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SARS-CoV-2 in migrant worker dormitories: Geospatial epidemiology supporting outbreak management

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A B S T R A C T

Background: Migrant worker dormitories—residential complexes where 10–24 workers share living spaces—account for the majority of cases of SARS-CoV-2 infection in Singapore. To prevent overspill of transmission to the wider population, starting in early April 2020, residents were confined to their dormitories while measures were put in place to arrest the spread of infection. This descriptive study presents epidemiological data for a population of more than 60 000 migrant workers living in two barracks-style and four apartment-style dormitories located in western Singapore from April 3 to June 10, 2020.
Methods: Our report draws from data obtained over the first 50 days of outbreak management in order to describe SARS-CoV-2 transmission in high-density housing environments. Cumulative counts of SARS-CoV-2 cases and numbers of housing units affected were analyzed to report the harmonic means of harmonic means of doubling times and their 95% confidence intervals (CI).
Results: Multiple transmission peaks were identified involving at least 5467 cases of SARS-CoV-2 infection across six dormitories. Our geospatial heat maps gave an early indication of outbreak severity in affected buildings. We found that the number of cases of SARS-CoV-2 infection doubled every 1.56 days (95% CI 1.29–1.96) in barracks-style buildings. The corresponding doubling time for apartment-style buildings was 2.65 days (95% CI 2.01–3.87).
Conclusions: Geospatial epidemiology was useful in shaping outbreak management strategies in dormitories. Our results indicate that building design plays an integral role in transmission and should be considered in the prevention of future outbreaks.

Background

Singapore is home to approximately 1.4 million migrant workers, of whom close to 300,000 are employed in the construction, manufacturing, marine shipyard, processing, or services industries, and housed in dormitories run by third-party private operators (Ministry of Manpower, 2019). There are 43 licensed, purpose-built dormitories, each approved to

Abbreviations: ARI, acute respiratory illness; PCR, polymerase chain reaction; *R*, reproductive number; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; T_d, doubling time; *V*, serial interval.

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accommodate between 1000 and 25,000 residents, with ten to 24 residents per housing unit. Prior to January 2020, public health efforts in the dormitories were largely focused on sanitation, food hygiene, and vector control. Overall, dormitories had two prevalent designs: a conventional apartment style, which offered facilities within each housing unit; or a more densely packed barracks-style, in which multiple units shared communal showers, toilets, and kitchens, which the dormitory operator would clean on a daily basis (Chin et al., 2020). As of July 31, 2020, migrant workers had accounted for 49,327 (94%) of the 52,205 cumulative total numbers of cases in Singapore (Ministry of Health, 2020c).

The first cases of SARS coronavirus 2 (SARS-CoV-2) infection in Singapore appeared on January 23, 2020, arising from travelers from China. This seeded local transmission and small clusters of cases, which were effectively controlled through extensive contact tracing as well as isolation of index cases and close contacts (Ministry of Health, 2020a). A second wave of infections occurred due to a large influx of travelers into Singapore from the UK, Europe, the USA and the Indian subcontinent before policies requiring quarantine of travelers were imposed. Clusters resulting from travelers involved sites frequented by migrant workers, who secondarily seeded the dormitories and work sites attended by workers from different dormitories, resulting in parallel outbreaks.

In early April, 25 dormitories were locked down and declared isolation areas by the government in order to prevent further transmission into the community (Ministry of Manpower, 2020a).

During the lockdown period, residents were asked to remain in their respective housing units and observe enhanced hygiene and safe distancing measures to the greatest extent possible (Ministry of Health, 2020b). Mingling was strongly discouraged, and food was delivered to each unit. In the western part of Singapore, the National University Health System established primary care, testing and management capabilities in 14 dormitories. Medical posts were operated 7 days a week, engaging more than 1000 nurses, dentists, physicians, and allied health professionals.

