THE CONSEQUENCES OF COVID-19 INSTIGATED RECOMMENDATIONS FOR INDOOR AIR QUALITY: A LITERATURE REVIEW

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ABSTRACT

The spread of COVID-19, as an airborne virus, opened a vast set of investigations within the realm of indoor air quality (IAQ) management and control. These investigations resulted in the publication of a series of recommendations and addenda that complement currently active IAQ standards and guidelines to meet the growing health and safety concerns of building owners, operators, and users. The hypothesis stands that the airborne transmission of the COVID-19 virus implies that more stringent indoor air quality control measures should be applied. Through a systematic review of selected recently published academic journals, this article explores the intended and non-intended consequences of the indoor air quality recommendations, guidelines, and standards.

Two main approaches of classifications are induced from the review. The first categorizes the consequences based on the intentionality (i.e., intended vs. unintended consequences) and temporal scope (i.e. short-term or long-term). The second categorizes consequences based on their area, namely, (1) spatial design, (2) occupants health, comfort and well-being (3) building performance and ventilation, (4) technology and energy efficiency (5) social equity, and (6) policy as well as building standards. This is one of the first reviews make explicit the consequences of COVID related of addenda and recommendations of IAQ standards and guidelines, providing new insights regarding the planned and unplanned consequences. The review also highlights some gaps in the available literature that researchers need to swiftly address before institutionalizing the current health recommendations in IAQ practices.

Keywords
Indoor Air Quality; COVID-19; Indoor Air Quality Guidelines; Built Environment; Buildings

SECTION 1: DEFINING RESEARCH SCOPE AND METHODOLOGY

1.1 INTRODUCTION

The spread of COVID-19, as an airborne virus, resulted in the publication of numerous investigations within the realm of indoor air quality (IAQ) management and control. The fact that occupants spend more than 90% of their time indoors and that indoor human exposure to air pollutants is at least double that of outdoor exposure; strengthens the urge to investigate means to cater for safe and healthy built environments(1). The hypothesis stands that the airborne transmission of the COVID-19 virus implies that more stringent indoor air quality control measures should be applied.

This has resulted in the publication of a series of recommendations and addenda that complement currently active IAQ standards and guidelines to meet the growing health and safety concerns of building owners, operators, and users. However, and while these recommendations aim to address the imminent health risks, they come with multi-faceted consequences– related to energy, comfort, and well-being, building operation, as well as products and technology adoption.

1.2 RESEARCH OBJECTIVES

This paper aims to investigate the intended and make explicit the non-intended consequences of recommendations published on IAQ in light of the pandemic. The research utilizes recent literature to study the implications of the issued recommendations on indoor air quality to achieve this. While several literature reviews have been published documenting the scientific evidence to improve IAQ during the pandemic, few published articles study the implications of such recommendations. The novelty of this research paper is - and more specifically, the primary objective of this paper - is to track the COVID-19 instigated recommendations on indoor air quality guidelines and potential multi-faceted consequences such as: the well-being of occupants, thermal comfort, energy efficiency, and building performance, design aspects, and technology use. The secondary aim of this paper is to understand the scientific basis for the recommended measures within air quality guidelines in the wake of the pandemic. The research paper also aims to understand the short and long-term consequences of such recommendations.

1.3 RESEARCH QUESTIONS

This research attempts to answer the following research questions:

- What are the main recommendations within academic literature on indoor air quality published in light of the pandemic?
- What are the consequences of such IAQ recommendations – and implications – on building design parameters, health, occupants' well-being, energy efficiency, building performance, and use of technology?
- After reviewing recommendations on indoor air quality affecting the built environment, what are the literature gaps that require immediate attention?

1.4 RESEARCH METHODOLOGY

The research followed a systematic review of available academic journals extracted from abstract and citation databases– namely, CrossRef and Scopus. The search parameters included "COVID" in the title and "Indoor Air Quality" in the keywords section. The search timeline was set from 2020 till 2021. More precisely, from March 2020 – since the lockdown measures in response to the pandemic were globally enforced – till August 2021. The search yielded 1078 results.

