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# Comparison of IAQ Standards in Healthcare Facilities with the aim of providing acceptable Standards in Iran

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**ABSTRACT**

Indoor air quality (IAQ) is a significant concern that affects comfort and health. It is well understood that hospitals are thermal environments in which comfort must be calibrated. This comparative study examined existing international standards of IAQ in Iranian health care facilities. A systematic review of studies on IAQ standards was conducted to test the hypothesis regarding which parameters, and at what level, can have an impact on hospital IAQ: EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH, Canadian, and OEL. The inclusion criteria were met by 34 of the 1886 studies that were screened from 2010-2021. The findings of the selected studies were classified into four categories for analysis: monitoring of IAQ according to standards (n=34), IAQ in healthcare facilities (n=1), impact of air pollution on human health (n=9), and interventions to improve IAQ (n=1). Based on these IAQ standards, the acceptable limit for CO2 6300 $*10^3$ $\mu g/m^3$, for CO 9000 $\mu g/m^3$, for Formaldehyde 19 $\mu g/m^3$, for NO2 37 $\mu g/m^3$, for O3 98 $\mu g/m^3$, for PM2.5 0.1 $\mu g/m^3$, for PM10 10 $\mu g/m$, and for SO2 31 $\mu g/m^3$ was suggested. The majority of studies conducted monitoring of pollutants in indoor environments used for homes and schools, with the majority of them relying on WHO IAQ standards. CO, PM, and NO2 concentrations have been the most studied and have the longest track record of research. The acceptable limit for IAQ parameters was proposed.

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## INTRODUCTION

The emergence of severe acute respiratory coronavirus syndrome 2 (SARS-CoV-2) led to a global outbreak of coronavirus in 2019 (COVID-19) (Agarwal et al., 2021; Amoatey et al., 2020; Kenarkoohi et al., 2020) (Kenarkoohi et al., 2020; Megahed & Ghoneim, 2021). Recent researches indicate a high correlation between COVID-19 and high levels of ambient air pollution which endanger the health of the population relative to the virus (Agarwal et al., 2021; Megahed & Ghoneim, 2021). Boboli et al. found temperature, relative humidity, PM levels, and the presence of an air cleaner were effective in the transmission of the virus (Baboli et al., 2021).

Therefore, in this study, IAQ has been reviewed based on acceptable parameters that affect indoor environment.

IAQ is related to the health and well-being of the occupants, and also, numerous scientific

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studies have linked the correlation between exposure to particulate matter (PM2.5) to a variety of human health issues, including respiratory and cardiovascular disease, and even premature death (Schmitt, 2016; Taj et al., 2016; US EPA, 2021; Xu et al., 2020). The relationships have been shown between specific indoor exposure - even at low levels - and the development or exacerbation of respiratory symptoms and asthma in allergic individuals, especially those who have not been previously sensitized (Kanchongkittiphon et al., 2015; Madureira et al., 2015; Ming et al., 2018; Sicard et al., 2012).

Local air quality affects the way we live and breathe; like the weather, it can change from day to day, and depending on the type, can lead to a healthy or unhealthy life (Adinyira et al., 2007; Künzli et al., 2000; Megahed & Ghoneim, 2021). Air quality is divided into two sub-categories: Indoor and Outdoor air quality. IAQ defines a situation where concerns about air quality mostly take place inside of the building (ACGIH, 2021; NIOSH, 2021)(Thorsen & Mølhave, 1967). IAQ is mentioned in many contexts such as: Residential (Casey et al., 2018; Cooper et al., 2021; Deng et al., 2021; Fazli & Stephens, 2018; Krarti & Aldubyan, 2021; Reddy et al., 2021; Shiue et al., 2019; Willand & Nethercote, 2020; Yang et al., 2019), office (Atarodi et al., 2018; Park & Chang, 2020; Staveckis & Borodinecs, 2021; Wu et al., 2021; Yuan et al., 2019; Zender – Świercz, 2020), medical (Afra et al., 2020; Monks et al., 2009; Remmert et al., 2020; Steinemann, 2017b, 2017a; Voinova, 2018), commercial (Alazazmeh & Asif, 2021; Baysal et al., 2021; Heo et al., 2019; Hussain et al., 2019; Karami et al., 2018; Pétigny et al., 2021), sports (Castro et al., 2015; La Guardia & Hale, 2015; Ramos et al., 2014), educational buildings (Hou et al., 2015; Kempe et al., 2015; Lee et al., 2017; Pacitto et al., 2020; Stabile et al., 2017; Vassella et al., 2021; Wang et al., 2015).

Recent studies have used measurement methods and as a result found that the interaction of clean indoor air with proper ventilation and adaptation to heat stress is important (Konstantinou et al., 2022; Shrestha et al., 2022).

Monitoring and controlling the microbiological quality of indoor air in hospitals is now an essential and key part of prevention strategies against acquired infections in hospitals. IAQ in medical centers is one of the important points that affect patients' comfort and affects their speed of recovery. The goal of a health care facility is to get people back to health, and it is important to note that poor air quality can make conditions worse.

Due to the negative effects on IAQ, and because of the vulnerable nature of those using health care facilities, this issue in treatment spaces is very important. Air pollution can also be predicted through GIS software as prevention to effectively control air quality (Zhalehdoost & Taleai, 2022).

The parameters affecting air quality studied in EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH, and Canadian standards include CO2, CO, Formaldehyde, NO2, O3, PM2.5, PM10, and SO2 (ACGIH, 2021; ASHRAE, 2021; BREEAM, 2020; ccm, 2021; LEED, n.d.; NIOSH, 2021; OSHA, 2021; US EPA, 2021; World Health Organization, 2010). By comparing their acceptable limits, many inconsistencies were revealed. These parameters are harmful to human health and disrupt daily activities. For example, carbon dioxide affects the central nervous system (OSHA, 1989). Carbon monoxide at very high levels can cause dizziness, anesthesia, and death. The EPA considers formaldehyde to be a potential carcinogen in humans (US EPA, 2021). Breathing air with high concentrations of NO2 can irritate the airways in the human respiratory system (Sicard et al., 2011). Sulfur dioxide also irritates the skin and mucous membranes of the eyes, nose, throat, and lungs (Sicard et al., 2012; Zhang et al., 2015). Chemical reactions of O3 with volatile organic compounds leads to the formation of secondary organic aerosols and particulate matter (PM) in medical centers so that these internal pollutants significantly affect the indoor environment (Elliot et al., 2016; Othman et al., 2020; Szigeti et al., 2016).