The first step in the response was to isolate the dormitories to prevent spread to the broader community. A strategy was developed that was anchored around the WHO four-pillar response model of case management, epidemiology, logistics, and community engagement (World Health Organization, 2015). Case management involved risk stratifying those who were diagnosed as having SARS-CoV-2 infection against the likelihood of having increased morbidity/mortality (Jordan et al., 2020). These high-risk cases were extracted and cared for in hospitals under close monitoring. The remaining lower-risk cases were isolated either in community facilities or in dedicated units within their dormitory, with daily clinical reviews, physiological monitoring, and telehealth support. Epidemiological overseeing within dormitories was supported by temporary staff, who assisted with data management and worked with clinicians to create user-friendly overviews for each dormitory. The aim of our study was to better understand the geospatial spread of SARS-CoV-2 infection, and to deploy healthcare resources in a data-driven manner.

The migrant worker dormitory residents were fairly homogeneous in terms of demographics—they were all male, tended to be between 20 and 55 years of age, and mostly hailed from South Asian countries. This epidemiological report describes the transmission dynamics of multiple outbreaks of SARS-CoV-2 among this particular demographic living in close quarters, and the possible effect dormitory design might have on transmission rates.

Materials and methods

All data collated for this study were obtained from primary care, administrative, and laboratory records generated over the period from April 3 to June 10, 2020. Disease surveillance largely took two forms in the dormitories: passive case detection through an onsite medical post and active case finding through close-contact investigations. Residents presenting to the medical post with symptoms of acute respiratory illness (ARI)—defined as rhinorrhoea, pharyngitis, cough, shortness of breath or fever—had a nasopharyngeal swab polymerase chain reaction (PCR) test using the Roche Cobas® 6800 assay (Mostafa et al., 2020). Two local laboratories provided additional PCR capacity: the National Public Health Laboratory, using the Life Technologies TaqPath COVID-19 Combo Kit, and the Defence Science Organization using a real-time PCR assay that was developed in-house. All three assays were reviewed and granted provisional authorization approval for SARS-CoV-2 diagnostic testing by the Singapore Health Sciences Authority, with effect from March 2020. In dormitories, where more than 80% of ARI cases were confirmed positive on PCR testing, clinical diagnosis was deemed sufficient to manage a patient as presumptive SARS-CoV-2 infection.

All migrant workers from the same housing unit as confirmed or presumptive cases were defined as close contacts. Where feasible, close contacts were isolated and tested by SARS-CoV-2 PCR. Whenever possible, confirmed and presumptive cases were either relocated from the dormitory to isolation facilities or isolated *in situ* with additional restrictions placed on their movements in the dormitory. This was on the understanding that all migrant workers would eventually be tested using a combination of serology and PCR testing, before lockdown restrictions could be lifted.

For this study we selected six dormitories with the highest transmission rates per unit capacity. Each residential building was treated as an independent population at risk. Our reporting and analyses were therefore conducted in sufficient detail to describe transmission characteristics for 52 residential buildings in total. Information used for this study was limited to time, location, and outcome of clinical consultations that resulted in a positive identification of SARS-CoV-2 infection. In Singapore, disease surveillance and investigations are mandated by the Infectious Diseases Act and the data from the dormitories were routinely reported to the Ministry of Health. No samples or additional data were collected specifically for the purposes of this manuscript.

Incident case data were compiled and epidemiological curves produced for each dormitory. Using Microsoft Excel, geospatial-heat-maps along with epi-curve templates were produced for each residential building, which could be readily updated by our clinical teams and data managers. Cases with missing addresses—approximately 3.5% of data-points—were omitted from the geospatial heat-maps but retained as far as possible in the dormitory-wide epidemiological datasets. A second set of descriptive data was compiled, treating each housing unit as a distinct entity. The onset of disease in any of the eight to 24 residents colocated within each housing unit was determined to be the onset of disease for that unit.

