Occupant loads and COVID-19: The impact on office building fire evacuation

Malte Larsson Silli | Division of Fire Safety Engineering | Faculty of Engineering | LUNDS UNIVERSITY

Occupant loads and COVID-19:
The impact on office building fire evacuation

Malte Larsson Silli

Lund 2022

Occupant loads and COVID-19: The impact on office building fire evacuation

Malte Larsson Silli

Report 5677
ISRN: LUTVDG/TVBB--5677--SE

Antal sidor/Number of pages: 37
Illustrationer/Illustrations: 15 Figures, 13 Tables

Sökord/Keywords
Occupant load, physical distancing, evacuation, COVID-19, office building

Abstract
COVID-19 was declared a world-wide pandemic in 2020, consequently affecting societies all around the globe. This thesis investigates one of these effects, namely how the pandemic affected occupant loads in office buildings and its subsequent effect on fire evacuation. Occupant load is one of many important factors when designing a building in regard to its fire safety, as it is a key component in determining and applying building regulations. By analysing data collected from video recordings of three different offices as well as performing a case study in which different occupant load levels and physical distancing were combined to determine evacuation time, the objectives of this thesis were accomplished. The results included, but were not limited to, that the restrictions of the COVID-19 pandemic affected occupant load levels to varying degrees, which combined with the common restriction of physical distancing proved to cause significant increases in modelled evacuation time. Due to the lack of research, it was difficult to determine whether this increase in time reflects real life fire evacuation scenarios during a pandemic or not. If this reflection was to be accurate, it would indicate an increased risk for occupants of office buildings during a pandemic similar to the one caused by COVID-19 in regard to fire safety. To counterbalance the increase in risk, potential changes in building codes might be appropriate, but in order to confirm this further research is strongly recommended.

Brandteknik
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

www.brand.lth.se
Telefon: 046 - 222 73 60

Division of Fire Safety Engineering
Faculty of Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

www.brand.lth.se
Telephone: +46 46 222 73 60

Preface

I would like to express my gratitude to the people who have supported me throughout my work on this thesis. It has been a long journey – one which included having puppies, my firstborn child, Julian, and getting married – from which I have learned a great deal of things.

Firstly, I would like to give a special thank you to Enrico Ronchi – Senior Lecturer at the Division of Fire Safety Engineering – for being my supervisor. He has provided me with invaluable guidance, support, and knowledge during every part of the thesis, but most importantly, he showed incredible understanding towards my eventful personal life. It made the difference between having to choose between what part to put my energy towards, and being able to give all of my attention to each respective part. This enabled me to fully enjoy every detail of this journey, including the writing of this thesis.

My second appreciation is towards Steve Gwynne – Adjunct Professor at the Division of Fire Safety Engineering. With his help, I was able to gain access to the data which enabled this thesis to be done in the first place. He also provided great help with deciding the direction of the thesis, along with helpful comments and insight.

The third, and final, person I want to show my gratefulness towards is Natalie Andersson Silli – the mother of my child, the parent of my two dogs Leia and Kiara, and my beloved wife. Her continuous encouragement and unending support allowed me to pursue the best possible version of this thesis. This journey has been an amazing experience, and I could not have done it without her.

Malte Larsson Silli

Södra Sandby – September 2022

Table of contents

1. Introduction

The following chapter is dedicated to giving the reader a proper introduction to the background information related to the thesis. It also clarifies what the purpose and objective is, as well as the limitations with the study.

1.1. Background

Throughout the history of mankind, people have been exposed to numerous illnesses and plagues that endangered their health and way of life (Adalja & A Nelson, 2020). In order to create proper responses and solutions to the ever-changing threat of disease – the scientists, researchers and engineers of their respective time worked towards this goal, which is still true today (Ashworth Underwood, 1998). The most recent threat of this kind is COVID-19 – a disease caused by the SARS-CoV-2 virus (World Health Organization, 2022). COVID-19 has been a Public Health Emergency of International Concern since January 2020 and a pandemic since March 2020 (World Health Organization, 2021). Several outbreaks have been occurring throughout the pandemic in various countries at different times (World Health Organization, 2022), and their management of the situation depended on governmental agency decisions and the severity of the outbreaks. Responses have ranged from recommendations to large-scale lockdowns (World Health Organization, 2022).

The reason why COVID-19 caused countries all over the world to react is because of its wide range of symptoms; most people who are infected will experience a respiratory illness comparable to a common cold and similarly recover without the requirement of medication or additional treatment (Chaves, Long, Koyfman, & Y.Liang, 2021). In the rarer cases however, people can develop more serious illnesses with long term effects and even die. People at a higher age and/or with pre-existing medical conditions such as cardiovascular disease and cancer are more likely to suffer the latter symptoms (Hendren, et al., 2020) (Chavez-MacGregor, Lei, & Zhao, 2022). The most common way for the disease to spread is through airborne particles originating from an infected person's mouth or nose. These are emitted every time air is exhaled, especially when coughing, sneezing or similar actions that uses more air than regular respiration (Salian, et al., 2021). Hence, the best methods of preventing transmissions are to stay at least 1 meter apart from other people, wear a mouth-and-nose covering mask made to filter the particles, and to properly and frequently wash/disinfect your hands (Chu, et al., 2020). (World Health Organization, 2022)

Consequently, this has affected how people move and how frequent they attend work on site (Diab-Bahman & Al-Enzi, 2020). Several categories of work are naturally restricted from performing their work-related tasks from home, while other categories can transition to complete almost all of their work from home. Office work can arguably be placed in both categories as the specifics of the daily tasks varies heavily between different companies. Either way, the matter in which employees interact with each other, as well as other working people, has most likely changed in order to restrict the transmission of COVID-19. The degree of change varies from country to country and workplace to workplace, but the fact remains that the virus has affected workplaces all over the world (Ritchie, et al., 2020). One phenomenon that has been observed across the world is lockdown fatigue, which has two different effects. One – people experience what is described as a state of exhaustion, with several symptoms such as shorter temper, sadness, anxiety, fear, and lack of motivation (Australian Psychological Society, 2020), and two – the public response to the lockdown measure weakens and subsequently lessens the restrictive effect that it has on the transmission of the virus (Goldstein, Yeyati, & Sartorio, 2021). This can lead to people returning to work in the middle of a lockdown, despite recommended (or even prompted) otherwise.

In this context, one of the most important factors when designing a building in regard to fire protection is occupant load; the amount of people that are located in the buildings, or parts of them, is sometimes the deciding factor between selecting a more extensive fire protection system, such as sprinklers, or not. It also affects the way that exits and emergency exits are designed, where details range from type of handles on the exit doors to total walking distance inside the building. All these decisions are not only important when determining the cost of the building project, but also for the safety of those intended to use the finished building. (National Fire Protection Association, 2022) (Spearpoint M. , 2020)

The maximum occupancy load in a building, or part of a building, is a pre-determined value which refers to how many people are allowed to be present in a building at one time. The value itself varies based on what type of building it is, what the building is used for, how much floor space there is and the means of egress available (Boverket, 2019). It is therefore a key component in determining and applying building regulations (National Fire Protection Association, 2022). An example of where the occupant load of a premise was exceeded more than twofold is the *Gothenburg discotheque fire* - the premises was designed to contain up to 150 people, but on the night of the fire there were almost 400 people. The fire, and the failed evacuation that followed, ended up injuring over 250 people, among which 60 died (Statens Haverikommission, 2001). Another example of a failed evacuation is a bomb scare evacuation from an office building in Sheffield, UK. During the evacuation attempt, there were long queues and several workers even reported that they were unable to move more than 15 steps from their desks before they were faced with a non-moving crowd. Approximately 10 minutes after the evacuation had begun, the police had investigated the issue and concluded that there was no threat and followingly asked the staff to return to the office. By that time, there were still an ongoing evacuation and many employees had not even managed to leave the building. This indicates that the designed occupant load was likely severely exceeded at the time of the evacuation. Fortunately, as the bomb threat turned out to be easily managed and not a threat, there were no injuries or casualties (Whittaker, 2022). Both examples highlight the impact that occupant load can have on an evacuation, especially if it exceeds recommendations.

This report investigates how the COVID-19 pandemic has affected three different offices' occupant loads and how the loads were affected by local restrictions and lockdowns. This has been done by studying a series of data collected through camera recordings of the respective offices' entrances. Two of the offices are located in Paris and one is located in London; these offices (and countries) were chosen primarily due to the availability of data. Furthermore, a simulation case study was made where the effects of physical distancing on evacuation time were studied at different levels of occupant loads. The reason why this is important to investigate is because building codes determining occupant loads have not changed during the pandemic, despite the physical distance provisions that have been given. An increase in the physical distance between people can change the flow of people, resulting in lower speeds and hence increased evacuation times (Ronchi, Nilsson, Lovreglio, Register, & Marshall, 2021). If the occupant loads remain unchanged or are reasonably comparable to the pre-pandemic values, potentially risky situations may arise when a rapid evacuation is necessary and people follow physical distancing. As long as less than the regular amount of people is present in the building, these competing factors will most likely not be a large issue. To this end, the results from the occupant load data analysis and a case study are compared and act as a basis for discussion whether office workers have been exposed to a higher level of risk or not.

The research hypothesis is that COVID-19 may have affected the occupant loads in office buildings in such a way that the numbers are lower than what regulations estimate and what they were in pre-pandemic conditions. The addition of physical distancing may result in increased evacuation times, especially at higher levels of occupant loads.

1.1. Purpose and objective

The purpose is to determine the effect of COVID-19 on occupant loads in a set of selected office buildings and assess whether this is associated with fire evacuation issues.

The objective is to look for correlations between observed occupant loads with different COVID-19 metrics (e.g., deaths reported locally, contaminated that day/week, hour of the day) and investigate its subsequent impact on fire evacuation.

The key research questions that are expected and intended to be answered by this analysis are the following:

1. What correlation between local official news regarding restrictions, metrics, or other data in relation to COVID-19 and the observed occupant loads in the respective studied office buildings can be observed?
2. How much does the addition of a physical distancing restriction affect the time it takes to fully evacuate a fictitious office building at different levels of occupant loads, and at what percentage level of occupant load does the evacuation time equal the normal evacuation time?
3. Were there any occasions during the pandemic where the occupants of each office were theoretically exposed to an increased risk level due to the physical distancing restriction, and what does this mean in practice?

1.2. Delimitations and limitations

The data that was used in this paper is limited to three different data sets; one based on an office with a maximum pre-pandemic occupancy of 940 people, one with 750 people and one with 10 people. This is not sufficient to draw a general conclusion, but to provide general insights into possible criticalities; more data would make this explorative study more conclusive but would significantly increase the workload beyond the scale of this thesis.

While there are several factors to consider when analysing how the risks related to occupant loads, such as physical distancing guidelines, behavioural differences, and changes in general movement, it is exclusively occupant loads that are being analysed in this paper.

Even if the data covers the changes in occupancy loads in offices based in two different countries, the fact that every country has had their own way of managing COVID-19 makes it difficult to apply the conclusion drawn from this paper on other countries. Any findings in this paper are exploratory and should only be applied to countries with similar circumstances and pandemic management approaches. Secondly, the coverage of the pandemic is not complete; the data covers a bit over a year of the pandemic and the time is distributed differently across the countries. With that said, both data sets cover the exact same type of building and are in similarly equal locations – large cities.

The way the camera data collection is set up may allow the same person to be registered several times, as each identified person is given a unique "object-ID". This may not have caused any major deviations from the actual situation, but in order to avoid this the camera feed would have to be observed and corrected. This would be a massive task and is dismissed due to the time restriction on this project.

The simulation case study is limited to investigating how physical distancing impacts the evacuation time of an office at maximum capacity. It does not go into detail on local average occupant loads, or how occupants react to the event of a fire in regard to maintaining physical distancing throughout the evacuation. There is currently, at the writing of this thesis, no studies covering whether people maintain physical distancing throughout an evacuation or not during a pandemic. By assuming that all occupants continue to practice it, the evacuation scenario is an example of a worst-case scenario and might therefore not be representative of real evacuation scenarios. The modelled office is a fictitious building which does not resemble a code-compliant existing office (e.g., emergency exits are not compliant to a specific fire code). The layout is based upon a real office to avoid having to design a new, fully code compliant layout from scratch. However, since the exact measurements of doors, stair-width and exits are only approximations, the office cannot be classified as code-compliant.

2. Literature review

In this section, the areas that were actively used in the analysis, simulation or discussion are presented. It covers why certain sources were used for gathering information, a couple of real-life evacuation examples, a description of the software used for the evacuation modelling, as well as a series of timeline graphics detailing the relevant events of the pandemic in the UK and France respectively. A visualisation of how the literature is presented can be seen in Figure 1.

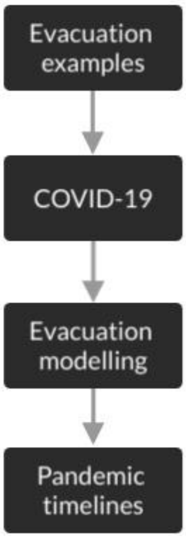

Figure 1 - Flowchart of the literature

Firstly, to gain a better understanding of how an evacuation can proceed during unfavourable circumstances, the selected examples are presented. They provide insight on the importance of occupant load in relation to a building's capacity to safely evacuate its occupants. Secondly, COVID-19 and the ways that it might affect occupant loads are presented. Physical distancing restrictions might effectively decrease the available area within a building (and hence maximum occupant load), as occupants are urged to maintain a larger distance between themselves and others compared to normal circumstances. Lockdown fatigue might cause people to disregard ongoing recommendations and unpredictably return to work, consequently causing changes in occupant loads. Thirdly, to further investigate how occupant loads might affect evacuations, evacuation modelling is introduced. The subchapter covers basic use cases of evacuation modelling and describes how the addition of physical distancing can affect crowd movement. Lastly, the customised pandemic timelines are presented. They provide an overview of the major events related to the COVID-19 pandemic in France and the UK. The process of making them is further explained in subchapter 3.1.