In particular, the absence of a complete and approved standard in medical use, especially in Iran. So far, no detailed standard has been proposed in the field of IAQ in medical environments.

Therefore, in this study, the acceptable limit given by different standards was examined, and a comprehensive standard for IAQ in medical environments was also suggested.

The following paragraphs will discuss every standard on IAQ and some of the journals who have taken interest on the subject. EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH, Canadian standards and OEL on IAQ has been considered.

Amendments of 1990 US Congress agreed that the Environmental Protection Agency should periodically analyze the costs and benefits of the Clean Air Act (Kinney et al., 2010). The EPA has set national ambient air quality standards for six major pollutants called "standard" air pollutants (US EPA, 2021).

ASHRAE merged with the American Association of Heating and Air Conditioning Engineers (ASHAE) in 1894 and the American Association of Refrigeration Engineers (ASRE) in 1904 to form ASHRAE as the American Association of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE, 2020a). ASHRAE offers two standards for IAQ, ASHRAE 62.1 and ASHRAE 62.2. These standards are classified as acceptable IAQ ventilation (ASHRAE, 2020b; Cansdale, James H., and MacPhee, 1972; Laverge et al., 2013; Ng et al., 2011) and acceptable indoor air conditioning and air quality in low-rise residential buildings (ASHRAE, 1989, 2019, 2020b).

LEED was established in 1993 under the direction of Robert K. Watson, and by 2006 was the founding chairman of the LEED Steering Committee, which included a broad consensus process involving nonprofits, government agencies, architects, engineers, developers, builders, product manufacturers, and other industry leaders (Cheng & Ma, 2015) (LEED, n.d.).

BREEAM (Building Research Establishment Environmental Assessment Method), first published by the Building Research Center (BRE) in 1990, is the longest method of assessing, rating, and verifying the sustainability of buildings in the world (Cole & Valdebenito, 2013) (BREEAM, 2020; Cheng & Ma, 2015; Pedro et al., 2019). Work began on BREEAM at the Building Research Center (based in Watford, UK) in 1988 (Cole & Valdebenito, 2013). BREEAM measures sustainable values in a range of categories, from energy to the environment; each of these categories includes the most important factors, including: Sustainable design and reduction of carbon emissions, durability and design flexibility, adaptation to climate change, environmental value, and biodiversity protection (Suzer, 2019).

NIOSH is responsible for recommending safety and health standards; the organization joined OSHA in 1974 in developing a set of occupational health standards for existing PEL materials (NIOSH, 2021) ((NIOSH), 1992). The internal environment in any building is the result of the interaction between the site, climate, building system, construction techniques, pollution sources and the occupants of the building (EPA & NIOSH, 1991)((NIOSH), 1992).

In 1970, the US Congress and President Richard Nixon established the Occupational Safety and Health Administration (OSHA), a national public health agency dedicated to the fundamental proposition that no worker should choose between life and work. OSHA law makes it clear that the right to a safe workplace is a fundamental human right (Martín Martín & Sánchez Bayle, 2018; OSHA, 2021).

WHO is the organization responsible for public health in the UN systems. From the past to the present, this organization has been concerned with the health aspects of air quality and the preparation of air quality guidelines in defining conditions for healthy air, and IAQ problems are recognized as important risk factors for human health in low-, middle- and high-income countries (World Health Organization, 2014).

The US Government Conference on Public Health (ACGIH) has developed guidelines for use in industrial health and the control of potential health risks (Moschandreas & Vuilleumier, 1999). The US Conference on Public Industrial Health (ACGIH) provides occupational standards that specify different threshold values (TLVs) for pollutants above which they are classed as incompatible (ACGIH, 2021).

In 2012, the Department of the Environment, except Quebec, agreed to implement an All Canada Air Quality Management System (AQMS). AQMS is a comprehensive approach to reducing air pollution in Canada and is the product of unprecedented cooperation by federal, provincial, and territorial governments and stakeholders. Federal, provincial, and territorial governments all have roles and responsibilities in implementing the system. (ccm, 2021; Wong et al., 2013).

Table 1, provides the acceptable limit of parameters that affect the amount of IAQ.

The standard used for examination on IAQ in Iran is OEL standard. This standard is also considered for healthcare facilities. Occupational Exposure Limit (OEL) is the concentration of a chemical in the air that most people can be exposed to without having a detrimental effect. Acceptable limits should not be considered as a definite boundary between safe and unsafe limits because in some people, even at concentrations below the exposure limit, harmful effects may occur ((OEL), n.d.). Table 2 shows the acceptable limit of pollution parameters from the perspective of the OEL standard.

## MATERIALS AND METHODS

The overall aim of this article is to answer the question 'what are acceptable levels of IAQ parameters in hospitals in Iran?' The method of the research is quantitative. A systematic review was carried out based on studies related to IAQ standards including: EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH and Canadian. In previous research, the parameters of CO2, CO, formaldehyde, NO2, O3, PM2.5, PM10, SO2 were the most commonly used (ACGIH, 2021; ASHRAE, 2020a; BREEAM, 2020; ccm, 2021; LEED, n.d.; NIOSH, 2021; OSHA, 2021; US EPA, 2021; World Health Organization, 2010).

This systematic review was developed using Systematic Reviews and Meta-Analyses statement (PRISMA) conducted by Moher et al., 2015. The standards for IAQ were investigated in this review. A systematic literature review was conducted using various search terms. Pubmed (https://pubmed.ncbi.nlm.nih.gov/) and Science direct (https://www.sciencedirect.com/) were searched for IAQ from February 2021 to July 30th, 2021 based on studies on IAQ standards including: EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH, Canadian, and OEL. The data was compiled and summarized in tables and charts. There were no barriers in carrying out the research. We used the following e-databases to search these databases from their establishment until July 30th, 2021: Science direct (n= 329) Phubmed (n= 1557). The search terms used in the databases were {"air pollution" OR "air pollutants" OR "air quality"} AND {"ACGIH" OR "ASHRAE, BREEAM" OR "Canadian" OR "EPA" OR "LEED" OR "NIOSH" OR "OEL" OR "OSHA" OR "WHO"} from 2010-2021 (Table 3). This strategy was replicated across all databases, with an integrated search in the title, abstract, and subject fields. The search was carried out in the Science Direct and Phubmed database (Table 4) using advanced search terms, selecting the abstract, title, keywords field, and all years of publication (Table 5).

