# SCENARIOS OF OCCUPATIONAL CAPACITY FOR HIGH EDUCATIONAL BUILDINGS IN THE TIME OF COVID

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The study investigates different scenarios for the occupational capacity of educational spaces in the time of the COVID pandemic. A whole system thinking approach is used to consider the integration of physical and tactical parameters. The former accounts for ventilation rates and furniture settings while the latter accounts for occupational densities. The research method started with a qualitative step: collecting data and information about the current situation and standards of spaces as well as local building codes for high educational buildings during pandemic outbreaks. Then, computer simulation programs were used to study indoor ventilation requirements inside an educational space (design studio) with varying occupational densities of 25%, 50%, 75% compared to a reference case of 100%. The result showed that occupation densities of 50% (IDA 2) and 75% (IDA 3) provide medium and moderate indoor air quality, respectively. Nevertheless, the latter can increase risk scenarios with the increase of carbon dioxide concentration level above 1000ppm. This requires increased airflow and the rate of air change by a rate of 40% above normal levels.

Keywords: COVID; high educational building; indoor air quality; whole system

## INTRODUCTION

The first case of novel coronavirus was recorded at the end of 2019 in Wuhan, China (Johnson, 2020). The virus spread worldwide, and local governments adopted precautionary measures to manage and control occupational densities particularly in public buildings (Medhat and Kassas, 2020). Recently in Egypt, 110 thousand people were affected by COVID-19 and still counting (World Health Organization, 2020b). Public buildings adopted contingency plans in response to the situation. Many countries put a set of regulations and tactical measurements to decrease the spread of the virus by managing the occupation density in educational spaces and set the precautionary distance between students and staff members (Schleicher, 2020). In April 2020, 94 percent of students worldwide were affected by the pandemic, which represented 1.58 billion youngsters and youth, from pre-primary to higher education, in 200 countries (De Giusti, 2020). Nevertheless, there were no defined parameters for universities to be taken into consideration during contingencies on the national scale, e.g., occupational densities in indoor spaces, hence, this leads to variation among them.

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Previous studies discussed the effect of COVID on the educational system and new means of online and blended teaching to reduce occupational densities indoors (Dua *et al.,* 2020). Other studies discussed the COVID effect on the indoor climate; occupation densities and occupants' health, comparing risk scenarios to normal operation and how this may affect post-pandemic architecture (Lassen, Josefsen and Goia, 2021; Megahed and Ghoneim, 2021). Furthermore, the discussion was expanded to energy consumption in relation to increased ventilation rates especially in public buildings (López Prol and O, 2020; Burridge *et al.,* 2021), where studies pointed to the increase in electricity demand (Edomah and Ndulue, 2020; Santiago *et al.,* 2021).

This study discusses means of evaluating the variations in occupational densities in indoor spaces of a university building in Egypt, taking a design studio as a sample for the study. The discussion adopts a whole system thinking approach taking into consideration physical measurements including variations in ventilation rates and furniture settings and tactical measurements including planning for occupational densities. The discussion expands to include means of compliance with the local building code for ventilation rates and techniques as well as for the instructions of the world health organization (WHO) for indoor occupation density in time of the COVID pandemic. This is in light of furniture organization standards for universities. Also, it considers recommendations for educational space's adaptation according to the decisions of the Egyptian ministry of health to increase safety and health. Hence, this study can be replicated to obtain a well-planned occupational strategy in the time of contingency for different educational spaces, e.g., lecture halls, classrooms, laboratories and staff rooms. This should be based on a profound study of airflow, ventilation rates and the type of educational activity undertaken which determines the furniture settings.

## LITERATURE REVIEW

This section investigates indoor air quality (IAQ) in the time of contingency by reviewing relevant journal papers and conference proceedings using science direct from 2011 to 2021. The query used the following keywords: IAQ, High educational buildings, COVID Pandemic, Indoor air quality, Ventilation and Whole system thinking. Previous literature discussed IAQ, ventilation regulations during COVID - 19 and precautionary measurements, but did not discuss the integration between physical and tactical measurements for proper management scenarios of occupational capacities in time of pandemics. The research hypothesis and review scenario are shown in Fig1.