Many scientific sources that have been used in this thesis has been found by using the search engines Google Scholar and LUBSearch, as they provide journals, articles and papers that are peer-reviewed and with a high level of credibility due to their equally credible respective source material. Another method used for finding relevant sources have been the snowball reference search; searching for articles and journals inside other references. Complementary scientific sources have also been provided from my supervisors. The method of finding other sources, such as the ones used for the examples and timelines, are explained in their respective chapters. The keywords that were used, together or separately, for finding the majority of the sources were the following: occupant load, physical distancing, evacuation, COVID-19 and office building.

The main processes of looking for sources consisted of: searching for research that supported the claims that were made, searching for references to explain given issues, and searching for references that provided data/information. The references that were found were reviewed based on a few inclusion/exclusion criteria, namely:

- Is the source related to occupant loads, office buildings and/or evacuation simulation?
- Does it contain information/data and/or studies about COVID-19 related areas and/or pandemics?
- Does it provide data which can be used in the case study?

If the answer was yes to any of the criteria above, the reference was considered for inclusion. During the writing of the thesis, some of the considered references were later excluded due to not being relevant or no longer fitting. Other references were only used initially to gain a better understanding of the subject before proceeding with the thesis and were thus excluded from the references. Around a total of 80 sources were reviewed and around 60 of them were deemed to be valuable based on the inclusion/exclusion criteria. The final number of sources which were used throughout the thesis work ended up being 49.

2.1. Evacuation examples

There are no reported fire evacuations with major consequences which occurred in a general office setting, at least not any that could be accessed through open web search engines. There are, however, several examples of occurrences where the occupant loads were too high and consequently led to failed evacuations in buildings other than offices. One of these instances is the Gothenburg discotheque fire – a historic event from Sweden, where a governmental agency report was accessible through their website. The second example is a recent evacuation of an office building without casualties and was found through searching for keywords such as “failed evacuation”, “office building”, “fire evacuation” and came from a British newspaper site.

2.1.1. Gothenburg discotheque fire

The Gothenburg discotheque fire is a widely used example of why fire safety is important because it highlights the potential consequences of not following fire safety regulations. Loose furnishing had been relocated to block and dissuade people from letting their friends in through the entrance without paying, the evacuation stairwell was full of flammable furniture and the establishment contained almost three times the amount of the maximum amount of people allowed – 398 people against the 150 people the space was designed to contain. (Statens Haverikommission, 2001)

The fire started when a group of adolescents purposely set the furniture in the stairwell aflame, which effectively eliminated the stairwell as an emergency exit. In the evacuation that followed, there were mass queuing and confusion around the other emergency exit – the main entrance - which was amplified due to the abnormally large amount of people. Had the guidelines been followed and only 150 people been present when the fire started, the queuing and confusion would most likely not have been as severe. There is no doubt that the lack of a second emergency exit contributed towards the casualty rate of the event, but the fact remains that the occupant load was way too high and consequently led to more people being injured. (Statens Haverikommission, 2001)

2.1.2. Sheffield office evacuation

The evacuation of the *Department for Education*'s office in Sheffield on May 18, 2022, was caused by a "police incident due to a suspect package" and ended up being a false alarm (Whittaker, 2022). While the evacuation itself might have been unnecessary, it serves as an excellent example of why it is important to never exceed the designed occupant load of a building.

After the evacuation had begun, queues began to form in the building's stairwell and by the exits to get off the upper floors. According to one of the workers, there were fire wardens on each floor that had not been able to evacuate properly and therefore were unable to direct people away from the building, which further slowed down the evacuation. At one point, the queues stopped moving entirely, and people were essentially trapped. When interviewed afterwards, several workers were quoted saying that the incident was "really scary" and that "We had been told to evacuate and yet couldn't do it". (Whittaker, 2022)

According to the article, the figures obtained by the newspaper reported that the number of staff at the office outnumbered the number of desks by almost two-to-one: 790 desks stretched between 1489 employees (Whittaker, 2022). It is not known how many of the workers attended the office at the time of the evacuation but judging from the massive queues and inability to evacuate the entire office in a reasonable manner, the designed occupant load was most likely severely exceeded.

2.2. COVID-19

While there are many different ways of acquiring information about COVID-19, one of the main sources used for introductory information is the World Health Organization (WHO)'s website. Ever since the virus was discovered in late 2019, they have continuously been updating it with the latest information regarding spread, recommendations, amount of people infected and other important information. Specific information regarding the symptoms, transmission or other effects of COVID-19 has been gathered from various scientific, peer-reviewed articles and websites.

2.2.1. Physical distancing

According to WHO's website, the lowest recommended physical distance is 1 meter. It is, however, phrased as "Keep physical distance of at least 1 metre…" and many countries, including the UK, applied the 2-meter guidelines (World Health Organization, 2022). A review of this distancing was released by the UK government, which shows the reasoning behind lowering the recommendation later (UK Government - Cabinet Office, 2020). In the review it was also mentioned that France was one of the countries that followed 1 m. It is confirmed on a French government website that physical distancing is strongly recommended, but the specific distance is not specified (French Government, 2022).

As 2 meters is the furthest physical distancing guideline that has been followed by one of the countries that is being covered in this thesis, that is the distance that was used during the simulation work.

2.2.2. Lockdown fatigue

COVID-19 has affected almost every aspect of peoples' lives, including their freedom, initially under several months, and later years. Due to the many effects caused by the pandemic; self-isolation, quarantining, curfews, border closures among many others, people had to severely change their daily lives (Australian Psychological Society, 2020). Not being able to move freely, being cut-off from normal social interaction, receiving daily news about a world-wide pandemic and constant worrying about the future are all factors which led to people getting lockdown fatigue (Australian Psychological Society, 2020). Symptoms like sleep disturbance, exhaustion and negative thoughts were more common, which in turn led to lack of motivation and difficulty focusing (Field, et al., 2021) (Marroquín, Vine, & Morgan, 2020).

The abovementioned effects that lockdown fatigue had on people may have led to the second effect – a decrease in effectiveness of lockdowns, and other similar restrictions which limit people's mobility, in relation to the transmission of COVID-19 (Goldstein, Yeyati, & Sartorio, 2021). After around four months of continuous or discontinuous lockdown, people are much less likely to respond accordingly to this type of restriction (Goldstein, Yeyati, & Sartorio, 2021). This makes it difficult to predict how many people attend their jobs, especially those who were able to work from home.

2.3. Evacuation modelling

Evacuation modelling is a tool which fire protection engineers can utilize to test, validate, and justify building designs by studying how occupants might move and behave during an evacuation. By being able to change occupant load, occupant characteristics, building layout, exit choices, among several other variables, evacuation modelling can be customized to suitably fit most scenarios. In this thesis, evacuation modelling has been used to study the relationship between occupant load and evacuation time, with and without a set physical distancing restriction. How the simulations were set up is further explained in subchapter 4.1.

The addition of physical distancing restrictions to a crowd adds several fundamental changes to how the crowd dynamics work in an evacuation scenario. The four main areas that are affected are:

1. Occupant loads in the specific area
2. Crowd movement (specifically the speed/density and flow/density relationships)
3. The way routes and exits are chosen
4. Behaviour within the group/crowd

(Ronchi, Nilsson, Lovreglio, Register, & Marshall, 2021)

2.3.1. Office occupancy loads in building regulations

The SFPE Handbook of Fire Protection Engineering is a comprehensive reference on fire protection engineering and performance-based fire safety (Society of Fire Protection Engineers, 2016). More than 130 authors from organizations and universities worldwide have contributed complete chapters on their respective area of expertise (Society of Fire Protection Engineers, 2016). One of the chapters covers "Egress Concepts and Design Approaches", which is the chapter used to find information about office building occupant loads used in the following case study.

Occupant load is a value that can be presented in many ways, depending on the context. The specified occupant loads for offices are 10 m^2 in the US, Spain, and Australia, 9 m^2 in Hong Kong and 6 m^2 in the UK (Bukowski & Tubbs, 2016). Unfortunately, France is not mentioned, but considering that the lowest load is also the load used in UK it was the most reasonable value to use during the simulation work. As it also happened to be the lowest, it generated the most conservative scenario.

2.4. Pandemic timelines

A set of timelines are presented in Figure 9 through Figure 12, which are visual summaries of the major restrictions and events which took place in France and the UK. To more easily be able to differentiate between the intervals of data, a rough set of pandemic stages has been established: *Early Pandemic, Mid Pandemic* and *Late Pandemic.* These stages are further explained at the end of section 3.3.

The information used to create the timelines had been taken from a wide array of local news channels, international news sites and governmentally run websites. Each event featured in the timelines has been confirmed on any of the aforementioned source category to ensure that the dates specified are correct. As part of the data analysis will be based around cross-referencing the data and the -events from the timeline, it is essential that the dates are correct. The respective source of each event is listed under references at the end of this paper.

2.4.1. French timelines

The first of the French timelines, presented in Figure 2 covers the first lockdown cycle that happened. The lockdown begun on the 17th of March 2020 and lasted in full effect until the 11th of May, where the first steps to ease the restrictions took place. More restrictions were lifted in the following month and essentially ended the lockdown at the end of the first pandemic stage.

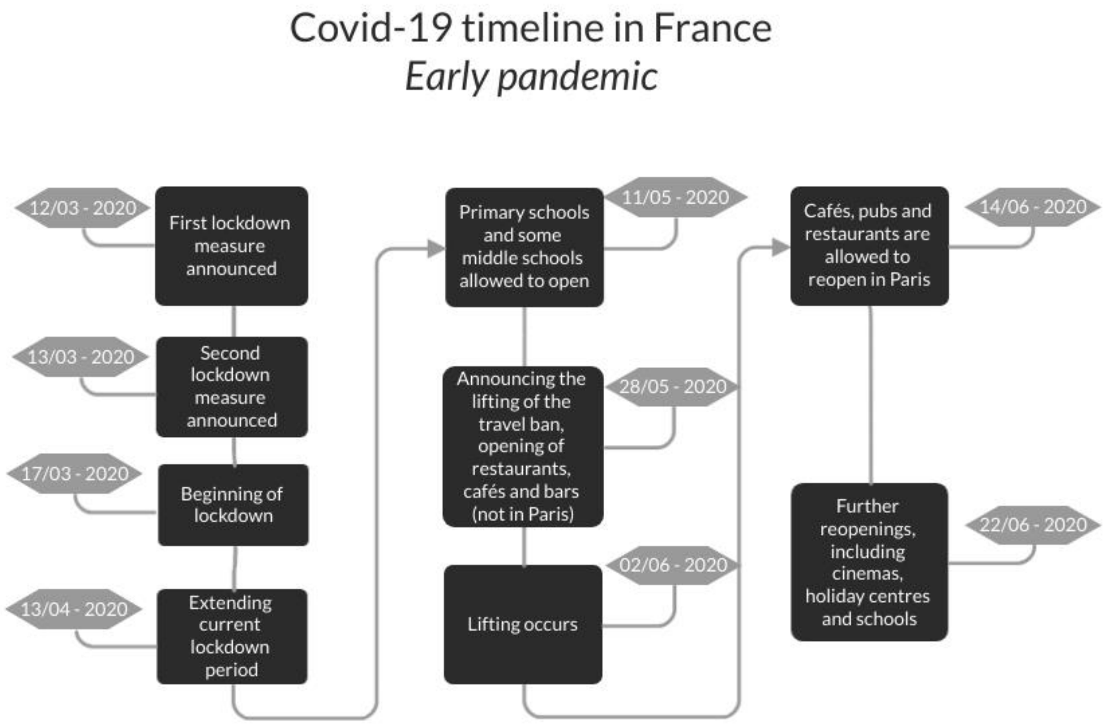

Figure 2 - Timeline of Early Pandemic in France

Figure 3 covers the second stage of the pandemic in France, and includes the official end of the first lockdown, followed by a steady increase in restrictions during the summer and autumn until the second lockdown is introduced on the 30th of October.