During the period 2010-2021, only original articles that investigated IAQ of environments using IAQ guidelines were included. The study was limited to publications in the English language. The following were the exclusion criteria: review and research articles, articles investigating IAQ of environments based on IAQ standards.

Data from included studies were extracted independently by the authors. All included titles and abstracts were screened, and full texts of articles that met the study's predetermined inclusion and exclusion criteria were reviewed. The following methodological data categories were defined for analysis and discussion of the results: standards, pollutants, monitoring time, and research location. The results of the selected studies were divided into four categories for analysis based on the main outcomes that the selected studies addressed: IAQ standards monitoring, IAQ in healthcare facilities, the impact of air pollution on human health, and interventions to improve IAQ.

**Table 1.** The acceptable limits of pollution parameters affecting IAQ desired by the World Health Organization (ASHRAE 62.1), EPA (www.epa.gov/criteria-air-pollutants/naaqs-table), LEED (LEED_v4.1, 2020), ACGIH (ASHRAE 62.1), Canadian standard (https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html), OSHA (OSHA, 2021), and NIOSH (NIOSH Publication No. 92-100)

| Parameters | WHO/Europe | EPA | LEED | ACGIH | Canadian | OSHA | NIOSH |
|---|---|---|---|---|---|---|---|
| **Carbon dioxide** | - | 9 ppm | | 5000 ppm 30000 ppm [15 min] | 3500 ppm [L] | 5000 | 5000 ppm 30000 ppm [15 min] |
| **Carbon monoxide** | 90 ppm [15 min] 50 ppm [30 min] 25 ppm [1 h] 10 ppm [ 8h] | – | 9 ppm; no more than 2 ppm above outdoor levels | 25 ppm | 11 ppm [8h] 25 ppm [1h] | 50 | 35 ppm 200 ppm [C] |
| **Formaldehyde** | 0.1 mg/m$^3$ (0.081 ppm) [30 min] | – | 20 µg/m$^3$ (16 ppb) | 0.3 ppm [C] | 0.05 ppm [L] | – | 0.016 ppm 0.1 ppm [15 min] |
| **Nitrogen dioxide** | 0.1 ppm [1 h] 0.02 ppm [1 yr] | 100 ppb | | 3 ppm 5 ppm [15 min] | 0.05 ppm [L] 0.25 ppm [L] | 5 ppm | 1 ppm [15 min} |
| **Ozone** | 0.064 ppm (120 $\mu$g/m$^3$) [8 h] | 0.070 ppm | 0.07 ppm | 0.05 ppm 0.08 ppm 0.1 ppm 02 ppm | 0.12 ppm [L] | 0.1 ppm | 0.1 ppm [C] |
| **$PM_{2.5}$** | - | 12.0 $\mu$g/m$^3$ | 12 µg/m$^3$ | 3 mg/m$^3$ [C] | 0.1 $\mu$g/m$^3$ [1 h] 0.040 $\mu$g/m$^3$ [1 h] keep indoor levels of PM2.5 as low as possible | – | – |
| **$PM_{10}$** | - | | ISO 14644-1:2015, cleanroom class of 8 or lower 50 µg/m3 Healthcare only: 20 µg/m3 | 10 mg/m$^3$ [C] | - | – | – |
| **Sulfur dioxide** | 0.048 ppm [24 h] 0.012 ppm [1 yr] | 75 ppb | | 2 ppm 5 ppm [15 min] | 0.38 ppm [5 min] 0.019 ppm | 5 ppm | 2 ppm 5 ppm [15 min] |

Note:
[C] = Ceiling limit
[L] = limited
mg/m3 = milligrams/meter cubed
ppm = parts per million

**Table 2.** The acceptable limit of pollution parameters from the perspective of the OEL standard (https://iums.ac.ir/files/vch/files/OEL.pdf)

| pollutants | STRL / C | TWA |
|---|---|---|
| **Carbon dioxide** | 30000 ppm | 5000 ppm |
| **Carbon monoxide** | - | 25 ppm |
| **Formaldehyde** | C 0.3 ppm | - |
| **Nitrogen dioxide** | - | 3 ppm |
| **Ozone** | - | 0.05 ppm |
| **Sulfur dioxide** | 2 ppm | - |

Note:
[C] = Ceiling limit
ppm = parts per million
Average Weight Exposure Time (TWA): A concentration of a chemical in the air that is provided for eight hours of daily work and forty hours of weekly work (OEL, 2021).
Short-Term Exposure Limits (STELs): It is the acceptable average exposure time / time of 12 minutes to a chemical agent that should never be more concentrated in this time of a shift, even if the average 7-hour exposure of employees is less than the OEL-TWA (OEL, 2021).
Ceiling Exposure Limits (C): A concentration of chemicals that should not be exceeded in any way (OEL, 2021).

**Table 3.** Search Strategies

| Description | Related to IAQ | IAQ, air quality |
|---|---|---|
| | Related to Pollution | Air pollution, air pollutant |
| | Related to Standards | ACGIH, ASHRAE, BREEAM, Canadian, EPA, LEED, NIOSH, OEL, OSHA, WHO |
| | Search Period | 2010-2021 |

**Table 4.** Number of studies based on IAQ standards

| Standards | Phubmed | Science direct |
|---|---|---|
| **EPA** | 219 | 23 |
| **ASHRAE** | 34 | 77 |
| **LEED** | 13 | 17 |
| **BREEAM** | 0 | 3 |
| **NIOSH** | 147 | 4 |
| **OSHA** | 33 | 3 |
| **WHO** | 961 | 159 |
| **ACGIH** | 22 | 4 |
| **Canadian** | 116 | 35 |
| **OEL** | 12 | 4 |
| Total | 1557 | 329 |

## RESULTS AND DISCUSSION

On December 31, 2019, an outbreak of COVID-19 appeared in Wuhan City, Hubei Province, China. It is a highly infective, transmissible, and catching disease caused by SARS-CoV-2. There is considerable debate in the scientific and research community about different ways of

