COVID-19 bacteria viability and transmission in a shared ducted air conditioning system in multi residential building

قابلية بقاء بكتيريا الكورونا وانتقالها في نظام تكييف الهواء ذات نظام مجاري الهواء المشتركة في مبنى سكني متعدد

by

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Abstract

The last year of 2020 by all thoughts, had changed the whole world normality. We have woken up on a sudden change of where whatever was granted, is not anymore. It is not granted that you go to work, to school, for grocery shopping or hang out as usual. It is not granted that holidays will be passed with families, and your plan to have the trip you were excited for is frozen till further notice. And above all, you might be in a risk of health issue and you were not aware of, and you might have put your most valuable people in your life in a health risk and you are not aware of.

The year of 2020 had started with a hit of a virus of SARS- Cov-2 named after its starting year at end of 2019 “COVID - 19”, that had changed our life and taken us to a phase of pandemic. The pandemic of COVID - 19 has been the hit, the topic, and the change. When things were so granted, we didn’t have the time to appreciate the little but not so little things anymore. We had time to reconnect within our small families, had time to talk and listen without saying later. We had time to sit together and share moments that had been lost in the hectic speed of life. Welcome back to those values!

This phase had urged the world to look into two scenarios for COVID - 19; one being the importance of limiting and stopping its spread; and the other scenario was to find the cure. The World Health Organization (WHO) had initiated and supported all studies, researches and experiments on the subject. This study will assist in the first target to look how the transmission of the virus is going into buildings and its services and what can be done to limit it.

نبذة عن البحث

يقوم هذا البحث على التغييرات الحياتية التي طرأت على حياتنا بسبب وباء و فيروس كورونا 19 . فجأة و بعد عن اتخذنا في دوامة الحياة والتكنولوجيا التي جعلت كل شيء في حياتنا ممنوح و متواجد ، عدنا لنجد أنفسنا في أشد الحاجة لنعيش أبسط الامور كما كنا سابقا". لقد صار من الصعب و فقط في الاستثناءات و الطوارئ ان نخرج من بيوتنا لأي من الاسباب كانت للعمل، او للتبضع او للتنزه ولقاء الاصدقاء و العائلة. اصبحت جميع مخططات السفر والسياحة حلم بعد ان كنا نستسهل السفر حول العالم.

العالم كله في سباق في اتجاهين كل منهما أشد قيمة من الآخر وهما : الاول هو الحد من انتشار الفيروس وتحولاته والاخر هو الوصول الى العلاج .

من خلال هذا البحث وهذه الدراسة سنتطرق للمعايير الهندسية و الميكانيكية التي نستطيع من خلالها تأكيد او نفي انتشار الفيروس في المكيفات و كيفية معالجة اي تسرب او انتشار من خلالها.

Acknowledgement

I would like first to thank this pandemic. As weird as it sounds, as deeply I feel I have to. Through this stage, I have looked into the value of things and people in my life. It made me face hard times and losses, but all of this, just to get me personally to another level of maturity. This year had me to value and enjoy my ethics, and values and stand so proud of them.

I want to thank my “Incredibles”; my life-partner, my honor of holding his name, Mohamad (for good and bad days standing up with me at all means). My heart and its beats, my pride of being their mum, my boys Ahmad and Adam for being my support system and my smile and laughs when things looked grey.

I want to thank Dr Kirk Shanks, for an outstanding assistance, academic, professional and educational in every step of this research. When things looked out of track, I wouldn’t have found a better support to get back on my targets.

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1. Introduction

In December 2019, there was a large outburst of a new coronavirus called SARS-CoV-2. Originating in Wuhan, China, the novel coronavirus was believed to cause the respiratory disease COVID-19. Earlier assumptions by the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) were that this virus had spreading conditions that mirrored those of the SARS virus that occurred in 2002-2003. SARS-CoV-2 was believed to have been passed to humans from bats. Genetic composition hypotheses relying on the transmission of the virus presented a transmission assumption based on the experience of SARS-CoV in 2003 through droplet of air and the transmission of the virus at adjacent range. During the 2002-2003 pandemic, SARS-CoV was reflected to be a disease of airborne transmission potential. SARS-CoV affected about 8,000 individuals and spread to 26 countries. The SARS-CoV mostly affected individuals within healthcare settings and subsided after nine months. In contrast to the SARS-CoV, COVID-19 potency has proved higher and has since affected virtually all part of the world. According to the World Health Organization, COVID-19 is mostly spread through saliva droplets and discharge from the nose when individuals who are infected cough or sneeze. Talking can also release the said droplets (Schoen, 2020). Further, available research shows that closed environments such as buildings and public transport tended to witness increase of the rate of transmission (Nishiura et al., 2020). There is reported evidence suggesting that aerosols play a significant role in the transmission of the virus. Aerosols behave like gases and can remain in the air for longer periods and travel further distances (Schoen, 2020). The WHO and the CDC have emphasized that while droplets and fomites play the leading role in the transmission of Covid-19, under certain conditions aerosols can lead to transmission.

The World Health Organization has since proclaimed COVID-19 as a global pandemic. When this was proclaimed in March 12 of 2020, there were around 120,000 cases; the disease had also spread to 120 countries and was responsible for at least 4000 deaths (ASHRAE, 2020, p.1). COVID-19 has turned into a pandemic more seriously impacting than SARS in 2003. Later databased studies and modeling of COVID-19 advised the likelihood of airborne disease transmission. There is deep concern about the possibility of transmission through air of different pathogens, especially SARS-CoV-2, among healthcare facilities staff, within office environments, in retail settings, workers in factories, occupants and residents of private and public facilities, and public in outdoor locations and in public transportation. By July 2021, cases reached more than 200 million COVID-19 worldwide and more than 4.5 million deaths (Weforum,2021). According to ASHRAE (2020), with infectious disease potentially being transmitted through aerosols, heating, ventilation and air conditioning (HVAC) systems can play a preponderant role in averting the transmissions from primary to secondary hosts. Aerosols are similar to droplets only that they are smaller and can remain suspended in the breathing zone for a relatively longer duration - minutes even hours. Droplets on the other hand fall to the ground owing to their large nature.

1.1. Problem Statement:

HVAC systems do impact the distribution of aerosols which persist in the air (ASHRAE, 2020). The concern of which this study lies on, is the potential of the transmission of Covid-19 in multi – residential building serviced by a shared central HVAC system and ductwork. When designed effectively HVAC systems can help reduce the likelihood of airborne transmission of disease. Filtration systems and ventilation by outdoor fresh air provided by HVAC systems are considered to have the ability to mitigate the airborne concentration of SARS-CoV-2 / COVID-19 (Shadpour & Johnson, 2020, p.24). Based on this prelude, HVAC systems may be used to reduce the potency of COVID-19.

1.2. Research Question:

This premise will form the basis of the following research. Where diseases can be transmitted through air, HVAC systems have the main effect on the transmission from the primary host to secondary hosts. Therefore, exposure of secondary hosts has to be reduced in order to contain the spread of infectious diseases. HVAC systems impact the distribution and filtration of pathogens. As exposure to airborne infections in aerosol form presenting a high risk to secondary hosts this study investigates the potential for transmission of COVID-19 through typical air conditioning systems in mid- and high-rise residential buildings, through confirming the below concerns:

Question 1: Does COVID-19 spread through HVAC system?

Question 2: Would HVAC operational strategy limit the spread?

Question 3: Are Filters limiting the transmission in HVAC system?

2. Aim and objectives:

2.1. Research Aim:

The main aim of this study is to determine, if COVID-19 virus can remain viable in the air and move from the original source through air conditioning systems to other spaces that share the same fresh air supply and extract air duct networks. The work will evaluate the likelihood of droplets and aerosols carrying COVID19 virus to disperse via air conditioning systems in a typical multi-residential apartment tower. The study will further identify approaches that are used for the operation of the HVAC system in the buildings and related to occupancy and scheduling and filter provision in the system that by hypothesis, may reduce the dispersion of aerosols carrying COVID-19 virus and evaluate the impact of air conditioning management has on dispersion potential. These issues will be investigated through the construction and use of bulk airflow contaminant dispersion models representing typical as-built airflow pathways in a generic multi-residential tower. The research study will additionally provide an up-to-date review on empirical studies of similar virus transmission and dispersion in air-conditioned buildings including reported studies of SARS2 transmissions in buildings. The factors affecting how long COVID-19 bacteria remains contagious and living under temperature and humidity variations and its lifetime would be discussed. The models will be developed to study the contaminants' dispersion in air-conditioned buildings.

2.2. Objectives

- To evaluate the likelihood of aerosols carrying COVID19 virus to disperse via air conditioning in a multi-residential apartment tower.
- To establish a bulk airflow model representing typical as-built airflow pathways in a multi-residential tower.
- To identify and assess operational solutions and approaches in air conditioning management that may assist in reducing the dispersion of aerosols carrying COVID - 19 virus, such as filters usage and assessment of working time for the HVAC system
- To determine if COVID – 19 contaminants get dispersed from an infected occupant of one residential unit to other residential units through HVAC system and cause infections of the tenants of those units.
- To detect if location of the source of infection in COVID – 19 towards the exposures / occupants in other residence units on the different floors make any difference towards the viral spread
- To distinguish if any scheduling in operational run of the HVAC system within the building have an impact on the dispersion of COVID - 19

3. Literature review

In the building mechanical systems, air conditioning systems are considered a significant milestone. Air conditioning traces its root to as early as second-century China. Chinese artisan Ding Huane fashioned a manually powered rotary fan used as an air conditioner in palace buildings (Varrasi. 2011). Several centuries later, Benjamin Franklin began working on fanning and evaporation concepts where alcohol could be evaporated to attain cooler temperatures. Willis Carrier is often accredited as the originator of the modern air conditioner (Ilahiet al., 2018; Varrasi. 2011). Carrier began experimenting on the laws of humidity with the objective of solving an application problem at a New York printing plant. Carrier's air conditioner was based on refrigeration concepts. Soon he formed the Carrier Air Conditioning Company of America in 1933. The first design by this company was a belt-driven air conditioner. This invention paved the way for the air-cooling system market (Varrasi. 2011). At the same time, the modern air conditioner has undergone many improvements, the concept that powers contemporary air conditioners remains the same as those outlined in Carrier's designs.

Air conditioning systems confer occupants of a building not only thermal comfort but also indoor air quality. The basic operation of any air conditioning system entails the absorption of warm air from a given space, processing of the said air with the help of a refrigerant and an array of coils to cool it; releasing the cool air back into the same space where the warm air had been collected originally. Refer to fig.1.

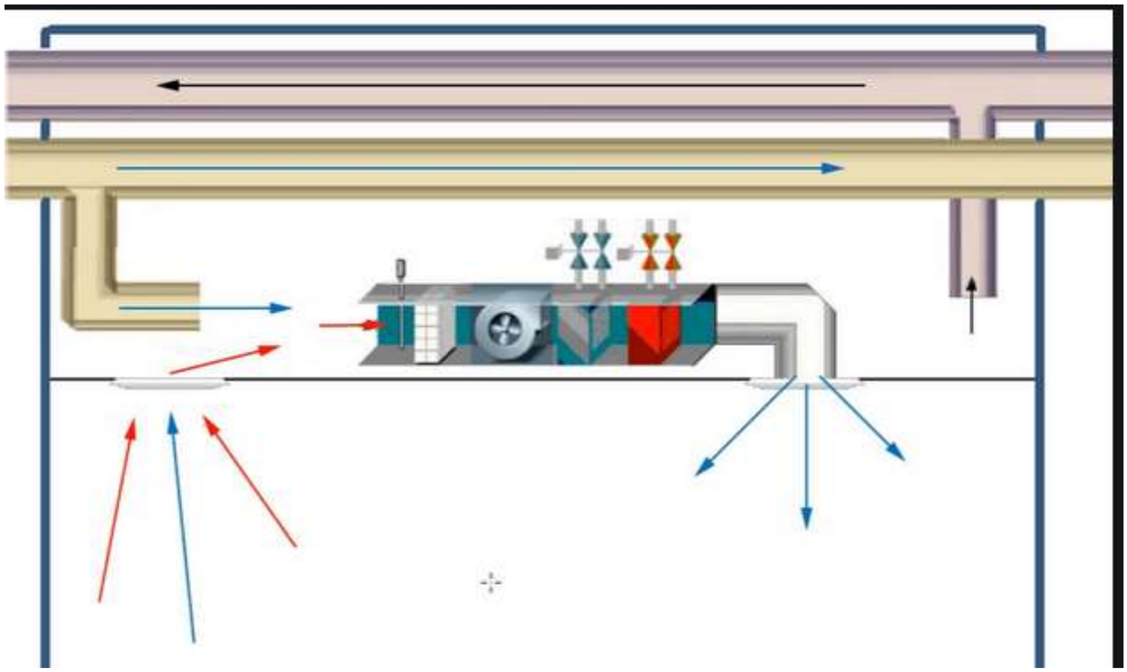


Figure 1. HVAC with FCU (Engineeringmindset, 2021)

The typical air conditioning system will be composed of 5 key components: refrigerants, expansion valve, condenser, compressor, and evaporator. Air conditioning systems may be classified into either central systems or those based on local systems relying on distribution, location, and zones (Seyam, 2018). In centralized systems, the air conditioning equipment is generally located away from the building apartment and delivers conditioned air via a ductwork system connected to the units being supplied. On the other hand, in a local system, the system will have a local ventilation, local air conditioning, split system, and local heating (Seyam, 2018). The central system may serve a singular unit but is often designated to serve several units; the latter approach is sought in the following study.

3.1 HVAC systems and modes

Invented in the early 1900s by Willis Carrier, the air conditioner has played an essential role in modern civilization. It has enabled numerous industries and continues to play a critical role in modern economies. Industries such as manufacturing, film, information technology, aviation, and many others have been greatly facilitated by air conditioners (Ilahiet al., 2018). Specifically, the ability to precisely control temperatures and humidity within buildings allows for better cinema halls, shopping malls, and factories. Air conditioners are also extensively used to cool servers that run modern internet. In highly humid and hot countries such as the UAE, the air conditioner is indispensable. It is extensively used in homes, offices, institutions, factories, malls, hotels, and other buildings to increase the comfort of building occupants (Hamdan and De Oliveira, 2019; Saghafifar and Gadalla, 2016). Air conditioning will form the basis of the following research work. Specifically, the study will focus on a centralized complete fresh air handling unit air conditioning system supplying pre-conditioned fresh air to individual fan coil units in each residential unit and corridor.

The system will also have a centralized extract fan that does not have a connected air path to the fresh air handling unit. The full fresh air air-handling unit will be located at roof level and supply pre-conditioned fresh air to fan coil units on each floor via fresh air duct risers. Similarly, exhaust air is drawn out of apartments and corridor by a extract fan located at roof level and connected to each floor via an extract duct riser. Air conditioning supply air diffusers and return air grilles for studio units and corridors on each floor are connected to the fresh air and extract risers by short branch ducts.

In the United Arab Emirates, there is a high demand for air conditioning systems to provide a comfortable and healthy indoor environment. Studies show that 90% of people in the UAE, and similar to United States of America, spend their time indoors, with 68% of them being in residential buildings (Cetin and Novoselac, 2015). In that case, there is a high demand and necessity for air conditioning, which is accomplished by the heating, ventilation, and air conditioning system (HVAC). Moreover, given the design and structure of buildings such as multi-storey buildings, the focus shifts towards residential centralized HVAC systems where the temperature is maintained from a central point (Wang, Li, and Wang, 2019). As much as HVAC systems are able to provide a comfortable and cool indoor environment, there are concerns in regard to air circulation and the associated viral load from contaminants. Since a central HVAC system connects air pathways between several floors, there is a possibility that aerosols and viral particles can be transmitted between different floors in a multi-storey building.

There are different HVAC systems which are used in several different typology of buildings such as commercial, residential and other public and industrial use. Depending on several conditions related but not limited to location, climate age, type and configuration of the building, the architectural design, the engineering recommendation and mainly the cost and budget, the HVAC system is selected where the outdoor fresh air is drawn into the buildings and conditioned whether heated or cooled and then circulated into the internal spaces, then exhausted outside to the ambient outdoor air or partly recirculated and reused in the system.

There are two major arrangements of HVAC systems: central system and local system. The type of the system depends on designing the primary equipment to be in a central location and to condition the whole building as a single unit, or decentralized as to be locally based into each zone and individually conditioning a separate zone of a structure. Thus, the water and air distribution system should be planned according to the classification of the intended system and the allocation of the primary equipment and the chosen distribution system.

In general, in a centralized system full of fresh air handling unit air conditioning, the major equipment serving the apartment is located away from the served zone in a central location that is suitable for the purpose – typically adjacent or atop the apartment. The main system must condition the equivalent thermal load for each apartment unit. A thermostat or other conditioning methods generally are deployed for such purposes (Seyam, 2018). As the basis of any air conditioning system is thermal transfer, the central system uses several mediums for said thermal transfer. Water or air, or both, is typically used for this purpose. Accordingly, the central system would either be an all-water system, all air system, or an air-water system. Aside from these, the main systems have cooling and heating panels and water-sourced heat pumps (Seyam, 2018). The centralized system also has combined outdoor air, filter, mixing box, preheat coil, cooling coil, reheat coil, humidifier, and supply and return air fans.

3.1.1. Air Conditioning Standards and Regulation

The American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE) standards are the top reference point in the heating, ventilation, and air conditioning (HVAC) industry. There are also other standards, such as the Chartered Institution of Building Services Engineers (CIBSE) though ASHRAE standards are generally deemed more extensive (ASHRAE, 2020; CIBSE, n.d.). Countries also often have local standards complimented by ASHRAE or CIBESE standards. Notwithstanding, in many countries, ASHRAE standards are deemed effectual and are often the default guiding principle used in air conditioning (Haines and Myers, 2010). According to their latest handbook, there are currently 87 operational guidelines and standards from ASHRAE (ASHRAE, 2020). These standards and guideline review topics such as reducing refrigerant emissions, indoor air quality, and thermal comfort, among other issues. ASHRAE standards may offer installation procedure, rating purposes, and other relevant information relating to HVAC systems. Air conditioning system designers regularly review the standards and guidelines offered by ASHRAE to understand the different standards, industry best practices, and guiding principles in air conditioning matters. The standards offered by ASHRAE ensure that buildings are compliant with the local regulations and that building owners use the latest industry technology and design techniques that ensure buildings are safer and more energy-efficient.

ASHRAE standards and guidelines offer a detailed account of central cooling and heating plants in their 2020 handbook. According to the standards, centralized air conditioning systems may be used in almost all building classes (ASHRAE, 2020). However, ASHRAE recommends this approach for very large buildings and complexes or buildings with a very high energy use density. According to ASHRAE, centralized air conditioning is particularly suited for maximizing the service life of air conditioning equipment. Examples of buildings that are good candidates for central air conditioning according to ASHRAE include industrial facilities, large office buildings, urban centers, museums, and similar institutions, high rise facilities, large hotels, condominiums, apartment complex, campus with a distribution of several buildings' hospitals and educational facilities (ASHRAE, 2020). All in all, ASHRAE's standards and guidelines play an important role in building mechanics. In the UAE, the ASHRAE and CIBSE standards extensively complement local standards.

The UAE has a hot arid climate with temperatures rising to about 50 degrees Celsius in the summer. This makes air conditioning of critical importance. The UAE's high summer temperatures mean that the electricity consumption in the operation of the air conditioning system is greatest in summer but is also high in other seasons compared to other climates. It is estimated that up to 70% of the UAE energy expenditure goes to cooling and air conditioning systems (DEWA, 2019). High electricity consumption means high levels of greenhouse gas emissions. The fact that the UAE's leading electricity source is from fossil fuels epitomizes a lot of greenhouse gas emissions. A number of approaches have been proposed to help arrest this problem one of which are localized green building regulations, e.g., Al Sa'fat (DUBAI Municipality, 2020)

Al Sa'fat is essentially a system of design, specification and operation standards introduced by authorities in the UAE to enhance buildings user safety and ensure sustainability. Specifically, it is based on Dubai Municipality Green Building Regulation and Specifications. Al Sa'fat was approved in 2016 as a green building rating system (Shibeika et al., 2020). Beginning October of 2020, Al Sa'fat replaced previous green building regulations and specifications. Al Sa'fat consists of a set of mandatory regulation that owners of building must abide by and other regulations at the discretion of building owners (Ahmed, 2019). Notwithstanding, owners can aim at achieving additional requirements for their building to obtain the Platinum or Golden Sa'fa.

3.2. Central HVAC system:

A central HVAC is an air conditioning system where the air is cooled at a central location and distributed to and from the rooms using fans or ductwork (Elnaggar and Alnahhal, 2019). In which case, the cooling, as well as heating process and the distribution of air, involve the fan coil unit and the air handler unit. However, it is important to note that the use of fan coil units is mostly applied in all water HVAC systems where water is the main fluid used in thermal energy transportation between the central HVAC and the conditioned room (Elnaggar and Alnahhal, 2019). Hence, it involves the circulation of chilled water for cooling as well as the circulation of hot water for the purposes of space heating. Since only water is the conditioned space by the central HVAC, fresh air is distributed through a different unit in order to ensure proper ventilation and air quality (Seyam, 2018). Therefore, a central HVAC system comprises either a 2-pipe system or a 4-pipe system. A 2-pipe system uses a single pipe for both hot water and cold-water heating and cooling, respectively (Seyam, 2018). On the other hand, the 4-pipe system has separate pipes for the heating water and the cooling of the chilled water.

3.2.a. Fan Coil Unit.

The fan coil unit is an important HVAC system package consisting of a fan, cooling/heating coil, air filters, and condenser drain pipe. In a central HVAC system located in a multi-Storey building, the fan coil unit is located on each floor, and air conditioning is controlled from a central location (Elnaggar and Alnahhal, 2019). In which case, the fan coil unit works in such a way that chilled water is circulated via the finned tube coils and while the fan receives conditioned air from the air handler unit

(Wang, Li, and Wang, 2019). Subsequently, the fan or blower is used to draw the warm circulated area from the conditioned space. The blower blows the warm air over the cooling coil at the fan coil unit, where it is cooled and dehumidified (Afram and Janabi-Sharifi, 2014). The dehumidified and cool air is then supplied to conditioned space or floors to provide the necessary room conditions. For energy saving, and in order to minimize the amount of cooling needed to precondition fresh ventilation air from outdoors, both fresh ventilated air and warm circulated air from the conditioned space are supplied to the back of the FCU. This energy saving measure is taken while ensuring adequate ventilation level for the space. During the process, there is the condensation of water due to the dehumidification of warm air. Hence, there is a need to drain the condensed water frequently.