### Concern for IAQ in educational buildings

IAQ is defined as the quality of a building's indoor environment with relation to occupants' health and safety (Karapetsis and Alexandri, 2016). Proper ventilation requires providing proper ventilation rates according to the number of occupants and type of indoor activity. This is in addition to considerations for the direction of airflow and distribution of air inside the space. According to the national ventilation code of Egypt, the ventilation rate of breathing inside closed spaces and is classified according to the metabolic activity inside a space e.g., 0.8 L/s for sitting, and from 1.3 to 2.6 L/s for light work. In addition, temperature, humidity and carbon dioxide concentration levels are some of the parameters that affect the air quality inside an indoor space. These different factors should be monitored for better IAQ with fewer pollutants (Ha, Metia and Phung, 2020; Marques *et al.,* 2020). Hence, previous studies pointed to the importance of monitoring $CO_2$ levels as a significant indication for the quality of ventilation rates, favouring natural ventilation when possible (Yang and Mak, 2020).

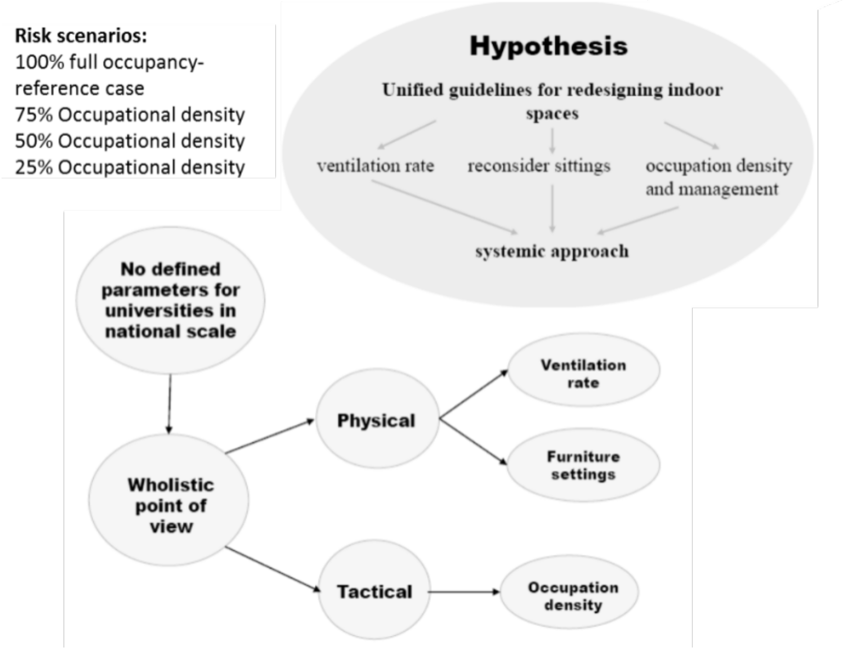
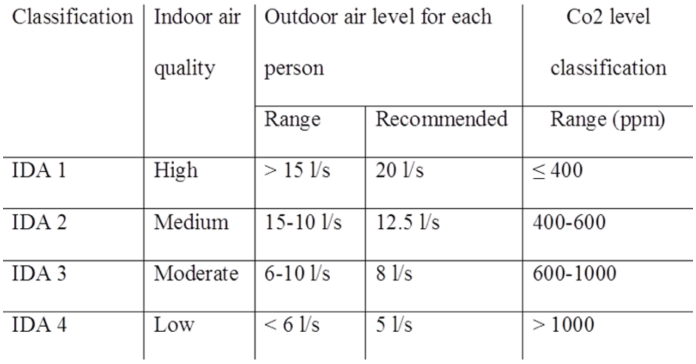


*Fig 1: The research approach*

It is noted that $CO_2$ based demand control achieves ventilation requirements in response to $CO_2$ concentration level monitoring (Pavlovas, 2011). The minimum fresh air in educational spaces according to ASHRAE and the Egyptian code for ventilation is 5 L/sec, while the mechanical ventilation is 0.9 L/sec. Indoor air quality classification is shown in Table 1, showing $CO_2$ level classification.