**Table 5.** Methodological analysis

| Reference (year) | Pollutant | Monitoring duration | Environment | standard | Country |
|---|---|---|---|---|---|
| **Abdel-Salam, 2021 (Abdel-Salam, 2021)** | (PM10 and PM2.5) and CO2 | 24 h | urban homes | WHO | Egypt |
| **Kephart et al. , 2021 (Kephart et al., 2021)** | NO2 | 48-hour | homes | WHO | Peru |
| **Woolley et al. , 2021 (Woolley et al., 2021)** | CO | Wednesday to Friday evening-Real-time 48-hour | homes | WHO | UK |
| **Ariunsaikha Sonomdasva, and Matsumi, 2020 (Ariunsaikhan et al., 2020)** | PM2.5 | 1 October 2018 to 30 December 2018 | residence apartments, houses (ger district), the National University of Mongolia (NUM), food courts or restaurants, and other indoor locations | WHO | Japan |
| **Branco et al. , 2020 (Branco et al., 2020)** | CO2, CO, formaldehyde, NO2, O3, TVOC, PM2.5 and PM10 | 2013/2014 (campaign 1) and 2015/2016 (campaign 2) | nursery and primary schools | WHO | Portugal |
| **Canha et al. , 2020 (Canha et al., 2020)** | CO2, CO, formaldehyde, VOCs,PM2.5 and PM10 | 450 min per bedroom and the sleeping period ranging from 22:00 to 09:20 | homes | WHO | Portugal |
| **Dobson et al. , 2020 (Dobson et al., 2020)** | PM2.5 | from November 2017 – September 2018 in Scotland<br>April 2018 – July 2018 in Florence<br>April 2018 – November 2018 in Greece<br>April 2018 – December 2018 in Milan<br>September 2018 – April 2019 in Catalonia | homes | WHO | Scotland, Greece, Catalonia, Milan and Florence |
| **Gould et al. ,2020 (Gould et al., 2020)** | PM2.5 | 48-h | homes | WHO | coastal and Andean Ecuador |

**Continiued Table 5.** Methodological analysis

| Reference (year) | Pollutant | Monitoring duration | Environment | standard | Country |
|---|---|---|---|---|---|
| **Ha et al. , 2020 (Ha et al., 2020)** | PM2.5, ozone, NO2, and ambient temperature | 2–4 days | pregnant women with and without asthma | EPA | USA |
| **Singer et al. , 2020 (Singer et al., 2020)** | PM2.5, formaldehyde, CO2 indoors, NOX | Seven days | homes | ASHRAE | California |
| **Giwa, Nwaokocha, and Odufuwa, 2019 (Giwa et al., 2019)** | CO2, PM2.5, and CO | before, during and after cooking. | homes | WHO | Nigeria |
| **Majd et al. , 2019 (Majd et al., 2019)** | PM2.5, CO and NO2 | December 2015 to May 2017 | schools | WHO | mid-Atlantic region |
| **Toyinbo et al. , 2019 (Toyinbo et al., 2019)** | temperature (T), CO, CO2 | December 2016 and January 2017 | schools | ASHRAE | Nigeria |
| **Whyte, Falcomer, and Chen, 2019 (Whyte et al., 2019)** | Radon | October to March | Homes | Canadian | Canada |
| **Pavilonis, Roelofs, and Blair, 2018 (Pavilonis et al., 2018)** | CO2 | August to November 2017 | nail salons | ASHRAE | USA |
| **Snider et al. , 2018 (Snider et al., 2018)** | PM2.5 | 48-hour period | rural households | WHO | China |
| **Vimercati et al. , 2018 (Vimercati et al., 2018)** | Radon | 2014–2015 | homes | WHO | Italy |
| **Zhan et al. , 2018 (Zhan et al., 2018)** | PM2.5 | July 24th to August 17th, 2016 | homes | WHO | Beijing |
| **Bartington et al. , 2017 (Bartington et al., 2017)** | PM2.5 and CO | 48-hour | kitchen | WHO | Nepal |
| **Lewis et al. , 2017 (Lewis et al., 2017)** | PM2.5 | December 2011-January 2012 | 105 homes | WHO | India |
| **Wylie et al. , 2017 (Wylie et al., 2017)** | PM2.5 and CO | 2011 - 2013 | HIV-negative women in | WHO | Tanzania |

**Continiued Table 5.** Methodological analysis

| Reference (year) | Pollutant | Monitoring duration | Environmen t | standar d | Country |
|---|---|---|---|---|---|
| | | | their first or second pregnancies | | |
| **Yip et al. , 2017 (Yip et al., 2017)** | PM2.5 and CO | 48-hour period | homes | WHO | USA |
| **Singh et al. , 2016 (Singh et al., 2016)** | O3, NOx, CO and PM2.5, TVOC, individual VOC and noise pollution | two weeks | Commercial Shopping Complex (CSC) | NIOSH | Delhi |
| **Abdel-Salam, 2015 (Abdel-Salam, 2015)** | PM2.5 and CO2 | from 25 March to 30 May | homes | EPA | Egypt |
| **Amadeo et al. , 2015 (Amadeo et al., 2015)** | O3, NO2, SO2 and PM10 | December 2008 to December 2009 | school | WHO | Guadeloupe (French West Indies) |
| **Can et al. , 2015 (Can et al., 2015)** | NO2, O3 and VOCs | 7 days | University | WHO | Turkey |
| **Dorizas et al. , 2015 (Dorizas et al., 2015)** | CO2 and PM | spring | schools | ASHRA E | Attika basin in Greece |
| **Fischer et al. , 2015 (Fischer et al., 2015)** | PM10, ozone | 2 weeks | schools | WHO | Sweden |
| **Madureira et al. , 2015 (Madureira et al., 2015)** | VOCs, aldehydes, particulate matter, ventilation rates and bio-aerosols | from November to March, during the years 2011–2013 | homes | WHO | Portugal |
| **Shen et al. , 2014 (Shen et al., 2014)** | CO2, CO, O3, formaldehyde, TVOCs, and bio-aerosols | January 19 to 21 | medical facility | EPA | Taiwan |
| **Ho et al. , 2013 (Ho et al., 2013)** | formaldehyde | summer and winter | factory | WHO | China |
| **Huang et al. , 2013 (Huang et al., 2013)** | formaldehyde and benzene | July 2008 to September 2012 | 410 dwellings and 451 offices | EPA | China |
| **Poulin et al. , 2012 (Poulin et al., 2012)** | Radon | 3 months | schools | Canadian | CANADA |
| **Branis, Safranek, and Hytychova, 2011 (Braniš et al., 2011)** | PM2.5 | 2005 - 2009 | gym | WHO | Prague |

transmitting the virus. Recent studies emphasized that the main modes of transmission were person-to-person, so social distancing, and hand-washing several times a day is necessary (Correia et al., 2020; Ghinai et al., 2020; Morawska & Cao, 2020). Covid-19 has had profoundly devastating effects on people all over the world, with quarantine effects intensifying on all activities that disrupt the global economy.