3.2.b. The Air Handler Unit.

The air handler unit is part of a central HVAC system located at a central location within a multi-storey building. In which case, they can be located at the basement of the building or the rooftop (Elnaggar and Alnahhal, 2019). The unit has a crucial role in that it facilitates the process of taking fresh air from the outside, cleaning, cooling or heating, and then directing the air to fan coil units located on each floor (Elnaggar and Alnahhal, 2019). Thus, it consists of a fan, cooling and or heating elements, sound attenuators, filter racks, and dampers that ensure preconditioning of fresh air conditioning before being supplied to fan coil units.

The Central HVAC system is located in a central equipment room located outside the served spaces, inside the building, on top or adjacent to it. The HVAC system deliver the conditioned air with its related thermal load by a delivery ductwork system to the required zones controlled by several controls such as thermostats in each space. The thermal energy is transferred by medians such as water or air and both of them, which are explained as all-air systems, all-water systems, air-water systems. Centralized HVAC system has water-based pumps along with coils for cooling and in certain locations for heating. Also, central HVAC system consists of combined devices in an air handling unit, which can contain supply and return air fans, humidifier, reheat coil, cooling coil, preheat coil, mixing box, filter, and outdoor air. Refer to fig.2.

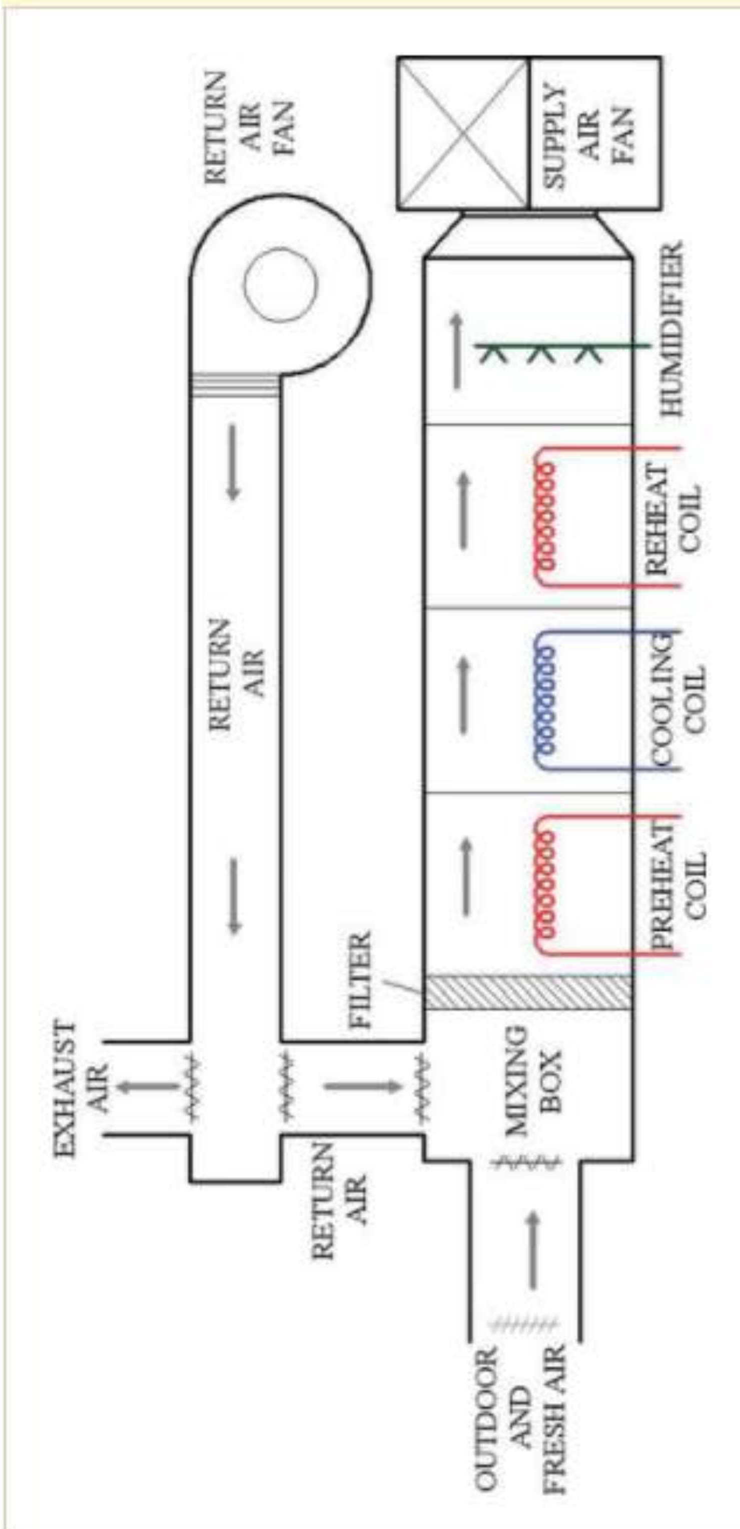


Figure 2. Equipment's arrangement in central HVAC system

3.2.1. All-air systems

The air is the delivery medium of thermal energy transfer through the building ductwork delivering systems. All-air systems are sub-based on the zoning classification as single zone and multizone, and airflow rate to be constant air volume (CAV) or variable air volume (VAV), terminal reheat, and dual duct.

A single zone system is the simplest in design and maintenance and the initial cost is low compared to others. It consists of an Air Handling Unit (AHU), heating and cooling sources, distribution ductwork, and fitted delivery devices. Several spaces fall into the same thermal zone supplied from a rooftop unit by ductwork to supply the conditioned air. Only few buildings types can be a single thermal zone, such as one-family residential buildings or buildings of single use according to same schedule like small to medium sized schools or kindergarten schools, while other categories of residential buildings such as high rise, and mixed use would be designed for different conditions based on occupancy and building structure.

A multi-zone all air set up must get fitted with separate supply air tubes. At the air conditioning system, supply hot and cold air, and return air, are mixed to meet each zone's thermal requirements. Each zone has its air conditioning that cannot get combined with air from other zones. Additionally, several zones with varied thermal needs require different supply tubes, as shown in Figure 3.

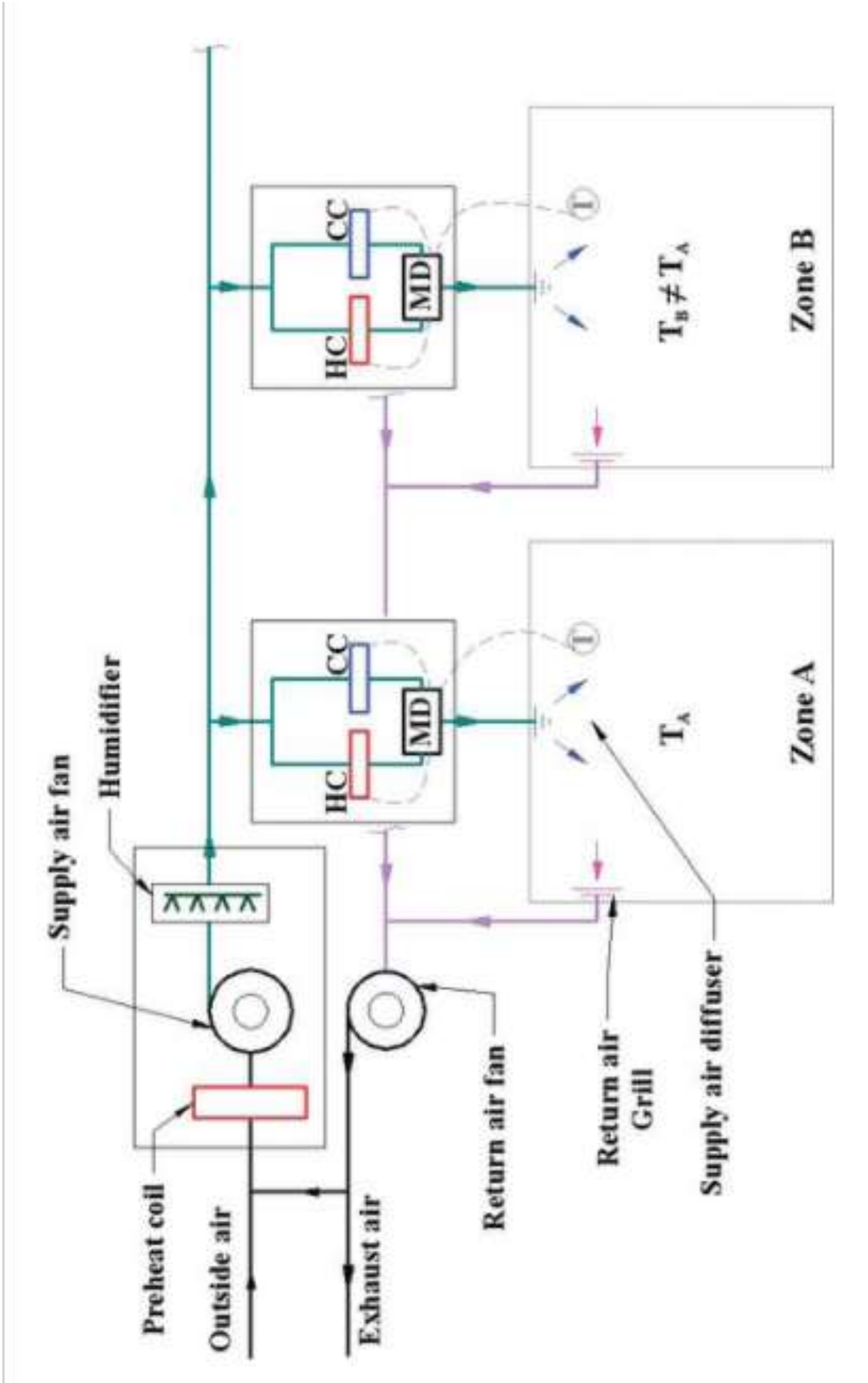


Figure 3. Multi-zone all-air central HVAC system diagram

A multi-zone all-air system comprises of an internal mixing damper and an air handling device with some parallel flow routes through heating and cooling coils. Based on the practical constraints on damper size and duct connections, it is advised that a single multi-zone is in the service of at least 12 zones. However extra air handlers could get utilized if additional zones are necessary. The multi-zone system can effectively condition many zones without the wastage of energy that is related to terminal reheat systems. Nevertheless, the Leakages in the decks of an air conditioning system, may diminish energy efficiency. One of the drawbacks is that several supply air tubes are needed to serve several zones.

3.2.2. All-water systems

In all-water system, heated and cooled water are distributed from a central system to the conditioned spaces. This system is smaller in size comparing to other types of systems due that water pipes as the distributor containers, this is due to that the water has higher heat capacity and density than air, and would require the lower volume to transfer heat. The all-water systems are split to heating-only system in cold climates that deliver to equipment such as radiators, whether they are floor or baseboard, heaters and air convectors, and in hot climates to cooling-only system that deliver to ceiling mounted units of which the main type is fan-coil units.

3.2.2.a Fan Coil Units

Fan-coil unit is a small unit that can be installed horizontally and/or vertically and supplied by circulation fan, for heating and cooling coils, through a control system. In central systems, the fan coil unit is connected simultaneously to both sources of heating as boilers, and cooling such as water chillers. The thermostat is the control for the desired temperature per zone, thus it controls the flow of water reaching to the units. Occupants of the space can adjust both the thermostat, and the louvers of the supply unit to achieve their comfort level. Nevertheless, two main disadvantages for the system prevail, the first is the ventilation air unless the units are linked to outdoor air, and the second is the associated noise level which is critical aspect in some zones or rooms.

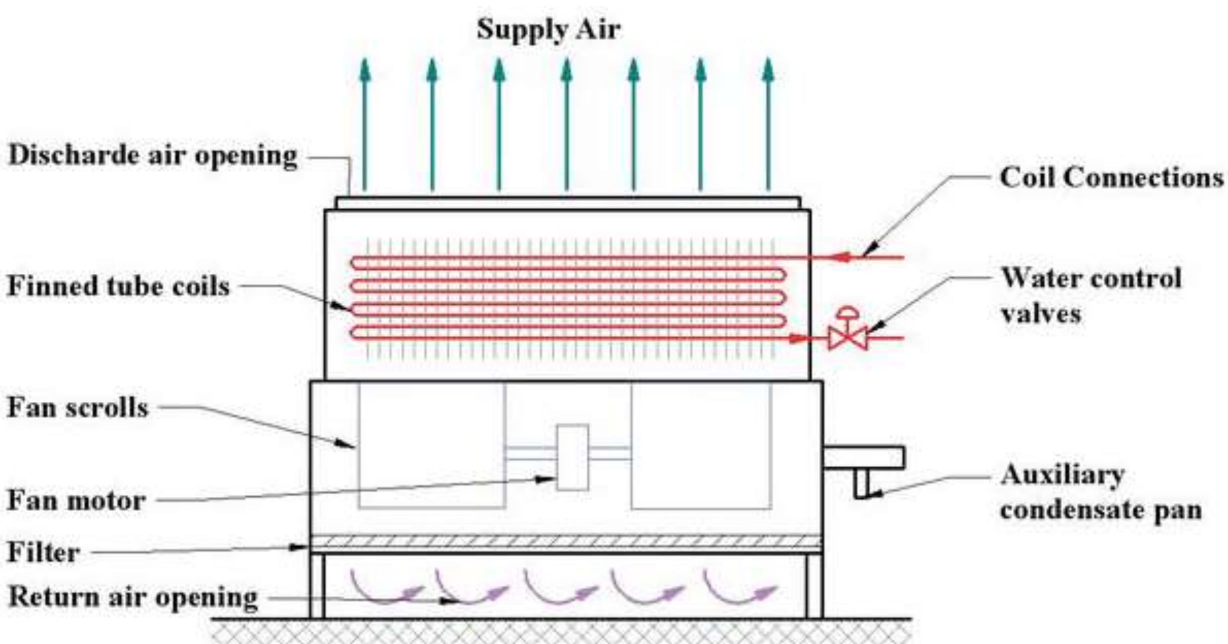


Figure 4. Fan Coil Unit

3.2.3. Air-water systems

The air-water system is a hybrid mix system combining advantages of both all-air and all-water systems. The volume i.e. noise level is reduced since the main medium (around 80-90%) to carry the thermal load is water through pipes whether it is heating or cooling water, and outdoor ventilation is properly adapted and the remainder (10-20%) conditioning of the load is through air. There are two types of equipment involved in the process: fan-coil units ad induction units.

3.2.3.a Fan Coil Units

A water system fan coil is similar to an air-water system unit. The distinction between the two is by the fact that both conditioned water and air supply are provided by central water systems and air handling units, whether chillers or boilers. The spaced linked to the fan-coil units receives ventilation air individually. The air-water systems' fan coil units are either 2 or 4-pipe systems.

3.2.3.b Induction Units

Externally, one can affirm that, induction units resemble fan coil units, but their internal operation is different. It replaces the forced convections of a fan in a fan coil unit by inducing air flow in a space through a cabinet utilizing high velocity air circulation from a central air handling unit. For a detailed explanation of the method, see Figure 4. The procedure is a mixture of two air flows, one primary from the air conditioning system and the other secondary from the return of the space. The mixture is conditioned to the optimum temperature by the water coil and then fed into the room

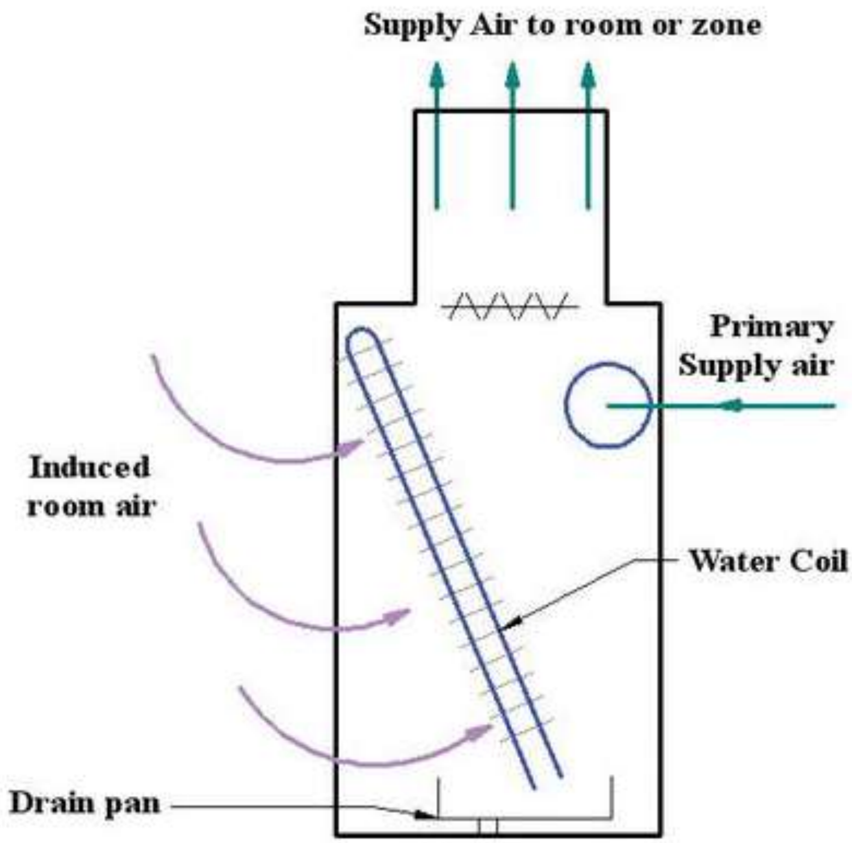


Figure 5. Induction unit

3.3. Ventilation and Air Filtration

HVAC systems modulate air quality of the spaces they serve and can therefore increase or decrease exposure to infectious particles in indoor environments. Air Conditioning is the filtration, heating, cooling, humidification and/or dehumidification of air before it is delivered to indoor spaces to provide both ventilation and thermal control. Ventilation is the supply and circulation of fresh outdoor air to indoor spaces. Commonly, HVAC systems maintains air cleanliness using filtration technologies, ventilation by diluting indoor air with clean outdoor air, and local exhaust extraction. This involves removal of potentially contaminated air to be exhausted safely outdoors, to decrease the risk of infection transmission. Thus, it is essential to understand the main need for ventilation for indoor spaces. Ventilation is related to respiration of humans within enclosed spaces, and for their thermal comfort feeling (psychological satisfaction of air movement, local air velocity 0.15 m/s (HANS,2005)) and for extraction of smoke in an event of fire outbreak. But ventilation is a must needed phenomena due to its capacity to dilute and remove contaminant such as volatile organic compounds (VOCs), moisture control and removal of odours and heat gains, along with the control of CO_2 level in any indoor spaces.

3.3.1 Air pollutants and aerosols:

The major objective for installing and designing ventilation system in a building and other enclosed areas is to reduce bacteria and air pollutants. These pollutants come in a variety of forms, including chemical and biological, and can induce a variety of syndromes and illnesses in the vicinity of the building's tenants. Building-related illnesses and syndromes like Sick Building Syndrome are most commonly caused by toxic black molds. The problem of SBS rises quickly especially in a damp and warm surrounding and can get ascribed to the air quality of a building in relation to the aerosol concentration. Furthermore, it is critical to remember that bacteria and viruses are ubiquitous in all buildings, particularly high-occupancy facilities such as schools and workplaces, where building-related illnesses and SBS can occur.

Building-related illnesses and SBS are becoming increasingly serious when the humidity levels are too high or too low. For instance, dust mites, are known to be highly allergic and feed on shed human skin cells that gather in carpeting, soft furnishings, carpeting, and other locations. Dust mites thrive in humidity levels above 70%, pollen allergy causes hay fever, which includes a runny nose and sneezing, and other respiratory disorders such wheezing, difficulty breathing, and asthma. Pollen can build up in a structure if sufficient filtering and ventilation are not maintained, as it can be carried inside on breeze through open windows or doors or brought in on clothing and shoes. In the same context, it has been proven that outdoor humidity can support viral spread since the virus fall with airborne droplets on surfaces thus can survive longer. Humidity level around 40-60 % had been noted as an optimum range to limit the spread (Sandoui, 2020)

Greenhouse gases can act as pollutants towards the air inside buildings and other enclosed human occupied spaces. People who use such enclosed environments may experience health problems as a result of these factors. Carbon Monoxide is known as the "silent killer" since it is odourless and colorless. Headaches, vomiting, dizziness, headaches, and nausea can all get caused by inhaling a small amount of Carbon Monoxide. Additionally, inhaling excessive levels of Carbon Monoxide, is known to induce death and a state of unconsciousness. Consequently, long-term exposure to a moderate quantity has been associated to a risk of heart disease because it affects oxygen transmission throughout the body. Sulphur Dioxide (SO2) is a colorless gas with a powerful odor. The gas has the potential to harm the respiratory system, particularly the lungs' functions, hence increasing the likelihood of respiratory infections. It irritates the eyes, causes mucus secretion and coughing, and aggravates illnesses like chronic asthma and bronchitis. Nitrogen Dioxide can be fatal in high concentrations. However, low concentrations of nitrogen dioxide (NO2) can be tolerated for lengthy periods of time and can exacerbate respiratory issues.

Some carbon-based compounds can evaporate in a building at room temperature. Several organic chemicals may have harmful effects on humans especially when absorbed within a building. Some of the construction and building materials get manufactured from organic elements like formaldehyde and several volatile organic compounds (VOCs) off gas from furniture and particle board for years, with the largest amounts generated in the first six months. Building-related disorders and SBS are caused by carbon-related gases. For instance, finishes such as the varnishes and paints, can increase the amount of VOCs in a building. Other causative factors of increase in the amount of VOC in the buildings includes, chemicals utilized in a structure, such as printer ink and marker pens, and cleaning supplies. Electronic equipment emits gases as a result of flame retardants and other additives employed during production. Additionally, deodorants, air fresheners, and fragrances, and fabric softener residues and laundry detergents on the tenants' clothing can increase the concentration of volatile organic compounds in the building.

3.4. HVAC Filters:

Heating, ventilation and air conditioning (HVAC) filters are part of the heating and cooling system at home or commercial buildings, which is used in filtering dust, pollen and pet dander among other small particles from the air that people who use the buildings breaths. HVAC filters trap these particles from air to prevent their circulation and hence reduce their chances of infecting people. The filter is used in a HVAC systems to maintain its performance and longevity of the HVAC system by protecting it from dust and airborne particles. This means it is an integral part of the system, yet often overlooked.