*Table 1: Indoor air quality classification, PN-EN 13779 classification of indoor air quality (IDA)*



| Classification | Indoor air quality | Outdoor air level for each person | | Co2 level classification |
|---|---|---|---|---|
| | | Range | Recommended | Range (ppm) |
| IDA 1 | High | > 15 l/s | 20 l/s | ≤ 400 |
| IDA 2 | Medium | 15-10 l/s | 12.5 l/s | 400-600 |
| IDA 3 | Moderate | 6-10 l/s | 8 l/s | 600-1000 |
| IDA 4 | Low | < 6 l/s | 5 l/s | > 1000 |

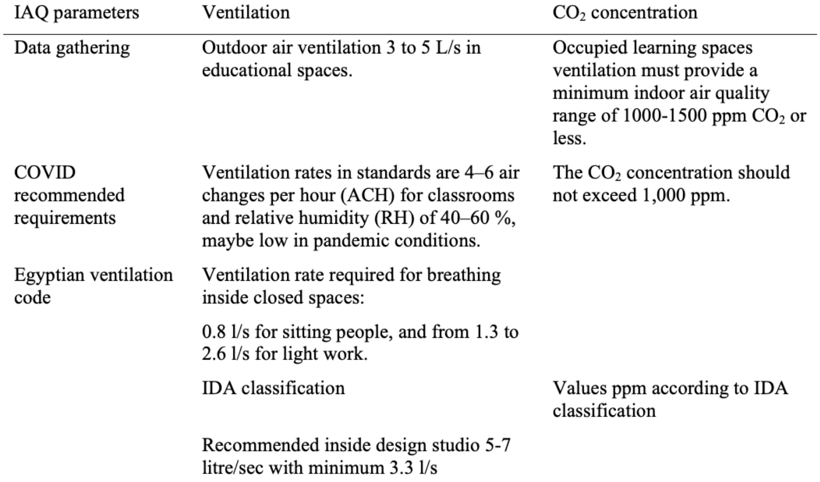
## Impact of COVID-19 in educational buildings

The WHO stated that the transmission methods of the virus include close direct contact with infected people of less than one meter especially in indoor closed spaces with poor ventilation. It can also occur by indirect contact through contaminated surfaces that can carry the infection agent for hours or days- depending on the surrounding climate or the material of that surface.

According to the WHO operational consideration of COVID-19, ventilation is one of the vital strategies that should be considered during pandemics in educational buildings and considered by increasing the natural airflow inside a space. As for using mechanical systems, it should depend totally on the outdoor air and HVAC operation system considered for two hours after and before occupation time (World Health Organization, 2020a).

Some researchers stated that the furniture layout has a great impact on the indoor airflow and the distribution of pollutants. Other researchers stated that furniture arrangements and the location of occupants inside indoor spaces have a low impact on the indoor quality of air as long as they do not block the airflow in large spaces (Zhuang, Li and Tu, 2014). Moreover, changing the pollutant source location is an optional decision, while rearranging occupants' locations is a good solution (Rim and Novoselac, 2010). The relation between IAQ parameters, Ventilation rates and $CO_2$ concentration is shown in Table 2.

*Table 2: IAQ parameters, Ventilation rates and $CO_2$ concentration*



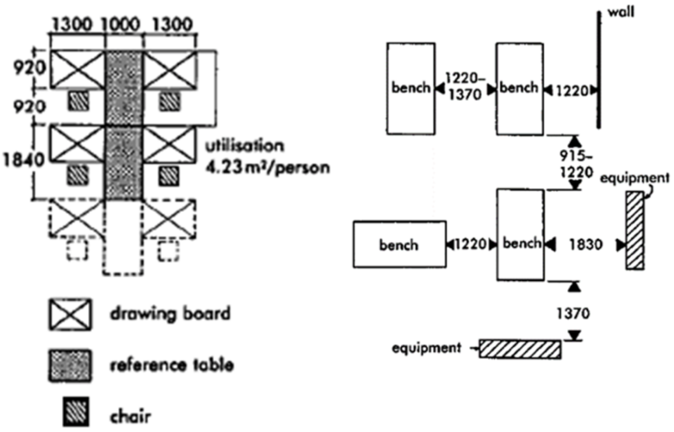
| IAQ parameters | Ventilation | $CO_2$ concentration |
|---|---|---|
| Data gathering | Outdoor air ventilation 3 to 5 L/s in educational spaces. | Occupied learning spaces ventilation must provide a minimum indoor air quality range of 1000-1500 ppm $CO_2$ or less. |
| COVID recommended requirements | Ventilation rates in standards are 4–6 air changes per hour (ACH) for classrooms and relative humidity (RH) of 40–60 %, maybe low in pandemic conditions. | The $CO_2$ concentration should not exceed 1,000 ppm. |
| Egyptian ventilation code | Ventilation rate required for breathing inside closed spaces: | |
| | 0.8 l/s for sitting people, and from 1.3 to 2.6 l/s for light work. | |
| | IDA classification | Values ppm according to IDA classification |
| | Recommended inside design studio 5-7 litre/sec with minimum 3.3 l/s | |