At the first stage, duplicates were eliminated from the database. To aid the filtration process, a relevance scoring – rated from zero to 3 where three is included, and zero is eliminated. The research team carried out the rating. The process followed inclusion and exclusion criteria. The inclusion criteria were that the title answered any of the identified research questions; the language of the article is in English; and that the article fell within the specified timeline. The exclusion criteria were technically any article that fell outside the scope of the research. The filtration process eliminated articles discussing ambient air quality during COVID-19, the effect of the lockdown measures on air quality, or air pollution – as an example. From this process, only 85 articles were retained and went through further analysis by the team by evaluating their abstracts, introduction, and concluding sections. The articles eliminated included the following topics: education, air transport or traffic, medical articles, and insights on tourism or mobility. Finally, only 29 articles were selected to be included within the scope of this research. They were categorized according to their scope: namely, indoor air quality, ventilation, energy, viral transmission, simulation, pollutants, and an additional sub-category. Articles were also tagged by their geographical scope whenever applicable.

The reviewed articles were further analyzed in terms of the recommendations they offer, and hence the deduced consequences of such recommendations. The team of authors categorized the impact of such consequences – short-term or long-term – and whether they are intended or non-intended on a consensus based.

1.5 PAPER ORGANIZATION

The remainder of the paper is organized as follows:

- Section II: Literature review – presents the main findings of the investigated literature bodies;
- Section III: Discussion; and finally
- Section IV: Concluding remarks and summary of main literature gaps.

SECTION II: LITERATURE REVIEW

2.1 INDOOR AIR QUALITY POLICY AND THE PANDEMIC

Rethinking air quality legislation – and inherently IAQ – was a primary concern for policymakers at the outset of the pandemic. This notion was brought to since air quality experts confirmed the strong correlation between air quality and the spread of the virus. Moreover, the topic of air quality policy resurfaced more when the airborne transmission of the virus was confirmed (2–5). However, in the context of the pandemic, air quality legislation appeared to be complex since there was no precedent or conclusive frameworks to follow. Thus, we can consider that air quality policy and guidelines remain experimental in focus, calling for in-depth investigations.

To begin with, an evident challenge in developing the policy responses to the COVID-19 is the time pressure put on governments and authoritative figures to take timely actions in response to the pandemic (6). Many of such timely policy responses fall under "emergency legislation" and "emergency regulations" (7), the most notable example of which is the lockdown procedures. Secondly, policy regulations and legislations issued by governments and policymakers around the world were - and still are - vital in tackling every stage of the health crisis with its associated social and economic effects. This indicates that integrating a multi-dimensional perspective and forecasting associated social and economic implications should be considered when developing such policies.

Concerning indoor air quality: (8) p. 351; Scotford's opinion piece brings to light justifications on why governments should shift their perception about air quality and air pollution legislation.

> "The regulatory approach to IAQ globally has been fragmented at best, and mostly non-existent in many countries… There is often an artificial indoor versus outdoor barrier in regulating air quality and setting air quality standards. […] The pandemic has starkly highlighted that air quality is a problem not only of public health but also of social inequality […]. Preliminary studies show higher morbidity and mortality from COVID–19 amongst people who live in areas of poor outdoor air quality."

Indeed, IAQ remains non-existent, much less regulated than ambient air quality or urban air quality. The distinction between indoor and outdoor air quality is also a major division in research, and little has been published on the intersectionality of the IAQ and ambient Air Quality (AQ).

Yet another challenge is navigating through the different guidelines and standards' addenda to set definite targets that could be communicated as a nationwide policy. In agreement with the same line of thought, D. Lewis (9) discusses the challenges of making the indoors safe, commenting on the role of the World Health Organization (WHO) in issuing guidance documents and The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards. D. Lewis claims that there are no set targets for the ventilation rates within indoor spaces (9). In other words, there are no agreed-upon ventilation rates – that are easily achievable – by both medical and non-medical facilities.

2.2 WHAT HAS BEEN PUBLISHED ON INDOOR AIR QUALITY DURING THE PANDEMIC?

IAQ has been tackled from a multitude of perspectives by researchers concerning the pandemic. General topic categories include policy and standards, viral transmission, ventilation, technology, simulation, and energy and building performance. These categories will make up the sub-heading of the literature review.

