2 as the oxidizing agent, efficient in removing every type of pollutant but it releases ozone as a by-product. Recent filter technologies like biodegradable SPI, having $PM_{2.5}$ absorbing efficiency of 92.3%, transparent PAN filters, SOP owning properties like self-disinfection, and inactivating aerosolized viruses; are also making their space in the market, thus providing IAQ.

6. Discussion and hypothesis

COVID-19 pandemic has made unprecedented impacts not only on health but also on the lifestyle, economy, and environment. This pandemic came up with certain questions such as its origin, affecting parameters and remedies to cure this situation, and prevention methods for the future as it is neither the first of its kind nor the last. The whole scientific community is engaged in finding the answers to these questions. Alongside, temperature and humidity, air quality is one such parameter that correlates with both COVID-19 and occupant health in indoor environment.

In ambient air, majorly $PM_{2.5}$ and NO_X were found to exacerbate the exposure to infection as COVID-19 is considered airborne by various studies and experiments (Ferguson et al., 2020; Wang & Li, 2021). These parameters not only worsen the situation in the outdoor environment,

Table 4
Analysis of air purifiers.

Filter types	Specifications	Applications	Key findings	References
Activated carbon	Obtained from carbonaceous materials, have a large surface area and porosity.	Find its application in adsorbing NO_2 and VOCs.	Cost friendly, possess good chemical, thermal and mechanical stability, cannot completely remove contaminants.	(Molina-Sabio & Rodríguez-Reinoso, 2004; Mondal & Saha, 2019; Nowicki et al., 2009)
HEPA filter	Removes up to 99.97% of particles that pass through.	Used worldwide in cleaning medical rooms and are placed in AHU for filtration of dust.	Costly, very efficient, Regular filter replacements, cannot remove particles size 200−300 nm, require pre-filters.	(Bolashikov & Melikov, 2007; Dey et al., 2017; Vijayan et al., 2015; Yang, 2012)
PCO	Uses metal-oxide semiconductors having high photocatalytic activity.	For the combined treatment of diverse pollutants	Complete reaction, ease of operation and maintenance, release ozone as a by-product	(Bolashikov & Melikov, 2007; Destaillats et al., 2012; Xu et al., 2018; Zhao & Yang, 2003)
Germicidal UV	Uses UV-C band wavelength radiation.	Widely used in hospitals for disinfecting surfaces.	Directly damages DNA of pathogens, releases ozone gas, require pre-filters	(Chang et al., 1985; Kierat et al., 2020; Nakpan et al., 2019; Wielick et al., 2021)
Ionization filter	Use high dc voltage through corona discharge	In industries and as portable purifiers in residential buildings	Low energy costs, reduced formation of harmful emissions, potential health benefits, excessive electrostatic discharge charges objects, O_3 emissions	(Dong et al., 2019; Grabarczyk, 2001; Shiue et al., 2011)

but also indoors as household air pollution is found to be 4–5 times more than outdoors and people spend most of their time in confined spaces. To alert people about the prevailing conditions of air quality, AQI is one of the important parameters that help society procure self-care decisions of stepping out. Different prediction models, numerical and statistical methodologies are used for accessing AQI across the globe. In the era of communication and advance technology, IoT and hybrid models have taken place in the market of forecasting owing to their precision and accuracy. The increasing AQI reveals escalating pollutant concentration which indirectly intensifies the prevailing pandemic (Barcelo, 2020). The pollutants increase in confined spaces, attributable to socio-cultural activities besides the temperature and relative humidity of conditioned space and prevailing climatic conditions. Moreover, the indoor environment can be degraded if proper ventilation is not provided in the buildings, urging for the sustainable development of the society by exploring the control methodologies for improving the air quality and eyeing on the safety of occupant's health considering this scenario.

The improvement methodologies discussed in this review paper are categorized into non-pharmaceutical measures and engineering controls. The detailed analysis of all the improvement techniques consisting of the characteristics of the applications namely facemasks, lockdown, social distancing, ventilation, and air purifiers, their advantages and disadvantages is represented in Table 5.

The non-pharmaceutical measures include using facemasks, following lockdown regulations, and maintaining the social distance between the occupants in indoor spaces. These measures have helped enormously in dropping down the peak of infected cases. Facemasks differing in materials are used extensively at workplaces, hospitals, and in residential, which may decrease the exposure risk to SARS-CoV-2, but its prolonged usage can cause risk to sensitive groups and those engaged in workouts. The excessive use of mask restricts the airflow, creating a high concentration of CO_2 in the body resulting in acidic nature of blood which causes hypercapnia and hypoxia that can be lethal. Moreover, it stipulates a fictitious feeling of protection paying no heed to much better safety measures like social distancing, hand sanitization, or use of face shields. The face shield can be an alternative to facemasks which can maintain CO_2 and O_2 exchange and can equally protect from exposure to the virus. Simulation results (Lindsley, Noti, Blachere, Szalajda, & Beezhold, 2014), showed 96% reduction in virus exposure as compared with facemask and even social distancing could decrease exposure by 92%. Moreover, it can be sanitized and be reused leading to environmental benefits. Also, one-time use and throw masks create medical waste which is harmful from an environmental perspective (Si, Shen, Liu, & Wu, 2021). So, more trials and studies of using face shields can help in better understanding its adaptation.

The lockdown imposed by the government of the countries, highly affected by the pandemic has twisted the concentration of the pollutants to a great extent at the early stages of the first wave of the pandemic, reducing pollutant concentration in the regions by 30–50%. But this measure did not provide a long-term solution due to its impact on the economy (Rahman et al., 2020).

Proper social distancing at an early stage can play a pivotal role in

Table 5
Analysis of the IAQ improvement techniques.