Apart from its role of protecting the HVAC system from damage, the filter is also designed to improve the quality of the interior air by ensuring it is free from dust particles that often cause allergic reactions and airborne particles that cause respiratory illnesses. The HVAC filter works by providing a physical barrier to the flow of particles being carried in the air through duct systems. As air is drawn in, particulates are caught by the filter and prevented from flowing further through a system while the clean and non-contaminated air is allowed to pass through. HVAC systems are designed with a filter at the point of air intake and also sometimes as part of local recirculating units close to indoor spaces, to further prevent any pollutants from being blown back inside a space.

Filters are rated in MERV which is the Minimum Efficiency Reporting Values. This is related to the filter’s efficiency and ability to have particles of different diameters trapped, ranging from 0.3to 10 microns. The higher the rating, the better the filter in capturing specific particles’ types, thus the more delicate locations the filter can be placed in.

MERV Rating	Average Particle Size Efficiency in Microns
1-4	3.0 - 10.0 less than 20%
6	3.0 - 10.0 49.9%
8	3.0 - 10.0 84.9%
10	1.0 - 3.0 50% - 64.9%, 3.0 - 10.0 85% or greater
12	1.0 - 3.0 80% - 89.9%, 3.0 - 10.0 90% or greater
14	0.3 - 1.0 75% - 84%, 1.0 - 3.0 90% or greater
16	0.3 - 1.0 75% or greater

Table 1. MERV rating for filters (EPA,2021)

3.4.1. Types of Filters in Relation to Size of Bacteria

Filters are made in different sizes with the size of bacteria in mind to improve their performance in cleaning the air circulating in the building spaces. Whilst high performance filters i.e. HEPA filters can filter out bacteria these are not common in residential air conditioning systems as they are more expensive, require more maintenance and cause an increase in required fan power. There are some reference sources which show the size of COVID-19 are as small as 1 micron (Cam.fil,2021), which means air conditioning filters that can stop bacteria may be suitable to stop COVID - 19 from circulating with the air in closed environments used by people. However, it is important to note that standard air condition filters do not stop bacteria.

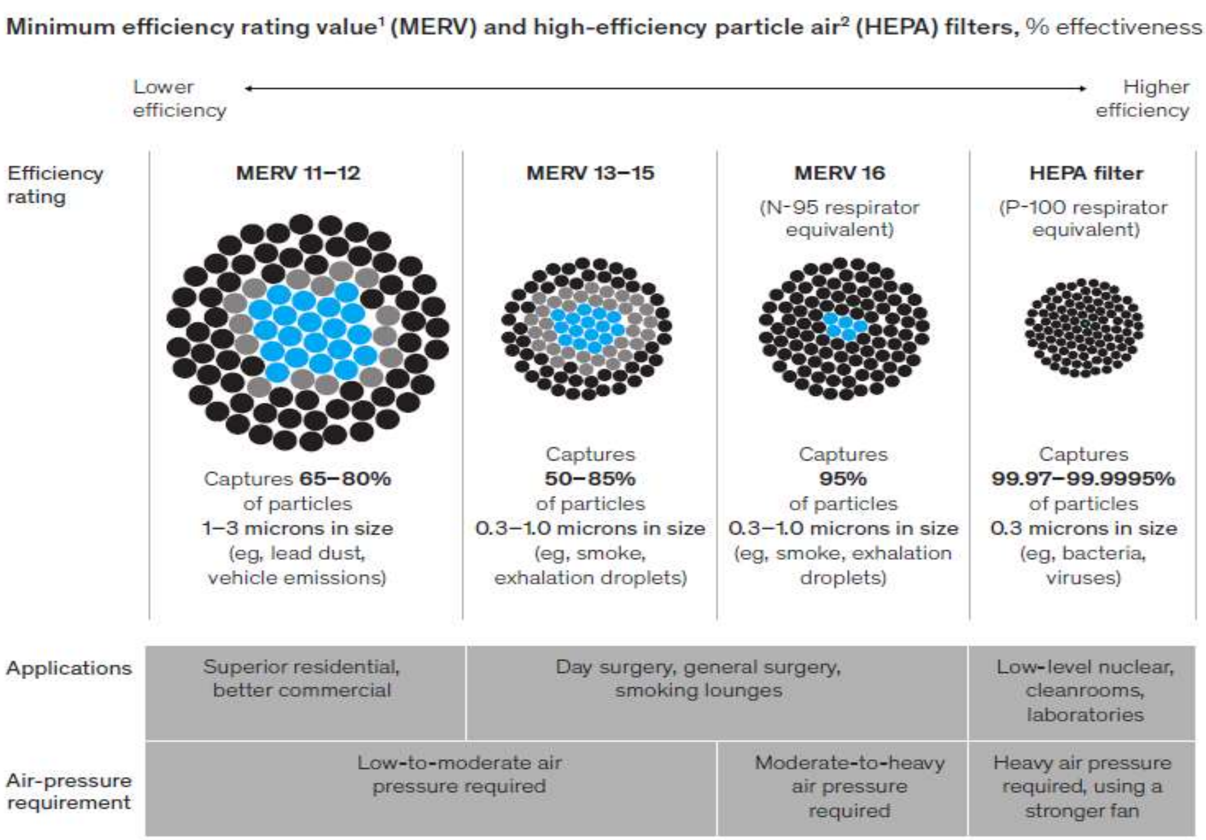


Figure 6. Filters and particles size. (Advanced Industries Practice, Mckinsey,2020)

Table 1 and figure 6 above identify filters rating towards particle size, which reflects its efficiency to reduce the spread of COVID-19 particle. Thus, filters of MERV rating of 10 and above are estimated to be efficient in keeping COVID – 19 in detention and limiting its circulation.

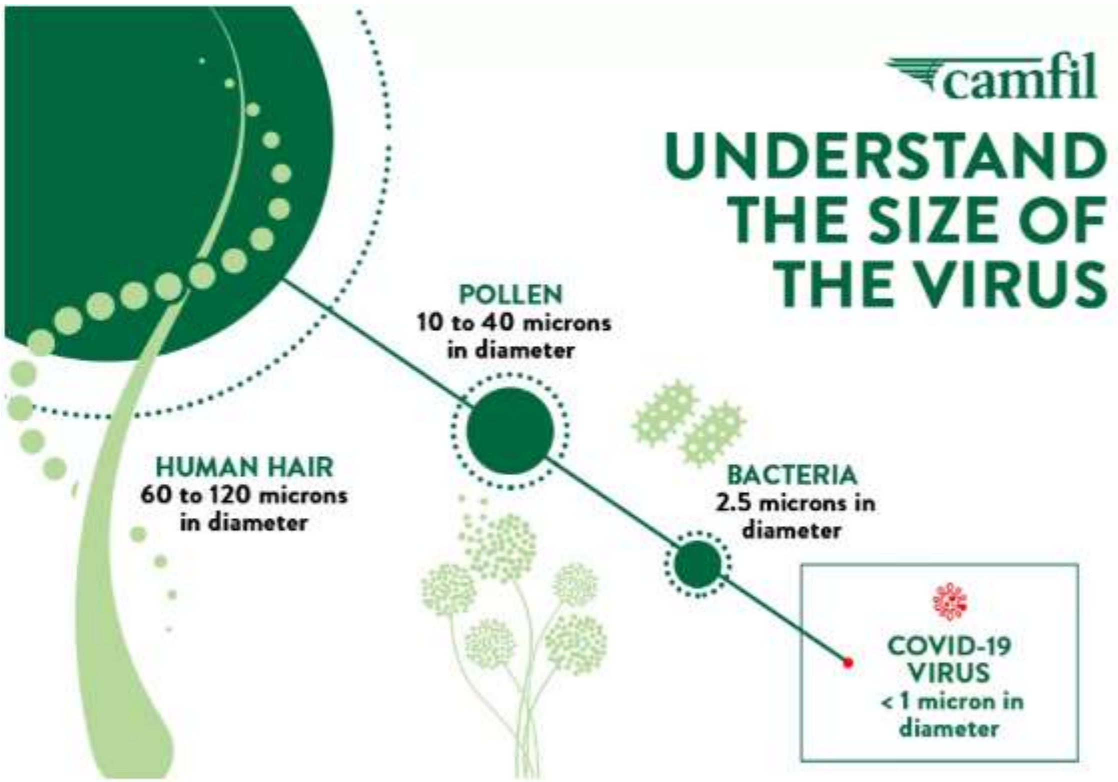


Figure 7. COVID-19 size proportional to daily particles (CAMfil,2021)

In UAE, the standard MERV filter to be applied for Ventilation and Air quality of the occupied building, is MERV 8 (Sa'fat, 2020). This filter standard was modeled to assess efficiency in reducing the spread of COVID – 19.

3.4.2. UV-C filters in HVAC

It is the Ultra Violet radiations disinfection process in which microorganisms in air are sanitized in the HVAC system just before penetrating the room ambient air. UVGI in the UV-C band is use in air-handling systems, air ducts and stand-alone air purifiers to

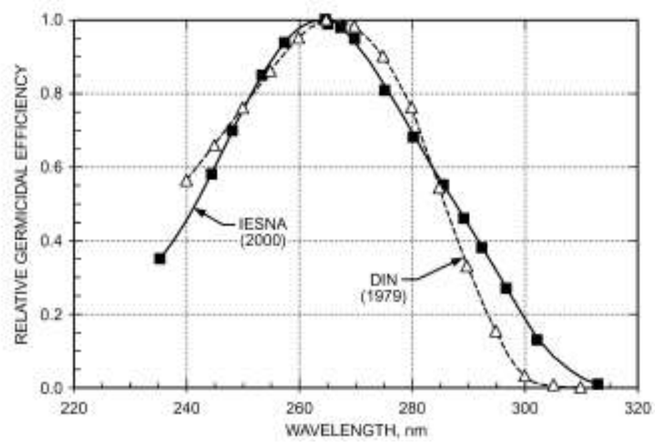


Figure 8. Relative Germicidal efficiency (ASHARE,2015)

neutralize biological contaminants, and its usage is getting increasingly common as humanity becomes increasingly worried about air quality with buildings. It works by inactivating or neutralizing biological particles using short-wave ultraviolet light (UV-C light). UV-C is a shortwave of 270 to 200 nanometers (nm) in the electromagnetic spectrum that is undetectable by human eyes. The UV-C wave is the most efficacious wavelength for germicidal suppression, and the frequency level near 265 nm (Riley, 1988; Schechmeister,1991) is the most optimal frequency level for both efficacy and radiation safety concerns. (ASHRAE, 2015).

As stated by Brickner et al. 2003, microorganisms' DNA is penetrated by UV-C rays, hence deactivating their harmfulness (CIE 2003). Figure 8 depicts the efficiency of

UV-C on DNA damage at different wavelengths. Most UV-C lamps can get defined as low-pressure mercury lamps that generate UV energy at a wavelength of 253.7 nm. Such a wavelength is extremely near to the ideal wavelength for deactivating viruses and bacteria. When the lamp is turned on, the mercury in the lamp vaporizes. As the lamp is switched on, the mercury vaporizes, and the mercury atoms accelerate and attain an excited state, emitting their energy as a result of the electrical field in the discharge. UV-C lamps used in an HVAC application have an inner treated coating that inhibits radiations below 200nm from being released as these can damage human tissue. UV lamps come in various shapes, and the gas combination, pressure, and, in some cases, lamp diameter are all tuned for increased UV output and longer lamp life. The presence of electrodes in mercury lamps is critical to the lamp's behavior. Hot and cold are the two main categories. Cold-cathode lights start instantly, while hot-cathode lamps use thermo-ionic emission to emit electrons. The electrodes in a hot cathode lamp get heated by current to begin discharge, and then the discharged current can retain the heat. A cold cathode lamp produces less UV-C than a hot cathode lamp, but it uses less energy and is easier to maintain.

A low-pressure mercury lamps can vaporize up to an optimal level of 25°C in still air, and the cold spot temperatures ought to be between 38 and 50°C to get maximum UV discharge. The cold-spot temperatures in flowing air may get too low to achieve the needed UV output. To achieve optimal UV output, a type of amalgam for the mercury in the lamp could help to raise the cold-spot temperature between 70 and 120°C.

UVC air disinfection helps to significantly reduce the number of airborne organisms in a room. UVC air disinfection entails air being driven into a UV disinfection device by natural convection, or the circulation of disinfection systems with incorporated UVC lamps. The UV light is protected with safety and health concerns in the latter approach, and the air flow and irradiation are calculated based on the type of bacteria and room size. Without a doubt, the approach will result in a significant reduction in airborne infections, which would be a factor in several disorders, including COVID 19. UVC emitters will be placed after the cooling coil and into its direction to be able to have the short wavelength shines towards the surface of the coil and penetrates into it. This would disinfect the air while being cooled from bacteria and viruses such as COVID 19 Refer to figure 9 below.

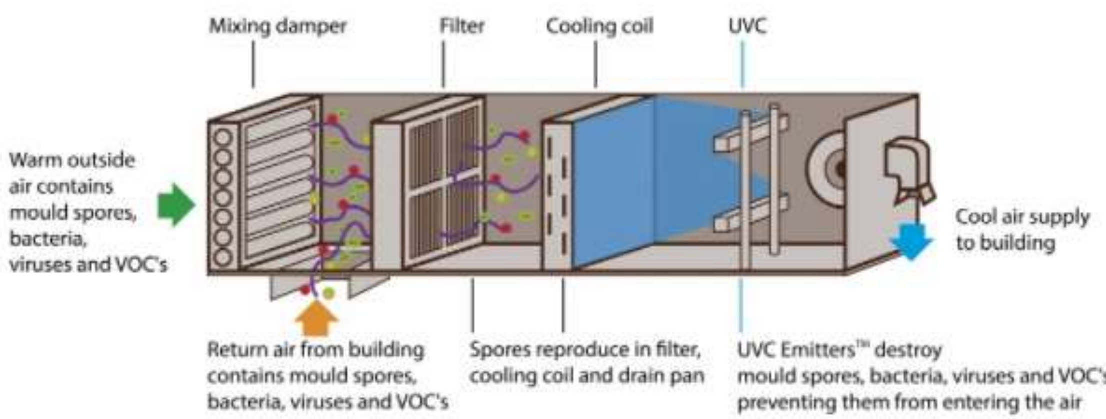


Figure 9. UVC filter in HVAC ductwork (e-co,2021)

3.5. COVID-19 Viral load transmission within indoor air:

The clearest definition of a viral load is “Viral load refers to the amount of virus in an infected person’s blood” (Ryding, 2020). It interprets the replication of cells into the blood, and the higher it is, the higher the infection is.

The issue of viruses and the means through which they are transmitted have taken center stage in many avenues lately. Currently, the coronavirus COVID - 19 has put professional and health experts on alert regarding understanding how the virus is transmitted as well as measures that can be taken to reduce the transmission (Morawska et al., 2020). However, scientists have determined that the virus is very contagious and can be spread through the air (CDC,2020). Hence, the virus spreads when infected persons sneeze, cough, and talk (Chirico, et al., 2020). The viral load also relates to the number of virions; which is related for individual virus particles in an infected human. From the latest reports, it has been found that if the majority of infection of a person is taking place in their lungs, then this leads to more shedding of covid-19 virions as aerosols but if the viral load is concentrated in the upper nasal pathways in an infected person then shedding of virions is more as relatively larger droplets which fall to the ground/surfaces quite quickly. In so doing, they expel respiratory droplets and particles that contain the coronavirus COVID - 19. (ECDC, 2020)

Consequently, recent studies have indicated that the COVID - 19 particles can travel greater distances, given the fact that they can stay active for up to three hours once released (Chirico, et al., 2020). Therefore, the question arises whether the use of central HVAC system could contribute to the spread of COVID-19 aerosols in an air-conditioned building. In most multi-residential buildings, the rooms tend to be relatively airtight and, in some cases, occupants rely fully on the HVAC system to provide fresh air; thus, they see no need of leaving the windows open for purposes of letting in the fresh air.

According to research by Knibbs, et al. (2011), confined indoor spaces tend to have poor ventilation hence prone to the escalated transmission of lung infections such as tuberculosis and respiratory infections as influenza. Additionally, in their review, Young & Hagan 2020 suggest that as much as the fresh air does not kill the virus, they are diluted in the air, thus reducing exposure. Accordingly, in a partially centralized HVAC system warm room air is continually recirculated and mixed with minimum proportions of fresh air by fan coil units that provide the cooling or heating of an indoor space. Thereby there is a high likelihood that virus concentrations can increase rapidly in such residential places. As such, there is a possibility that the virus can be transmitted from one floor to the other due to the recirculation and redistribution of the air in the HVAC system (Morawska et al., 2020).

Although intensive research has not been undertaken regarding the association between HVAC systems and virus load, the central HVAC type of system with common fresh air and extract air duct networks raises a major concern. Thus, there is a need for measures that will help reduce transmission of contaminated air from one part of a building to another.

3.5.1. Examples of Air Conditioning role in the spread of COVID-19

The function of ventilation in COVID-19 outbreaks has been proven in three major investigations conducted in China by the Coronavirus Research Committee. There was a pre-symptomatic index in those epidemics, and circulation of air in a confined space facilitated by air conditioning.

The initial outbreak occurred in a restaurant in Guangzhou, China, where ten cases reported positive across three families. They expressed symptoms two weeks after eating lunch at a five-story restaurant with no windows on January 23. (ECDC, 2020) The dining room was set up so that tables were separated by more than a meter. Other guests in the restaurant were not infected, despite the fact that those three families were seated along the path of airflow generated by the air conditioning. The transmission of SARS-CoV-2-infected respiratory droplets via airflow created by air conditioning is discussed in the report.

A re-circulating attribute of the air conditioning system was described as a possible mechanism of transmission in the two more occurrences that occurred in January 2020. One of them was a 150-minute event in a temple when seven cases were recorded out of 172 attendees, all of whom had direct interaction with the index case. The most catastrophic epidemic occurred on a 100-minute bus ride, where 34% of passengers (23 out of 67) got infected (ECDC, 2020). The idea that the bus's airflow aided the virus's spread was validated as a significant finding, despite the fact that all passengers seated near the windows stayed healthy.

One of the most recent outbreaks was for a two-day workshop event in Hangzhou; 30 participants came from various places, stayed in different hotels, and did not share meals at the workshop site. (ECDC, 2020) For the 4-hour session, the participants were divided into four groups, each with $50m^2$ and $75m^2$ of space. The air - conditioning system is a unified service with an automated timer for 10 minutes of indoor recirculation mode every four hours in each room. During the workshop no attendees displayed any symptoms, but 15 of them were infected with COVID-19 less than a week afterwards.

3.5.2. Description of SARS-COV 19:

With the help of an electron microscope, coronavirus are reflected as positive-stranded RNA viruses, crown-shaped with spikes on the envelope. It has round or elliptic and often pleomorphic form, and a diameter of approximately 60–140nm (Advanced

Table 1 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) detections in the air of hospital rooms of infected patient.

Patient	Day of illness	Symptoms reported on day of air sampling	Clinical Ct value[a]	Airborne SARS-CoV-2 concentrations (RNA copies m^{-3} air)	Aerosol particle size	Samplers used
1	9	Cough, nausea, dyspnea	33.22	ND	>4 μm	NIOSH
				ND	1–4 μm	
				ND	<1 μm	
				ND	-	SKC filters
2	5	Cough, dyspnea	18.45	2,000	>4 μm	NIOSH
				1,384	1–4 μm	
				ND	<1 μm	
3	5	Asymptomatic[b]	20.11	927	>4 μm	NIOSH
				916	1–4 μm	
				ND	<1 μm	

Figure 10. Air Sampling in hospitals by Singapore Coronavirus Research team, May 2020

Industries Practice ,2020). This family of viruses can cause respiratory, enteric, hepatic, and neurological illness that may lead to fatal cases. They can cause common colds and respiratory and extra-respiratory manifestations. It is believed to be sensitive to ultraviolet rays and heat and can be effectively inactivated by lipid solvents including 75% or higher ethanol, and/or chlorine-containing disinfectant. In a later study done by the Singapore 2019 Novel Coronavirus Outbreak Research team, in Airborne Infections Isolation Rooms (AIIR) at the National Centre for Infectious Diseases, Singapore, a screening for surface and air samples of COVID-19 patients for SARS-CoV-2 RNA were conducted. The air sampling detected positive particles of sizes 1–4μm and >4μm despite these rooms having 12 air changes per hour. (Nature communications, May 2020).

3.5.3. Ventilation of Buildings and Virus Transmission

High occupancy structure and publicly-accessed commercial buildings such as supermarkets and shopping malls, hotels and restaurants depend on controlled ventilation system to regulate the circulated air in the closed spaces. At the same time, homes routinely use air conditioning during the hot weather period. Subsequently, the importance air conditioning and ventilation systems in both private homes and publicly accessed building cannot be over emphasized. They are considered effective methods of preventing infections and spread of airborne diseases in workplaces and public places through procedural controls. Air conditioning and ventilation is part of the framework for occupation health and safety measures implemented to protect human health by reducing the health risks to the public indoor spaces. In this regard, they prevent the transmission of contaminants and to ensure air supplied to the building spaces are clean and fresh.

A well-maintained ventilation system could reduce the risk of transmitting disease-causing organisms and viruses through the air. In another study and air and surface sampling taken through the university of Nebraska medical center for the 13 infected cases from Diamond Princess Cruise ship, the shredding of the virus and its spread to other zones was verified but in different percentage according to the conditions of the environment where each sampling was taken. Pressure difference and air flow had an identified impact (Santarpia, 2020). In this context, well-maintenance means that ventilation system is inspected regularly and that most efficient filters are used to ensure that airborne contaminants do not get into the building spaces. Thus, during the maintenance, filters should be changed according to the manufacturer's recommendations to maintain their efficient operations, which also depends on the periodic cleaning of the duct systems (Quian and Zheng, 2018). Poorly maintained and operated air conditioning or ventilation system could potentially contribute to virus transmission through two mechanisms. First, the system could recirculate contaminate air back to the building space causing the infection. Second, it could create an indoor temperature and humidity conditions that support the survival of the virus for a long period, thus, increases rate of users' exposure to the virus.