2.2.1 HVAC System Operations and Ventilation

As noted by M. Awada (10), a 100% elimination of the virus through stringent control of Heating, ventilation, and air conditioning (HVAC) operations is possible. This conclusion is further broken down by N. Agarwal (11), in which the author reviews recent literature comparing ventilation recommendations by both researchers and international authority organizations. The compilation of evidence presented the following:

- In agreement with M. Awada (2,10), the ventilation rate is not guaranteed to completely eliminate the viral load. However, it can reduce the viral load carried by the droplet. The recommended ventilation rate varies for each building typologies, and guidelines differ on the exact rate. As observed by Awada (10), this is one area of research where conclusive evidence is not yet found Awada highlights that "Although most of the terms and suggestions from the reviewed guidelines are similar, the exact ventilation rate that would minimize the transmission of an airborne virus is not provided and needs further research (10) p.7." For example: "The ventilation rate of 288 m^3/hr/person is suggested by WHO for health care settings which can be achieved either by natural or mechanical ventilation," J Atkinson*et al.* (12) p. 8 as cited in Agarwal (11). Chen *et al.* (13)., provide recommendations for the ventilation of indoor spaces to reduce transmission rates of the COVID-19 virus. The authors propose a mathematical model to "determine the required ventilation rate of an indoor space based on the activity type (13) p.1," and further propose "methods to achieve adequate ventilation rates (13) p.3."
- Depending completely on natural ventilation is not possible within enclosed environments – especially office buildings whose facades are made entirely of glass and non-operable curtain walls (11). This point, however, depends on the design of the building, and its degree of application would be a case-by-case scenario.
- If HVAC operational guidelines are not applied correctly, they can worsen the viral transmission and become a source of contamination by itself (11).
- Air recirculation in indoor environments is not recommended as suggested by ASHRAE and REHVA (14,15). In addition, increasing natural ventilation, decreasing population density, and maintaining a "maximum outside airflow for 2 h before and after the building is occupied (14)" – as recommended by ASHRAE: Guidance for Building Operations During the COVID-19 Pandemic, May 2020.
- In agreement with Azuma *et al.* (16), controlling the environmental quality parameters such as temperature and relative humidity are necessary to decrease the degree of contamination – whereby high temperatures and low humidity levels were evidenced to decrease infection rates (17–20).
- Reducing occupancy density and maintaining physical distance are among the factors contributing to lowering ventilation rates (14).

In a more structured literature review, although with not as many detailed recommendations, (21) Bhagat breaks down the many parameters influencing the transmission of the COVID-19 virus within an indoor space. This includes types of ventilation, types of airflow patterns, people's behavior or influence within a space, droplets' size, and means of transmission. The discussion points are backed up by either mathematical models, computational simulations, or quantitative evidence.

With more specific focus on air purifiers, Mousavi *et al.* (22) studies the effect of air purifiers in parallel to mechanical ventilation within a dentistry clinic. The paper shows that mechanical ventilation plays a greater role in diluting pollutants whereby the air purifiers positively improve indoor air quality by lowering Particulate Matter (PM 2.5) and Total Volatile Organic Compounds (TVOC). Sodiq *et al.* (3) also, studying air purifiers in combination with HVAC operations dynamics recommends using innovative solutions such as the integration of Ultraviolet Germicidal Irradiation (UGVI) that is used simultaneously with nano-porous air filter to effectively reduce the spread of the COVID-19 virus and other harmful microbes in indoor spaces.

On more practical grounds, other researchers provide recommendations or more of a "cleaning protocol" for the maintenance of HVAC systems in non-medical settings (23). They further emphasize the role of the High-Efficiency Particulate Air (HEPA) filters in improving indoor air quality and the Minimum Efficiency Reporting Values - MERV 13 to 16 filters as recommended by ASHRAE (24). Maintenance and cleaning protocols – in addition to regular measures of social distancing and facial masks – are necessary to reduce the risk of viral transmission but are not a 100% guarantee.

2.2.2 Viral Transmission

Closely tied to the study of HVAC systems operations and ventilation methods, is the means of viral transmission, and the implications of HVAC operations on reducing – or accelerating – the virus. Lynch and Goring (25) present depressurization as a practical technique to adapt best a room (the case study showed that of a nursing home) to improve air quality and airflow to reduce viral transmission rates. Their recommendations are simplified five steps to convert the space into a negative air pressure zone. The basic logic behind such a transformation is that air will not flow outside the room when a door opens, and thus contamination will remain restricted.