Doubling times (T_d) were computed for each of the 52 residential buildings, based on case counts and the number of units affected (Appenidx A). Scatter plots were drawn for each of the six dormitories to display every doubling interval recorded. The harmonic mean of doubling times was used to express a summary statistic for each residential building. Likewise, a summary statistic for each dormitory was derived using the harmonic mean of harmonic means, as had been done in other studies on SARS-CoV-2 transmission (Muniz-Rodriguez et al., 2020; Oliveiros et al., 2020; Pellis et al., 2020). The 95% confidence interval for each statistic was used to reflect the uncertainty of our estimate.

Table 1
Details of migrant worker dormitories.

Dormitory	Occupancy rate (%)	Blocks	Number of housing units	Residential building type	Maximal number of residents per housing unit
A	23,600 (94)	10	2,200	Barracks style	12
B	13,000 (77)	19	1120	Barracks style	14
C	11,433 (89)	5	800	Apartment style	16
D	7,269 (79)	8	630	Apartment style	16
E	5,880 (75)	8	693	Apartment style	12–24
F	3,300 (67)	4	348	Apartment style	14

A second set of harmonic means of harmonic means was computed using data aggregated from all barracks-style and apartment-style residential buildings. Given that doubling times were independent and similarly skewed in distribution, the Mann–Whitney *U*-test was used to assess whether residential building type was associated with doubling times. Using the following formula (Jones, 2007) estimated reproductive numbers (R) were calculated:

$$R = [\log(2)V/T_d] + 1$$

where $V = 4$ is the serial interval for SARS-CoV-2 transmission (Du et al., 2020). All harmonic means of harmonic means, with their respective 95% confidence intervals, were visualized using forest plots. All statistical analyses were performed using STATA14.

Results

Table 1 provides an overview of the occupancy of the six dormitories. Dormitory residents were all male, between 20 and 55 years of age, and hailed from Bangladesh, India, China, Myanmar, Thailand, Sri Lanka, or Malaysia.

Early into the outbreak, dormitories A and B saw consistently high proportions of PCR-positive ARIs. Our case definition for dormitories A and B was therefore amended to identify presumed positive patients based on clinical symptoms alone from Day 21 and Day 3, respectively. The epidemiological curves in Figure 1 demonstrated an outbreak pattern, with multiple peaks across the dormitories. Only dormitory B showed a consistent decline in new cases over the period of observation. Cumulative curves for dormitories A and B also showed a degree of levelling off approaching Day 50, while case numbers in dormitories C to F continued to rise.

The epidemiological curves for standardized case numbers per 1000 residents for each of the 52 residential buildings (Supplementary Material Figures S1 and S2) demonstrated a heterogeneous pattern not seen on dormitory-level aggregate data. As early as day 14, geospatial heatmaps for individual buildings (Figure 2) demonstrated that infection control measures were unlikely to contain the disease within housing units.

As the outbreak evolved, the strategy of screening close contacts was discontinued, but increased personal engagement saw more symptomatic workers presenting. Therefore, we began to track the percentage of susceptible housing units, as shown in Figure 3. Barracks-style dormitories exhibited a rapid decline in the percentage of unaffected units, while apartment-style dormitories saw a more gradual decrease.

By day 50 the proportion of susceptible units differed markedly from the proportion of residents, as shown in Table 2. For example, in dormitory F, 87% of residents were assumed to be unaffected at Day 50, while as many as 31% of housing units had already registered an index case.

Visual comparison of doubling times for case counts and housing unit numbers (Supplementary Material Figures S3 and S4) revealed that transmission slowed as the outbreaks progressed. Overall, however, only dormitory A resembled a typical outbreak, where doubling times generally increased with each generation (Galvani et al., 2003). Forest plots of the harmonic means of harmonic means of doubling times in Figure 4 showed dormitory-specific estimates ranging from 1 to 4 days for case counts and from 2 to 8 days for housing units.