Ventilation air is calculated based on ASHRAE62.1, and comes by following one of those equations:

$$Q_{tot} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

where

Q_{tot} = total required ventilation rate, cfm

A_{floor} = dwelling-unit floor area, ft^2

N_{br} = number of bedrooms (not to be less than 1)

$$Q_{tot} = 0.15A_{floor} + 3.5(N_{br} + 1)$$

where

Q_{tot} = total required ventilation rate, L/s

A_{floor} = dwelling-unit floor area, m^2

N_{br} = number of bedrooms (not to be less than 1)

Building that depend on central ventilation and/or climate control system need efficient filters for better operations. This can be achieved by installing a highly efficient filter such as MERV EPA, 2019, or HEPA filters that capture virus and other airborne contaminants more effectively (Perry, 2016). Manufacturers' recommendations should be given first priority when installing and maintaining filters. There are efficient filters that are also designed for residential use to ensure circulation of clean and fresh air in the residential buildings. Therefore, to reduce the survival rate and viability of the SARS-COV2 virus in the indoor spaces, climate control systems should not be set at cold temperatures below 21^0C (Chin et al., 2020) or on "dry" low humidity below 40% because these are the threshold conditions for the survival of the virus (Chan et al., 2011; Van Doremalen et al., 2020). In summary, a well-maintenance and operation of air conditioner, ventilator and other climate control systems in buildings significantly reduce risks of transmitting virus.

3.5.4. General Precaution Measures to Reduce Virus Transmission

One of the things that needs to be done is to reduce the circulation of the virus in public and living spaces. The precautionary measures such as keeping physical distancing should be maintained because of the high rate of pre-symptomatic transmission among the publics (Gandhi, 2020). The use of face masks should be maintained to prevent droplets through peaking and coughing from reaching the surfaces. Facial protection through wearing of facemask, will not however, prevent a person wearing it from contracting the virus, but it will reduce chances of spreading it to others (Koehler and Rule, 2020).

Suspected and confirmed Covid-19 patients should be placed under isolation and quarantine respectively so that they are removed from the public places. While in isolation or quarantine facilities, they should wear masks at all times to reduce the droplets from coughing, which may increase virus transmission within the facility. Well ventilation is also necessary for the rooms and places where suspected and confirmed Covid-19 patients are isolated or quarantined, and the ventilators to be cleaned periodically for continuous flow of clean and fresh air. Negative-pressure and HEPA filter ventilations should be installed in the clinical facilities where Covid-19 patients are kept to prevent the spread of the virus in the entire facility.

Management of residential buildings and commercial facilities should install efficient air conditioning and industrial ventilation systems in those structures, and conduct regular maintenance and cleaning to reduce unintended risks of virus transmission. During warm weather, the cooling system should be set between 23.8^0C and 26.9^0C while the RH is kept between 50-60% to reduce the growth rate of molds (CDC, 2015). Further regular cleaning should be undertaken by the staff and public members to reduce the transmission rate. Studies shows that the virus does not reproduce outside the living cells but it has the ability to survive on surfaces and air for a considerably long period of time to facilitate the transmission to people (Van Doremalen, 2020; and Fears, 2020). Thus, frequent sanitization of surfaces is necessary to prevent transmission.

In buildings other than hospitals where ventilation systems operate in closed spaces such as hotels and restaurants, offices, schools and malls, the most recommended model is a high-efficiency particulate air (HEPA) filter with the highest

MERV rating to recirculate the air. Installation of HVAC units such as the packaged terminal air conditioning (PTAC), which operate outside the central mechanism in air circulation is necessary (Dietz et al., 2020). Occupants of any building space should maintain safe hygiene practices including the wearing of masks, frequent washing of hands with soap and water and keeping physical distancing to avoid transmission. The management of these building facilities should also encourage occupants to practice these safety guidelines.

In cases where air conditioning or ventilation systems are unavailable as common with residential homes and commercial buildings in warm climates, it is necessary to install air purifier devices such as fans, and frequently open windows to allow for the recirculation and hence distribution of fresh air into closed spaces to reduce contaminants (WHO, 2009). Proper maintenance of appliances such as air purifiers based on the manufacturer recommendations to achieve optimum operations. For the buildings that use fans to circulate fresh air, they should be installed where direct exhaustion of the room air to the outdoor environment through the windows and other openings is possible (WHO, 2009). However, the use of fan is only encouraged in a room with one person only, but it is not suitable for collective spaces with many people but minimal air exchange between indoor and outdoor environment (HCSP, 2020). Where fans are used in circulating the air, precautions should be taken to minimize a scenario whereby the fan is blowing air from one occupant to another as this may increase transmission risks (CDC, 2020).

3.5.5. Studies on the Role of Ventilation on COVID-19 transmission

Many studies have reflected substantial evidence showing that air conditioning and ventilation plays a significant role in virus transmission through indoor recirculation of the virus. One of the key important avenues of contracting the virus is through direct droplets when people are within 2 meters apart, although airborne transmission occurs when the physical distance is more than 2 meters (Santarpia, 2020, Fears, 2020; and Van Doremalen, 2020). Furthermore, contaminated surfaces may significantly contribute to transmission of the virus, especially in a climate-controlled indoor environment where the ventilator is poorly functioning. Such conditions create a breeding environment for the survival of the virus for a longer period to facilitate transmission. However, and up to this stage in researches and studies, there is no strong evidence supporting that a well-maintained ventilation and air conditioning systems may have significant contribution to the transmission of Covid-19 disease.

Two recent studies conducted on air sampled in an immediate environment of Covid-19 patients with significant viral load in a health facility showed that there was no SARS-CoV-2 virus in the air samples studied (Chen et al., 2020; and Ong et al., 2020). The results of the two different studies were alluded to a potentially well-maintained and efficient air conditioning and ventilation systems within the hospital environment. A different study on air sampled from a long distant flight revealed no evidence in transmission of the virus from Covid-19 passenger to the person seated next to them, which was also associated with efficient ventilation and filtration of the cabin air (Schwartz et al., 2020).

Evidence from two early studies suggest that the use of central ventilation and air conditioning in big buildings may lead to spread of certain viruses as they circulate air from one person to another (Zhao et al., 2003; and Li et al., 2005). The two different studies therefore concluded that ventilation either has a problem or it was not possible to conclude its efficiency or ineffectiveness. The study from China by Jianyun et al. (2020) claimed that air conditioning and ventilation systems spread COVID-19 disease in a restaurant. However, Dietz et al. (2020) noted significant limitation with that study. From these studies, it can be concluded that a well-maintained ventilation system that operates effectively reduces the transmission risks in both residential and commercial buildings. Therefore, regular inspection, maintenance and cleaning of air conditioning systems should be considered as part of the measures to prevent transmission.

There are also studies that reflect that low temperature and relative humidity (RH) in the indoors environment facilitate virus transmission, if considering the characteristics of SARS-2 / COVID-19 are similar to SARS-1. The primary role of ventilation and air conditioning systems is the provision of a thermally comfortable environment for the occupants while improving the quality of the circulated air in the indoor spaces. Early studies that examined the role of indoor temperature and RH on the SARS-CoV-1, MERS-CoV and H1N1 virus transmission revealed that temperatures below 21^0C and RH below 40% tend to increase the survival time of these viruses and influenza on dry surfaces (Otter et al., 2016). An earlier study specifically revealed that SARS-CoV-1 can survive for 14 days under air-conditioned context with temperatures of between 22-28^0V and RH of between 30-60^0C (Chan et al., 2011). However, when exposed to a temperature of 56^0C, SARS-CoV-1 virus become inactive within 15 minutes in a laboratory context (WHO, 2003).

A recent study confirms the similar survival characteristics between SARS-CoV-1 and SARS-CoV-2 viruses (Van Doremalen et al., 2020). In support of the findings, Sun et al. (2020) asserts that findings for SARS-CoV-1 tend to be true to those of SARS-CoV-2 virus. The WHO warns against exposure to sun or ambient temperature above 25^0C because no evidence shows this practice prevents infection or cures Covid-19 patients, but instead increases the risk of sunburn and associated health problems (WHO, 2020).

3.5.6. Recommendation for Ventilation Enhancement:

Ventilation is an important factor in preventing a concentration accumulation of the virus that causes COVID-19 whilst diluting it before it can transfer from a source room to another room in a building. The World Health Organization (WHO, 2020) developed a recommendation that could be considered in improving indoor ventilation in HVAC professionals as a way of reducing the spread of COVID-19 in living and commercial spaces. One of the recommendations was to consider the use of natural ventilation for air circulation by opening windows where possible and when it is safe to do so, which depends on the nature of air within the building's surrounding atmosphere. For mechanical systems, WHO (2020) recommends the need to increase the percentage of outdoor air circulation. This requires economizer modes (wherever used) to be disabled or turned off to maximize ventilation airflow. They advise for the need to increase the total airflow supply into occupied spaces as much as possible as a way of maintaining the freshness and cleanliness of the air. This means that it is necessary to disable demand-control ventilation, which reduce the air supply based on temperature or occupancy.

According to the WHO (2020) recommendations, the central air filtration can be improved as much as possible without diminishing the designed airflow rate. In this regard, inspecting filter housing and racks is recommended to ensure there is appropriate filter fit and eventually conduct a check on ways to minimize the bypassing of filters. The HVAC system can be run at a maximum airflow for two hours before and after occupying the space to improve dilution of extract in accordance with manufacturer's recommendations. It is necessary to reevaluate the position of supply and exhaust air diffusers as well as airflow control by dampers. Measurable pressure differentials should be generated by adjusting the imbalance between zone supply and extract air flow rates. For commercial buildings, the staff should work in a clean ventilation zone without any high-risk areas such as exercise facilities or visitor reception. To achieve this, the exhaust fans in restroom facilities should be functional and operating at their full capacity by the time the building is occupied.

3.5.7. Recommendations for Indoor Public Areas

Public places such as workplaces, schools should have clean and fresh air circulating. According to WHO (2020), it is necessary to increase the ventilation rate in these public places by circulating fresh and clean air using natural or mechanical methods that do not recirculate the air. However, some situations, which are often based on air condition in the surrounding atmosphere, can lead to recirculation. In this case, filters should undergo regular cleaning, in buildings where individuals working are exposed to medium or high risk of contracting COVID-19. Such jobs may include those working as the frontline health providers in healthcare facilities, retail sectors, and domestic accommodation. These places expose workers to high risks, maintaining the cleanliness and freshness of the circulating air.

In ASHRAE (2003), four different air quality strategies in a building are outlined. The methods are eliminating the source, local hooding or screening with the exhaust or recirculation for air cleaning, dilution of contaminants by increasing the general ventilation rate. And when above approaches are not feasible, the strategy would be to apply general ventilation air-cleaning with or without increased flows. The fourth option is generally tricky as the contaminant is thoroughly dispersed in the facility (ASHRAE, 2003). When designing process ventilation, the most important aspects may be considered trivial but are still very important (Antonsson et al., 2005; Goodfellow and Smith, 1982; & Rohdin, 2008). The following as some of the critical proposals for consideration when designing the ventilation process of building spaces, as recommended by different researchers:

1) The first one is to consider the user's proximity to the contaminant's source. The contaminant's concentration decreases with increasing distance from the source and must capture a larger air volume to trap the contaminant. It seems essential in minimizing the capturing space (Goodfellow and Smith, 1982).
2) The second consideration is a gravitational force because the contaminated air moves have similar movement as clean air. The assertion is based on the common belief that polluted air falls to the floor. However, this is only true for large air containing particles which deposit on the floor (ACGIH, 2004; Goodfellow and Smith, 1982).
3) Air jets move large quantities of air. Simultaneously, as the volume increases, and so is the decrease in the concentration of contaminants.
4) Air movement is created by ventilation, moving objects, and buoyancy effects from heat sources such as machines and persons. Persons moving near a contaminant source may affect the airflow pattern and make contaminants move in proximity to the head region if the process ventilation is poorly designed (Antonsson et al., 2005).

In similar concept of contaminants of high-risk disease, industries of which machines are used for blasting and grinding equipment eject contaminants to the atmosphere. According to ACGIH (2004), there is a need to design a local exhaust system that can capture these contaminants ejected from machines and equipment. In this regard, Goodfellow and Smith (1982) recommend installing a static pressure gauge and testing system to deal with such contaminants with the fan being the last component to be selected. According to Cascetta and Rosano (2001), conducting an assessment on the velocity field near the rectangular exhaust hood is necessary by using different empirical formulae. Rueegg et al. (2004) outline the procedure for capturing the local contaminants using other exhaust systems by arguing that reinforced exhaust system gives a higher efficiency of capturing.

Goodfellow and Tähti (2001) provide an outline that explains three factors governing the methods and processes of designing industrial ventilation and techniques of developing local exhausts to deal with the locally ejected contaminant. First, the authors explain that the first consideration for industrial ventilators and local exhausts is the target level of toxic target and the amount or concentration of the contaminants in the working environment. When these parameters are addressed in the design and development, they lead to a highly effective ventilation system that meets the customized needs. The second factor to consider is the occupied zone, and the way personnel move within the building. The objective of this factor is to determine whether the contaminant source is constant or temporary. Third, the design should consider whether the contaminant source is widely spread or it is just dispersed from a smaller region (Goodfellow and Tähti, 2001; and Antonsson et al., 2005). Those 3 main concepts are of potential approach to look into solutions to prevent spread of COVID -19 in different building occupancy types.

The above design principles may look simple to implement, but several issues must play for a successful outcome. Though it is possible to predict and measure different processes, the mechanisms involved in achieving the overall system's function involves advanced computational fluid dynamic (CFD) simulations (Rohdin, 2008). The simulation of the product’s efficiency and functionality is essential to assert the possible outcome. The CFD simulations help achieve a complex industrial ventilation project that provides efficient circulation of fresh and clean air as explained by ASHRAE (2003) and emphasized in different studies of Goodfellow and Tähti (2001) and Rohdin (2008).

3.6. Contaminant Modelling

The air quality of spaces including hospitals, office blocks, residential apartments, schools and other spaces play an important role in the health and well-being of individuals who occupy these spaces.s According to Temenos et al. (2015), indoor air quality continues to attract a lot of research owing to the health impact it elicits. Virulent maladies caused by air pollutants such as influenza virus or lung cancer caused by radon gas can easily be spread in building whose air quality is poor. With the current Covid -19 pandemic, the importance of air quality in building cannot be over emphasized. One of the tools currently in use in the analysis of the air quality of spaces in the contaminant Transport modeling (CONTAM) software (García-Tobar, 2018). The CONTAM software is basically a multizone program that can be used to analyze air quality within building. Factors such as personal exposure, contaminant concentration and airflows can be determined using the CONTAM software. The CONTAM software has recently been used to model Fate and Transport of Indoor Microbiological Aerosols (FaTIMA) an online program that has the ability to arrest the spread of the COVID - 19. FaTIMA is a web-based program that can be used to decrease the concentration of the COVID - 19 in spaces and thus arrest its spread. CONTAM and FaTIMA form the basis of the following document. The FaTIMA program is a great boon the first against the spread of the novel COVID - 19 virus.

In March the World Health Organization officially declared COVID - 19 virus as a global pandemic (Jebril, 2020). Many countries-initiated lockdown measures among other strategies to help contain the spread of Covid-19 to its population due to the highly contagious nature of Covid-19 (Li et al., 2019). As the COVID - 19 virus waves eased and some semblance of normalcy began in cities, restrictions in public spaces were eased. Now organizations such as ASHRAE continue to work hand in glove with government and healthcare organizations with the objective of coming up infrastructural based solutions such as improving building HVAC system in an effort to contain the virus (Ng et al., 2021). In the US, the National Institute of standards and Technology (NIST) had developed CONTAM Software in 2005 as a tool for appraising the air quality in buildings and modelling how contaminants spread in buildings based on bulk airflows and temperature and pressure differences as well as physical and biological characteristics of contaminant sources and receivers. CONTAM since then, has been developed to add the indoor space air conditioning loops with simple air handling systems and simulation with Energy plus and to be able to work with schedule, ducts, controls, occupant exposure, and simulation results. CONTAM Software has since been used to fashion Fate and Transport of Indoor Microbiological Aerosols (FaTIMA), an online tool that and be used to mitigate the spread of the COVID - 19 virus.

3.6.1. Description of the CONTAM Software

CONTAM Software is based on work by researchers from the National Institute of standards and Technology (NIST). The software may be loaded on Windows or Linux. CONTAM software is not protected by any copyright laws; it is in effect in the public domain pursuant to Title 17 Section 105 of the US Code (National Institute of standards and Technology, n.d.). The software is basically a multizone indoor air quality and ventilation program that NIST has been developing for several years. CONTAM software is designed to determine factors such as personal exposure, contaminant concentration and airflows. Accordingly, the software has the capability to predict the exposure of airborne contaminant and eventual risk posed to occupants of a building in which contaminants are presents. Further, CONTAM software can be used to determine how airborne contaminants are dispersed in a building and the pertinent processes that facilitate said dispersion. In short, the software highlights the concentration of contaminant dispersed by airflows, or the concentration of contaminants transformed by an assortment of processes such as filtration, adsorption, radio chemical and chemical transformation and deposition of the surfaces of building among other process. Apart from these, CONTAM software has the ability to determine airflows in rooms. Effectively, aspects such as room to room airflows that are furnished by mechanical means can be determined by the software. The program can also determine exfiltration and infiltration and the effects of buoyancy outdoor and indoor air temperature difference (National Institute of standards and Technology, n.d.). Overall, CONTAM software is a program developed by federal government researchers working at NIST and may be used by the public in an assortment of ways including determining personal exposure, contaminant concentration and airflows in building.

Based on the above prelude, CONTAM software can be a very useful program in the determination of air quality within rooms such as office blocks, hospitals, and apartment buildings among other spaces that are frequented by many persons. The fact that the program can calculate relative pressures between zones and the airflow rates of a building and duct networks makes it an effective tool for assessing many air qualities factors. Specifically, the program can assess whether the ventilation rates in a building are adequate (National Institute of standards and Technology, n.d.). The program may also be used to determine difference in ventilation rates over time and how the ventilation air inside a building is distributed. Apart from these uses, the CONTAM software can aid ins providing estimates regarding the impact of envelope air-tightening on the building's infiltration rates and how these are impacting the building's energy needs. The program has additionally been extensively utilized in fashioning and analyzing smoke management systems in buildings. Further, the fact that this program can predict air quality in buildings gives designers an excellent view of the indoor air quality of a building before the building is constructed and occupied. These helps designers, architectures and engineers evaluate ventilations design decisions, building material selection decisions and so on. It also helps designers, architectures and engineers decide on the best indoor air quality control technologies to use in the building (National Institute of standards and Technology, n.d.). Further, personal exposure based on the patterns of occupants may be determined as a result of CONTAM software predictive power.

3.6.2. FaTIMA as a Tool to Mitigate the COVID - 19 Virus

Currently, researchers at NIST have fashioned an online tool that can be used to help mitigate the spread of the COVID - 19. Accordingly, the tool works by decreasing the concentration of novel coronavirus containing aerosols in spaces such as offices, hospitals, apartment building, and retail stores among other spaces. Dabbed the Fate and Transport of Indoor Microbiological Aerosols (FaTIMA), this tool takes into account factors such as aerosol properties, filtration and ventilation and based on these, estimates the concentration of aerosols one may expect to encounter in a particular space (Dols et al., 2020). Based on this tool, occupant exposure to the novel COVID - 19 may be reduced (National Institute of standards and Technology, n.d.). FaTIMA largely relies on CONTAM Software. As highlighted prior, CONTAM software has been deployed previously to solve several airflow issues. The main difference between FaTIMA and CONTAM is that while the latter is used to provide a general modeling tool that users can used to solve a range of room air quality problems, the former is used to target a specific problem i.e., how to reduce/eliminate bioaerosols containing pathogens such as the COVID - 19 from a room.

FaTIMA essentially works by making calculations based on factors such as air filter efficiencies, ventilation, portable air cleaners and room geometry. The web interface of this tool consists of an input and a results section. In the input section, aspects such as occupant exposure, initial concentration, zone geometry, and burst source among other inputs (National Institute of standards and Technology, n.d.; Ng et al., 2021). These determine the amount of small airborne particles in a given space. Apart from these, the specifics of the aerosols that contain the virus must be outlined if the tool is to work optimally. Specifically, aspects such as how quickly the aerosols deposit onto surfaces and the size of the said aerosols are some of the specifics that ought to be outlined.

In Ng et al. (2020), simulations based on FaTIMA were conducted. In the study, the effect of HVAC related controls and face masks was evaluated. School going children aged between 5 and 8 years old were used in the study. The classroom was based on ANSI/ASHRAE 62.1-2019 and the integrated exposure determined for one contagious person. According to these researchers the classroom was assumed to have a terminal unit of a seventy percent recirculation rate with MERV 6 filter. These authors conducted simulations to appraise two control methods in combination and then separately. Specifically, one micro meter aerosols were used; the three-control method included portable air cleaner that had a clean air delivery rate of 300cfm, MERV 13 filtration and masks with 30 percent filter efficiency.

The baseline cases were compared with the scenarios implemented where the said scenarios were divided with the baseline scenario. The aim here was to determine the normalized exposure. The results obtained by these authors show that in the face covering scenario, the normalized integrated was 0.49. What these meant was that exposure over the 6-hour period which the simulation was run led to a reduction of exposure by about 49%. The results further showed that the reduction of exposure was about 50% for both MERV 13 filtration and portable air cleaner scenarios meaning that the normalized integrated were about 0.5 for both scenarios. These authors however found that where the scenarios were combined the normalized integrated increased to about 0.7 meaning that exposure was reduced by 70 percent.

FaTIMA was also used to evaluate aerosol exposure in ventilated spaces in Ng et al. (2021). Accordingly, Ng et al. (2020) described a simulation study in which they the reduction of aerosol as a result of making changes in the building HVAC system and non HVCA system such as operating portable air cleaner or wearing a mask were compared. The work also estimated the uncertainties in the efficacy associated with the above controls and the combination of these control. FaTIMA as the main simulation tool was used for modeling biological aerosol release in 2 classrooms and an assembly room that had disparate HVAC systems including wall unit system, terminal unit system, dedicated outdoor air system and central air handling system. These authors evaluated exposure for aerosols from whence viruses were transported. In the assembly room the source of aerosol had been present for five hours prior to assessment. The exposure was then evaluated for 1 hour. In the two classrooms, these authors evaluated the exposure for six hours as the source continually discharge aerosols.

The results obtained in this research provide insights that could be of great advantage for school administrators. The results show that in the spaces discussed, masks with a protection efficiency of 25% helped the occupants of the said spaces reduce exposure by 4 percent compared to the base case -not wearing masks. Masks with a protection efficiency of 85-90 percent conferred the space occupants with a protection efficiency of 99%. Masks with low protection efficiency on the hand helped reduced exposure by 15 percent. These authors were also able to show that wearing masks with an inhalation and exhalation protection efficiency of 25 % in combination with HVCA systems with MERV 13 filtration reduced exposure by an average of 71 percent for terminal unit systems, dedicated outdoor air systems and central air handling systems.

One hundred percent outdoor air combined with central air handling systems reduced exposure by 70 percent. Using a 569 $L \cdot s^{-1}$ exhaust fan or 297 clean air delivery portable air cleaners in concert with face masks led to a 68 percent reduction in exposure. These authors also found that by combining all the controls the exposure reduced by an average of 85 percent.