Applications	Characteristics	Advantages	Disadvantages	References
Face masks	Personal protective equipment helps prevent transmission from the infected droplets.	Cost-friendly, seals face properly, filter out the microparticles effectively.	Causes irritation in the eyes, hampers volume of speech, prolonged usage can cause hypercapnia and hypoxia in sensitive groups.	(Abboah-Offei et al., 2021; Rader et al., 2021; Gondim, 2021; Li et al., 2020; Ahmad et al., 2020; Scheid et al., 2020)
Lockdown	A particular country or a city undergoes shutdown and stays at home.	Efficient reduction in infection rates; improves air quality as pollutants get diluted and reduced.	Travel issues and can cause an economic recession if implemented for a long duration.	(Latif et al., 2021; Kumari & Toshniwal, 2020; Mahato et al., 2020)
Social distancing	Maintaining a physical distance of 1–3 m from other individuals.	Helps in delaying the peak of disease, reduces the required ventilation rate in confined space, better compared to facemasks for sensitive groups in indoor spaces.	Adversely affects mental health, conflicts with ethical and religious sentiments, monitoring violates an individual's privacy.	(Sun & Zhai, 2020; Qureshi et al., 2020; Guo, Qin et al., 2021; Cato et al., 2020; Marroquín et al., 2020)
Ventilation	Inside-outside air exchange for diluting contaminants in confined spaces.	Provide required ventilation rate, thermal comfort, and maintains the health of occupants.	Extracting 100% fresh consumes more energy, lacks self-disinfecting capability	(Ge et al., 2020; Megahed & Ghoneim, 2020b; Morawska et al., 2020; Schoen, 2020)
Air purifiers	Filters the contaminants from indoor spaces.	Reduces the risk of household contagion, some can filter PM and others can kill the pathogens.	High installation cost, high energy consumption, only cleans the air that passes through it.	(Chang et al., 1985; Chen et al., 2010; Dey et al., 2017; Grabarczyk, 2001; Mondal & Saha, 2019; Roy et al., 2018; Shiue et al., 2011; Yang, 2012)

reducing the frequency of transmission. Additionally, it can help in delaying the peak of disease, thereby reducing the burden on the health care system and providing more time for implementation of countermeasures. It can also cause some negative impacts on the economy and individual freedom due to quarantine, isolation, travel restrictions, and border control. Contact tracing or real-time monitoring also violates people's privacy and can conflict with ethical and religious principles due to the cancellation of mass gatherings. Although social distancing can cause some negative impacts, they play a crucial role in reducing the severity of a pandemic, especially in indoor spaces.

Engineering control strategies include providing proper ventilation rate indoors and adopting cleansing measures or technologies for removing both the pollutants and pathogens from the confined areas, stemming healthy IAQ giving rise to the sustainability of cities and society. Passive designs are being approached for prevention against air pollution and disease control. However, these should be complemented with outdoor ventilation and air cleaners (Leng, Wang, & Liu, 2020). The use of air conditioning systems in pandemic has been a controversial topic as some suggested, its usage can exacerbate the situation while others recommended using an HVAC system for diluting the contaminants in indoor spaces. But the solution lies in its optimal designing and usage method. Recirculation of air in the HVAC system can be the source of infection which can be solved either by extracting 100% fresh air by using a mechanically ventilated heat recovery system or by using self-disinfecting filters like UVGI in the system itself.

Air cleaners or air purifiers are one of the most common improvement technologies suggested in this pandemic. Air purifiers are available in varieties based on the filter medium used. The most appropriate filters suggested for the current scenario are HEPA filters, ionizers, and UVGI filters. These filters can be portable or can be combined with the ventilation system. The portable filters can remove contaminants from the surroundings only. So, the optimization of the arrangement of people and placing the air purifiers accordingly in confined space can be beneficial.

Overall, the pandemic urges us to adopt a new, better, and sustainable lifestyle for the betterment of ourselves, humankind, and nature. The change in the style of working, by avoiding crowding at offices and work from home, providing more space for residencies than commercial buildings, and paving the way towards smart cities is the urgent need (Beria & Lunkar, 2021).

7. Conclusion and remarks

The astonishing speed of contagion of peculiar global pandemic COVID-19 made scientists dissect the factors aiding the exacerbation of the pandemic and assess all the possible preventive measures to combat the disease. This review paper scrutinized the relativity of air quality and COVID-19 and IAQ improvising techniques. The key inferences from the reviewed articles and recommendations for the development of sustainable society and environment are briefed underneath:

- AQI has been of great advantage for the public as it makes them aware of the pollution level in their region and acts accordingly. So far, AQI is forecasted considering 5 parameters, PM_{10}, NO_2, O_3, CO, and SO_2; but the small number of toxic compounds in the air can also probably result in critical issues. Consequently, it is desirable to consider the toxic compounds while forecasting AQI.
- The positive connection between air pollutants ($PM_{2.5}$ and NO_2) and COVID-19 contagion urges to level the air quality index. Employing preventive measures to mitigate air pollution can kill two birds with a stone, reducing exposure rate as COVID-19 is airborne and fight against climate change. Thus, accomplishing two of the sustainable development goals.
- The health of occupants in confined spaces should be of utmost priority. The reviewed articles inferred that IAQ can be enhanced using non-pharmaceutical measures and engineering controls, but both have their pros and cons. The best way is to find a middle ground for all the techniques that can help reduce infection risk.
- It can be concluded from the review that facemasks are beneficial in outdoor spaces or crowded places. But its prolonged usage indoors can cause hypercapnia and hypoxia, especially in sensitive groups. Face shields are one of the alternatives that can be focused, as they allow better airflow and are reusable, thus decreasing medical waste.
- Lockdown was widely implemented across the globe to slump the peak of rising cases. Also, it benefited the environment in its early phase, but it cannot be considered a potential solution for the long-term due to its adverse impact on the economy.
- Social distancing has been one of the effective non-pharmaceutical measures in indoor areas and can considerably reduce infection risk. Although, social distancing was quite difficult to maintain attributable to low-income households, socio-cultural sentiments, and mental health; Government, IoT, learning-based models, and various social media platforms helped to make this possible. Social distancing can be encouraged by providing incentives and monitoring public places. Moreover, medical robots, unmanned aerial vehicles can be utilized to reduce human presence in essential tasks.
- From the viewpoint of engineering controls, ventilation can help dilute contaminants and reduce infection risk. As suggested, air should not be recirculated, and using 100% fresh air can consume more energy . It is now time to move towards smart city design models where hygiene ventilation can be done using 100% fresh air with efficient energy consumption for sustainability.
- Air purifying filters having self-disinfecting capabilities have been proved beneficial to bring down the transmission of potential airborne or aerosolized COVID-19. UV germicidal filter, ionization filters, PCO, or newly emerging SOP can be of good help for the inactivation of the virus in residential and public buildings. But they are not able to protect the people from direct and indirect exposure.
- There is an urgent need to modify the HVAC system used in indoor spaces by integrating mechanical ventilation with air purifying techniques like UVGI to protect occupants from future bio-attacks like the one we are facing.

Overall, it can be seen that all the solutions are condition-specific and implementing only one or two of these measures may not help in limiting the COVID-19 cases. However, approaching these techniques together or integrating them can account for a feasible solution that may help mitigate the present condition and prevent an alike situation in the future. As the world is trying to come back at its normal pace, it is recommended to reduce the occupancy density and adopt smart building designs for a sustainable future.