Z. Noorimotlagh *et al.* (4) provides a systematic review of literature discussing possible airborne transmission methods of the COVID-19 virus in the indoor air environment. The authors provide recommendations to indoor air quality experts to improve the indoor environment:

- The provision of ventilation systems, especially displacement ventilation
- To attempt to redesign the space with an intention to increase the existing ventilation rate and efficiency
- More stringent prevention and control policies (air quality and ventilation techniques) should be applied within hospital wards of COVID-19 patients in order to reduce infection rates. A recommended strategy is "isolate the COVID-19 patients with high viral loads in the exhaled air in the first weeks of infection (4) p.4."
- Promoting social distancing – as per the WHO recommendations – and avoiding over-crowding.

Not only is a complete elimination of viral transmission through HVAC operations control is not possible, but the literature provides evidence that the 6 ft social distancing common recommendation by WHO is contested. Anchordoqui and Chudnovsky (2)– in which both authors are physicists – simulates the droplet / COVID-19 virus in an aerosol form and track its motion within a room. The results of the simulation showed that 1) the virus can stay suspended in air for hours, and 2) through air flow simulation – which is further complicated by the central air conditioning flow; the virus spreads more than the recommended 6 ft of social distancing. Moreover, the physicists conclude that the 3) "inhaled viral load depends on the virus concentration in the air and the time of exposure," where the varying concentration depends on several parameters – including: "the location of doors and windows, ventilators, heaters, movement of people, etc (2) p.3."

2.2.3 Sick Building Syndrome Versus Occupants Health and Indoor Environmental Quality

Literature linking occupants' health and comfort to IAQ is not a new topic. Among the well-researched issues that resurfaced during the pandemic are the Sick Building Syndrome (SBS), its antonym "healthy buildings" as well as the Indoor Environmental Quality (IEQ) index.

The Sick Building Syndrome "is a complication that can appear to building occupants along with general, mucosal and skin symptoms such as headache, fatigue and irritation in the upper respiratory tract, throat, eyes, nose, hands and/or facial skin (26) p.1." There are several practical measures enlisted by (26)– and others - to prevent and /or limit the SBS effect - such measures include: regular ventilation of the household, ensuring sufficient air exchange, cleaning surfaces, using the kitchen hood for ventilation when cooking. Such measures are necessary to enhance the health of occupants within buildings. R. Afshari (27) emphasizes the correlation between improved indoor air quality and better health / immune system of a given population.

Occupants' health goes hand in hand with the term "healthy buildings.", which can be considered the antonym of sick buildings. Instead of asking why buildings make us feel so sick, researchers are now asking how buildings can make us feel healthy? The notion of a healthy building entails that "a building continues to maintain optimal occupant physical, mental, and social well-being conditions during extreme events and over extended periods (10)." The idea of healthy buildings did not dominate the well-being research agenda since the start of the pandemic, but well before that. It is a buildup of several concerns – including: climate change, aging demographics in the northern part of the globe, as well as the general lifestyle changes accompanied by long-working hours and peaking levels of anxiety and stress (10).

The indoor environmental quality (IEQ) refers to "the quality of building" environments in relation to the health and well-being of those who occupy space within it (28). There are many parameters – combined – that assess the environmental quality of a given space. Such parameters include the indoor air quality in addition to the thermal comfort, noise levels, water quality, the interior design and furnishing within a space, the general social health and mental well-being of occupants ...etc (10). Or in other words, how a space contributes to enhancing the performance of such parameters. There are two main methods by which to assess occupants' health within a building: physical measurements and surveys (10).

A more structured assessment methods are put forward by buildings' performance standards are a means to assess the extent of "healthy" buildings physical performance. Examples of such standards and associated certification programs include the WELL standards (29), Building Research Establishment Environmental Assessment Method (BREEAM) (30), Leadership in Energy and Environmental Design (LEED) (31), and Fitwell (32).

