WALLS OF AIR:

A Retrofit for Equitable Indoor Air Quality

by

Charlotte Damus

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Poor indoor air quality and lack of space for adequate isolation within postwar towers increase the risk of negative effects on resident health leaving them more vulnerable to infectious diseases. The unequal ability to isolate safely within residential spaces during the Covid-19 pandemic is worsened by the assumption that isolation is a purely spatial issue.Ventilation and filtration mitigation strategies are already common in spaces with a high risk of contaminant spread, such as hospitals and labs, however, their active use in preventing the spread of infectious diseases in residential spaces is less common. Recognition of the airborne nature of the Covid-19 virus strengthened the importance of focusing on indoor air quality and airflow management to hinder the spread of the virus while designing a flexible space for living and isolation.

While working parallel to the ever-changing information about Covid-19, an analysis of domiciliary Covid-19 mitigation strategies, and a discussion of overcrowding, tower renewal, and air quality in relation to health narrowed the scope of research to exploring how the retrofit of postwar towers can improve occupant health and well-being. This thesis expands upon the agenda of the Tower Renewal Partnership with a postwar tower retrofit that incorporates flexible living spaces within units while prioritizing occupant physical and mental health through a focus on air quality and management to decrease occupant vulnerability to the spread of infectious disease. The versatile components of the retrofit design allow for ease of application across Toronto's postwar tower stock and thereby provide over half a million people with strategies to maintain good indoor air quality and improve occupant health.

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INTRODUCTION

This section presents a brief exploration of the historical relationship between architecture and the prevention of disease transmission to establish the relevance of discussing infectious disease spread mitigation through an architectural lens.

HISTORICAL CONTEXT

4000 BC – AD 300

Architecture has a historical role in creating spaces for isolation in the prevention of disease transmission. It began with a spatial focus on physically isolating infected people and contaminants.[1] Hippocrates rejected the trusted supernatural explanations for disease spread and considered that human behaviour and their surrounding environment influenced the spread of diseases.[2] Some ancient civilizations believed water quality affected health and they developed sewerage systems that ensured a spatial separation between wastewater and source water.[3] The ancient Romans built sophisticated thermal bath complexes to serve their hygiene-conscious societies.[4]

[1] Bogdan A. Fezi, "Health Engaged Architecture in the Context of Covid-19," *Journal of Green Building* 15, no. 2 (2020): 186, https://doi.org/10.3992/1943-4618.15.2.185.
[2] "Lesson 1: Introduction to Epidemiology," Centers for Disease Control and Prevention, last modified May 18, 2012, https://www.cdc.gov/csels/dsepd/ss1978/lesson1/section2.html.
[3] Stavros Yannopoulos, Christos Yapijakis, M. Kaiafa-Saropoulou, Georgios P. Antoniou, and A. Angelakis, "History of sanitation and hygiene technologies in the Hellenic World," *Journal of Water, Sanitation and Hygiene for Development* 7, no. 2 (February 2017): 166, https://doi.org/ 10.2166/was hdev.2017.178.
[4] Yannopoulos, Yapijakis, Kaiafa-Saropoulou, Antoniou, and Angelakis, "History of sanitation," 173.

In *The 10 Books on Architecture*, Vitruvius includes his thoughts on the relationship between air and disease. An exhausted patient would be further worn by wind or air that is in "constant agitation".[5] However,

> "a mild, thick air, without draughts and not constantly blowing back and forth, builds up their frames by its unwavering steadiness, and so strengthens and restores people who are afflicted with these diseases."[6]

This quotation shows the effects of air on health were considered in early architectural discourse.[7]

300 - 1700

In the Middle Ages, religion took precedence over science and spatial isolation became the main form of protection against rapid disease-spread as the sanitary infrastructure developed by the ancients was overlooked.[8] Entire buildings dedicated to the act of quarantine, such as leprosaria and lazaretti, were constructed to fight the frequent pandemics of this period. Often located on the outskirts of cities, these buildings isolated the infected patients from the rest of the population.[9]

1700 - 1900

In the 1700s, the growing awareness about the relationship between good health and fresh air was influenced by the observations made by army doctors working in drafty, makeshift shelters. Compared to those treated in the monumental, crowded hospitals, patients seemed to heal more often in the makeshift shelters.[10] By the end of the century, cross ventilation became a key component in the design of healthy hospitals,[11] providing "walls of fresh air"[12] on either side of of patients to separate them.[13]

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[5] Vitruvius, *The Ten Books on Architecture* (New York: Dover Publications, Inc., 1960), 25.
[6] Ibid, 26.
[7] Ibid, 25-26.
[8] Yannopoulos, Yapijakis, Kaiafa-Saropoulou, Antoniou, and Angelakis, "History of sanitation," 174.
[9] David Garcia, "Distant space: the architecture of quarantine," The Architectural Review, June 8, 2020, https://www.architectural-review.com/buildings/health/distant-space-the-architecture-of-quarantine.
[10] Robert Jan van Pelt, class lecture, ARCH 540 Temporary Architecture, University of Waterloo School of Architecture, Cambridge, ON, Fall 2020.
[11] Ibid.
[12] Jeanne Kisacky, "Restructuring Isolation: Hospital Architecture, Medicine, and Disease Prevention," *Bulletin of the History of Medicine* 17, no. 1 (2005): 8, https://www.jstor.org/stable/44448152.

Early mechanical ventilation systems also emerged in the 1700s for use in spaces not well suited for natural ventilation, such as cramped navy ships, prisons, and hospitals, where diseases spread like wildfire.[14] Renovations to the New York Hospital in the late 1800s saw the invisible walls provided by natural cross ventilation created artificially by a mechanical ventilation system. With exhaust and supply ducts attributed to each patient bed, it was the goal of the system to provide "individual, distinct, isolating "rooms" of pure air around each patient in a ward".[15]

1900 - Present

The need to separate patients with air was transformed in the tuberculosis sanatoria of the mid-1900s where large outdoor porches allowed patients to rest and recover in the fresh air.[16] This health-driven design strategy was echoed within residential spaces. After the invention of the mosquito net proved the night air did not cause malaria, sleeping outside in porches enclosed in screens became a common practice.[17]

A boom in technology during the twentieth century saw the rapid development of mechanical heating, ventilation, and air conditioning (HVAC) systems.[18] Modern knowledge of airborne contaminant spread[19] strengthens the importance of maintaining good air quality. In spaces where the risk of contaminant spread is high, like hospitals and labs, advanced environmental system strategies such as air filtration, and room pressurization are integral to the design of those buildings.[20] The ability of these strategies to improve indoor air quality should not be overlooked in residential spaces[21]

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[13] Kisacky, "Restructuring Isolation," 8.
[14] van Pelt, ARCH 540 Temporary Architecture, Fall 2020.
[15] Kisacky, "Restructuring Isolation," 30.
[16] Jonathan Ore, "How the pandemic has put building design and ventilation back into the public health conversation," CBC, October 30, 2020, https://www.cbc.ca/radio/spark/how-the-pandemic-put-building-design-and-ventilation-back-into-the-public-health-conversation-1.5783970.
[17] Charlie Hailey, "From Sleeping Porch to Sleeping Machine: Inverting Traditions of Fresh Air in North America," *Traditional Dwellings and Settlements Review* 20, no. 2 (2009): 29, https://www.jstor.org/stable/41758699.
[18] Reyner Banham, *The Architecture of the Well-Tempered Environment* (University of Chicago Press, 1984).
[19] Public Health Ontario, *COVID-19 Transmission Through Large Respiratory Droplets and Aerosols… What We Know So Far* (Toronto, ON: Public Health Ontario, 2021), accessed September 13, 2021, https://www.publichealthontario.ca/-/media/documents/ncov/covid-wwksf/2021/05/wwksf-transmission-respiratory-aerosols.pdf?la=en.
[20] S. Al-Rajhi, M. Ramaswamy, and F. Al-Jahwari, *IAQ in Hospitals – Better Health through Indoor Air Quality Awareness* (Texas A&M University: 2010), accessed December 31, 2021, https://oaktrust.library.tamu.edu/handle/1969.1/94139.
[21] Naglaa A. Megahed, and Ehab M. Ghoneim, "Indoor Air Quality: Rethinking rules of building design strategies in post-pandemic architecture," *Environmental Research* 193, (February 2021): 7, https://doi.org/ 10.1016/j.envres.2020.110471.

where a reliance on modern medicine to protect against the spread of illness,[22] sparked by the popularization of antibiotics,[23] remains.

THESIS STRUCTURE

The intertwined historical relationship between architecture and medical science, as briefly explored in this introduction, promoted the question of how the current pandemic will influence architectural design. An exploration into architecture's present-day role in the prevention of infectious disease spread began. A specific problem emerged as research progressed: Poor indoor air quality and lack of space for adequate isolation within postwar towers increase the risk of negative effects on resident health leaving them more vulnerable to infectious diseases. This thesis tackles the problem and the resulting work is presented in four parts.

Part One: Scope

outlines and contextualizes the thesis problem within the City of Toronto. A discussion of factors contributing to health inequality during the Covid-19 pandemic leads to the identification of a project site.

Part Two: Method

documents the graphic style transformation as it evolved parallel to the ever-changing knowledge of the Covid-19 virus. A transition from a focus on physical barriers to an emphasis on the complexity of both drawing and mitigating the spread of an airborne virus is illustrated.

Part Three: Design

uses the final iteration of the graphics exploration to address the thesis problem in a postwar tower retrofit design proposal.

Part Four: Impacts

demonstrates the versatility of the design proposal through its superposition on an existing postwar tower retrofit plan and argues for the prioritization of occupant health in design.

CONCLUSION

The Covid-19 pandemic is a strong reminder of the fragility of urban civilizations in situations where the medical response is not instantaneous. As evidenced by the long standing relationship between architecture and medical science, architecture has a role in the prevention of infectious disease spread.

[22] Sarah Zhang, "We're Just Rediscovering a 19th-Century Pandemic Strategy," *The Atlantic*, February 22, 2021, https://www.theatlantic.com/health/archive/2021/02/bad-air/618106/.
[23] Fezi, "Health Engaged Architecture," 191.

PART ONE: SCOPE

The Problem

Covid-19

Opportunity: Tower Renewal Partnership

Air Pollution

INTRODUCTION

This section introduces the thesis problem and contextualizes it within the City of Toronto. The uneven distribution of Covid-19 cases in Toronto as illustrated in a frequently updated Covid-19 case rate map leads to a focus on residential spaces as sites of concern.[24] A discussion of overcrowding, tower renewal, and air quality in relation to health narrows the scope of research to exploring how the retrofit of postwar towers can improve occupant health and well-being.

THE PROBLEM

Poor indoor air quality and lack of space for adequate isolation within postwar towers increase the risk of negative effects on resident health leaving them more vulnerable to infectious diseases.

COVID-19

Unequal Vulnerability

> "The difficulties in mitigating COVID-19 are a reminder that cities still await urban planning and public health to, in unison, address the health disparities and class inequalities of the urban environment."[25]

[24] "Covid-19: Neighbourhood Maps," City of Toronto, last updated 2022, https://www.toronto.ca/home/covid-19/covid-19-pandemic-data/covid-19-neighbourhood-maps-data/.
[25] Kara Murphy Schlichting, and Melanie A. Kiechle, "Invisible Inequalities: Persistent Health Threats in the Urban Built Environment," *Journal for the History of Environment and Society* 5, (2020): 166, https://doi.org/ 10.1484/J.JHES.5.122472.

Due to a complex network of inequalities, portions of the population are more vulnerable than others during the Covid-19 pandemic. Individual health is influenced by factors including age, occupation, financial status, and place of residence.[26] Those who are older, notably 60 years or older, tend to be at a higher risk of serious infection.[27] Underlying medical conditions and compromised immune systems lead to increased risk.[28] Members of BIPOC (Black, Indigenous, and People of Colour) communities might be denied proper medical care.[29] Essential workers unable to work from home face an increased chance of exposure to viruses.[30] Households with school-age children who participate in in-person learning face a higher risk of bringing viruses into the home.[31] Lastly, an important factor for this thesis, people residing in overcrowded living situations are at greater risk of infection due to the limited ability to self-isolate.[32]

Overcrowding

The negative health implications of overcrowding pre-date the Covid-19 pandemic.[33] A study of place of residence in relation to tuberculosis transmission reveals ‘“The tuberculosis mortality is proportional to the housing density; the danger of infection is all the greater when the residents are more cramped in their housings.”’[34] Living in close quarters with limited personal space provides an excellent breeding ground for bacteria and viruses, promoting the rapid spread of infectious illnesses through these spaces.[35] The Covid-19 pandemic reinforced this ease of disease-spread: “The evidence in Toronto is clear: overcrowded housing is

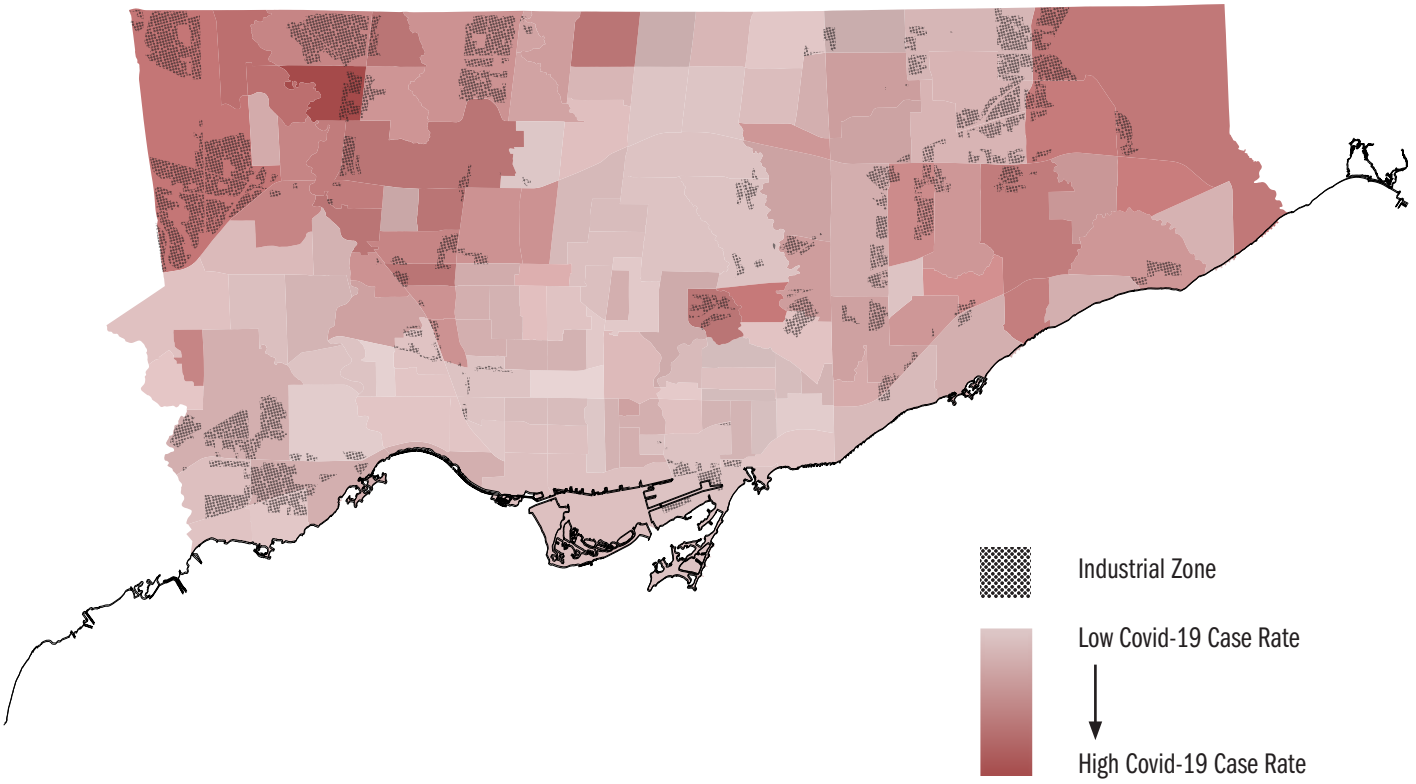
[26] “Vulnerable Populations and COVID-19,” Government of Canada, last modified October 2, 2020, accessed March 1, 2021, https://www.canada.ca/en/public-health/services/publications/diseases-conditions/vulnerable-populations-covid-19.html.
[27] Ibid.
[28] Ibid.
[29] Whitney N. Laster Pirtle, “Racial Capitalism: A Fundamental Cause of Novel Coronavirus (COVID-19) Pandemic Inequities in the United States,” *Health Education & Behaviour* 47, no. 4 (April 26, 2020): 505, https://doi.org/ 10.1177/1090198120922942.
[30] Government of Canada, “Vulnerable Populations and COVID-19.”
[31] Nancy Schimelpfeng, “Kids Are Getting COVID-19 at School and Spreading It to Families,” *Healthline*, last modified September 24, 2020, https://www.healthline.com/health-news/kids-are-getting-covid-19-at-school-and-spreading-it-to-families.
[32] Stephanie Elliot, and Scott Leon, “Crowded housing and COVID-19: Impacts and solutions,” *Wellesley Institute*, last modified July 24, 2020, https://www.wellesleyinstitute.com/housing/crowded-housing-and-covid-19-impacts-and-solutions/.
[33] James Krieger, and Donna L. Higgins, “Housing and Health: Time Again for Public Health Action,” *American Journal of Public Health* 92, no. 5 (May 2002): 758, https://doi.org/10.2105/ajph.92.5.758.
[34] Fezi, “Health Engaged Architecture,” 190.
[35] Elliot, and Leon, “Crowded housing and COVID-19.”

associated with increased Covid-19 infection rate."[36] The ability to self-isolate and maintain physical separation to prevent the spread of viruses is limited in homes where occupants outnumber rooms. Furthermore, in the wake of the pandemic, working from home may remain a more common practice[37] and a lack of adequate space to live, work, and relax can have adverse effects on mental health.[38]

Covid-19 in Toronto

It would be near impossible to propose a solution that addresses every factor associated with increased vulnerability. The research scope was narrowed through a study of the uneven distribution of Covid-19 case rates throughout Toronto shown in a frequently updated neighbourhood map.[39] Patterns connecting the high-risk neighbourhoods were identified during a comparison between the case-rate map and neighbourhood demographic data made available by the 2016 census. The high-risk neighbourhoods tend to be located near industrial zones, have low incomes, and house a high percentage of visible minorities.[40] Many of the neighbourhood buildings were constructed in the 1960s and 1980s[41] and, made worse by declining income rates and increases in rent, they are overcrowded and falling to disrepair.[42] This comparison reveals that place of residence has an impact on vulnerability. People living in older, poorly maintained buildings in less desirable locations are at a higher risk of falling ill.

[36] Elliot, and Leon, "Crowded housing and COVID-19."
[37] Tahsin Mehdi, and René Morissette, "Working from home: Productivity and preferences," Statistics Canada, last modified April 1, 2021, accessed January 1, 2022, https://www150.statcan.gc.ca/n1/pub/45-28-0001/2021001/article/00012-eng.htm.
[38] Elliot, and Leon, "Crowded housing and COVID-19."
[39] City of Toronto, "Covid-19: Neighbourhood Maps."
[40] "Neighbourhood Profiles," City of Toronto, last modified 2021, accessed November 30, 2020, https://www.toronto.ca/city-government/data-research-maps/neighbourhoods-communities/neighbourhood-profiles/.
[41] Ibid.
[42] Susan MacDonnell, Jamie Robinson, Vladimir Mikadze, Laura McDonough, and Alan Meisner, *Poverty by Postal Code 2: Vertical Poverty* (United Way Toronto, January 2011), 43, https://www.unitedwaygt.org/document.doc?id=89.



[Fig.01] Industrial zones and neighbourhood Covid-19 case rates in Toronto, ON.

Residential Architecture Preventing Infectious Disease Spread

General thoughts surrounding concepts like spatial organization, density, and ventilation were put forward in architectural discourse when considering the influence of the Covid-19 pandemic on reshaping residential spaces.[43] With a nod to the mid-1900s tuberculosis sanatoria, ventilation became important while investigating the movement of Covid-19 aerosols.[44] The need for residential spaces to become more flexible and be able to transform in response to sudden environmental changes grew with homes being expected to accommodate a wider variety of activities from work, relaxation, recreation, and isolation.[45] In a move away from open plan designs, consideration to provide distinct delivery spaces, decontamination spaces, and space for self-isolation emerged.[46] The incorporation of increased storage[47] and more partitions are expected to be of interest to potential buyers.[48]

It is not enough to only focus on the transformation of new residential constructions. The retrofit of existing residential spaces, especially affordable and rental housing, into spaces that prioritize occupant health would allow people to reap the benefits of any potential improvements without losing their homes.[49] In addition to the health-related benefits, compared to demolition and complete reconstruction, retrofitting postwar towers has lower cost and lower carbon impacts.[50]

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[43] Duncan Nielsen, "17 Architects and Designers on How the Pandemic Will Change Our Homes Forever," Dwell, last modified April 6, 2020, accessed February 26, 2021, https://www.dwell.com/article/architects-say-coronavirus-covid-19-pandemic-will-change-home-design-ee29c873.

[44] Ore, "How the pandemic has put building design and ventilation back into the public health conversation."

[45] Daniela D'Alessandro, Marco Gola, Letizia Appolloni, Marco Dettori, Gaetano Maria Fara, Andrea Rebecchi, Gaetano Settimo, and Stefano Capolongo, "COVID-19 and Living space challenge. Well-being and Public Health recommendations for a healthy, safe, and sustainable housing," *Acta Biomedica* 91, no. 9-S (July 20, 2020): 64-65, https://doi.org/10.23750/abm.v91i9-S.10115.

[46] Dirk HR Spennemann, "Residential Architecture in a Post-Pandemic World: Implications of Covid-19 for New Construction and for Adapting Heritage Buildings," *Journal of Green Building* 16, no. 1 (February 15, 2021): 199-215, https://doi.org/10.3992/jgb.16.1.199.

[47] Jeffrey Steele, "Five Architects Sketch Views On Post-Pandemic Residential Design," *Forbes*, May 16, 2020, https://www.forbes.com/sites/jeffsteele/2020/05/16/five-architects-sketch-views-on-post-pandemic-future-of-residential-design/?sh&&sh=daff03076751#61;6f46bd3a7675.

[48] Nielsen, "17 Architects and Designers on How the Pandemic Will Change Our Homes Forever."

[49] Tower Renewal Partnership, *Ken Soble Tower Transformation: A Case Study in Deep Retrofit and Housing Renewal*, (Toronto, ON: Tower Renewal Partnership, 2020), 16.

[50] Tower Renewal Partnership, *Ken Soble Tower Transformation*, 54.

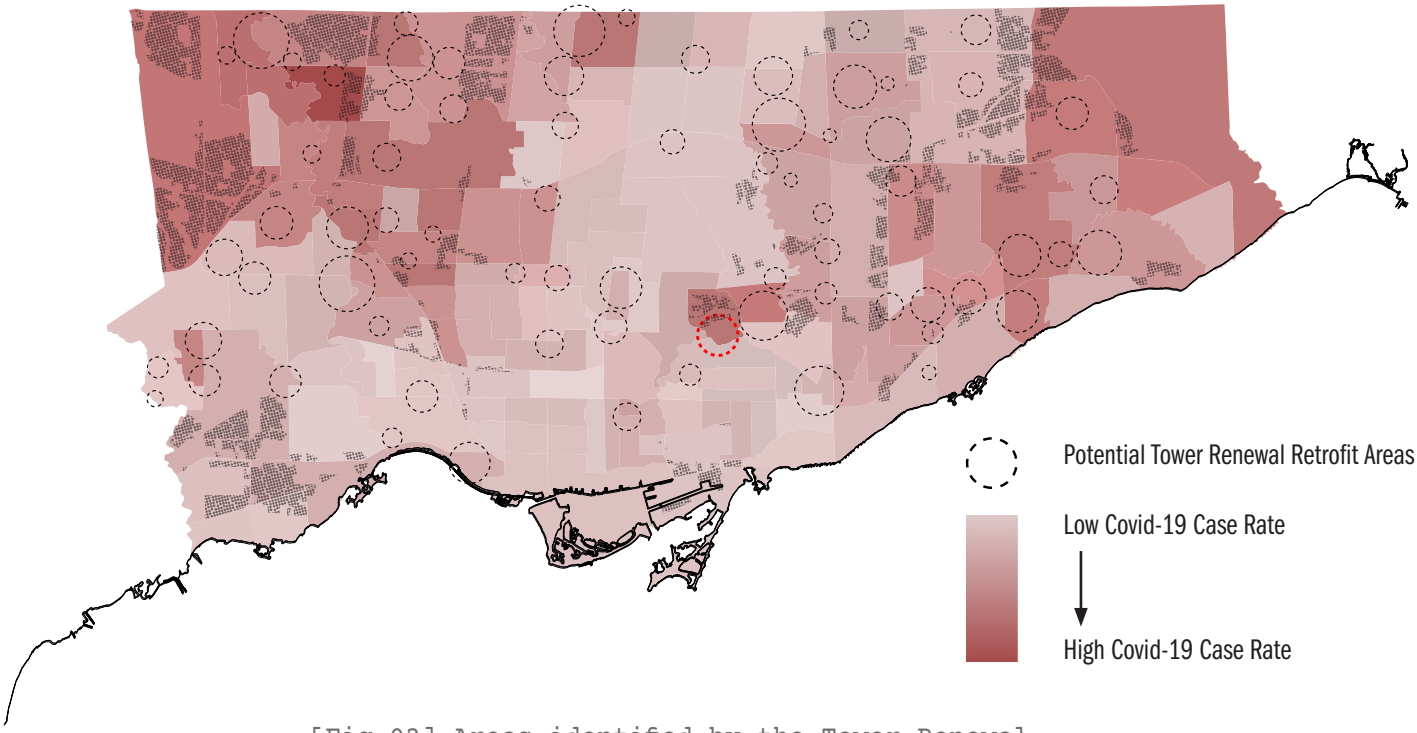
OPPORTUNITY: TOWER RENEWAL PARTNERSHIP

The need to preserve and restore existing residential buildings existed before the pandemic. The Tower Renewal Partnership was introduced over ten years ago to address the decline of the postwar towers and extend their lifespan while transforming them into healthy spaces to live in.[51] It is estimated there are over 1000 postwar, concrete towers in Toronto[52] housing more than half a million residents. The iconic towers make up a significant portion of the city's rental and affordable housing, however, at over 50 years old, they are far past their prime.[53]

Reports published by the Tower Renewal Partnership presents possible solutions to improve both the quality of living for the residents and the energy performance of the buildings.[54] Three under-performing areas are often explored (the building envelope, the ventilation and HVAC systems, and thermal bridging) in the development of standardized solutions to be applied to multiple buildings to revitalize the entire postwar tower landscape.[55]

A return to the neighbourhood case rate map shows that the potential retrofit areas identified by the Tower Renewal Partnership are often located in neighbourhoods with high Covid-19 case rates.[56] This is not surprising since, as stated previously, many of the buildings in the high-risk neighbourhoods were constructed between the 1960s and 1980s.[57] This connection supports the decision to explore the retrofit of an ageing postwar tower in this thesis.

[51] Ya'el Santopinto, and Graeme Stewart, "Pandemic effect: Housing retrofits," *Canadian Architect*, last modified August 3, 2020, accessed August 17, 2021, https://www.canadianarchitect.com/pandemic-effect-housing-retrofits/.
[52] Rob Jowett, "Retrofit Ambitions," *Novae Res Urbis Toronto*, July 23, 2021, 2, https://www.eraarch.ca/wp/wp-content/uploads/2021/08/RetrofitAmbitions_RobJowett_NRU210723.pdf.
[53] Tower Renewal Partnership, *Thermal Comfort & Cooling in Apartment Towers*, (Toronto, ON: Tower Renewal Partnership, May 2017), 3.
[54] Tower Renewal Partnership, *Understanding the Tower Landscape*, (Toronto, ON: Tower Renewal Partnership, December 2016), 2.
[55] Tower Renewal Partnership, *Advancing Building Retrofits*, (Toronto, ON: Tower Renewal Partnership, January 2020), 13.
[56] "The Tower Renewal Project," ERA Architects, accessed August 19, 2021, https://www.eraarch.ca/project/the-tower-renewal-project/.
[57] City of Toronto, "Neighbourhood Profiles."



[Fig.02] Areas identified by the Tower Renewal Partnership for potential renewal in relation to neighbourhood Covid-19 case rates in Toronto, ON.

Existing Postwar Tower Air Quality

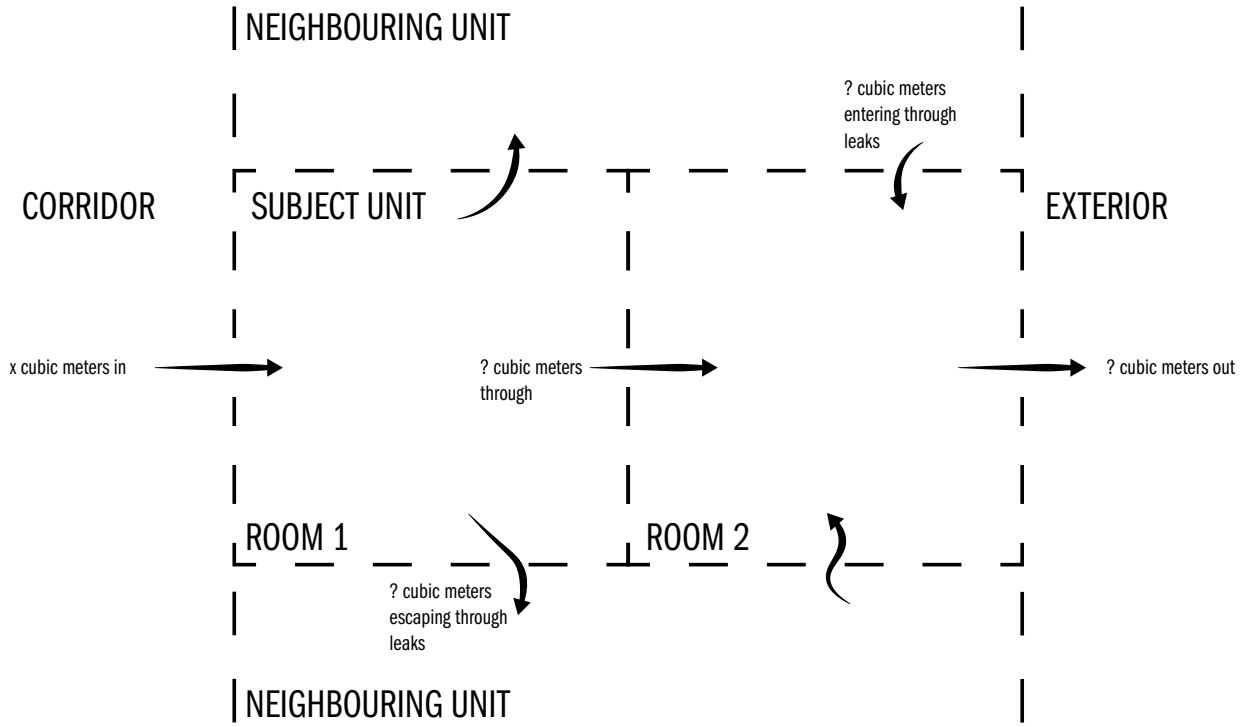
The Tower Renewal Partnership originated from concerns around greenhouse gas emissions and the social-driven desire for investment within the communities. However, throughout the Covid-19 pandemic, the apparent unequal access to a healthy home shifted the focus of the partnership to prioritize the goal of providing healthy housing.[58] Current health-related concerns within the postwar towers include poor indoor air quality.[59]

The postwar towers in their existing state are often fitted with centralized HVAC systems that utilize corridor pressurization to provide units with supply air.[60] These older systems need upgrading as the supply air provided to each unit through the corridor is insufficient and wasteful.[61] Supplementing the lack

[58] Santopinto, and Stewart, "Pandemic effect: Housing retrofits."
[59] Tower Renewal Partnership, *Advancing Building Retrofits*, 19.
[60] Ibid, 21.
[61] Ibid, 21.

of mechanical supply air with natural ventilation is unreliable in many postwar towers as most windows cannot open wide enough to provide sufficient ventilation for entire units.[62]

A lack of recent envelope upgrades supports the likelihood of leaky envelopes in the postwar towers.[63] It is assumed that the units are equipped with exhaust fans in the kitchen and bathrooms and when the fans are running, make-up air must be introduced to the units.[64] Without an airtight envelope, this air may be pulled from neighbouring units through the leaks in the unit envelopes or pulled under the front doors from the hallway and risks the unwanted spread of airborne contaminants.[65]



[Fig.03] Leaky unit with air permeable partition diagram.

[62] Tower Renewal Partnership, *Advancing Building Retrofits*, 22.
[63] Tower Renewal Partnership, *Thermal Comfort & Cooling in Apartment Towers*, 4.
[64] Joseph Lstiburek, *BA-1507: Measure Guideline: Ventilation Guidance for Residential High Performance New Construction – Multifamily*, (Building Science Corporation, September 16, 2015), 15.
[65] Tower Renewal Partnership, *Advancing Building Retrofits*, 21.

AIR POLLUTION

Concerns around indoor air quality extend beyond the discussion of airborne disease transmission. Air pollution is the fifth-highest risk of mortality worldwide and the 11th risk in Canada.[66] Air pollution causes a variety of health problems.[67] Some, like Sick Building Syndrome,[68] are short-term with effects such as headache, fatigue, and nose, eyes, and throat irritation. Other long-term effects are more serious and cause damage to organs such as the heart, lungs, and brain. Heart attacks, COPD, and an increased risk of stroke are a few examples of these serious conditions.[69] In 2016, 15,300 Canadian deaths were credited to air pollution, and it was calculated that there were 35 million acute respiratory symptom days and 2.7 million asthma symptom days throughout the year.[70]

The average person remains indoors approximately 90% of the time.[71] People living with poor indoor air quality, such as those living in ageing postwar towers, are at a higher risk of negative health conditions[72] and therefore, in the case of an event like the Covid-19 pandemic, are more vulnerable to the spread of disease due to the presence of underlying medical conditions.[73]

Poor indoor air quality affects mental health and has negative impacts on productivity and comfort.[74] This is often seen in studies involving the air quality of office spaces[75] and

SHORT TERM

TIREDNESS/HEADACHE
DIZZINESS
COUGHING/SNEEZING
DIFFICULTY BREATHING
INCREASED MUCOUS
DRY/IRRITATED EYES, NOSE, THROAT, AND SKIN (SICK BUILDING SYNDROME INCLUDED)

LONG TERM EFFECTS

ASTHMA
ALLERGIES
COPD
LEGIONNAIRE'S DISEASE

ANGINA
ARRHYTHMIA
HEART ATTACK
HEART FAILURE
HYPERTENSION

INCREASED RISK OF STROKE

[Fig.04] Health problems related to air pollution.

[66] Health Canada, *Health Impacts of Air Pollution in Canada: Estimates of premature deaths and nonfatal outcomes*, (Ottawa, ON: Health Canada, March 2021), https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/2021-health-effects-indoor-air-pollution/hia-report-eng.pdf.
[67] "Health effects of air pollution," Government of Canada, last modified 2021, accessed November 21, 2021, https://www.canada.ca/en/health-canada/services/air-quality/health-effects-indoor-air-pollution.html.
[68] Sumedha M. Joshi, "The sick building syndrome," *Indian Journal of Occupational & Environmental Medicine* 12, no. 2 (August 2008): 61-64, https://doi.org/10.4103/0019-5278.43262.
[69] Government of Canada, "Health effects of air pollution."
[70] Health Canada, *Health Impacts of Air Pollution in Canada.*
[71] Frank J. Kelly, and Julia C. Fussell, "Improving indoor air quality, health and performance within environments where people live, travel, learn and work," *Atmospheric Environment* 200, (December 2018): 90, https://doi.org/10.1016/j.atmosenv.2018.11.058.
[72] MacDonnell, Robinson, Mikadze, McDonough, and Meisner, *Poverty by Postal Code 2: Vertical Poverty*, 62.
[73] Government of Canada, "Vulnerable Populations and COVID-19."
[74] Megahed, and Ghoneim, "Indoor Air Quality," 2.
[75] Kelly, and Fussell, "Improving indoor air quality, health and performance," 105.

schools,[76] however similar effects would be present in residential spaces. The assumption that working from home will remain more common post-pandemic[77] reinforces the validity of superimposing office space concerns about indoor air quality onto residential spaces.

Air pollution will increase amid the changing climate.[78] As air pollution increases, the risk of negative health outcomes increases.[79] More people will experience noticeable effects of air pollution and therefore concern for the quality of air within occupied spaces will increase.[80] Good indoor air quality should be an essential in residential spaces.[81] The provision of clean air prioritizes the general health of occupants and reduces their vulnerability to illness in times of emergency, like the Covid-19 pandemic.[82]

Passive Air Filtration to Combat Air Pollution

> "…providing ventilation air through windows does not enable the removal of exterior air contaminants, as a mechanical system with filtration would."[83]

Energy consumption concerns have led to the resurgence of passive strategies for architectural functions such as heating, cooling, and ventilating.[84] Air pollution, mentioned above as a growing concern with climate change, has the potential to undermine the benefits of natural ventilation by bringing

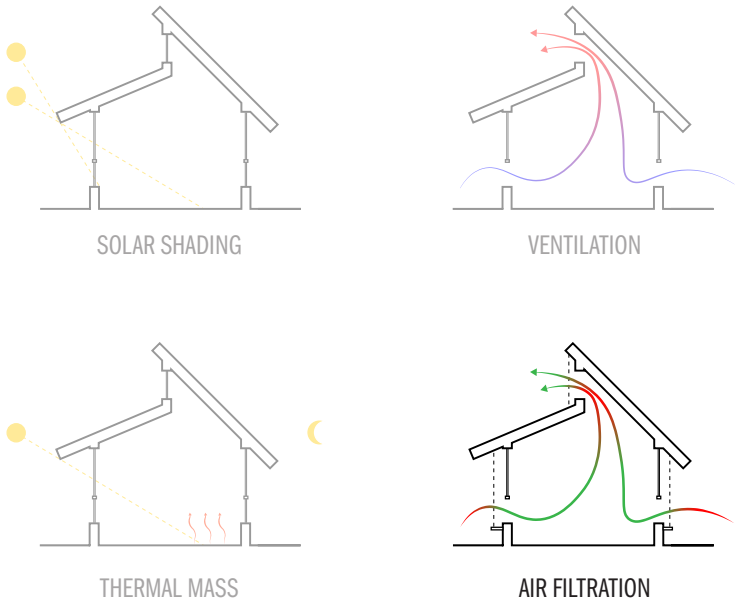
[76] Alessandra Cincinelli, and Tania Martellini, "Indoor Air Quality and Health," *International Journal of Environmental Research and Public Health* 14, no. 11 (October 2017), 3, https://doi.org/10.3390/ijerph14111286.
[77] Mehdi, and Morissette, "Working from home."
[78] Neal Fann, Terry Brennan, Patrick Dolwick, Janet L. Gamble, Vito Ilacqua, Laura Kolb, Christopher G. Nolte, Tanya L. Spero, and Lewis Ziska, "Chapter 3: Air Quality Impacts," *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, (2016), https://health2016.globalchange.gov/air-quality-impacts.
[79] Health Canada, *Health Impacts of Air Pollution in Canada*.
[80] "Indoor Air Quality: Everything You Need to Know and More," Gateway Mechanical Services, last modified May 31, 2021, accessed September 2, 2021, https://gatewaymechanical.ca/indoor-air-quality-guide/.
[81] Megahed, and Ghoneim, "Indoor Air Quality," 7.
[82] Ibid., 6.
[83] BC Housing, *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*, (Burnaby, BC: BC Housing, 2015), 6, https://www.bchousing.org/research-centre/library/residential-design-construction/heat-recovery-ventilation-guide-murbs.
[84] Benjamin Duraković, "Passive Solar Heating/Cooling Strategies," in *PCM-Based Building Envelope Systems: Innovative Energy Solutions for Passive Design*, (Cham: Springer International Publishing, 2020), 39.