In the present study, we conducted a comprehensive literature search for original studies on air quality in the indoor environment. The search yielded 1886 articles, of which 64 had their full texts reviewed and 34 met the inclusion criteria. Figure 3 depicts a flow chart of the study selection process. Table 4 and Figure 1 show the number of studies based on IAQ standards.

It was discovered that the majority of studies were conducted in accordance with WHO guidelines (23 studies). Other studies were examined based on the EPA (4 studies), ASHRAE (4 studies), Canadian (2 studies), and NIOSH (1 study).

The majority of studies (23 studies) concentrated on homes and schools (9 studies). Other studies were conducted in healthcare facilities, nail salons, offices, shopping malls, and drinking places.

It was noted that the large number of studies (4 studies) were conducted in the United States or China in factories, homes, and nail salons. Among 13 different pollutants, the concentrations of carbon monoxide (CO), particulate matter (PM), and nitrogen dioxide (NO2) were the most investigated, and the most extensive research was done on carbon monoxide (CO), particulate matter (PM), nitrogen dioxide (NO2), Formaldehyde, Ozone (O3) and Radon (Table 6). The monitoring lasted at least a morning and afternoon, and up to four years. Only one study used interventions to improve IAQ, which consisted of attempting to reduce PM2.5 emissions (Table 7).

Based on IAQ standards reviews, one study investigated IAQ in a healthcare facility. According to the findings, AgZ filtering could be used as a feasible engineering measure for hospitals to control their bacteria and fungi parameters in IAQ management (Table 9).

From the 34 studies selected, only 9 investigated the impact of indoor air pollution on human health. The sample sizes and results are shown in Table 8.

Also, after investigating on IAQ standards. The results were compiled into a table by comparing ASHRAE, NIOSH, OSHA and ACGIH standards in the United States, also the international

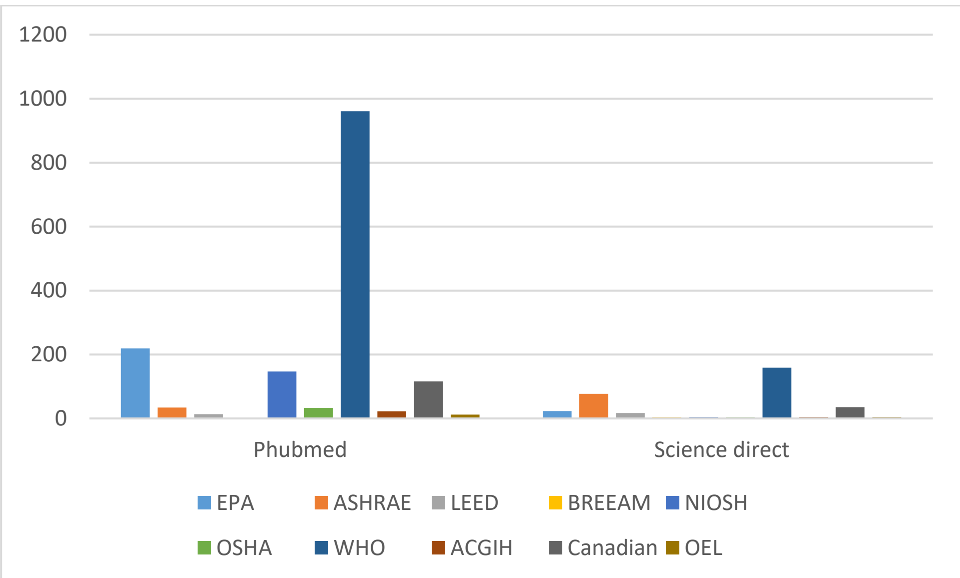


**Fig. 1.** Number of studies based on IAQ standards

**Table 6.** Number of studies by pollutant and period of investigation

| Pollutant | Studies | Period of investigation |
|---|---|---|
| **PM** | 22 | 2011-2021 |
| **Co** | 11 | 2014-2020 |
| **NO2** | 9 | 2015-2021 |
| **CO2** | 9 | 2015-2021 |
| **VOCs** | 5 | 2014-2020 |
| **Formaldehyde** | 5 | 2013-2020 |
| **O3** | 4 | 2014-2020 |
| **Radon** | 3 | 2012-2019 |
| **bio-aerosols** | 2 | 2014-2015 |
| **Temperature** | 2 | 2019-2020 |
| **NO** | 2 | 2016-2020 |
| **benzene** | 1 | 2013 |
| **SO2** | 1 | 2015 |

**Table 7.** Studies with Interventions to improve IAQ

| Reference (year) | Interventions | Results | Conclusions |
|---|---|---|---|
| **Dobson et al. , 2020 (Dobson et al., 2020)** | smoking | Eight of the homes with concentrations higher than the WHO guideline limit at baseline dropped below that level at the follow-up. Participants expressed positive attitudes toward the effectiveness of air quality feedback in follow-up interviews. | Within the context of this study few homes became totally smoke-free. |

LEED standard developed by the American Green Building Organization, the BREEAM standard developed by the United Kingdom, the standard set by the WHO in the United Nations system and the Canadian standard in Canada. However, it is not possible to say which organization offers the most negligent and strictest standard, since this varied from parameter to parameter. For example, when considering the carbon dioxide parameter, the Canadian standard proposes the lowest value, while other standards have allowed a higher value for IAQ. Also, considering the formaldehyde parameter, the ACGIH standard is the highest and the NIOSH standard is the lowest among the mentioned standards for IAQ.

By comparing each of the standards that were proposed for each type of user, we conclude that the recommended acceptable limit offered for each parameter in each type of standard varies across the organizations. In addition, none of the standards explicitly mention that they provide a specific standard for IAQ in health care facilities.

It is not possible to implement the standards of one particular organization for health care, because each organization has provided different acceptable limits for different parameters. For example, for the SO2 parameter, the Canadian standard has the lowest value and the OSHA standard has the highest value.