A less known building performance standard is the Greenship Interior Space rating system, adopted in Indonesia, focusing on the Indoor Health and Comfort. Wardhani *et al.*(1) presents a review of relevant literature on indoor health and comfort criteria that need to be revised in order to reduce infection rates of COVID-19 within a confined space. Wardhani *et al.* (1) analyzes the Greenship International Rating system in light of the pandemic and benchmarks published recommendations on IAQ to better adapt the performance criteria on the Indoor Health and Comfort. The recommendations for adjusting the indoor health and comfort criteria include:" introducing outside air, stopping air recirculation, reducing indoor user capacity, and reducing indoor biological and chemical pollutants."
The extent by which occupants' health is considered the priority objective within such standards is not affirmative. (10) makes the point that often the multi-stakeholder group in charge of commissioning the building – designers, architects, contractors, sub-contractors, building operators …etc – have conflicting information and perspectives that hinder implementing the performance criteria that contribute to a higher indoor environmental quality; and cost is often the sole determining factor.

2.2.4 Technology and Innovation

With no doubt innovative approaches can make policies more effective – as documented by the OECD policy documents on COVID - 19 (6,7). Digital tools developed in response to the COVID-19 pandemic "provide potential opportunities for policymakers to address the challenges posed by the pandemic (6) p.2." However, such digital tools are entangled with breaching individual and privacy rights (7). These digital tools include mobile applications that track locations of individuals, mobility patterns, and agglomerate personal and health data; all of which come in with their set of strengths and challenges.
As an example for an innovative mobile application that attempts to monitor indoor air quality was devised by Mumtaz *et al.*(33). The published paper presenting the proof-of-concept study devising an indoor air

quality sensors system that detects 8 types of indoor pollutants, together with metrological measurements, claims to provide real-time results projected on the web and a mobile application. The proposed solution is said to "offer several advantages including remote monitoring, ease of scalability, real-time status of ambient conditions and portable hardware (33) p.1."
Ding *et al.* (34) are in agreement that Artificial Intelligence (AI) and machine learning is recommended for more stringent and timely control of ventilation and airflow requirements within a given space – for instance, the use of (Computational Fluid Dynamics (CFD) modeling.

2.2.4 Energy and Building Performance

A particular research niche that is trending within the indoor air quality and COVID-19 dilemma is the energy efficiency consequences of running the HVAC systems on such high ventilation rates for improved indoor air quality and the overall building performance. In other words, the question raised by researchers is how to balance between meeting the HVAC ventilation standards – which consumes much energy – and at the same time optimize energy efficiency requirements? This research predicament is tackled from a multitude of angles: whether designing more efficient HVAC and ventilation systems, experimenting with IAQ thermal comfort thresholds, or studying the effect of natural ventilation – separately or combined with mechanical ventilation – on the overall energy performance of the building.

Anastasi *et al.* (35) elaborate on the challenges of achieving energy efficiency measures and thermal comfort standards within smart buildings. The author proposes simulation modeling to balance energy efficiency and comfort parameters. Among the proposed innovations is to detect IAQ parameters through sensors and infrared technology to detect the temperature of occupants. The infrared cameras are meant to detect the occupant's presence and movement and, as a result, operate the HVAC system according to optimal conditions – considering the area where occupants are and the required thermal comfort conditions. On the other hand, the sensors are there to obtain "direct interaction with the occupants to check the main environmental variables and comfort conditions (35) p.3." Further, G. Anastasi *et al.* the paper provides an overview of the available sensors' technologies – including those detecting CO_2 concentrations, temperature, and humidity levels.

On more generalized grounds – i.e. not specific to smart buildings - G. Settimo and P. Avino (36) emphasize the "dichotomy between indoor air quality and energy efficiency" during the pandemic. The authors present high level strategies and recommendations of governments attempting to resolve such an impactful challenge. The editorial piece brings to light the dichotomies linking energy efficiency and IAQ. The authors make a point that the controversy of prioritizing human health through focusing on Indoor Air Quality (IAQ) is not a new issue. The debate was tackled from another point of view – such as that of the Sick Building Syndrome (SBS) – refer to earlier literature review section on 2.2.3 Sick Building Syndrome Versus Occupants Health *and* Indoor Environmental Quality.
Attempting to find practical implementable solutions, D. Aviv *et al* (37) present an innovative HVAC design that attempts to decouple ventilation and thermal control. The results show that: "increasing outdoor air in standard systems can double cooling costs, while increasing natural ventilation with radiant systems can halve costs (37) p.1."
Trying to pinpoint optimal ventilation rates within educational settings are Balocco *et al.* (38) , Alonso *et al.* (39) and Bazant *et al.* (5)**.** While Balocco (38) studies the ventilation design of a historical school building balancing energy savings and ventilation conditions in order to reach an optimized indoor air quality scenario that ensures the sustainability of the school as a healthy building; Alonso (39) studies the effect of recommendations of international guidelines to over-ventilate with a fresh outdoor air supply especially in educational facilities. The latter studies such effects on thermal comfort and indoor air quality in winter for two classrooms in Southern Spain. Alonso (39) concludes that– with regards to the analysis of standards - 60 percent of operational hours cause thermal discomfort conditions.
On the other hand, Bazant (5) proposes an updated guideline for mitigating the indoor airborne viral transmission of COVID-19 – an adaptation of an existing standard – based on carbon dioxide monitoring.