Disclosure

The work reported in this article forms a part of the Post Graduation work of the first author being carried out at CSIR-CBRI, Roorkee. The article is published with the permission of the Director, CSIR-Central Building Research Institute, Roorkee.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abboah-Offei, M., Salifu, Y., Adewale, B., Bayuo, J., Ofosu-Poku, R., & Opare-Lokko, E. B. A. (2021). A rapid review of the use of face mask in preventing the spread of COVID-19. *International Journal of Nursing Studies Advances, 3*, Article 100013. https://doi.org/10.1016/j.ijnsa.2020.100013

Ahlawat, A., Wiedensohler, A., & Mishra, S. K. (2020). An overview on the role of relative humidity in airborne transmission of sars-cov-2 in indoor environments. *Aerosol and Air Quality Research*. https://doi.org/10.4209/aaqr.2020.06.0302

Ahmad, M. D. F., Wahab, S., Ali Ahmad, F., Intakhab Alam, M., Ather, H., Siddiqua, A., et al. (2020). A novel perspective approach to explore pros and cons of face mask in prevention the spread of SARS-CoV-2 and other pathogens. *Journal of the Saudi Pharmaceutical Society*. https://doi.org/10.1016/j.jsps.2020.12.014

Ahmed, I., Ahmad, M., Rodrigues, J. J. P. C., Jeon, G., & Din, S. (2021). A deep learning-based social distance monitoring framework for COVID-19. *Sustainable Cities and Society, 65*, Article 102571. https://doi.org/10.1016/j.scs.2020.102571

Amoatey, P., Omidvarborna, H., Baawain, M. S., & Al-Mamun, A. (2020). Impact of building ventilation systems and habitual indoor incense burning on SARS-CoV-2 virus transmissions in Middle Eastern countries. *The Science of the Total Environment, 733*, Article 139356. https://doi.org/10.1016/j.scitotenv.2020.139356

Antony Aroul Raj, V., Velraj, R., & Haghighat, F. (2020). The contribution of dry indoor built environment on the spread of Coronavirus: Data from various Indian states. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2020.102371

Atkinson, J., Chartier, Y., Lúcia Pessoa-Silva, C., Jensen, P., Li, Y., Seto, W.-H., et al. (2016). *Natural ventilation for infection control in health-care settings*. World Health Organization.

Babcock, L. R., & Nagda, N. L. (1972). Indices of air quality. In W. A. Thomas (Ed.), *Indicators of environmental quality* (pp. 183–197). Boston, MA: Springer US.

Bader, N., Sager, U., Schneiderwind, U., & Ouederni, A. (2019). Foam and granular olive stone-derived activated carbons for NO_2 filtration from indoor air. *Journal of Environmental Chemical Engineering, 7*, Article 103005. https://doi.org/10.1016/j.jece.2019.103005

Barcelo, D. (2020). An environmental and health perspective for COVID-19 outbreak: Meteorology and air quality influence, sewage epidemiology indicator, hospitals disinfection, drug therapies and recommendations. *Journal of Environmental Chemical Engineering*. https://doi.org/10.1016/j.jece.2020.104006

Bashir, M. F., Ma, B., Bilal, Komal, B., Bashir, M. A., Tan, D., et al. (2020). Correlation between climate indicators and COVID-19 pandemic in New York, USA. *The Science of the Total Environment, 728*, Article 138835. https://doi.org/10.1016/j.scitotenv.2020.138835

Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z. J., Weinmayr, G., Hoffmann, B., et al. (2014). Effects of long-term exposure to air pollution on natural-cause mortality: An analysis of 22 European cohorts within the multicentre ESCAPE project. *Lancet*. https://doi.org/10.1016/S0140-6736(13)62158-3

Beig, G., Ghude, S. D., & Deshpande, A. (2010). *Scientific evaluation of air quality standards and defining air quality index for India* (pp. 1–31). Pune: Indian Institute of Tropical Meteorology.

Beria, P., & Lunkar, V. (2021). Presence and mobility of the population during the first wave of Covid-19 outbreak and lockdown in Italy. *Sustainable Cities and Society, 65*, 102616. https://doi.org/10.1016/j.scs.2020.102616

Berman, J. D., & Ebisu, K. (2020). Changes in U.S. air pollution during the COVID-19 pandemic. *Science of the Total Environment, 739*, Article 139864. https://doi.org/10.1016/j.scitotenv.2020.139864

Bishoi, B., Prakash, A., & Jain, V. K. (2009). A comparative study of air quality index based on factor analysis and US-EPA methods for an urban environment. *Aerosol and Air Quality Research, 9*, 1–17. https://doi.org/10.4209/aaqr.2008.02.0007

Boccardo, L. (2021). *Contact Lens and Anterior Eye Self-reported symptoms of mask-associated dry eye: A survey study of 3, 605 people, Contact Lens and Anterior Eye* (pp. 27–29). https://doi.org/10.1016/j.clae.2021.01.003

Bolashikov, Z. D., & Melikov, A. K. (2007). Methods for indoor air disinfection and purification from airborne pathogens for application in HVAC systems. In *IAQVEC 2007 Proceedings - 6th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings: Sustainable Built Environment, 2* pp. 565–572).

Borro, M., Di Girolamo, P., Gentile, G., De Luca, O., Preissner, R., Marcolongo, A., et al. (2020). Evidence-based considerations exploring relations between sars-cov-2 pandemic and air pollution: Involvement of pm2.5-mediated up-regulation of the viral receptor ace-2. *International Journal of Environmental Research and Public Health, 17*, 1–13. https://doi.org/10.3390/ijerph17155573

C. Control Center of Disease. (2020). *Strategies for optimizing the supply of face masks*. Control Center of Disease.

Cannistraro, G., & Ponterio, L. (2009). Analysis of air quality in the outdoor environment of the city of Messina by an application of the pollution index method, international journal of civil, enviromental, structural. *Construction and Architectural Engineering*.

Cao, W., Fang, Z., Hou, G., Han, M., Xu, X., Dong, J., et al. (2020). The psychological impact of the COVID-19 epidemic on college students in China. *Psychiatry Research*. https://doi.org/10.1016/j.psychres.2020.112934

Cato, S., Iida, T., Ishida, K., Ito, A., McElwain, K. M., & Shoji, M. (2020). Social distancing as a public good under the COVID-19 pandemic. *Public Health, 188*, 51–53. https://doi.org/10.1016/j.puhe.2020.08.005

Cdc.gov/coronavirus. (2020). *What you should know about COVID-19 to protect yourself and others*. Cdc.

Centers for Disease Control and Prevention. (2020). *How to protect yourself and others*. Cdc.