**Table 8.** Results of studies investigating air quality impact on health

| Reference | Sample (n) | Results | Conclusion |
|---|---|---|---|
| **Branco et al. , 2020 (Branco et al., 2020)** | 648 pre-schoolers (3–5 years old) and 882 primary school children (6–10 years old) | Reported active wheezing was associated with higher NO2, and reduced FEV1 was associated with higher O3 and PM2.5, despite NO2 and O3 in schools were always below the 200 μg m−3 threshold from WHO and National legislation, respectively. | Sensitized children to common aeroallergens were more likely to have asthma during childhood when exposed to particulate matter in schools. |
| **Whyte, Falcomer, Chen, 2019 (Whyte et al., 2019)** | federal workplaces (7600) | 2% of federal workplaces have radon concentrations above 200 Bq m−3, which is also significantly lower than the 7% of residential homes that tested above 200 Bqm−3. | Most of the radon exposure received by an individual comes from home where radon levels, on average, are a factor of 2 higher than in the workplace. |
| **Pavilonis, Roelofs, Blair, 2018 (Pavilonis et al., 2018)** | Nail salons (10) | CO2 measurements could potentially be used to provide an initial determination of acceptable IAQ for the purposes of compliance with the standard. | This study suggests a decrease in CO2 concentrations is associated with a reduction in TVOC concentrations have not been considered a suitable strategy for monitoring or achieving acceptable IAQ. |
| **Lewis et al. , 2017 (Lewis et al., 2017)** | Household (105) | In this research article, ICS use was associated with 91% reduced use of firewood, substantial time savings for primary cooks, a 72% reduction in PM2.5, a 78% reduction in PAH levels, and significant reductions in water-soluble organic carbon and nitrogen in household air samples. | A lot of significant gains from promoting rural biogas stoves in a context in which traditional stove use persists was found, although pollution levels in ICS households still remained above WHO guidelines. |
| **Amadeo et al. , 2015 (Amadeo et al., 2015)** | elementary schools (30) | A 1-μg/m3 increase in medium-term exposure to outdoor close-proximity pollution by $O_3$ was associated with a PEF decrease. | The results suggest that $O_3$ could have an acute effect on child lung function in the Caribbean even at a low concentration (below the WHO guidelines). |
| **Can et al. , 2015 (Can et al., 2015)** | University | The concentrations obtained from the stained-glass workshop were much higher than the other sampling points. | Lifetime cancer risks for the people working in the department such as faculty members and technicians were obtained higher than USEPA acceptable risk value. |
| **Madureira et al. , 2015 (Madureira et al., 2015)** | dwellings (68) | Low levels of VOCs and aldehydes, acceptable ranges of temperature and humidity has been shown in this study. CO2, PM2.5, PM10, bacterial concentrations was at high levels. | Concentrations of particulate matter and culturable bacteria were frequently higher than guidelines/reference values. |
| **Huang et al. , 2013 (Huang et al., 2013)** | 410 dwellings and 451 offices | The indoor formaldehyde concentrations were above the acute Reference Exposure Level (REL) recommended by the OEHHA. The indoor benzene concentrations | In the tested buildings, formaldehyde exposure may pose acute and chronic non-carcinogenic health risks to the occupants, whereas benzene exposure |

**Continiued Table 8.** Results of studies investigating air quality impact on health

| Reference | Sample (n) | Results | Conclusion |
|---|---|---|---|
| | | exceeded the reference concentration (RfC) recommended by the U.S. EPA. | may pose chronic non-carcinogenic risks to the occupants. |
| **Branis, Safranek, and Hytychova, 2011 (Braniš et al., 2011)** | elementary school gym | The average outdoor concentration of PM2.5 was higher than the indoor value and the corresponding average from the nearest fixed site monitor. | Indoor exercise in polluted urbanized areas may increase the overall exposure and thus represent a potential health risk to young individuals during physical education at schools. |

**Table 9.** Studies based on IAQ in healthcare facilities

| References (year) | Pollutions | Standard | Results | Conclusion |
|---|---|---|---|---|
| **Shen et al. , 2014 (Shen et al., 2014)** | CO2, CO, O3, formaldehyde, TVOCs, and bio-aerosols (bacteria and fungi) | EPA | The cumulative bio-aerosol removals for bacteria and fungi were 900 and 1,088 colony-forming units (CFU) g_1 after 24 hr and were above 3,100 and 2,700 CFU g_1 after 120 hr. | From the research results, it is suggested that AgZ filtering could be used as a feasible engineering measure for hospitals to control their bacteria and fungi parameters in IAQ management. |

According to Figure 3, for example, for the CO2 parameter, the Canadian organization has offered the lowest level and OSHA, NOISH and ACGIH have offered the highest limit. Also, for the CO parameter, OSHA has the lowest and NIOSH has the highest limit, for Formaldehyde, NIOSH has the lowest and ACGIH has the highest, for NO2, WHO has the lowest and OSHA has the highest. Also, for parameter O3, ACGIH has the lowest limit and Canadian organization has the highest limit, and for parameter PM2.5, Canadian has the lowest limit and EPA has the highest limit and for parameter PM10, ACGIH is the lowest limit. In addition, the EPA has provided the maximum acceptable limit. Finally, for the SO2 parameter, WHO provided the lowest and OSHA provided the highest acceptable limit indoors. Table 10 shows the minimum and maximum of acceptable limitations offered for parameters that affect IAQ arranged by EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH, Canadian, and OEL IAQ standards.

Also, theses based on IAQ and measurements in Tehran university have been studied for further investigation about IAQ in Iran. In his thesis, Alireza Nejad used the meteorological model MM5 (Fifth Generation Mesoscale Model), which is the driver of the multi-scale air quality model, to find out that the correlation of MM5 can be used to predict the concentrations of many pollutants and then compare them with observational data. This model provides an opportunity for decision-makers and policymakers to help improve air pollution control (Alireza Nejad, 2009). Cheraghi obtained eight architectural models by examining the architectural patterns and location of the spaces, according to which he would improve the interior qualities. Then with C.F.X. simulation software of problem data and hypotheses (such as mechanical