Estimates of doubling times within residential building types suggested that overall transmission was significantly slower in apartment-style buildings. The number of cases doubled approximately 1.7 times faster in barracks-style buildings ($p = 0.003$), while

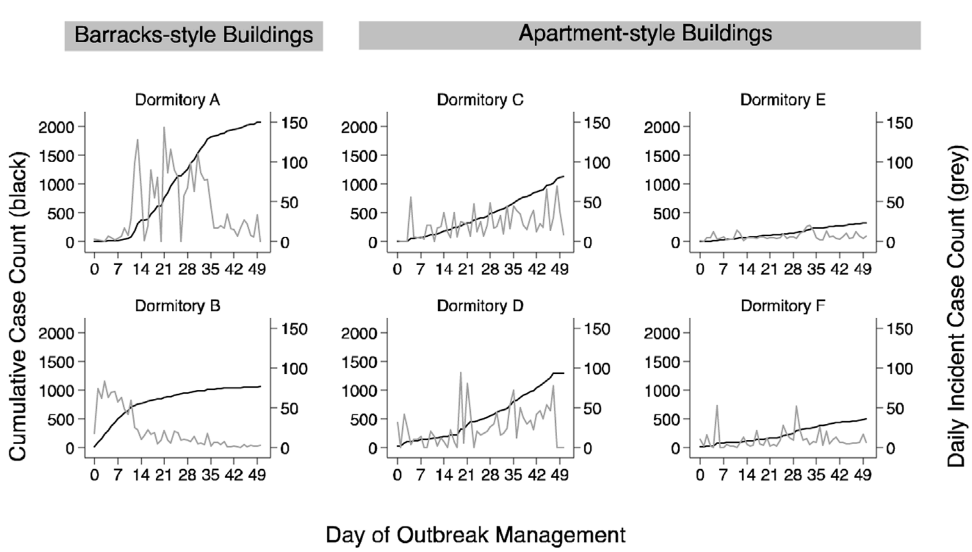

Figure 1. Epidemiological overview of incident (grey line) and cumulative (black line) cases in six dormitories of SARS-CoV-2 infection over the first 50 days of outbreak.

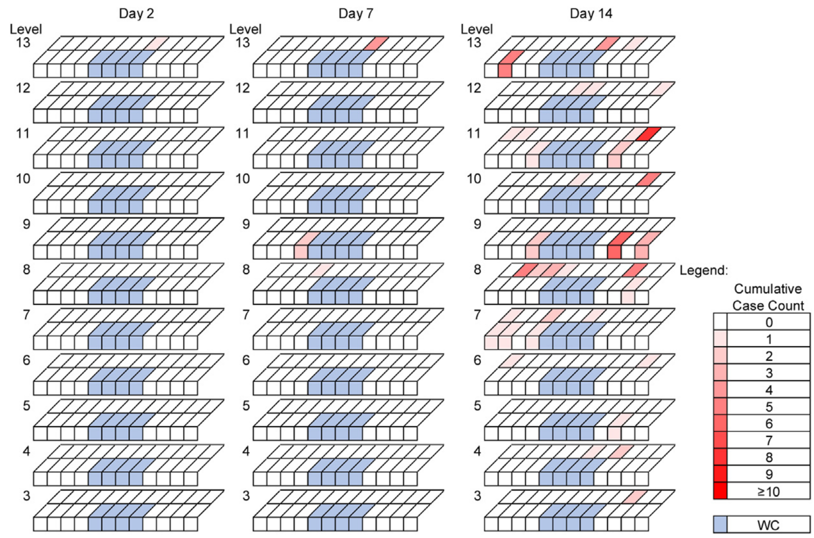

Figure 2. Example of geospatial spread of infections in one residential block of dormitory A reflecting D2, D7, and D14. WC: water closet.