[Fig.05] Wildfire smoke over San Francisco.

[Fig.06] City Smog in Thailand.

[Fig.07] Highway traffic burning fossil fuels.

outdoor pollution into the home.[85] Though currently requiring more development to be established as a common passive strategy, the concept of passive air filtration may have the potential to address this issue if further explored.



[Fig.8] The potential inclusion of air filtration among the established passive strategies.

Though the current non-mechanical air filtration technologies require more development before its usage becomes common, a few early precedents have emerged.[86] Algae is being explored as a method of biofiltration with the plants transforming carbon dioxide into oxygen.[87] A product called BreatheBrick explores the use of a cyclone filtration system within masonry modules to remove large particles like dirt and dust from the air.[88] On a building in Mexico, a façade installation with a photocatalytic coating of titanium dioxide works to remove nitrogen oxide pollution from the air leaving behind calcium nitrates, water, and traces of carbon dioxide.[89]

[85] Megahed, and Ghoneim, "Indoor Air Quality," 3.
[86] Ibid., 5.
[87] "Photo.Synthetica Curtain," ecoLogicStudio, accessed September 21, 2021, https://www.ecologicstudio.com/projects/photo-synth-etica.
[88] Fathima Shirin, and Anjana Jayakumar, "Breathe Brick," International Research Journal of Engineering and Technology (IRJET) 7, no. 4 (April 2020), https://www.irjet.net/archives/V7/i4/IRJET-V7I4523.pdf.
[89] "How It Works," prosolve370e, accessed September 2021, http://www.prosolve370e.com/how-it-works-1.

A team of researchers are developing a façade textile coated with a photocatalytic chemical to allow entire buildings to be wrapped and become air cleaners while maintaining visibility from windows.[90]

Most of the precedents propose ways to clean the outdoor environment and address the issue of pollution caused by the burning of fossil fuels. Therefore, their use would likely only be beneficial in select situations. If the technology for passive air filtration was developed further to incorporate a wider range of contaminants, such as volatile organic compounds and viruses, this thesis speculates the potential incorporation of a passive air filtration product within residential spaces would improve indoor air quality and decrease reliance on active filtration systems. Inspired by the existing precedents while understanding the required future development, the thesis design proposal imagines how passive air filtration, should it be proved to be effective, might be incorporated in a retrofit plan.

CONCLUSION

A complex network of inequalities has left portions of the population more vulnerable than others during the Covid-19 pandemic. The uneven distribution of Covid-19 case rates throughout Toronto[91] supports the idea that place of residence impacts vulnerability.

Poor indoor air quality and lack of space for adequate isolation within postwar towers increase the risk of negative effects on resident health which renders them more vulnerable to infectious diseases.

This thesis extends from the agenda of the Tower Renewal Partnership with a proposal to retrofit postwar towers to incorporate flexible living spaces within units that prioritize occupant physical and mental health through a focus on air quality and management and decrease occupant vulnerability to the spread of infectious disease.

[90] Hildegard Suntinger, “Textile facades on buildings filter harmful pollutants from the air,” Innovation Origins, last modified October 29, 2020, accessed September 2021, https://innovationorigins.com/en/textile-facades-on-buildings-filter-pollutants-from-the-air/.
[91] City of Toronto, “Covid-19: Neighbourhood Maps.”

PART TWO: METHOD

September 2020 to March 2021: Exploring Isolation
April to July 2021: An Airborne Virus
August to November 2021: Air Quality and Management

INTRODUCTION

This thesis was conducted over the course of the Covid-19 pandemic. The world attempted to get ahead of the novel virus while confronted with almost daily updates "about the virus, how it behaves, and the best strategies for dealing with it."[92] The information surrounding the subject was ever-changing and as a result, the research and the corresponding graphic representations evolved parallel to the knowledge of Covid-19 transmission. This chapter delves into this evolution tracing the transformation of considering isolation a purely spatial problem to understanding it as a more complex system involving spatial and environmental components.

SEPTEMBER 2020 TO MARCH 2021:

Exploring Isolation

Covid-19: The established Covid-19 mitigation methods focus on 2m physical separation and intensification of hygienic practices

Thesis: Considers the spatial impacts of the 2m radius and various moments of human interaction.

Graphic Representation: Focuses on the physical barrier, the bubble, and the movement of individual people through space.

[92] Megahed, and Ghoneim, "Indoor Air Quality," 2.

Categories of Isolation

Two categories of isolation are outlined in a paper by Jeanne Kisacky: spatial isolation which relies "on building design and detail to create a physically distinct space"[93] to contain contaminants, and procedural isolation which relies on "ordered hygienic regulations, activities and responsibilities"[94] that help prevent people from spreading contaminants.[95]

The two categories emerged from a historical analysis of the development of architectural design and isolation practices of the New York Hospital as motivated by the evolving understanding of infectious disease transmission. Established in the eighteenth century as a "self-purifying container of light and air"[96] built isolated on the outskirts of the city, the hospital transformed over the following century and a half to facilitate an isolation "system of physical barriers and elaborate rules to control the physical interaction of people and things."[97]

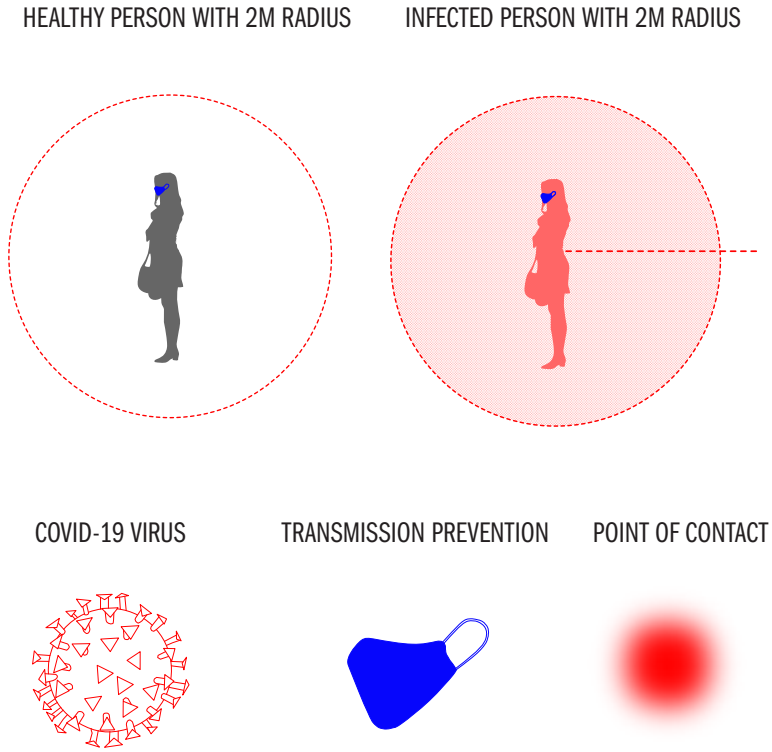
Authorities around the world, including the Government of Canada, have recommended isolation strategies belonging to both categories during the current pandemic. For example, dedicating a room within a house to isolating an infected person could be categorized as spatial isolation while wearing a mask and increasing the disinfection of hands and high-touch surfaces could be categorized as procedural isolation.[98]

[93] Kisacky, "Restructuring Isolation," 20.
[94] Ibid, 20.
[95] Ibid, 20.
[96] Ibid, 46.
[97] Ibid, 46.
[98] "Coronavirus disease (COVID-19): Prevention and risks," Government of Canada, last modified February 26, 2021, accessed March 1, 2021, https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/prevention-risks.html.

A Note on Graphics

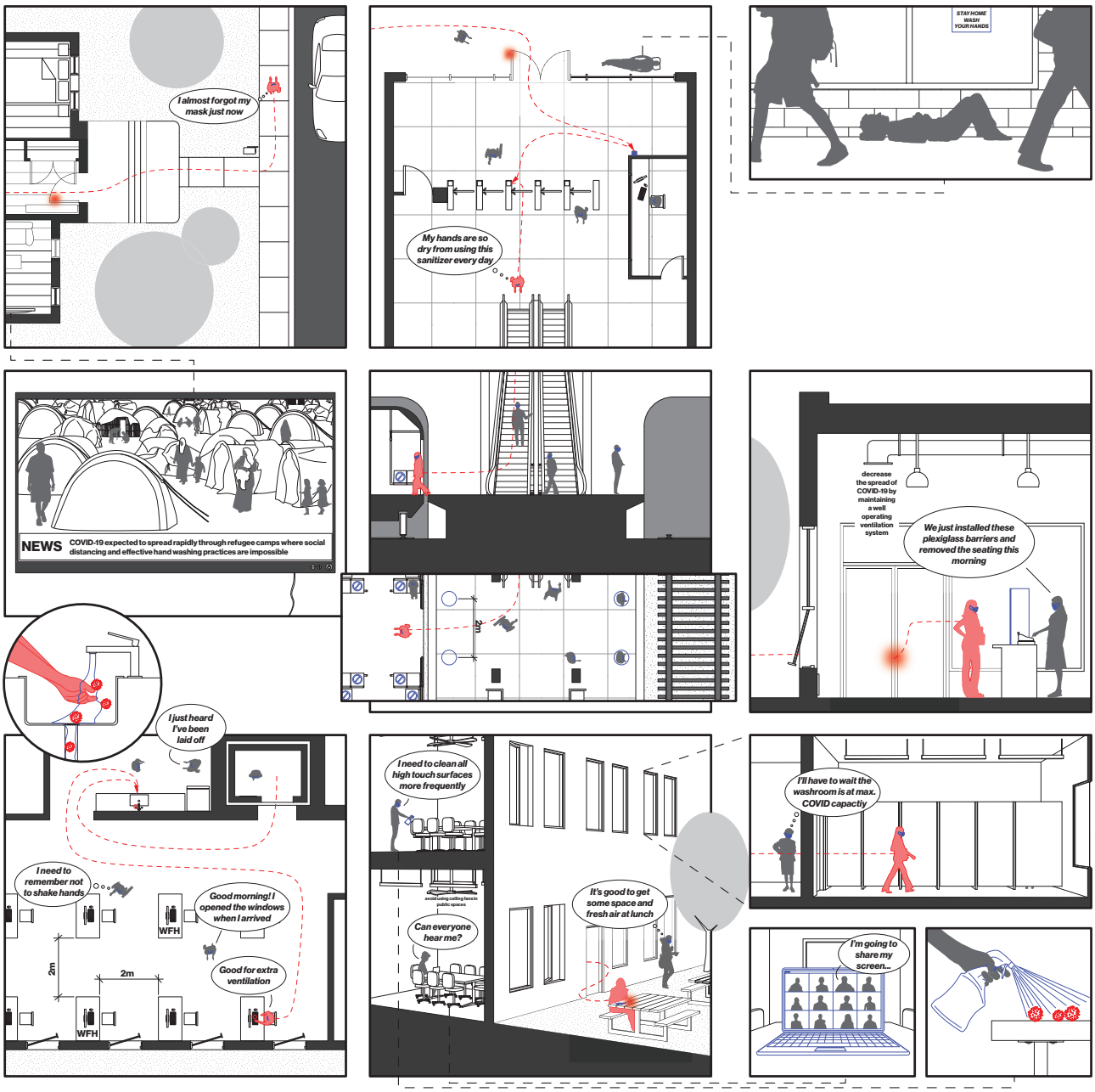
Part of the investigation undertaken for this thesis revolved around an exploration of ways to graphically depict mitigation strategies. Attempts to spatialize the various mitigation methods in drawings and diagrams were made with the iterations motivated by the constant flow of new information about the spread of the Covid-19 virus.

The exploratory graphics used in the first few months of research reflect the initial public health focus on spatial and procedural methods of isolation. An early exercise from the autumn of 2020 explored a day in the life of an individual during the early days of the pandemic where they are made aware of many factors (as discussed previously) leading to a person's increased vulnerability. The influence of the constant reminders to maintain six feet of separation, to wear a mask, and to wash hands frequently is evident within the drawing. The inclusion of these mitigation strategies make one more congnisant of the path of travel through a space, potential interactions within a space, and importantly, the spaces where the built environment fails to provide adequate protection in terms of physical distance.

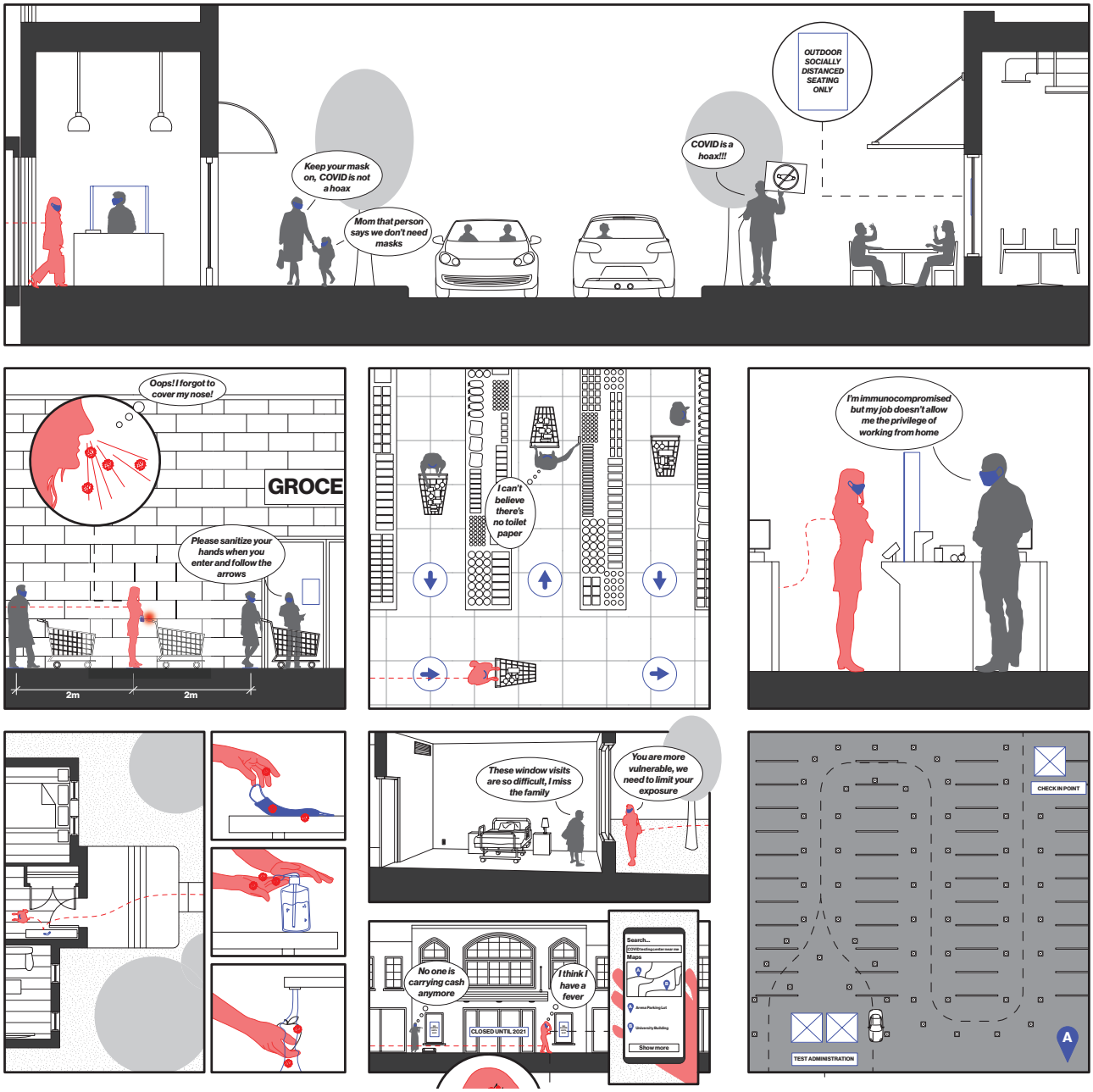


[Fig.09] Graphic legend for drawings.

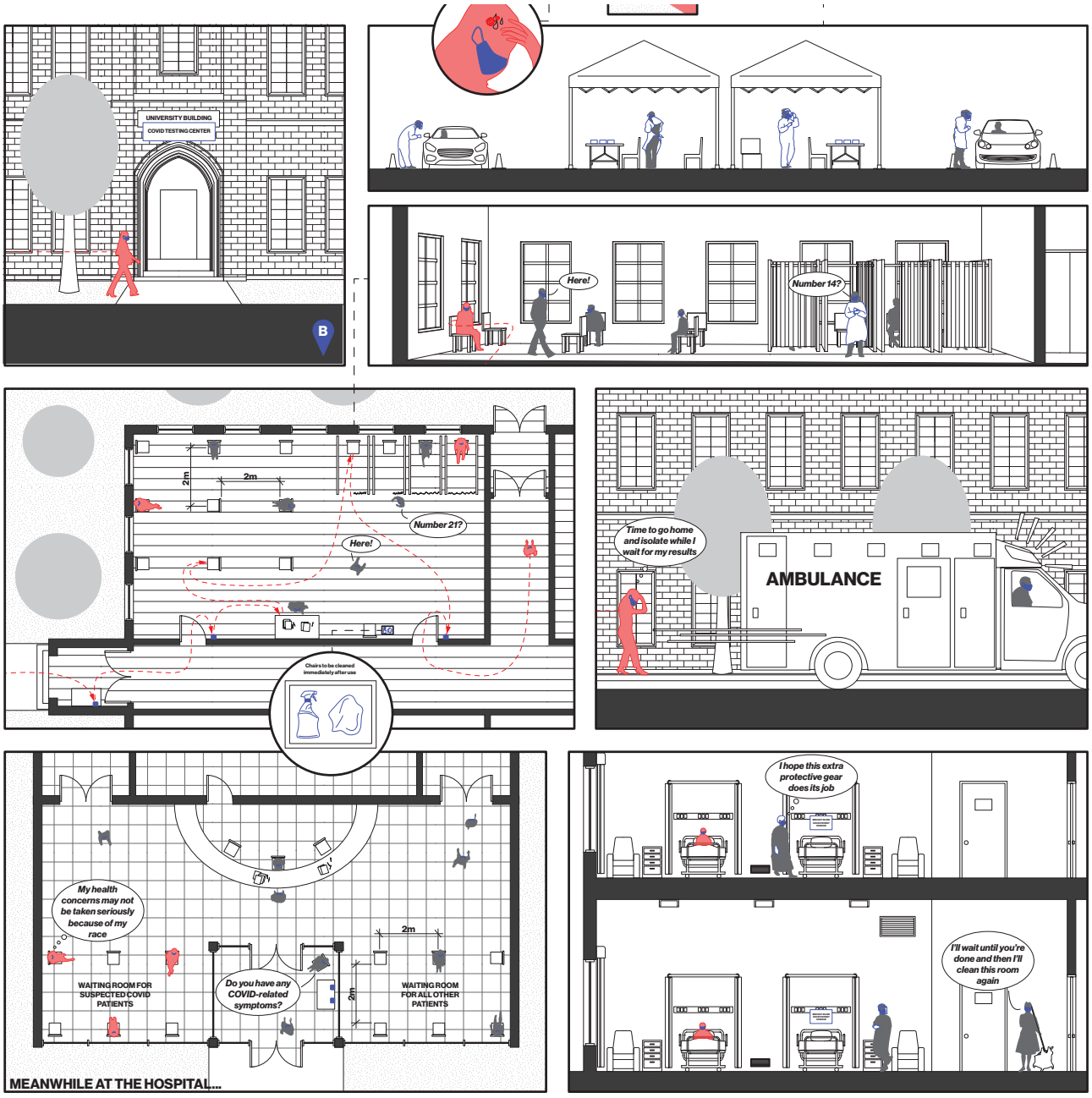
Inspired by graphic novels, the following drawings are a speculative exploration of different spaces and types of interactions one might experience throughout a day. The spatial organization of movement and increased focus on hygienic practices are illustrated through the inclusion of early pandemic precautions.



[Fig.10] A day in the life of a privileged individual living in the GTA during the Covid-19 pandemic with safety measures implemented: Part 1

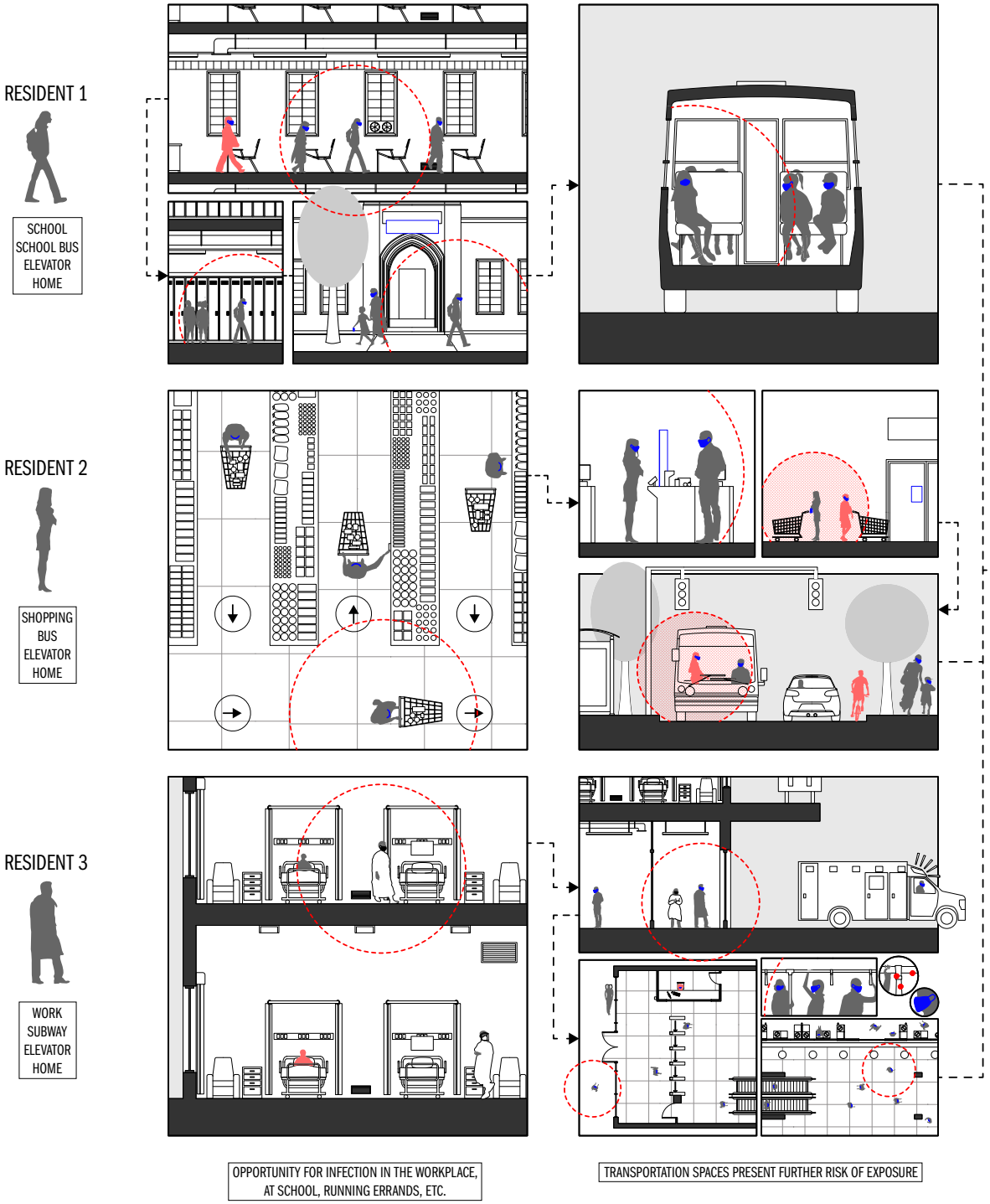


[Fig.11] A day in the life of a privileged individual living in the GTA during the Covid-19 pandemic with safety measures implemented: Part 2

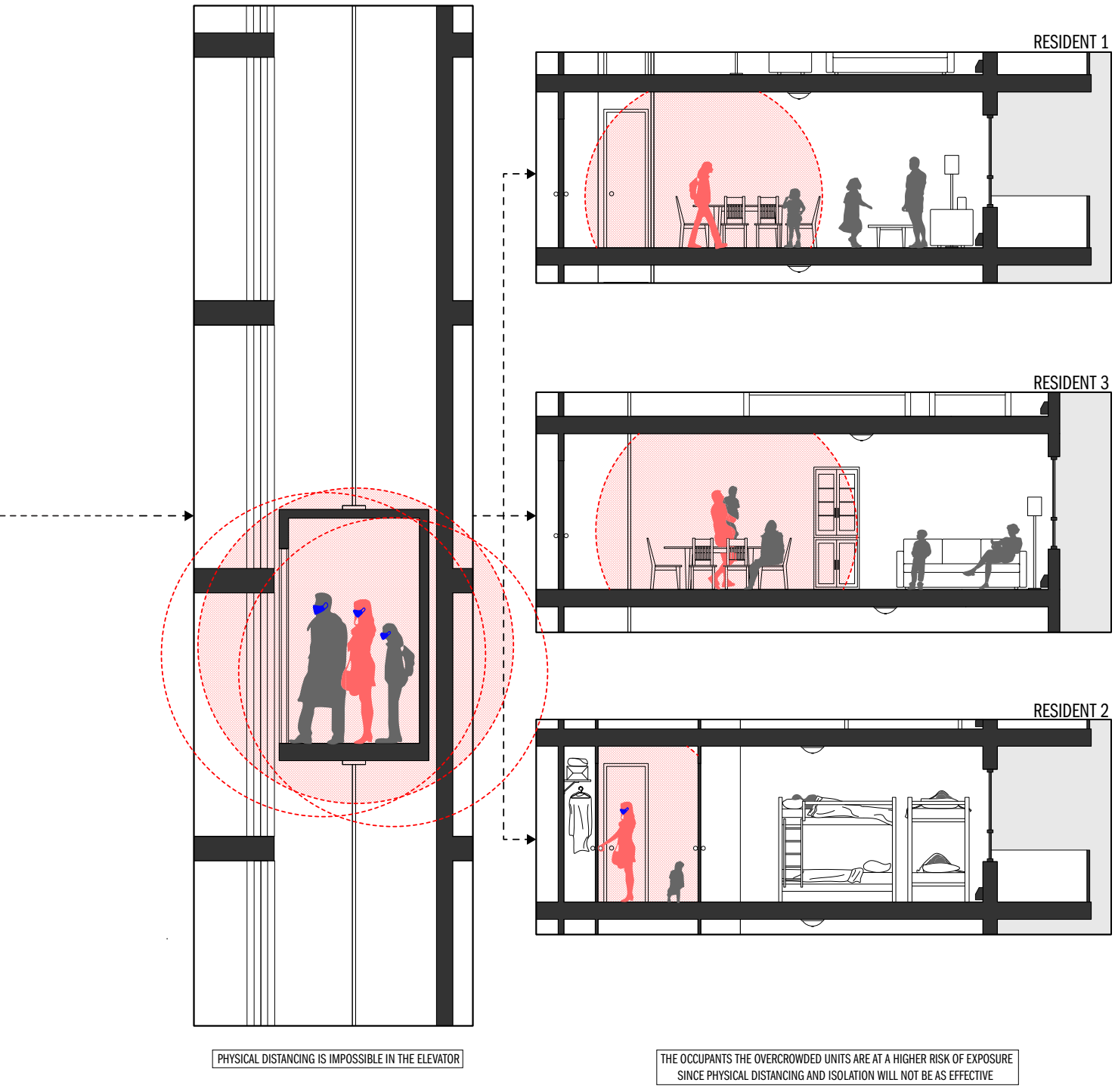


[Fig.12] A day in the life of a privileged individual living in the GTA during the Covid-19 pandemic with safety measures implemented: Part 3

As the focus of research turned to residential spaces, specifically apartment buildings, the increased risk of infectious disease spread through a building due to close interaction in the narrow hallways and elevators is clear when observing isolation through a spatial lens.



[Fig.13] Close contact within an apartment building facilitating the spread of Covid-19.



The Collective Knowledge of Isolation

After narrowing the scope to residential spaces, the research focused on understanding the collective knowledge of the methods and aesthetics of preventing infectious disease spread.

There are preconceived perceptions of the aesthetics of isolation and it is important to understand these perceptions when exploring the incorporation of isolation spaces in design. The aesthetics of isolation spaces and methods often have medical and scientific associations which are strengthened by various depictions in pop culture and the media.

Isolation in Pop Culture

Spatial isolation strategies are commonly depicted in pop culture. Plastic, hazmat suits, and people communicating from opposite sides of transparent barriers dominate the aesthetics of isolation found throughout pop culture. Whether it is a scene from E.T. the Extra-Terrestrial,[99] or First Man,[100] (to name only a couple of examples), the message is clear and unchanging: each variation of the transparent barrier separates a contaminated environment from a clean environment.

Procedural isolation methods are scattered throughout pop culture as well, for example, scrubbing in before a procedure on a medical drama.

Isolation in the Media

Similar isolation ideas are reflected in the response to Covid-19 in public spaces. Physical transparent barriers in places such as restaurants and stores become commonplace. Frequent reminders to wear a mask and wash hands are supported by authorities.[101]

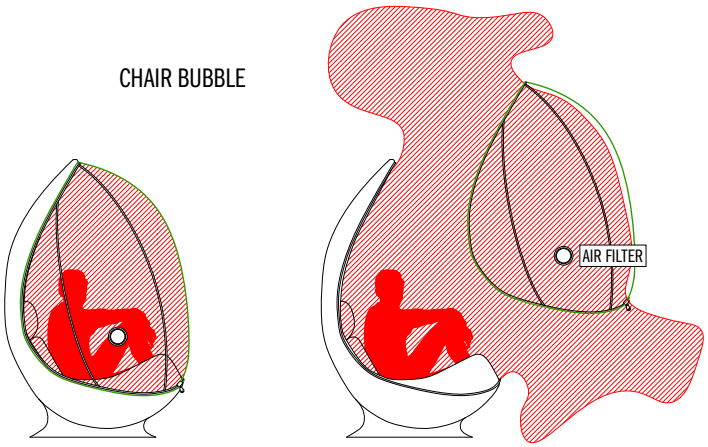
[99] *E.T.: The Extra-Terrestrial*, directed by Steven Spielberg, (1982; Los Angeles, Universal Pictures), Amazon Prime Video.
[100] *First Man*, directed by Damien Chazelle, (2018; Los Angeles, Universal Pictures), Netflix.
[101] Government of Canada, "Coronavirus disease (COVID-19): Prevention and risks."

Initial Design Response to Isolation in Residential Spaces

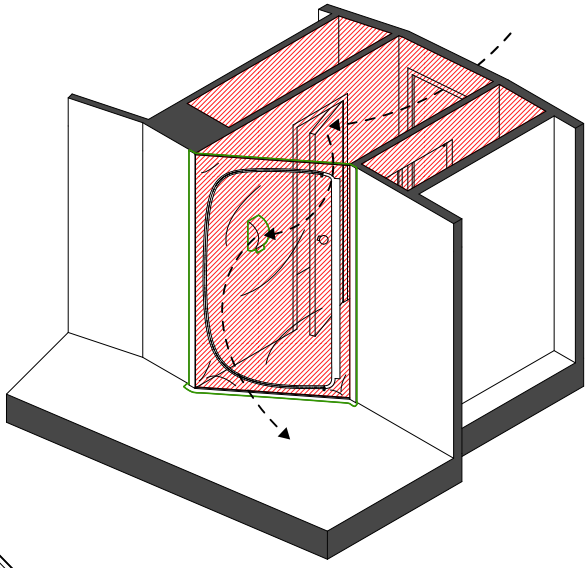
An exploration of how various isolation methods might be employed in residential spaces was undertaken. Early conceptual ideas depict strategies such as transparent barriers fitted around doors to isolate rooms, the creation of temporary rooms within rooms, and a hazmat suit to be worn at home. The initial design response in search of equitable isolation opportunities within residential spaces (see Figures 18 and 19) was influenced by the concept of spatial isolation and pulled from the database of precedents found in pop culture and the media. The physical barrier persisted as the key player at this stage of the exploration.

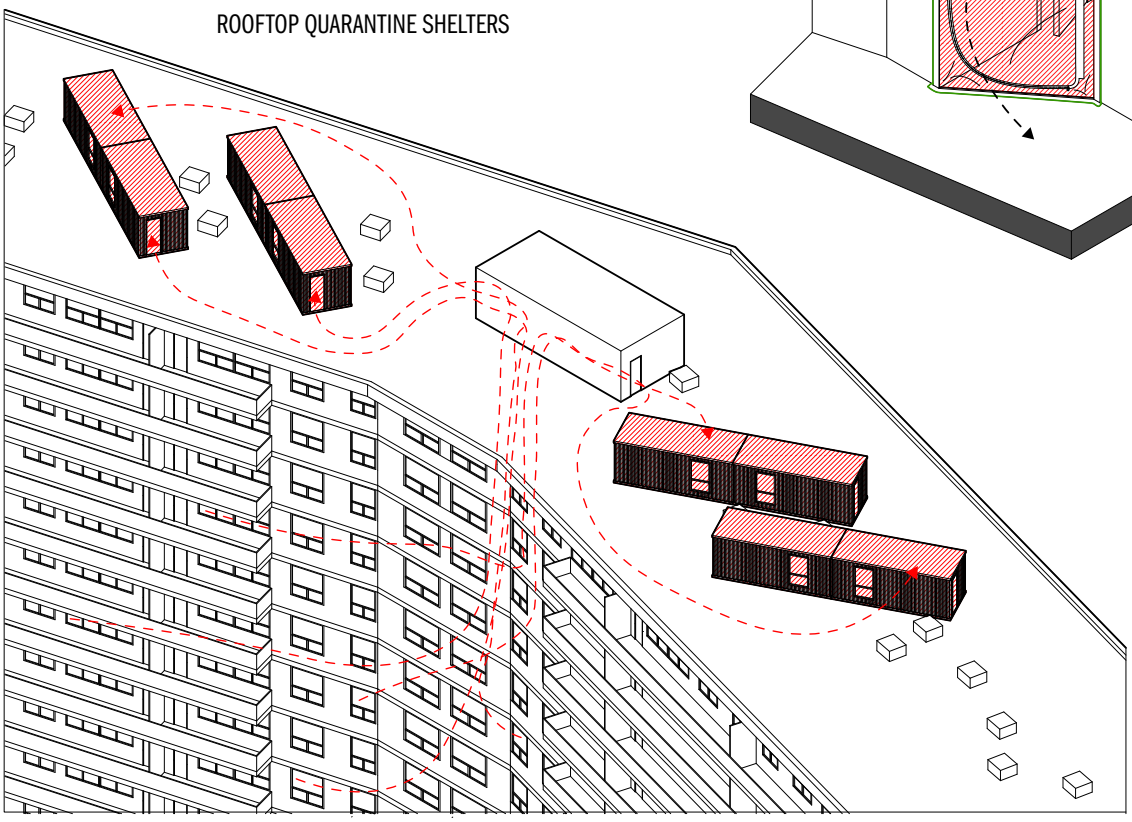
Isolation is a Spatial Problem

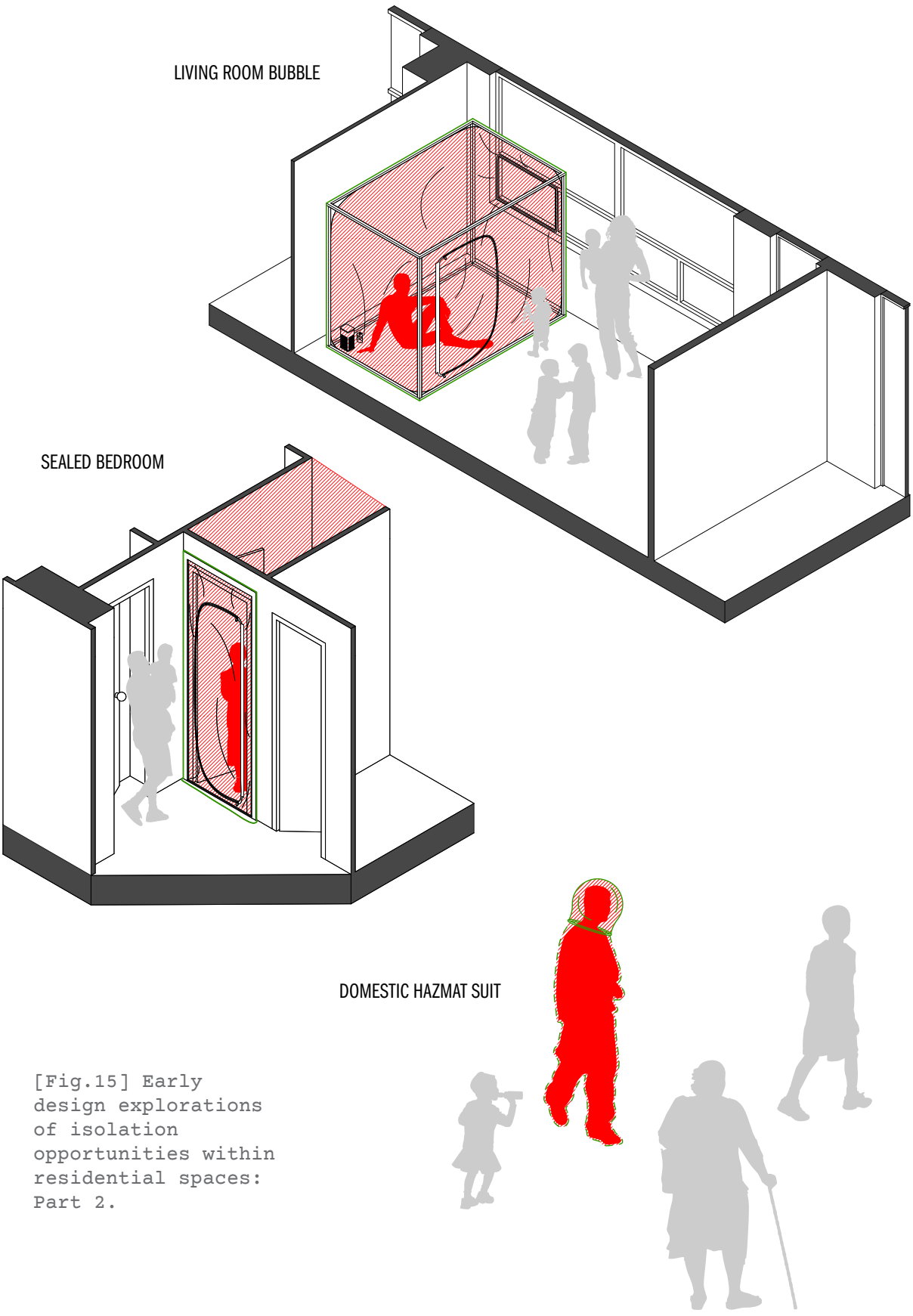
This exploration of isolation illustrates society's reliance on and trust in the physical barrier and the cooperation of the community to provide safety in times of medical emergency.