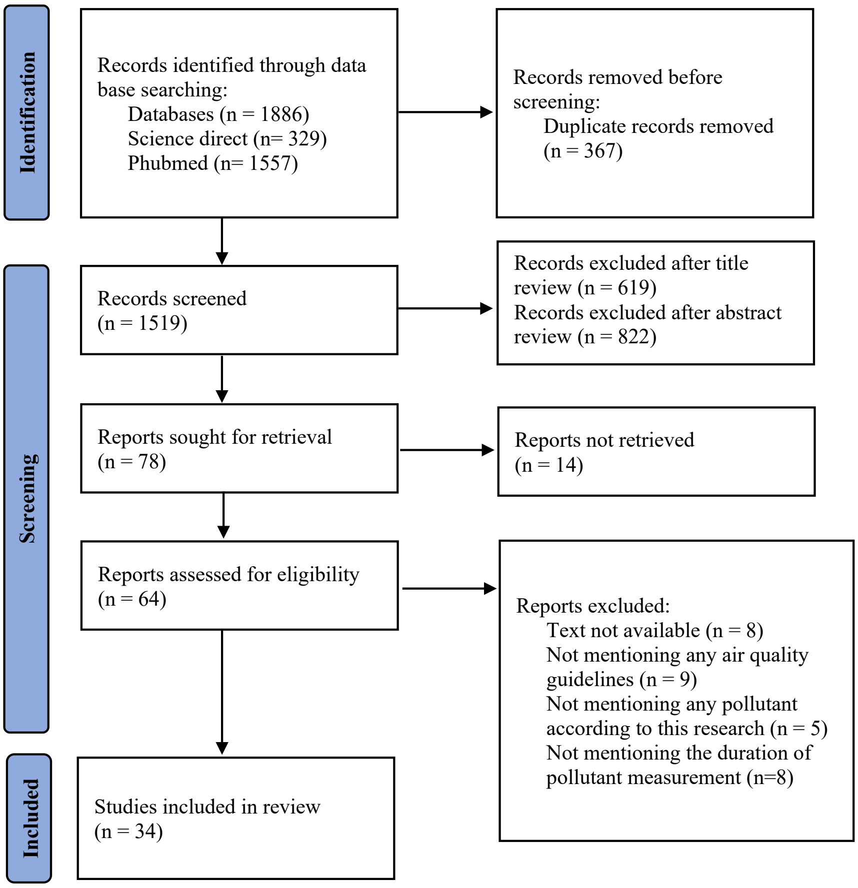


**Fig. 2.** Identification of studies via databases and registers

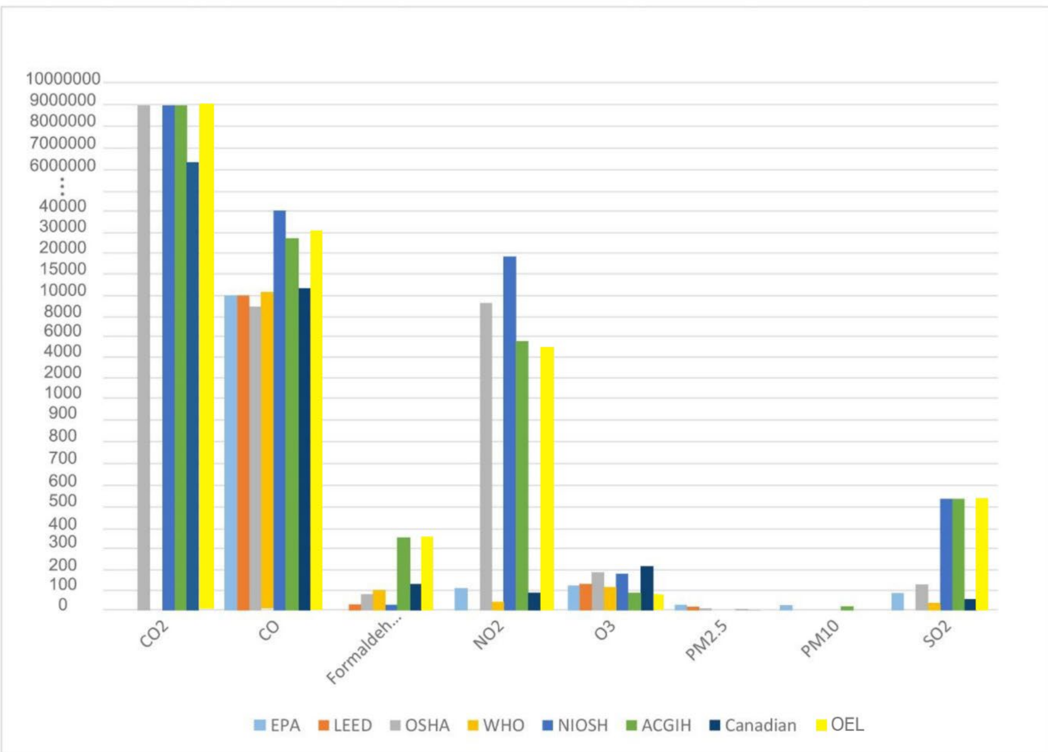


**Fig. 3.** Acceptable limitation for parameters that affect IAQ according to IAQ guidelines

**Table 10.** Minimum and maximum of acceptable limitations offered for parameters that affect IAQ

| parameters | Minimum | Maximum |
|---|---|---|
| **CO2** | Canadian | OSHA, ACGIH, NIOSH, OEL |
| **CO** | LEED, EPA | NIOSH |
| **Formaldehyde** | NIOSH | ACGIH, OEL |
| **NO2** | WHO | OSHA |
| **O3** | ACGIH | Canadian |
| **PM2.5** | Canadian | EPA |
| **PM10** | ACGIH | EPA |
| **SO2** | WHO | OSHA, OEL |

**Table 11.** The acceptable limitations offered for parameters that affect IAQ

| parameters | standard | amount |
|---|---|---|
| **CO2** | Canadian | $6300 * 10^3$ μg/$m^3$ |
| **CO** | LEED, EPA | 9000 μg/$m^3$ |
| **Formaldehyde** | NIOSH | 19 μg/$m^3$ |
| **NO2** | WHO | 37 μg/$m^3$ |
| **O3** | ACGIH | 98 μg/$m^3$ |
| **PM2.5** | Canadian | 0.1 μg/$m^3$ |
| **PM10** | ACGIH | 10 μg/$m^3$ |
| **SO2** | WHO | 31 μg/$m^3$ |

air intake, natural outlets, pollutant entry, solar radiation, thermal conductivity, architectural components, and data of Tehran's hot and cold seasons) architectural models have been evaluated and concluded that architectural patterns have a positive effect on air quality (Cheraghi, 2017).

In their thesis, Rajabi Hazaveh and Motalei tried to improve IAQ by examining the form and location of the building and the surrounding green spaces (Motalei, 2014; Rajabi Hazaveh, 2017). Also, Mohammadi, by examining the pollutants and considering the distribution of land uses in the outdoor area, has concluded that the distribution of land uses such as roads, residential, industrial, and commercial networks around measuring stations have a great role in air quality (Mohammadi, 2014).

In his thesis, Oliayee attempted was made to investigate the significant relationship between the symptoms caused by the residents and the concentration of pollutants in the building. By using the correlation coefficient obtained between the concentration of pollutants and the residents' responses, it was found that sick buildings were not counted (Oliayee, 2012).