The paper is supplemented by mathematical model to enable the "prediction of airborne transmission risk from real-time CO2 measurements (5) p.1." Examples are provided to showcase how the data can be presented – as per the guideline requirements – within university classrooms and office spaces.

SECTION III: DISCUSSION

Across the published literature on IAQ and the pandemic and the general literature of guiding documents, a set of instigated consequences has been deduced by the authors. While some of such consequences are intentional – others are not. Spatial design, occupant's health and comfort, building performance, ventilation and energy efficiency requirements, technology use, health and social equity, and policy implications; are some of the overlapping consequences deduced.

3.1 SPATIAL DESIGN

Architecturally speaking, the requirements for social distancing and decreasing the number of occupants within a given space would inherently mean that the spatial zoning needs are to cater for more isolated spaces, with more reliance on natural ventilation – if possible. For example, in office spaces, moving away from open working spaces to sheltered single – or small number of occupants – offices is evident. Another example is in a medical setting, the large open space zones – whether in waiting rooms areas or in large wards – would not be a preferred design. The same applies to commercial spaces. Whether restaurants or retail shopping centers, a more outdoors-oriented setting would be a preferred design. Schools - and educational facilities in general - are yet another building typology – like offices– that would move towards smaller spatial requirements per classroom, to host a small number of students per classroom.

3.2 OCCUPANT'S HEALTH AND THERMAL COMFORT

Health over comfort. This is in short, what is learned from the recently published literature and guidelines. Generally speaking, if guidelines are to be followed word-for-word, occupants are to spend most of their indoor time in thermal discomfort – especially in the winter season. But then again, health here is meant as physiological health and not psychological well-being. The isolation of spaces has un-explored implications on well-being: including anxiety, stress, and depression.

3.3 BUILDING PERFORMANCE AND VENTILATION

The call for blasting HVAC units, increasing ventilation rates, and adopting the latest air purifiers technology means that occupants' comfort and health will always be a competing priority with energy efficiency standards. The consequences of such an already existing debate are that more advancements in HVAC design will take place to balance energy efficiency performance, air purification, and filtration.

Moreover, central HVAC units are in principle to be reconsidered – if occupant's health remains a top priority. Literature has shown that viruses can be transmitted to a well-wider distance than the promoted 6 ft social distancing guideline - in the presence of centralized HVAC units.

3.4 TECHNOLOGY USE AND ENERGY EFFICIENCY

One more evident observation is that technology will play a more powerful role in monitoring IAQ parameters to decrease viral transmission and improve the energy efficiency of installed ventilation systems.

By the aid of AI dynamic sensors that follow occupant's movements – in what was brought forward in the smart buildings' discussion – will be yet another means to monitor IAQ, energy efficiency of ventilation systems, and whistle-blow in case of contamination is detected. The consequence of such technological direction implies that open access data and its social privacy implications are another aspect to consider.

3.5 HEALTH AND SOCIAL EQUITY

A less touched upon the topic is the social equity implications of relying on technology – not yet affordable - to improve IAQ and mitigate viral transmission. The argument of the (lack) of social equity is strengthened by the spatial requirements – more individualistic spaces – which might not be an affordable option for the larger community. The social equity challenge is not limited to residential accommodations but to most building typologies. For instance, hospitals during peak seasons of the pandemic were overcrowded, this meant that keeping with high quality standards such as in the isolation wards or ICU units was not realized in all other hospital zones.