Chang, J. C. H., Ossoff, S. F., Lobe, D. C., Dorfman, M. H., Dumais, C. M., Qualls, R. G., et al. (1985). UV inactivation of pathogenic and indicator microorganisms. *Applied and Environmental Microbiology*. https://doi.org/10.1128/aem.49.6.1361-1365.1985

(Sean) Chang, H., Capuozzo, B., Okumus, B., & Cho, M. (2021). Why cleaning the invisible in restaurants is important during COVID-19: A case study of indoor air quality of an open-kitchen restaurant. *International Journal of Hospitality Management, 94*, 102854. https://doi.org/10.1016/j.ijhm.2020.102854

Chao, C. Y., Wong, K. K., & Cheng, E. C. (2002). Size distribution of indoor particulate matter in 60 homes in Hong Kong. *Indoor and Built Environment*. https://doi.org/10.1159/000063489

Chelani, A. B., Chalapati Rao, C. V., Phadke, K. M., & Hasan, M. Z. (2002). Formation of an air quality index in India. *The International Journal of Environmental Studies, 59*, 331–342. https://doi.org/10.1080/00207230211300

Chen, C., Zhao, B., Cui, W., Dong, L., An, N., & Ouyang, X. (2010). The effectiveness of an air cleaner in controlling droplet/aerosol particle dispersion emitted from a patient's mouth in the indoor environment of dental clinics. *Journal of the Royal Society, Interface, 7*, 1105–1118. https://doi.org/10.1098/rsif.2009.0516

Cheng, W. L., Chen, Y. S., Zhang, J., Lyons, T. J., Pai, J. L., & Chang, S. H. (2007). Comparison of the revised air quality index with the PSI and AQI indices. *The Science of the Total Environment, 382*, 191–198. https://doi.org/10.1016/j.scitotenv.2007.04.036

Coker, E. S., Cavalli, L., Fabrizi, E., Guastella, G., Lippo, E., Parisi, M. L., et al. (2020). The effects of air pollution on COVID-19 related mortality in Northern Italy. *Environmental & Resource Economics, 76*, 611–634. https://doi.org/10.1007/s10640-020-00486-1

Cole, M. A., Ozgen, C., & Strobl, E. (2020). *Air pollution exposure and COVID-19. Discussion paper series. IZA DP No. 13367* (p. 31).

CPCB. (2014). *National air quality index*. Central Pollution Control Board (CPCB).

Das, A., Ghosh, S., Das, K., Basu, T., Dutta, I., & Das, M. (2021). Living environment matters: Unravelling the spatial clustering of COVID-19 hotspots in Kolkata megacity, India. *Sustainable Cities and Society, 65*, Article 102577. https://doi.org/10.1016/j.scs.2020.102577

Davies, A., Thompson, K. A., Giri, K., Kafatos, G., Walker, J., & Bennett, A. (2013). Testing the efficacy of homemade masks: would they protect in an influenza pandemic? *Disaster Medicine and Public Health Preparedness*. https://doi.org/10.1017/dmp.2013.43

Destaillats, H., Sleiman, M., Sullivan, D. P., Jacquiod, C., Sablayrolles, J., & Molins, L. (2012). Key parameters influencing the performance of photocatalytic oxidation (PCO) air purification under realistic indoor conditions. *Applied Catalysis B, Environmental, 128*, 159–170. https://doi.org/10.1016/j.apcatb.2012.03.014

Dey, E., Choudhary, U., & Ghosh, S. K. (2017). *A review on surface modification of textile fibre by High Efficiency Particulate Air (HEPA) Filtration process* (pp. 190–193).

Diaz Milian, R., Foley, E., Bauer, M., Martinez-Velez, A., & Castresana, M. R. (2019). Expiratory central airway collapse in adults: Anesthetic implications (Part 1). *Journal of Cardiothoracic and Vascular Anesthesia*. https://doi.org/10.1053/j.jvca.2018.08.205

Dong, W., Liu, S., Chu, M., Zhao, B., Yang, D., Chen, C., et al. (2019). Different cardiorespiratory effects of indoor air pollution intervention with ionization air purifier: Findings from a randomized, double-blind crossover study among school children in Beijing. *Environmental Pollution, 254*, 113054. https://doi.org/10.1016/j.envpol.2019.113054

ECDC. (2020). *Considerations relating to social distancing measures in response to the COVID-19 epidemic*. European Centre for Disease Prevention and Control.

Esposito, S., & Principi, N. (2020). To mask or not to mask children to overcome COVID-19. *European Journal of Pediatrics*. https://doi.org/10.1007/s00431-020-03674-9

Ferguson, L., Taylor, J., Davies, M., Shrubsole, C., Symonds, P., & Dimitroulopoulou, S. (2020). Exposure to indoor air pollution across socio-economic groups in high-income countries: A scoping review of the literature and a modelling methodology. *Environment International, 143*. https://doi.org/10.1016/j.envint.2020.105748

Fu, X., & Zhai, W. (2021). Examining the spatial and temporal relationship between social vulnerability and stay-at-home behaviors in New York City during the COVID-19 pandemic. *Sustainable Cities and Society, 67*.

Ge, X. Y., Pu, Y., Liao, C. H., Huang, W. F., Zeng, Q., Zhou, H., et al. (2020). Evaluation of the exposure risk of SARS-CoV-2 in different hospital environment. *Sustainable Cities and Society, 61*, Article 102413. https://doi.org/10.1016/j.scs.2020.102413

Gondim, J. A. M. (2021). Preventing epidemics by wearing masks: An application to COVID-19, Chaos. *Solitons and Fractals, 143*, Article 110599. https://doi.org/10.1016/j.chaos.2020.110599

Goyal, P., Chan, A. T., & Jaiswal, N. (2006). Statistical models for the prediction of respirable suspended particulate matter in urban cities. *Atmospheric Environment, 40*, 2068–2077. https://doi.org/10.1016/j.atmosenv.2005.11.041

Grabarczyk, Z. (2001). Effectiveness of indoor air cleaning with corona ionizers. *Journal of Electrostatics, 51–52*, 278–283. https://doi.org/10.1016/S0304-3886(01)00058-4

Grinshpun, S. A., Mainelis, G., Reponen, T., Willeke, K., Trunov, M. A., & Adhikary, A. (2001). Effect of wearable IONIZERS on the concentration of respirable airborne particles and microorganisms. *Journal of Aerosol Science*. https://doi.org/10.1016/s0021-8502(21)00157-9