In Ebrahimi's thesis, an attempt has been made to measure the amount of particulate pollutants smaller than 10 microns and benzene-toluene-ethylbenzene and xylene, in sports clubs with different types of class systems. The ventilation and the number of people present in the club have been measured and compared with the necessary standards. The measured amounts of toluene, ethylbenzene, and xylene pollutants are less than 10% of the permissible limits. The measured amounts of benzene pollutants are much less than the standard limits. Research also has shown that no safe concentration can be determined for benzene, so efforts should be made to reduce this pollutant as much as possible. However, the amount of suspended particles in some cases exceeds the standard limit and it is necessary to implement the recommended measures to reduce it (Ebrahim, 2017).

In her research, Mianesaz, investigated the air quality of this building, the modeling of the distribution of particles inside this building and the selection of critical points to measure the number of pollutants have been carried out by Ansys Fluent software, and the results of the measurement have been compared with the standard values, and finally, solutions have been presented to improve the air quality (Miane saz, 2018).

Also, Beitollahi et al. in their research on measurements in hot spring baths in Iran found out that hot springs in Abegarm-e-Mahallat are responsible for the elevated concentrations of radionuclides (especially 226Ra) in the region (Beitollahi et al., 2007). And, in their research, Shafiepour et al., have been focused to survey the concentration of pollutants in two important museums in Iran and consequently, the data produced by mathematical models were compared with real measured data. They suggest that an effective filter in mechanical systems and reduction in air change rate can lead to a more controlled situation in IAQ pollutant status.

In reviewed articles, IAQ standards monitoring, IAQ in healthcare facilities, the impact of air pollution on human health, and interventions to improve IAQ were investigated. Few studies have been conducted on IAQ in healthcare facilities (n=1) and interventions to improve IAQ (n=1) require more attention. In related theses, it has been concluded that the proper placement of land uses in urban space, the plan and arrangement of spaces, the management of green space around buildings, and the continuous measurement and prediction of air pollution affect its improvement. Also, some researchers suggest finding ways to control and minimize the amount of pollutions. The purpose of this study is to review the articles in this field, review the standards and find a suitable standard for IAQ in healthcare facilities in Iran. This research is due to the comprehensive review of special field, studies based on real measurements, and library research. In this study, the specific climate of each region and neighborhood has not been considered. It is hoped that future research will address this issue more specifically.

## CONCLUSION

This study compared existing international standards for IAQ in health care facilities, with the goal of providing guidelines for contaminant exposure limits in Iran. The study concentrated on the findings of the literature on IAQ standards for health care facilities. The content was divided into four sections in general: Systematic review on IAQ based on IAQ standards, an introduction on IAQ standards, considering the importance of Covid-19 on IAQ in health care facilities, and also, providing eligible standards on IAQ for health care facilities in Iran.

It was discovered that there were few studies conducted based on IAQ standards installed in health care facilities. The majority of studies focused on homes and schools, and most of them were conducted in the United States or China in factories, homes, and nail salons. CO, PM, and NO2 concentrations were the most studied, and CO, PM, NO2, formaldehyde, O3, and radon had the most research history. These pollutants were within the limits established by guidelines in most studies. The monitoring lasted at least a morning and afternoon, and up to four years. Only one study used interventions to improve IAQ, which consisted of attempting to reduce PM2.5 emissions. Based on IAQ standards, one study investigated IAQ in a healthcare facility. The majority of studies were carried out in accordance with WHO IAQ standards. According to the findings, AgZ filtering is proposed as a feasible engineering measure for hospitals to control their bacteria and fungi parameters in IAQ. From the 34 studies selected, only 9 investigated the impact of indoor air pollution on human health. Studies that examined the association between air quality and health demonstrated the negative effects of pollution.

The following items were obtained from the review of each section: According to EPA, ASHRAE, LEED, BREEAM, NIOSH, OSHA, WHO, ACGIH and, Canadian IAQ standards, the exposure guidelines for $CO_2$ ranged from 6300 $*10^3$ $\mu g/m^3$ to 9000$*10^3$ $\mu g/m^3$ offered by Canadian and OSHA, ACGIH, NIOSH. Also, the exposure guidelines for CO ranged from 9000 μg/m³ to 40000 μg/m³ offered by LEED, EPA and NIOSH. For Formaldehyde, the exposure guidelines ranged from 19 μg/m³ to 368 μg/m³ offered by NIOSH and ACGIH. The exposure guidelines for NO2 ranged from 37 μg/m³ to 9408 μg/m³ offered by WHO and OSHA. The exposure guidelines for O3 ranged from 98 μg/m³ to 235 μg/m³ offered by ACGIH and Canadian. The exposure guidelines for $PM_{2.5}$ ranged from 0.1 μg/m³ to 35 μg/m³ offered by Canadian and EPA. The exposure guidelines for $PM_{10}$ ranged from 10 μg/m³ to 20.0 μg/m³ offered by ACGIH and EPA. In addition, the exposure guidelines for $SO_2$ ranged from 31 μg/m³ to 13000 μg/m³ offered by WHO and OSHA.

- Recent research found that poor IAQ was a clear factor in spreading Covid-19. Considering the importance of this issue, more attention on this problem must be expected.
- It is more likely that sensitized children to have asthma during childhood when exposed to particular matter despite the measured pollutants being under the WHO guidelines.
- CO2 measurement could be used to provide acceptable IAQ.
- Recent studies found out O3 can have an acute effect on child lung function even at low concentrations.
- Agz filtering can control bacteria and fungi parameters in healthcare facilities.
- Monitoring IAQ can lead to better IAQ in buildings.
- Bearing in mind the importance of this issue, contaminant exposure guideline limits for IAQ parameters have been suggested for healthcare facilities in Iran.

The conclusions from the results of the analyses carried out are summarized in Table 11. Parameters that commonly affect IAQ have been listed by comparing the limitations which each organization has offered.

According to Table 11, it is suggested that $CO_2$, CO, Formaldehyde, $NO_2$, $O_3$, $PM_{2.5}$, $PM_{10}$, and $SO_2$ should be held at the minimum level, for the comfort of the patients. Also, OEL standard should be considered for IAQ values in Iran. But by comparing the acceptable limitation for parameters that affect IAQ, it was noticed that some parameters are missing such as, PM2.5 and PM10. In addition, the acceptable levels of some parameters were high considering some users, such as those in health care facilities. The proposed guidelines in Table 11 are suggested to be considered for healthcare facilities in this review.

Furthermore, for future articles, detailed studies on IAQ in health care and standards relating to the subject need to be carried out to maintain or improve the IAQ in health care facilities. In addition, it is recommended that there are localized guidelines for every city due to the impact of different climates and locations that each area may have.

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## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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