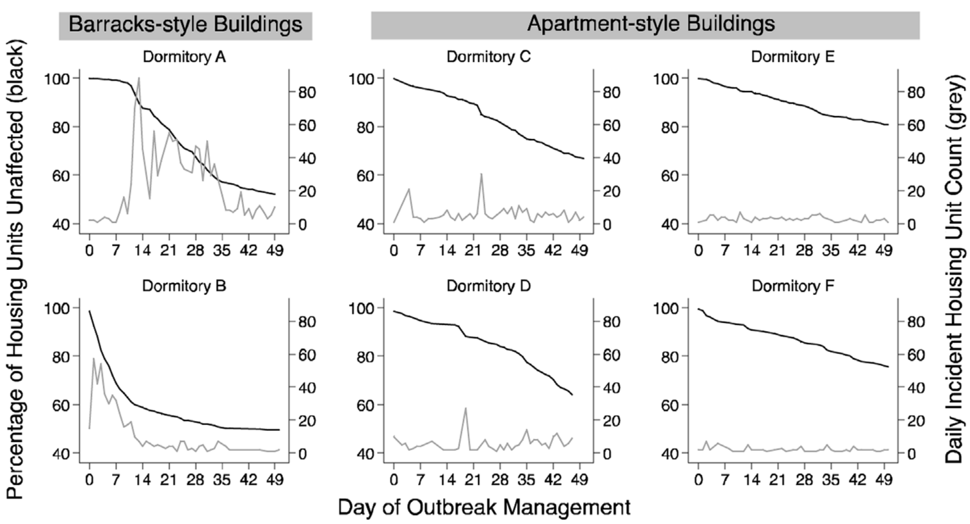

Figure 3. Epidemiological overview of percentage of unaffected housing units and daily number of units with an index case in six dormitories.

the number of housing units affected doubled 3.4 times faster ($p < 0.0001$). Using a serial interval of 4 days that has been previously estimated for SARS-CoV-2 transmission in the community, we computed average *R* values of 2.77 and 2.05, respectively, for barracks- and apartment-style buildings.

Discussion

A number of studies have described the epidemiological features of SARS-CoV-2 transmission (Park et al., 2020). Our epidemiological findings confirmed a high level of heterogeneity in the transmission of SARS-CoV-2 in migrant worker dormitories based on existing infrastructure (Bagdasarian and Fisher, 2020). Tacit knowledge of this heterogeneity played an important role in managing clinical care, prioritizing our logistics, and directing risk communications and community engagement under complex circumstances. We have shown that the style of infrastructure design was significantly associated with the pace of transmission, as reflected in case and housing unit doubling times, and the R_0.

In the barracks-style dormitories our early data suggested mature outbreaks that would quickly exceed the capacity of local isolation facilities. Therefore, each dormitory created cohorting spaces to house uncomplicated younger cases, who were seen daily by visiting medical teams.

Where temporal surveillance painted a limited picture of disease transmission, heat-maps based on geospatial information proved invaluable as a proxy measure for the stage and pace of the outbreaks (Centers for Disease Control and Prevention, 2006). The information gleaned from geospatial mapping drove us to rapidly increase the scale of medical services provided. Relying heavily on resources within the hospital community, we developed culturally appropriate education material, describing the early symptoms of SARS-CoV-2 infection and preventative actions, in the six languages—Hindi, Tamil, Bangladeshi, Burmese, Mandarin, and Malay—spoken by the dormitory residents. We paid special attention to high-risk groups (Jordan et al., 2020). Residents aged 45 years and over were actively screened using intranasal swabbing. Those with a negative result were transferred to a separate isolation facility. PCR-positive residents aged 45 and over were referred to hospital and observed as inpatients. Swab-positive residents with a history of high BMI, cardiovascular risk factors, or chronic lung disease were also assessed as high risk and referred to hospital (Wang et al., 2020).