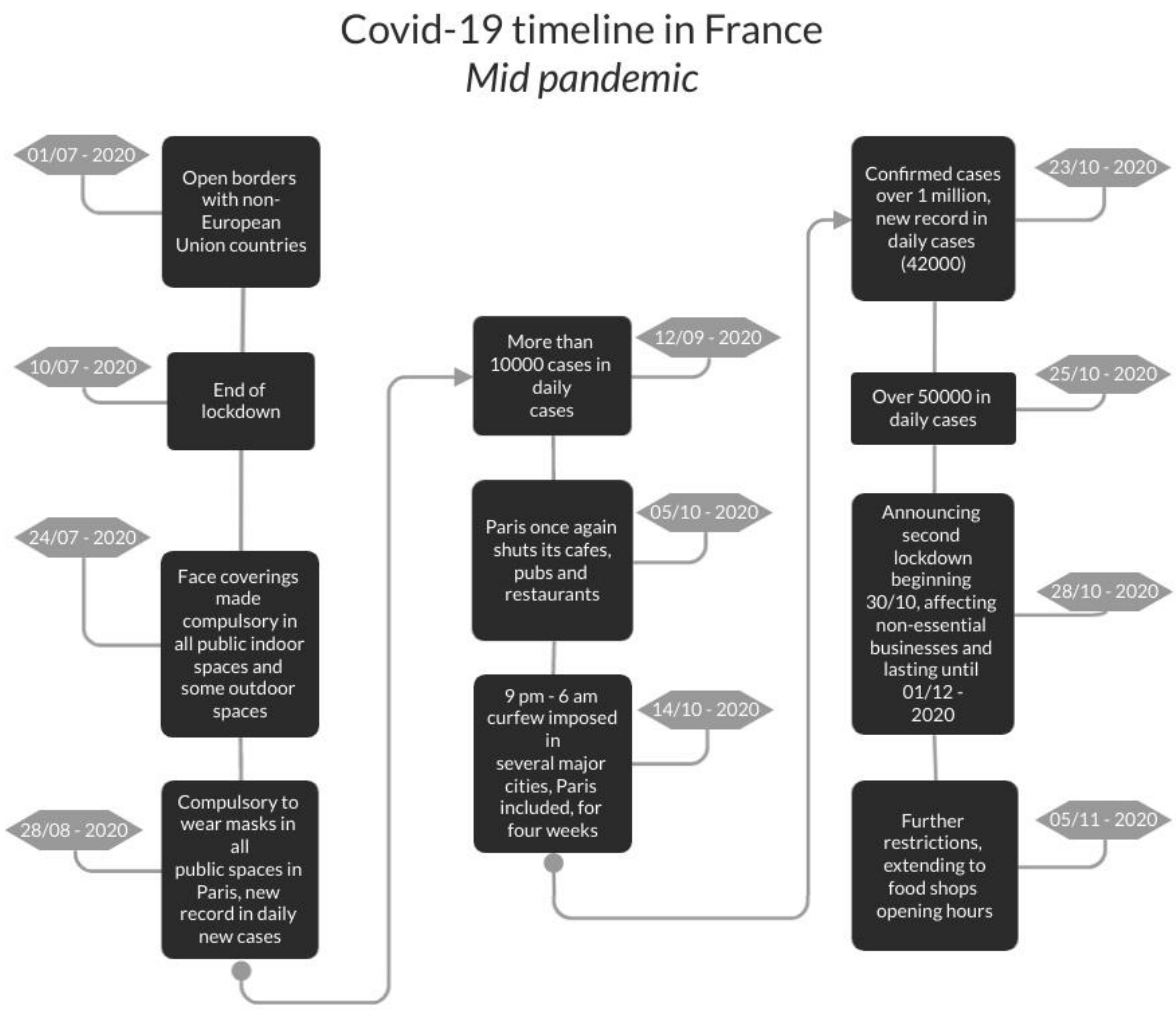

Figure 3 - Timeline of Mid Pandemic in France

2.4.2. English timelines

The first of the English timelines covers the *Mid Pandemic* and is presented in Figure 4. It begins with a final easing of restrictions from a previous lockdown, but a month later the restrictions begin anew. Several restrictions are implemented during the following month until the second lockdown is introduced on the 5th of November 2020, lasting until the 2nd of December.

A short explanation of the tier system which is mentioned in the timeline is presented in Table 1.

Table 1 - Explanation of the tier system present on the 15/10 - 2020. (Brown & Kirk-Wade, 2021)

Tier	Gatherings	High-street business
1 – Medium	People prohibited from socialising in groups of more than six (unless for an exempt purpose).	Hospitality businesses must close at 10 pm.
2 – Large	People prohibited from visiting and meeting people they do not live with indoors.	Hospitality businesses must close at 10 pm.
3 – Very high	People prohibited from mixing with other households both indoors and in most outdoor settings.	Hospitality businesses must close at 10 pm. Pubs, bars and restaurants must serve alcohol with a "substantial meal". This rule means that "wet pubs" close.

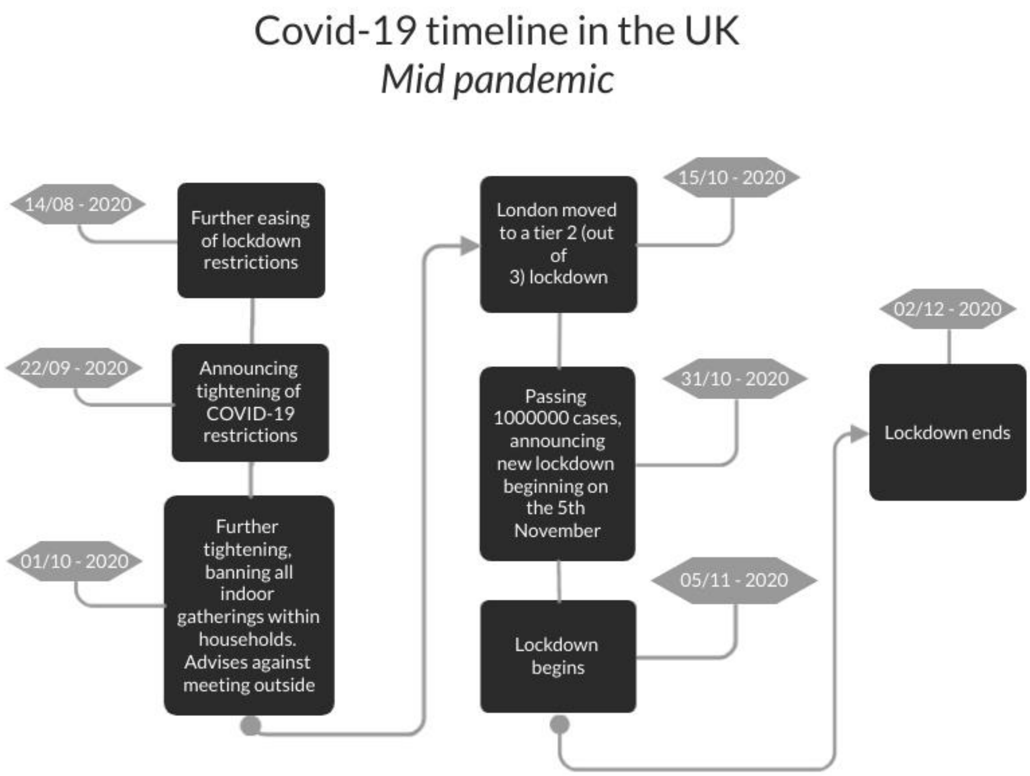

Figure 4 - Timeline of Mid Pandemic in the UK

Figure 5 covers the *Late Pandemic* in the UK and is rather eventless compared to the ones covering previous stages. A third lockdown is introduced on the 4th of January 2021 and lasts beyond the interval of this stage.

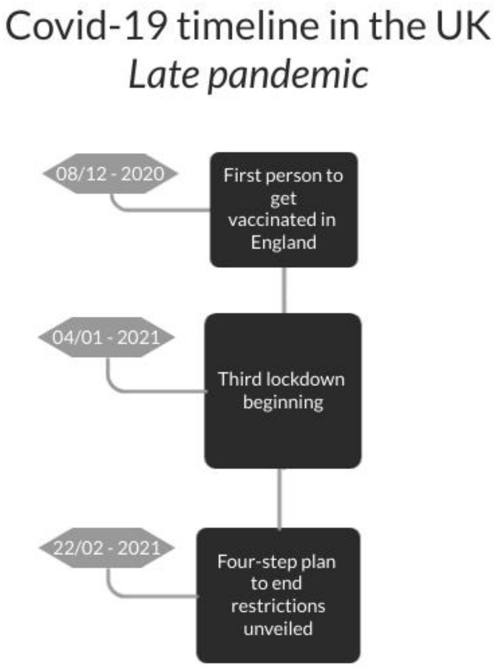

Figure 5 - Timeline of Late Pandemic in the UK

3. Methodology for data collection

There were several methods of collecting data that were considered for monitoring the pedestrian movement in and out of the office buildings before deciding on camera recordings. The four main candidates were GPS (Global Positioning System) data collection, Wi-Fi sensors, data collection with Bluetooth and camera recording data collection. Each of the methods naturally came with their respective advantages and limitations.

GPS data collection allows for larger scale areas to be monitored with a relatively high accuracy of between 3-18 meters, with positioning being updated every few seconds (Rout, Nitoslawski, Ladle, & Galpern, 2021) and (Millonig, Brändle, Ray, Bauer, & Van der Spek, 2009). It does, however, require unobstructed satellite signals in order to remain accurate and is therefore less suitable for indoor monitoring. Moreover, the GPS performance may decrease in urban regions (Millonig, Brändle, Ray, Bauer, & Van der Spek, 2009). As it was office building occupant loads in particular that this thesis focuses on, this option was left out.

Wi-Fi signals can be analysed and filtered to determine a smartphone user's position very accurately within indoor environments (Incheol, Eunmi, & Huikyung , 2012), as well as used to estimate pedestrian flow (Baoqi, Guoqiang, Yong, & Yun, 2021). While this method may provide valuable results by monitoring how people move within buildings, this level of detail was not required when the focus was occupant loads and was therefore excluded.

Data collection with Bluetooth can be used to track other Bluetooth devices from within around 100 meters (Millonig, Brändle, Ray, Bauer, & Van der Spek, 2009). The main advantage of using this method would be that Bluetooth detection devices could be distributed across chosen office buildings' entrances to gather information about the occupant loads. Unfortunately, this method of gathering data is heavily dependent on individuals having their Bluetooth turned on when entering the offices, which was why this method was not chosen.

Camera recordings enables the user to obtain detailed information about the monitored area, including the trajectory of identified pedestrians (Millonig, Brändle, Ray, Bauer, & Van der Spek, 2009). They are, however, very dependent on placement, calibration, and imaging setup. Moreover, due to their limited individual coverage, a large number of cameras might be needed to properly cover the area of interest (Millonig, Brändle, Ray, Bauer, & Van der Spek, 2009). In the case of this thesis, only the entrances would be necessary to cover in order to determine occupant loads, which negates disadvantages of placements and quantity. The use of existing camera installations would further eliminate the disadvantages of calibration and imaging setup, as these aspects would most likely be managed previously. Conveniently, data collected by this method was available. Apart from being the most appropriate method given the focus of this thesis, the availability of data also naturally affected the decision of choosing this method.

The following subsections are dedicated to the description of how the analysis of the data and case study was conducted. The camera recording data constituted the foundation upon which this thesis was built and was hence provided before any work was done. Every following step was created in an effort to best utilize the data.

3.1. Creation of timelines

The first step was to study both the United Kingdom's and France's Coronavirus timelines, as the offices from which the data has been gathered are located in these two countries. Each major event deemed to have a potential impact on the occupant loads, such as implemented restrictions, changes in restrictions and death/infection tolls, were noted and placed in the edited timelines presented in Figure 2 through Figure 5. These acted as a basis for analysing each of the datasets, where the goal was to identify how these events have affected the number of people coming to the offices.

3.2. Data gathered from camera recordings

The next step was to analyse the method of gathering data and whether further complementary data could be collected. The data was obtained through a British consultancy firm - Movement Strategies. The chosen method of data gathering was utilizing camera recordings of office entrances; two offices based in Paris, and one based in London. Other options that were considered included looking at officially available statistics, making a limited and local observation in a suitable location or to send out a mass-email containing a survey with questions regarding office occupancy. Out of these, the camera recording method was considered the most suitable and reliable option, as it provides detailed insight in a couple of chosen locations. It was also able to cover two large cities without exposing anyone related to this thesis to COVID-19 (in contrast to local observations, interviews or similar).

In order to process the desired data, the cameras were setup according to the following description:

1. Defining the entrance door by drawing a range of screenlines covering the location of the door. These screenlines will act as means for determining whether a person enters or exits the building. Crossing the lines from one side to the other will mean that a person enters the building, and vice versa – see Figure 6.
2. Each person recognised by the camera is given an object ID and every event created by the same ID is grouped together.
3. Counting how many object IDs are seen crossing each of the screenlines for each minute.
4. Averaging the counts seen for all the screenline across that minute.
5. Once the counts of people seen entering and exiting each building per minute, a sum of these counts can be made and aggregated to get the count of people entering and exiting per hour and per day.

Figure 6 - One of the camera locations with visualised screenlines. The image has been blurred to maintain anonymity.

3.3. Surveillance data presentation and formatting

The data contained occupant load information about an office in London and two offices based in Paris. The occupancy data from one of the Paris offices, *FrBuilding 1,* ranges from 2020-02-12 to 2020-12-09, whereas the data from the other Paris office, *FrBuilding 2*, ranges from 2020-06-01 to 2020-12-10. Lastly, the data from the London office, henceforth referred to as *UKBuilding*, ranges from 2020-06-24 to 2021-03-25.

The data from the Paris offices was divided into two differently detailed parts; one that shows the occupant load during each office hour of every day during the same time period (see Table 3), and one that shows the average occupant load in the office during each day of the respective time period (see Table 4). The data from the London office was limited to a daily interval, showing the maximum occupant load during each day (see Table 5). In Table 2, the maximum capacity (pre-pandemic) for each office is presented.