[Fig.14] Early design explorations of isolation opportunities within residential spaces: Part 1.







[Fig.15] Early design explorations of isolation opportunities within residential spaces: Part 2.

APRIL TO JULY 2021:

An Airborne Virus

Covid-19: The idea that Covid-19 is airborne decreases the importance of the 2m radius.

Thesis: Focus shifts to consider entire spaces as zones of infection rather than just the 2m bubble around an individual person.

Graphic Representation: Evolves to incorporate time and attempts to illustrate where and for how long an infected person occupies a space within a residential setting.

Airborne Disease Transmission

Further into the pandemic, the airborne transmission of Covid-19 was more seriously considered.[102] Airborne disease transmission occurs when pathogens are dispersed through droplets or aerosols.[103] This dispersion occurs when a person exhales, whether it is while coughing, singing, sneezing, talking, or even breathing.[104]

The "risk for infection decreases with increasing distance from the source and increasing time after exhalation."[105] Large droplets fall to the ground closer to the source of exhalation and therefore, as the distance from the source grows, the concentration of viral particles in the air decreases, lowering the risk of infection. The concentration of remaining suspended aerosol particles becomes diluted over time as the initial spray mixes with other airstreams.[106] It became clear that distance and time are two important metrics when dealing with airborne disease transmission.

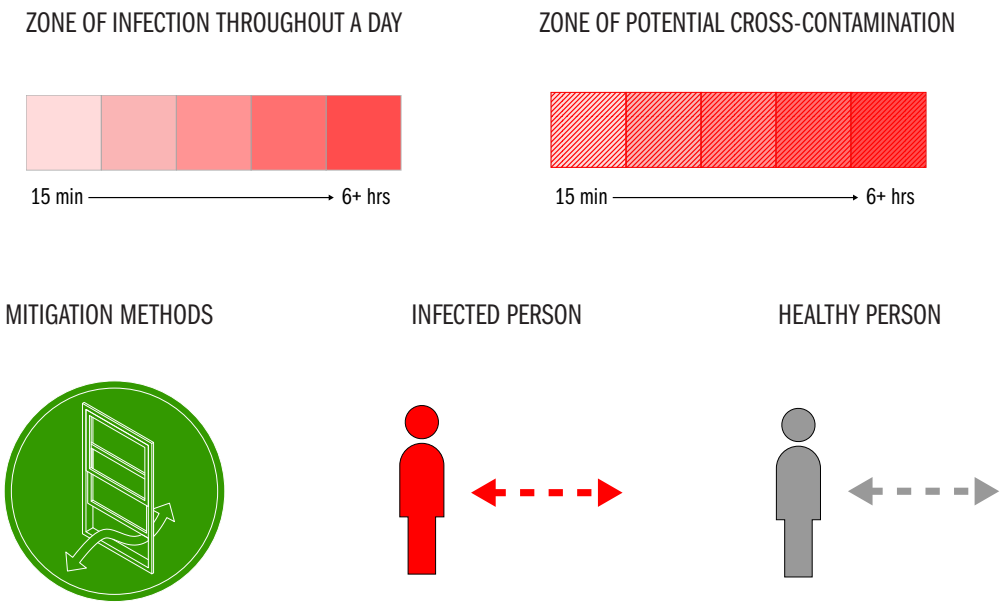
Influenced by the knowledge of the airborne transmission of Covid-19, the two-metre radius, while still considered important to maintain in real life, decreased in relevance graphically. Time became an important metric to consider

[102] "Surface to air," *The Economist*, May 29, 2021, 71-73.
[103] Binish Ather, Taaha M. Mirza, and Peter F. Edemekong, "Airborne Precautions," in *StatPearls [Internet]*, (Treasure Island, FL: StatPearls Publishing, 2021), https://www.ncbi.nlm.nih.gov/books/NBK531468/.
[104] "SARS-CoV-2 Transmission," Centers for Disease Control and Prevention, last modified May 7, 2021, accessed September 13, 2021, https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html.
[105] Ibid.
[106] Ibid.

when acknowledging that the virus can travel beyond two metres from the source[107] and remain suspended in the air after the source had left the room.[108]

A Note on Graphics

Instead of limiting the zone of infection to around an infected person, a method to graphically depict areas within residential spaces as zones of infection was developed. The zones of infection are shown through a gradient grid. Focusing on the infected person, the darker shades of red indicate longer periods of time spent within a space while the lighter shades of red indicate shorter periods of time. The red hatch overlay illustrates spaces with a risk of cross contamination; where both healthy and infected people may occupy. The green icons call out the specific mitigation methods employed by the occupants.



[Fig.16] Graphic legend for drawings.

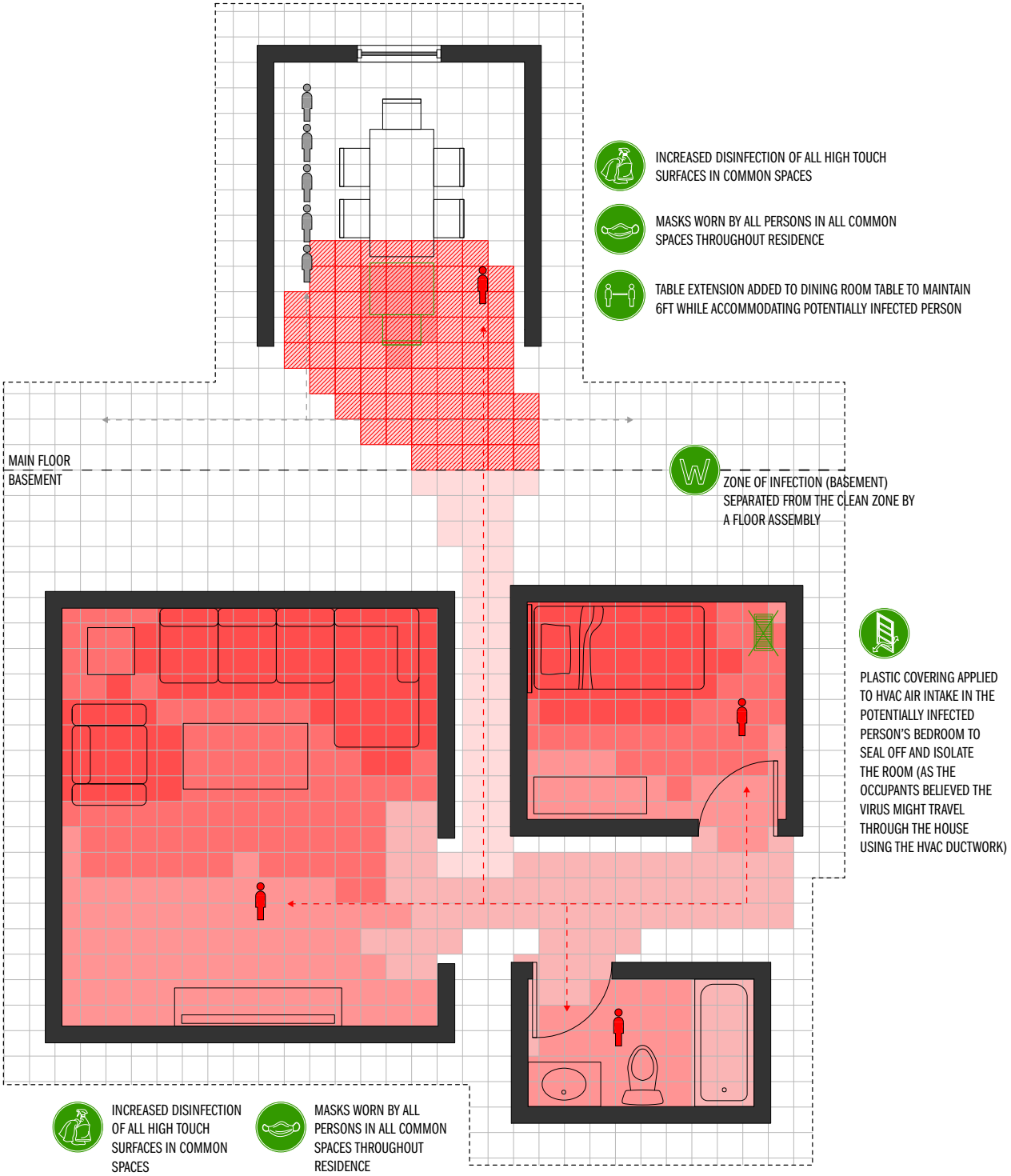
[107] Hua Qian, Te Miao, Li Liu, Xiaohong Zheng, Luo Danting, and Yuguo Li, "Indoor transmission of SARS-CoV-2," *Indoor Air: International Journal of Indoor Environment and Health* 31, no. 3 (October 31, 2020): 639-645, https://doi.org/10.1111/ina.12766.
[108] "Indoor Air and Coronavirus (COVID-19)," United States Environmental Protection Agency, last modified August 19, 2021, accessed September 5, 2021, https://www.epa.gov/coronavirus/indoor-air-and-coronavirus-covid-19.

Domiciliary Isolation Strategies

A collection of eighteen stories outlining strategies to prevent the spread of Covid-19 within different homes were analyzed to gain an understanding of the present-day approach to isolation in residential spaces.

Scenario One

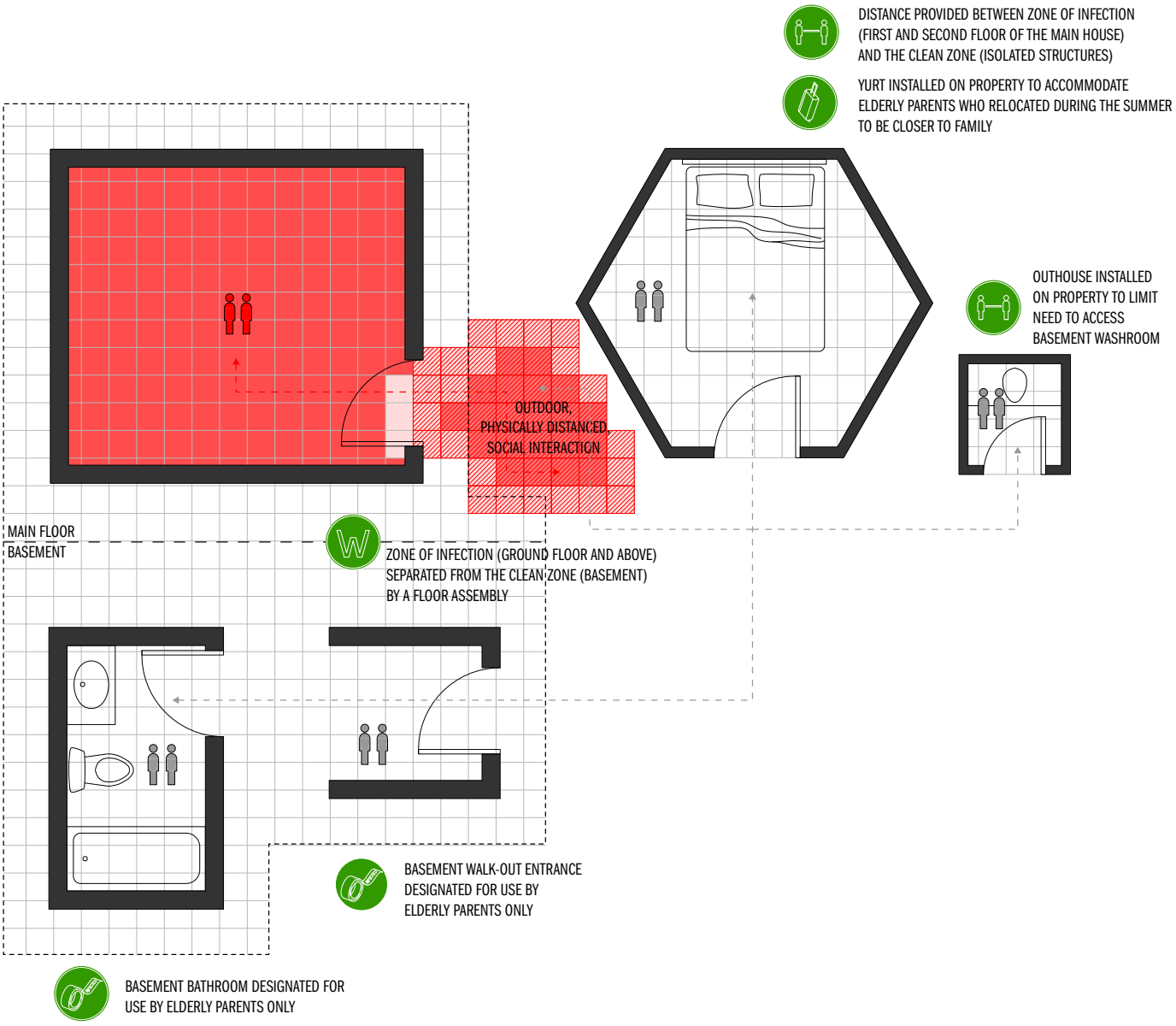
Scenario One outlines the at-home Covid-19 mitigation strategy of a family living in a single-family home. The six occupants are comprised of two adults and four adult children. The second oldest child returned from an exchange term abroad at the beginning of the pandemic and proceeded to quarantine in the basement for two weeks as a precaution. The occupants believed that the virus might travel through the house using the ducts, therefore the air vent in the basement bedroom was covered with plastic to isolate the room from the rest of the HVAC system. The child was allowed to join the family in the dining room for dinner only. An extra table was set up at the end of the long dining table to further increase the distance between the healthy and the infected. Masks were worn by everyone in the common spaces when the child was present and the disinfection of all the high touch surfaces in the house was increased.



[Fig.17] Scenario One.

Scenario Two

Scenario Two depicts the at-home Covid-19 mitigation strategy of a couple who provide safe accommodation on their property for one partner's elderly parents. The elderly couple relocated to spend the warmer months closer to family. The large rural property allowed for the installation of a yurt and an outhouse. The walkout entrance to the basement was designated for use by the elderly couple who could use it to access the shower in the basement. The only interaction between the two couples was outside while maintaining the prescribed two-meter physical distance.

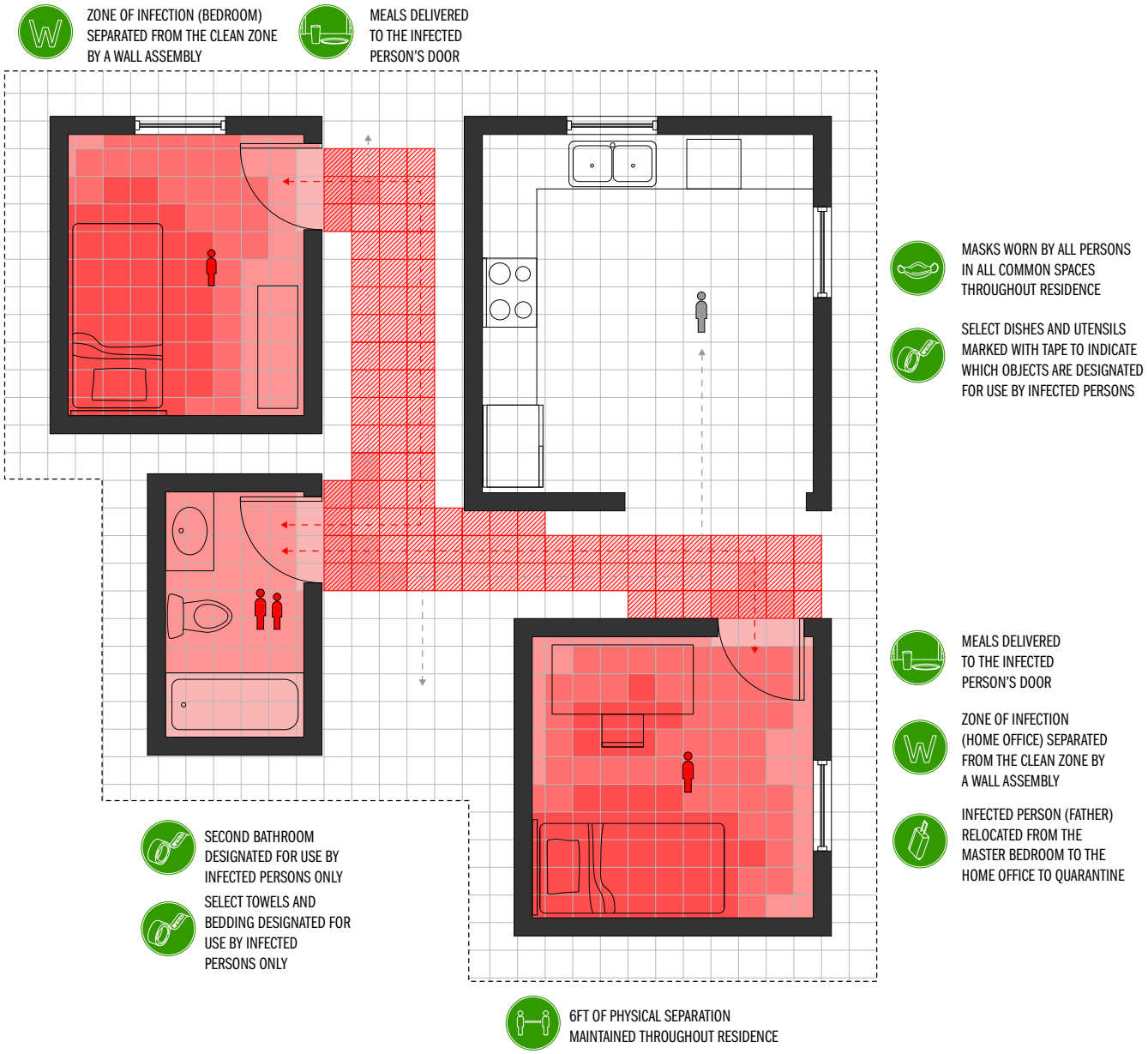


[Fig.18] Scenario Two.

Scenario Three

Scenario Three shows the at-home Covid-19 mitigation strategy of a family where both the father and the daughter contracted the virus. The daughter quarantined in her bedroom while the father relocated from the master bedroom to isolate in the home office where a spare bed was set up. The second bathroom was designated for use by the infected persons only. Select towels and bedding, as well as kitchen utensils and dishes, were to be used by the infected persons only. Tape was used to designate the dishes and utensils to ensure there would be no cross-contamination. Meals were delivered to the doors of the quarantined persons to maintain the continuity of the physical separation. The only situation for potential interaction between the healthy and infected persons was when an infected person was en route from their room to the bathroom. However, masks were worn by all persons in the common spaces of the house to help mitigate this.[109]

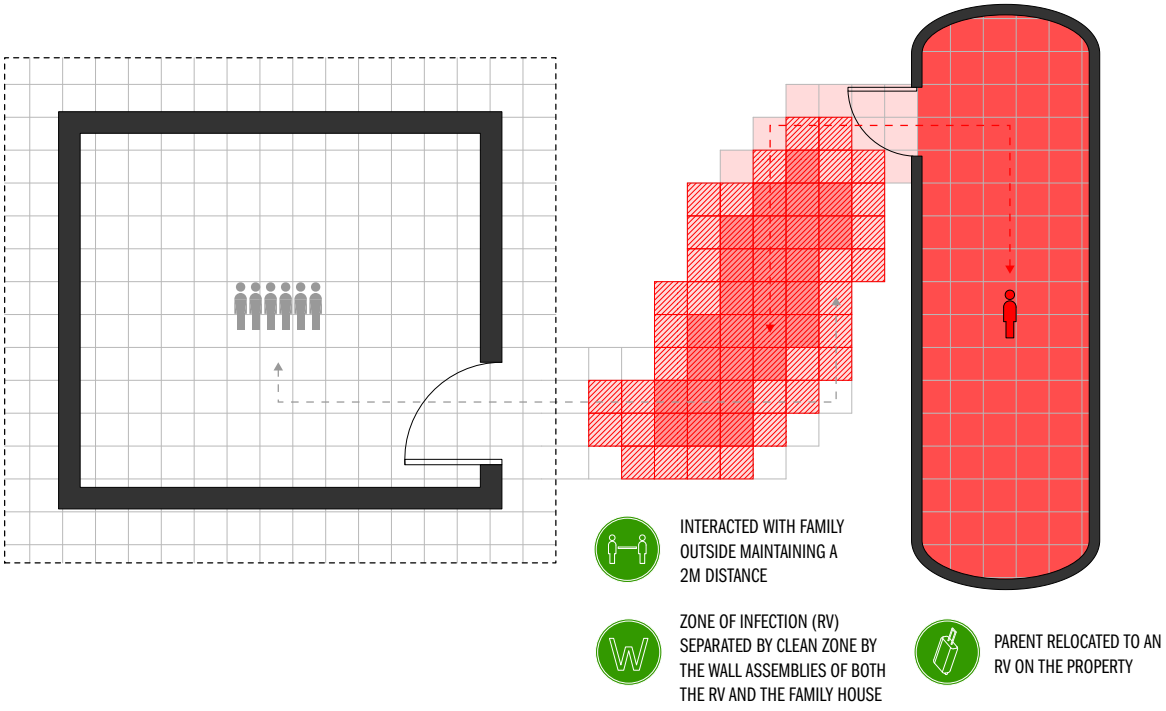
[109] Modern Aging - Holistic Health and Wealth After 50, "My Family has Mild Coronavirus. here's our Home Covid-19 Treatment Plan," YouTube, last modified March 26, 2020, accessed February 3, 2021, https://www.youtube.com/watch?v=udprEtDVmIY.



[Fig.19] Scenario Three.

Scenario Four

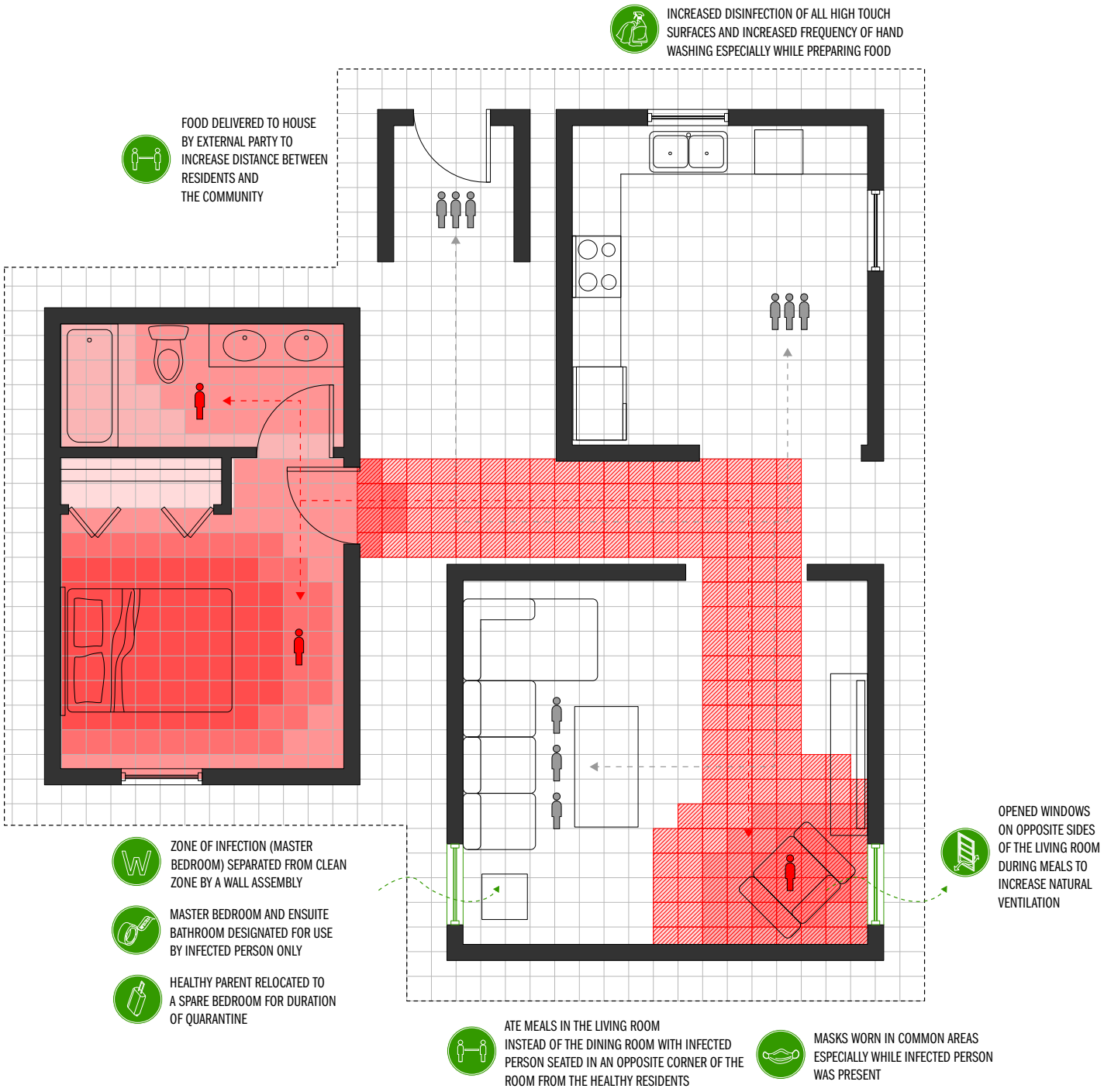
Scenario Four deals with a family of six where one parent is a healthcare worker. To protect the family, the at-risk parent relocated from the home to an RV which was set up on their large property. The only interaction between the healthy and the potentially infected occurred outside while maintaining the recommended two-meter physical distance.



[Fig.20] Scenario Four.

Scenario Five

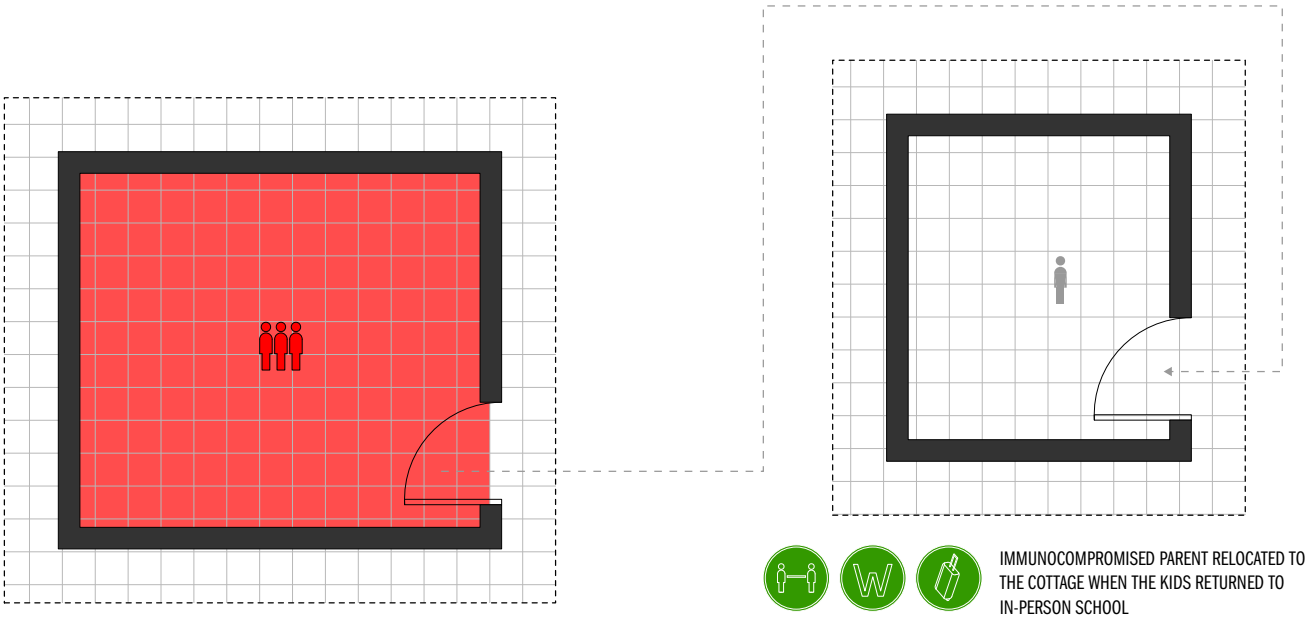
Scenario Five outlines the story of a family of four mitigating the spread of Covid-19 in their home when one parent becomes infected. The healthy parent relocated to a spare bedroom so the infected parent could quarantine in the master bedroom and utilize the ensuite bathroom. This helped to minimize the need for the infected person to occupy the common spaces in the house. However, at dinner, the infected person joined the rest of the family in the living room. The two parties, the healthy and the infected, sat at opposite corners of the room to maximize the distance between them. Windows were opened on either side of the room to incorporate natural ventilation for the duration of the meal. When not eating, masks were worn by everyone. Those who prepared the food wore a mask and increased their hand washing. All high touch surfaces throughout the house were subject to increased disinfection. Everyone strived to be conscious of which objects they touched, especially the infected parent. Furthermore, to limit their contact with the community, they had external parties deliver groceries to the front door. Those who prepared the food wore a mask and increased their hand washing. All high touch surfaces throughout the house were subject to increased disinfection. Everyone strived to be conscious of which objects they touched, especially the infected parent. Furthermore, to limit their contact with the community, they had external parties deliver groceries to the front door.



[Fig.21] Scenario Five.

Scenario Six

Scenario Six depicts a simple solution where an immunocompromised parent relocated to the family cottage as a precaution when the kids returned to in-person school.

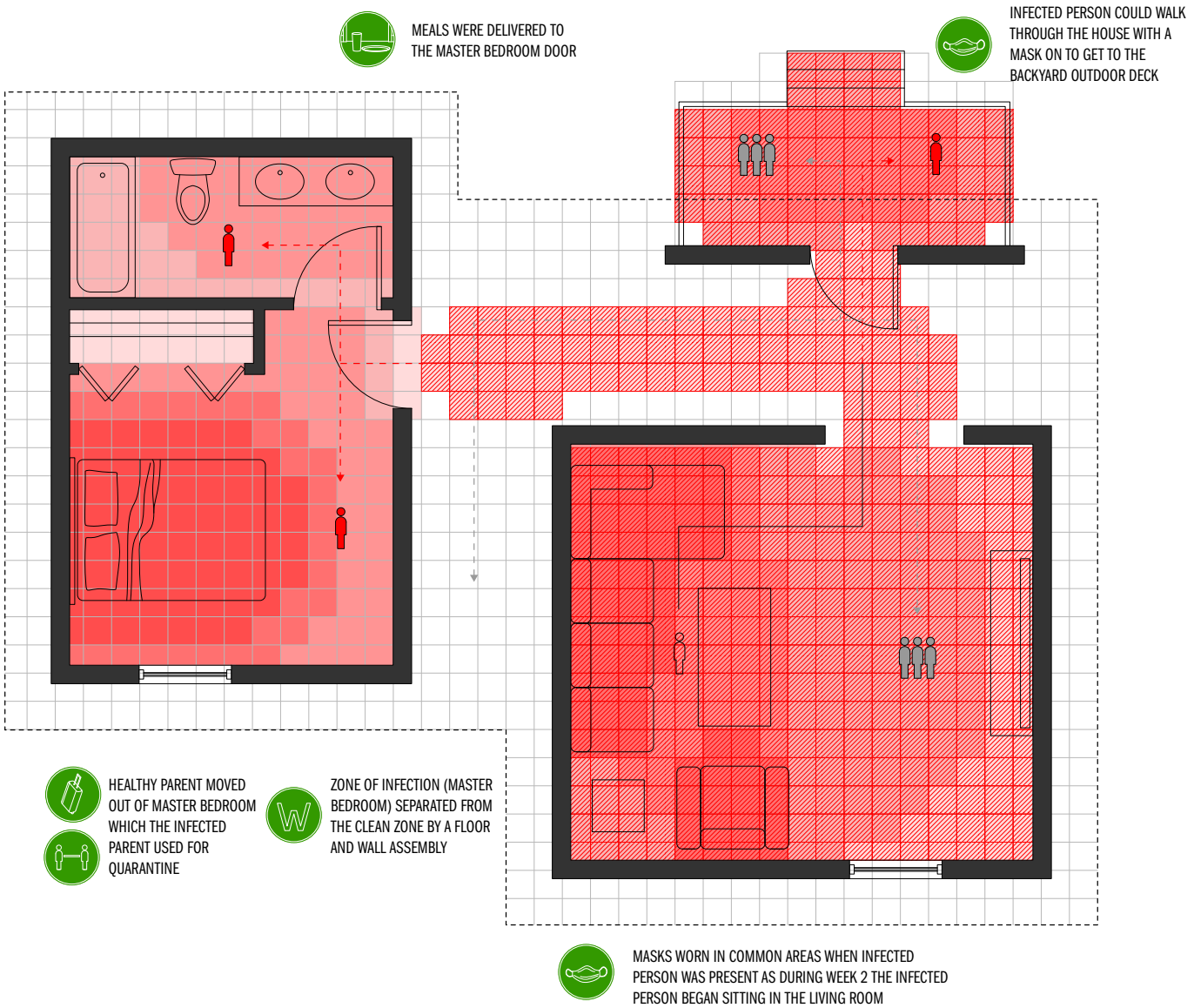


[Fig.22] Scenario Six.

Scenario Seven

Scenario Seven shows the Covid-19 spread mitigation strategy employed by another family where a parent fell ill. The infected parent quarantined in the master bedroom and had access to the ensuite bathroom. The healthy parent relocated to a spare bedroom for the two-week quarantine period. Meals were delivered to the master bedroom door. The infected parent could walk through the house with a mask on to access the backyard deck for some fresh air. During the second week, the infected parent spent a couple of hours per day in the living room for a change of scenery. Masks were worn in all common areas when the infected parent was present.[110]

[110] AM Kato, "My Mom's Coronavirus Experience | COVID-19 Daily Vlogs," YouTube, last modified April 2, 2020, accessed February 3, 2021, https://www.youtube.com/watch?v=5js-W-dF_PI.

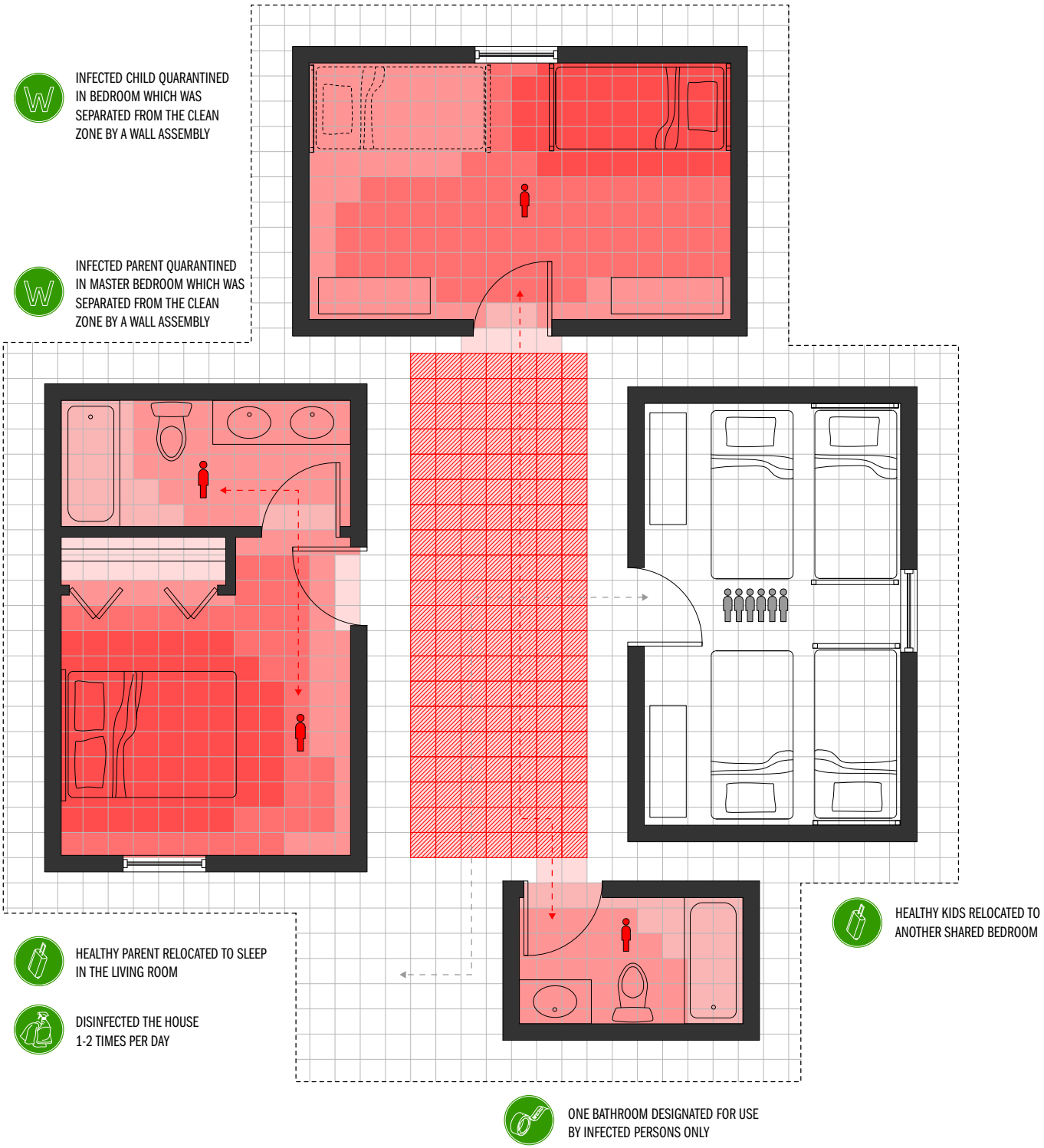


[Fig.23] Scenario Seven.