## Whole system thinking

A system is a frequent interacting and interrelated components that integrate forming a unified whole or a common purpose. It consists of variables and sub-variables and any change in them affects the whole system. System thinking is an approach to know how the elements interact in the system and enable solving complex problems (Hassan *et al.,* 2020). Vensim is general-purpose software for simulation created by Ventana Systems, Inc. of Harvard, Massachusetts in 1985. It was developed to solve difficult management problems, but its use is extended to several other applications. In 1991, the first version was released and was primarily intended for a specialist of model designers who had some experience developing and using dynamic simulation models. Also, it is used to build, run and analyse models (Environment, 2007). It performs on two levels of model analysis; causal loop diagram (sometimes called influence diagrams) and the stock and flow analysis. On one hand, the former shows the causal relations between variables. An arrow going from A to B indicates that A causes B. Causal loop diagrams can be very helpful in conceptualizing and communicating structures. Hence, feedback enables revising the system's structure and operating parameters (Environment, 2007). On the other hand, the Stock and flow diagrams show the dynamic change of variables in time. It is a way of representing the structure of a system with more detailed information. Stocks (Levels) are important to express the system's behaviour; flows (Rates) cause stocks to change. Stock and flow diagrams are the first step to develop a simulation model because they help define the types of variables that are important in causing behavioural change (Environment, 2007). Vensim software is used to visualize the integration between different parameters to make it easy to know what and how each variable affects others.

**Case study and standards for Design studio**

The study discussed an educational space (design studio), located on the ground floor on the north façade of the building (A) at the British university in Egypt. This provided a comprehensive view of occupants' health and wellbeing. According to the national standards, the required $CO_2$ concentration inside the design studio during the pandemic should be less than 1000 ppm, this means that according to the national ventilation code of Egypt the classification of indoor air quality should be (high, medium or moderate) according to occupation densities. Moreover, the required ventilation rates should range from a minimum of 3.3 l/s to a maximum of 7 l/s with 4-6 air change hours. According to the national ventilation code of Egypt that in design, drawing studio, an occupation of 20 people for 100 square meters per floor, should achieve a minimum ventilation limit of 3.3 litres/sec and recommended of 5-7 litre/sec. Full data about the case study is summarized in Table 3. The standard spacing between workstations is 1.4 meter and between the wall and workstation is 1.2 meter and the pathway between rows equal to 1 meter as shown in Fig2.



| Studios | m2 /UFA |
|---|---|
| Drawing Studios Architecture,<br>Town Planning, Engineering | 2.8/student (1st year)<br>2.2/student (2nd/3rd year) |
| Design studios postgraduates | 2.8/student |