Table 2 - Maximum capacities of the offices pre-pandemic where the data was captured.

Office	Maximum capacity
FrBuilding 1	750
FrBuilding 2	940
UKBuilding	10 (7) *

*Maximum capacity, according to the data provider, varied between 7-10 depending on the stage of the pandemic.

Table 3 - Example of sampled data from FrBuilding 1, detailing average and maximum occupant load during each office hour of the day. The occupant load is measured in the number of people being present in the office.

Date	Hour	Average Occupant load	Max Occupant load
2020-02-12	6	3	8
2020-02-12	7	3	8
2020-02-12	8	3	8
2020-02-12	9	3	8
2020-02-12	10	3	8
2020-02-12	11	3	8
2020-02-12	12	0	0
2020-02-12	13	15	93
2020-02-12	14	149	187
2020-02-12	15	182	190
2020-02-12	16	181	197
2020-02-12	17	116	164
2020-02-12	18	5	45
2020-02-12	19	0	0
2020-02-12	20	0	0

Table 4 - Example of sampled data from FrBuilding 2, detailing average and maximum occupant load during a day covering a two-week period. The occupant load is measured in the number of people being present in the office.

Date	Average Occupant load	Max Occupant load
01/06/2020	28	47
02/06/2020	85	160
03/06/2020	9	38
04/06/2020	66	113
05/06/2020	38	56
06/06/2020	0	9
07/06/2020	47	85
08/06/2020	132	235
09/06/2020	150	263
10/06/2020	150	254
11/06/2020	103	197
12/06/2020	94	160
13/06/2020	9	28
14/06/2020	19	38

Table 5 - Example of sampled data from UKBuilding detailing average and maximum occupant load during a day covering a two-week period. The occupant load is measured in the number of people being present in the office.

Date	Max Occupant load
2020-06-24	2
2020-06-25	0
2020-06-26	0
2020-06-29	1
2020-06-30	1
2020-07-01	1
2020-07-02	0
2020-07-03	1
2020-07-06	2
2020-07-07	2
2020-07-08	1
2020-07-09	1
2020-07-10	1
2020-07-13	1

As can be seen in Table 3, Table 4 and Table 5, the different offices' occupant loads, and capacities varies heavily between themselves. In order to be able to compare them, they need to be adjusted according to their respective maximum capacity. Henceforth, all occupant load data will be presented in percentages of maximum capacity. It will also be split into three main sections of the pandemic: early pandemic, mid pandemic, and late pandemic. To avoid unnecessary small overlaps in data, the three sections will be strongly correlated with the data coverage and is presented below. This is **not** an official labelling of the different stages in the pandemic - this is only to more easily be able to distinguish the different sections of data. The date intervals of the three stages are specified in Table 6.

Table 6 - Specification of pandemic stages

Stages	Date interval
Early Pandemic	12/02/2020 - 25/06/2020
Mid Pandemic	25/06/2020 – 10/12/2020
Late Pandemic	10/12/2020 – 25/03/2021

4. Methodology for the evacuation simulation

The modelling software chosen for the simulation is Pathfinder, developed by Thunderhead Engineering. It is an agent-based continuous microscopic model in which it is possible, among several variables, to study the impact of occupant loads and physical distancing on evacuation time (Thunderhead Engineering, 2022). It allows for a detailed customisation of the layout of the model, the occupants, and their behaviour. The way that physical distancing is modelled in Pathfinder allows the user to study a worst-case scenario; every occupant moves as an individual, not a group (Thunderhead Engineering, 2022). This means that the physical distancing is always enforced, no matter the initial positioning of the occupants and relationships between them. This is important because family members, and/or people from the same household, tend to stay together during crowd movement (Eliyan, Halabi, & Saleh, 2018) and are less likely to follow physical distancing restrictions towards each other (Pouw, Toschi, van Schadewijk, & Corbetta, 2020). As the simulation scenarios were built to represent an office environment, it was reasonable to assume that the occupants would not belong to the same household group and therefore move as individuals.

To be able to investigate the possible subsequent effects that COVID-19 can have on fire evacuation, a set of evacuation simulations were conducted. They covered different evacuation scenarios and the results aimed to show how the time it takes to evacuate a building change when the occupants are following physical distancing guidelines. The same scenarios were used to determine the occupant load required to reach the corresponding evacuation time without physical distancing. These results were later compared with the occupant loads recorded during the different pandemic stages across the three offices.

The reasoning behind the focus and direction of the simulations is that, in general, evacuating more people takes more time than evacuating less people. Building codes are generally accounted for conservatively, which essentially means that there is a safety margin built into the value – the actual amount of people is expected to be lower than the amount of people the building is designed for (Milke & Caro, 1996). If a building is designed for a higher occupant load, and its means of egress capabilities designed thereafter, it can be expected that a lower occupant load will evacuate faster. Consequently, by using the higher occupant load value, the design has an increased safety margin (Spearpoint & Hopkin, 2018). However, the addition of physical distancing will increase the time it takes to evacuate due to the decrease in flow (Ronchi, Nilsson, Lovreglio, Register, & Marshall, 2021). As a result, the safety margin decreases and is potentially close to an unacceptable level of evacuation time in regard to the safety of the occupants. By performing the simulations, the difference between evacuation scenarios without physical distancing and the same scenarios with physical distancing has been able to be studied.

4.1. Simulation description

In order to perform the simulations, an example office has been built. It consists of five floors, connected with u shaped stairs and their respective landing platforms. The layouts of the five floors are almost identical to each other; the only differences being that the top floor does not have stairs moving up, the bottom floor does not have stairs moving down and that the exits are located on the bottom floor, next to the stairs (visualised by the bright green lines). The office area corresponds to 255 m^2, excluding the area of the stairs and landing platform between each floor. See Figure 7 for the office layout, and Figure 8 for a complete view of the model office.

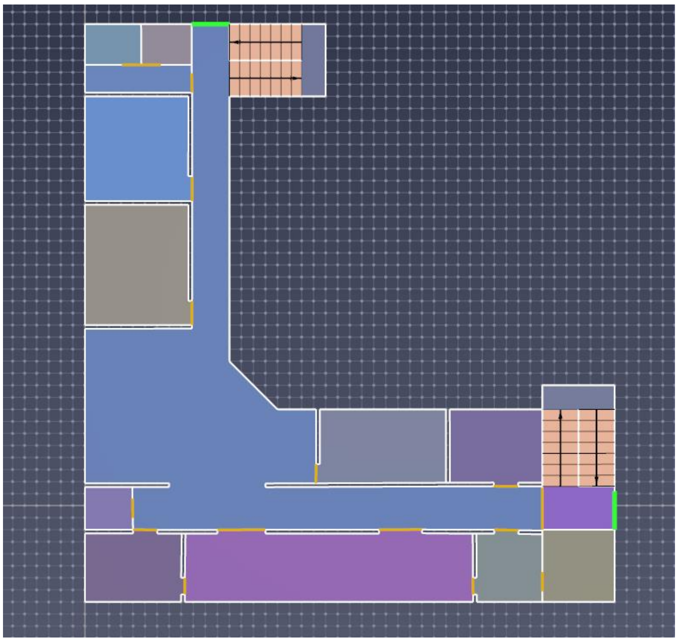

Figure 7 - Pathfinder model layout, bottom floor

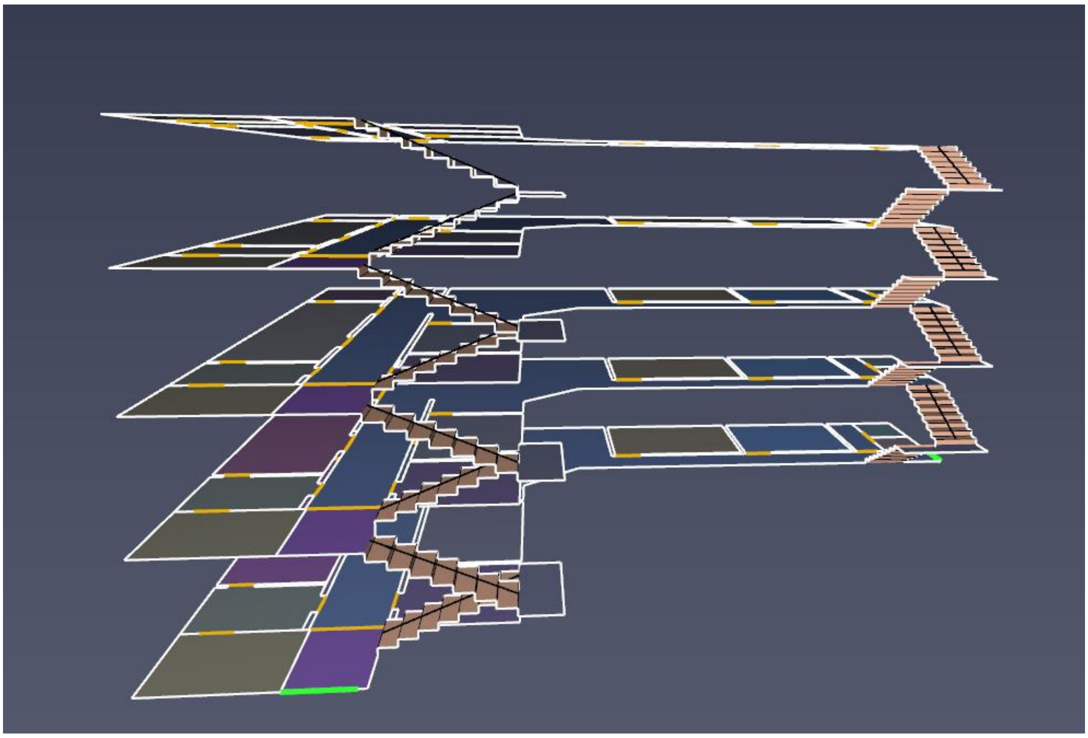

Figure 8 - Pathfinder model, side view of all floors

The occupant profile that was used in the simulations assumes that the average office worker is an adult and moves at a speed of 1.27 m/s (Gwynne & Boyce, 2016). According to a comprehensive research summary of office worker statistics and demographics in the US, the average age of an employed office worker is 46 years old (Zippia, 2022). It is not unreasonable to assume that the average age of office workers in similar countries, such as France and the UK, is also similar.

Pre-evacuation delays - which are supposed to represent the time it takes for the occupants to begin their evacuation after being notified of a potential fire - were added to the profiles based on research data from the SFPE Handbook. They were implemented as a normal distribution with a mean value of 66 s, a minimum value of 0 s and a maximum value of 300 s (Gwynne & Boyce, 2016). The standard deviation was not provided in the data and have been manually calculated to be 22 s according to the "3 Sigma Rule" (Encyclopedia of Mathematics, 2018).

The maximum number of people on each floor was set to 42; this was based on the UK regulations regarding occupant loads in office building, which is 6 m^2 per person (Bukowski & Tubbs, 2016).

All other modifiers were left at their default values, except for physical distancing – this was either off, or at 2 meters according to the highest physical distancing restriction between the studied countries (UK Government - Cabinet Office, 2020). By leaving the other values at default, it was easier to isolate the impact of occupant load and physical distancing, rather than having too many confounding variables. Values that were left as default are further explained in 4.1.1.

The simulations were divided into five different scenarios based on the percentage of occupants who are complying to physical distancing: 0 %, 10 %, 20 %, 50 % and 100 %. To maintain the maximum capacity, the remaining percentage was filled with occupants who do not maintain physical distancing. The scenario with no physical distancing is here referred to as the "normal" scenario when used in non-table related text. It is supposed to represent how occupants moved pre-COVID-19. The purpose of the three scenarios with mixed profiles is to see how impactful the addition of physical distancing was, and if the expected increase in time was linear to the increasing amount of physical distance occupants.

In order to gain credible results, convergence of results was evaluated, since the evacuation simulator make use of random sampling from distributions (Ronchi, Reneke, & Peacock, 2014) (Smedberg, Kinsey, & Ronchi, 2021). To do so, a simple method was used, ensuring that every scenario was simulated until the difference in average evacuation time was below 5 % for at least 10 consecutive runs.

To summarize the impact of physical distancing on evacuation times, a set of simulations were made with each respective scenario (excluding the normal scenario) where the goal was to find the number of occupants where the average evacuation time matched the normal evacuation time. The convergence criteria were the same for these sets; the new average evacuation time had to be within 5 % of the normal evacuation time for at least 10 consecutive runs. The purpose of these sets of simulations were to clearly see how much of a difference the addition of physical distancing compliance makes when trying to evacuate a building and the effect that this has on the maximum occupant levels for each scenario. The theoretical reduction in occupant load was then used to analyse the surveillance data to look for dates and/or periods of time where the occupant load of the different offices reached potentially dangerous levels.

Description of the different scenarios and a summary of the input values used are presented in Table 7 and Table 8.