In conclusion, while FATIMA can give insights regarding the air quality of pertinent spaces, it can not model nor study the spread of contaminants from a space to another. The findings that FATIMA can assist in reading is about the impact within a certain space, to make it safe from air contaminants. But the software does not include ducting network into results and won’t provide the impact of spread of the COVID-19 on adjacent spaces or spaces linked by air circulation element such as risers and ducts.

4. Methodology of the study and Analysis

The study will focus on a centralized full fresh air handling unit. The unit will be supplying pre-conditioned fresh air to individual fan coil units in each residential unit and corridor. It will also have a centralized extract fan that does not have a connected air path to the fresh air handling unit, i.e., the extract will be full exhaust. However, in practice, it will likely have a thermal connection to the entire fresh air handling unit, such as by a run-around-coil or air-to-air heat exchanger (e.g., an enthalpy or sensible heat recovery wheel), which would provide some degree of pre-cooling the incoming fresh air. A central air conditioner will consist of two critical sections, the outdoor unit, and the indoor unit. In effect, the number of separate units and corridors in a building will determine the number of indoor units. The outdoor unit will consist of a condenser coil and a compressor; a single outdoor unit located in the vicinity of a building is used.

Indoor Unit

A thermostat will be mounted on each conditioned space unit in a building. The primary role of the thermostat is to monitor and control the temperature of the indoor air in each pertinent space or room. In effect, the indoor space will begin cooling when the thermostat is triggered due to the temperature increase. As the temperature in a given space increases, it will trigger the thermostat, indicating the cooling mechanism need to be initiated. Accordingly, a signal to power the air conditioner will be sent. The fan in the indoor unit will pull warm air inside the space via a return air duct. The warm air will first be filtered. Here, lint, dust, and other impurities will be removed from the warm air. The filtered warm air will then be passed over the evaporator coils that are cold due to condensed refrigerant. The evaporator coils will absorb heat from the warm air thus cooling it. The indoor unit blower fan will then blow cool air back into the space, thereby cooling the temperatures in the space. The latter will continue until the thermostat senses that the temperatures inside the space are favorable.

Outside Unit

Meanwhile, in the evaporator coil, the refrigerant liquid converts to gas as it cools the warm air. The refrigerant now in gas form leaves the indoor unit via a copper tube and is passed to the outside unit's compressor. The compressor is essentially a pressurizing pump that pressurizes the gas refrigerant. Once compressed, the refrigerant gas is sent to the condenser coil. The condenser coil has a large fan that pulls outdoor air through the condenser coil, thereby absorbing the indoor units' heat energy, thus cooling the warm refrigerant gas. When this happens, the refrigerant gas is converted back to liquid. The refrigerant liquid now travels back to each indoor unit via a copper tube. The liquid refrigerant can now absorb the heat from the indoor spaces depending on the signal from the thermostat, and the process repeats continuously until each indoor space achieves optimum temperature level.

HVAC systems modulate aerosol distribution and can therefore increase or decrease exposure to infectious droplets, surfaces, and intermediary fomites in a variety of environments. The main lead for this study is to determine rational engineering scenarios to understand the risk of transmission from infected people by having a thorough understanding of how effectively the disease is transmitted through air conditioning systems in buildings that typically have high density occupancy. Commonly, HVAC systems have to ensure air-cleaning, e.g. using filtration technologies, ventilation, e.g. by diluting indoor air with clean outdoor air, and local exhaust extraction, i.e. removal of potentially contaminated air to be exhausted safely outdoors, to decrease the risk of infection transmission.

For the purpose of this study, a series of contaminant transmission scenarios multiple simulations were conducted of a CONTAM model of a portion of a multi-residential high rise building. A basecase model was built using the freely available CONTAM software developed by the US National Institute of Standards and Technology (NIST). The basecase model represented a block of 9 apartment units i.e. 3 units per floor over 3 floors, i.e., 3 units horizontally and 3 floors vertically with corridors shared across the 3 units on each floor, all having their own apartment FCU which is supplied with conditioned fresh air from one of three centralized fresh air handling unit's located on the roof. The residential units are modelled as studios each of 5 meters in depth and 8 meters in length, of 2.3 meters clear height and a plenum of 0.7 meter height above the occupied zone where the FCU and ductwork is located. Refer to figures 12, 13 and 14 below. Each studio unit was fitted with air supply and air return 4 sides outlets that were provided in the false ceiling. The returned air is recirculated to the studio unit, after being mixed with the fresh air supplied from the FAHU through the ductwork to the plenum. The centralized pre-conditioned fresh air supply provides the minimum ventilation required by Al Sa'fat regulations. A ductwork riser connects rooftop fresh air handling units and extract fans to each floor to provide the circulation of fresh air into ductworks and to the FCUs for the units and the corridors, as well as the return of the extracted air from the units and corridors to the roof.

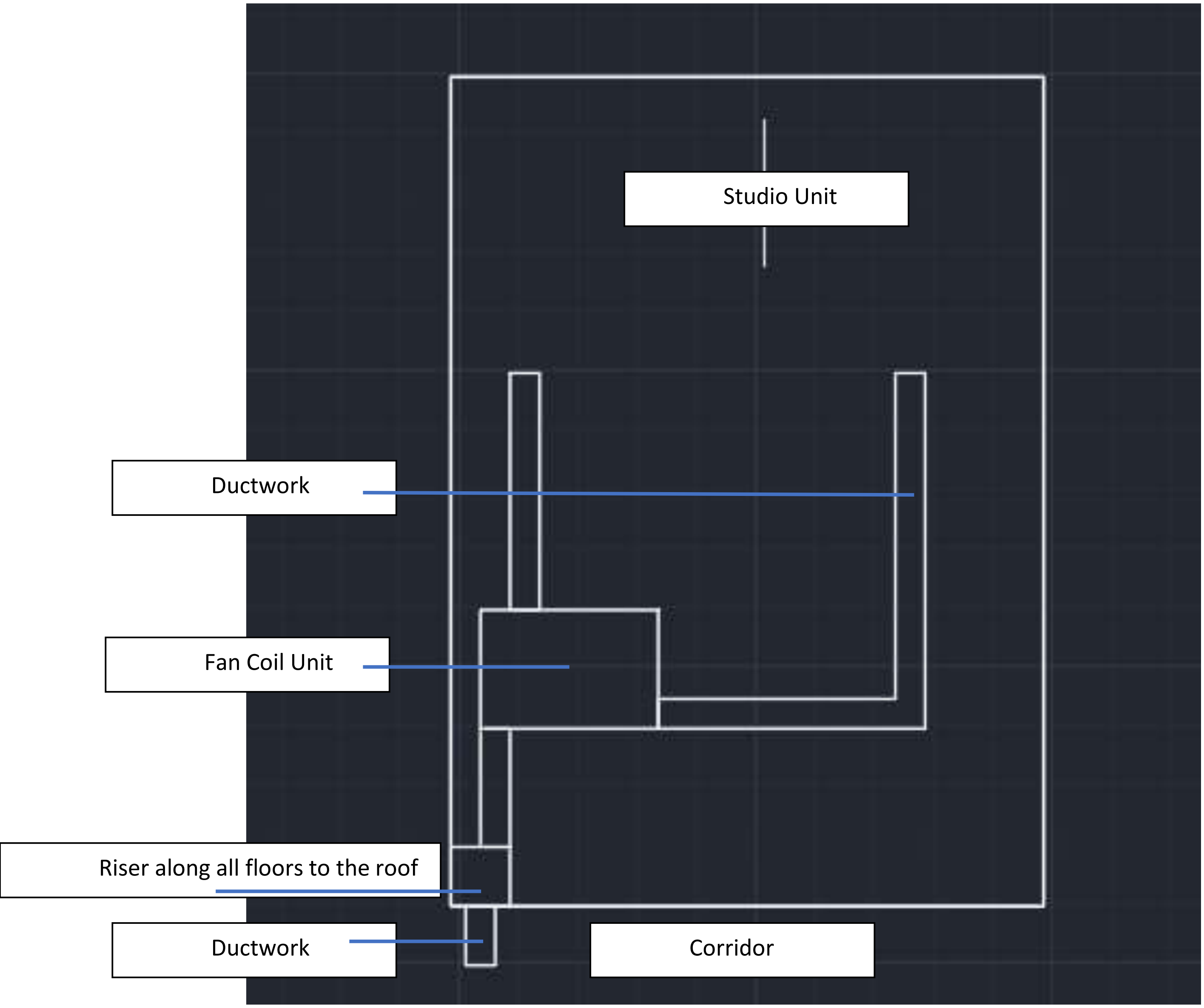


Figure 11. Typical Single Unit ductwork and FCU location

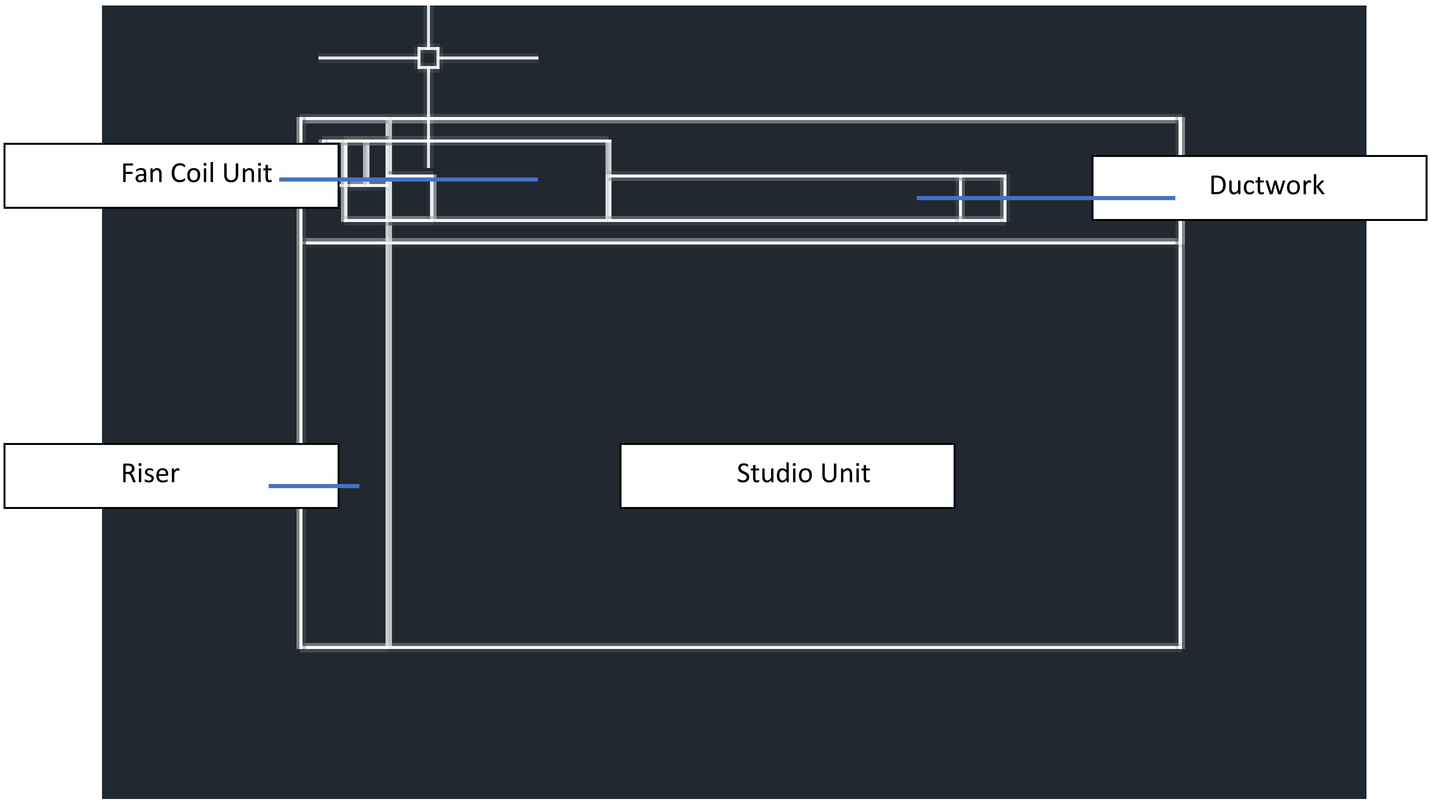


Figure 12. Elevation reflecting positioning of FCU and ductwork in the plenum of the studio unit

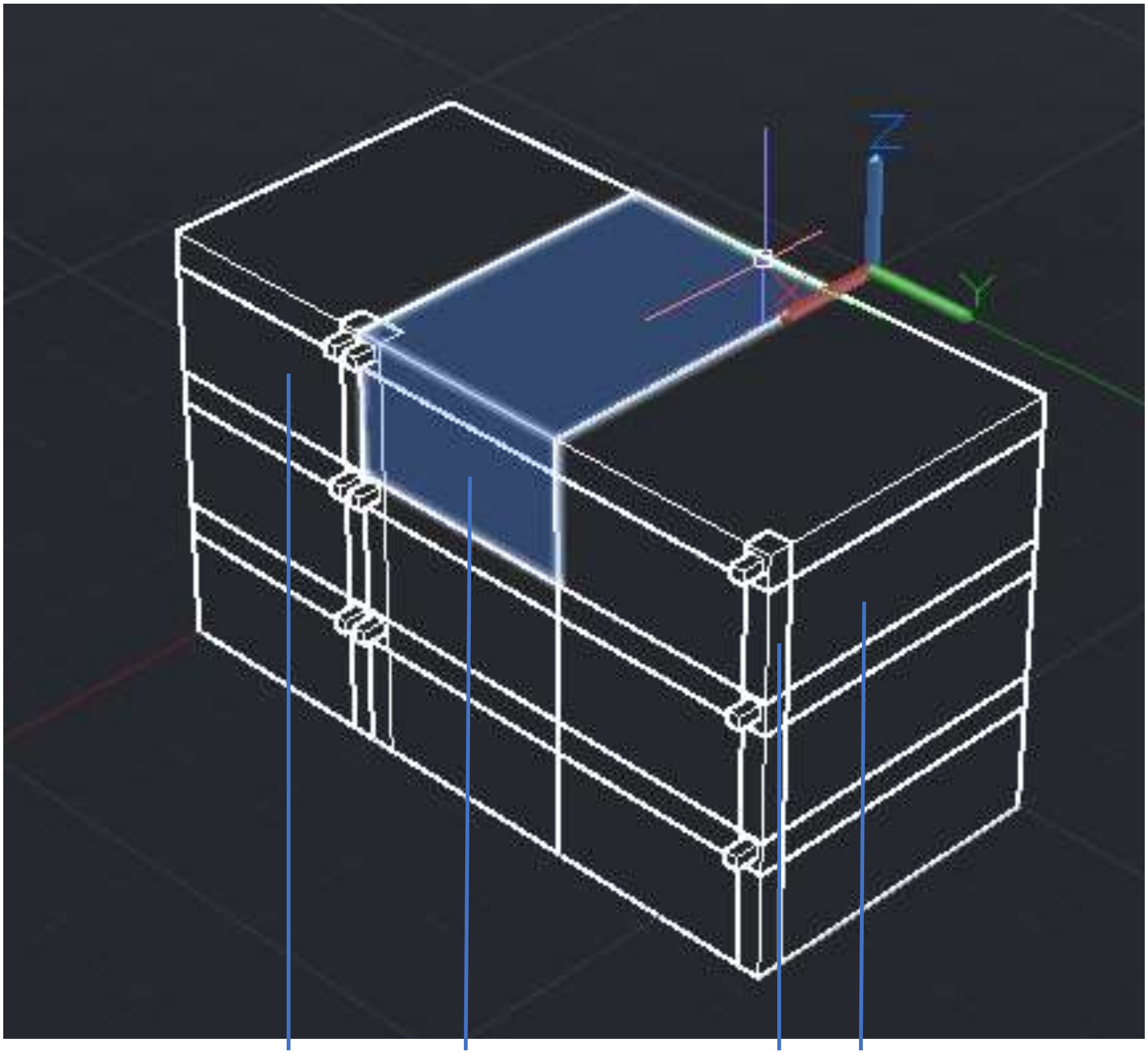
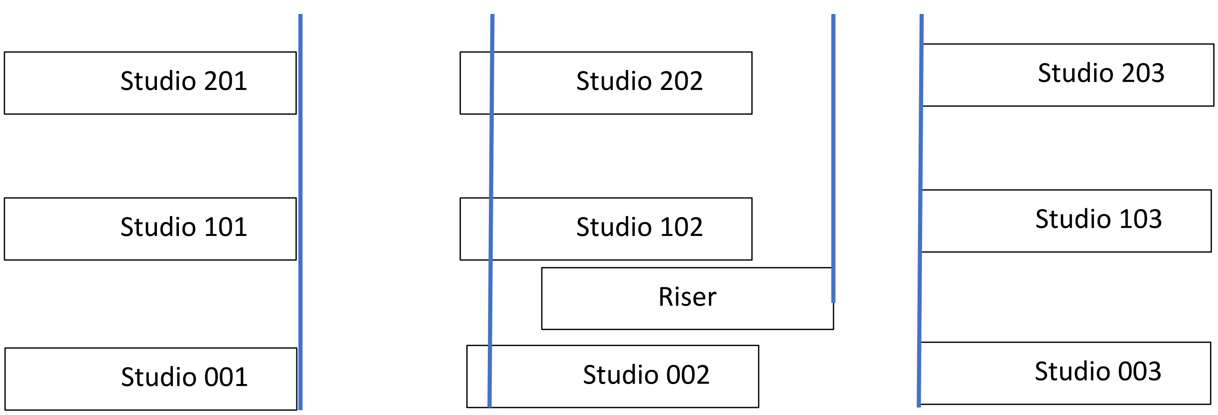


Figure 13. Units positioning reflecting risers connecting to the roof Fresh Air Handling Unit



Multiple scenarios, refer to Table 02 below, representing various combinations of apartments having their FCU's on & off and changing the apartment location of COVID-19 virus source were built.

Scenarios	FCU on for 24 hrs	FCU on for 12 hrs	COVID - 19 Infection Location	COVID - 19 Infection X 4	Filters
A1	ALL Units & Corridors	NO	Ground Floor Studio 002	no	no
A2	ALL Units & Corridors	NO	1st Floor Studio 102	no	no
A3	ALL Units & Corridors	NO	2nd Floor Studio 202	no	no
B	All Corridors and Studio 102	other units	1st Floor Studio 102	no	no
C	ALL Units & Corridors	no	1st Floor Studio 102	yes	no
D	ALL Units & Corridors	no	1st Floor Studio 102	no	yes

Table 2. CONTAM Simulation Scenarios listing

Scenario A was taken on three options where all 9 studio units have their FCUs on as well as all corridors FCUs, and source of contamination is an infected person with COVID-19 in one of units.

Scenario A1, the source of infection is the occupant of studio 002, the middle unit of the Ground Floor.

Scenario A2, the source of infection is located in studio 102.

Scenario A3, source of infection is located in studio 202.

Basecase is defined from those 3 options.

Scenario B is having the infected person in quarantine in his unit which is the basecase defined in Scenario A. His air conditioning system is running on for twenty-four hours, the building corridors system running on for 24 hours, but the other studio units are having their HVAC on for twelve hours and half of the day is turned off due to people leaving their residences to go to work for almost 12 hours a day.

Scenario C defines that the infection level is higher in the basecase and the higher concentration level may have an impact on the spread of the contaminants through the HVAC system.

Scenario D is a case where and as per Sa'fat regulations, MERV 08 filter is required to be placed in the HVAC system and if this would have any impact on limiting the spread of COVID – 19.

These operational scenarios would result reflecting pressure differences between the 9 apartment units and would show if any change of pressure differences caused by differences in apartment air conditioning system operation can have any impact on the transmission or limitation of spread of COVID-19 virus between apartments in a multi-residential building. The findings could be used to determine what building/facility management actions should be taken when a positive case of COVID-19 occurs in multi-residential buildings.

4.1. Building the CONTAM Model

CONTAM is a multizone indoor air quality analysis computer - based software designed to help in determining the following:

•*Airflow Rates*: for infiltration, bulk room-to-room airflow rates in HVAC system within building, and buoyancy effects due to the difference of air temperature between indoor and outdoor air.

•*Contaminant Concentrations:* to verify and understand the dispersal of airborne contaminants from different sources, and transported by airflow; adsorption of the contaminants to building materials, gaps and cracks, and building finishing.

•*Personal Exposure*: to verify the exposure of occupants towards airborne contaminants in order to assess the related health risk.

For the purpose of this research, CONTAM is selected for its ability to calculate building airflow rates and relative pressures between zones of the building. It helps to assess the adequacy of ventilation rates in a building, and determine the variation in ventilation rates over time, and to verify how ventilated air gets distributed within a building. CONTAM reflects by its simulation the impact of the air-tightened envelope on infiltration rates.

The following mass balance equation (1) (NIST, Nov.2006) is used to describe contaminant transport in a multizone building:

$$\frac{dm_{\alpha,i}}{dt} = -R_{\alpha,i}C_{\alpha,i} - \sum_j F_{i,j}C_{\alpha,i} + \sum_j F_{j,i}\left(1-\eta_{\alpha,j,i}\right)C_{\alpha,j} + m_i\sum_\beta k_{\alpha,\beta}C_{\beta,i} + G_{\alpha,i} \qquad (1)$$

$m_{\alpha,\, i}$ = mass of contaminant α in zone i (kg)

$R_{\alpha,\, i}$ = removal coefficient for contaminant α in zone i (kg/s)

$C_{\alpha,\, i}$ = concentration mass fraction of contaminant α in zone i (kg/kg)

$F_{i,j}$ = rate of airflow from zone i to zone j (kg/s)

$F_{j,i}$ = rate of airflow from zone j to zone i (kg/s)

$\eta_{\alpha', j,i}$ = filter efficiency in the path from zone j to zone i (kg/kg)

$C_{\alpha, j}$ = concentration mass fraction of contaminant α in zone j (kg/kg)

m_i = mass of air in zone i (kg)

$k_{\alpha, \beta}$ = kinetic reaction coefficient in zone i between species α and β (1/s)

$C_{\beta, i}$ = concentration mass fraction of contaminant β in zone i (kg/kg)

$G_{\alpha, i}$ = generation rate of contaminant α in zone i (kg/kg)

It helps to take into consideration that the program has also been used for the design and analysis of smoke management systems [Klote, et al. 2012]. The review of contaminant concentrations is used to investigate the indoor air quality performance of buildings models, before being built and occupied, impacts on ventilation systems, review indoor air quality performance of buildings and the building facility 's control technologies. Predicted contaminant concentrations is also verified to evaluate exposure of occupants based on occupancy rates and activity.