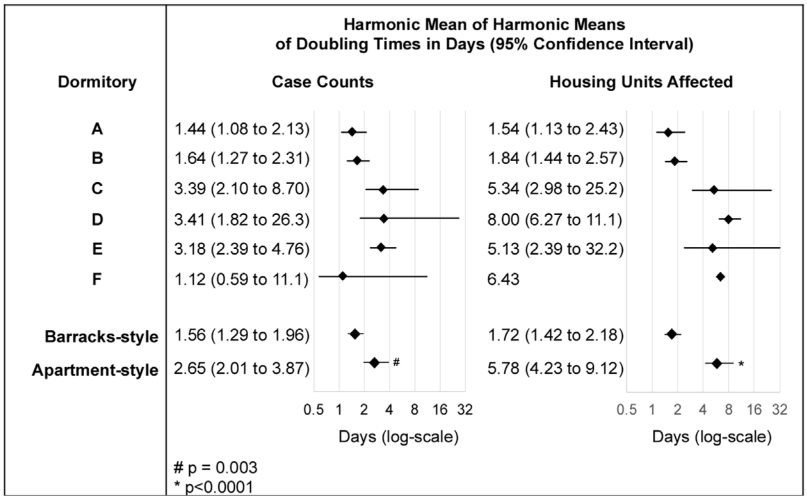

Figure 4. Harmonic mean of harmonic means of doubling times for cumulative case counts and counts of housing units affected.

Table 2
Summary of key outbreak parameters in respective dormitories.

Dormitory	Peak daily incident case count	Peak incidence rate per 1000 occupants	Day 50			
			Cumulative case count	Percentage of residents assumed susceptible	Cumulative housing units affected	Percentage of housing units susceptible
A	72	3.05	2080	91.2%	1,198	45.5%
B	96	7.38	1058	91.9%	502	48.2%
C	50	4.37	1134	90.1%	381	52.4%
D	47	6.38	654	91.0%	235	62.7%
E	21	3.57	329	94.4%	151	78.2%
F	28	8.48	522	84.2%	97	72.1%

In a closed population, such as a migrant worker dormitory under lockdown, the growth rates of cumulative case counts could provide an understanding of the maturity of an outbreak (Vynnycky and White, 2010). This notion would hold true as long as cases could be detected and recorded reliably, for example through active syndromic surveillance. However, in SARS-CoV-2 transmission where the majority of persons might have experienced only mild symptoms, reliance on case numbers alone would have produced a false impression. Contemporary reports on close contact transmission risk have suggested that 15–89% of household members could be affected by secondary transmission. (Bi et al., 2020; Li et al., 2020; Qian et al., 2020). Given that these studies were conducted primarily in households that were families, we assumed that the risk of transmission in high-density dormitories was likely to be higher. By tracking the proportion of household units affected we were equipped with an implicit understanding of how much further the outbreak could progress.

The shorter doubling times in dormitories A and B suggested that large barracks-style buildings created conditions that hampered infection control. Infrastructural factors included increased mingling of residents and contact with a contaminated environment when using shared facilities (Kampf et al., 2020). We suspect that the design of housing units in dormitory B impeded cross-ventilation (Bahl et al., 2020). Additional challenges included the scaling up of medical operations, logistics, and effective risk communication in larger dormitories.

Large, uncontrolled outbreaks have the potential to overwhelm hospital systems, leading to increased morbidity and mortality; therefore, apartment-style residences should be favored from a public health perspective (Ji et al., 2020). The Singapore government has already taken steps that will in due course see migrant worker dormitories reduce population density and limit the sharing of kitchen, bathroom, and toilet facilities (Ministry of Manpower, 2020b). These changes should impact on other aspects of migrant worker safety, including the risk of other respiratory, diarrheal, and vector-borne infectious diseases.

Our data were derived from routine reporting across six dormitories of varying size and design, and demonstrated a field epidemiologist's perspective of this massive cluster. Many cases were surely not identified because of asymptomatic and mild disease, meaning that our doubling times are likely to represent an overestimate.

Our experience of managing SARS-CoV-2 transmission in migrant worker dormitories highlights the importance of field epidemiology in dealing with multiple, heterogeneous outbreaks. We have identified that building design could play an integral role in the prevention of future outbreaks. The experience shared here may help inform outbreak response efforts in other large populations living in close confinement (Montoya-Barthelemy et al., 2020).

Conflicts of interest

None declared.

Funding source

This study received no funding. The authors had access to all data used in the study and bore final responsibility for the decision to submit for publication.