Scenario Eight

In an extreme case, Scenario Eight outlines the mitigation of Covid-19 in a home where two parents and twenty-one children reside. In total, one parent and twelve children contracted Covid-19 although not all at the same time. The healthy parent relocated to the living room couch so the infected parent could sleep in the master bedroom alone. The kids all shared bedrooms as there were so many of them. When one got infected, the healthy kids would move their mattresses into another bedroom so those who were infected could quarantine in a bedroom alone. One bathroom in the house was designated for use by infected persons only. In addition, the house was disinfected one to two times per day. Those who prepared the food wore a mask and increased their hand washing. All high touch surfaces throughout the house were subject to increased disinfection. Everyone strived to be conscious of which objects they touched, especially the infected parent. Furthermore, to limit their contact with the community, they had external parties deliver groceries to the

[111] Inside Edition, "How does Family of 40 Quarantine when 12 have Coronavirus?," YouTube, last modified May 6, 2020, accessed February 3, 2021, https://www.youtube.com/watch?v=53FeT9wrHt0.

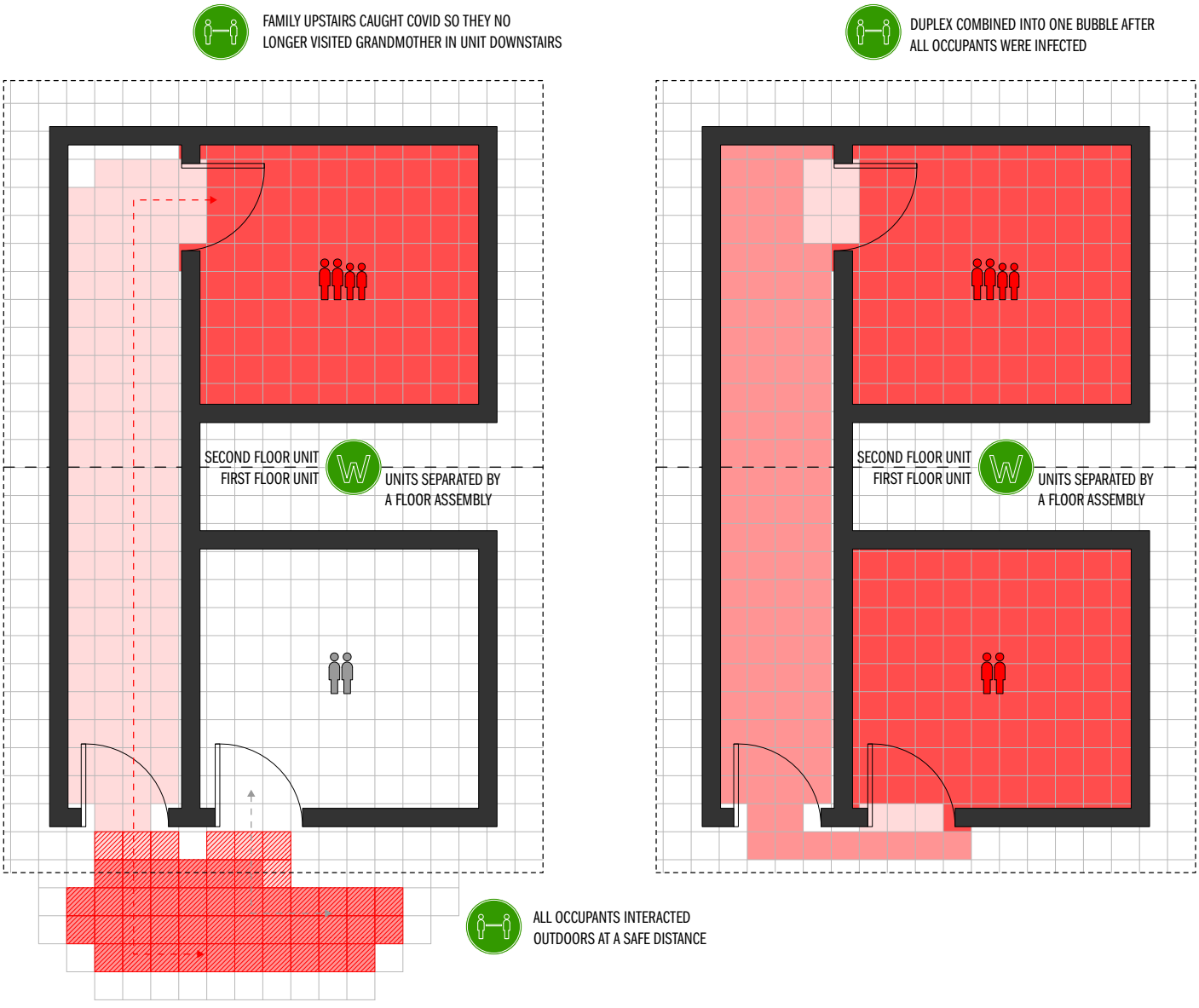


[Fig.24] Scenario Eight.

Scenario Nine

Scenario Nine revolves around the mitigation strategies of six people living in a duplex. The second-floor unit is home to a couple and their two young kids and the downstairs unit is home to the grandmother and a non-related roommate. When the occupants of the second-floor unit contracted Covid-19, they no longer ventured downstairs to visit the grandmother. Any social interaction was done outside maintaining the prescribed two-meter distance. However, the roommate caught Covid-19 and passed it on to the grandmother, the two units combined into one bubble as everyone had been infected.[112]

[112] StuckinVermont, "The Downes Family Recovers from COVID-19," YouTube, last modified April 22, 2020, accessed February 3, 2021, https://www.youtube.com/watch?v=R_1hcxR5ijk.

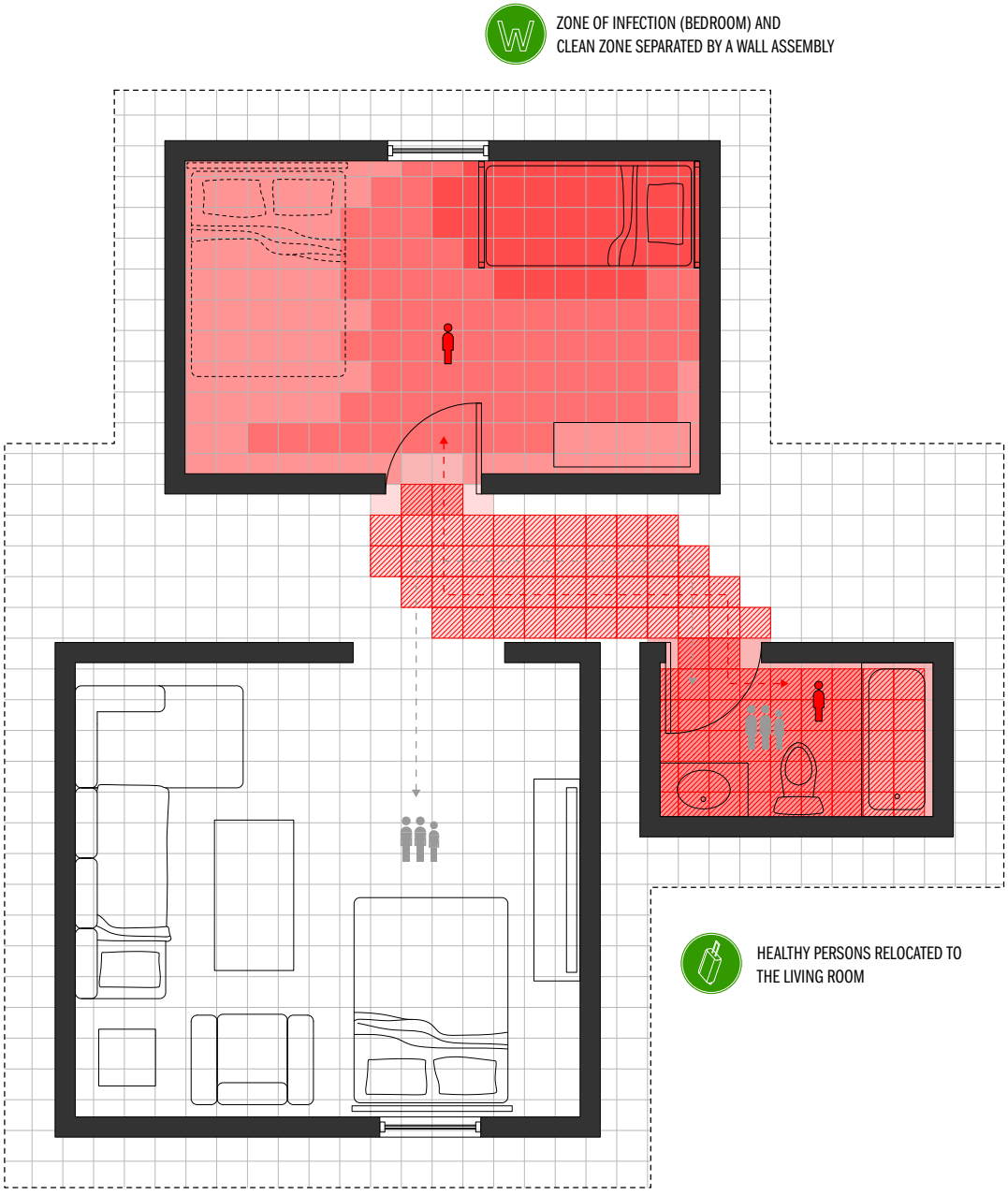


[Fig.25] Scenario Nine.

Scenario Ten

Scenario Ten outlines a story in which one person in the family caught Covid-19. This family of four, comprised of two parents and two young children, lives in a one-bedroom apartment. They all sleep in one room which makes mitigating the spread of Covid-19 more difficult. However, the infected person would quarantine in the bedroom while the rest of the family members would relocate to the living room. Potential interaction would occur in the bathroom as it is shared by all occupants or when the infected person travelled from the bedroom to the bathroom.[113]

[113] Jackie Botts, "The Neighbourhoods Where COVID Collides with Overcrowded Homes," CalMatters, last modified June 12, 2020, accessed February 3, 2021, https://calmatters.org/projects/california-coronavirus-overcrowded-neighborhoods-homes/.

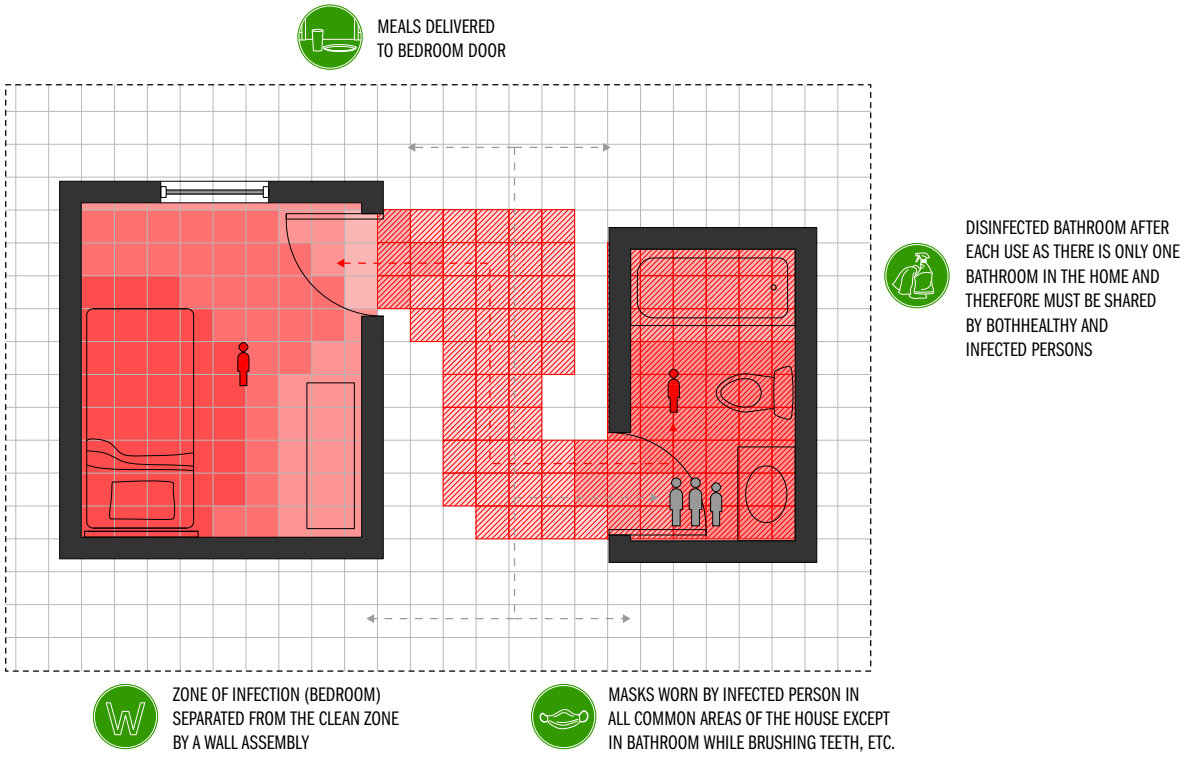


[Fig.26] Scenario Ten.

Scenario Eleven

Scenario Eleven depicts the Covid-19 spread mitigation strategies of a family in which one child, a daughter, contracts the virus. She quarantines in her bedroom and gets her meals delivered to her door. There is only one bathroom in the house so it must be shared by both the infected and healthy residents. As a result, it is disinfected after each use. Masks are worn by everyone in all common areas of the house, except in the bathroom when brushing teeth, etc.[114]

[114] Unraveling Architecture, "Living with COVID-19 DAY IN MY LIFE in QUARANTINE VLOG | & how I Kept My Family Safe (from Corona)," YouTube, last modified July 11, 2021, https://www.youtube.com/watch?v=jKlerR81DOM.

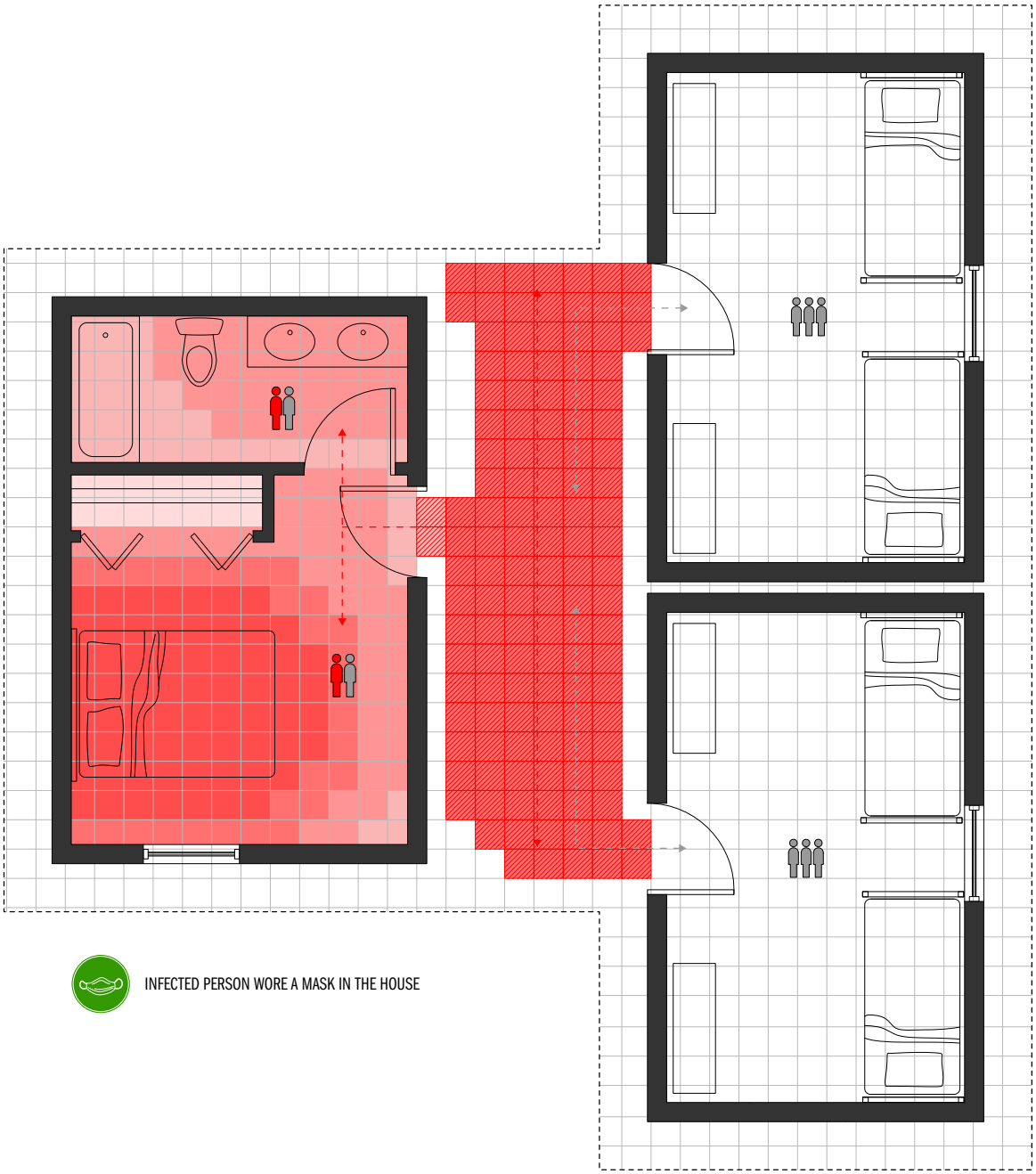


[Fig.27] Scenario Eleven.

Scenario Twelve

Scenario Twelve outlines the Covid-19 spread mitigation strategies of a family of eight living in a three-bedroom apartment. One parent contracts the virus and wears a mask while in the apartment. There is a higher risk of cross-contamination in this scenario.[115]

[115] The New York Times, "'This is Crazy': Inside a N.Y.C. Apartment during Coronavirus | Quarantine Diaries," YouTube, last modified April 22, 2021, accessed February 3, 2021, https://www.youtube.com/watch?v=CxtsJG4S5qk.

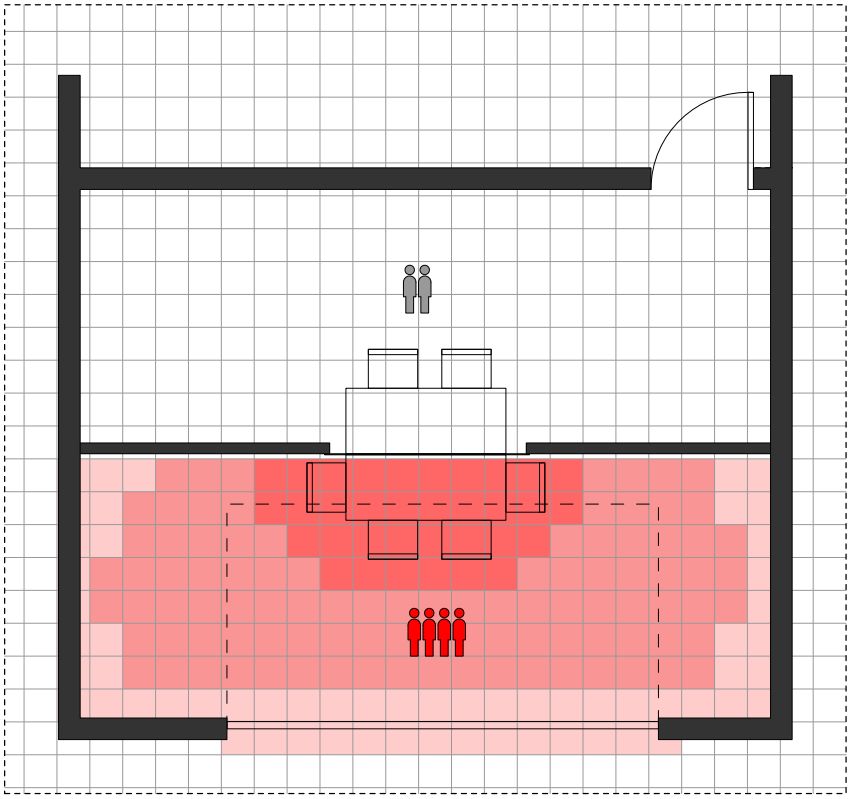


[Fig.28] Scenario Twelve.

Scenario Thirteen

Scenario Thirteen shows how one family created a Covid-19 safe hangout in a garage. A man divided his parents' garage with a simple wood-framed, plastic-covered wall. In the center, he installed a plexiglass window. At the window location, a table was run through the wall so everyone could eat together and see each other face to face. The hole created for the table was sealed before use.[116]

[116] Tom Rader, "Pottstown Man Builds COVID-Safe Christmas Hangout in Elderly Parents' Garage," 69 WFMZ-TV News, last modified December 22, 2020, accessed January 18, 2021, https://www.wfmz.com/news/area/southeastern-pa/pottstown-man-builds-covid-safe-christmas-hangout-in-elderly-parents-garage/article_22c4343a-441f-11eb-9357-0bd898888d92.html.



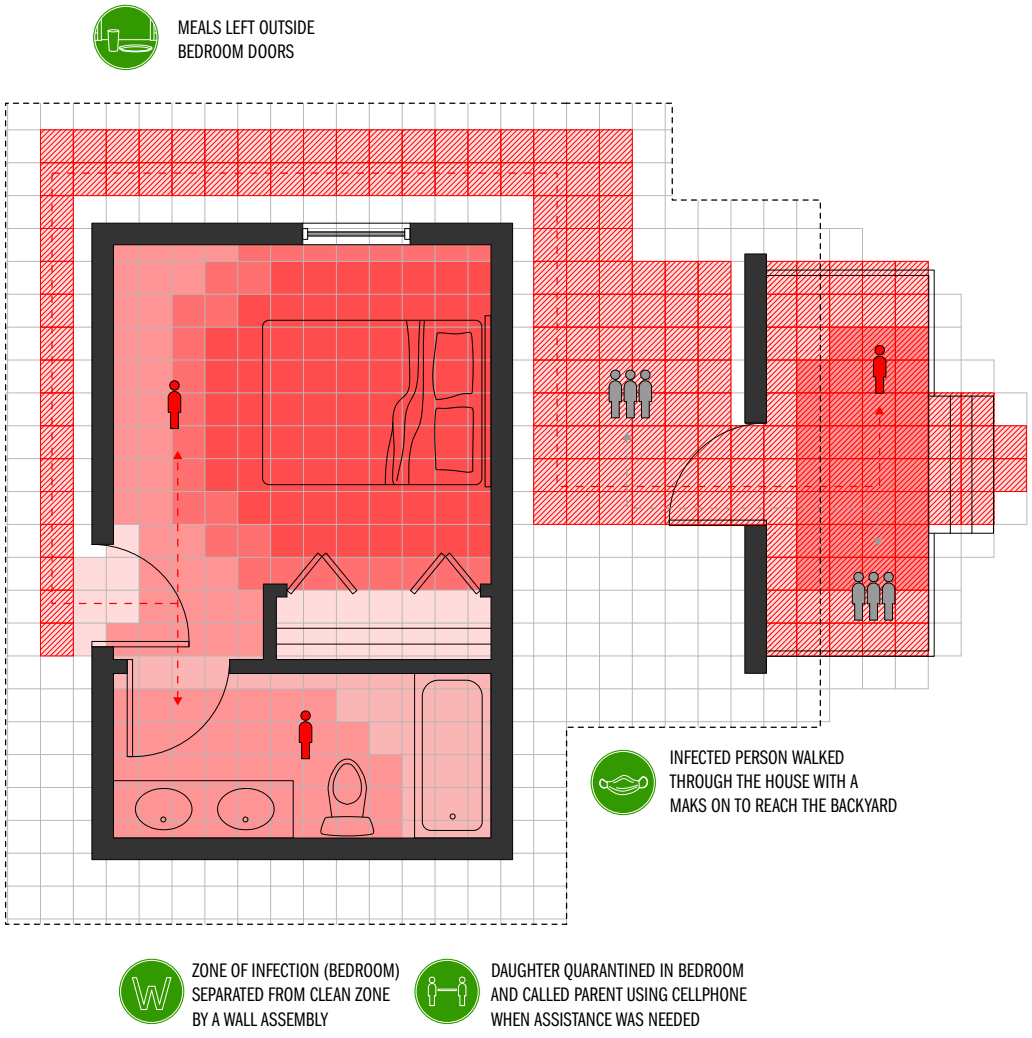
GARAGE DIVIDED BY A WOOD FRAMED, PLASTIC COVERED WALL WITH A PLEXIGLASS WINDOW. TABLE RUN THROUGH THE WALL SO THEY COULD EAT “TOGETHER” AND SEE EACH OTHER FACE TO FACE

[Fig.29] Scenario Thirteen.

Scenario Fourteen

Scenario Fourteen depicts an at-home Covid-19 mitigation strategy of a family in which a daughter contracts the virus. She quarantined in her bedroom which has an ensuite bathroom. Her meals were delivered to her bedroom door. She used her cellphone to call a parent when she required assistance or food. She was able to walk through the house with a mask on to access the backyard.[117]

[117] Jazzy Anne, "I had COVID-19. this is how I Spent My 2 Weeks in Isolation," YouTube, last modified September 25, 2020, accessed March 4, 2021, https://www.youtube.com/watch?v=0dhCCOgJYpc.

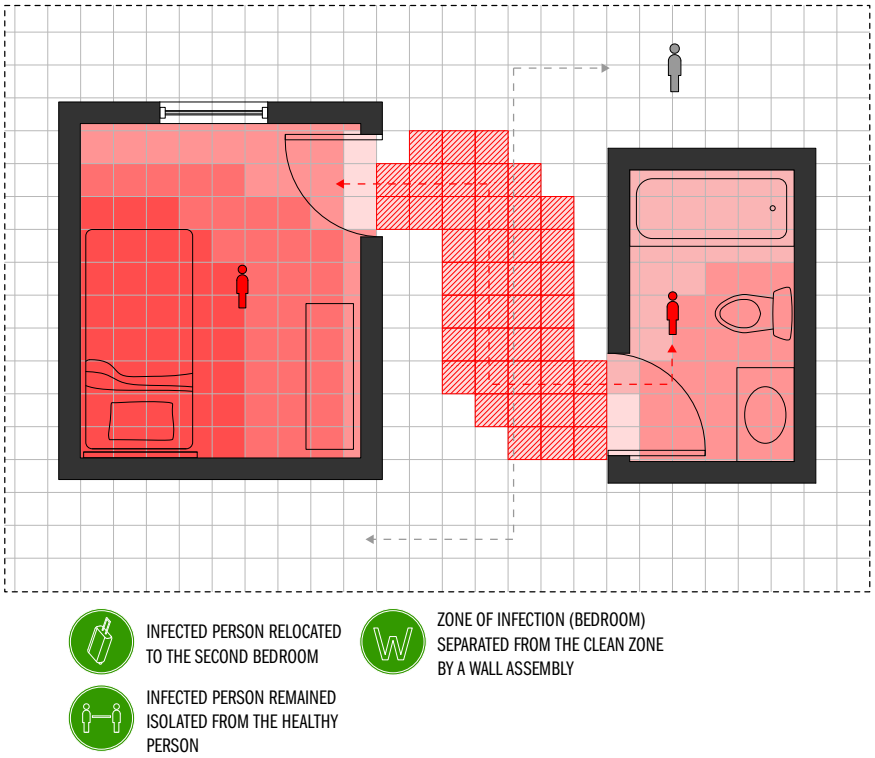


[Fig.30] Scenario Fourteen.

Scenario Fifteen

Scenario Fifteen outlines the Covid-19 spread mitigation strategy of a couple living in a two-bedroom apartment. One occupant caught Covid-19 and remained isolated within the second bedroom. The second bathroom was designated for use by the infected person only.[118]

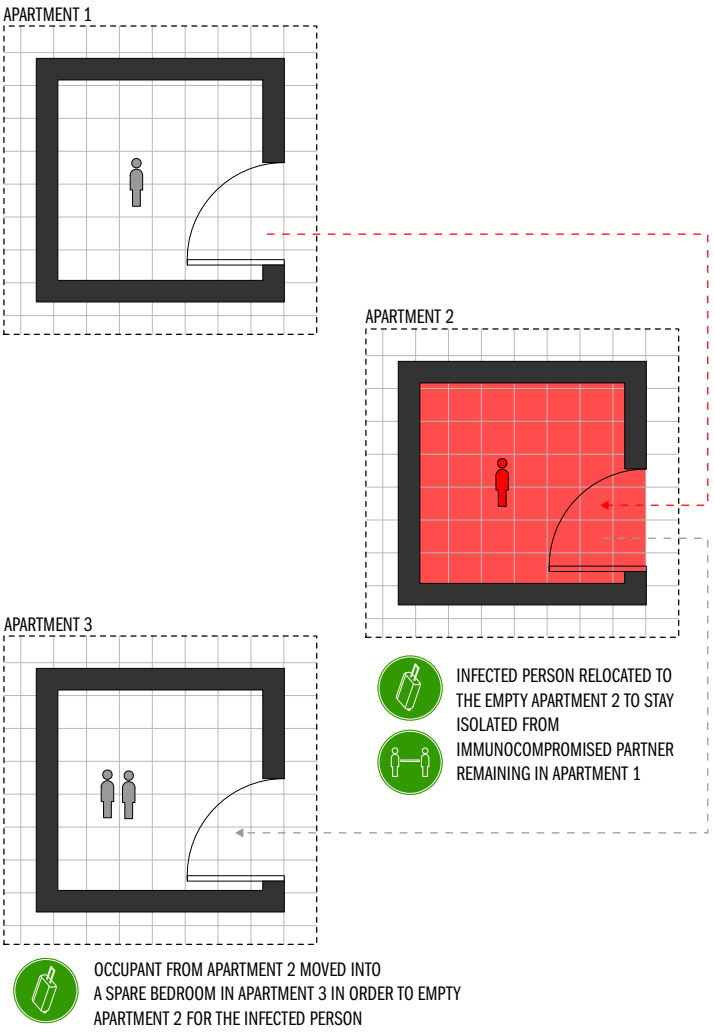
[118] Candace Lowry, "I had Coronavirus: My Experience," YouTube, last modified November 17, 2020, accessed March 4, 2021, https://www.youtube.com/watch?v=oWkBz4PDOYM.



[Fig.31] Scenario Fifteen.

Scenario Sixteen

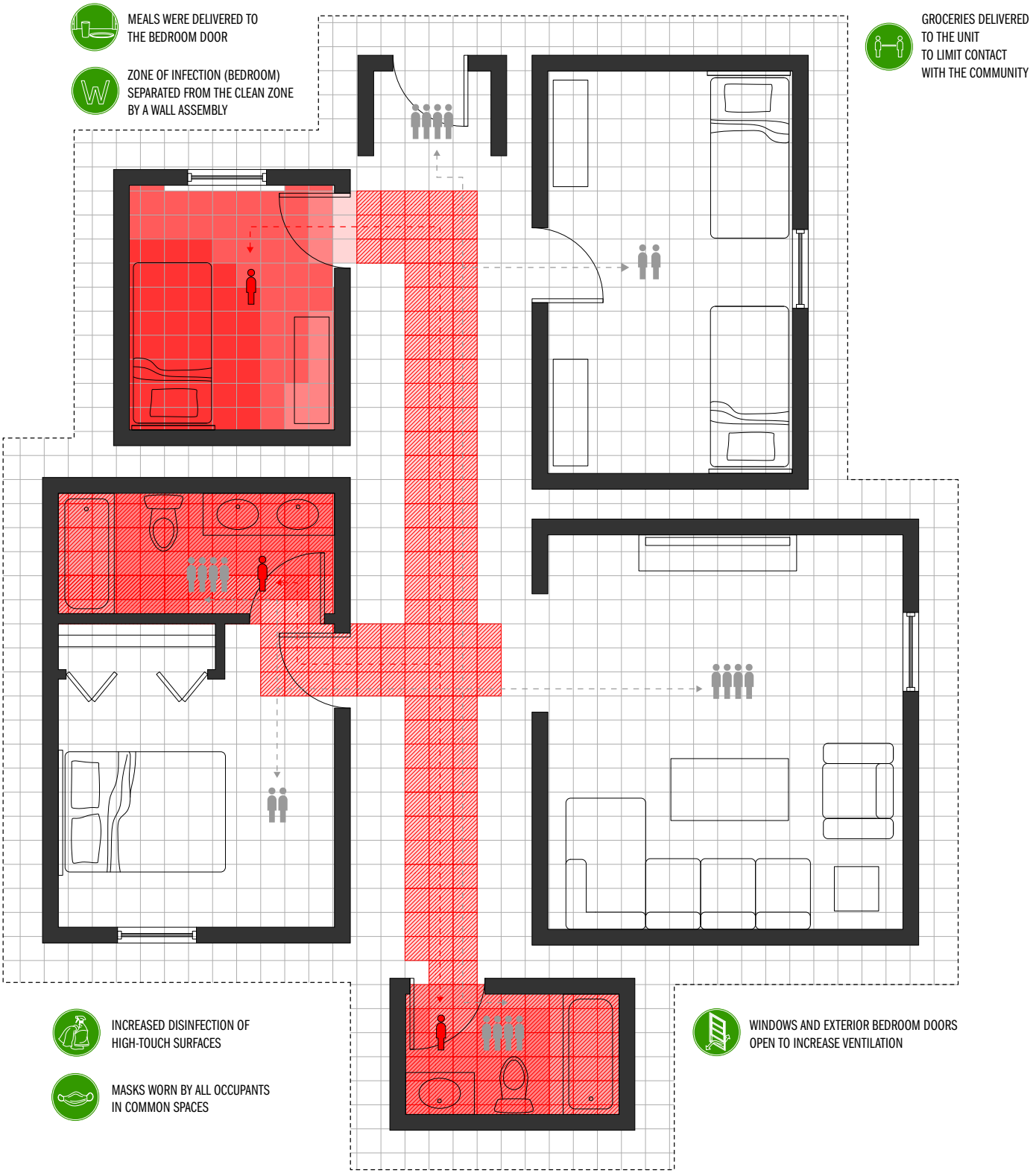
Scenario Sixteen depicts a Covid-19 mitigation strategy that involves three households. One occupant contracted Covid-19 and decided to relocate to a different apartment (Apartment 2) to protect her immunocompromised partner. The owner of Apartment 2 moved in with a friend in Apartment 3 as there was a spare bedroom available there. Apartment 2 was then empty for the infected person to occupy for a two-week quarantine.



[Fig.32] Scenario Sixteen.

Scenario Seventeen

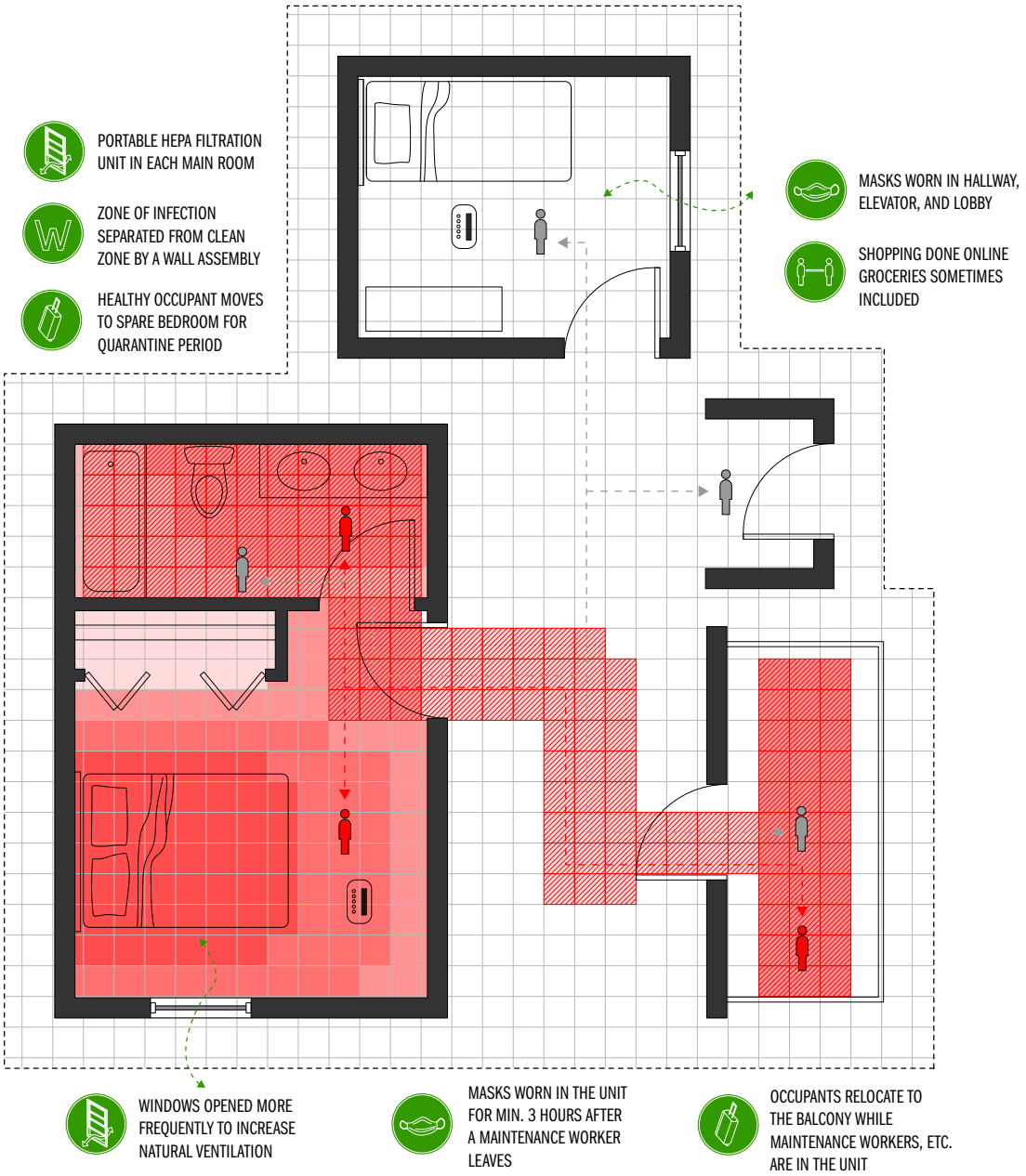
Scenario Seventeen illustrates the mitigation strategies used by a family of five living in a three bedroom apartment. Two of the daughters share a bedroom and the two bathrooms in the unit are shared by all members. The difficulty to maintain physical distance within the unit heightened the concerns of lack of screening for visitors in the building and lack of space throughout the rest of the building, particularly the elevators. The occupants of the unit have a stronger focus on hygiene and increased the disinfection of high touch surfaces. If someone were to contract Covid-19 they would quarantine in a bedroom, have meals delivered to their door, and all occupants would wear masks in the common spaces. To increase distance from the community, groceries would be delivered to the apartment by a third party.