The process of building the basecase model and reviewing to the results involved five main tasks:

a. Building Idealization: design a specific model for the study, based on typical three studio units placed horizontally and vertically overlaying three typical floors with their plenum ceiling services and a top roof floor holding the main fresh air handling unit where all risers connect. This was reflected as relevant space conditions within the space layout, ventilation, and air conditioning system configuration, in order to have the assessment in later stages as real as possible.

b. Schematic Representation: to design a scheme and drawing of the spaces with all main components such as spaces dimensions, heights, risers, number of floors, configuration of spaces and services.

c. Define Building Components: input data and details related to building components such as air leakage paths (windows, doors, cracks) and defining them into two main categories of cracks and gaps of small and medium size, ventilation system elements (fans, ducts, vents) with standard conditions and flow rates. Temperature was designed for 22°C as supply temperature, 28°C of return temperature, and weather condition was taken as of 40°C ambient temperature with a relative humidity of 80%, and others such as operational schedule of the services. Each of these elements is associated with this set of parameters into the model, which was informed against HVAC engineering standards handbooks, estimated building specific data according to the study case to be in UAE and was included into the model parameters.

d. Simulation: Simulation parameters were set for running the simulation such as weather conditions, operating schedule of the services such as 24hours operation on or off and proposed running time of 12hours on and 12hours off, contaminant's location proposal and this has been proposed into different locations over the units horizontally and vertically till a base case was defined by having the contaminant being a person infected by covid 19 virus available on the 3rd floor mid-unit. Provision of exposure points/

occupants was limited to 4 points to help the running of the simulation and limiting comparison of cases. CONTAM provides a macroscopic model of the building. Thus, all characteristics of the zones are set to particular values for temperature, flowrate, pressure and contaminant generation. This stage required determining the type of analysis needed; whether steady state, transient or cyclical, and a number of other simulation parameters. A check on all airflow paths (4-way diffusers and cracks/gaps) to be on 24hr schedule, all plenum supply is set to on an operation of 24hr on 22°C schedule, and riser duct sections use the 28°C schedule, and all fan flow rates for supply fans are same as for extract fans, and running on 24hr operation, was a defining set of conditions to provide real operation and thus nearest to be real results.

e. Review and Record Results: in this stage, CONTAM provides the simulation results plotted on the screen and get these results reviewed and recorded into a file for reflection on spreadsheet program. Airflows and pressure differences at each flow element and contaminant concentrations per zone can be viewed directly in the results plotting. As a researcher and software user, the information is related to this study's analysis in terms to be related to the contamination of covid 19 infection and have a thorough examination of the related results for further reflection.

4.2. HVAC type of the multi-story residential building:

For the purpose of our investigation, the type of ventilation and air conditioning system under simulation, is the essential type of system configuration that is widely common in multi-storey residential buildings. More precisely, it represents a FCU in each residential unit to control the temperature of the conditioned space and each of these FCU is supplied by preconditioned outdoor fresh air from a centralized fresh air handling unit (FAHU). The FAHU preconditions and/or precools outdoor fresh air to a suitable temperature, i.e., 22°C, and then uses its fan to supply this to the back of each residential units FCU.

Fan Type	Flow Rate from roof fans to risers' sections supplying 3 floors	Flow Rate in Riser sections supplying 2 floors	Flow Rate supplying 1 floor and floor branches	Recirculation Flow Rate in studio units
Fresh Air Fan	42 l/s	28 l/s	14 l/s	
Fan Coil Unit				80 l/s
Extract Fan	42 l/s	28 l/s	14 l/s	

Table 3. Flow Rates applied in the Model

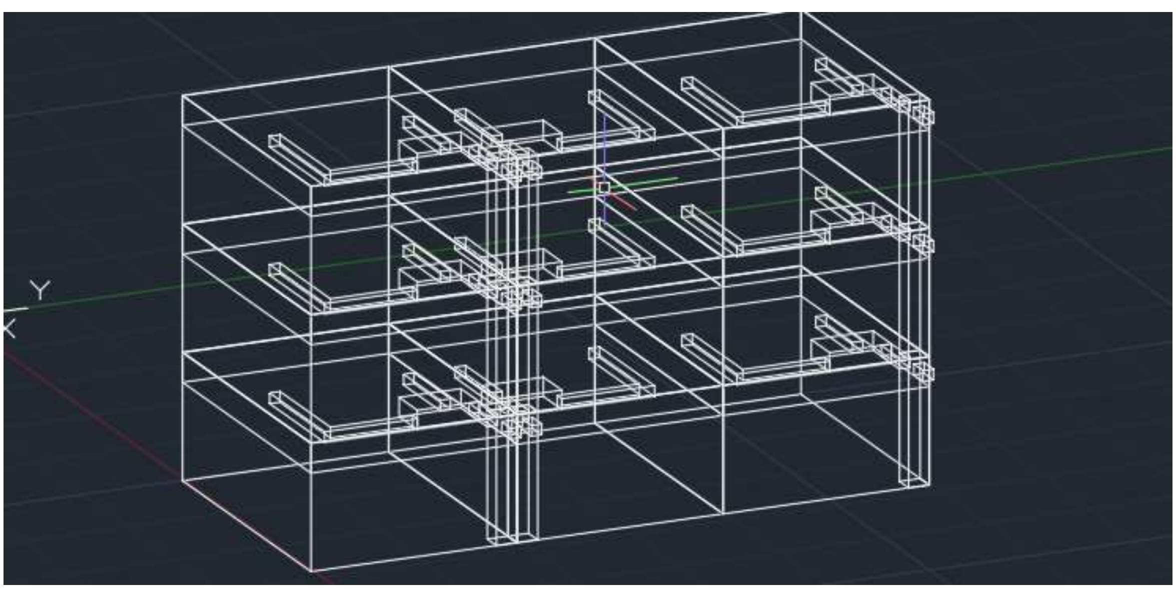


Figure 14. Model Risers and ductwork overlay

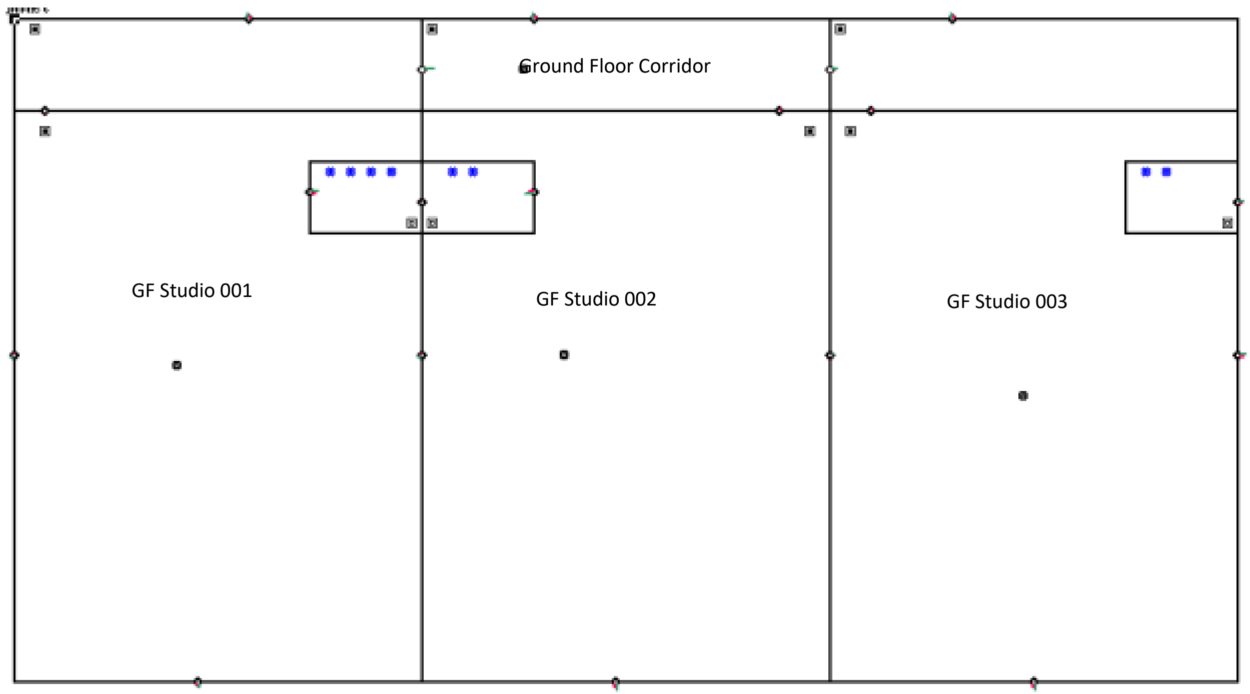


Figure 15. Ground Floor Layout

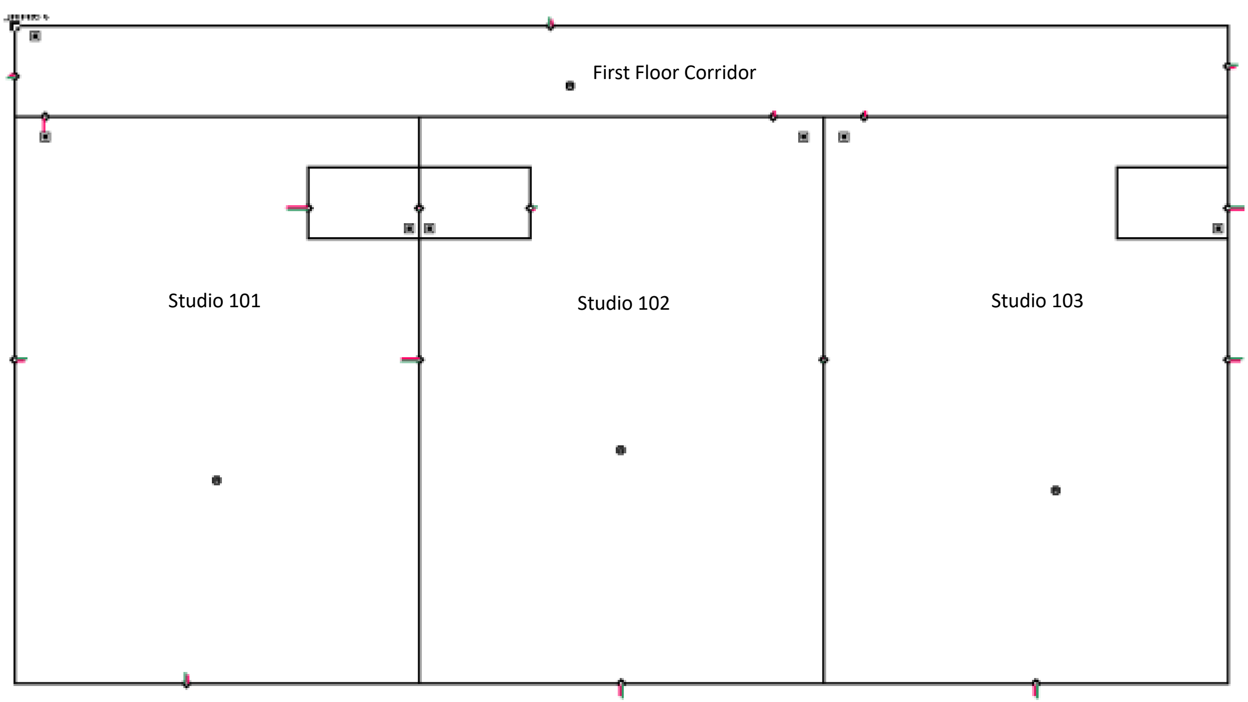


Figure 16. First Floor Layout

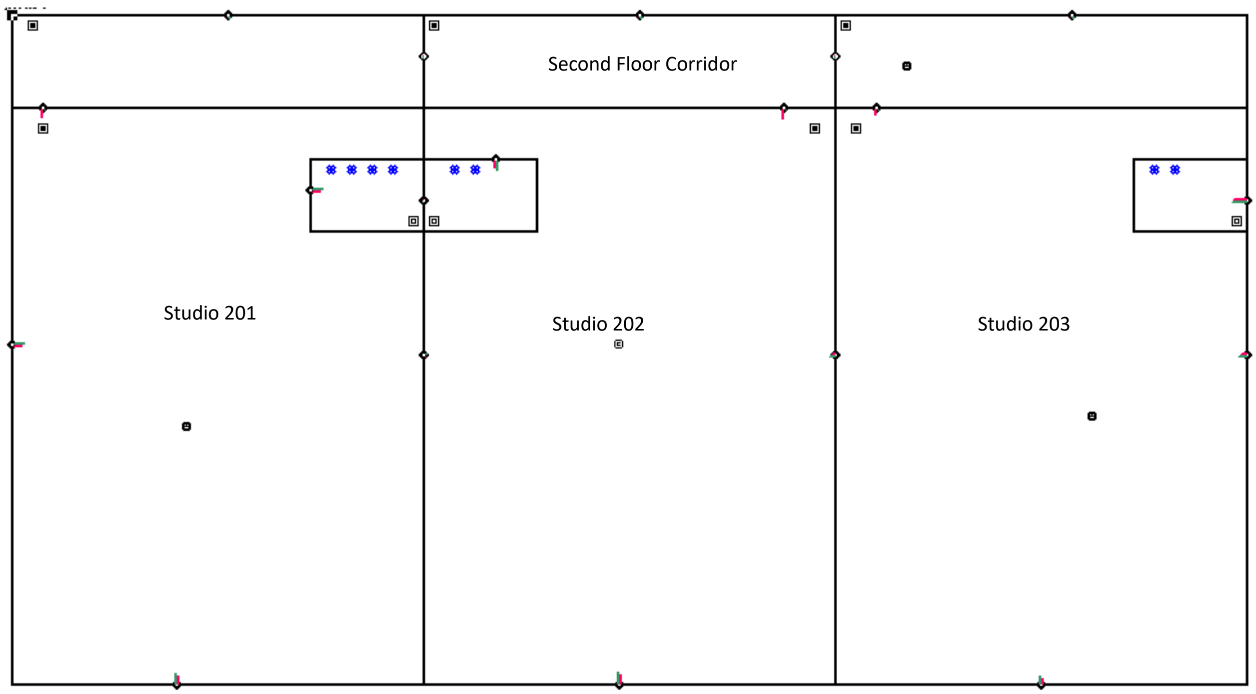


Figure 17. Second Floor Layout

4.3. Model FCU type and flow rates:

The modelling exercise takes into account a background infiltration rate of 0.15 air changes/hour of (Al Safat-501.05), as expected due to small openings around window frames, door frames, wall-floor junctions and services holes through the building envelope. The ventilation rates based for the modelling is in accordance with *Al Sa'fat* – 401.01, ASHRAE 62.1, 62.2 and 170. Refer to Table 02 available in section 4.1 above. In the model, the ventilation rate proposed is in accordance to ASHRAE 62.1, and since our proposed unit is less than 47m² and is a studio type, the required ventilation is 14L/s (table 4-1b, ASHRAE 62.1). This figure is based on an occupancy of two persons per unit, where at any time, this occupancy is increased by 3.5l/s per each additional person in unit.

	Bedrooms				
Floor Area, m^2	**1**	**2**	**3**	**4**	**5**
<47	14	18	21	25	28
47 to 93	21	24	28	31	35
94 to 139	28	31	35	38	42
140 to 186	35	38	42	45	49
187 to 232	42	45	49	52	56
233 to 279	49	52	56	59	63
280 to 325	56	59	63	66	70
326 to 372	63	66	70	73	77
373 to 418	70	73	77	80	84
419 to 465	77	80	84	87	91

Table 4. Ventilation Air Requirements, l/s (ASHRARE 62.1)

4.4. SARS-2 Covid-19 specifications:

It has been reported that quanta emission rates of an infected asymptomatic source for SARS-CoV-2, depend on activity level, and was found around 10^8 copies mL^{-1}. The rates are calculated based on different respiratory activities, respiratory parameters, and activity levels. Buonanno et al (2020), report that the human average generation and aerosol shedding rate of SARS-CoV-2 is 10.5 quanta/h for breathing and normal conversation speaking respiratory activities, and 320 quanta/h while at rest. In terms of light activity level, the rates are 33.9 quanta/h in normal conversation and breathing state and 1.03×10^3 quanta/h at normal rest. (G. Buonanno, April 2020).

For the purpose of this study, the emission rate is considered for people resting at home with light activity in their residence. The generation rate is set as 1.03×10^3 quanta/h in the model.

Covid-19 species, based on studies provided had been known for a set of properties which were added to the basecase model to define the COVID-19 contaminant, see table 5 below. These properties included the molar mass of the Covid-19 which is the measuring average atomic mass, the mean diameter is the diameter size of the virus, its decay rate which is the half-life to become inactive and with all set of components, and up to this stage, Covid-19 was determined to be a trace contaminant with no impact on heat exchange nor the density of the air.

Species Properties

Molar Mass:	200	kg/kmol
Diffusion Coefficient:	1e-06	m^2/s
Mean Diameter:	0.1	µm
Effective Density:	1.37	kg/m^3
Specific Heat:	1000	J/(kgK)
Decay Rate:	0.00193	1/s
UVGI Susceptibility Constant:	500	mÂ^2/J
Default Concentration:	0	kg/kg
Trace Contaminant:	Trace	
Use in Simulation:	Use	

Table 5. Covid19 species properties adapted in CONTAM

5. Results Analysis:

The development of the Contam COVID-19 model went through a sequence of model building checking results and adjusting to arrive at the final base-case model used to test various issues affecting dispersion.

To reflect on the impact of dispersion of COVID-19 contaminant particles, the contaminant concentration is plotted for each occupied space in units of quanta/cm^3 of the air volume in a zone. The simulation was run for fourteen days as it is the safety margin period within which the infection could disperse throughout the model building. However, as all boundary conditions, airflow rates, outdoor ambient temperature, and COVID-19 generation rate do not vary throughout the fourteen days. A steady-state solution for one day was sufficient to assess if the COVID-19 virus dispersed from the source studio location.

5.1. Scenario A (A1-A2-A3):

To set base-case conditions, the location of an infected person with COVID-19 was trialed in three locations of the middle studio unit on each of the three floors. The chosen unit was the middle one for easy check and quick reference on the impact on each adjacent unit from each side (below, above, left, and right) of the proposed infected unit and fans running on a 24-hour schedule. Refer to table 2 in section 4 for each scenario-specific condition, such as fan running schedule, infection of COVID – 19 location, and filters provision.

The findings of the simulation run were that the highest level of dispersion, i.e., the COVID-19 contaminant spreading to other zones, was under the condition of the infected person being located in the middle studio on the second floor (2ndFlr202), see table 6 and figures 18 to 20 below for the concentration level of COVID-19 plotting.

Occupied zone	Source in Ground Floor Studio 002 (Scenario A1)	Source in 1st Floor Studio 102 (Scenario A2)	Source in 2nd Floor Studio202 (Scenario A3)
Studio Ground floor 001	0	0	0
Studio Ground floor 002	0.0000091	0.00000065	0.00000072
Studio Ground floor 003	0	0	0
Ground floor corridor	0	0	0
Studio 1st floor 101	0	0	0
Studio 1st floor 102	0.00000032	0.000008	0.00000051
Studio 1st floor 103	0	0	0
First floor corridor	0	0	0
Studio 2nd floor 201	0	0	0
Studio 2nd floor 202	0.00000025	0.000000405	0.0000066
Studio 2nd floor 203	0	0	0
Second floor corridor	0	0	0

Table 6. Building zone COVID-19 concentration levels per location of infected occupant

The concentration levels of the infection of COVID-19 were the highest in the units where the infected person was occupying, dropping into units stacked vertically with the infected unit but with no transmission to horizontally adjacent units.

5.1.1. Scenario A1:

First Source case was placed on Ground floor middle studio unit (Studio 002) and running the simulation had shown that all adjacent spaces were not impacted. Their graph was zero unless the units placed above 002, i.e., 102 and 202, their readings showed a slight impact and equivalent in both spaces, as per the below chart in fig.18.

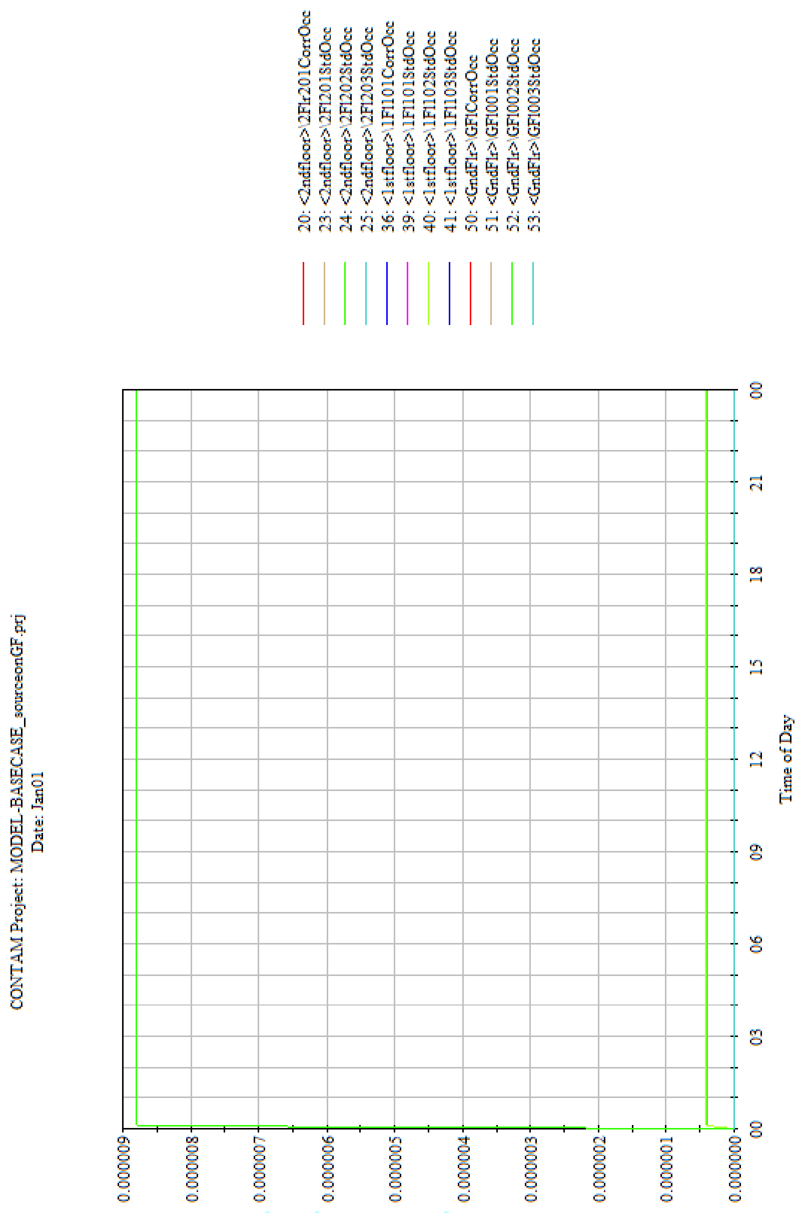


Figure 18. CONTAM Chart for all studio units COVID-19 concentrations with source in Ground Floor Studio 002

5.1.2. Scenario A2:

Second trial in Scenario A, referred to as A2, the source is placed on the First-floor middle unit (Studio 102), and running the simulation had provided the below graph reading, where only vertically stacked units (002 and 202) with 102 had revealed slight rate of dispersion of virus into their spaces. Other units had shown no contamination of COVID-19. Refer to the chart in fig.19 below.