Ethical approval

The Second Schedule of Singapore's Human Biomedical Research Act stipulates that national public health research, as defined in and conducted in accordance with section 59A of Singapore's Infectious Diseases Act, is excluded from the definition of human biomedical research. This means that an ethical review and approval by an institutional review board was not required to analyse and report on the surveillance dataset. No samples or additional data were collected specifically for the purposes of this manuscript.

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Appendix A. Calculation of doubling times

When compiling doubling times (T_d) we made two key assumptions: each residential building would experience its own outbreak following the emergence of at least one index case; and transmission was confined within each residential building. Daily cumulative case counts (A_t) were tabulated along with corresponding daily growth rates (g_t), which were calculated based on cumulative case counts for the day of interest and one day prior using Eq. (1):

$$g_t = \frac{A_t}{A_{t-1}} \quad (1)$$

Then a second set of tables, in the format shown in Table A1, was compiled for each residential building to capture every doubling step (n) and the respective expected case count (E_n) using Eq. (2):

$$E_n = 2^n \times A_0 \quad (2)$$

The tables were then expanded by cross-referencing E_n with the smallest corresponding values of $A_t$that were still larger than E_n to determine the day (t_n) when the doubling step had occurred. As t_n would always reflect integers we calculated the precise time elapsed (T_n), as shown in Eq. (3):

$$T_n = t_n + \frac{\ln\left(\frac{2^n \times A_0}{A_{t_n - 1}}\right)}{\ln(g_{t_n})} \quad (3)$$

Finally, we elicited the actual doubling time intervals (T_d) by subtracting the time elapsed between successive doubling steps.

Table A1
Tabulation of doubling steps for a single residential building.

Doubling step	Expected cumulative case count	Earliest Day when $A_t > E_n$	Time elapsed	Doubling time interval
0	E_0	0	0	0
n	E_n	t_n	T_n	$T_d = T_n - T_{n-1}$

References

Bagdasarian N, Fisher D. Heterogenous COVID-19 transmission dynamics within Singapore: a clearer picture of future national responses. BMC Med 2020;18 (June (1)):164.

Bahl P, Doolan C, de Silva C, Chughtai AA, Bourouiba L, MacIntyre CR. Airborne or droplet precautions for health workers treating COVID-19?. J Infect Dis 2020;(April) jiaa189.

Bi Q, Wu Y, Mei S, Ye C, Zou X, Zhang Z, et al. Epidemiology and transmission of COVID-19 in Shenzhen China: analysis of 391 cases and 1,286 of their close contacts. Lancet Infect Dis 2020;20(August (8)):911–9.

Centers for Disease Control and Prevention. Principles of Epidemiology in Public Health Practice, Third Edition: An Introduction to Applied Epidemiology and Biostatistics. October [internet]. [cited June 13 2020]. Available from:. Atlanta GA: US Department of Health and Human Services; 2006. https://www.cdc.gov/csels/dsepd/ss1978/index.html.

Chin C, Chow C, Tay T. The Next-Generation Foreign Workers' Dormitory. (2020) [Internet]. [cited June 13 2020]. Available from:. Singapore: EdgeProp; 2020. https://www.edgeprop.sg/property-news/next-generation-foreign-workers%E2%80%99-dormitory.

Du Z, Xu X, Wu Y, Wang L, Cowling BJ, Meyers LA. Serial interval of COVID-19 among publicly reported confirmed cases. Emerg Infect Dis 2020;26(June (6)):1341–3.

Galvani AP, Lei X, Jewell NP. Severe acute respiratory syndrome: temporal stability and geographic variation in death rates and doubling times. Emerg Infect Dis 2003;9(August (8)):991–4.

Ji Y, Ma Z, Peppelenbosch MP, Pan Q. Potential association between COVID-19 mortality and health-care resource availability. Lancet Glob Health 2020;8(April (4)):e480.

Jones JH. Notes on R_0. California, 323. Department of Anthropological Sciences; 2007. p. 1–9 May.