[Fig.33] Scenario Seventeen.

Scenario Eighteen

Scenario Eighteen outlines the strategies used by an elderly couple living in an apartment unit. As general precautions, portable HEPA filtration units were set up in every room of the apartment, shopping was done online (sometimes including groceries), windows were opened more frequently, and masks were worn in the common spaces of the building such as elevators, hallways, and the lobby. If any outsiders, such as maintenance workers, needed to be in the unit, the couple would retreat to the balcony for the duration of the visit. Then, they would wear masks within the unit for a minimum of three hours after the visitors had left. If a member of the household were to catch the virus, they would attempt to operate in different spaces within the apartment to maintain physical distance.



[Fig.34] Scenario Eighteen.

Scenario Discussion

While these eighteen scenarios are unique, similarities can be identified. Common strategies include:

- the infected person quarantining in a bedroom
- wearing masks in shared spaces
- increased surface disinfection
- restricting the interaction between healthy persons and infected persons to the outdoors
- meals delivered to the infected person's door
- the infected person joining the rest of the family during meals while maintaining physical distance

A key observation is that the majority of the disease-spread prevention methods employed in the various homes can be classified as either spatial or procedural mitigation methods and there are fewer examples of ventilation and filtration strategies.

It is important to note most of these scenarios represent the Covid-19 mitigation strategies employed by people living in spaces with access to adequate spatial isolation. However, the opportunity for spatial isolation is not available in all residence typologies, including overcrowded homes (the dangers of which were discussed previously) increasing the vulnerability of the residents. Considering the airborne transmission of Covid-19, in spaces where spatial and procedural isolation strategies are less effective, environmental isolation, through the use of ventilation and filtration isolation strategies, could help mitigate the spread of an infectious illness.[119]

Discussion on Graphics

How do you draw time? This question, found handwritten the notes recorded during this period of research, was a key driver in the graphic representation development. The use of a gradient, with less time represented by a lighter shade and more time represented by a darker shade, was determined to be a comprehensive method of representing the relationship between viral load and length of time. The gradient grid provided a clear graphic framework to produce the speculative

[119] Megahed, and Ghoneim, "Indoor Air Quality," 7.

visual diagrams illustrating the risk of occupying the same spaces as an infected person.

The lack of knowledge in the spatial configuration of each residence presented a challenge and was addressed with the intentional abstraction of the built environment, reinforcing the speculative nature of the diagrams.

AUGUST TO NOVEMBER 2021:

Air Quality and Management

Covid-19: Airborne nature of Covid-19 is well established.

Thesis: Shifts to consider the importance of air quality and airflow management in the prevention of disease transmission and maintenance of general health in overcrowded, poorly ventilated spaces.

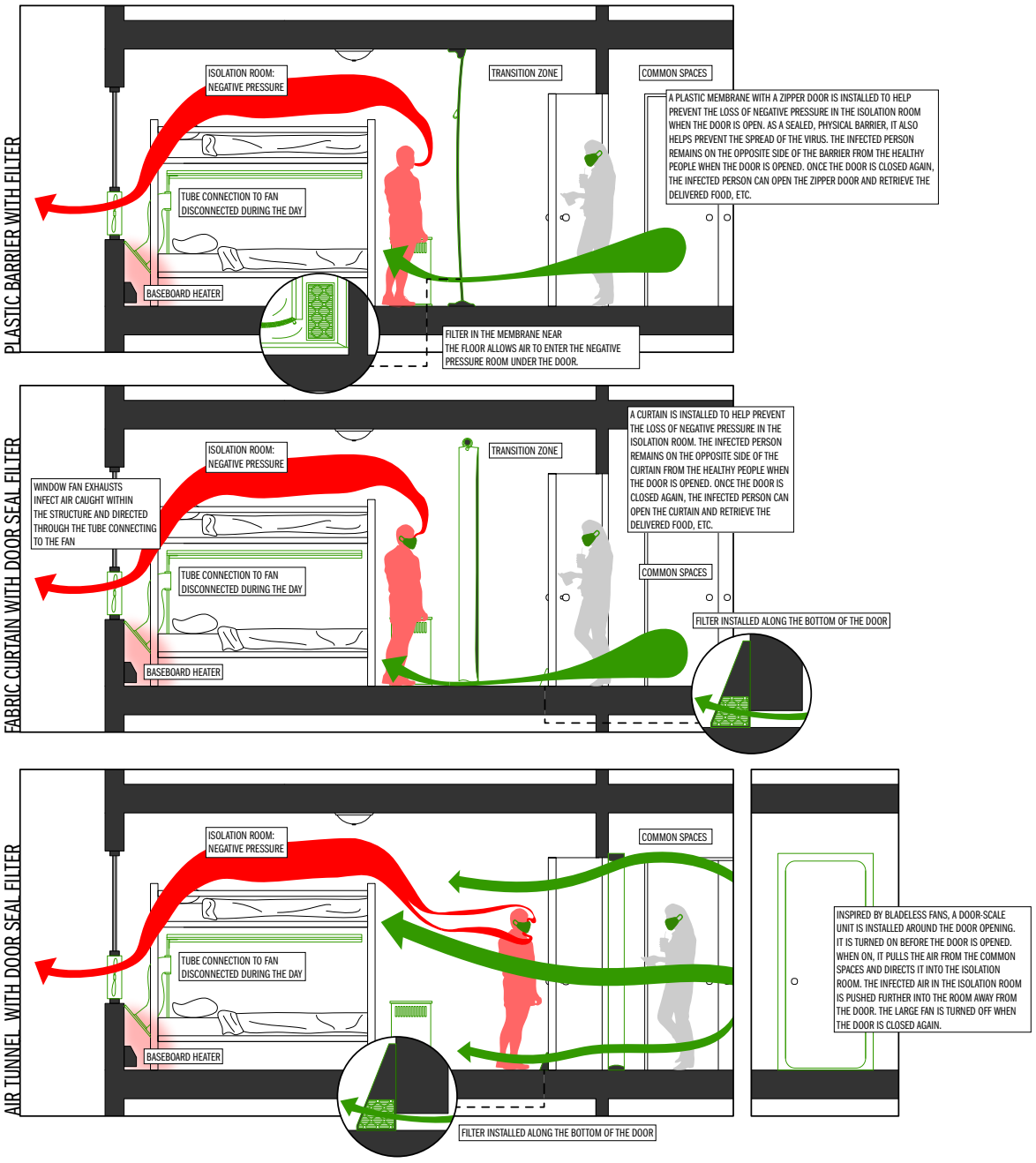
Graphic Representation: Focuses on illustrating the quality and movement of air within a residential space through the layering of colour, hatches, and symbols.

Crowded Spaces and Airborne Transmission

Crowded spaces can be considered spaces with a high risk of contaminant spread as the more people there are in a space, the greater the chance for virus introduction and transmission. The need for adequate ventilation increases as the number of people in a space increases.[120] There is a greater risk of transmission within proximity to the infected source, however, the risk of infection can persevere despite increased distances. These situations often feature a combination of a lack of source control (for example, an infected person not wearing a mask) and inadequate or no ventilation of the space being occupied.[121] Under the right conditions, suspended aerosol particles can travel through an entire space and remain in a room after the source of infection has left.[122] The focus of this thesis evolved to consider how the incorporation of environmental isolation strategies, like air filtration and room pressurization, could decrease the risk of contaminant spread in crowded spaces.

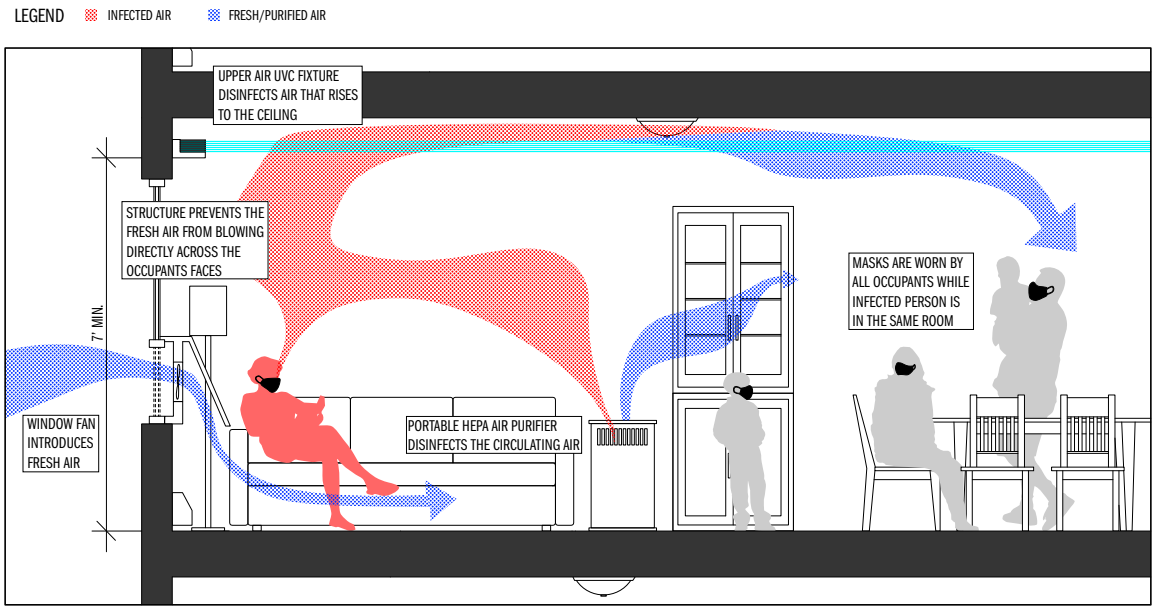
[120] "Ventilation and Coronavirus (COVID-19)," United States Environmental Protection Agency, last modified June 8, 2021, accessed September 5, 2021, https://www.epa.gov/coronavirus/ventilation-and-coronavirus-covid-19.
[121] Public Health Ontario, *COVID-19 Transmission Through Large Respiratory Droplets and Aerosols.*
[122] United States Environmental Protection Agency, "Indoor Air and Coronavirus (COVID-19)."

With this redirected focus came a graphic exploration to establish a method of visulizing air movement and quality. The early iterations were solid red and green bubbles with arrows indicating the direction of air flow.



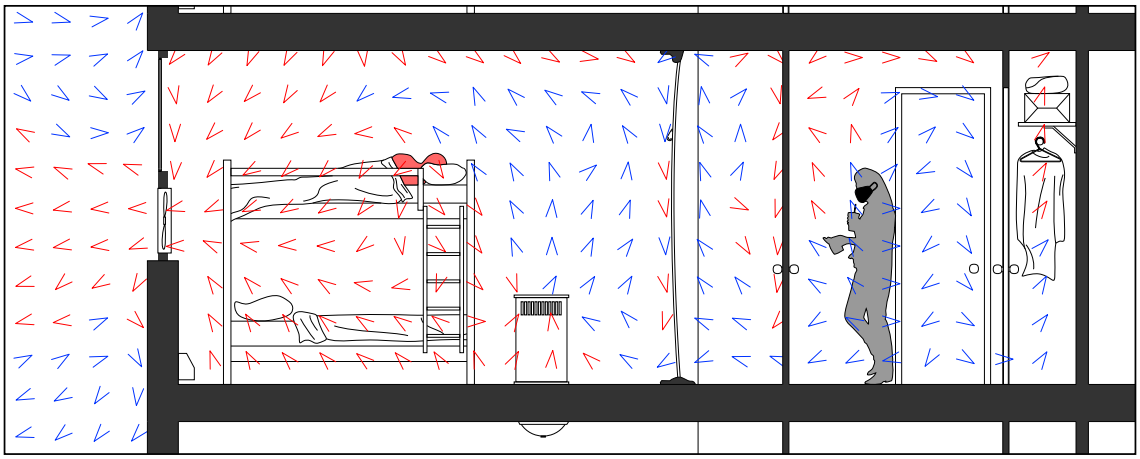
[Fig.35] Graphic style using red and green bubbles with a solid fill.

The colour green was later swapped with blue to follow a more conventional representation of exhaust and supply air. The solid fill became a dotted hatch to acknowledge the fact that air is not solid.



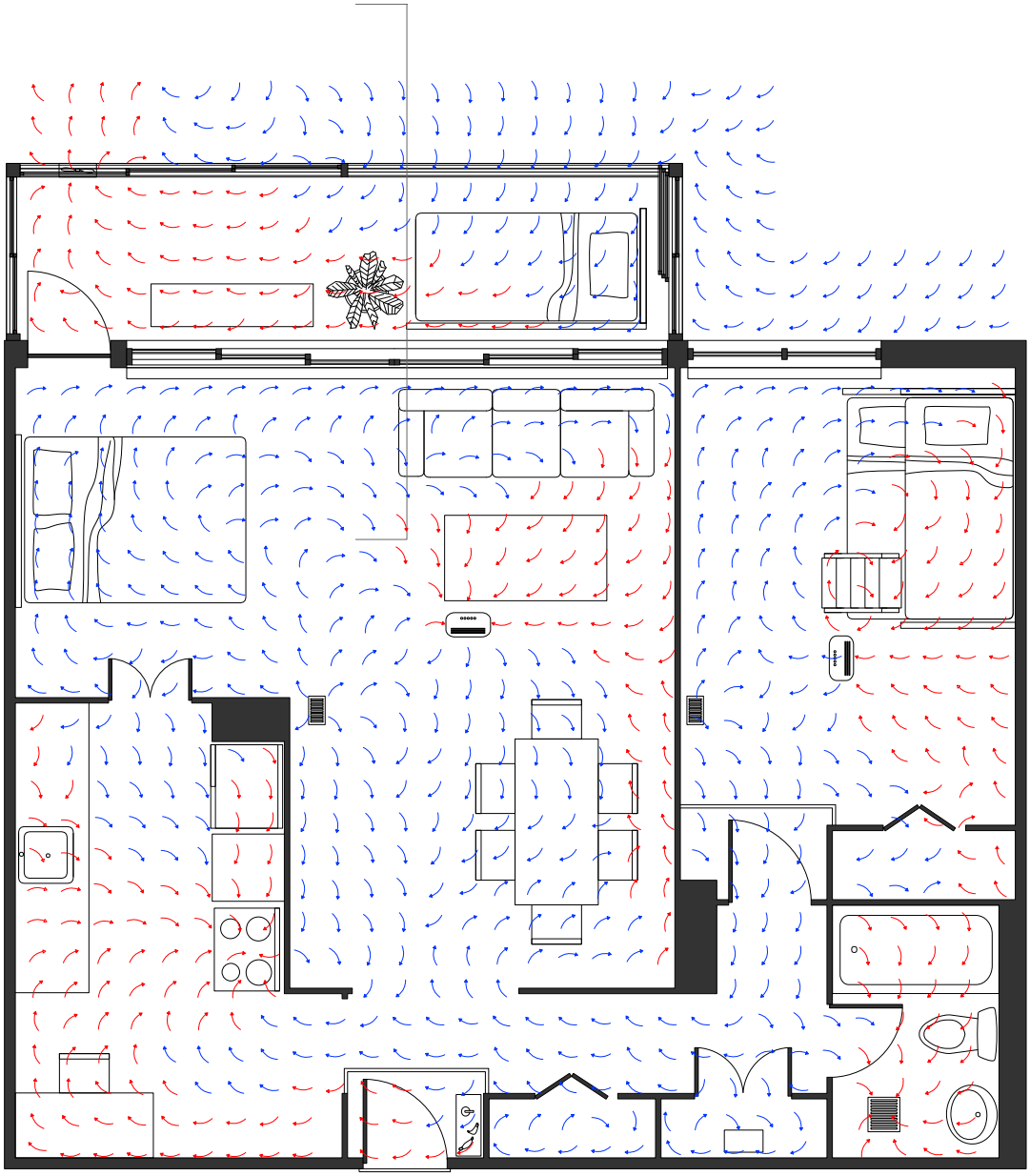
[Fig.36] Graphic style using red and blue bubbles with a dotted fill.

Understanding the difficulty of knowing the exact movement of air, the bubbles were replaced by a grid of red and blue angles to abstract the direction of airflow further.



[Fig.37] Graphic style using red and blue angles indicating general air movement.

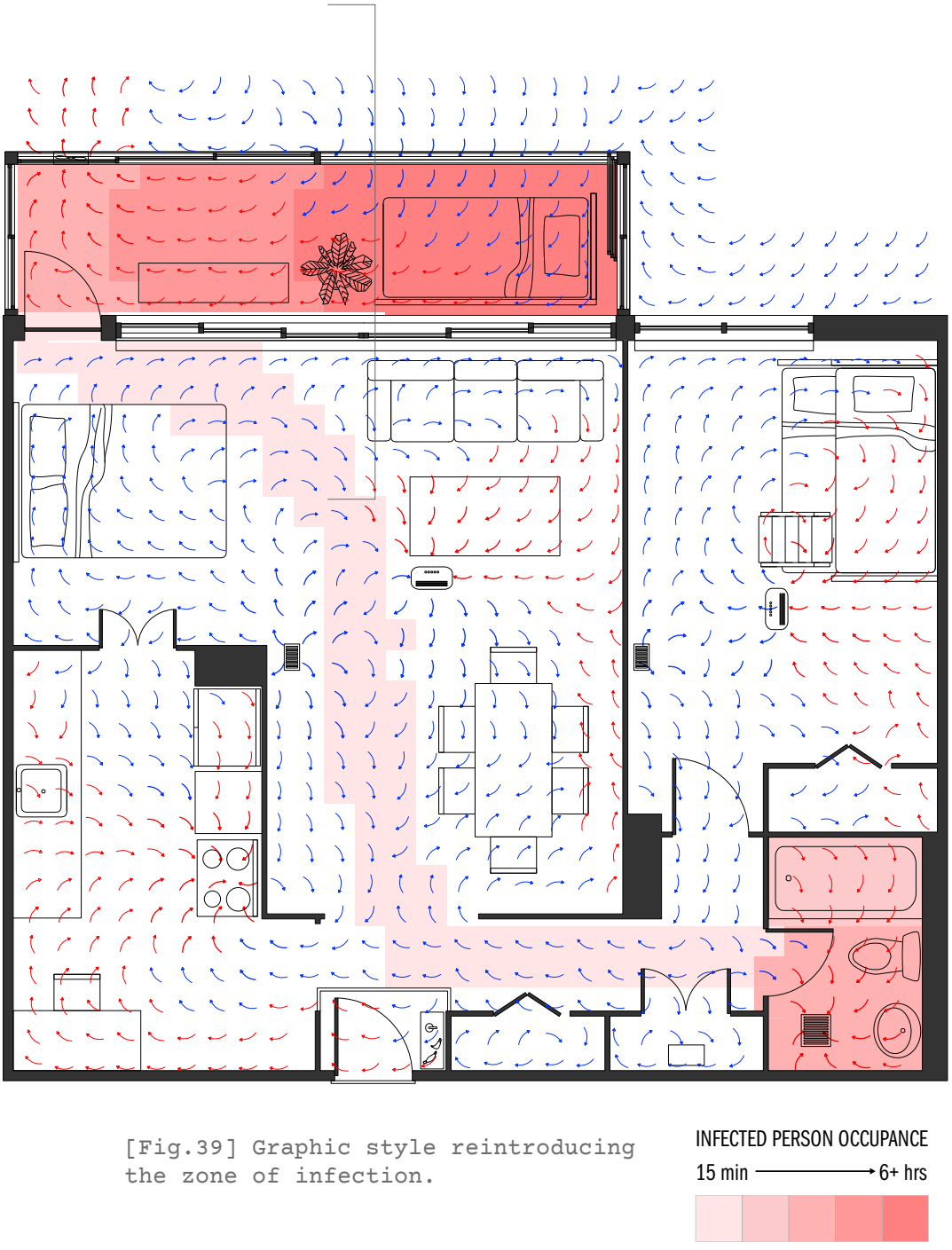
The symbols used became curved arrows to add a stronger feeling of flow to the drawing. It is important to note that, as they are used in this thesis, the arrows represent abstract air movement and are not derived from any calculations or computational fluid dynamics (CFD) software.



[Fig.38] Graphic style using red and blue arrows indicating general air movement.

The use of only red and blue hindered the ability to differentiate between the various air qualities present, which include fresh, filtered, stale, and infected.

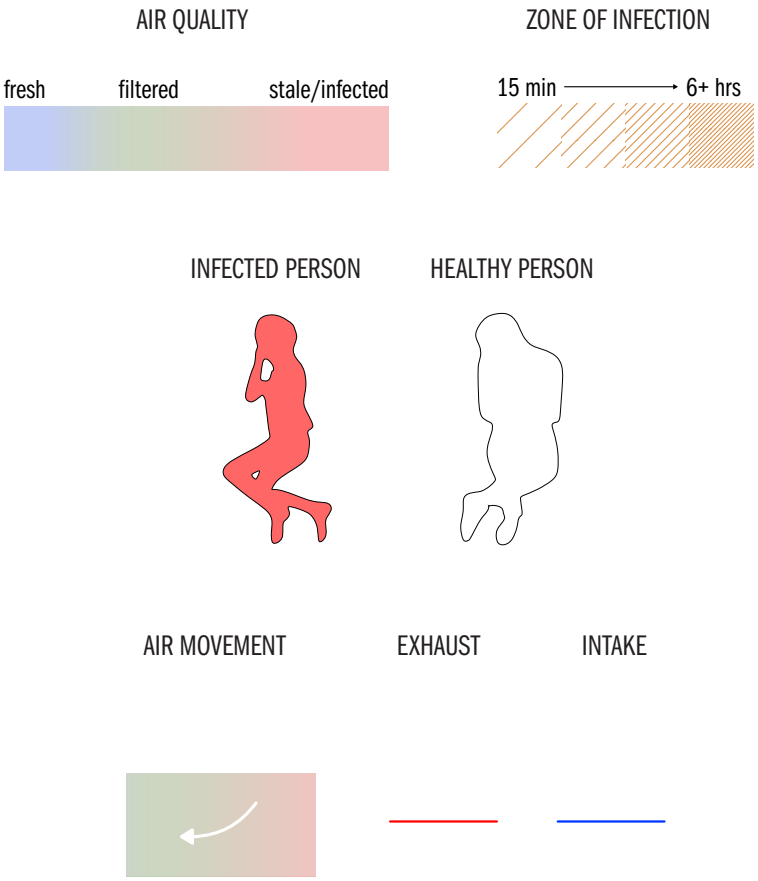
To indicate which red arrows pertain to infected air, the zone of infection grid was reintegrated into the graphic style. However, the difference between fresh and filtered air was still unclear.



[Fig.39] Graphic style reintroducing the zone of infection.

A Note on Graphics

As the movement and quality of air became a focus during the final months of research, time was spent to highlight the shift from emphasizing physical barriers to exploring air as an entity in the drawings. In the final graphic iteration, air quality is represented by a colour gradient with a grid of white arrows overlaid to indicate abstract air movement. The zone of infection remains but becomes a hatch gradient instead so it can also be superimposed on the air quality gradient. A final notable change in the graphics is the transition from a dark poche to a white poche to make the invisible visible.



[Fig.40] Legend for the final graphic iteration.

CONCLUSION

The graphic representation of isolation and mitigation strategies evolved along with knowledge about the spread of the Covid-19 virus. The exploration began with a spatial and procedural focus, tracing how a person moves through a space and the individual measures taken to prevent disease transmission. In public spaces, ideas about the 2m separation distance were strong and arrows on the ground directed traffic. Masks and temporary barriers provided additional protection. These strategies, as physical and spatial, were straight-forward to draw. However, as the pandemic progressed, the graphics had to evolve to match the complexity of airborne disease transmission.

The question of how to make the invisible visible drove the later graphic iterations. The complexity of airborne transmission required the development of a multi-layered graphic strategy. A system of colours, symbols, and hatches work together to schematically illustrate the various air qualities and movement through a space as influenced by people, mechanical devices, and architectural design. The separation of the zone of infection, the quality of air, and the direction of air movement allows both the reader and designer to study a specific componenet of the system with ease. This separation also allows for a more conscious understanding of the relationships between the different components, for example, what happens to the air movement when another portable HEPA filtration unit is introduced or what happens to the air quality if the zone of infection is expanded to occupy a second room.

There is room for further refinement of the final graphic iteration developed for this thesis. With the likely continuation of concern over indoor air quality, carried forward from the pandemic and maintained by increased air pollution due to climate change, the establishment of a comprehensive system for the graphic representation of air quality and movement could be integral to the process of designing healthy spaces to live. Furthermore, a visual aid could be informative for the occupants of the designed spaces and help ensure their understanding of the mitigation and preventative features incorporated in their home.

The consideration of isolation as a spatial issue has contributed to the inequality in the ability to isolate safely within residential spaces. The Covid-19 pandemic is a reminder that, when mitigating the spread of an airborne infectious illness, "successful solutions consider environmental health and prioritize [indoor air quality]".[123] As reliance on modern medicine increased, the role of architecture in the prevention of infectious disease spread decreased.[124] However, the pandemic clarified that the use of environmental strategies for mitigating the spread of disease should not be overlooked in residential spaces.[125]

[123] Megahed, and Ghoneim, "Indoor Air Quality," 7.
[124] Fezi, "Health Engaged Architecture," 191.
[125] Megahed, and Ghoneim, "Indoor Air Quality," 7.

PART THREE: DESIGN

The Retrofit Phases
Phase One: Off-the-Shelf
Phase Two: The Unit and HVAC
Phase Three: The Balcony
Phase Four: The Façade
Phases One to Four: Benefits and Cost

INTRODUCTION

This chapter presents a response to the problem of poor indoor air quality and lack of space for adequate isolation in ageing postwar towers through a proposed retrofit design. A postwar tower in Thorncliffe Park was selected as the thesis project site, a decision informed by the research presented earlier. In addition to the poor indoor air quality facilitated by outdated HVAC systems,[126] the units in the ageing towers of this neighbourhood each house anywhere from four to eleven people making many of them overcrowded.[127] The neighbourhood has approximately 30,000 residents despite being designed for only 12,000.[128] In combining high density, poor indoor air quality, and low income residents, this aging tower provides a worst case setting to explore potential solutions for mitigating the spread of airborne infectious diseases.

The design work focuses on three building components: the unit, the balcony, and the façade. The retrofit is split into four phases which can be inserted among the four energy retrofit levels outlined in a report by the Tower Renewal Partnership.[129] In this retrofit, occupant health is prioritized through a focus on air quality and management during the design of a flexible, intermediate space for living and isolation.

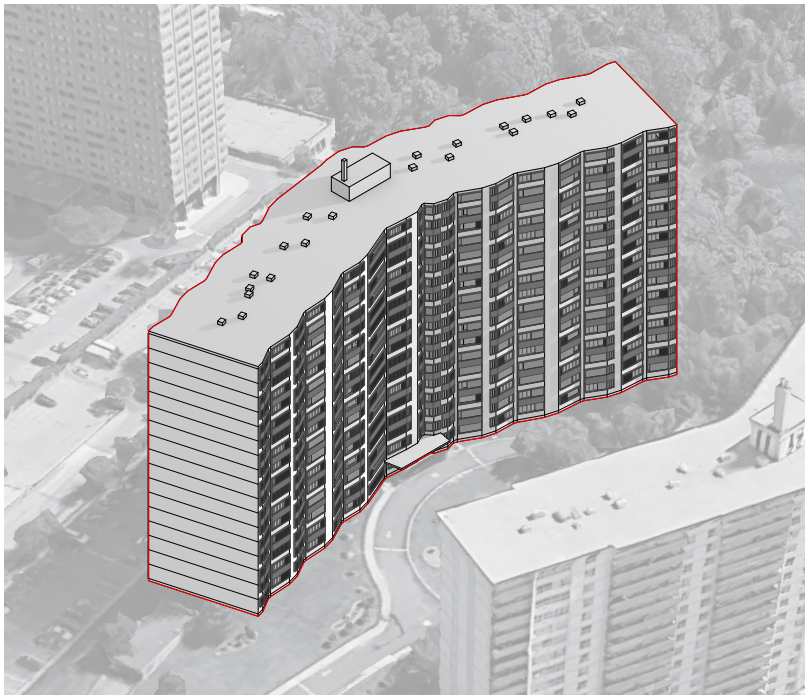
[126] Tower Renewal Partnership, *Advancing Building Retrofits*, 21.
[127] Vik Adhopia, "How one of Toronto's COVID-19 hot spots is struggling through the pandemic," CBC, last modified June 23, 2020, accessed February 16, 2021, https://www.cbc.ca/news/health/thorncliffe-park-covid-1.5622560.
[128] Flavie Halais, "How Toronto is Revitalizing its Aging Suburban Residential Towers," Government Technology, August 14, 2015, https://www.govtech.com/fs/how-toronto-is-revitalizing-its-aging-suburban-residential-towers.html.
[129] Tower Renewal Partnership, *Advancing Building Retrofits*, 6-7.

[Fig.41] 79 Thorncliffe Park Dr. existing building.

[Fig.42] Thorncliffe Park, Toronto, ON.

THE RETROFIT PHASES

The four phases of the thesis retrofit can be implemented sequentially or independently on a case-by-case basis.



[Fig.43] 79 Thorncliffe Park Dr. retrofit axonometric.

PHASE ONE: OFF-THE-SHELF

Phase One is designed to be executed by the occupants in buildings that have undergone recent deep energy retrofits or where there are no funds or imminent plans for retrofit. In relation to the Tower Renewal Partnership retrofit levels,[130] as an off-the-shelf intervention, Phase One can be implemented at any level.

0 YEARS

A QUICK-FIX APPROACH FOR IMPROVED INDOOR AIR QUALITY AND PROVISION OF A SAFER ISOLATION SPACE.

Retrofit Strategy

INTRODUCE OFF-THE-SHELF PRODUCTS FOR AIR FILTRATION AND ROOM PRESSURIZATION.

Pros

- QUICK INSTALLATION
- CONTROLLED BY OCCUPANT
- LOW COST
- IMPROVED INDOOR AIR QUALITY WITH AIR FILTRATION
- INCREASED CONTROL OVER SPREAD OF CONTAMINANTS WITH ROOM PRESSURIZATION
- CAN BE APPLIED TO ANY RESIDENTIAL BUILDING

Cons

- LESS EFFECTIVE WITH LEAKY ENVELOPES
- DOES NOT ADDRESS LACK OF SPACE IN THE UNITS
- DOES NOT ADDRESS POOR PASSIVE VENTILATION IN THE UNITS
- DOES NOT ADDRESS INADEQUATE SUPPLY AIR TO THE UNITS

Implementation

EXISTING BUILDING (FOR VIRAL OUTBREAK)

PHASE TWO: THE UNIT AND HVAC

Phase Two aligns with common energy retrofit plans for buildings nearing the end of their lifecycle. Simliar to Tower Renewal Partnership's Medium Energy Retrofit (Level 2), Phase Two focuses on HVAC system and envelope upgrades.[131]

1 YEAR

SHORT-TERM ENVELOPE AND ENVIRONMENTAL SYSTEM UPGRADES TO INCREASE THE EFFICACY OF THE FIRST PHASE.

Retrofit Strategy

UPGRADE THE HVAC SYSTEM AND COMPARTMENTALIZE THE UNITS.

Pros

- IMPROVED INDOOR AIR QUALITY WITH UNITS RECIEVING SUFFICIENT SUPPLY AIR
- IMPROVED ENVIRONMENTAL CONTROL WITHIN UNITS THROUGH DECENTRALIZED HVAC SYSTEM
- CAN BE APPLIED TO ANY MULTI-UNIT RESIDENTIAL BUILDING

Cons

- DOES NOT ADDRESS LACK OF SPACE IN THE UNITS
- DOES NOT ADDRESS POOR PASSIVE VENTILATION IN THE UNITS
- INCREASED COST

Implementation

SYSTEM RETROFIT (FOR GENERAL IAQ IMPROVEMENT)

[130] Tower Renewal Partnership, *Advancing Building Retrofits*, 6-7.
[131] Ibid, 7.

PHASE THREE: THE BALCONY

Phase Three is intended for buildings where extensive retrofit is required such as HVAC upgrades, envelope upgrades, and window and door replacements. It parallels the Tower Renewal Partnership's Deep Energy Retrofit and Complete Retrofit (Level 3 and 4 respectively).[132]

5 YEARS

MORE EXTENSIVE RETROFIT TO INCREASE THE AREA OF THE UNITS WHILE IMPROVING INDOOR AIR QUALITY.

Retrofit Strategy

REMOVE EXISTING BALCONIES AND INSTALL NEW EXTENDED, ENCLOSED BALCONIES.

Pros

- INCREASED UNIT AREA
- FLEXIBLE INTERMEDIATE SPACE TO BE PROGRAMMED BY THE OCCUPANTS
- INCREASED OPPORTUNITY FOR SAFE ISOLATION
- THERMAL BUFFER DECREASES ENERGY LOADS
- IMPROVED INDOOR AIR QUALITY WITH UNITS RECIEVING SUFFICIENT MECHANICAL SUPPLY AIR AND PASSIVE VENTILATION
- CAN BE APPLIED TO ANY MULTI-UNIT RESIDENTIAL BUILDING

Cons

- INCREASED TIME TO COMPLETE RETROFIT
- POTENTIAL NEED FOR OCCUPANTS TO VACATE UNIT FOR A PERIOD
- INCREASED COST

Implementation

EXTENSIVE RETROFIT, NEW BUILD (FOR GENERAL IAQ IMPROVEMENT AND VIRAL OUTBREAK PRECAUTION)

PHASE FOUR: THE FACADE

Phase Four is imagined as a future extension to Phase Three as the technology for the components proposed requires further development. However, if made feasible, the design features of Phase Four are generic enough to be implemented during any of the earlier phases.

10+ YEARS

IMAGINING THE USE OF PASSIVE AIR FILTRATION UNDER THE PRESSURE OF CLIMATE CHANGE.

Retrofit Strategy

INSTALL AIR FILTRATION CURTAINS ON THE FACADE.

Pros

- IMPROVED INDOOR AIR QUALITY
- PASSIVE AIR FILTRATION STRATEGY
- LOW ENERGY LOADS
- CAN BE APPLIED TO ANY RESIDENTIAL BUILDING

Cons

- EXPENSIVE INITIAL COST
- CURRENT TECHNOLOGY REQUIRES MORE DEVELOPMENT AS RELIABLE PRODUCTS ARE NOT YET AVAILABLE. IT IS STILL A RELATIVELY THEORETICAL CONCEPT

Implementation

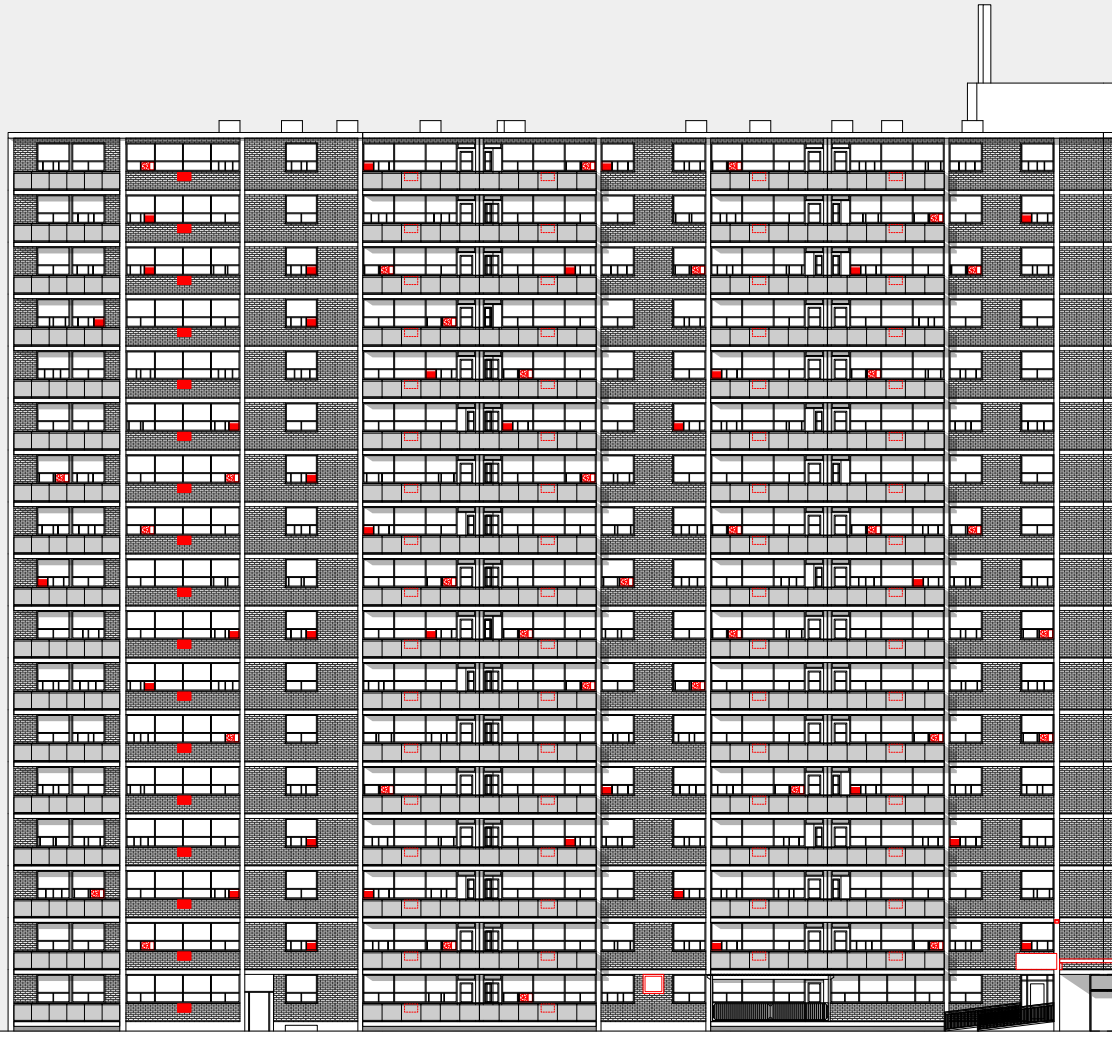
EXTENSIVE RETROFIT, NEW BUILD, POTENTIAL FOR APPLICATION ON EXISTING BUILDINGS (FOR IAQ IMPROVEMENT)

[132] Tower Renewal Partnership, *Advancing Building Retrofits*, 7.

The four retrofit phases are explored in a one-bedroom unit, however the standardized strategies of the retrofit are designed to be applicable to every unit size and other postwar towers throughout the city.