Table 7 - Scenario description

	Occupants complying to physical distancing	**Occupants <u>not</u> complying to physical distancing**
Scenario 1	0 %	100 %
Scenario 2	10 %	90 %
Scenario 3	20 %	80 %
Scenario 4	50 %	50 %
Scenario 5	100 %	0 %

Table 8 - Parameter values used in all simulations

Parameter	**Values**	
Office area per floor	255 m^2	42 occupants per floor, 210 in total
Occupant density	1 person per 6 m^2	
Walking speed	1.27 m/s	
Physical distancing	2 m	
Pre-evacuation time (Normal distribution)	Min: 0 s Max: 300 s Mean: 66 s Std. dev.: 22 s	

4.1.1. Default values

Variables that were left at their default values include the following:

- Path planning
- Occupant profiles (e.g. characteristics, movement, door choice)
- Occupant behaviour (specific goals such as “goto waypoint”, “goto exit” and “idle until”)
- Flowrates through doors and openings

The occupant’s <u>path planning</u> in Pathfinder is simulated with the “Locally quickest” algorithm. It essentially calculates the fastest path out of the current room, which is repeated until the occupant has exited the simulation (Thornton, O'Konski, Klein, Hardeman, & Swenson, 2012).

<u>Occupant profiles</u> can be customised to simulate a diverse demographic, including changes to body shape/size (default is a cylinder with a diameter of 90,16 cm, which is based on average measurements of male and female persons), door choices (default is according to the “Locally quickest” algorithm, but preferences can be set), and movement speeds (was specifically determined for this thesis and applied across all occupants). Other “advanced” variables include physical distancing, acceleration time and slow factor – these are turned off by default. (Thunderhead Engineering, 2022)

Occupant behaviour can be modified if certain groups or individuals are expected to move in certain ways. Setting goals can simulate occupants moving towards specific exits, rooms, elevators or waypoints, and if no goals are set the occupants will move according to the "Locally quickest" algorithm. (Thunderhead Engineering, 2022)

Flowrates control how many occupants can pass a given opening per second (e.g. 1 pers/sec) and is by default unlimited. This means that the actual flowrate will be decided by the width of the door, along with width and speed of the occupants. (Thunderhead Engineering, 2022)

5. Analysis of the collected surveillance data

In Figure 9, the average occupant load before the restrictions were implemented is observed to be around 50 percent, naturally dropping close to zero on the weekends. On the 12th of March, the first lockdown measure was announced, along with a second announcement on the 13th. A noticeable drop in occupant load can be observed, dropping to 37% on the 13th. The occupant load dropped further as the lockdown went live after noon on the 16th, where occupancy is at a maximum of 15%. Lockdown was extended on the 13th of April, where occupant load is 0%. It stays around 0 % until the 6th of May, where the average starts to climb a week before the lockdown is supposed to end. As more restrictions were lifted, the average occupant load increased, but remained lower than the pre-pandemic values.

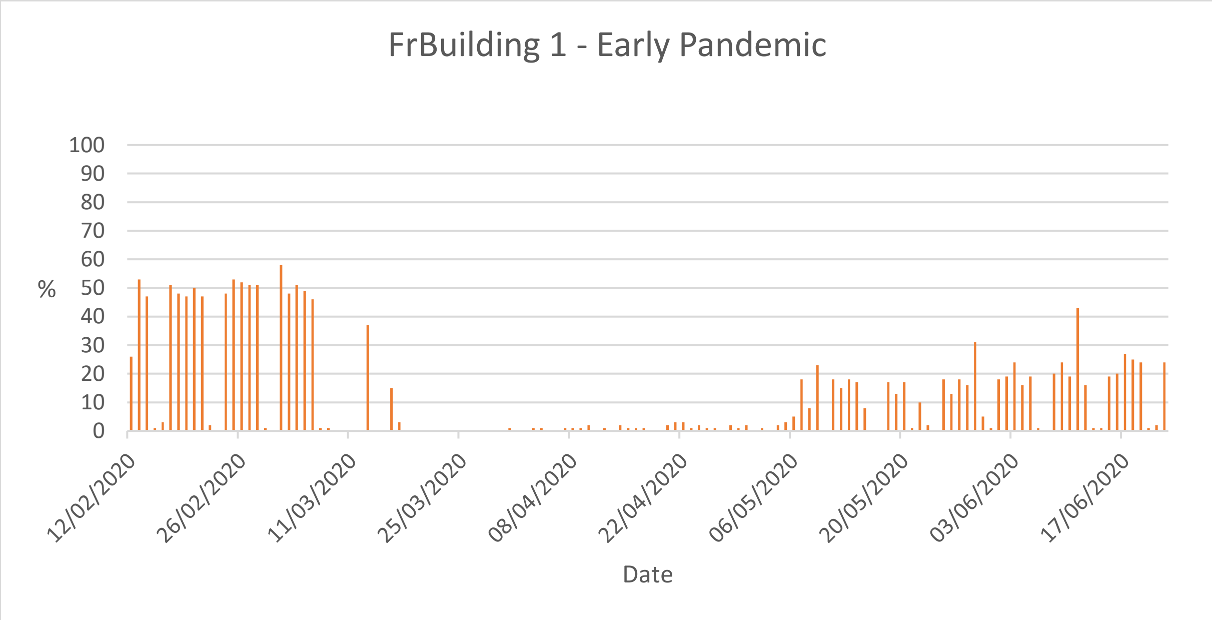

Figure 9 - Percentage of maximum occupant load (750) during the Early Pandemic period on a daily scale.

Worth noting is that even if the lockdown went live at noon, people still used the office throughout the day, as can be seen in **Table 9**.

.

Table 9 - Hourly occupant load in percentages in FrBuilding 1 on the 16th of March 2020. Hours should be read as: hour:00 -> hour:59 (i.e. hour 6 = 06.00 -> 06.59).

Date	Hour	Max Occupant load (%)
2020-03-16	6	0
2020-03-16	7	0
2020-03-16	8	2
2020-03-16	9	6
2020-03-16	10	9
2020-03-16	11	10
2020-03-16	12	10
2020-03-16	13	11
2020-03-16	14	14
2020-03-16	15	14
2020-03-16	16	15
2020-03-16	17	14
2020-03-16	18	10
2020-03-16	19	8
2020-03-16	20	7

The graph showing the data collected from UK Building during the period *Mid Pandemic*, **Figure 10**, started off at a low occupancy load, around 20% (which corresponds to two people). The 6th of August, there was a noteworthy spike in the occupancy load reaching 86% of the maximum capacity. This does not correlate with any major event on the timeline and should therefore be interpreted as a coincidence, as this level of occupancy load was not reached again throughout this stage of the pandemic. About a month passed before the next spikes; the first one occurred on the 10th of September and the second one on the 24th. The following five instances of the occupancy load reaching 57%, or four people, are noteworthy as not only are the previous restrictions still in place, but two other major events also occur on the 15th and 31st of October – London being moved from a tier 1 to a tier 2 (out of 3) lockdown and the total amount of cases exceeding 1 000 000 people, respectively. A new lockdown period began on the 5th of November, and as expected, occupancy load dropped accordingly. After the lockdown ended on the 12th of December, there was a spike as the employees returned to the office after being gone for almost a month.

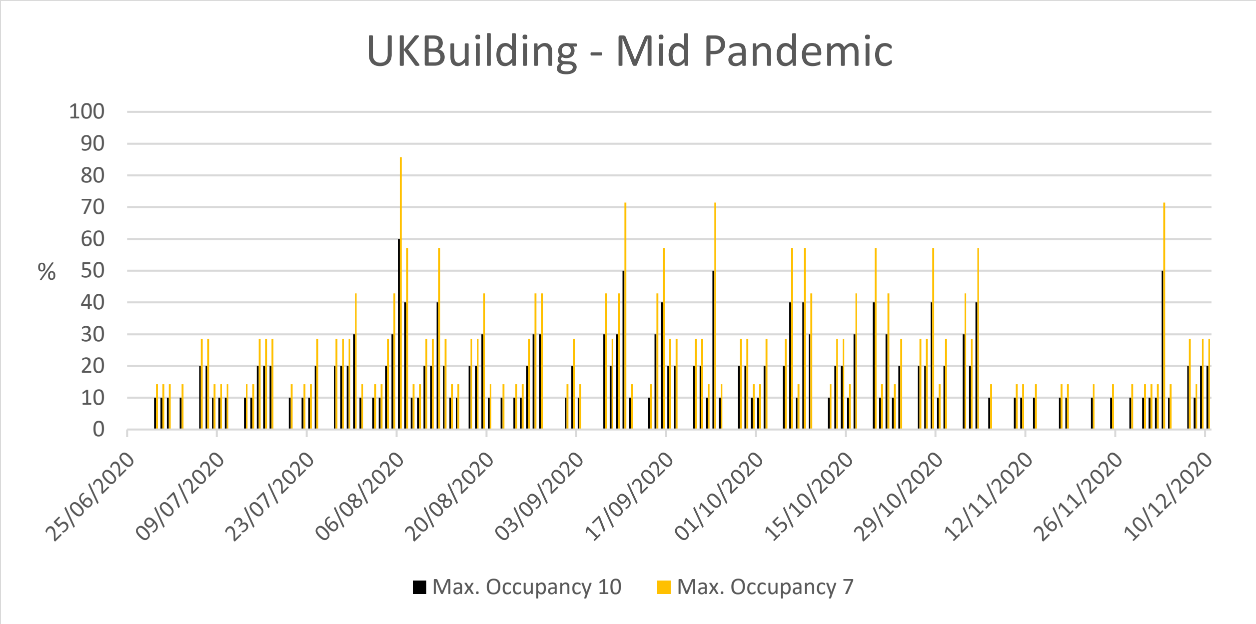

Figure 10 - Percentage of maximum occupant load (7-10) during the Mid Pandemic period on a daily scale.

Figure 11 and Figure 12 cover both of the French offices during the Mid Pandemic but differ greatly in occupant load levels and how they are distributed. *FrBuilding 1* averaged just below 30 % of its maximum occupancy load, before and after the end of the lockdown on the 10th of July. *FrBuilding 2* had a lower occupancy load before the end of the lockdown and rose to approximately 20 % afterwards. On the 24th of July, face coverings were made compulsory in all public indoor spaces and the two offices reacted to this in two opposite ways. The occupant load in *FrBuilding 1* steadily dropped and remained well below 20 % until the beginning of September, but *FrBuilding 2*'s spiked and even reached 50 % the week after. It remained at a value over 30 % until the end of August.

On the 28th of August, face coverings were made compulsory to wear in all public spaces in Paris. The occupant levels in both offices rose after this announcement; *FrBuilding 1*'s climbed to 30 % after a week and remained between 30- and 40 % during September, whereas *FrBuilding 2*'s immediately spiked to over 60 % and stayed above 50 % almost every weekday until the second week of October. The key aspect to note here is that the compulsory face coverings most likely made the difference in deciding whether to work from home or the office, as the facial protections would have heavily decreased the risk of catching the virus.

FrBuilding 1's level remained at 30 % until the end of the period – despite there being a second lockdown which begun on the 30th of October. *FrBuilding 2*'s level followed the same pattern, except that it was a bit higher at first. The effect of the second lockdown can barely be seen at all. There is a week in the beginning of December where both offices were completely empty but without any official announcement.

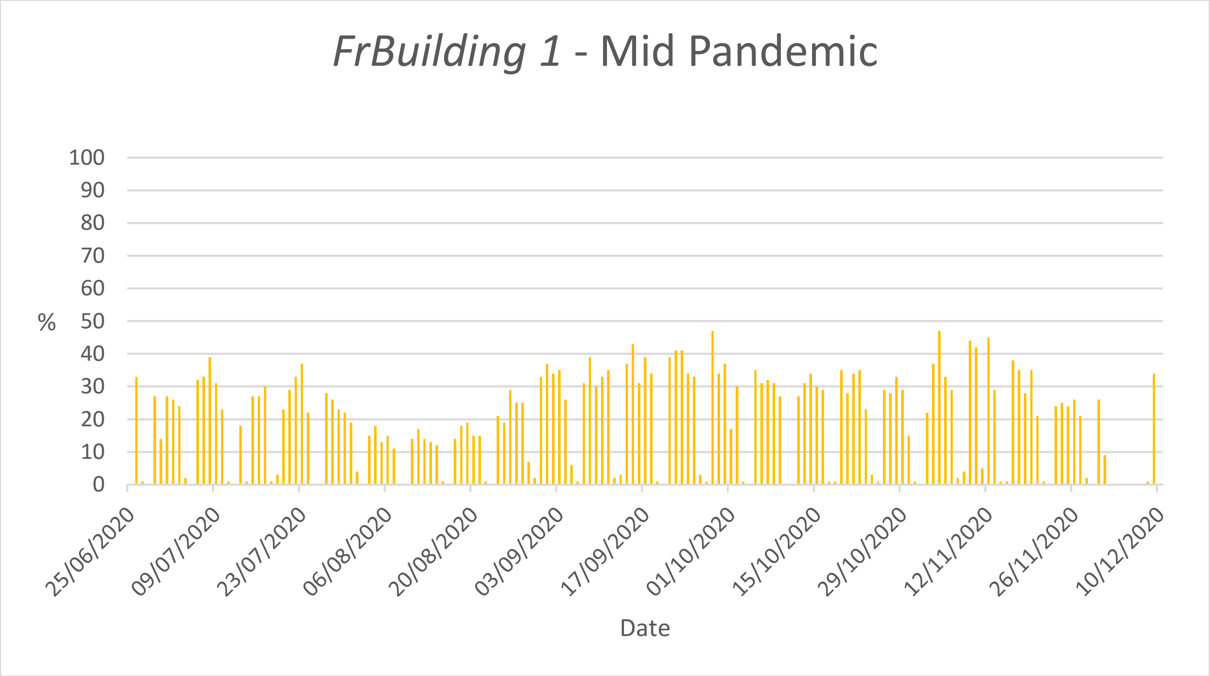

Figure 11 - Percentage of maximum occupant load (750) during the Mid Pandemic period on a daily scale.