Grinshpun, S. A., Mainelis, G., Trunov, M., Adhikari, A., Reponen, T., & Willeke, K. (2005). Evaluation of ionic air purifiers for reducing aerosol exposure in confined indoor spaces. *Indoor Air, 15*, 235–245. https://doi.org/10.1111/j.1600-0668.2005.00364.x

Guo, Z. D., Wang, Z. Y., Zhang, S. F., Li, X., Li, L., Li, C., et al. (2020). Aerosol and surface distribution of severe acute respiratory syndrome coronavirus 2 in hospital wards, Wuhan, China, 2020. *Emerging Infectious Diseases*. https://doi.org/10.3201/eid2607.200885

Guo, Y., Qian, H., Sun, Z., Cao, J., Liu, F., Luo, X., et al. (2021). Assessing and controlling infection risk with Wells-Riley model and spatial flow impact factor (SFIF). *Sustainable Cities and Society, 67*, 102719. https://doi.org/10.1016/j.scs.2021.102719

Guo, Y., Qin, W., Wang, Z., & Yang, F. (2021). Factors influencing social distancing to prevent the community spread of COVID-19 among Chinese adults. *Preventive Medicine, 143*, 106385. https://doi.org/10.1016/j.ypmed.2020.106385

Heal, M. R., Kumar, P., & Harrison, R. M. (2012). Particles, air quality, policy and health. *Chemical Society Reviews, 41*, 6606–6630. https://doi.org/10.1039/c2cs35076a

Heyder, J. (2004). Deposition of inhaled particles in the human respiratory tract and consequences for regional targeting in respiratory drug delivery. *Proceedings of the American Thoracic Society*. https://doi.org/10.1513/pats.200409-046TA

Hoffmann, M. R., Martin, S. T., Choi, W., & Bahnemann, D. W. (1995). Environmental applications of semiconductor photocatalysis. *Chemical Reviews*. https://doi.org/10.1021/cr00033a004

Hu, M., Roberts, J. D., Azevedo, G. P., & Milner, D. (2021). The role of built and social environmental factors in Covid-19 transmission: A look at America's capital city. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2020.102580

Huang, A., Cao, L., Chen, J., Spiess, F. J., Suib, S. L., Obee, T. N., et al. (1999). Photocatalytic degradation of triethylamine on titanium oxide thin films. *Journal of Catalysis*. https://doi.org/10.1006/jcat.1999.2617

Ikram, M., & Yan, Z. J. (2017). Statistical analysis of the impact of AQI on respiratory disease in Beijing: Application case 2009. *Energy Procedia, 107*, 340–344. https://doi.org/10.1016/j.egypro.2016.12.169

Jiang, Y., Zhao, B., Li, X., Yang, X., Zhang, Z., & Zhang, Y. (2009). Investigating a safe ventilation rate for the prevention of indoor SARS transmission: An attempt based on a simulation approach. *Building Simulation*. https://doi.org/10.1007/s12273-009-9325-7

Jin, T., Li, J., Yang, J., Li, J., Hong, F., Long, H., et al. (2021). SARS-CoV-2 presented in the air of an intensive care unit (ICU). *Sustainable Cities and Society, 65*, 102446. https://doi.org/10.1016/j.scs.2020.102446

Jo, J. H., Jo, B. W., Kim, J. H., & Choi, I. (2020). Implementation of iot-based air quality monitoring system for investigating particulate matter (Pm10) in subway tunnels. *International Journal of Environmental Research and Public Health, 17*, 1–12. https://doi.org/10.3390/ijerph17155429

Khoder, M. I. (2002). Atmospheric conversion of sulfur dioxide to particulate sulfate and nitrogen dioxide to particulate nitrate and gaseous nitric acid in an urban area. *Chemosphere, 49*, 675–684. https://doi.org/10.1016/S0045-6535(02)00391-0

Kierat, W., Augustyn, W., Koper, P., Pawlyta, M., Chrusciel, A., & Wyrwol, B. (2020). The use of UVC irradiation to sterilize filtering face piece masks limiting airborne cross-infection. *International Journal of Environmental Research and Public Health, 17*, 1–14. https://doi.org/10.3390/ijerph17207396

Kumar, A., & Goyal, P. (2011). Forecasting of daily air quality index in Delhi. *The Science of the Total Environment, 409*, 5517–5523. https://doi.org/10.1016/j.scitotenv.2011.08.069

Kumar, A., & Goyal, P. (2013). Forecasting of air quality index in Delhi using neural network based on principal component analysis. *Pure and Applied Geophysics*. https://doi.org/10.1007/s00024-012-0583-4

Kumar, P., Hama, S., Omidvarborna, H., Sharma, A., Sahani, J., Abhijith, K. V., et al. (2020). Temporary reduction in fine particulate matter due to 'anthropogenic emissions switch-off' during COVID-19 lockdown in Indian cities. *Sustainable Cities and Society, 62*, Article 102382. https://doi.org/10.1016/j.scs.2020.102382

Kumari, P., & Toshniwal, D. (2020). Impact of lockdown on air quality over major cities across the globe during COVID-19 pandemic. *Urban Climate, 34*, Article 100719. https://doi.org/10.1016/j.uclim.2020.100719

Kurt, A., & Oktay, A. B. (2010). Forecasting air pollutant indicator levels with geographic models 3 days in advance using neural networks. *Expert Systems with Applications*. https://doi.org/10.1016/j.eswa.2010.05.093

Kyrkilis, G., Chaloulakou, A., & Kassomenos, P. A. (2007). Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: Relation to potential health effects. *Environment International, 33*, 670–676. https://doi.org/10.1016/j.envint.2007.01.010

Lai, A. C. K. (2002). Particle deposition indoors: A review. *Indoor Air*. https://doi.org/10.1046/j.0905-6947.2002.1r159a.x

Latif, M. T., Dominick, D., Hawari, N. S. S. L., Mohtar, A. A. A., & Othman, M. (2021). The concentration of major air pollutants during the movement control order due to the COVID-19 pandemic in the Klang Valley, Malaysia. *Sustainable Cities and Society, 66*, Article 102660. https://doi.org/10.1016/j.scs.2020.102660

Leng, J., Wang, Q., & Liu, K. (2020). Sustainable design of courtyard environment: From the perspectives of airborne diseases control and human health. *Sustainable Cities and Society, 62*, 102405. https://doi.org/10.1016/j.scs.2020.102405

Leung, N. H. L., Chu, D. K. W., Shiu, E. Y. C., Chan, K. H., McDevitt, J. J., Hau, B. J. P., et al. (2020). Respiratory virus shedding in exhaled breath and efficacy of face masks. *Nature Medicine*. https://doi.org/10.1038/s41591-020-0843-2