3.6 POLICY IMPLICATIONS AND RATING SYSTEMS

Considering guidelines as part of the soft policy interventions, there is a lot to be said about the implications of IAQ guidelines published during the pandemic – on the long-run. Guidelines are continued to be written in a temporary spirit, assuming that the pandemic is a short-lived health hazard. Question is: what if it is here to stay? In other words, one of the lessons learnt from the pandemic is the ease of viral transmission within enclosed areas. In that light, guidelines need to be written with a much clearer language to account for long-term affordable solutions, that can be universally applied.

Complementing guidelines, are the green buildings rating systems. Currently published certification systems – such as LEED - do not offer much for healthy and well-ventilated buildings – in the proposed capacity of IAQ recommendations. The majority of the published rating systems were focused on the other end of the spectrum – namely: energy performance, which contradicts current IAQ recommendations focus of healthy buildings and healthy occupants in the new normal post the COVID-19 era. Other standards, including WELL standards (29) – which are more focused on wellbeing might gain more grounds. Potentially, new rating systems will emerge to allow for a new label of airborne safe buildings – though the evidence is yet early to concur the "the rise of new rating systems."

Table 1: Instigated Consequences Related to IAQ and COVID-19 Reviewed Literature

Category	**Consequence**	**Based on (Reference)**	**Expected Impact**		**Type of Consequence**	
			Short-term	**Long-term**	**Intended**	**Non-Intended**
Spatial Design	Reducing viral transmission	(4,9,13,17)		√	√	
	Number of occupants decreased within a space	(10,13,35)		√		√
Occupant's Health and Thermal Comfort	Prioritizing physiological health of occupants	(1,10,38)		√	√	
	Thermal comfort becoming a secondary priority to eliminating or reducing viral transmission.	(16,39)	√			√
	Building certification systems might have a larger market in the future	(1,10)		√		√
Building Performance and Ventilation	Energy inefficiencies as a result of excessive reliance on HVAC systems	(35–38)	√			√
	Increase of carbon footprint of buildings	(35–38)	√			√
	Social distancing might not be an effective precautionary measure in	(2)	√		√	

Category	Consequence	Based on (Reference)	Expected Impact		Type of Consequence	
			Short-term	Long-term	Intended	Non-Intended
	indoor environments relying on mechanical ventilation.					
Technology Use and Energy Efficiency	Unintentional invasion of privacy due to dynamic monitoring aspects	(33)		√		√
	HVAC design innovations	(3,34)		√	√	
	Energy in-efficiencies	(35–38)	√			√
	Increase in carbon footprint of buildings	(35–38)	√			√
Health and Social Equity	(In) Affordability of Solutions to decrease viral transmission (technology use and mechanical ventilation)	(6–8)		√		√

SECTION V: CONCLUDING REMARKS

As the basis of its discussion, the research paper documented and analyzed the key published recommendations for indoor air quality practices in the wake of the COVID pandemic. The analysis was conducted using a qualitative descriptive approach categorizing the type of recommendations – distinguishing between intended and not intended consequences of such recommendations. The analysis presented in this work reveals key trends which provide insights for building operators and designers. It also uncovers a possible shift in the longevity of such consequences where most of the listed consequences have a long-term impact – refer to **Table *1*.**

A few words, the pandemic set a revolution on IAQ research – and it remains a work in progress:

- While the issued guideline documents during the pandemic are considered a temporary intervention; the recent medical evidence suggests that the virus – and its evolving variants -is here to stay (40). This suggests that prioritizing health will remain a permanent shift within issued standards and guidelines. Notably, the social distancing and the implications of decreasing the number of occupants within a space is yet to see a more substantial presence in building standards and codes.
- This realization urges authority associations and organizations to advance standards and guidelines with primary objectives that integrate both health priorities and sustainability aspects. Finding the balance between energy cost effectiveness, economic use of resources, social dimensions and health and comfort of occupants will be the challenge for current and future policymakers in attempt to issue a comprehensive indoor air quality standard(s). A simple straightforward existing dichotomy is the call for maximizing ventilation and filtration while paying minimal attention to the energy costs such operations incur.
- With reference to tech-use in monitoring IAQ parameters, innovations utilizing dynamic sensors and AI technology will have more influence in the future. Commercializing such technology for the wider use – with a focus on affordability and ease of utilization – is a work that will see the light in the near future.
- Although the research on optimal design for the HVAC ventilation systems and air purifiers is picking up, there is still no affirmative answer on what to expect on energy efficiency performance on the long run.

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