The Existing Building

The existing building is a 17 story, concrete tower containing a variety of units ranging from bachelor to three-bedroom. The building is equipped with a centralized HVAC system which provides each unit with air using corridor pressurization. This system, as it is common with postwar towers, is most likely underperforming.[133]

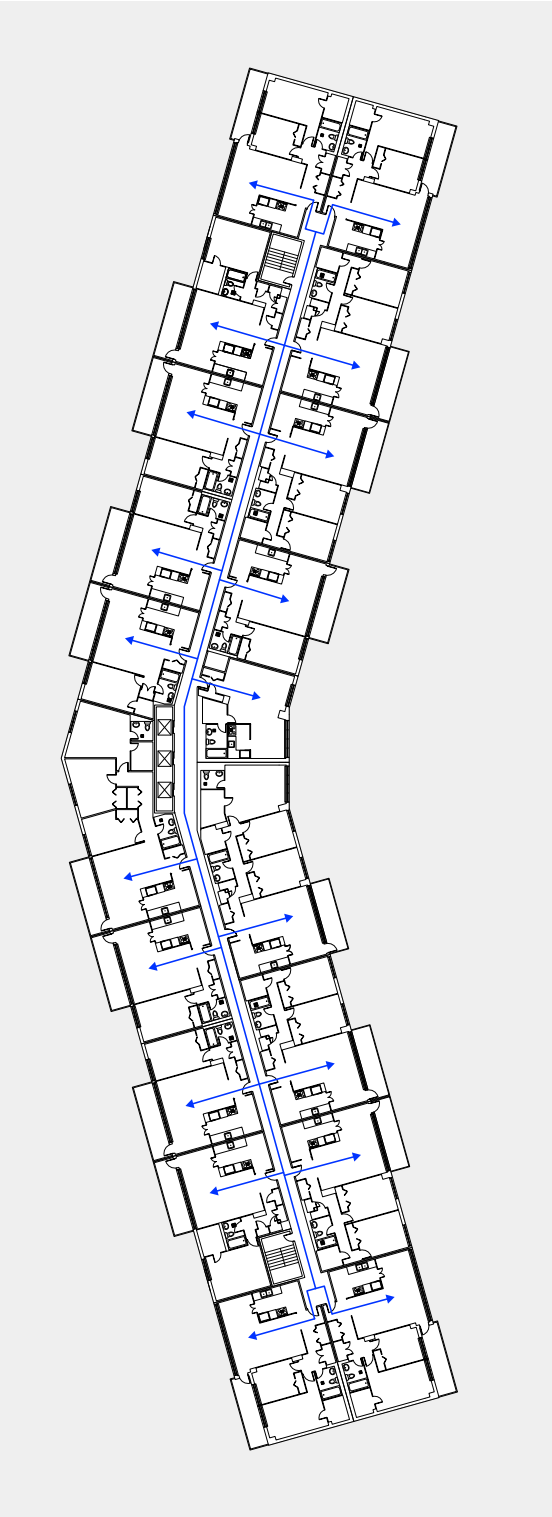


[Fig.44] Existing elevation (view has been flattened).

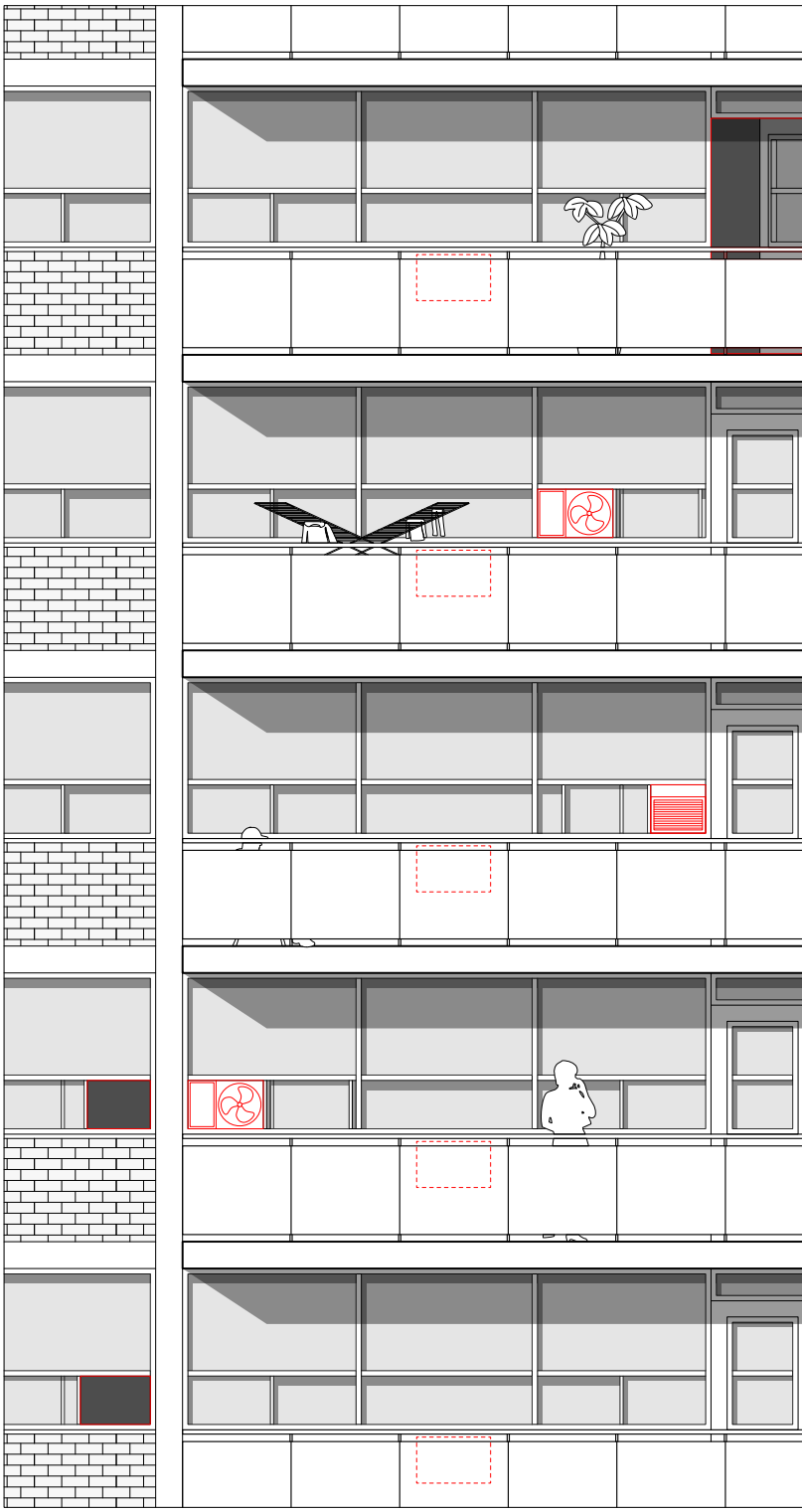
[133] Tower Renewal Partnership, *Advancing Building Retrofits*, 19-21.

The façade of the building is symmetrical, save for the scattering of HVAC-related interventions implemented independently by the occupants to complement the existing, underperforming system. A scan of the façade reveals air conditioning units, window fans, open windows, and open doors. The occupants take advantage of the additional space provided by the balconies animating them with temporary occupation, drying clothes, and extra storage.[134]

[134] "Google Maps Street View Thorncliffe Park", Google Maps, accessed November 2021, https://www.google.com/maps/@43.704855,-79.3411777,3a,54y,352.43h,105.93t/data=!3m7!1e1!3m5!1sn6HKjvKOIkvmErRulvbr9A!2e0!5s20180901T000000!7i13312!8i6656.



[Fig.45] Existing typical floor plan with corridor pressurization.



[Fig.46] Existing elevation with occupant implemented HVAC interventions.

PHASE ONE: OFF-THE-SHELF

The components included in the first phase of the retrofit are intended to be brought into the unit by the occupants to provide rudimentary environmental improvements in their units. The components facilitate air filtration and room pressurization strategies that support a general improvement to indoor air quality[135] and the reduced spread of infection through the unit[136] in times of emergency respectively.

Air Filtration

To improve the general indoor air quality, a portable high efficiency particulate air (HEPA) filtration unit is set up in each main room of the unit.[137] This supplements any filtration incorporated into the existing HVAC system.[138]

Two HEPA filtration units are included in the example. The first is set up in the bedroom and the second is set up in the common space. A specific source of contamination might not be identified when the filtration units are being used for general air cleaning. In this case, the filtration unit should be centrally located with the clean air expelled towards higher occupancy areas.[139] However, if a source of air contamination is known, for example, an infected person, the filtration unit should be located close to the source to clean the contaminated air as soon as possible.[140]

Though the efficacy of HEPA filtration against the Covid-19 virus is still in question,[141] the removal of a large portion of small particles and aerosols will help decrease their vulnerability when faced with an infectious illness like Covid-19, and more, by the reduced risk of developing underlying medical conditions.[142]

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[135] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, (Public Health Ontario, December 2020), 4, https://www.publichealthontario.ca/-/media/documents/ncov/ipac/2021/01/faq-covid-19-portable-air-cleaners.pdf?la=en#:~:text=Although%20no%20direct%20scientific%20evidence,air%20and%20potentially%20reduce%20exposure..

[136] "Hospital Isolation Rooms," University of Michigan Health: Michigan Medicine, last modified May 27, 2020, https://www.uofmhealth.org/health-library/abo4381.

[137] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.

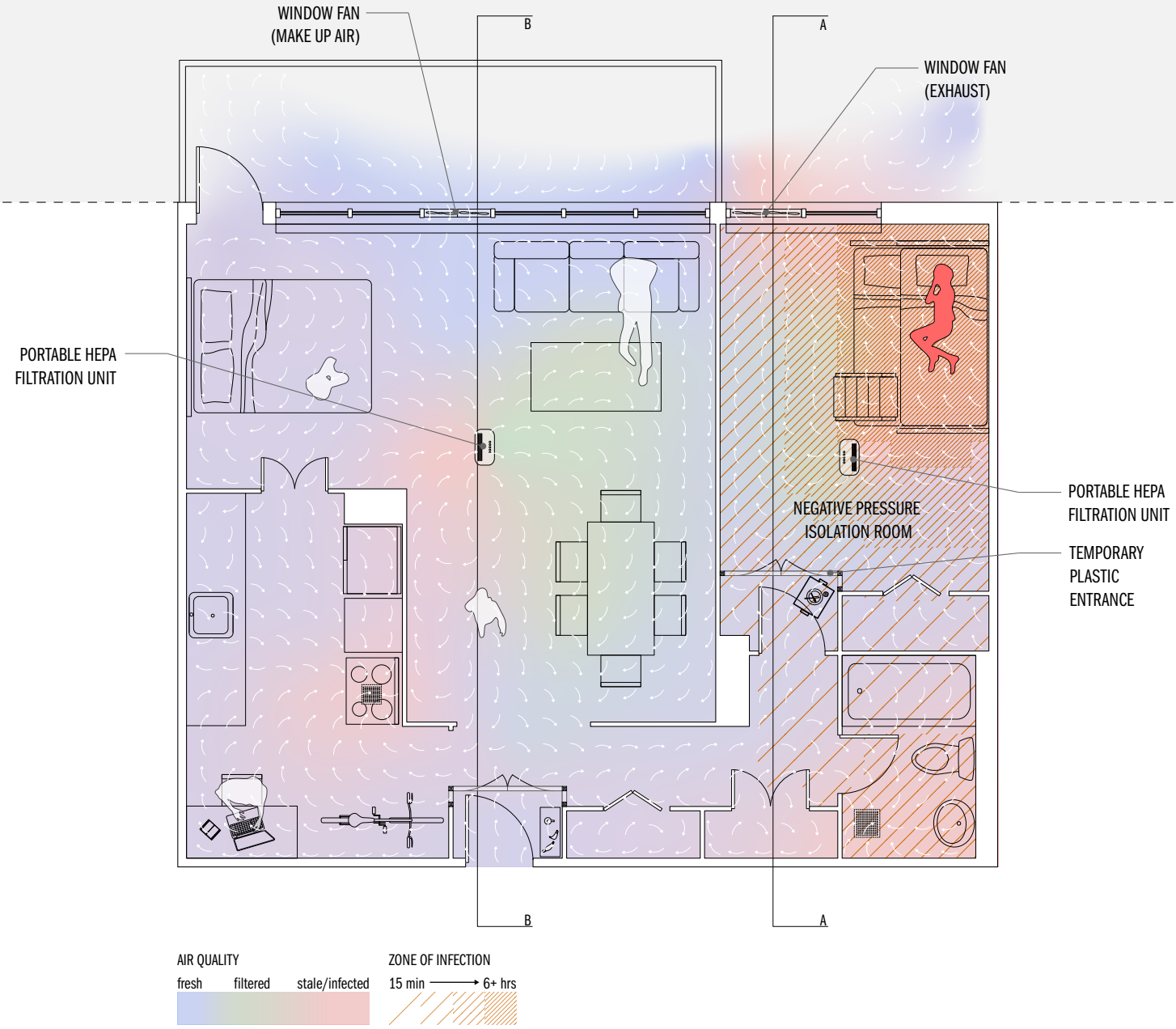
[138] ASHRAE, *In-Room Air Cleaner Guidance For Reducing Covid-19 In Air In Your Space/Room*, (January 2021), https://www.ashrae.org/file%20library/technical%20resources/covid-19/in-room-air-cleaner-guidance-for-reducing-covid-19-in-air-in-your-space-or-room.pdf.

[139] *Residential Air Cleaners A Technical Summary*, (United States Environmental Protection Agency, July 2018), 9, https://www.epa.gov/sites/default/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf.

[140] *Residential Air Cleaners*, 37.

[141] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.

[142] Government of Canada, "Vulnerable Populations and COVID-19."



[Fig.47] One-bedroom floor plan: Phase One retrofit.

Room Pressurization

If the need for isolating an occupant arises, negative pressurization of a room is a useful tool in preventing the spread of contaminants through the rest of the unit.[143] In a negative pressure room, the air is exhausted from the room and expelled to the outdoors. As the air is exhausted, new air is pulled into the room often under a door or unintentionally through envelope or partition leaks. In summary, "less air is supplied than is exhausted."[144] This strategy is often used in hospitals to isolate airborne infections and prevent them from spreading throughout the building.[145] A simple negative pressure isolation room can be created with the installation of a window fan and a temporary secondary doorway.[146]

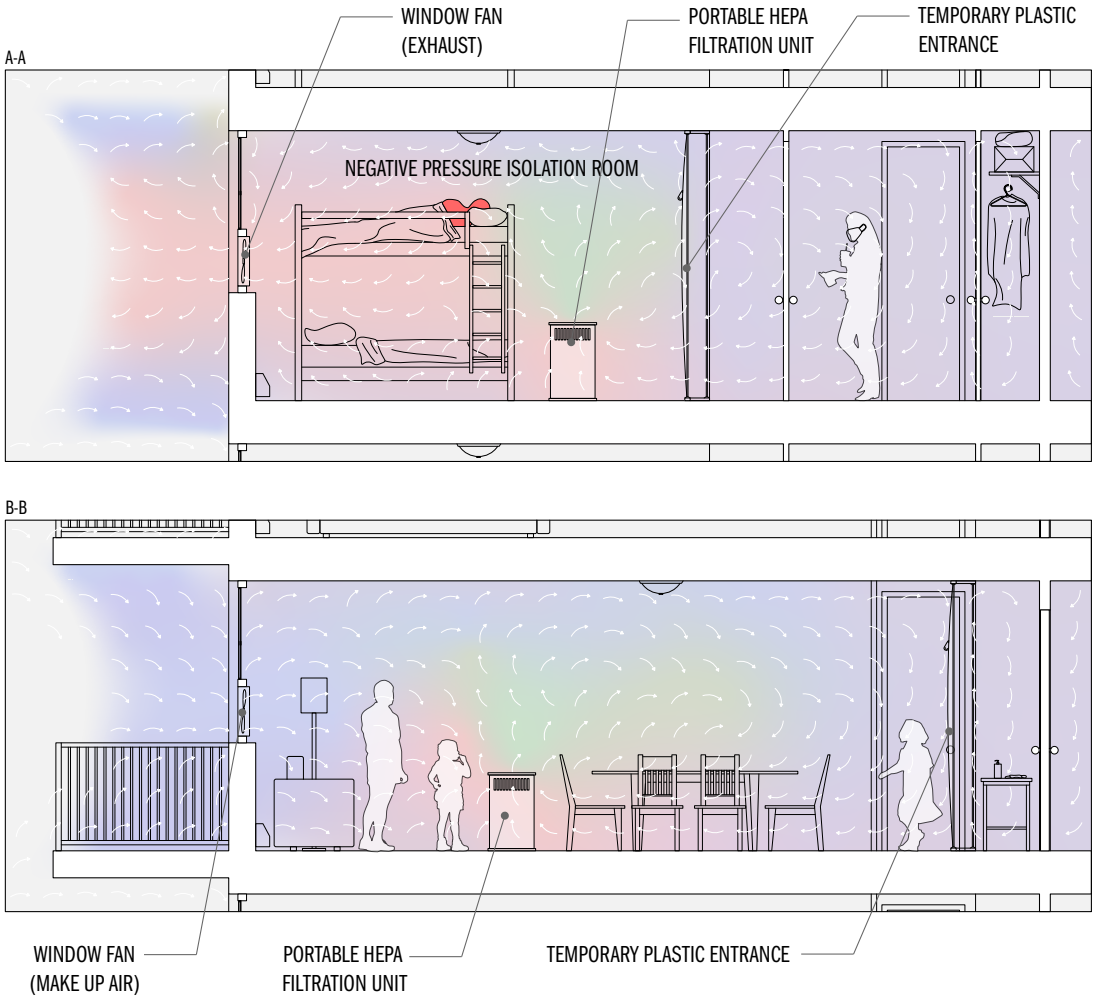
To set up the negative pressurization isolation room, the infected person isolates in a room, in this case, the bedroom. A window fan is inserted into the bedroom window to exhaust the air out of the room.[147] The contaminated air forced outside is replaced by new air which is pulled into the bedroom from the rest of the unit.[148] Exhausting air from a space without controlled make-up air "causes air to come into your building through places you probably don't want air to come through while carrying stuff or picking up stuff you don't want inside your building."[149] Therefore, a second window fan pulling air into the common space helps to ensure the make-up air is introduced from the desired location.

To help maintain the depressurization of the isolation room, a plastic barrier with a zipper door is installed inside the bedroom as a secondary airlock-inspired entrance to the room. Therefore, a constant barrier is maintained between the bedroom and the unit as only one door would be opened at a

[143] Wei Sun, "Controlled Environments: Room Pressure, Flow Offset, Airtightness and Pressurization Strategies," *ASHRAE Journal* 62, no. 12 (December 2020), 70, https://www.nxtbook.com/nxtbooks/ashrae/ashraejournal_HJETUK/index.php#/p/62.
[144] *Building Air Quality: A Guide for Building Owners and Facility Managers*, (U.S. Environmental Protection Agency, December 1991), 8, https://www.epa.gov/indoor-air-quality-iaq/building-air-quality-guide-guide-building-owners-and-facility-managers.
[145] Univeristy of Michigan Health: Michigan Medicine, "Hospital Isolation Rooms."
[146] ASHRAE, *Guidance for Covid-19 Risk Reduction in Residential Buildings*, (ASHRAE, June 24, 2021), https://www.ashrae.org/file%20library/technical%20resources/covid-19/guidance-for-residential-buildings.pdf.
[147] ASHRAE, *Guidance for Covid-19 Risk Reduction in Residential Buildings*.
[148] Univeristy of Michigan Health: Michigan Medicine, "Hospital Isolation Rooms."
[149] Joseph Lstiburek, "BSI-070: First Deal with the Manure and Then Don't Suck," Building Science Corporation, last modified June 11, 2014, https://www.buildingscience.com/documents/insights/bsi-070-first-deal-with-the-manure.

time, either the permanent bedroom door or the temporary plastic door.[150]

The space between the two doors creates a transition zone. For example, a healthy person delivering food to the isolated person can open the bedroom door and leave the meal in the space between the two doors. Once the bedroom door is closed again, the isolated person can open the temporary door and retrieve the food. The transition zone provides a buffer between the healthy and infected occupants.[151]



[Fig.48] Bedroom and common space sections: Phase One retrofit.

[150] Sun, "Controlled Environments," 70.
[151] Ibid, 70.

Impacts

The first phase of the retrofit provides options for residents to improve their everyday indoor air quality and manage the flow of air through their unit to facilitate better isolation when needed. The introduction of the HEPA filtration units helps to address the issue of poor indoor air quality by providing supplemental air cleaning within the unit.[152] The creation of a negative pressure isolation room allows for the better isolation of an identified source of contamination by preventing contaminated air from circulating through the entire unit.[153] The two interventions act together to decrease the concentration of the virus in the air throughout the unit and thereby decrease the likelihood of virus inhalation by the healthy occupants when a family member is ill.

PHASE TWO: THE UNIT AND HVAC

It can be assumed that the units of the tower are not airtight due to a lack of recent envelope upgrades.[154] Leaky envelopes, and more importantly leaky interior partitions, are a concern as they allow air to be pulled into the unit from unwanted locations, such as a neighbouring unit, with the potential to carry airborne contaminants.[155] As referenced earlier, this often occurs when exhaust fans, common in the kitchen and bathroom, are running without the provision of a proper source of make-up air.[156] A lack of control over when and where air enters the unit undermines the air filtration and management efforts outlined in the first phase of retrofit.

The existing HVAC system creates another opportunity for cross-contamination between units. The system is centralized and utilizes corridor pressurization. The fresh supply air is delivered to the corridors where it could become contaminated before entering each unit. The issue of the leaky envelope extends to the centralized HVAC system as the introduction of fresh air to the unit through pressurization relies on a non-airtight unit envelope.[157]

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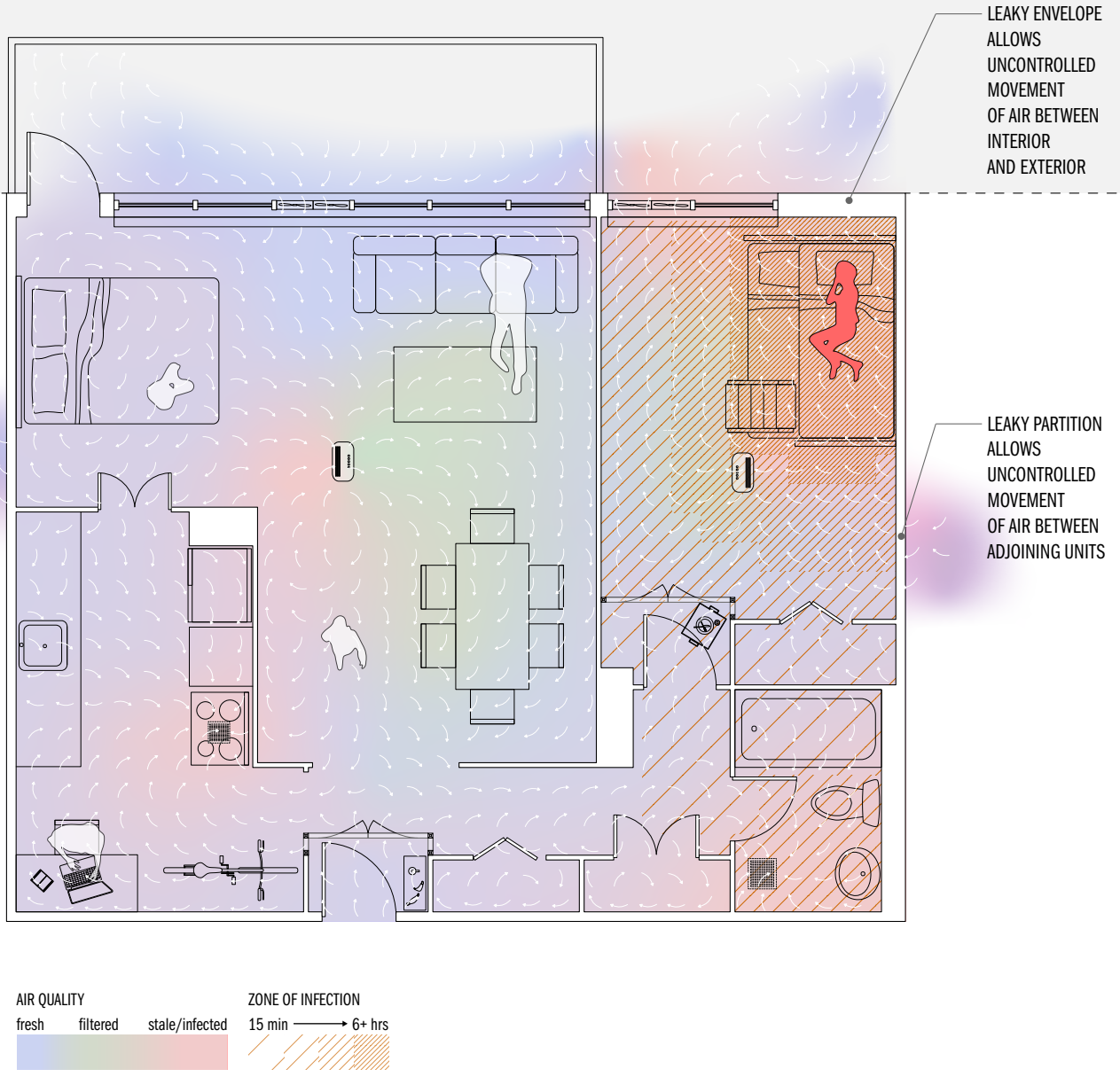
[152] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.
[153] Sun, "Controlled Environments," 63.
[154] Tower Renewal Partnership, *Advancing Building Retrofits*, 15-19.
[155] John Straube, *Understanding and Controlling Air Flow in Building Enclosures*, (University of Waterloo), http://www.civil.uwaterloo.ca/beg/Downloads/8thBSTC%20Air%20Flow%20Control.pdf.
[156] Lstiburek, "BSI-070: First Deal with the Manure and Then Don't Suck."
[157] Tower Renewal Partnership, *Advancing Building Retrofits*, 19-21.

These two issues, leaky envelopes and a centralized HVAC system, inform the second phase of the retrofit. This phase extends beyond the scope of the occupants to involve the building owner and field professionals with the implementation of an HVAC system upgrade, and unit compartmentalization.



[Fig.49] Leaky unit.

HVAC Upgrade

The concerns generated by the underperforming, centralized HVAC system are addressed with the installation of decentralized in-suite energy recovery ventilators (ERV) in each unit. The ERVs provide each unit with balanced ventilation and through the decentralization of the HVAC system, the occupants gain increased environmental control within their units and the risk of mechanically-induced cross-contamination of air between units is decreased.[158]

The ducts, concealed within bulkheads, are mostly run along the perimeter to limit decreasing the floor-to-ceiling height of the entire unit area through the installation of a dropped ceiling. A more efficient duct layout could be determined during a reconfiguration of the unit plan[159], however it is not explored at this stage.

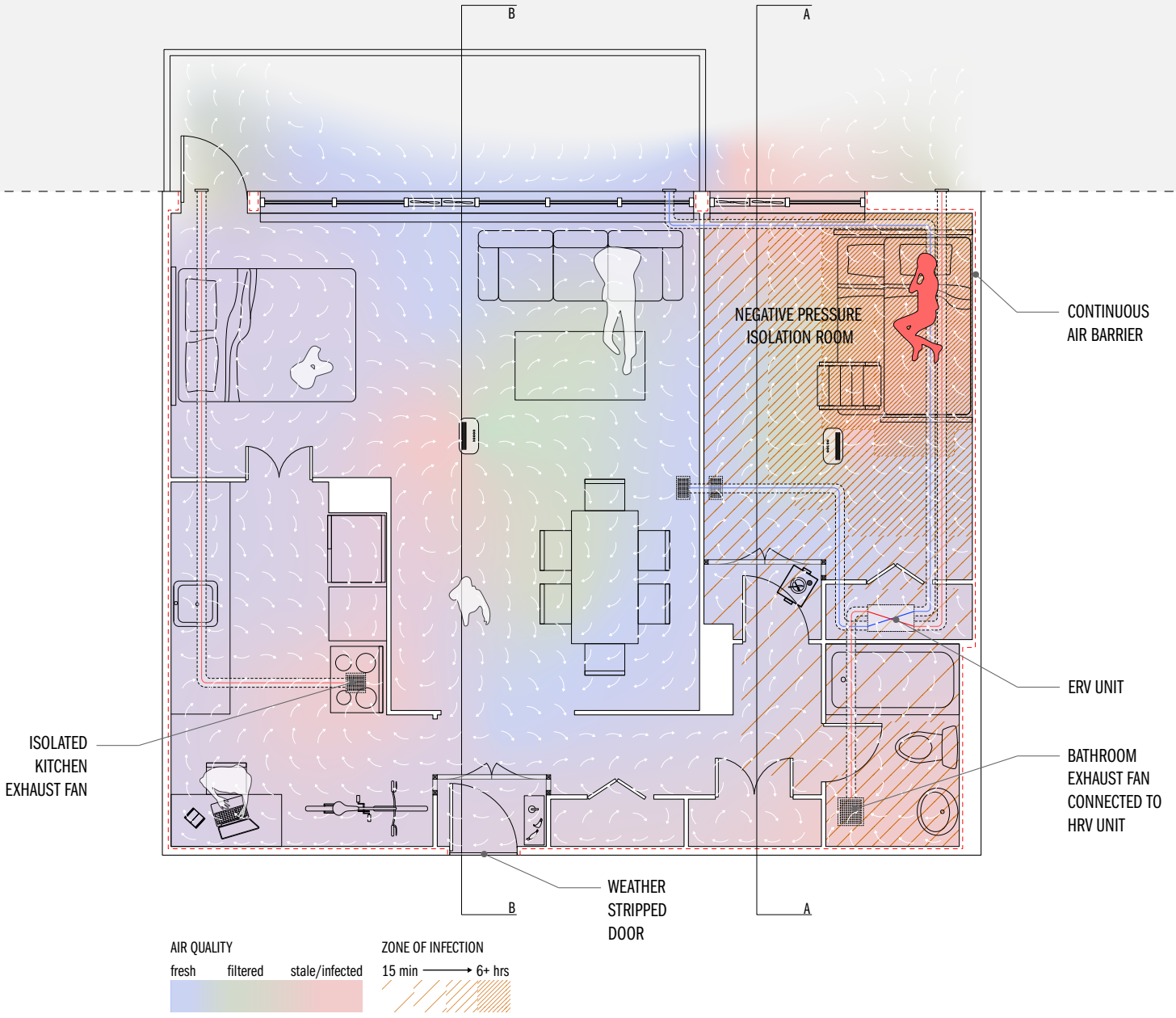
Unit Compartmentalizaion

Each unit is enclosed with an airtight barrier to remedy the leaky partitions. This compartmentalization, often done to combat the stack effect in multi-story buildings, seals the air leaks between units to prevent the unwanted movement of air between neighbours.[160] The front door of each unit is weather-stripped to prevent any contaminated air from entering from the corridor as the units no longer rely on corridor pressurization for supply air.[161]

Impacts

The decentralized HVAC systems and compartmentalized units provide the tower residents with increased control over the environments within their units and improve the general indoor air quality.[162] The in-suite ERVs supply the corresponding units with sufficient air[163] and, through the decentralization of the system, eliminates the potential cross-contamination risk of a centralized HVAC system.[164] The

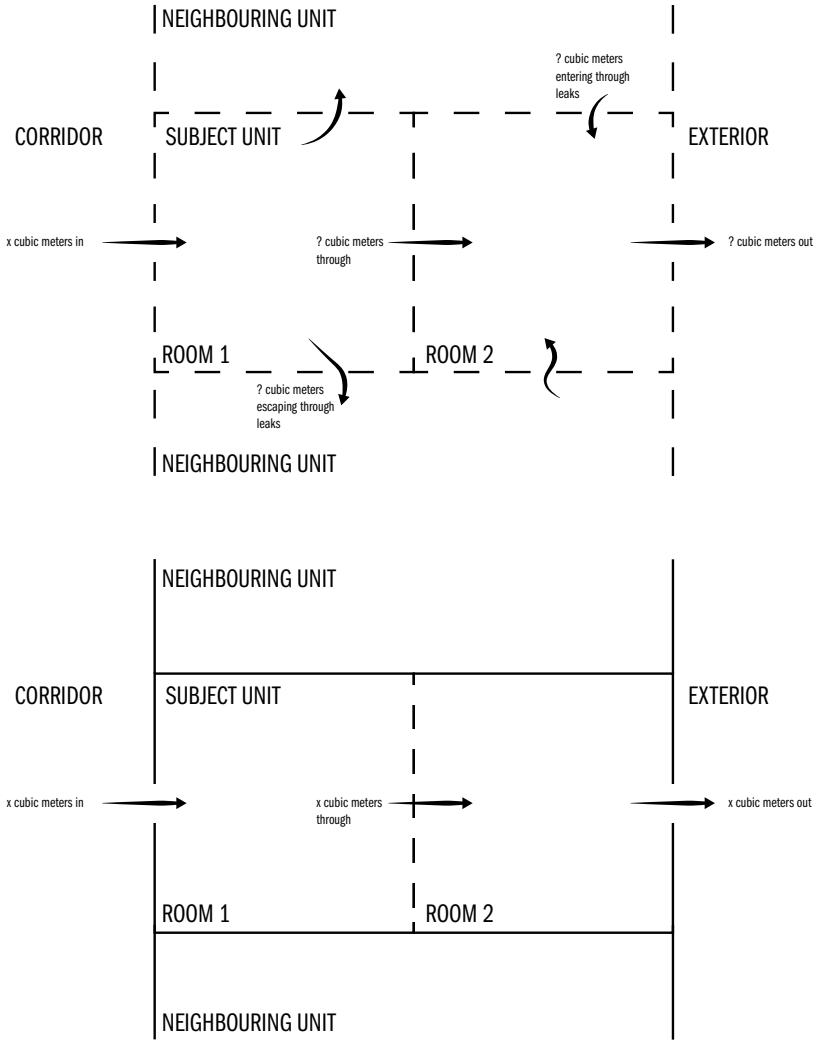
[158] BC Housing, *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*, 7.
[159] Ibid, 23.
[160]Joseph Lstiburek, "BSI-108: Are We Sealing The Right Walls In Buildings*?," Building Science Corporation, last modified December 18, 2018, https://www.buildingscience.com/documents/building-science-insights-newsletters/bsi-108-are-we-sealing-right-walls-buildings.
[161] Joseph Lstiburek, "HVAC in Multifamily Buildings," Building Science Corporation, October 24, 2006, https://www.buildingscience.com/documents/digests/bsd-110-hvac-in-multifamily-buildings.
[162] BC Housing, *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*, 7.
[163] Ibid, 12.
[164] Tower Renewal Partnership, *Advancing Building Retrofits*, 21.



[Fig.50] One-bedroom floor plan: Phase Two retrofit.

compartmentalization of the units[165] further prevents airborne contaminants from passing between neighbours.[166]

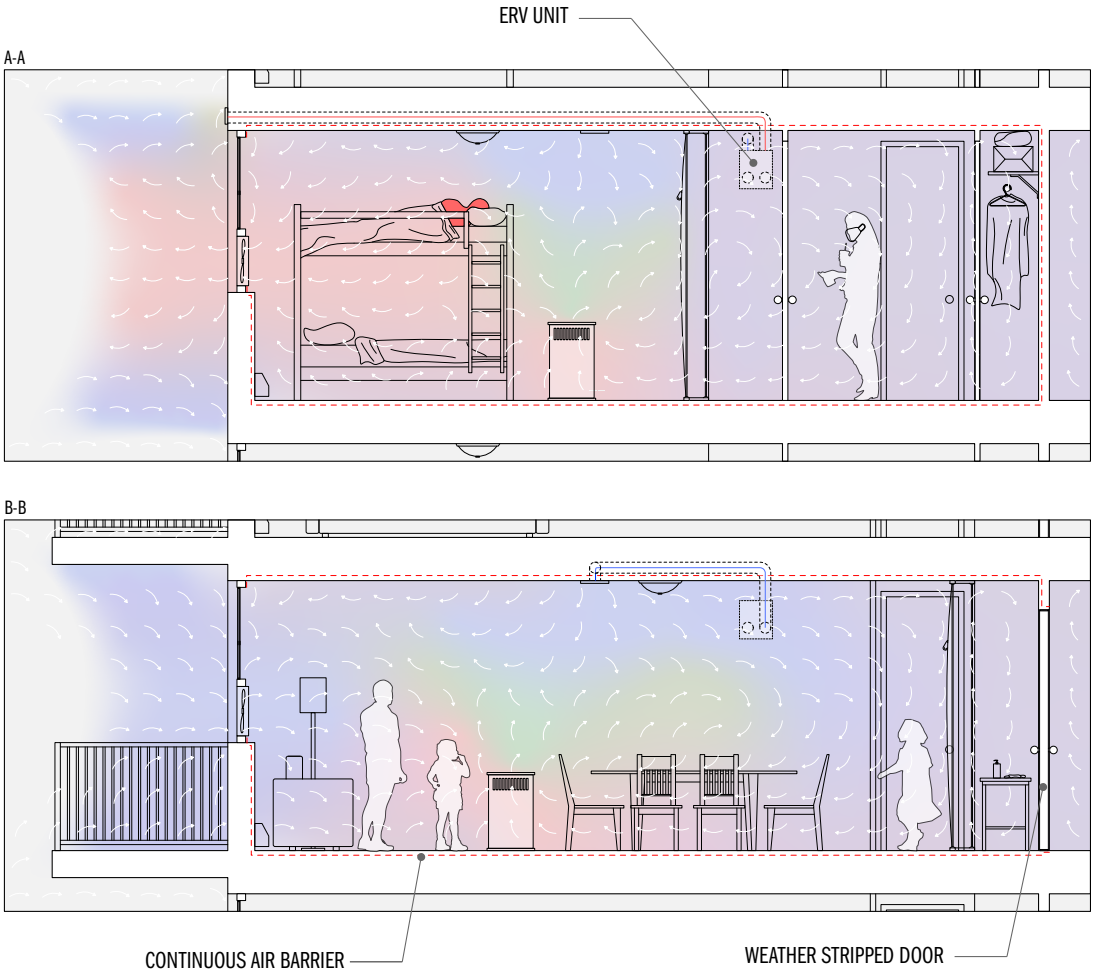
The increased control of air movement and air quality within the unit provided in Phase Two increases the efficacy of the occupant-implemented strategies of the first phase.[167] The introduction of a HEPA filtration unit will further improve indoor air quality by providing supplemental air cleaning within the unit.[168] With unit compartmentalization,[169] the



[Fig.51] Leaky vs. airtight unit with air permeable partition diagram.

[165] Lstiburek, "BSI-108: Are We Sealing The Right Walls In Buildings*?."
[166] Straube, *Understanding and Controlling Air Flow in Building Enclosures*.
[167] BC Housing, *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*, 7.
[168] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.
[169] Lstiburek, "BSI-108: Are We Sealing The Right Walls In Buildings*?."

emergency creation of a negative pressure isolation room is more effective as it is less likely for unwanted, potentially contaminated air to be pulled into the room from the neighbours to replace the exhausted air.[170]



[Fig.52] Bedroom and common space sections: Phase Two retrofit.