Li, Y., Liang, M., Gao, L., Ayaz Ahmed, M., Uy, J. P., Cheng, C., et al. (2020). Face masks to prevent transmission of COVID-19: A systematic review and meta-analysis. *American Journal of Infection Control, 000*. https://doi.org/10.1016/j.ajic.2020.12.007

Li, B., Peng, Y., He, H., Wang, M., & Feng, T. (2021). Built environment and early infection of COVID-19 in urban districts: A case study of Huangzhou. *Sustainable Cities and Society, 66*, 1–10. https://doi.org/10.1016/j.scs.2020.102685

Li, L., Zhao, X., Li, Z., & Song, K. (2021). COVID-19: Performance study of microplastic inhalation risk posed by wearing masks. *Journal of Hazardous Materials, 411*, 1–9. https://doi.org/10.1016/j.jhazmat.2020.124955

Liao, J., Ye, W., Pillarisetti, A., & Clasen, T. F. (2019). Modeling the impact of an indoor air filter on air pollution exposure reduction and associated mortality in Urban Delhi household. *International Journal of Environmental Research and Public Health, 16*. https://doi.org/10.3390/ijerph16081391

Lindsley, W. G., Noti, J. D., Blachere, F. M., Szalajda, J. V., & Beezhold, D. H. (2014). Efficacy of face shields against cough aerosol droplets from a cough simulator. *Journal of Occupational and Environmental Hygiene*. https://doi.org/10.1080/15459624.2013.877591

Liu, C., Hsu, P. C., Lee, H. W., Ye, M., Zheng, G., Liu, N., et al. (2015). Transparent air filter for high-efficiency PM 2.5 capture. *Nature Communications*. https://doi.org/10.1038/ncomms7205

Liu, G., Xiao, M., Zhang, X., Gal, C., Chen, X., Liu, L., et al. (2017). A review of air filtration technologies for sustainable and healthy building ventilation. *Sustainable Cities and Society, 32*, 375–396. https://doi.org/10.1016/j.scs.2017.04.011

Liu, Y., Ning, Z., Chen, Y., Guo, M., Liu, Y., Gali, N. K., et al. (2020). Aerodynamic characteristics and RNA concentration of SARS-CoV-2 aerosol in Wuhan hospitals during COVID-19 outbreak. *BioRxiv, 86*. https://doi.org/10.1101/2020.03.08.982637

Lowther, S. D., Deng, W., Fang, Z., Booker, D., Whyatt, D. J., Wild, O., et al. (2020). How efficiently can HEPA purifiers remove priority fine and ultrafine particles from indoor air? *Environment International, 144*. https://doi.org/10.1016/j.envint.2020.106001

Ma, S., Li, S., & Zhang, J. (2020). The spread of COVID-19 in China at its initial stage: A township-level analysis in association with the built environment. *SSRN Electronic Journal, 67*, Article 102752. https://doi.org/10.2139/ssrn.3692537

Mahato, S., Pal, S., & Ghosh, K. G. (2020). Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *The Science of the Total Environment, 730*, 139086. https://doi.org/10.1016/j.scitotenv.2020.139086

Maher, B. A., Ahmed, I. A. M., Karloukovski, V., MacLaren, D. A., Foulds, P. G., Allsop, D., et al. (2016). Magnetite pollution nanoparticles in the human brain. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1605941113

Mandal, T., Gorai, A. K., & Pathak, G. (2012). Development of fuzzy air quality index using soft computing approach. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-011-2412-0

Marroquín, B., Vine, V., & Morgan, R. (2020). Mental health during the COVID-19 pandemic: Effects of stay-at-home policies, social distancing behavior, and social resources. *Psychiatry Research, 293*, Article 113419. https://doi.org/10.1016/j.psychres.2020.113419

Megahed, N. A., & Ghoneim, E. M. (2020a). Antivirus-built environment: Lessons learned from Covid-19 pandemic. *Sustainable Cities and Society, 61*, Article 102350. https://doi.org/10.1016/j.scs.2020.102350

Megahed, N. A., & Ghoneim, E. M. (2020b). Indoor air quality: Rethinking rules of building design strategies in post-pandemic architecture. *Environmental Research*. , Article 110471. https://doi.org/10.1016/j.envres.2020.110471

Miaskiewicz-Peska, E., & Lebkowska, M. (2012). Comparison of aerosol and bioaerosol collection on air filters. *Aerobiologia*. https://doi.org/10.1007/s10453-011-9223-1

Molina-Sabio, M., & Rodríguez-Reinoso, F. (2004). Role of chemical activation in the development of carbon porosity. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. https://doi.org/10.1016/j.colsurfa.2004.04.007

Mondal, S., & Saha, P. (2019). *Removal of VOCs and improvement of indoor air quality using activated carbon air filter removal of VOCs and improvement of indoor air quality using activated carbon air filter senior associate professor*. School of Civil Engineering, KIIT Deemed to be Un. https://doi.org/10.1007/978-981-15-5235-9

Morawska, L., Tang, J. W., Bahnfleth, W., Bluyssen, P. M., Boerstra, A., Buonanno, G., et al. (2020). How can airborne transmission of COVID-19 indoors be minimised? *Environment International, 142*. https://doi.org/10.1016/j.envint.2020.105832

Murena, F. (2004). Measuring air quality over large urban areas: Development and application of an air pollution index at the urban area of Naples. *Atmospheric Environment, 38*, 6195–6202. https://doi.org/10.1016/j.atmosenv.2004.07.023

Nakpan, W., Yermakov, M., Indugula, R., Reponen, T., & Grinshpun, S. A. (2019). Inactivation of bacterial and fungal spores by UV irradiation and gaseous iodine treatment applied to air handling filters. *The Science of the Total Environment, 671*, 59–65. https://doi.org/10.1016/j.scitotenv.2019.03.310

Noorimotlagh, Z., Jaafarzadeh, N., Martínez, S. S., & Mirzaee, S. A. (2021). A systematic review of possible airborne transmission of the COVID-19 virus (SARS-CoV-2) in the indoor air environment. *Environmental Research, 193*, Article 110612. https://doi.org/10.1016/j.envres.2020.110612

Nowicki, P., Pietrzak, R., & Wachowska, H. (2009). Influence of the precursor metamorphism degree on preparation of nitrogen-enriched activated carbons by ammoxidation and chemical activation of coals. *Energy and Fuels*. https://doi.org/10.1021/ef801094c

Obuchi, E., Sakamoto, T., Nakano, K., & Shiraishi, F. (1999). Photocatalytic decomposition of acetaldehyde over TiO_2/SiO_2 catalyst. *Chemical Engineering Science*. https://doi.org/10.1016/S0009-2509(99)00067-6