*Fig 2: Standards of furniture settings in a typical drawing studio*

# METHOD

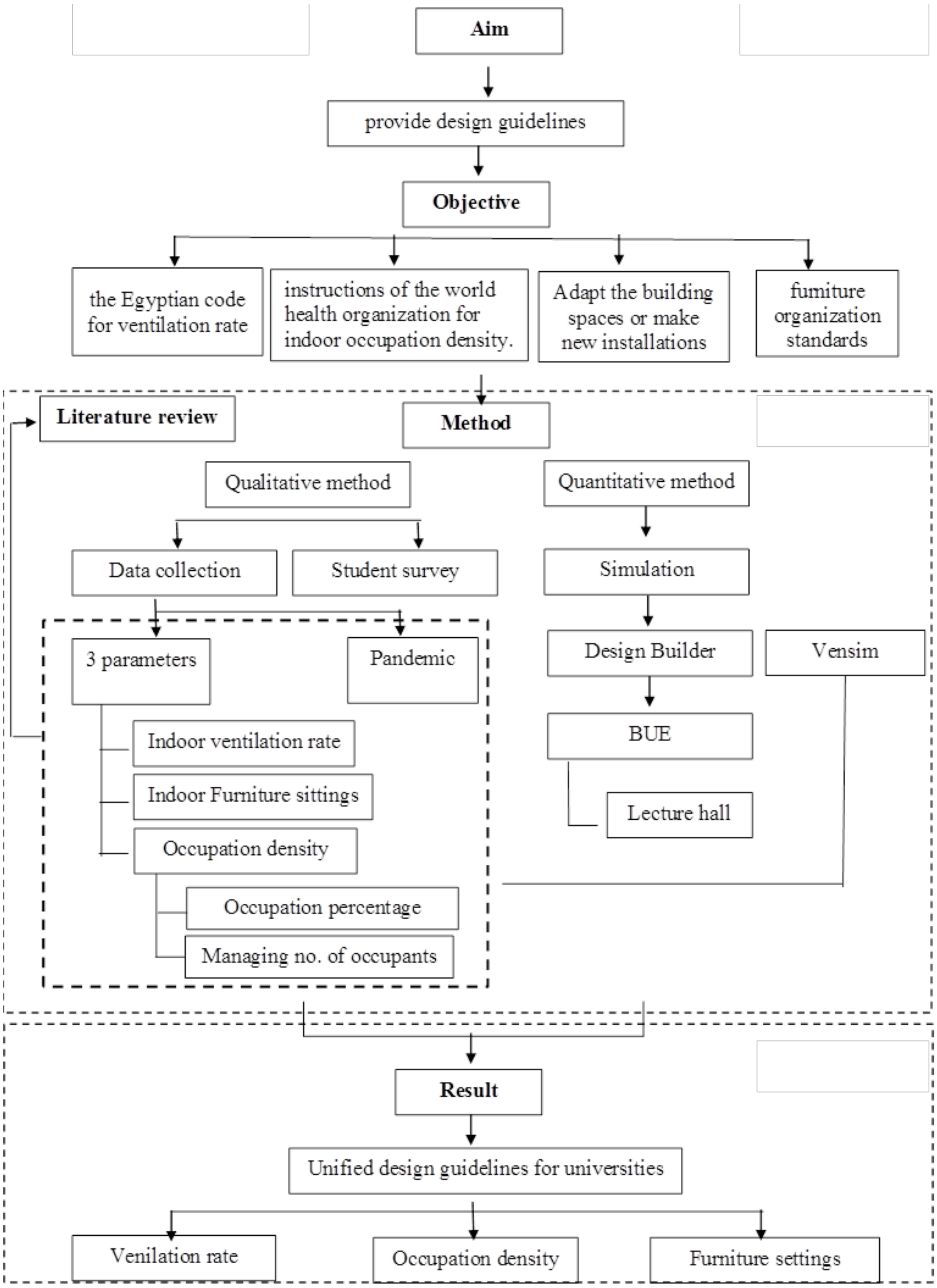
The study used computer simulation as shown in Fig3. Design-Builder is a computational fluid dynamics (CFD) software tool to show the air pressure, airflow, air temperature distribution, relative humidity for indoor and outdoor that leads to thermal comfort.

These can be used to assess the integrated environmental performance such as energy, comfort, and ventilation of existing and new buildings. It allows you to rapidly compare the function and performance of a building's design and deliver results on time. Also, it calculates thermal comfort and indoor temperature based on different types of ventilation systems (Baharvand *et al.,* 2013).

*Table 3: Data collection*

| Existing case parameters | Data |
|---|---|
| Occupied floor area (m2) | 116.6 |
| Occupied volume (m3) | 355.4 |
| Number of occupants | 40 |
| Furniture | 40 drawing table |
| | 40 chairs |
| | 1 instructor table with chair |
| HVAC system | Centralized cooling system (VAV) |
| Number of windows | 7 |
| Number of doors | 1 |

*Fig 3: Research methodology*



The computer simulation was used to study indoor ventilation requirements inside an educational space (design studio) with varying occupational densities of 25%, 50%, 75% compared to a reference case of 100% while studying variations in furniture settings and ventilated rates from a whole system thinking approach to see interrelations of these varying parameters. This is summarized in Fig4.