[170] Lstiburek, "BSI-070: First Deal with the Manure and Then Don't Suck."

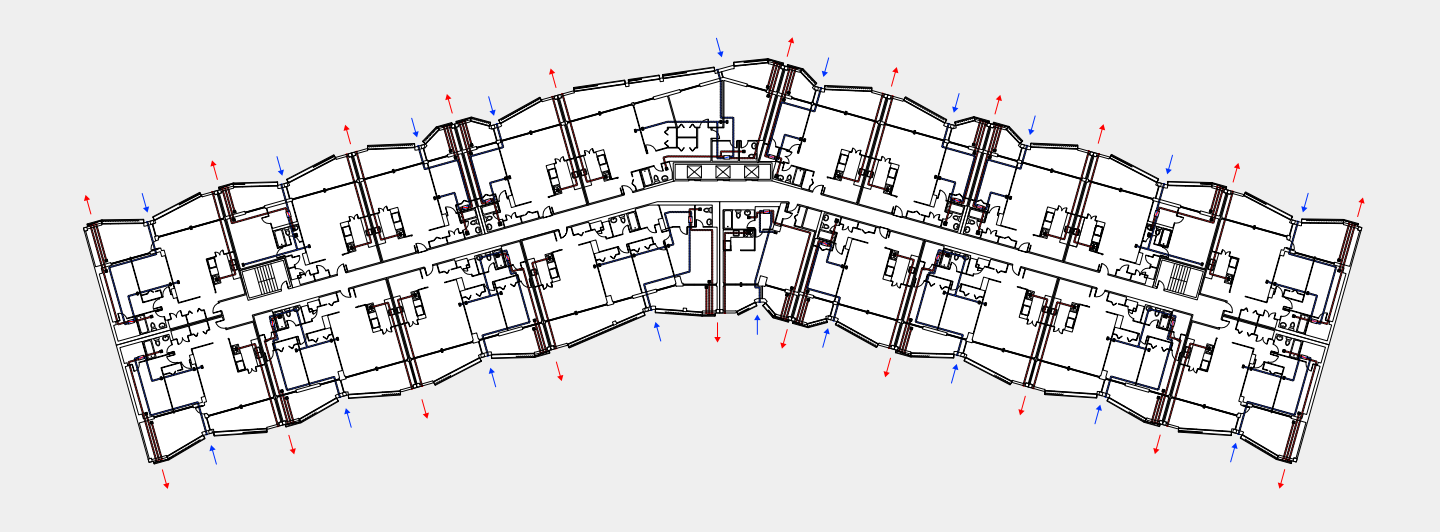
PHASE THREE: THE BALCONY

Phase One and Two of the retrofit address the issue of poor indoor air quality within the tower units. The third phase of the retrofit expands the scope to also address the issue of lack of space within the often-overcrowded units.[171] The replacement of the existing balconies is explored. The proposed extended and enclosed balconies create a flexible, intermediate space that would allow the easy expansion and contraction of the unit. In addition to an increase in square footage, the passive strategy of a thermal buffer zone created by enclosed balconies[172] has the potential to decrease the energy loads of the tower.[173] Furthermore, as part of the concrete floor slabs, the existing balconies impair the thermal performance of the tower.[174] The new balconies are attached using an Isokorb® product to reduce the thermal bridging and potential resulting mould growth.[175]

The Façade vs. Intake and Exhaust Vents

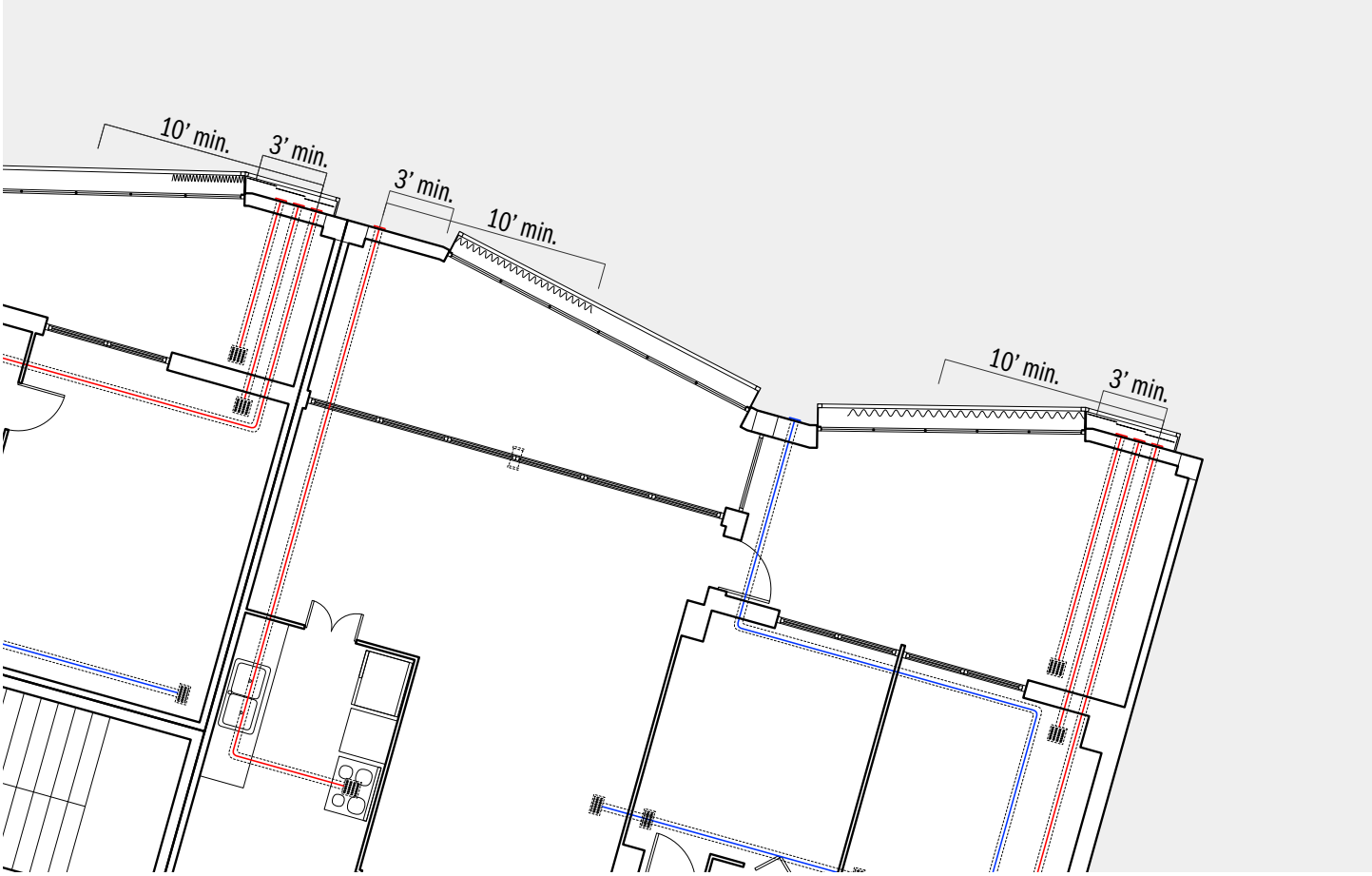
The proposed balconies run the entire width of each unit to wrap the tower in a new facade. The in-suite ERVs carried over from Phase Two help inform the design of the façade. The exhaust vents are minimum ten feet from the intake vents as required. The exhaust vents are also at minimum three feet from window openings.[176] The angled walls, inspired by the folded layers of a furnace filter, indicate points of intake and exhaust along the facade of the tower. Points of exhaust protrude from the building and points of intake tuck into the building. This conceptually derived offset of faces helps to further increase the required distances.

[171] Adhopia, "How one of Toronto's COVID-19 hot spots is struggling through the pandemic."
[172] Susanne Gosztonyi, Magdalena Stefanowicz, Ricardo Bernardo, and Åke Blomsterberg, "Multi-active façade for Swedish multi-family homes renovation – Evaluating the potentials of passive design measures," *Journal of Façade Design & Engineering* 4, no. 3 (2016): 11-12, https://doi.org/10.7480/jfde.2017.1.1425.
[173] Catherine Slessor, "Building Study: Lacaton & Vassal's renovation of a Bordeaux housing estate," Architects' Journal, August 9, 2019, https://www.architectsjournal.co.uk/buildings/building-study-lacaton-vassals-renovation-of-a-bordeaux-housing-estate.
[174] Tower Renewal Partnership, *Advancing Building Retrofits*, 23.
[175] "SCHÖCK ISOKORB® RT: Insulated balcony connections for renovation projects," SCHÖCK, last modified June 2021, https://www.schoeck.com/view/9565/Isokorb_RT_for_Renovations_brochure_CANADA___9565__.pdf/en-us.
[176] "Info-606: Placement of Intake and Exhaust Vents," Building Science Corporation, March 7, 2014, https://www.buildingscience.com/documents/information-sheets/information-sheet-placement-of-intake-and-exhaust-vents.



[Fig.53] Points of intake and exhaust on the typical floor plan: conceptual.

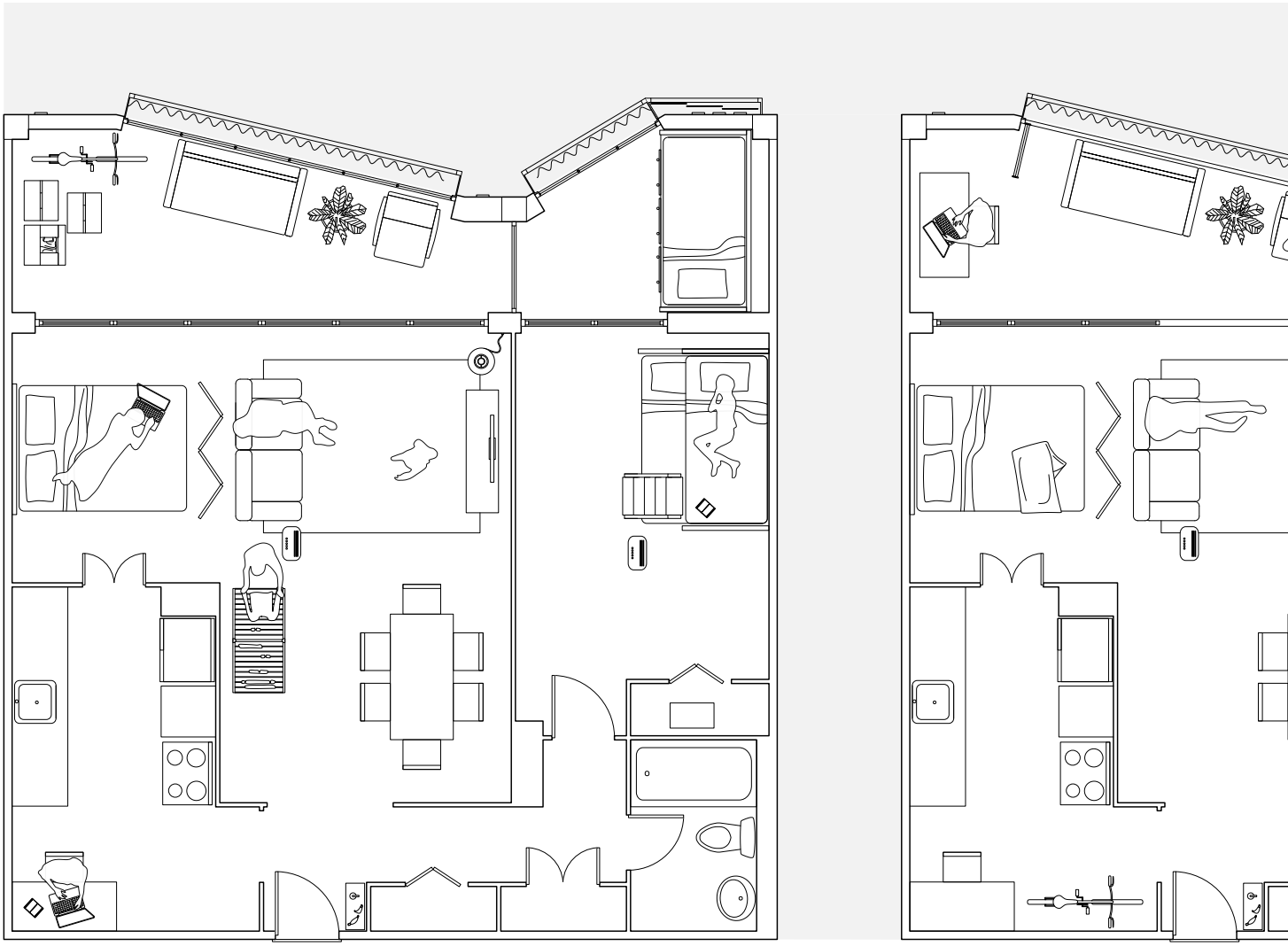
[Fig.54] Points of intake and exhaust on the typical floor plan: technical.



Flexible Space

The spatial expansion and contraction of the unit is enabled by retractable doors and windows. The balcony becomes a transformable space with the ability to increase the area of the adjoining rooms or provide the unit with additional rooms.

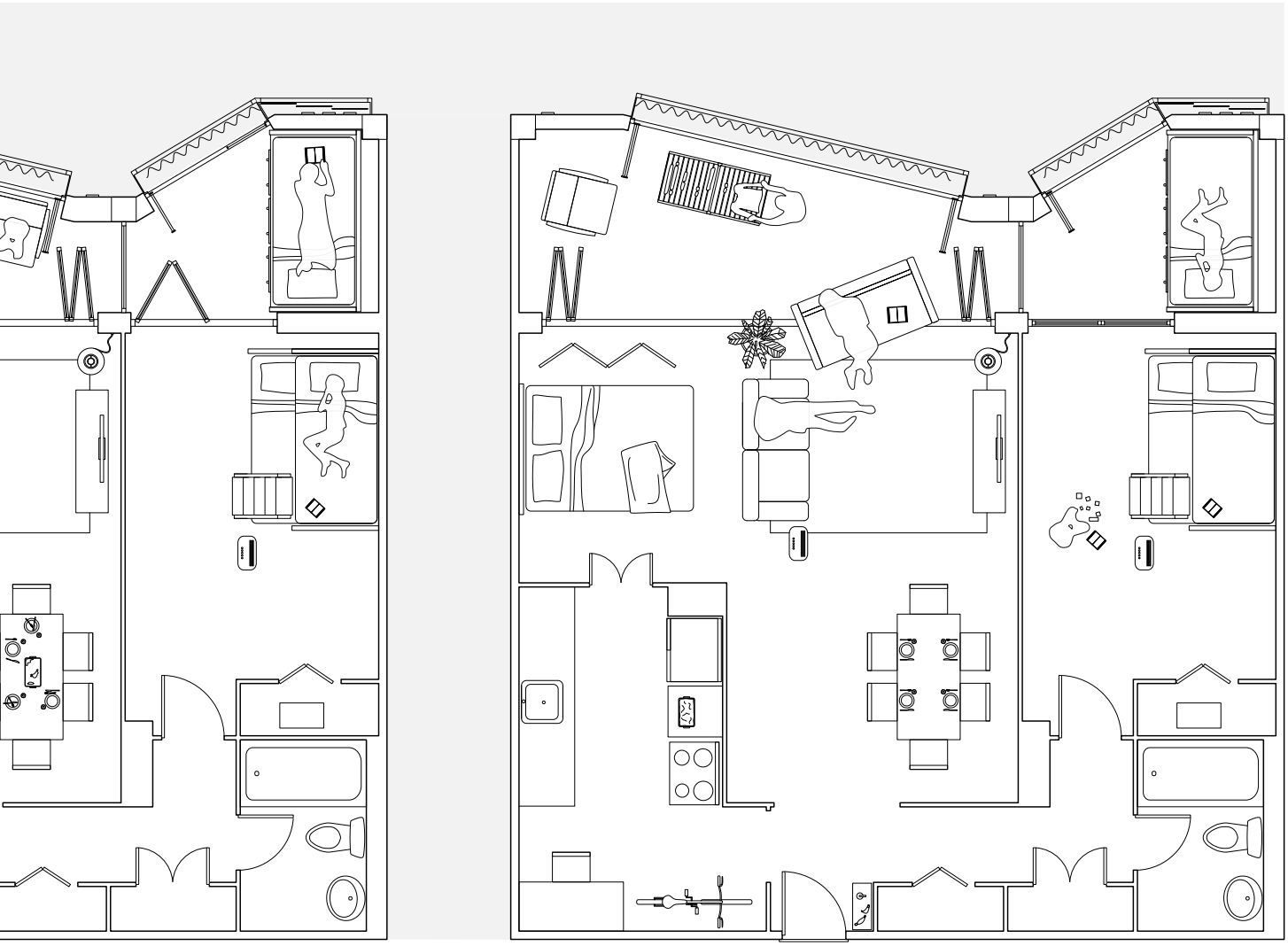
The wall and windows of the existing unit exterior wall are removed and replaced by a transparent wall of retractable doors. When the doors are open, the unit interior and the balcony merge into one space providing the occupants with more space for daily activities. The partial closure of doors to the balcony creates more niches within the unit. Fully closed doors separate the balcony and the unit once again.



[Fig.55] Flexible living space in a one-bedroom unit.

This flexible space transforms the unit into one capable of accommodating a greater variety of activities whether they are related to work, recreation, or rest.

The inclusion of retractable windows along the balcony balustrade allows the space to transition between exterior and semi-interior. In its semi-interior state, the unit gains a couple of rooms. Though the balcony is not insulated, the extra rooms created could be occupied during most months of the year at the discretion of the occupants' thermal comfort levels extending the use of the balcony to at least three seasons.[177] Furthermore, when it becomes too cold for human occupation, the sheltered space could be used for extra storage and free up space within the unit interior.



[177] Gosztonyi, Stefanowicz, Bernardo, and Blomsterberg, "Multi-active façade for Swedish multi-family homes renovation," 20.

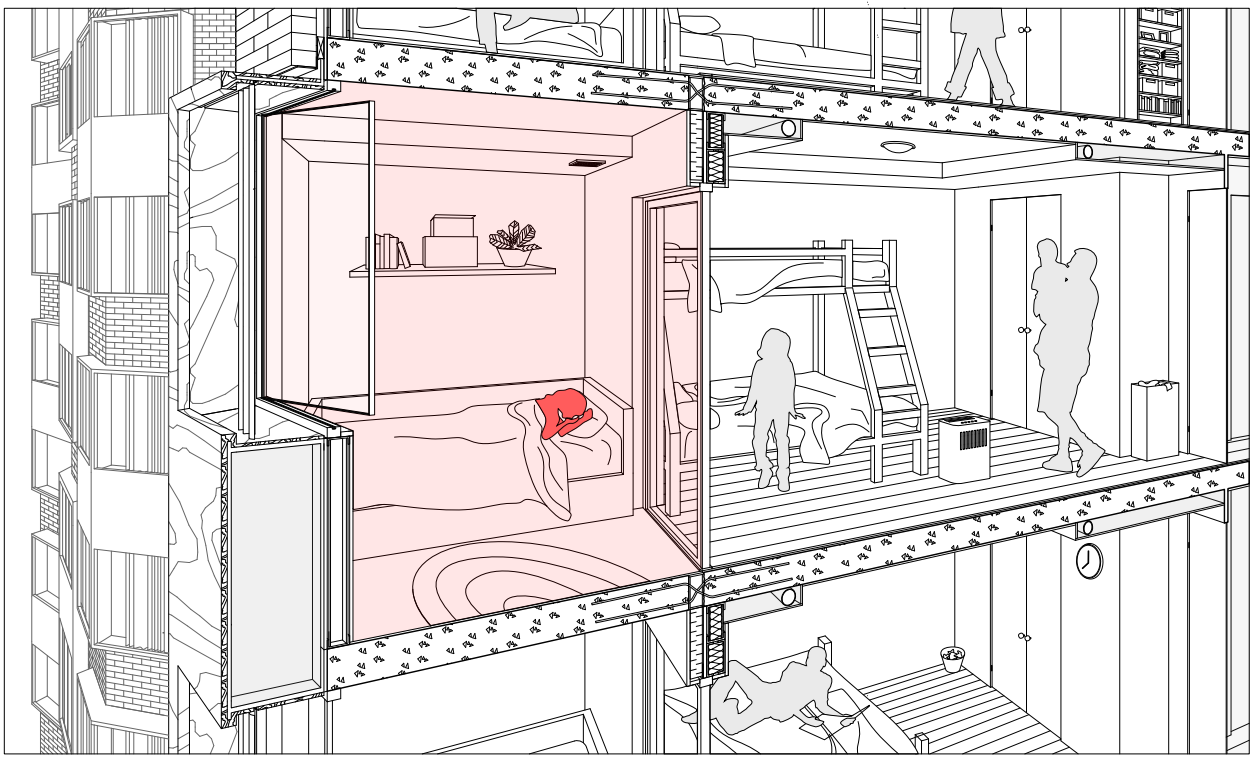
The Sleeping Porch

The initial interest in exploring balconies derives from earlier research into sleeping porches. The enclosed balcony space is unprogrammed leaving it up to the occupants to decide its use, however, a portion of the balcony is designed to be transformed into a dedicated sleeping space with ease. The new sleeping porch can be fully isolated from the rest of the unit if desired. Through this, the adaptable addition to the unit not only addresses the issue of a lack of space within the units of the tower but also provides further opportunity for isolation.

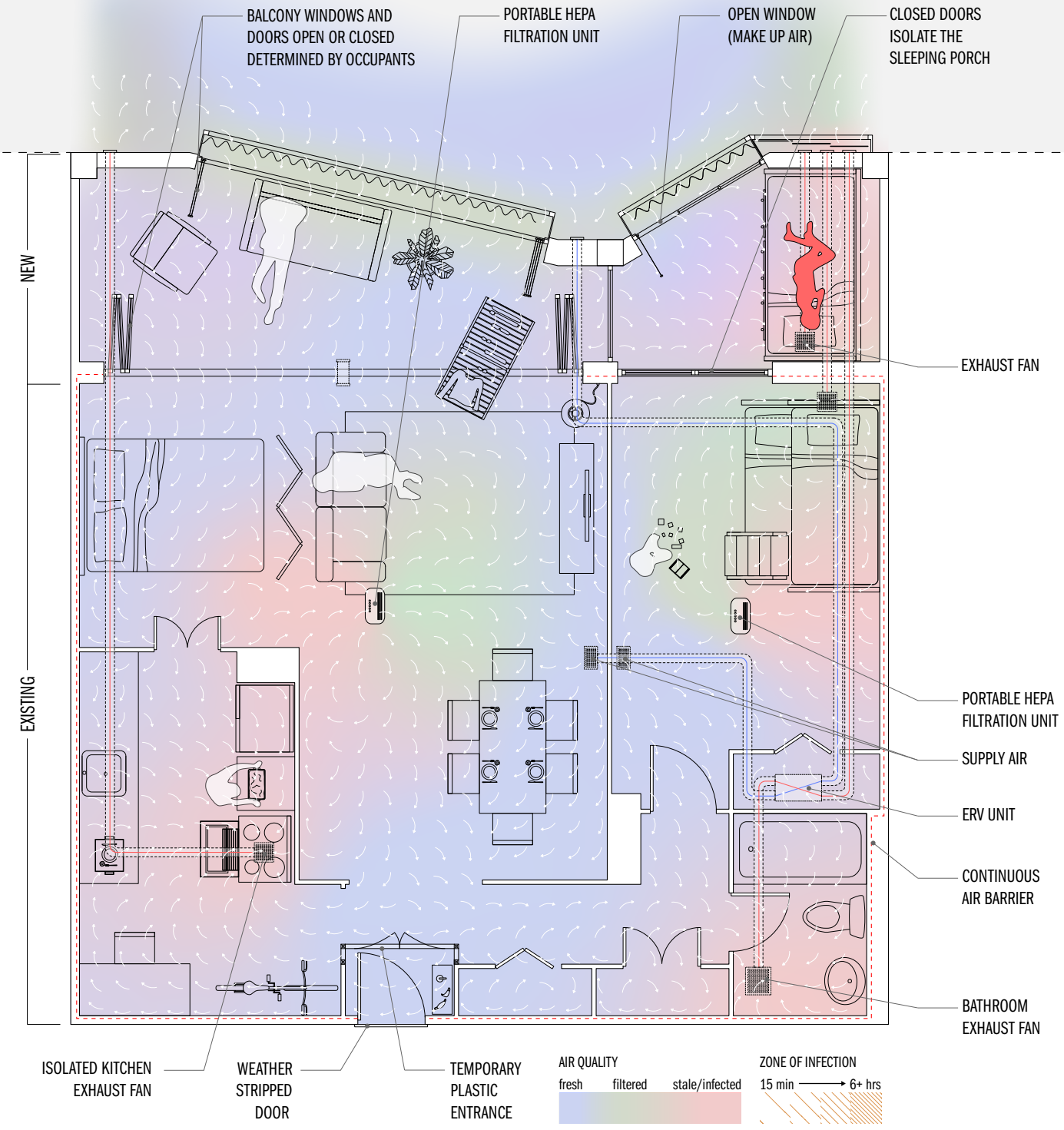
The Isolated Sleeping Porch

The sleeping porch provides an additional opportunity for isolation within the unit if needed. The doors between the sleeping porch and the bedroom close to isolate the person sleeping outside. Emulating a negative pressure isolation room, a fan is installed in the ceiling of the balcony to exhaust the air to the outdoors and pull fresh make-up air through an open window.[178] Therefore, aside from when the infected person travels to the washroom, contaminants are confined to the sleeping porch and are expelled away from the building before they can disperse inside.

[Fig.56] A sleeping porch included on the new enclosed balcony.



[178] Univeristy of Michigan Health: Michigan Medicine, “Hospital Isolation Rooms.”



[Fig.57] One-bedroom unit with isolated sleeping porch.

Negative Pressure Isolation Room

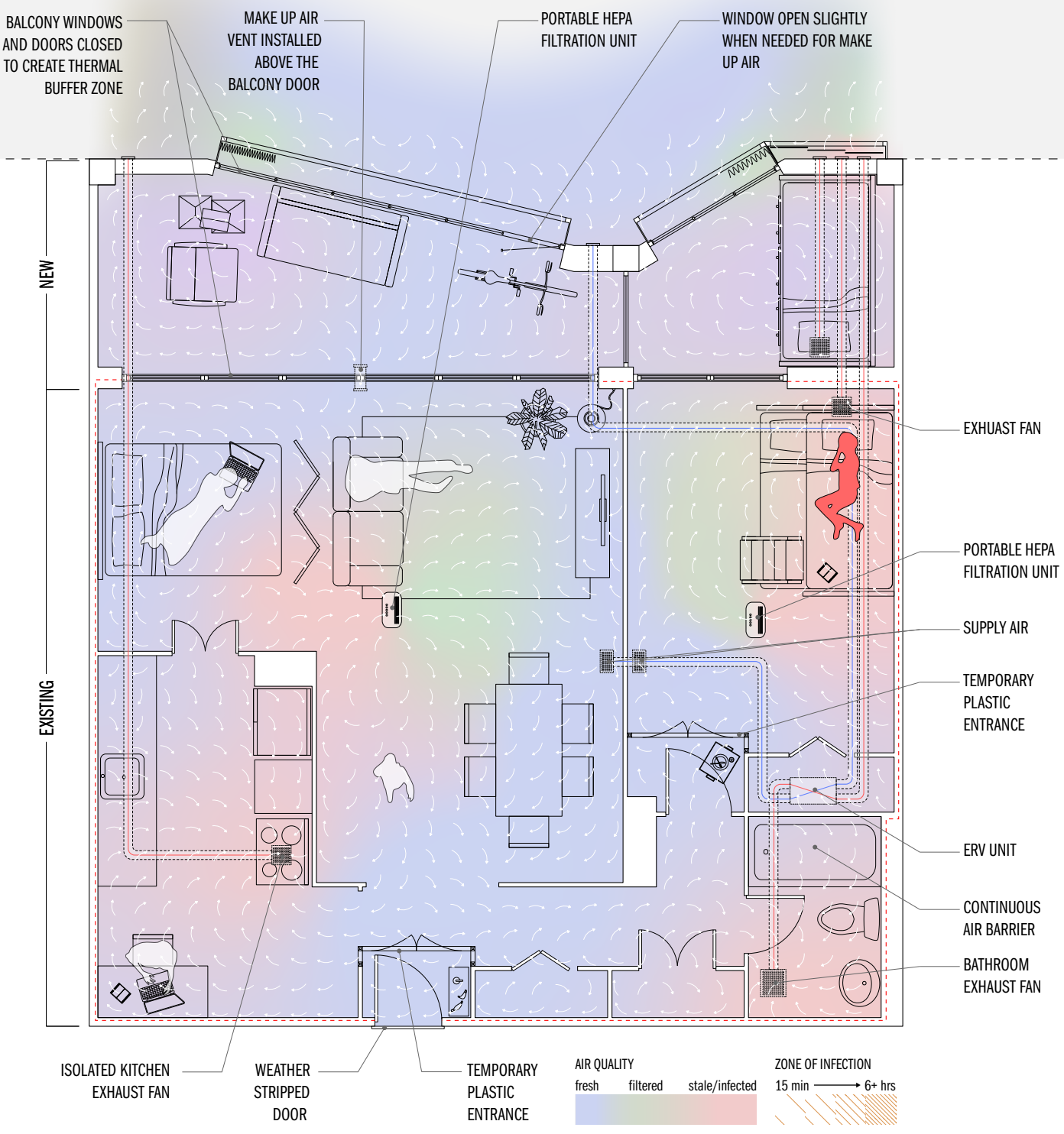
Sleeping on the balcony is weather-dependent because the space is not insulated. During the months when it would be too cold to spend an entire night outside, the bedroom is designed for easy transformation into a negative pressure isolation room when required. An exhaust fan, like the one included in the sleeping porch, is installed in the bedroom ceiling. This eliminates the need for the occupants to purchase and set up a window fan as they would during Phase One and Two.[179] When an infected person isolates in the bedroom, the pre-installed fan would be turned on to exhaust the air within the bedroom directly to the exterior.[180]

Both exhaust fans, on the sleeping porch and in the bedroom, are isolated from the unit's ERV. The ERV system is concerned with providing constant ventilation to the unit[181] while the two additional exhaust fans would be run intermittently on an as-needed basis, emulating the temporary installation of the window fans during the first two phases.[182] Therefore, like a kitchen range hood, the systems are separated.[183] However, when the exhaust fans are running, they will upset the balanced ventilation provided by the ERV.[184]

To lessen the destabilization of the ventilation, a make-up air vent is installed above the doors in the common space. The make-up air vent provides a controlled location for air to be pulled into the unit and replace the exhausted bedroom air.[185] The vent, an intentional path of least resistance, decreases air leakage entering from neighbouring units in the case of unit compartmentalization deficiencies (common in locations such as partition walls and ceiling penetrations).[186]

A temporary plastic entrance can be set up inside the bedroom door to help maintain the negative pressurization of the bedroom with the resulting transition zone between the two

[179] ASHRAE, *Guidance for Covid-19 Risk Reduction in Residential Buildings*.
[180] Univeristy of Michigan Health: Michigan Medicine, "Hospital Isolation Rooms."
[181] BC Housing, *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*, 7.
[182] ASHRAE, *Guidance for Covid-19 Risk Reduction in Residential Buildings*.
[183] Lstiburek, "BSI-070: First Deal with the Manure and Then Don't Suck."
[184] ASHRAE, *Guidance for Covid-19 Risk Reduction in Residential Buildings*.
[185] Ahmet Biler, Aslihan Unlu Tavil, Yuehong Su, and Naghman Khan, "A Review of Performance Specification and Studies of Trickle Vents," *Buildings* 8, no. 11 (November 6, 2018): 1-41, https://doi.org/10.3390/buildings8110152.
[186] James Higgins, Daniel Haaland, and Lorne Ricketts, *Illustrated Guide: Achieving Airtight Buildings*, (BC Housing, September 2017), 26.



[Fig.58] One-bedroom unit with negative pressure isolation room.

doors.[187] The use of the bedroom as a negative pressure isolation room is expected to be infrequent. Furthermore, it is assumed the illness transmission being prevented will not always be as dangerous as the Covid-19 virus and the health risks of the momentary depressurization of the isolation room would be less of a concern. The secondary entrance is supplementary, and the occupant remains responsible for its acquisition and installation.

It is important to note that the ducts run from the interior of the unit through the uninsulated enclosed balcony to the exterior. Therefore, the portion of the ducts located within the balcony space are to be insulated to match the insulation levels within the unit.[188]

Air Filtration

Portable HEPA filtration units can be set up like Phase One and Two to provide supplemental air cleaning.[189] However, when the windows and doors of the balcony are open to allow the unit to blend with the exterior environment, the efficacy of a portable filtration unit will decrease.[190] In this scenario, the filtration units could remain off and the occupants would rely on fresh air dilution to decrease the concentration of any contamination in the air.[191]

Impacts

The third phase of the retrofit addresses the issue of lack of space within the postwar tower while carrying forward the indoor air quality improvements implemented during the first and second phases. This retrofit of an overcrowded apartment unit prioritizes occupant health through a focus on air quality and management during the design of a flexible space that expands and contracts as desired by the occupants and provides additional space for isolation if required.

[187] Sun, "Controlled Environments," 70.
[188] BC Housing, *Heat Recovery Ventilation: Important Considerations for Builders and Designers*, (Burnaby, BC: BC Housing), 7, https://www.bchousing.org/research-centre/library/builder-insight/builder-insight-14.
[189] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.
[190] *Residential Air Cleaners*, 16.
[191] "Adding more fresh air to indoor spaces," University of Rochester, last modified September 2, 2020, https://www.rochester.edu/coronavirus-update/adding-more-fresh-air-to-indoor-spaces/.

PHASE FOUR: THE FACADE

The fourth phase of the retrofit returns to the focus on improving indoor air quality. This phase imagines the application of a photocatalytic material being used to filter the incoming fresh air. As mentioned before, air pollution has the potential to undermine any health benefits provided by natural ventilation by carrying outdoor pollution into the home. The introduction of a passive air filtration product could help offset this issue.

The technology used as inspiration for this phase would require more development for it to be more widely applicable and effective. For the purposes of the thesis, the proposed material to be used is the same as the façade textile precedent which targets airborne nitrogen oxides.[192] Nitrogen oxides (NOx) are a form of air pollution often resulting from the use of fossil fuels. Exposure to NO_2 specifically can lead to health effects such as a decrease in lung function, asthma, COPD, and inflammation of the airway. NO_2, along with $PM_{2.5}$ and ozone, "account for the majority of population health impacts from air pollution."[193]

The use of the material is proposed in two locations: a curtain to be hung outside the balcony windows and screens installed on the façade in front of the sleeping porch and bedroom exhaust vents.