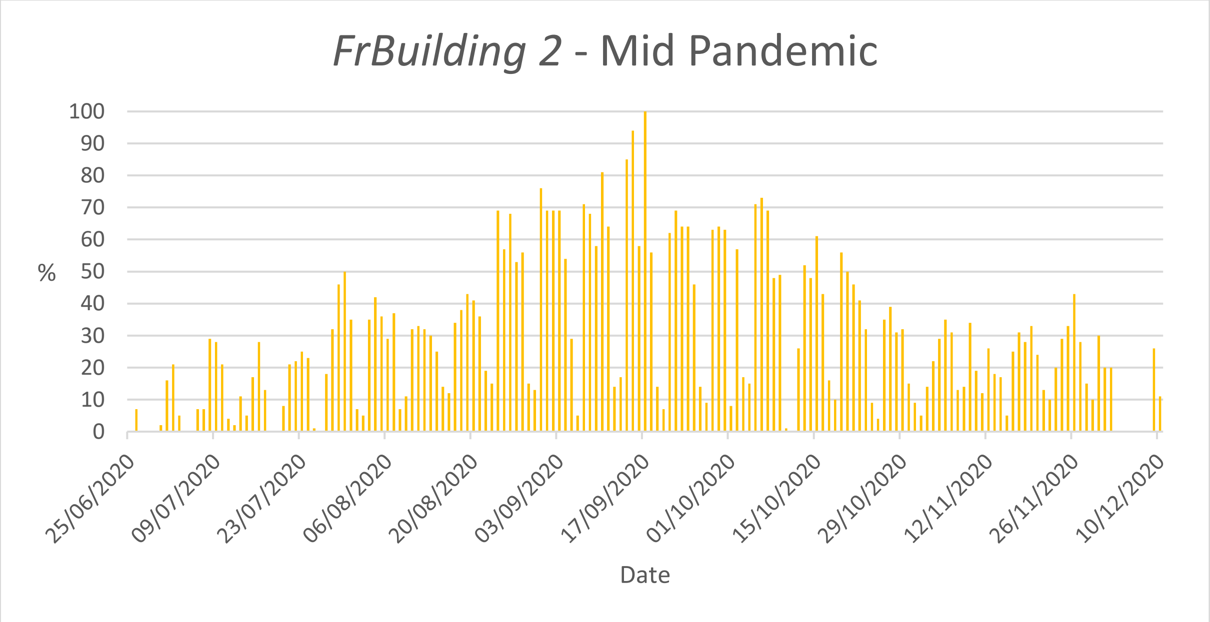

Figure 12 - Percentage of maximum occupant load (940) during the Mid Pandemic period on a daily scale.

The Late Pandemic is a relatively short period compared to the Mid Pandemic, and the timeline does not include nearly as many events. The most noteworthy observation in **Figure 13** is the spike on the 21st of December, which most likely was the last day of work before the holidays. The third national lockdown began on the 4th of January 2021, and the occupant load level remained relatively the same throughout the rest of the period. While it looks like there are massive jumps in occupant loads, the amount of people in the office only varied between 1-4 people, and no correlation can be seen to the events.

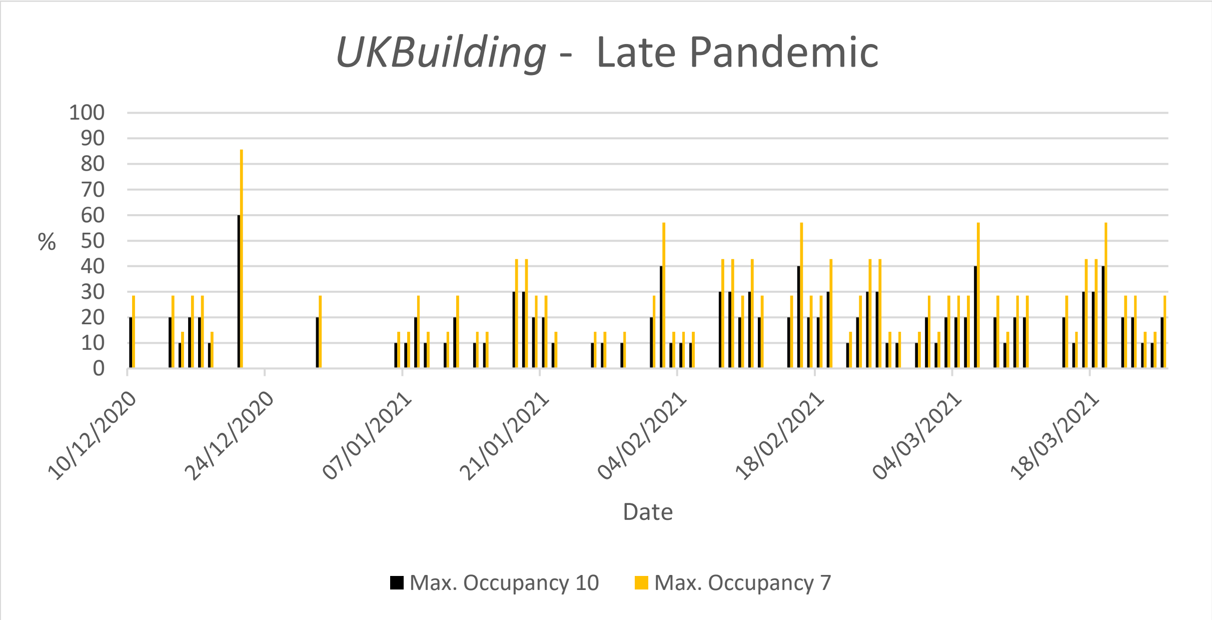

Figure 13 - Percentage of maximum occupant load (7-10) during the Late Pandemic period on a daily scale.

6. Results of the case study simulations

The simulation results are presented below, in Tables 10 - 13. The first set of simulations are the ones presented in Table 10. Testing the two extreme case scenarios first shows that adding physical distancing to the occupant restrictions more than doubles the time it takes to evacuate the building. The visuals given when running the simulations showed that adding physical distancing made people queuing when trying to evacuate down the stairs – see Figure 14 - as only a single file of occupants was "allowed" with the given width of the stairs.

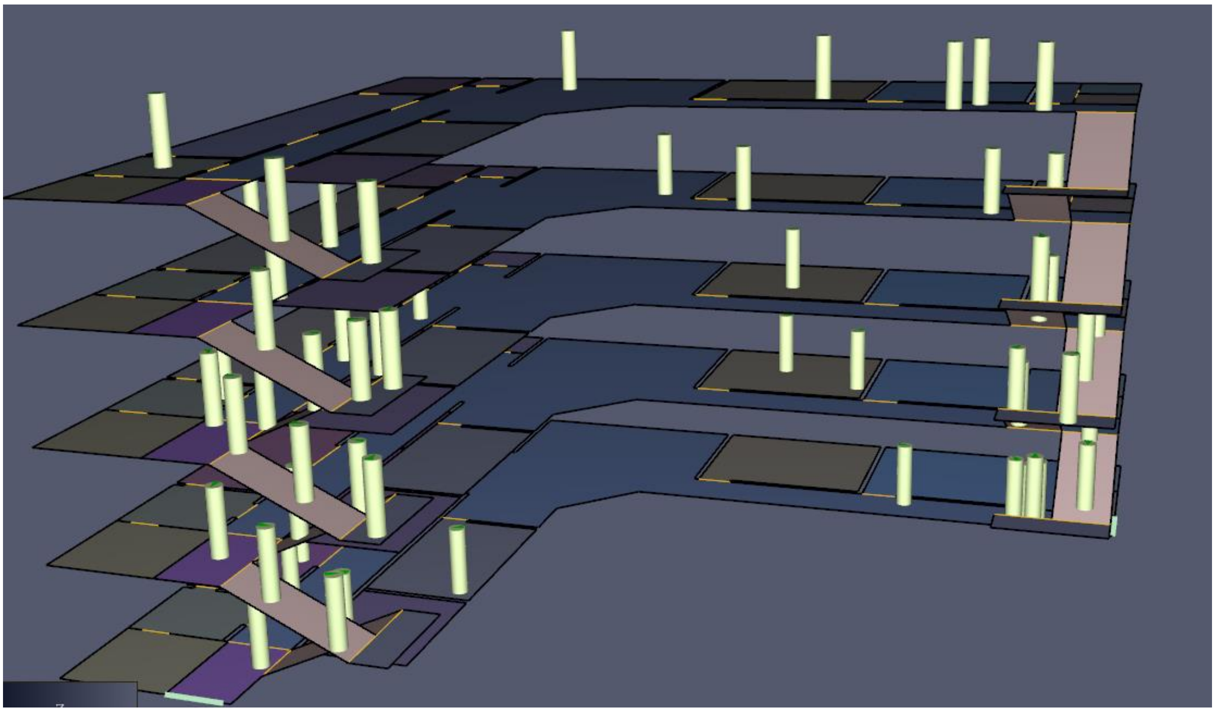

Figure 14 – Visual example of queuing of occupants in the stairs

Table 10 – Evacuation times for scenarios fully with or without physical distancing

	Scenario 1	**Scenario 5**
Lowest time	159 s	362 s
Highest time	194 s	390 s
Mean	176 s	374 s

As can be seen in Table 11, the increase in time per added percent of physical distancing occupants is not linear. The increase from 0 to 10 percent is 4 seconds, whereas the increase from 10 to 20 percent is 19 seconds. The expected time increase at 50 percent should theoretically be at least three times as large compared to the previous interval but ends up being around 18 seconds per 10 %. The expected difference between 50 % and 100 % should therefore be around 89 seconds (5*17.7) but ends up being 122 seconds.

Table 11 - Evacuation times for scenarios with mixed amounts of physical distancing

	Scenario 2	Scenario 3	Scenario 4
Lowest time	168 s	190 s	242 s
Highest time	192 s	208 s	269 s
Mean	180 s	199 s	252 s

Table 12 and Figure 15 shows the percentage increase in time to evacuate compared to scenario 1.

Table 12 - Mean values and percentage difference of all scenarios

	Mean evacuation time	Percentage increase in time
Scenario 1	176 s	-
Scenario 2	180 s	2.3 %
Scenario 3	199 s	13.1 %
Scenario 4	252 s	43.2 %
Scenario 5	374 s	112.5 %

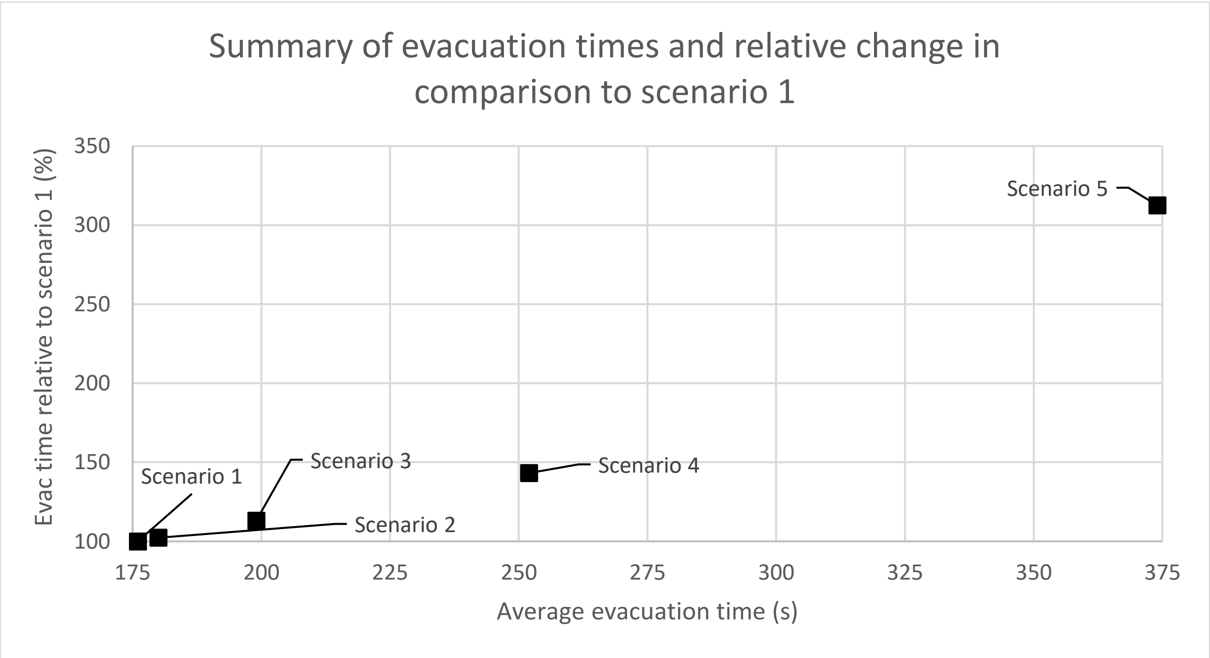

Figure 15 - A visualised summary of the results

The results in Table 13 are the required new level of occupant loads for the simulated office in order to maintain approximately the same evacuation time as scenario 1.