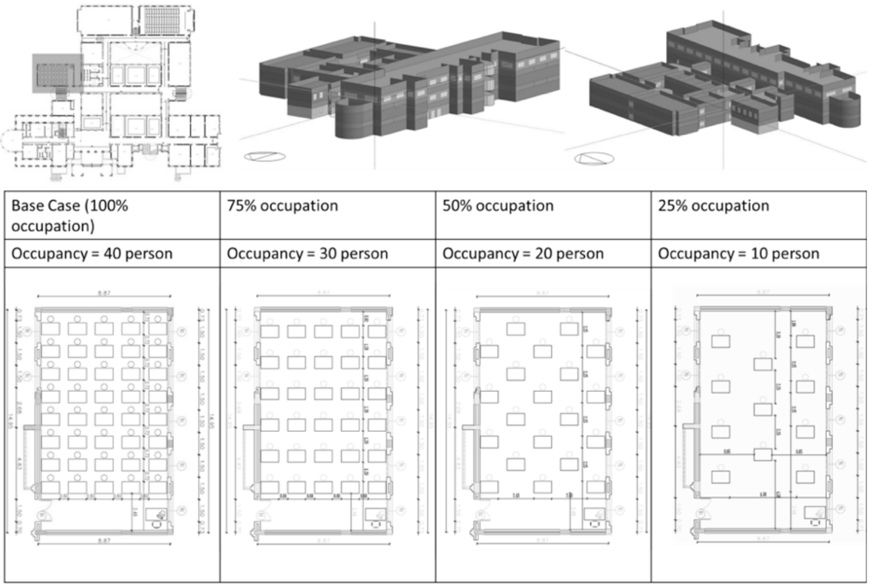
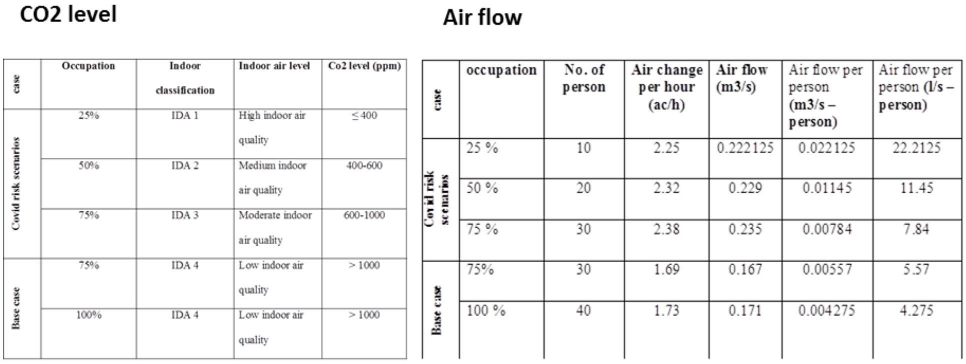


*Fig 4: Summarizing the four tested scenarios of occupational capacities*

# RESULTS

The results investigated different occupational scenarios inside the design studio compared to ventilation specifications of the local building code. This showed that occupation densities of 50% (IDA 2) and 75% (IDA 3) provide medium and moderate indoor air quality, respectively. Nevertheless, the latter can increase risk scenarios with the increase of carbon dioxide concentration level above 1000ppm. This requires increased airflow and the rate of air change by a rate of 40% above normal levels as shown in Table (4).

*Table 4: The variation in co2 levels and airflow rates as a result of the tested scenarios of indoor occupational capacity*



**CO2 level**

| case | Occupation | Indoor classification | Indoor air level | Co2 level (ppm) |
|---|---|---|---|---|
| Covid risk scenarios | 25% | IDA 1 | High indoor air quality | ≤ 400 |
| | 50% | IDA 2 | Medium indoor air quality | 400-600 |
| | 75% | IDA 3 | Moderate indoor air quality | 600-1000 |
| Base case | 75% | IDA 4 | Low indoor air quality | > 1000 |
| | 100% | IDA 4 | Low indoor air quality | > 1000 |