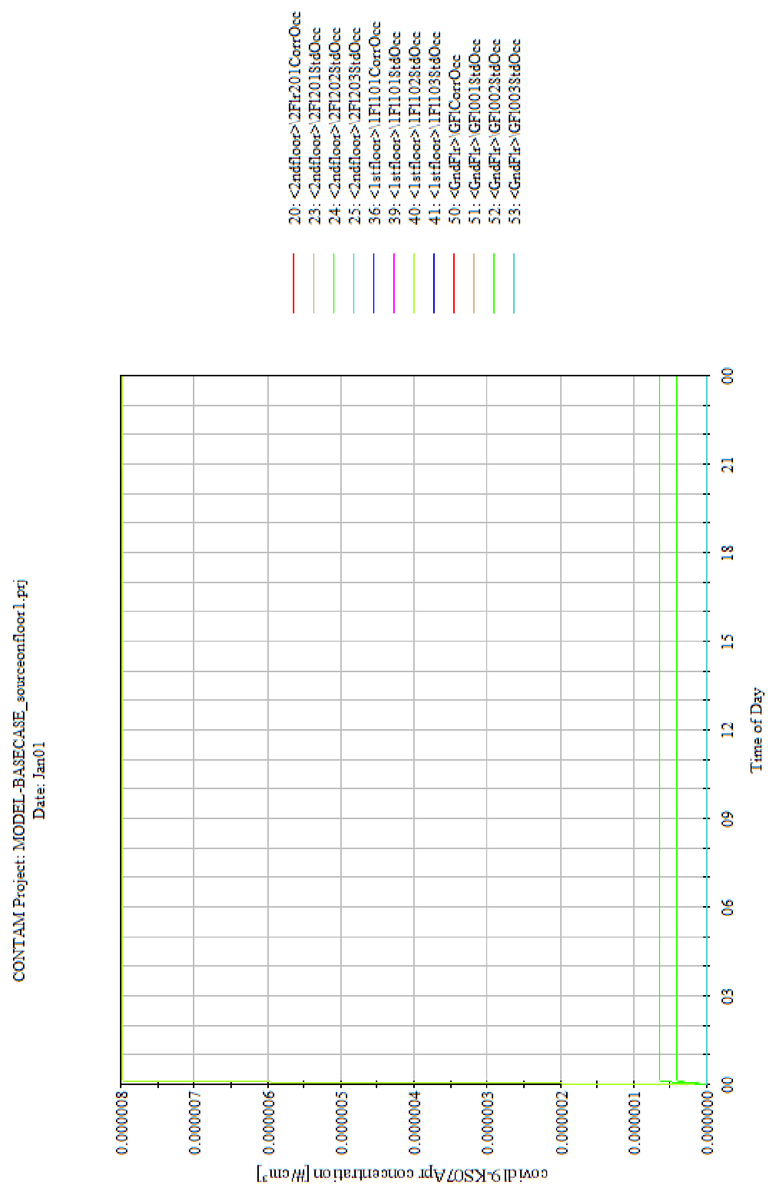


Figure 19. CONTAM Chart for all studio units COVID-19 concentrations with source in First Floor Studio 102

5.1.3. Scenario A3:

The third option for source allocation was placed on the second-floor middle unit (Studio 202). Running the simulation had highlighted that only vertical transportation of the spread of COVID-19 had occurred, and the two impacted units had very near findings. Refer to fig.20 below.

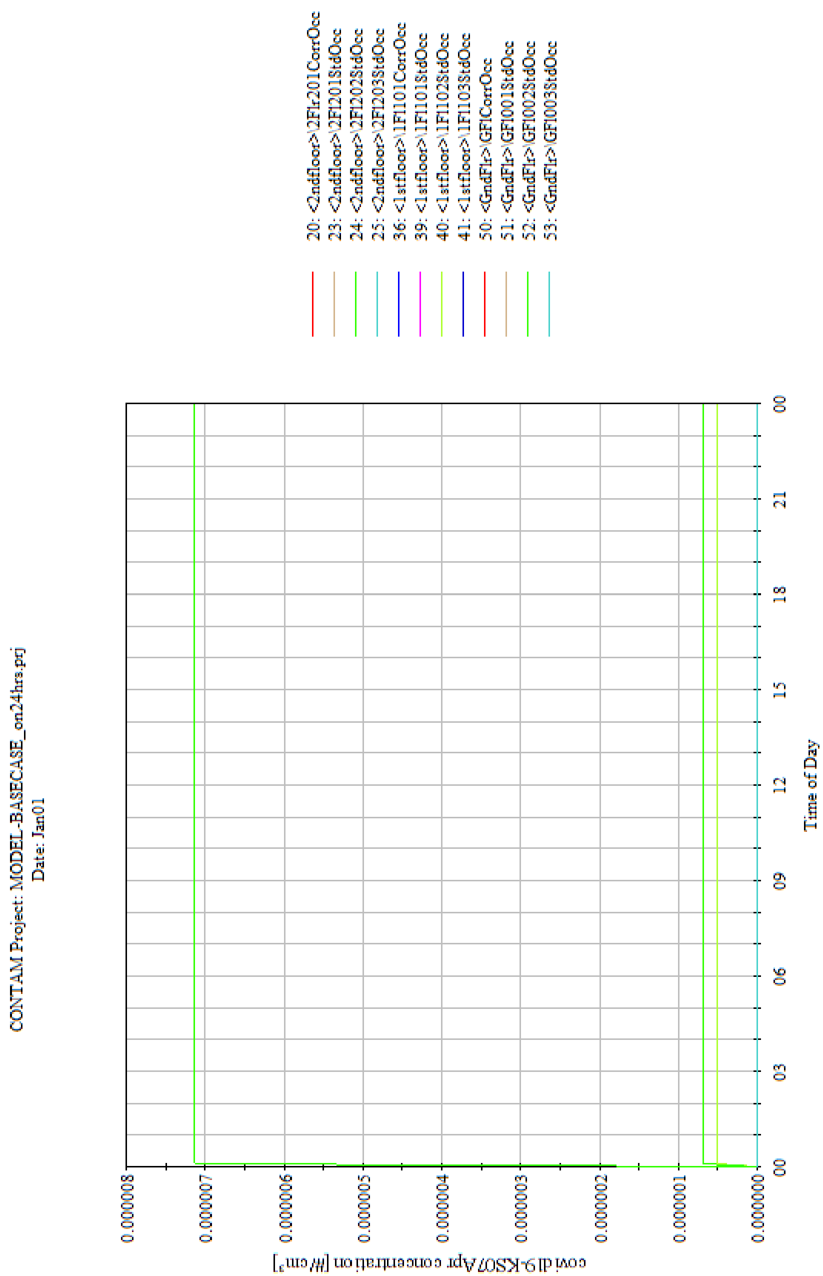


Figure 20. CONTAM Chart for all studio units COVID-19 concentrations with source in Second Floor Studio 202

According to the findings above, contaminants only reach the middle units on all three floors, i.e., Ground floor Studio 001, 1st Floor Studio 101, and 2nd Floor Studio 202. This indicates that dispersion is only taking place through the common risers. This can be linked to both pressure difference and airflow rates. These findings are only true for this particular model setup which includes things like very small cracks & airgaps between adjacent units and not many gaps around openings between units & corridors.

The dispersion is not highly quantifiable as it has been plotted; for example, in scenario A1, the infection concentration in the infected unit 002 is 9.1×10^{-6}, whereas the concentration levels in units 102 and 202 are 0.32×10^{-6} and 0.25×10^{-6} respectively.

The simulation shows that the highest dispersion spread of the COVID- 19 infections is in Scenario A3, where the infected person is staying on the 2nd-floor middle studio unit 202. The concentration levels have been plotted 6.6×10^{-6} in unit 202 , 0.72×10^{-6} in 002 and 0.51×10^{-6} in 102.

According to the reflected results, the following scenarios are simulated on a base case where the infected person is located on the 2nd-floor unit 202. Thus, scenario A3 is the reference condition among the comparison of all results.

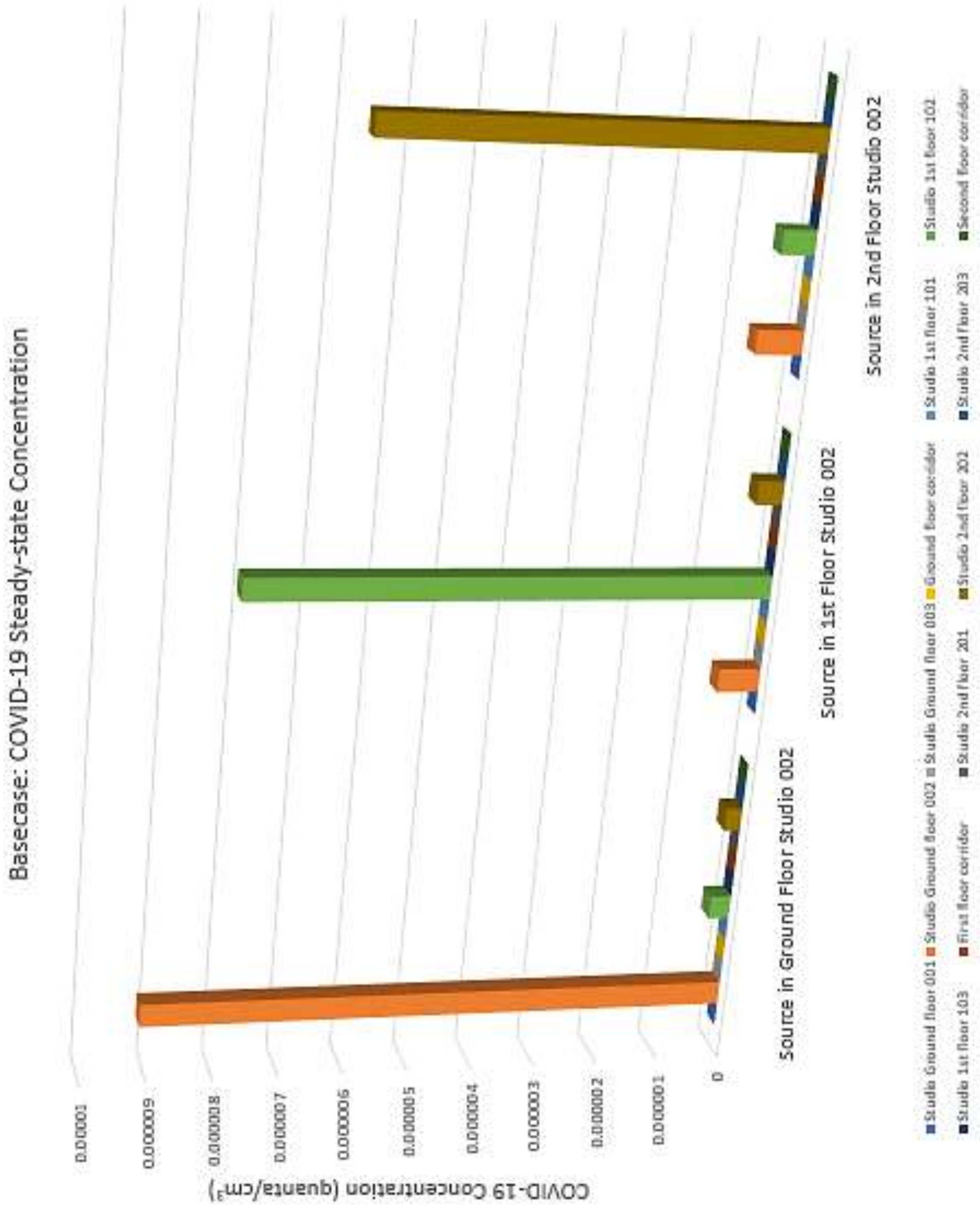


Figure 21. Graphs reflecting the 3 cases studied for virus dispersion

5.2. Scenario B: All Non-infected Residents with HVAC off during working hours

The model was reset and rerun to be representing variations in covid-19 dispersion and variations in concentration levels by altering the operation timing of fans. The infected person in Covid-19 is located in the middle unit of the second floor (studio 202). It is estimated a weekday where the infected person is quarantined in his studio, running his AC on for 24hrs, while the other tenants leave the house for work and the AC is put off for a duration of 12hrs. The HVAC system will be operating for 24 hours for all the floors' corridors.

The pattern of having FCU's not running when occupants are away at work during the daytime from 8 am to 8 pm resulted in an appropriate step change in concentration level. See Table 7 and Figures 22-23 below.

Occupied zone	Scenario B
Studio Ground floor 001	0
Studio Ground floor 002	0.000000685
Studio Ground floor 003	0
Ground floor corridor	0
Studio 1st floor 101	0
Studio 1st floor 102	0.00000051
Studio 1st floor 103	0
First floor corridor	0
Studio 2nd floor 201	0
Studio 2nd floor 202	0.0000071
Studio 2nd floor 203	0
Second floor corridor	0

Table 7. Scenario B - Contaminant source on 2nd floor, workday schedule for HVAC

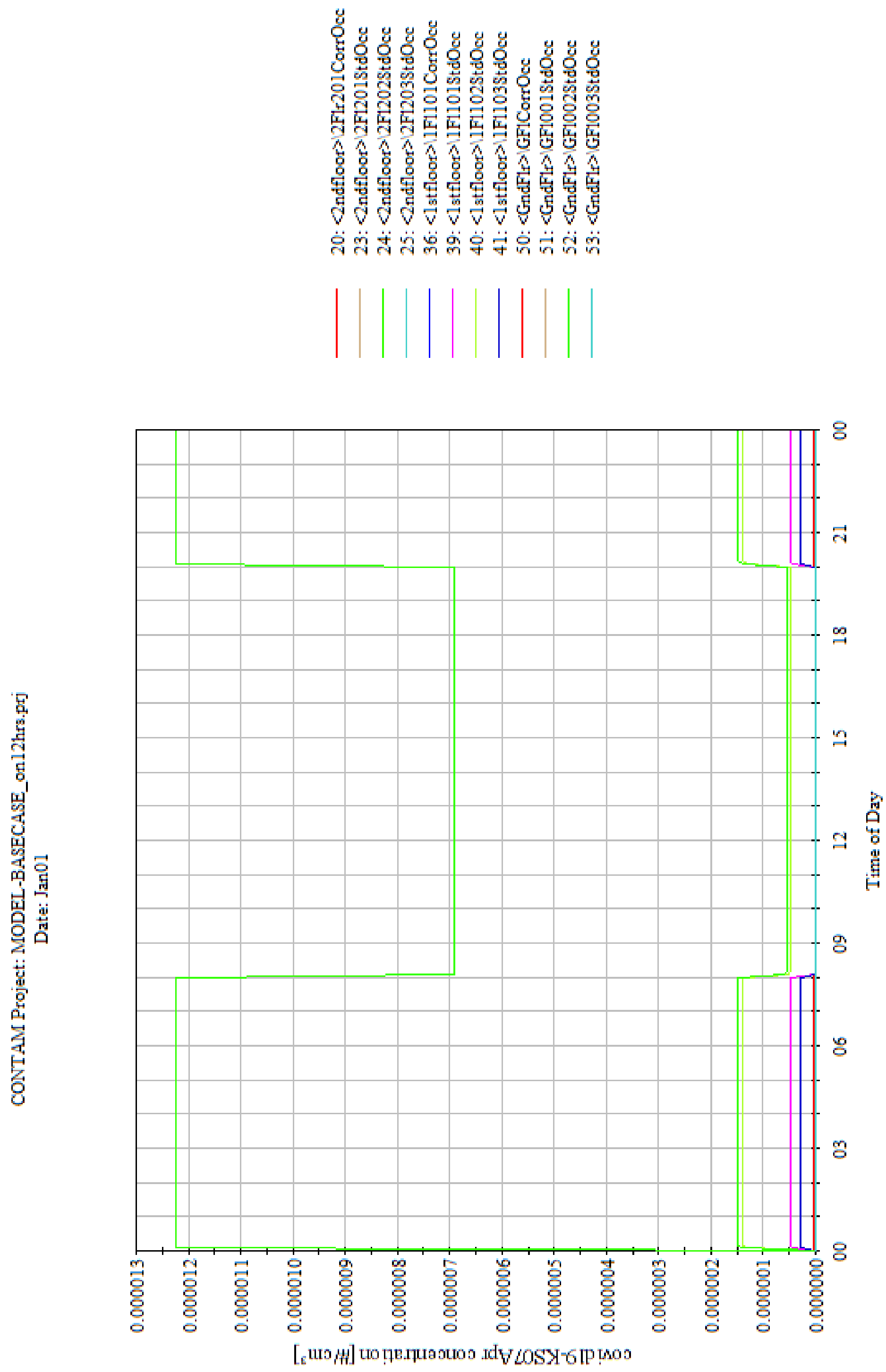


Figure 22. Scenario B CONTAM simulation on the base case

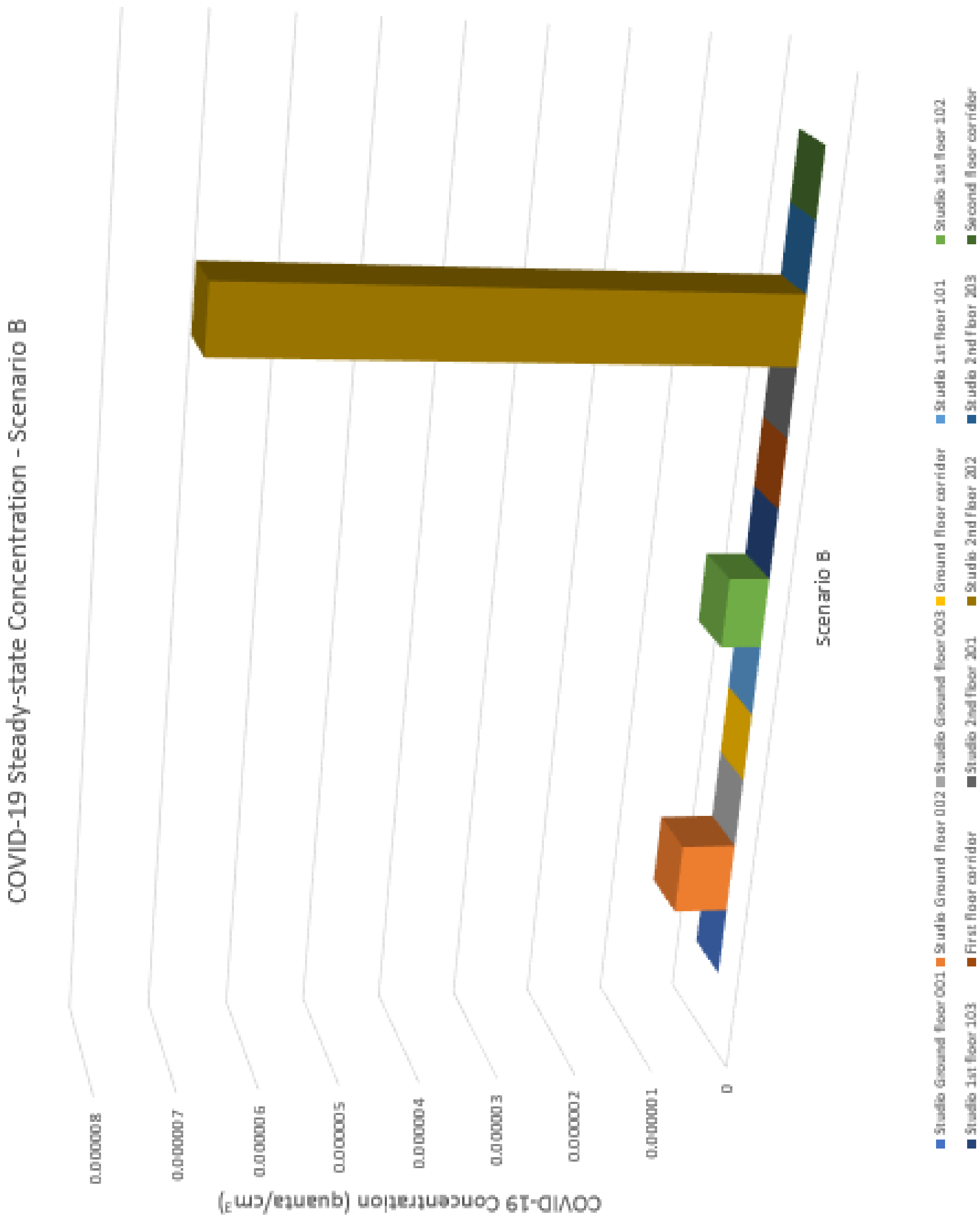


Figure 23. Graphs reflecting Scenario B for virus dispersion

5.3. Scenario C: Multiple infected occupants in the same studio

In this scenario, the infection level is higher since several occupants in the studio had been infected, so the generation rate had been multiplied.

For the simulation run, the generation rate had been increased to 4000 quanta/hr from an initial 1000 quanta/hr generation rate applied earlier. Only one person was in minimal conversation and no activity level. It is estimated a maximum of 4 occupants per unit, having ongoing conversations and a light activity level.

The results show a higher dispersion rate of COVID – 19 when more than one infected person is in the middle 2nd-floor studio; see Table 8 and Figure 24-25 below.