Ogen, Y. (2020). Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. *The Science of the Total Environment, 726*, Article 138605. https://doi.org/10.1016/j.scitotenv.2020.138605

Ott, W. R., & Hunt, W. F. (1976). A quantitative evaluation of the pollutant standards index. *Journal of the Air Pollution Control Association*. https://doi.org/10.1080/00022470.1976.10470358

Ott, W. R., & Thorn, G. C. (1976). Air pollution index systems in the United States and Canada. *Journal of the Air Pollution Control Association*. https://doi.org/10.1080/00022470.1976.10470272

Park, H., Park, S., & Seo, J. (2020). Evaluation on air purifier's performance in reducing the concentration of fine particulate matter for occupants according to its operation methods. *International Journal of Environmental Research and Public Health, 17*, 1–14. https://doi.org/10.3390/ijerph17155561

Pei, Z., Han, G., Ma, X., Su, H., & Gong, W. (2020). Response of major air pollutants to COVID-19 lockdowns in China. *The Science of the Total Environment, 743*, Article 140879. https://doi.org/10.1016/j.scitotenv.2020.140879

Qureshi, A. I., Suri, M. F. K., Chu, H., Suri, H. K., & Suri, A. K. (2020). Early mandated social distancing is a strong predictor of reduction in peak daily new COVID-19 cases. *Public Health*. https://doi.org/10.1016/j.puhe.2020.10.015

Rader, B., White, L. F., Burns, M. R., Chen, J., Brilliant, J., Cohen, J., et al. (2021). Mask-wearing and control of SARS-CoV-2 transmission in the USA: A cross-sectional study. *The Lancet Digital Health, 7500*, 1–10. https://doi.org/10.1016/s2589-7500(20)30293-4

Rahman, M. A., Zaman, N., Asyhari, A. T., Al-Turjman, F., Alam Bhuiyan, M. Z., & Zolkipli, M. F. (2020). Data-driven dynamic clustering framework for mitigating the adverse economic impact of Covid-19 lockdown practices. *Sustainable Cities and Society, 62*, 102372. https://doi.org/10.1016/j.scs.2020.102372

Rahmani, A. M., & Mirmahaleh, S. Y. H. (2021). Coronavirus disease (COVID-19) prevention and treatment methods and effective parameters: A systematic literature review. *Sustainable Cities and Society, 64*, Article 102568. https://doi.org/10.1016/j.scs.2020.102568

Rodriguez-Morales, A. J., Katterine Bonilla-Aldana, D., Tiwari, R., Sah, R., Rabaan, A. A., & Dhama, K. (2020). Covid-19, an emerging coronavirus infection: Current scenario and recent developments – An overview. *Journal of Pure & Applied Microbiology*. https://doi.org/10.22207/JPAM.14.1.02

Roy, A., Mishra, C., Jain, S., & Solanki, N. (2018). A review of general and modern methods of air purification. *Journal of Thermal Engineering, 5*, 22–28. https://doi.org/10.18186/THERMAL.529054

Saadat, S., Rawtani, D., & Hussain, C. M. (2020). Environmental perspective of COVID-19. *The Science of the Total Environment, 728*, Article 138870. https://doi.org/10.1016/j.scitotenv.2020.138870

Santarpia, J., Rivera, D., Herrera, V., Morwitzer, M. J., Creager, H., Santarpia, G., et al. (2020). Transmission potential of SARS-CoV-2 in viral shedding observed at the university of Nebraska Medical Center. *Scientific Reports*. https://doi.org/10.1101/2020.03.23.20039446

Saxena, P., Agarwal, S., Punn, N. S., Sonbhadra, S. K., Nagabhushan, P., & Soundra Pandian, K. K. (2020). Unleashing the power of disruptive and emerging technologies amid COVID-19: A detailed review. *ArXiv*.

Scerri, M., & Grech, V. (2020). To wear or not to wear? Adherence to face mask use during the COVID-19 and Spanish influenza pandemics. *Early Human Development*. , Article 105253. https://doi.org/10.1016/j.earlhumdev.2020.105253

Scheid, J. L., Lupien, S. P., Ford, G. S., & West, S. L. (2020). Commentary: Physiological and psychological impact of face mask usage during the covid-19 pandemic. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph17186655

Schoen, L. J. (2020). Guidance for building operations during the COVID-19 pandemic. *ASHRAE Journal*.

Serin, S., & Caglar, B. (2020). The effect of different personal protective equipment masks on health care workers' cardiopulmonary resuscitation performance during the Covid-19 pandemic. *The Journal of Emergency Medicine*, 1–7. https://doi.org/10.1016/j.jemermed.2020.11.005

Shenfeld, L. (1970). Ontario's air pollution index and alert system. *Journal of the Air Pollution Control Association*. https://doi.org/10.1080/00022470.1970.10469451

Shiue, A., Hu, S. C., & Tu, M. L. (2011). Particles removal by negative ionic air purifier in cleanroom. *Aerosol and Air Quality Research*. https://doi.org/10.4209/aaqr.2010.06.0048

Shorfuzzaman, M., Hossain, M. S., & Alhamid, M. F. (2021). Towards the sustainable development of smart cities through mass video surveillance: A response to the COVID-19 pandemic. *Sustainable Cities and Society, 64*, Article 102582. https://doi.org/10.1016/j.scs.2020.102582

Si, H., Shen, L., Liu, W., & Wu, G. (2021). Uncovering people's mask-saving intentions and behaviors in the post-COVID-19 period: Evidence from China. *Sustainable Cities and Society, 65*, Article 102626. https://doi.org/10.1016/j.scs.2020.102626

Sicard, P., Lesne, O., Alexandre, N., Mangin, A., & Collomp, R. (2011). Air quality trends and potential health effects – Development of an aggregate risk index. *Atmospheric Environment*. https://doi.org/10.1016/j.atmosenv.2010.12.052

Sowlat, M. H., Gharibi, H., Yunesian, M., Tayefeh Mahmoudi, M., & Lotfi, S. (2011). A novel, fuzzy-based air quality index (FAQI) for air quality assessment. *Atmospheric Environment, 45*, 2050–2059. https://doi.org/10.1016/j.atmosenv.2011.01.060

Sublett, J. L. (2011). Effectiveness of air filters and air cleaners in allergic respiratory diseases: A review of the recent literature. *Current Allergy and Asthma Reports*. https://doi.org/10.1007/s11882-011-0208-5

Sun, C., & Zhai, Z. (2020). The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2020.102390

Tan, M., Wang, Y., Luo, L., & Hu, J. (2021). How the public used face masks in China during the coronavirus disease pandemic: A survey study. *International Journal of Nursing Studies, 115*, Article 103853. https://doi.org/10.1016/j.ijnurstu.2020.103853

Thom, G. C., & Ott, W. R. (1973). Air pollution indices: a compendium and assessment of indices used in The United States and Canada. *Air Pollut indices, compend and assess of indices used in the US and Can*.