**Air flow**

| case | occupation | No. of person | Air change per hour (ac/h) | Air flow (m3/s) | Air flow per person (m3/s – person) | Air flow per person (l/s – person) |
|---|---|---|---|---|---|---|
| Covid risk scenarios | 25 % | 10 | 2.25 | 0.222125 | 0.022125 | 22.2125 |
| | 50 % | 20 | 2.32 | 0.229 | 0.01145 | 11.45 |
| | 75 % | 30 | 2.38 | 0.235 | 0.00784 | 7.84 |
| Base case | 75% | 30 | 1.69 | 0.167 | 0.00557 | 5.57 |
| | 100 % | 40 | 1.73 | 0.171 | 0.004275 | 4.275 |

Then, the results were configured in a cause-and-effect vensim diagram to show the effect of interrelations as shown in Fig 5. Loop A, starting by IAQ if it increases inside the space the ventilation rate increases, by the time when ventilation increase, the IAQ increases. This feedback loop is reinforced loop moves anticlockwise, as the loop starts and finishes with IAQ increases. Loop B starts with IAQ if it increases inside the space, the occupation density increases, hence, the IAQ decreases. This feedback loop is a balancing loop and moves clockwise, as it begins with IAQ increases and the loop finished by decreasing IAQ. Loop C starts with IAQ if it increases inside the space the occupation increases so the furniture increases, and the ventilation rate decreases so the IDA decreases. This loop is a balancing loop and moves anti-clockwise, as at the beginning IAQ increases and the loop finishes by decreasing the IAQ.

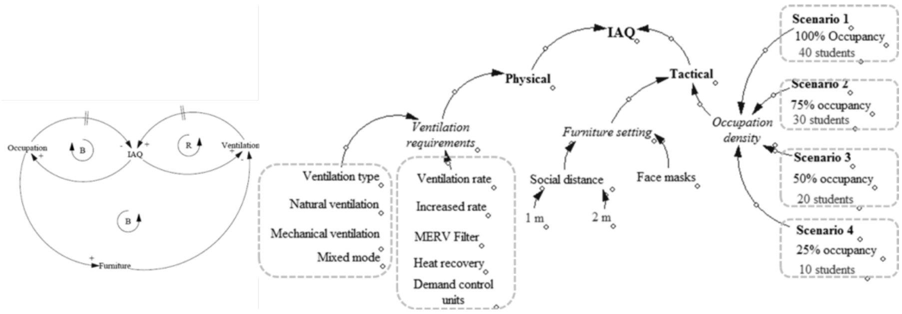


*Fig 5: Integration of parameters and possible occupation scenarios for IAQ*

## DISCUSSION

The results can be discussed using a system thinking approach to show the integration of three distinct parameters to maintain proper IAQ during the pandemic time. This shall provide better occupants' health and reduce the risk of infection.

The simulation output may be used to investigate the building level, block, and zone, requirements depending on the input data and expected outcome. These can in turn widen the perspective of the system thinking approach. The main outputs for the simulation calculation are energy consumption, heating and cooling loads, light distribution and the CFD model that show air distribution of temperature distribution inside or outside the building. On the building scale simulation, the data can be generated from the simulation calculation tab are including unoccupied zones, zone data output on building and block level, report, surface heat transfer, environmental calculations, comfort, internal gains, energy, HVAC and temperature distribution, the output of daylight map, and construction and surface details.

## CONCLUSION

This study investigates occupational scenarios in an educational space in a university building for a better IAQ in time of the COVID pandemic. This highlights the integration of distinct parameters such as space dimension, furniture settings, and occupation density and ventilation rates. The discussion adopts a whole system thinking approach taking into consideration physical measurements including variations in ventilation rates and furniture settings and tactical measurements including planning for occupational densities. This is useful to set updated building operation plans based on the latest scientific findings. For a case study building, four scenarios were proposed based on occupancy: 100%, 75%, 50% and 25%. The former showed great risk scenarios due to the limited design for flexibility in indoor spaces. The second was a possible scenario that won't endanger students' health but would require more ventilation rates. Finally, the third scenario provides acceptable ventilation measures and balanced energy needs. Hence, an occupation density of 75-50% is recommended indoors during the time of the pandemic. Furthermore, recommendations for applying natural ventilation and design for flexibility in furniture settings shall reduce the risk of contamination.

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