Occupied zone	Scenario C
Studio Ground floor 001	0
Studio Ground floor 002	0.0000027
Studio Ground floor 003	0
Ground floor corridor	0
Studio 1st floor 101	0
Studio 1st floor 102	0.00000205
Studio 1st floor 103	0
First floor corridor	0
Studio 2nd floor 201	0
Studio 2nd floor 202	0.0000071
Studio 2nd floor 203	0
Second floor corridor	0

Table 8. Scenario C - Impact of Higher Generation rate for Contaminant source on 2nd floor,HVAC on for 24hrs

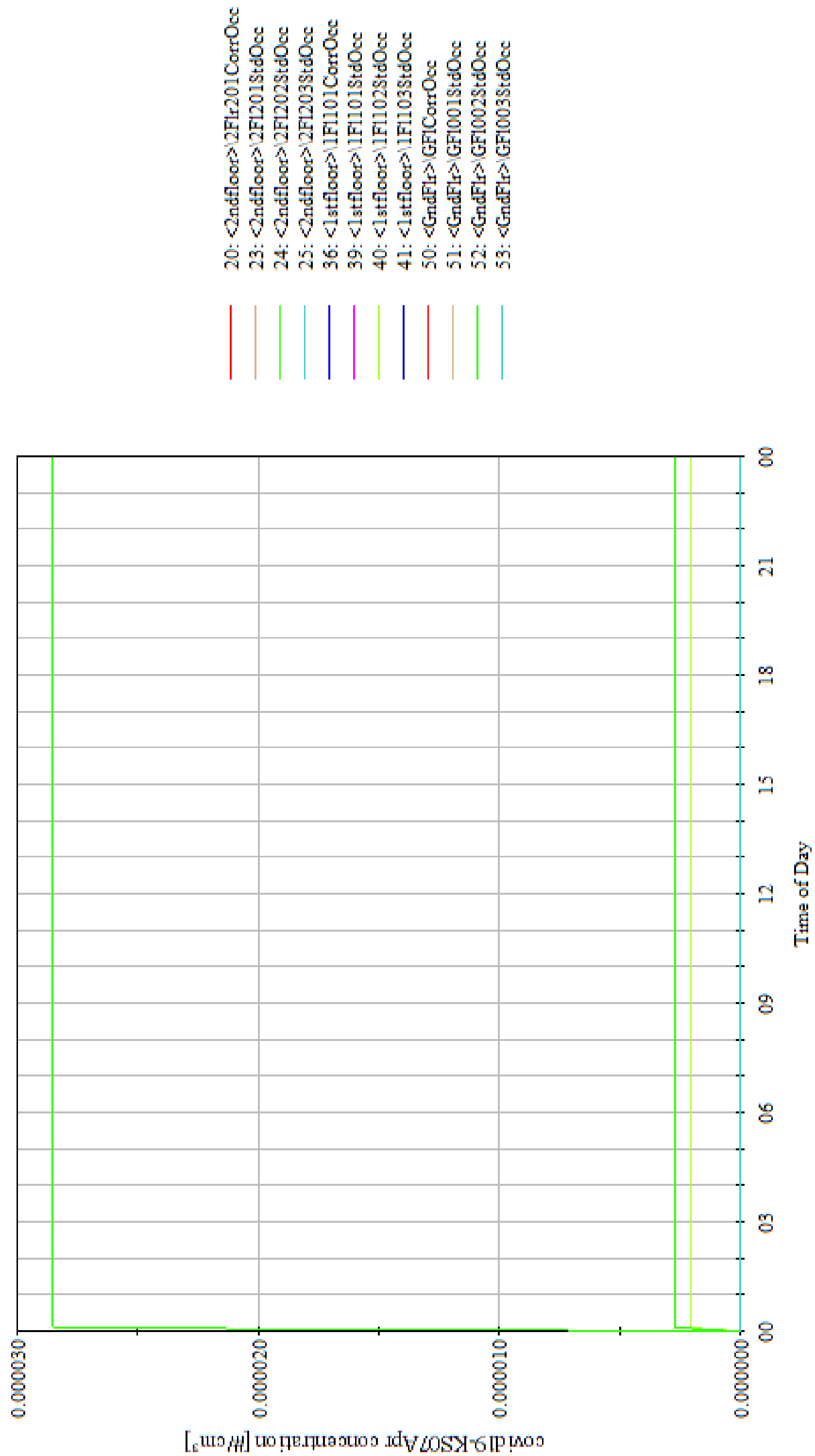


Figure 24. Scenario C - Higher concentration of contaminants in 202 and HVAC 24 hrs on

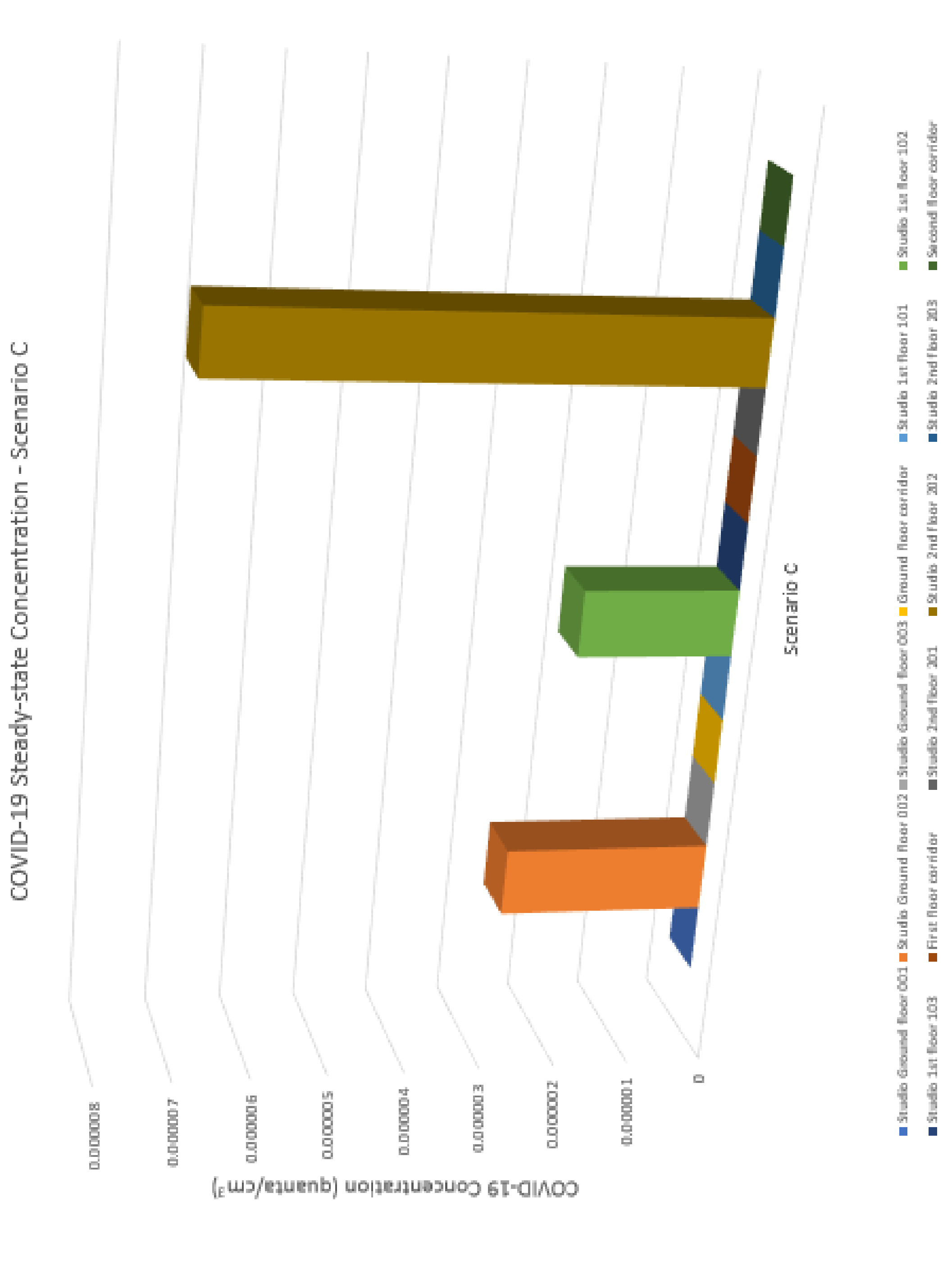


Figure 25. Graphs reflecting Scenario C for virus dispersion

5.4. Scenario D: Standard FCU mesh filters

The previous results have been for ‘worst-case scenario’ construction where key components of fan coil units, i.e., plenum section metal mesh filter, and common ducts, i.e., backdraft dampers, were not included in the model. However, the following results show the impact of including filter of MERV-8 in all of the FCUs of the base case of having the source available in mid-unit of the 2nd floor. Refer to table 9 and figures 26-27 below.

Occupied zone	Scenario D
Studio Ground floor 001	0
Studio Ground floor 002	0.00000052
Studio Ground floor 003	0
Ground floor corridor	0
Studio 1st floor 101	0
Studio 1st floor 102	0.000000395
Studio 1st floor 103	0
First floor corridor	0
Studio 2nd floor 201	0
Studio 2nd floor 202	0.0000066
Studio 2nd floor 203	0
Second floor corridor	0

Table 9. Scenario D - Findings of inclusion of MERV-8 in all FCUs of the base case of source on 2nd floor,HVAC on for 24hrs

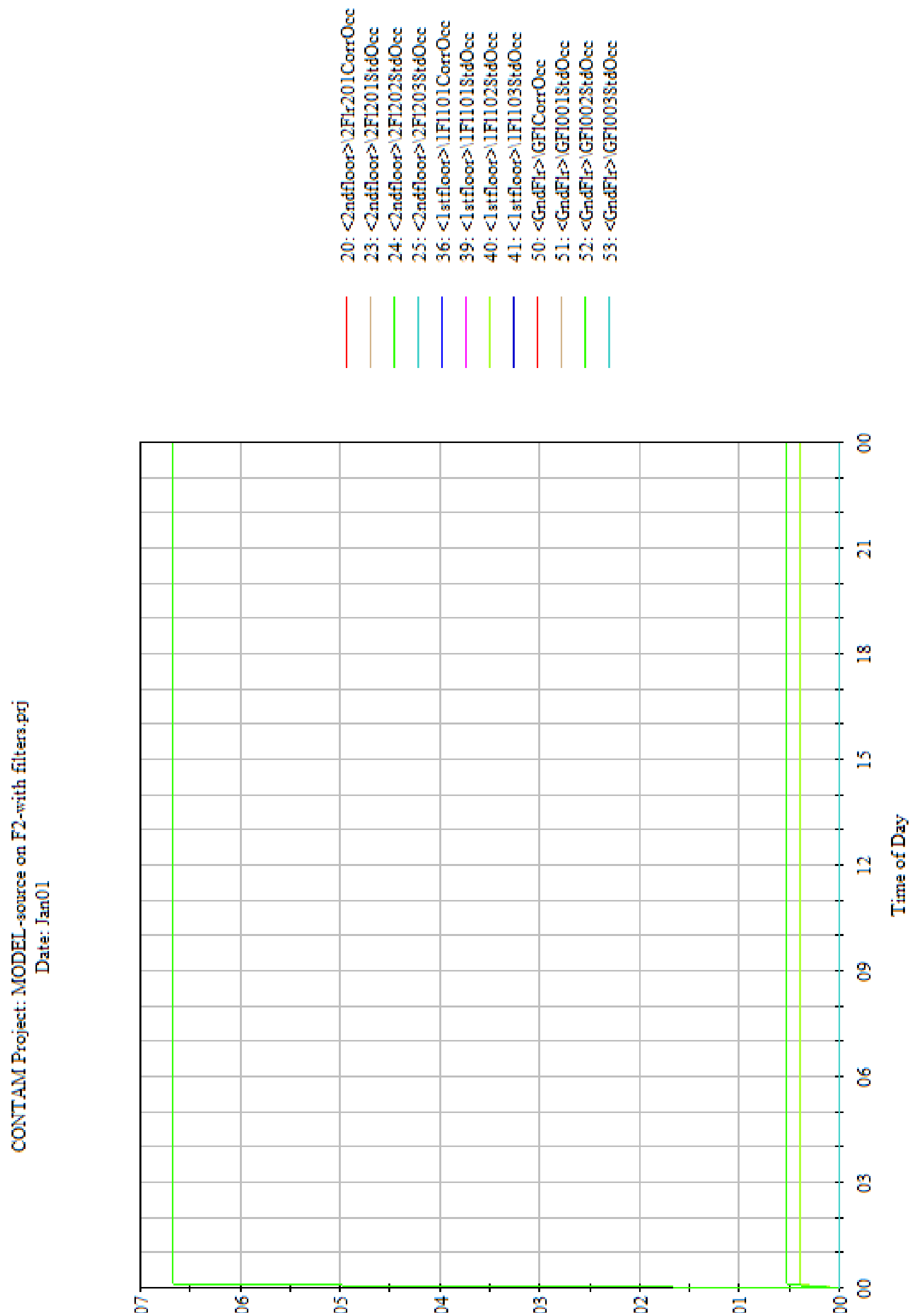


Figure 26. Scenario D - Contam plot for inclusion of filters in all FCUs in base case source on 2nd floor, HVAC on for 24hrs

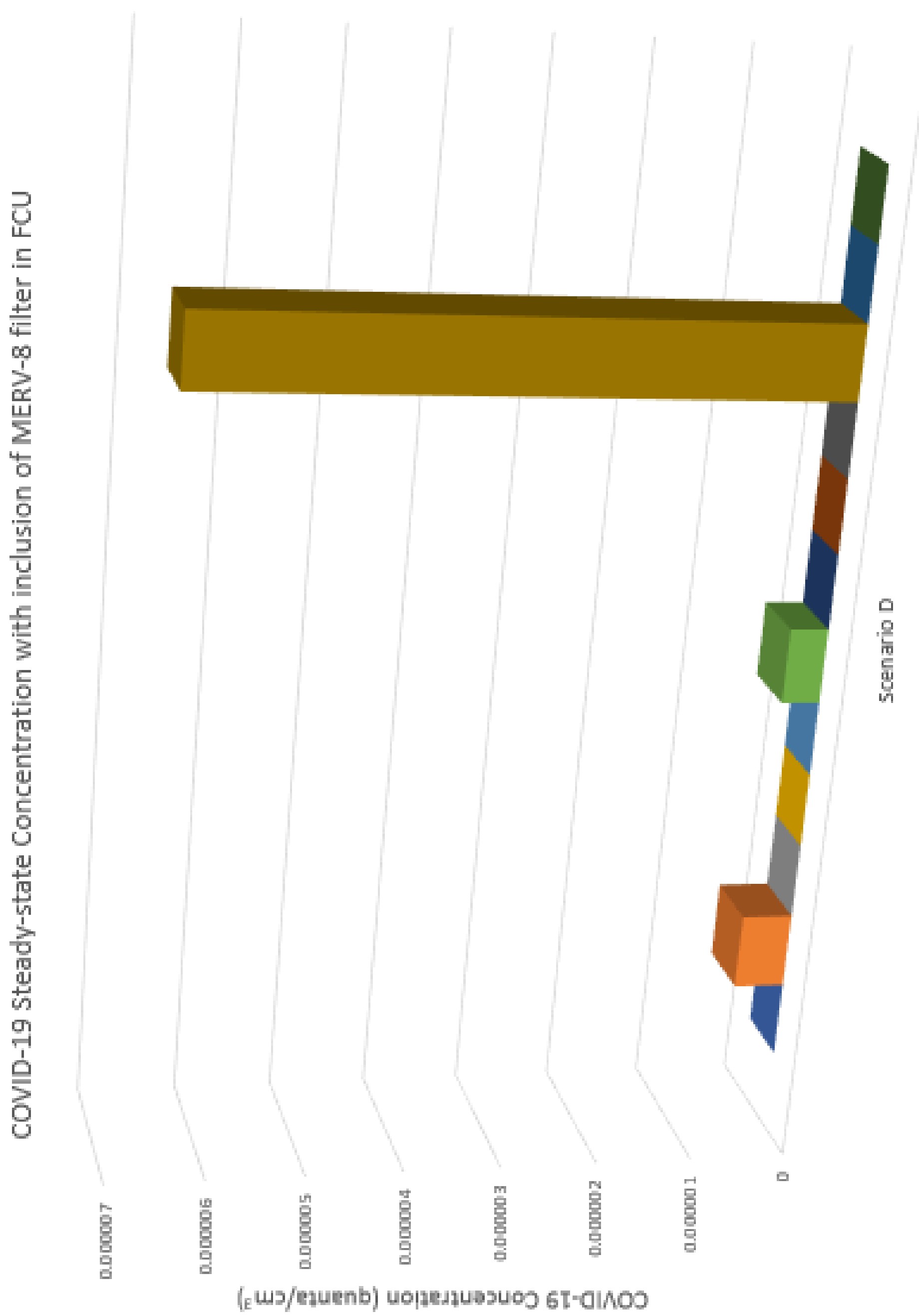


Figure 27. Graphs reflecting Scenario D for virus dispersion

5.5. Results Discussion:

The results taken from CONTAM simulation model scenarios show that contaminant concentration (in units of quanta/cm^3) ramp-up for a short period and then, at a certain level, remain constant throughout the simulated period. This has been reflected in scenarios A1-A2-A3-C and D. In scenario B, the concentration level increases to a maximum at the start, then steps down, then again increase within the day according to the HVAC operating schedule.

Those results effectively show that the generation rate of contaminants in any zone reaches a point where any additional contaminant the source generates is removed by the change of air in the zone. This applies to this model in its present conditions because the air change is at a constant flow rate. The generation rate is at a constant rate; the level of a contaminant in a zone will reach a steady-state level and not increase or decrease from this level unless something changes with the source generation rate or the airflow rate of the fan coil unit or of the fresh air and extract fans. But in reality, airflow rates will be continually rising and falling as fans switch on and off to provide different levels of cooling, and the cooling load in some zones changes throughout the day and night.

In a study done in quarantine and isolation rooms in hospitals in the University of Nebraska medical center in May 2020, the contamination was sampled as a range of gene copies/l of air (Santarpia,2020). And noting that 10^5 copies/l is found as the bench level to detect the infection in humans when the infection is based on 10^3 quanta/h (G. Buonanno, 2020). The gene copies found in the air samples of CONTAM model findings were as low as 7.2x 10^{-7} based on the same emission rate of 10^{3} quanta/h. From the above results, it has been confirmed that there is a dispersion of Covid-19 aerosols through the HVAC system, but the infection risk is low.

The results from the simulation model show that the transmission occurs through units sharing the same risers carrying common fresh air & extract duct systems. This risk of dispersion through cracks and gaps in-wall/roof construction elements drops to negligible but only to the conditions in the model built for this study and its limitations.

It is noticeable that through the results provided by the simulation, the level of dispersion steeped when the infection was placed in the higher level of the model in studio 202, and the concentration has transmitted the maximum to the ground floor unit 002. This can be related to several conditions. The pressure difference and airflow rates through the riser provoke transmission of air holding the virus particles to lower levels due to its air mass change from the extract of the air room. Another reason could be the difference in temperature between the riser's air (28°C) and the extracted air (22°C), which may cause condensation within the ductwork and cause higher humidity levels. This would create a better environment for the COVID-19 particles to be carried by air particles and transmitted to lower levels due to air mass getting heavier.

Comparing the Scenario A3 (set as the base case) results to scenario B, the difference in the values of the results was negligible. The infected unit 202 in scenario A3 showed a concentration of 6.6 x 10^{-6} and unit 002 was at 7.2 x $10^{-7,}$ wherein Scenario B, where the HVAC system was running for 12 hours for non-infected units, the results were 7.1 x 10^{-6} for 202 and 6.85x 10^{-7} for 002. It can be highlighted that running the HVAC continuously in the units has no further impact in limiting the spread of the

COVID-19 virus. This is only applicable to the model conditions where the units are simple studio units and typical services in the building. Further studies can be done for a different mix of apartment units in a residential building and more complex services for verification.

Scenario C highlighting the increase of concentration level of COVID-19 in the infected unit, had proven results of 7.1×10^{-6} in unit 202 and 2.7×10^{-6} in unit 002. The infected unit concentration is still the same, but the dispersed level had risen. This could come back that the concentration level of contaminants rises and stay steady after a certain level where no further infection can impact it in the same zone. Still, this higher concentration would be transmitted to other units where any connection or ventilation and air change can assist.

Scenario D, highlighting the provision of MERV 08 filter in the HVAC system, had shown the following results of 6.6×10^{-6} in unit 202 and 5.2×10^{-7} in unit 002. While compared to scenario A3, these values show a drop in the transmission level of the virus, indicating that filters' usage impacts the dispersion of COVID-19. But assessing with a higher rate of filters such as MERV 11 or UVC filters is recommended for better efficiency due to COVID-19 particle sizing.

6. Conclusion

The main goal of this study is to determine if COVID-19 particles can be transmitted in a central shared ducted HVAC system in residential buildings. To achieve this goal, a base-case model that represents a typical UAE high-rise residential building following Dubai regulations and international norms and standards was established through CONTAM software. In the process, a study on the conditions of the HVAC central system and filters were collected. Then, collection of the last reviewed and verified data about COVID-19 contaminants were analyzed for implementation in the model study.

Then, several operational scenarios were approached based on various recent studies and researches. These approaches included providing a schedule of running the HVAC system, whether full operation or workday schedule of 12-hours on only, estimating higher concentration levels of infection in source unit, and provision of a standard-rated filter within the system. The simulation run for the provided scenarios and their conditions were conducted to verify the likelihood of the spread of the virus and to help in improving the building and its HVAC performance in case of the spread of aerosols-based viruses.

Looking at how the central HVAC air conditioning works, it is evident that the system depends on one central air handler located at the rooftop to facilitate the distribution of conditioned air to various floors of the multi-story building via the fan coil unit. In that case, the system works so that it allows drawing of both unconditioned air from the environment and the conditioned air from the conditioned spaces. Therefore, given the recirculation of air back and forth in the conditioned space, there is no doubt that different particles and microorganisms are likely to be carried along. Aerosols of small droplets can spread through air conditioning systems within building structures. This study extends the built hypothesis and knowledge towards that change of the residential placement of the infected person inside the building and its connection to the shared services and ductwork with other units impact the spread of COVID-19 particles.

6.1. Limitations on the study findings:

There were some limitations to this study that need to be acknowledged. The research and information about COVID-19 are recent and not final and get updated with every new confirmed data on the virus acknowledged by reliable entities such as World Health Organization or ASHRAE.

Another concern that this study can not generalize is that impact of the COVID-19 spread in HVAC is related to the air conditioning system where the model provided feedback on centralized common fresh air supply and in multi-residential buildings. The findings can be completely different when conditions change, whether the building type or the HVAC system and its operational criteria.

Based on the findings of this study, it is recommended that further work be carried out to assess the transmission of the COVID-19 virus in more complex residential buildings having several apartments types and more complex HVAC systems. Then they can investigate the efficiency of the provided approaches and solutions and further solutions.

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