Table 13 - Adjusted levels of maximum occupant load

	New maximum occupant load needed to maintain the "no physical distancing" evacuation time	**Percentage of normal occupant load**
Scenario 2	191	91.0 %
Scenario 3	171	81.4 %
Scenario 4	113	53.8 %
Scenario 5	81	38.6 %

7. Discussion

The main finding of the surveillance data, which also answers research question one, is that the effects of many restrictions on occupant loads become increasingly unpredictable the further into the pandemic they are introduced, but also how they can differ despite happening in the same area at the same time. Comparing Figure 9 and Figure 11 with their respective timelines shows a clear difference in responses; the occupant load during the early pandemic dropped to almost 0 after the lockdown had gone live, whereas the occupant load during the mid-pandemic was nowhere close to 0 in the beginning of the period, despite the fact that there was an on-going lockdown. This is a clear sign of lockdown fatigue - the lockdown restrictions began to ease in early May, but it was still very much in effect.

The largest differences can be seen between Figure 11 and Figure 12, where two offices in the same area during the same time period reacted vastly different to the same restrictions and news. The introduction of face coverings being mandatory in public indoor spaces made the occupant loads go in two different directions, but when the restrictions were applied in all public spaces both of the occupant loads rose. Compulsory face coverings most likely made the difference in deciding whether to work from home or the office, as the facial protections would have heavily decreased the risk of catching the virus (Howard, et al., 2021). On the contrary, masks being mandatory could have meant that the risk of being exposed to COVID-19 was higher than before, which would explain the earlier decrease in occupant load.

The respective time periods of Figure 10 and Figure 13 do not share many similarities, except that a lockdown begins during both. As opposed to the earlier lockdown, the latter does not seem to have any real impact on the immediate and future occupant load of the office. However, this might have to do with the relatively low sample size of occupants, as the maximum number is almost a tenth of the French offices.

As clearly seen in the results from the simulation, physical distancing heavily increases the time it takes to evacuate a building, which partly answers the second research question. Although there is barely any difference between the normal case and when 10 % of the occupants are complying with physical distancing, every increase of 10 % beyond that is very noticeable. In this case, the evacuation time more than doubles if every occupant is practicing physical distancing. This fact is very case study specific, but it is definitely worth highlighting since this practically means that building evacuation can be severely affected by physical distancing.

Comparing the different scenarios to the normal case and adjusting the maximum occupant loads to match the normal evacuation time resulted in a heavy decrease of people, especially in scenario 4 and 5. If half of the people in an office maintain physical distancing, the maximum amount of people in said office has to be reduced by nearly 50 % in order to retain the time it takes for the occupants to evacuate. Physical distancing provisions have been mandated since the beginning of the COVID-19 pandemic, which hypothetically means that it is not unreasonable to believe that at least 20 % of people in an office workplace practices it – which in turn would mean that the new maximum of the occupant load is decreased by almost 20 %.

To assume that 100 % of the occupants will comply with physical distancing of 2 meters in the event of an evacuation is questionable. There is no research on this, but the impending danger of a fire may prevail over the danger of getting COVID-19 through standing or walking close to your colleague while evacuating. That being said, in the case study it was showed that any occupant load above 39 % can be considered to be at a theoretically increased risk in case of a fire – this answers the second part of the research question two. This percentage can fluctuate given the different levels of complexity and variability of office buildings and its occupants, but we still cannot neglect the problem.

7.1. Highest recorded occupant levels

The following subsection is dedicated to answering the third and final research question.

During the Early Pandemic in FrBuilding 1, the highest recorded occupant load (post the first lockdown) was 43 %. If it is assumed that the results of the case study were applicable on this building and the threshold of 39 % applied, the slightly higher occupant load would have resulted in a slightly higher evacuation time compared to normal if 100 % of the occupants would have practiced physical distancing of 2 meters. However, the case study featured a generic office layout and is most likely not representative of the layout of FrBuilding 1's, nor do the scenarios represent the same level of occupants. A strict application of "An occupant load over 39 % is dangerous, an occupant load under 39 % is safe" will in almost every case not give a credible result. As mentioned above, the sheer variability between offices makes it very difficult to predict the behaviour of evacuating occupants in a specific office, unless the case study is tailored towards said specific office. That being said, the case study shows a definite increase in evacuation time, but the exact threshold of danger vs. no danger is hard to determine.

The occupant load of the UKBuilding during both the mid- and late pandemic reached occupant loads above 50 % on several occasions. While it theoretically might have put the occupants in a riskier position, the fact that the total number of occupants were very low should effectively have eliminated the risk of there being any queueing.

FrBuilding 1 during the Mid Pandemic stayed at a relatively low level – hovering around 30 % occupant load the majority of the time. There were around 10 instances when the occupant load went above the 39 % threshold, with a maximum level of occupant load of 47 % on two occasions. As long as no more than every other person maintained physical distancing during any of the 10 instances, they would not have been exposed to an increased risk.

However, FrBuilding 2 during the Mid Pandemic had a period between 24th of August and the 22nd of October where the occupant load did not drop below 40 % once. In fact, it even went as high as 100 % on one occasion. Depending on the ratio of occupants following the restrictions concerning physical distancing, the total evacuation time for the entire office would have been higher, or significantly higher, than the one assumed in the building regulations. Despite being an unlikely scenario, if 100 % of the occupants had practiced physical distancing in the event of an evacuation, the case study showed that it would have taken the occupants more than double the normal time to evacuate.

7.2. Limitations, further research, and the way forward

As the camera recorded data was limited to three different data sets, it naturally restricted the comprehensiveness of the analysis - especially considering that the only data set from the UK that was available covered an office with a maximum occupant load of 10 people. While the available data allowed for cross-referencing of observed occupant loads and pandemic events despite being relatively limited, the analysis would have generated more conclusive results if more offices, and offices of different sizes in both countries, had been covered. Comparing several offices of similar sizes across the two countries with each other would have been more beneficial than comparing one small office with two larger offices. Moreover, adding more offices would facilitate the process of determining if the occupants' reactions to the pandemic events were representative across the majority of offices, or if they were the exception to the rule. The analysis of UKBuilding's occupant load throughout the Mid- and Late Pandemic was made more difficult due to the lower occupant count, as a single person represented either 10 or 14 % of the maximum occupant load. The occupants of FrBuilding 1 and 2 reacted in different manners to the same pandemic events, and while it made for a good basis for discussion, it is impossible to determine which reaction (if either) is representative for the average office. The fact that only two countries were covered also makes the results difficult to apply to any office located anywhere other than in France or the UK. Nevertheless, results may be indicative of possible issues that may arise.

The case study was focused on the differences in evacuation time at different occupant loads, with and without the restriction of physical distancing. The occupant load values that were used were not based on local averages, but were instead pre-determined intervals to simplify the simulation process. Had the simulations been based on averages, and separate simulations been made for and tailored towards each of the respective offices, the results would have been directly comparable to each of the offices. The critical occupant load threshold could then, instead of being a value generally applied across all offices, be individually determined for each office. This would in turn enable the study to cover whether the offices were at an increased risk or not in further detail. Furthermore, adding different physical distancing values, different movement speeds for the occupants depending on gender, age and/or disabilities, customised exit choices and group dynamics would most likely strengthen how well the simulations represent real life, thus making the results more credible. Unfortunately, the scope of this thesis did not allow for the numerous variations to be further investigated and is therefore strongly recommended for future research.

Despite the limitations of this analysis, it does shed some light on the currently unexplored area of the combination of office occupant loads, COVID-19 restrictions, and changes in evacuation time. Similar studies have been made regarding how the restrictions have affected evacuation, such as the study made at the *University of Technology* in Lodz, Poland. The report, titled "*The safe evacuation of persons from a building operating within COVID-19 restrictions*" (Brzezinska, Baranski, Bryant, & Haznar-Baranska, 2022), showed similar results compared to this study. They used a sports hall building in their simulations, along with a significantly more detailed method of performing their Pathfinder simulations, but the results were very similar to what was found in this case study. Another study, conducted at *Dalhousie University* in Halifax, Canada, investigated the pedestrian movement at an international airport. The study aimed to develop a pedestrian microsimulation model that implemented a social force model to simulate regular, as well as pandemic, movement scenarios (Alam, Ahsanul Habib, & Holmes, 2022). In spite of using a different software than in this analysis, the results showed that physical distancing is likely to increase queue time at airports, which in turn might suggests that airport authorities have to make changes to the airport infrastructure and implement queue management processes to mitigate the negative effects of the restriction (Alam, Ahsanul Habib, & Holmes, 2022). Again, while the setting is different from the setting used in this analysis, the results remain similar.

Taking all aspects into consideration – should the way forward include changes to existing building codes to account for the potential risks that may arise in case of a pandemic similar, or worse, than the COVID-19 pandemic or not? The results from this analysis indicate that physical distancing can negatively impact the evacuation time of office buildings, which in turn can potentially cause occupants to be at an increased risk. It is, however, strongly recommended that further research on this topic is made, as implementing a new set of conditional building codes is no small or easy task. On one hand, if properly implemented and enforced, it could potentially alleviate the conditions of office workplaces in case of a pandemic and reduce the risk of reaching critical evacuation times. On the other hand – is it feasible for governments to implement new, conditional building codes tailored towards possible societal circumstances that are not guaranteed to occur within a reasonable amount of time? And if they are implemented, shall they apply to all existing offices without exception? Will this cause currently usable office spaces to be unusable and in need of mandatory structural/layout changes before they can be used again? There is a plethora of questions that need to be answered before a change like this can be implemented, which again highlights the need for further research.

8. Conclusion

The purpose of this analysis was to determine the effects of COVID-19 on occupant loads and assess whether it is associated with fire evacuation issues or not. To clarify the focus, three key research questions were formulated which were later discussed and answered in detail:

The correlation between local news and the observed occupant loads in the studied offices varies heavily depending on how late into the pandemic they are introduced, but also across the offices. The two French offices reacted differently to the same restrictions during the same period, despite having similar maximum occupant loads and both being located in Paris. One explanation to this is lockdown fatigue, but in order to affirm this claim further studies need to be done.

The addition of physical distancing heavily affects the evacuation time of the fictional case study office, especially at higher levels of occupant load. In the worst-case scenario, in order to maintain the same evacuation time as the normal scenario, the adjusted maximum occupant load had to be just below 39 % of the normal maximum. This would, theoretically, in practice mean that offices cannot contain more than 39 % of their normal maximum occupant load without subjecting the occupants to a higher level of risk in regard to evacuation time.

There were on several occasions levels of occupant loads in the three offices where the occupants would have been exposed to an increased risk level if the occupants would have practices physical distancing. However, as there have been no studies regarding whether people maintain physical distancing during an evacuation or not, it is unclear if the occupants were actually at an increased risk.

9. The way forward

As the key research questions were answered, the need for a fourth and conclusive question arose, namely: What is the way forward, given the results of the analysis? What research should be done, which measures should be taken and why?

The way forward needs to contain more research in this area, as the scope of this thesis is relatively limited. More and different offices need to be studied across multiple countries. Any simulation work needs to include more variables and office layouts to better represent real offices and their occupants. This study has, however, highlighted the impact that physical distancing has on the time it takes to evacuate an office building. The findings of this thesis suggests that regulations concerning occupant loads in office buildings might have to be adjusted to properly reflect how people move and evacuate, while possibly maintaining physical distancing, during future situations similar to the COVID-19 pandemic in order to ensure the safety of occupants. Needless to say, if an even deadlier and more transmissible virus happens in the future, there needs to be some changes as to how the evacuation safety of office spaces, or any other place, is managed. Whether it is reasonable or not to change building codes, occupants in a fire evacuation scenario should never have to choose between safety from an on-going fire or safety from an on-going pandemic.

References

Adalja, A., & A Nelson, C. (2020). Plague: Still a Threat, but Evidence and Preparedness Are Keys to Fighting Back. *Clinical Infectious Diseases*, 1-2.

Alam, J., Ahsanul Habib, M., & Holmes, D. (2022). Pedestrian movement simulation for an airport considering social distancing strategy. *Transportation Research Interdisciplinary Perspectives*.

Ashworth Underwood, E. (1998, July 20). *Britannica Group*. Retrieved from britannica: https://www.britannica.com/science/history-of-medicine/Traditional-medicine-and-surgery-in-Asia

Australian Psychological Society. (2020). *Managing lockdown fatigue.* Retrieved from Psychology.org.au: https://psychology.org.au/getmedia/74e7a437-997c-4eea-a49c-30726ce94cf0/20aps-is-covid-19-public-lockdown-fatigue.pdf

Baoqi, H., Guoqiang, M., Yong, Q., & Yun, W. (2021). Pedestrian Flow Estimation Through Passive WiFi Sensing. *IEEE Transactions on Mobile Computing Volume: 20, Issue: 4*.

Boverket. (2019). *Boverket´s mandatory provisions and general recommendations, BBR.* Retrieved from Boverket: https://www.boverket.se/globalassets/publikationer/dokument/2019/bbr-2011-6-tom-2018-4-english-2.pdf

Brown, J., & Kirk-Wade, E. (2021, 12 22). *Coronavirus: A history of English lockdown laws.* Retrieved from House of Commons Library: https://commonslibrary.parliament.uk/research-briefings/cbp-9068/

Brzezinska, D., Baranski, M., Bryant, P., & Haznar-Baranska, A. (2022). The safe evacuation of persons from a building operating within COVID-19 restrictions. *Building Services Engineering Research and Technology, Vol 43, Issue 4*.