Triberti, S., Durosini, I., & Pravettoni, G. (2021). Social distancing is the right thing to do: Dark Triad behavioral correlates in the COVID-19 quarantine. *Personality and Individual Differences, 170*, Article 110453. https://doi.org/10.1016/j.paid.2020.110453

Tzampoglou, P., & Loukidis, D. (2020). Investigation of the importance of climatic factors in COVID-19 worldwide intensity. *International Journal of Environmental Research and Public Health, 17*, 1–25. https://doi.org/10.3390/ijerph17217730

USEPA. (2004). *Air quality criteria for particulate matter, air quality criteria for particulate matter*.

V. and A.C. The Federation of European Heating. (2020). *How to operate and use building services in order to prevent the spread of the coronavirus disease (COVID-19) in workplaces*. Rehva.

van den Elshout, S., Léger, K., & Nussio, F. (2008). Comparing urban air quality in Europe in real time. A review of existing air quality indices and the proposal of a common alternative. *Environment International*. https://doi.org/10.1016/j.envint.2007.12.011

van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., et al. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *The New England Journal of Medicine*. https://doi.org/10.1056/nejmc2004973

Versoza, M., Heo, J., Ko, S., Kim, M., & Park, D. (2020). Solid oxygen-purifying (SOP) filters: A self-disinfecting filters to inactivate aerosolized viruses. *International Journal of Environmental Research and Public Health, 17*, 1–11. https://doi.org/10.3390/ijerph17217858

Vijayan, V. K., Paramesh, H., Salvi, S. S., & Dalal, A. A. K. (2015). Enhancing indoor air quality – The air filter advantage. *Lung India, 32*, 473–479. https://doi.org/10.4103/0970-2113.164174

Vultaggio, M., Varrica, D., & Alaimo, M. G. (2020). Impact on air quality of the covid-19 lockdown in the urban area of palermo (Italy). *International Journal of Environmental Research and Public Health, 17*, 1–12. https://doi.org/10.3390/ijerph17207375

Wang, Y. (2021). Government policies, national culture and social distancing during the first wave of the COVID-19 pandemic: International evidence. *Safety Science, 135*, 105138. https://doi.org/10.1016/j.ssci.2020.105138

Wang, J., & Du, G. (2020). COVID-19 may transmit through aerosol. *Irish Journal of Medical Science*. https://doi.org/10.1007/s11845-020-02218-2

Wang, Q., & Li, S. (2021). Nonlinear impact of COVID-19 on pollutions – Evidence from Wuhan, New York, Milan, Madrid, Bandra, London, Tokyo and Mexico city. *Sustainable Cities and Society, 65*, Article 102629. https://doi.org/10.1016/j.scs.2020.102629

Wick, P., Malek, A., Manser, P., Meili, D., Maeder-Althaus, X., Diener, L., et al. (2010). Barrier capacity of human placenta for nanosized materials. *Environmental Health Perspectives*. https://doi.org/10.1289/ehp.0901200

Wielick, C., Ludwig-Begall, L. F., Dams, L., Razafimahefa, R. M., Demeuldre, P.-F., Napp, A., et al. (2021). The use of germicidal ultraviolet light, vaporised hydrogen peroxide and dry heat to decontaminate face masks and filtering respirators contaminated with an infectious norovirus. *Infection Prevention in Practice, 3*, Article 100111. https://doi.org/10.1016/j.infpip.2020.100111

Wu, Q., & Lin, H. (2019). A novel optimal-hybrid model for daily air quality index prediction considering air pollutant factors. *The Science of the Total Environment, 683*, 808–821. https://doi.org/10.1016/j.scitotenv.2019.05.288

Wu, X., Nethery, R. C., Sabath, B. M., Braun, D., & Dominici, F. (2020). Exposure to air pollution and COVID-19 mortality in the United States. *MedRxiv*.

Xu, T., Zheng, H., & Zhang, P. (2018). Performance of an innovative VUV-PCO purifier with nanoporous TiO_2 film for simultaneous elimination of VOCs and by-product ozone in indoor air. *Building and Environment, 142*, 379–387. https://doi.org/10.1016/j.buildenv.2018.06.047

Yadav, R., Korhale, N., Anand, V., Rathod, A., Bano, S., Shinde, R., et al. (2020). COVID-19 lockdown and air quality of SAFAR-India metro cities. *Urban Climate, 34*, Article 100729. https://doi.org/10.1016/j.uclim.2020.100729

Yang, C. (2012). Aerosol filtration application using fibrous media - an industrial perspective. *Chinese Journal of Chemical Engineering*. https://doi.org/10.1016/S1004-9541(12)60356-5

Yoda, Y., Tamura, K., Adachi, S., Otani, N., Nakayama, S. F., & Shima, M. (2020). Effects of the use of air purifier on indoor environment and respiratory system among healthy adults. *International Journal of Environmental Research and Public Health, 17*. https://doi.org/10.3390/ijerph17103687

Zhang, Y., Feng, G., Bi, Y., Cai, Y., Zhang, Z., & Cao, G. (2019). Distribution of droplet aerosols generated by mouth coughing and nose breathing in an air-conditioned room. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2019.101721

Zhao, J., & Yang, X. (2003). Photocatalytic oxidation for indoor air purification: A literature review. *Building and Environment, 38*, 645–654. https://doi.org/10.1016/S0360-1323(02)00212-3

Zhao, B., Liu, Y., & Chen, C. (2020). Air purifiers: A supplementary measure to remove airborne SARS-CoV-2. *Building and Environment, 177*, Article 106918. https://doi.org/10.1016/j.buildenv.2020.106918

Zheng, Y. Y., Ma, Y. T., Zhang, J. Y., & Xie, X. (2020). COVID-19 and the cardiovascular system. *Nature Reviews Cardiology, 17*, 259–260. https://doi.org/10.1038/s41569-020-0360-5

Zhu, S., Lian, X., Liu, H., Hu, J., Wang, Y., & Che, J. (2017). Daily air quality index forecasting with hybrid models: A case in China. *Environmental Pollution, 231*, 1232–1244. https://doi.org/10.1016/j.envpol.2017.08.069