The Intake Curtain

Curtains are to be hung in a structure outside of the enclosed balcony windows. This curtain can be opened and closed by the occupants as desired based on air pollution levels, thermal comfort, or privacy. As air interacts with the coating on the curtain, the coating in combination with UV exposure, converts the airborne nitrogen oxides into benign salts which are left behind on the curtain and washed away with the next rainfall.[194]

In addition to being a filter, the curtain acts as an operable sunshade providing the occupants with another passive layer of environmental control.[195]

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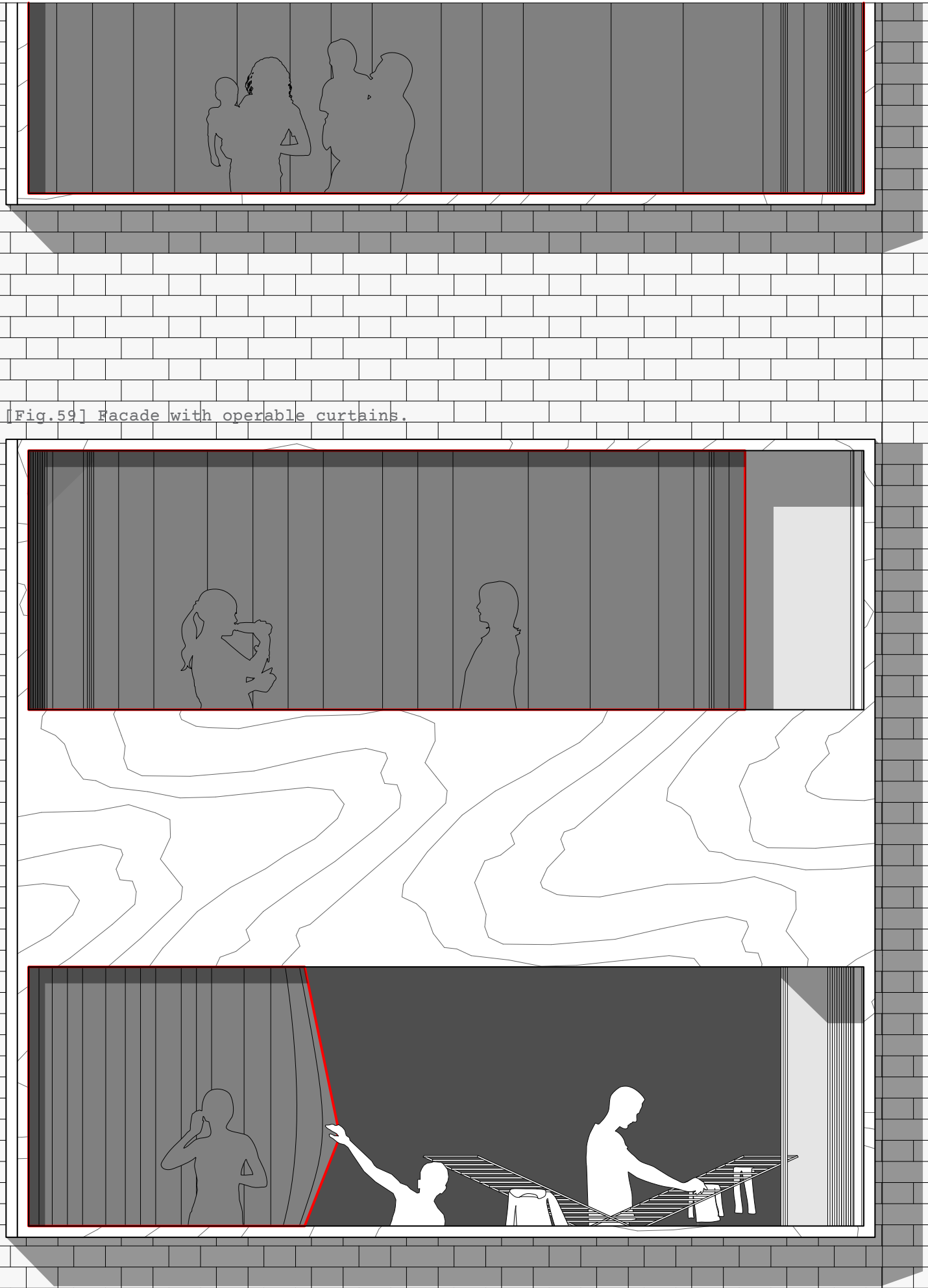
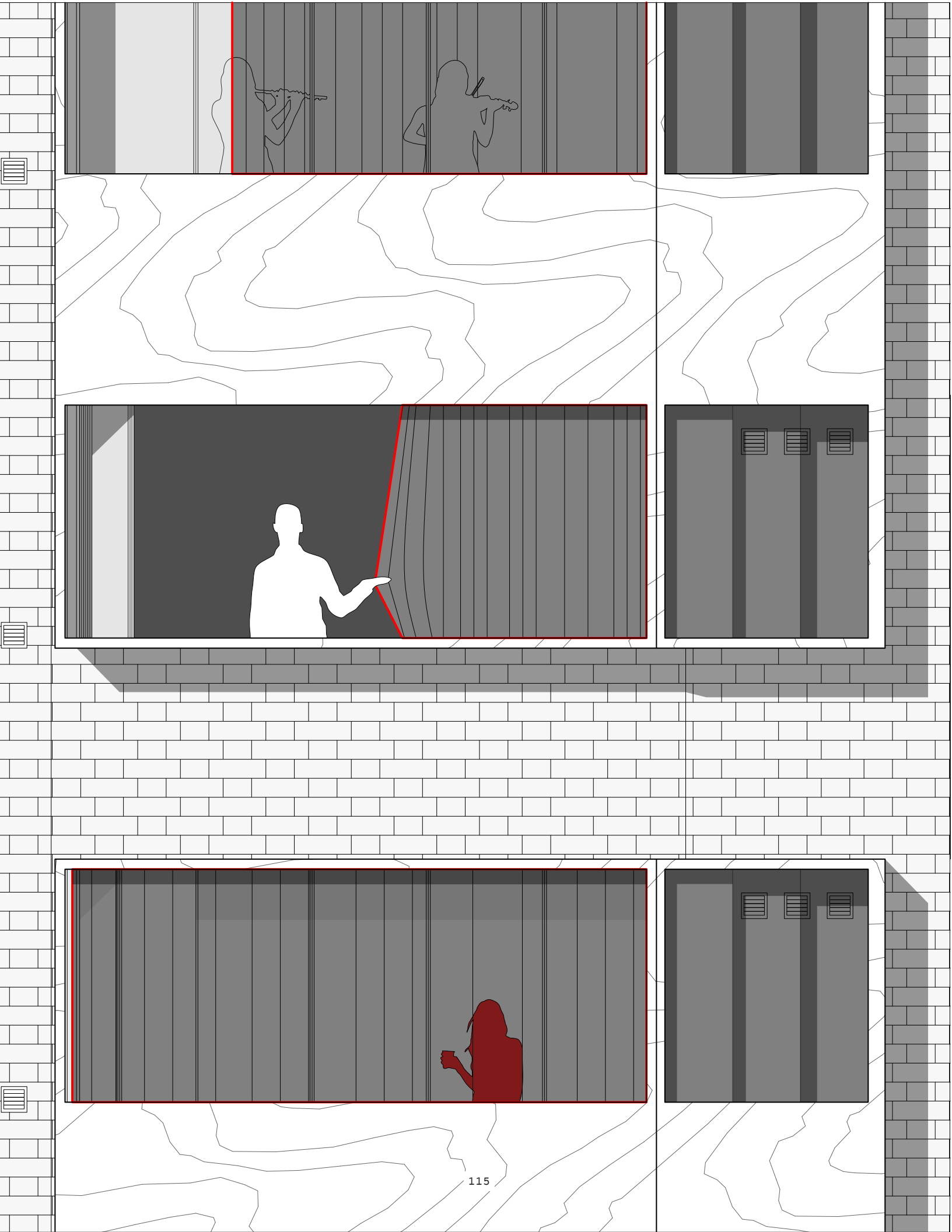
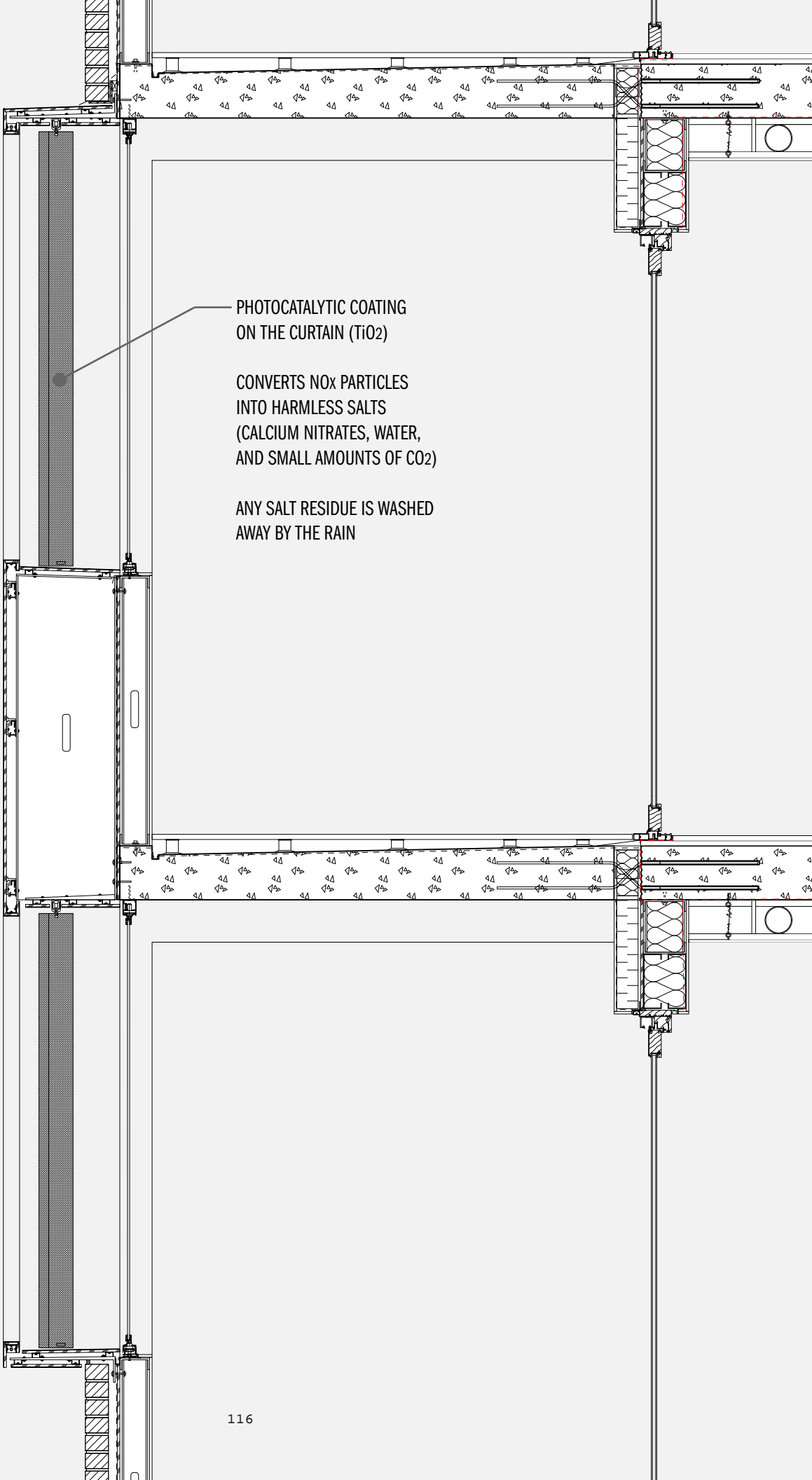
[192] Suntinger, "Textile facades on buildings filter harmful pollutants from the air."
[193] Health Canada, *Health Impacts of Air Pollution in Canada.*
[194] Suntinger, "Textile facades on buildings filter harmful pollutants from the air."
[195] "What is Solar Shading?," Enviroscreen Systems, last modified January 24, 2020, https://www.enviroscreen.org.uk/what-is-solar-shading/.



[Fig.59] Facade with operable curtains.





[Fig.60] Balcony detailed wall section.

The Exhaust Screen

The second location for the photocatalytic coating is on the textile screens installed over the sleeping porch and bedroom exhaust vents. The stale air exhausted through these vents is unfiltered and has the potential to contain pollution. The coated screens provide a layer of filtration before the exhaust air enters the outdoor environment. Emulating the precedents, the goal of the use of passive air filtration is not only to improve the indoor air quality but improve outdoor air quality as well.

Impacts

The fourth phase of the retrofit explores the integration of passive air filtration in the expression of the façade to address the issue of air pollution with an architectural solution. The technology required for this phase to be effective is still in its infancy. If further developed, the concept of passive air cleaning as a way of mitigating air quality deterioration driven by the climate crisis may have the potential for wide-spread future application.

PHASES ONE TO FOUR: BENEFITS AND COST

The cost, labour, and time required generally increases with each phase, however so does the improvement to the indoor environment. As mentioned previously, each phase would be implemented under difference circumstances, ranging from a quick emergency response to an extensive retrofit providing a healthier space to live that facilitates an easy transformation into a safe space for isolation.

Phase One: Off-the-Shelf

Cost $ **Labour ●** **Time ●**

Implement when: a viral outbreak occurs

The first phase is intended to be a low cost option that does not require the hiring of professionals for installation. As stand-alone items, the interventions presented in this phase can be purchased by the occupants and set up independently within their units. Due to the energy required to power the window fans and the portable HEPA filtration units, the ongoing energy cost may be increased. Since the application of this phase is intended for emergency use during a viral outbreak, the fans and filtration units would be used less frequently, lessening the increase in energy cost.

Phase Two: The Unit and HVAC

Cost $$ Labour ●● Time ●●

Implement when: a building has an under-performing ventilation system

There is an increase in initial cost to implement the second phase. Upgrading the HVAC system to insuite ERVs and compartmentalizing the units would require the hiring of professionals for the design and installation of the Phase Two interventions. As a partial retrofit of the building, there would also be an increase in labour and time required to complete the phase. However, there is a potential decrease in energy-related costs long-term due to less energy consumption facilitated by a more efficient HVAC system and an airtight envelope.

The use of portable HEPA filtration units and window fans may offset the decrease in energy-related costs, however, similar to Phase One, their active use would be intermittent. Furthermore, due to better control over the general indoor air quality and air flow management provided by the compartmentalization and insuite ERVs, the efficacy of the filtration units and negative room pressurization would increase. As a result, the health benefits would increase as well.

Phase Three: The Balcony

Cost $$$ Labour ●●● Time ●●●

Implement when: a building requires extensive upgrades, specifically to the HVAC system and the envelope

The initial cost increases again with Phase Three due to the demolition of the existing facade and the construction of the proposed enclosed balconies, the hiring of professionals, and an increase in construction time and labour required. Furthermore, tenant relocation is a likely requirement during the implementation of this phase.

The benefits of Phase Three may outweigh the increased cost. The upgraded HVAC system and the introduction of a thermal buffer zone along the facade have the potential to decrease ongoing energy costs. The increase in square-footage through the inclusion of a flexible, three-season living space would make the units more desirable to potential occupants. The prioritization of occupant health during the design would result in a more comfortable, healthy living space after construction further improving marketability.

Phase Four: The Facade

Cost $$$$ Labour ● Time ●

Implemented when: future application eventually merged with Phase Three

The cost of Phase Four is high due to the lack of available products. The technology proposed in this phase requires further development and the efficacy of the products will need to be proven before widespread application occurs.

However, if the efficacy of a passive air filtration product like the one proposed in this thesis was proven, it could be added to the facade of existing or new buildings to help improve the general indoor air quality. As a passive intervention, the recurring cost after installation would be low (potential maintenance cost depending on the material developed).

CONCLUSION

The four phases of retrofit respond to the problem of poor indoor air quality and lack of space for adequate isolation in ageing postwar towers. From supplemental air filtration and negative room pressurization to HVAC system upgrades and unit compartmentalization to the provision of a flexible, expandable and contractable living space, the four phases propose strategies to improve and control indoor air quality, providing healthy homes everyday and in times of emergency.

PART FOUR: IMPACTS

Flexible Retrofit
Ken Soble Tower

INTRODUCTION

The components of each phase of the proposed retrofit are general enough to be applied to every unit within the selected tower and the units of other towers. This chapter explores the impacts of the proposed design's application to the entire postwar tower stock of Toronto and imagines this integration through a case study involving the Ken Soble Tower, the current retrofit of which is documented by the Tower Renewal Partnership.[196]

FLEXIBLE RETROFIT

Widespread Application

The retrofit proposed in the previous section does not alter the interior layout of the unit. Instead, designed as an exterior balcony addition, it expands the existing floor plan. Unit compartmentalization and HVAC system upgrades are transferable interventions not tied to a specific floor plan, as are setting up portable HEPA filtration units, window fans, and temporary plastic barriers. The generalization of the retrofit components allows for their easy application to the postwar tower stock in Toronto and more.

Population Affected

The Tower Renewal Partnership locates approximately 310,000 Toronto households within towers built between 1946 and 1985 using 2016 census data. This accounts for almost half of the city's high-rise households.[197]

[196] Tower Renewal Partnership, *Ken Soble Tower Transformation*.
[197] Ibid, 99.

The average number of people per household in 2016 was 2.42,[198] therefore estimating that around 752,000 people (310,000 x 2.42) live in towers with inadequate ventilation and filtration and as a result, may be subject to higher levels of air pollution.

Integrating the ideas of environmental isolation discussed in the design work with the Tower Renewal Partnership agenda improve the air quality of this population and by extension, decrease their vulnerability to illness.

KEN SOBLE TOWER

> "The Ken Soble Tower rehabilitation can provide a piece of the crucial roadmap needed to guide future projects."[199]

The revitalization of the Ken Soble Tower, a postwar tower located in Hamilton, is well underway. The project is outlined by the Tower Renewal Partnership in a case study report intended to help guide future tower retrofits.[200]

Similar to this thesis' design proposal, establishing airtightness and upgrading the HVAC system are among the retrofit objectives.[201] A notable difference is the current retrofit plans for the Ken Soble Tower outline that the existing balconies are to be removed and replaced with juliette balconies.[202] Though it would help with thermal bridging and was done for accessibility reasons, the loss of private outdoor space could be seen as a drawback.[203] Furthermore, in a pandemic situation, the loss of a balcony means the loss of potential space for occupant isolation as demonstrated in this thesis through the retrofit proposal.

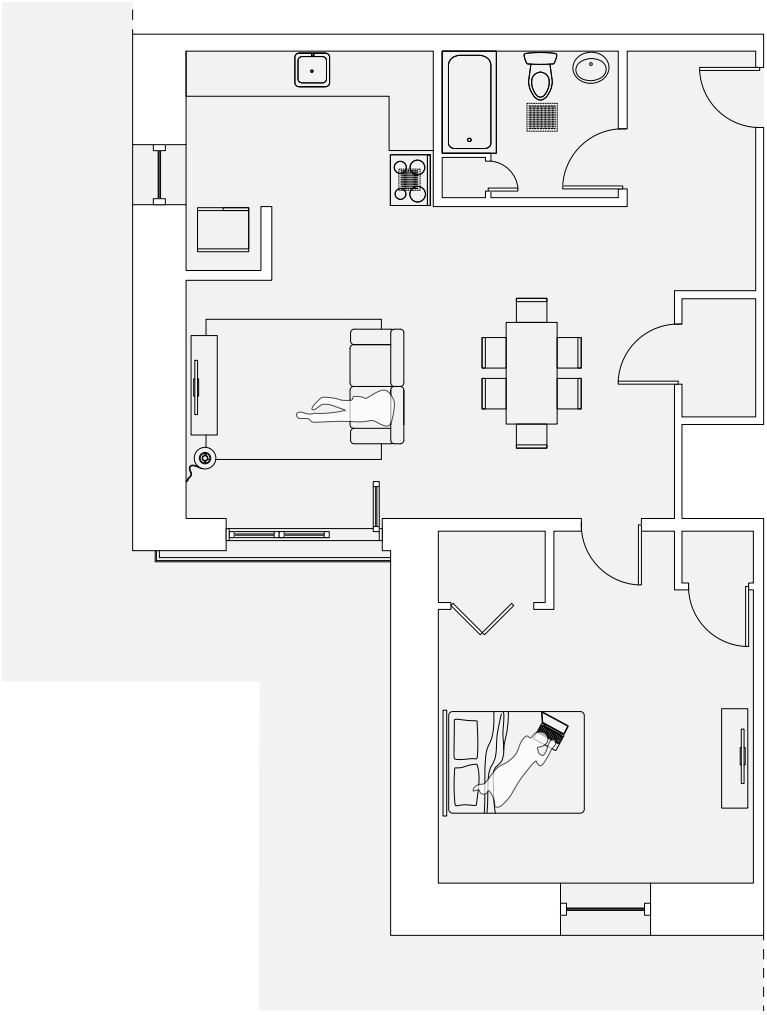
Thesis design integration with the Ken Soble Tower Retrofit

The inclusion of an enclosed balcony to provide a flexible living space with increased opportunity for safe isolation when required could be viewed as excessive due to the

[198] City of Toronto, *2016 Census: Age and Sex; Type of Dwelling*, (City of Toronto, May 4, 2017), 3, https://www.toronto.ca/wp-content/uploads/2017/10/96d7-2016-Census-Backgrounder-Age-Sex-Dwelling-Type.pdf.
[199] Tower Renewal Partnership, *Ken Soble Tower Transformation*, 6.
[200] Ibid, 6.
[201] Ibid, 49-51.
[202] Ibid, 49.
[203] Ibid, 49.

increased cost of materials, labour, and time required for installation. However, with a population more aware of the effects of air quality on health (sparked by the Covid-19 pandemic and continued by the climate crisis threat of worsening air pollution), protecting occupant health through design could become a higher priority in the architectural field.

The inclusion of the enclosed balcony complete with a sleeping porch within the existing Ken Soble Tower retrofit design is explored to address this identified problem. The focus on providing clean air and safe spaces for isolation in this integration with the existing retrofit plans further prioritizes occupant health, both in general and in times of emergency. This quick case study demonstrates the ease of widespread application of the retrofit presented in this thesis.

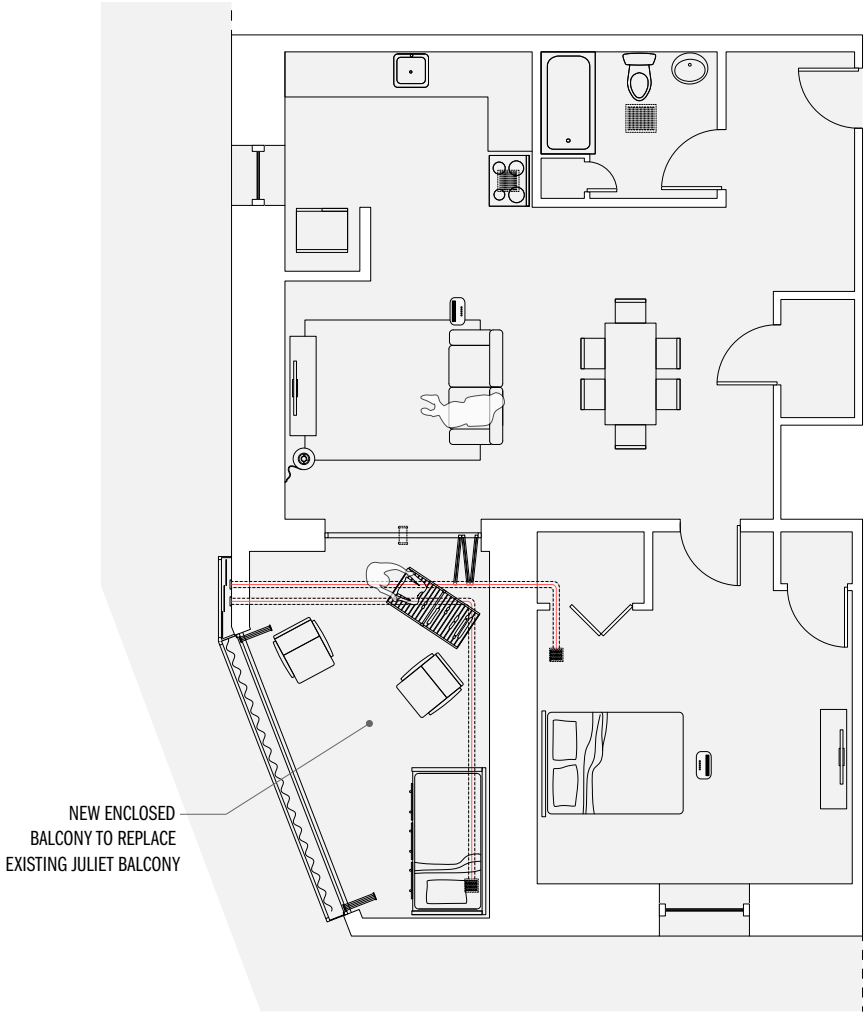


[Fig.61] Ken Soble Tower existing retrofit.

Enclosed Balcony

The new balcony is fitted with retractable doors and windows. The unit can expand and contract, providing an extra room or increasing the area of the common space. The transformable, intermediate space can be programmed as desired by the occupants, used for work, recreation, or rest.

The three-season balcony can be used as a sleeping porch with open windows allowing fresh air to flood the space. During the colder months, the doors and windows of the balcony remain closed, and the space becomes a thermal buffer zone[204] potentially used for extra storage and limited human occupation.



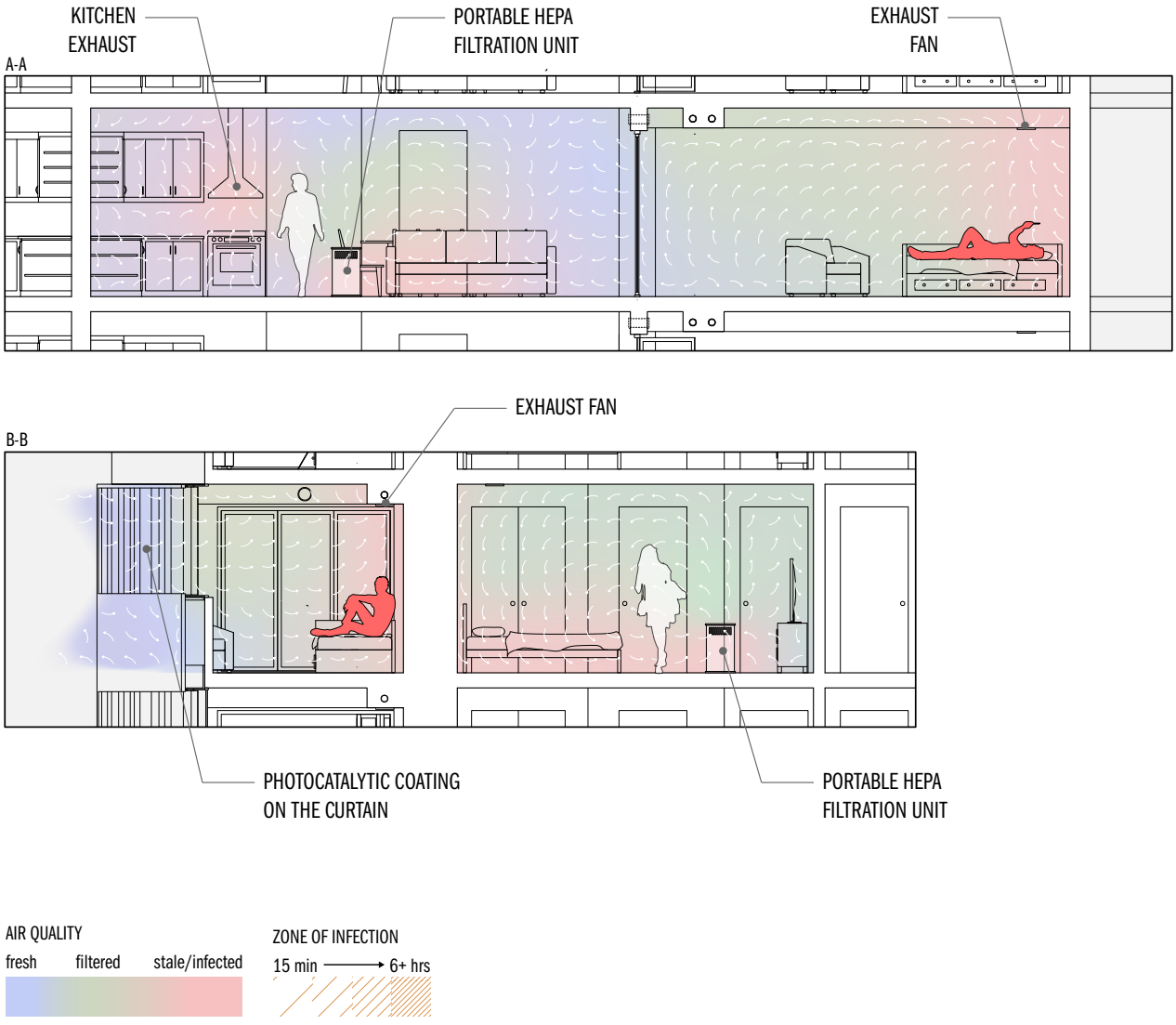
[Fig.62] Ken Soble Tower proposed retrofit.

[204] Gosztonyi, Stefanowicz, Bernardo, and Blomsterberg, "Multi-active façade for Swedish multi-family homes renovation," 13.

Isolated Sleeping Porch

If isolation is required, the doors between the balcony and unit interior are closed. An exhaust fan installed in the ceiling is turned on to remove infected air from the balcony, expelling it outside. An open window introduces fresh make-up air.

[Fig.63] Ken Soble Tower floor plan with isolated sleeping porch.



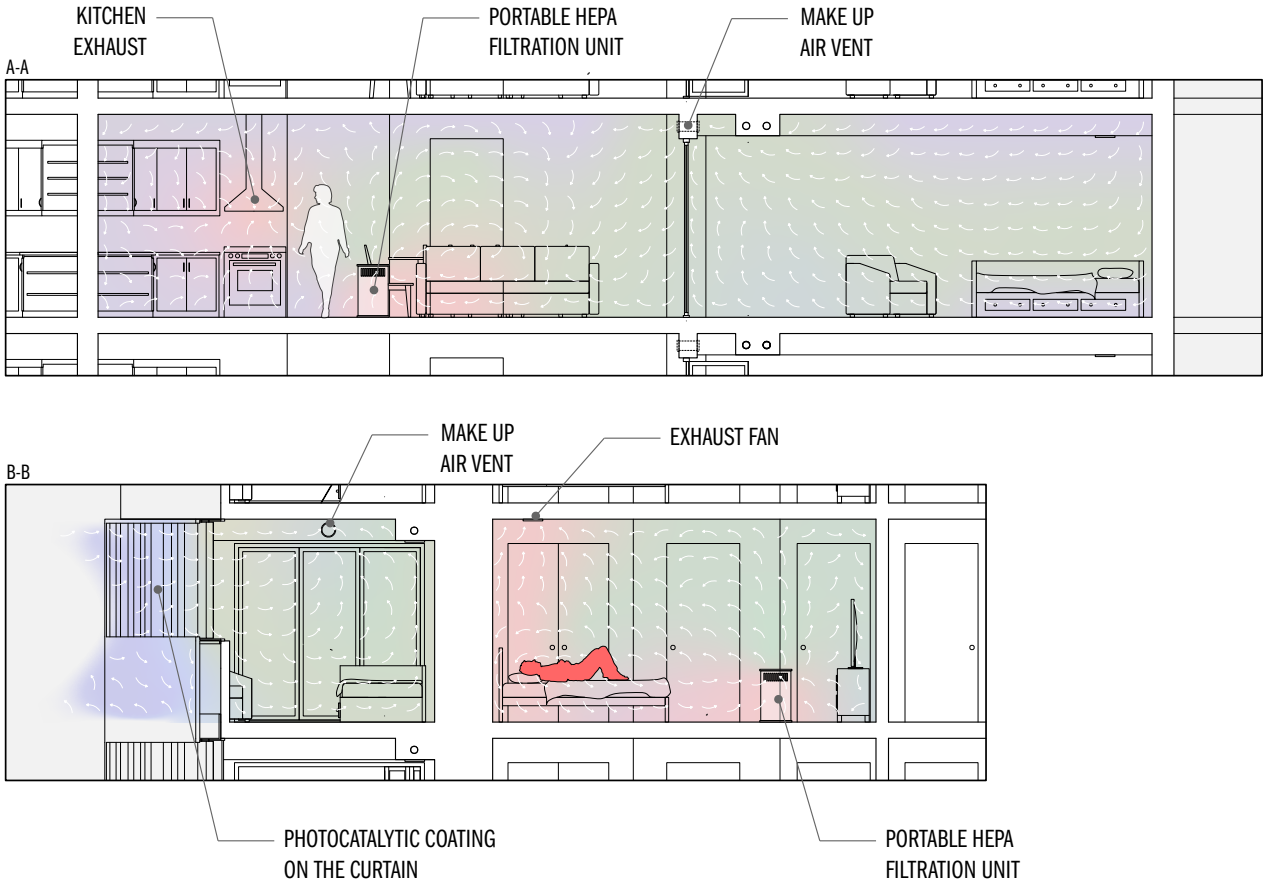
[Fig.64] Ken Soble Tower sections with isolated sleeping porch.

Negative Pressure Isolation Room

If isolation is required and it is too cold to sleep on the balcony, the bedroom can be transformed into a negative pressure isolation room. Like the balcony, the bedroom is

[Fig.65] Ken Soble Tower floor plan with negative pressure isolation room.

equipped with a fan that exhausts the air in the bedroom directly to the outdoors. A through-wall make-up vent is installed above the balcony doors to allow the controlled introduction of fresh air to replace the air being exhausted by the fan in the bedroom.[205] To complete the negative pressure isolation room, a secondary temporary entrance can be set up by the occupants inside the bedroom to help maintain the negative pressurization and create a transition zone between the bedroom and the unit.[206]



[Fig.66] Ken Soble Tower sections with negative pressure isolation room.

[205] Biler, Tavil, Su, and Khan, "A Review of Performance Specification and Studies of Trickle Vents," 1-41.
[206] Sun, "Controlled Environments," 70.

Air Filtration

The residents could be informed of the health benefits of using a portable HEPA filtration unit to increase air cleaning within their unit. The decision to set up a filtration unit within their unit would improve the general indoor air quality within the unit and reduce the development of negative health conditions.[207] However, if the windows and doors of the balcony are open, the efficacy of any portable filtration units would decrease,[208] and the occupants would rely on fresh air dilution to reduce the concentration of airborne contaminants.[209]

CONCLUSION

This brief case study using the Ken Soble Tower demonstrates the transferable nature of the retrofit proposed in this thesis. Toronto's ageing postwar towers need varying degrees of renewal. The four phases of retrofit (especially Phases One to Three) have the potential to be applied across the postwar tower stock and improve the indoor air quality for approximately 750,000 people.

[207] Public Health Ontario, *Use of Portable Air cleaners and Transmission of COVID-19*, 4.
[208] *Residential Air Cleaners*, 16.
[209] University of Rochester, "Adding more fresh air to indoor spaces."

CONCLUSION

Conclusion
Next Steps

CONCLUSION

The consideration of isolation as a purely spatial issue has led to inequality in the ability to isolate safely within residential spaces during the pre-vaccine era of the Covid-19 pandemic, as illustrated by the uneven distribution of Covid-19 case rates throughout Toronto. In addition to lack of space for adequate isolation due to overcrowding, the poor indoor air quality within many of Toronto's postwar towers increases the risk of negative effects on resident health. As a result, occupants are more vulnerable to infectious diseases.

Reliance on modern medicine shifted the task of preventing the spread of infectious diseases away from architecture. However, the Covid-19 pandemic has been a harsh reminder of the importance of designing environments that prioritize occupant health.

This thesis explored the potential for ventilation and filtration strategies to be used in combination with the design of a flexible, intermediate space to provide more opportunities for effective isolation within postwar tower units. The four retrofit phases outline strategies to improve and control indoor air quality at varying scales of intensity. The first phase is catered to the occupant, focusing on off-the-shelf methods of air filtration and negative room pressurization to be installed in buildings recently renovated or without plans for imminent retrofit. The second phase carries the ideas of the first phase forward while introducing and highlighting the benefits of installing decentralized insuite ERVs and compartmentalizing the units. Intended for buildings undergoing intense upgrades,

the third phase increases the scale of the retrofit to incorporate the installation of enclosed balconies along the entire face of each unit. The occupants are provided with expandable and contractible living spaces that increase the square-footage of their units and provide more opportunity for spatial isolation. In consideration of an increase in air pollution sparked by the changing climate, the fourth phase of the retrofit imagines the future incorporation of passive air filtration along the facade to clean the naturally ventilated air. Each phase of the retrofit prioritizes the health of the occupant in everyday scenarios and in times of emergency, such as the Covid-19 pandemic.

The retrofit proposal expands from the agenda of the Tower Renewal Partnership by providing a translatable design strategy. Due to the generic components outlined in each phase, theoretically the entire postwar tower stock of Toronto could be retrofitted using one or more of the proposed retrofit phases. Aside from the exterior addition of an enclosed balcony, none of the retrofit phases alter the unit floor plans. This ease of application, as demonstrated in the brief case study using the Ken Soble Tower, would allow for indoor air quality improvement and an increase in unit size for approximately 750,000 people.

Sparked by apparent need during the Covid-19 pandemic, the prioritization of occupant health through the use of ventilation and filtration strategies during the design of a flexible space for living and spatial isolation in a postwar tower retrofit acknowledges architecture’s historical role in preventing the spread of infectious diseases. Despite the increased cost during retrofit, the inclusion of air quality-oriented flexible spaces that provide opportunities for safe isolation should not be viewed as excessive but rather be made a standard requirement. The danger faced by society during the pre-vaccine era of the pandemic should be a strong reminder to those in the architectural field of the responsibility to design healthy environments; that complete reliance on modern medicine for protection is not sustainable. The climate crisis and the threat of future pandemics could increase general public awareness of the negative health effects of poor air quality resulting in pressure on authorities to prioritize occupant health in residential space. A concerted effort should be made to focus on environmental improvements in high risk communities, such as Thorncliffe Park, to decrease the inequality of infectious disease spread.

NEXT STEPS

Design

The alteration of the unit floor plan would be a next step for this project. This would provide an opportunity to explore how the idea of an expandable and contractible living space could be spread throughout the unit instead of limited to the exterior wall. This would be beneficial not only in terms of providing increased options for spatial isolation but would provide occupants with a home that could transform and accommodate more daily activities in a world where staying home all day may remain more common. Furthermore, the layout of the ERV ducting could be made more efficient through a unit plan reconfiguration.

Explorations into unifying the components required to set up the negative pressure isolation room would be another next step. The transformation of a bedroom into a negative pressure isolation room could be automated, connecting the exhaust fan, make up air vents/opening of windows, and a built-in temporary secondary entrance in a single system. This would increase the ease of use for the occupants.

Graphic Representation

The effect of indoor air quality on occupant health cannot be overlooked. As the climate crisis leans towards an increasingly unstable exterior environment, moving forward, the importance of indoor air quality should strengthen in the architecture field.

The development of comprehensive graphics, as explored in Part Two of this thesis, could provide opportunities for more intentional planning of indoor air quality and air flow management within spaces (residential and more) early on in the design process. By making the invisible visible, the air contained within a space becomes an architectural element, something that can be manipulated to improve the quality of a space. The act of drawing the air can force the designer to fully consider its effect on future occupants.

Time is a dimension often considered when imagining how spaces are used and altered over a period, especially spaces designed to be flexible. In terms of this thesis, the effect of time on air quality was important to consider, namely how

long the source of infection occupied a space. Through the graphic visualization of air, the relationship between indoor air quality and time could be further explored.

Lastly, beyond their use in the design process, refinement of the graphics such that a lay person could understand them could provide a visual tool to aid occupants in managing their indoor environments.

BACK MATTER

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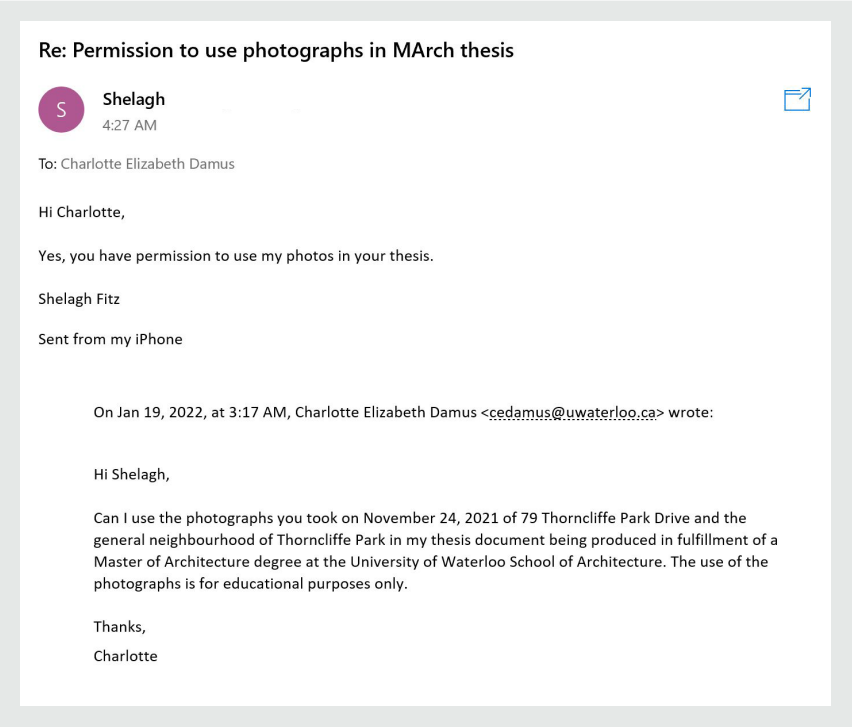

Re: Permission to use photographs in MArch thesis

Shelagh
4:27 AM

To: Charlotte Elizabeth Damus

Hi Charlotte,

Yes, you have permission to use my photos in your thesis.

Shelagh Fitz

Sent from my iPhone

On Jan 19, 2022, at 3:17 AM, Charlotte Elizabeth Damus <cedamus@uwaterloo.ca> wrote:

Hi Shelagh,

Can I use the photographs you took on November 24, 2021 of 79 Thorncliffe Park Drive and the general neighbourhood of Thorncliffe Park in my thesis document being produced in fulfillment of a Master of Architecture degree at the University of Waterloo School of Architecture. The use of the photographs is for educational purposes only.

Thanks,
Charlotte

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