Bukowski, R., & Tubbs, J. (2016). Egress Concepts and Design Approaches. In S. o. Engineers, *SFPE Handbook of Fire Protection Engineering - Fifth Edition* (pp. 2012-2046). Springer.

Chaves, S., Long, B., Koyfman, A., & Y.Liang, S. (2021). Coronavirus Disease (COVID-19): A primer for emergency physicians. *The American Journal of Emergency Medicine*, 220-229.

Chavez-MacGregor, M., Lei, X., & Zhao, H. (2022). Evaluation of COVID-19 Mortality and Adverse Outcomes in US Patients With or Without Cancer. *JAMA Oncol. 2022*, 69-78.

Chu, D. K., Akl, E. A., Duda, S., Solo, K., Yaacoub, S., & Schünemann, H. J. (2020). Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. *The Lancet Vol. 395 Issue 10242*, 1973-1987.

Daamen, W., Yuan, Y., Duives, D., & Hoogendorn, S. (2016). Comparing three types of real-time data collection techniques. *Proceedings of Pedestrian and Evacuation Dynamics 2016*, 568-574.

Diab-Bahman, R., & Al-Enzi, A. (2020). The impact of COVID-19 pandemic on conventional work settings. *International Journal of Sociology and Social Policy*, 909-927.

Eliyan, L., Halabi, O., & Saleh, M. (2018). Modeling Family Behavior in Crowd Simulation. *International Conference on Computer and Applications (ICCA).* Beirut, Lebanon: ICCA.

Field, T., Mines, S., Poling, S., Diego, M., Bendell, D., & Veazey, C. (2021). COVID-19 Lockdown Fatigue. *American Journal of Psychiatric Research and Reviews*.

French Government. (2022, 06 04). *Coronavirus - Protective measures.* Retrieved from France Diplomacy: http://web.archive.org/web/20220604070322/https://www.diplomatie.gouv.fr/en/coming-to-france/coming-to-france-your-covid-19-questions-answered/coronavirus-protective-measures/

Goldstein, P., Yeyati, E. L., & Sartorio, L. (2021). *Lockdown Fatigue: The Diminishing Effects of Quarantines on the Spread of COVID-19.* Cambridge: Harvard University.

Gwynne, S., & Boyce, K. (2016). Engineering Data. In S. o. Engineers, *SFPE Handbook of Fire Protection Engineering - Fifth Edition* (pp. 2429-2551 (2449)). Springer.

Hendren, N. S., de Lemos, J. A., Ayers, C., Das, S. R., Rao, A., Carter, S., . . . Grodin, J. L. (2020). Association of Body Mass Index and Age With Morbidity and Mortality in Patients Hospitalized With COVID-19. *Circulation Vol. 143 No. 2*, 135-144.

Howard, J., Huang, A., Li, Z., Tufekci, Z., Zdimal, V., van der Westhuizen, H.-M., . . . Rimoin, A. W. (2021). An evidence review of face masks against COVID-19. *PNAS Vol. 118 No. 4*.

Incheol, K., Eunmi, C., & Huikyung , O. (2012). Observation and motion models for indoor pedestrian tracking. *2012 Second International Conference on Digital Information and Communication Technology and it's Applications (DICTAP)*.

Marroquín, B., Vine, V., & Morgan, R. (2020). Mental health during the COVID-19 pandemic: Effects of stay-at-home policies, social distancing behavior, and social resources. *Psychiatry Research*.

Milke, J. A., & Caro, T. C. (1996). A Survey of Occupant Load Factors in Contemporary Office Buildings. *Journal of Fire Protection Engineering Volume: 8 issue: 4*, 169-182.

Millonig, A., Brändle, N., Ray, M., Bauer, D., & Van der Spek, S. (2009). Pedestrian Behavior Monitoring: Methods and Experiences. *Behavior Monitoring and Interpretation - BMI*, 11-42.

National Fire Protection Association. (2022, February). *CALCULATING OCCUPANT LOAD.* Retrieved from NFPA: https://www.nfpa.org/-/media/Files/Code-or-topic-fact-sheets/CalculatingOccupantLoadFactSheet.pdf?fbclid=IwAR0H0Oc2CjHab5A37fUH_ncxaOo7SjWRaMT4ho9OmdVIE6pQTA6_off9Dwg

Pouw, C. A., Toschi, F., van Schadewijk, F., & Corbetta, A. (2020, October 29). *Monitoring physical distancing for crowd management: Real-time trajectory and group analysis*.

Retrieved from Plos One: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0240963#sec022

Ritchie, H., Mathieu, E., Rodés-Guirao, L., Appel, C., Giattino, C., Ortiz-Ospina, E., . . . Roser, M. (2020). *Policy Responses to the Coronavirus Pandemic*. Retrieved from Our World in Data: https://ourworldindata.org/policy-responses-covid

Ronchi, E., Nilsson, D., Lovreglio, R., Register, M., & Marshall, K. (2021). The Impact of Physical Distancing on the Evacuation of Crowds. In *Crowd Dynamics - Modeling and Social Applications in the Time of COVID-19* (pp. Vol. 3, pp. 133-156). New York, USA: Birkhäuser Verlag.

Ronchi, E., Reneke, P. A., & Peacock, R. D. (2014). A method for the analysis of behavioural uncertainty in evacuation modelling. *Fire Technology*, 1545-1571.

Rout, A., Nitoslawski, S., Ladle, A., & Galpern, P. (2021). Using smartphone-GPS data to understand pedestrian-scale behavior in urban settings: A review of themes and approaches. *Computers, Environment and Urban Systems*.

Salian, V. S., Wright, J. A., Vedell, P. T., Nair, S., Li, C., Kandimalla, M., . . . Kandimalla, K. K. (2021). COVID-19 Transmission, Current Treatment, and Future Therapeutic Strategies. *Molecular Pharmaceutics*, 754-771.

Smedberg, E., Kinsey, M., & Ronchi, E. (2021). Multifactor Variance Assessment for Determining the Number of Repeat Simulation Runs in Evacuation Modelling. *Fire Technology*, 2615-2641.

Society of Fire Protection Engineers. (2016). *SFPE*. Retrieved from SFPE Handbook of Fire Protection Engineering, 5th edition: https://www.sfpe.org/publications/handbooks/sfpehandbook

Spearpoint, M. (2020, 05 02). Building occupant numbers for egress calculations.

Spearpoint, M., & Hopkin, C. (2018). A Review of Current and Historical Occupant Load Factors for Mercantile Occupancies. *Journal of Physics: Conference Series, Volume 1107, Issue 7*.

Statens Haverikommission. (2001). *Brand på Herkulesgatan i Göteborg, O län, den 29–30 oktober 1998.*

Thornton, C., O'Konski, R., Klein, B., Hardeman, B., & Swenson, D. (2012). New Wayfinding Techniques in Pathfinder. *Pedestrian and Evacuation Dynamics 2012*, 1315-1322.

Thunderhead Engineering. (2022, 08 09). *Pathfinder*. Retrieved from thunderheadeng: https://www.thunderheadeng.com/pathfinder?gclid=CjwKCAjw6MKXBhA5EiwANWLODCiUscNYIzdQ7lXcavl3lzD4zR-146RH3wnnqssKWM_Rr4h84wnPCRoCTEsQAvD_BwE

Thunderhead Engineering. (2022, 09 25). *Thunderheadeng*. Retrieved from Pathfinder User Manual: https://support.thunderheadeng.com/docs/pathfinder/2022-2/user-manual/

UK Government - Cabinet Office. (2020, 06 24). *Review of two metre social.* Retrieved from GOV.UK: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/894961/6.6731_CO_Review_of_two_metre_Social_Distancing_Guidance_FINAL_v3_WEB_240620.pdf

Whittaker, F. (2022, 05 24). Staff say overcrowding hampered bomb scare evacuation at DfE's Sheffield office. *Schools Week*.

World Health Organization. (2021, January 29). *Listings of WHO's response to COVID-19*. Retrieved from WHO: https://www.who.int/news/item/29-06-2020-covidtimeline

World Health Organization. (2022, 05 10). *Advice for the public: Coronavirus disease (COVID-19)*. Retrieved from WHO: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

World Health Organization. (2022, 08 09). *Coronavirus disease (COVID-19)*. Retrieved from WHO: https://www.who.int/health-topics/coronavirus#tab=tab_1

World Health Organization. (2022, 08 09). *WHO Coronavirus (COVID-19) Dashboard*. Retrieved from WHO: https://covid19.who.int/

World Health Organization. (2022, 08 09). *WHO Coronavirus (COVID-19) Dashboard - Measures*. Retrieved from WHO: https://covid19.who.int/measures

Zippia. (2022, 09 22). *OFFICE WORKER DEMOGRAPHICS AND STATISTICS IN THE US*. Retrieved from Zippia: https://www.zippia.com/office-worker-jobs/demographics/?src=sp-popout-scrolled

Timeline references

France Early Pandemic

12/3, 13/3 – 2020 First/second lockdown measure announced: https://www.france24.com/en/video/20200312-coronavirus-pandemic-french-president-emmanuel-macron-makes-televised-address

17/3 – 2020 Beginning of lockdown: https://www.france24.com/en/20200317-french-lockdown-comes-into-force-in-bid-to-curtail-spread-of-deadly-virus

13/4 – 2020 Extending current lockdown period: https://www.francetvinfo.fr/sante/maladie/coronavirus/direct-coronavirus-prolongation-du-confinement-reouverture-des-ecoles-et-des-commerces-regardez-l-allocution-televisee-d-emmanuel-macron_3913673.html

11/5 – 2020 Primary schools and some middle schools allowed to open: https://www.bbc.com/news/world-europe-52615733

28/5 – 2020 Announcing the lifting of the travel ban, opening of restaurant, cafés and bars (not in paris): https://www.theguardian.com/world/2020/may/28/global-report-france-eases-coronavirus-travel-restrictions

2/6 – 2020 Lifting occurs: https://www.france24.com/en/20200602-france-lifts-more-covid-19-restrictions-what-you-need-to-know-for-phase-ii

14/6 – 2020 Cafés, pubs and restaurants are allowed to reopen in Paris: https://www.theguardian.com/world/live/2020/jun/14/coronavirus-live-news-ew-beijing-cluster-sparks-fears-of-second-wave-as-brazil-cases-top-850000?page=with:block-5ee641548f08cea6cb54b474

22/6 – 2020 Further reopening, including cinemas, holiday centers and schools: https://deadline.com/2020/05/france-cinemas-re-opening-date-set-coronavirus-1202945374/

France Mid Pandemic

1/7 – 2020 Open borders with non-european union countries: https://www.connexionfrance.com/article/French-news/France-to-open-non-EU-borders-from-July-1-and-Europe-tomorrow-June-15-but-restrictions-on-UK-still-apply

10/7 – 2020 End of lockdown: https://www.reuters.com/article/us-health-coronavirus-france-idUSKBN23H0W0

24/7 – 2020 Face coverings made compulsory in all public indoor spaces and some outdoor spaces: https://www.reuters.com/article/us-health-coronavirus-france-idUSKCN24J0L7

28/8 – 2020 Compulsory to wear masks in all public spaces in Paris, new record daily new cases: https://www.bbc.com/news/world-europe-53934952

12/9 – 2020 More than 10000 cases in daily cases: https://www.reuters.com/article/us-health-coronavirus-france-casualties-idUSKBN2630XZ

5/10 – 2020 Paris once again shuts its cafés, pubs and restaurants: https://www.connexionfrance.com/article/French-news/Covid-19-Paris-on-maximum-alert-bars-and-cafes-to-close

14/10 – 2020 9-6 pm curfew imposed in several major cities. Paris included, for four weeks: https://www.france24.com/en/20201014-live-macron-expected-to-announce-tougher-covid-19-measures-as-france-s-cases-rise

23/10 – 2020 Confirmed cases over 1 million, new record in daily cases (42000): https://www.reuters.com/article/uk-health-coronavirus-france-casualties-idUKKBN2782IN

25/10 – 2020 Over 50000 in daily cases: https://crisis24.garda.com/alerts/2020/10/france-health-authorities-record-highest-daily-rise-of-covid-19-cases-october-25-update-49

28/10 – 2020 Announcing second lockdown beginning 30/10, affecting non-essential businesses and lasting until 1/12 – 2020: https://www.bbc.com/news/world-europe-54716993

5/11 – 2020 further restrictions, extending to food shops opening hours: https://medicalxpress.com/news/2020-11-paris-tightens-virus-lockdown.html

UK Mid Pandemic

14/8 – 2020 Further easing of lockdown restrictions: https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf

22/9 – 2020 Announcing tightening of COVID-19 restrictions: https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf

15/10 – 2020 London moved to a tier 2 (out of 3) lockdown: https://www.abc.net.au/news/2020-10-15/london-tier-2-covid-19-lockdown-with-millions-banned-from-mixing/12772826

31/10 – 2020 Passing 1000000 cases. Announcing new lockdown beginning of the 5th of November: https://www.bbc.com/news/uk-54763956

5/11 – 2020 Lockdown begins: https://www.legislation.gov.uk/uksi/2020/1200/made

02/12 – 2020 Lockdown ends: https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf

UK Late Pandemic

8/12 – 2020 First person to get vaccinated in England: https://www.bbc.com/news/uk-55227325

4/1 – 2021 Third lockdown beginning: https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf

22/2 – 2021 Four-step plan to end restrictions unveiled: https://www.instituteforgovernment.org.uk/sites/default/files/timeline-lockdown-web.pdf