Jordan RE, Adab P, Cheng KK. Covid-19: risk factors for severe disease and death. BMJ 2020;368(March):m1198.

Kampf G, Todt D, Pfaender S, Steinmann E. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. J Hosp Infect 2020;104(March (3)):246–51.

Li W, Zhang B, Lu J, Liu S, Chang Z, Cao P, et al. Characteristics of household transmission of COVID-19. Clin Infect Dis 2020;71(November (8)):1943–6.

Ministry of Health. 23 Jan 2020 Confirmed Imported Case of Novel Coronavirus Infection in Singapore; Multi-Ministry Taskforce Ramps up Precautionary Measures. [internet]. [cited June 15 2020]. Available from:. Singapore: Ministry of Health; 2020. https://www.moh.gov.sg/news-highlights/details/confirmed-imported-case-of-novel-coronavirus-infection-in-singapore-multi-ministry-taskforce-ramps-up-precautionary-measures.

Ministry of Health. Strong National Push to Stem the Spread of COVID-19. [internet]. [cited June 15 2020]. Available from:. Singapore: Ministry of Health; 2020. https://www.moh.gov.sg/news-highlights/details/strong-national-push-to-stem-spread-of-covid-19.

Ministry of Health. 31 July 2020 Daily Report on COVID-19. [internet]. [cited August 15 2020]. Available from:. Singapore: Ministry of Health; 2020. https://www.moh.gov.sg/docs/librariesprovider5/local-situation-report/20200731_daily_report_on_covid-19_cabinet.pdf.

Ministry of Manpower. Foreign Workforce Numbers. [internet]. [cited June 15 2020]. Available from:. Singapore: Ministry of Manpower; 2019. https://www.mom.gov.sg/documents-and-publications/foreign-workforce-numbers.

Ministry of Manpower. Dormitories Gazetted as Isolation Areas. [internet]. [cited June 15 2020]. Available from:. Singapore: Ministry of Manpower; 2020. https://www.mom.gov.sg/covid-19/dorms-gazetted-as-isolation-areas.

Ministry of Manpower. Joint MND-MOM Media Release on New Dormitories with Improved Standards for Migrant Workers. [internet]. [cited June 15, 2020]. Available from:. Singapore: Ministry of Manpower; 2020. https://www.mom.gov.sg/newsroom/press-releases/2020/0601-joint-mnd-mom-media-release-on-new-dormitories-with-improved-standards-for-migrant-workers.

Montoya-Barthelemy A, Lee CD, Cundiff D, Smith E. COVID-19 and the correctional environment: the American prison as a focal point for public health. Am J Prev Med 2020;58(June (6))888–91 2020.

Mostafa HH, Hardick J, Morehead E, Miller JA, Gaydos CA, Manabe YC. Comparison of the analytical sensitivity of seven commonly used commercial SARS-CoV-2 automated molecular assays. J Clin Virol 2020;130(September):104578.

Muniz-Rodriguez K, Chowell G, Cheung CH, Jia D, Lai PY, Lee Y, et al. Doubling time of the COVID-19 epidemic by province, China. Emerg Infect Dis 2020;26(August (8)):1912–4.

Oliveiros B, Caramelo L, Ferreira NC, Caramelo F. Role of temperature and humidity in the modulation of the doubling time of COVID-19 cases. medRxiv 2020;13. . [Preprint]. [cited June 15 2020]: Available from: https://www.medrxiv.org/content/10.1101/2020.03.05.20031872v1.

Park M, Cook AR, Lim JT, Sun Y, Dickens BL. A systematic review of COVID-19 epidemiology based on current evidence. J Clin Med 2020;9(March (4)):967.

Pellis L, Scarabel F, Stage HB, Overton CE, Chappell LH, Lythgoe KA, et al. Challenges in control of Covid-19: short doubling time and long delay to effect of interventions. medRxiv 2020;23. . [Preprint]. [cited June 15 2020]: Available from: https://www.medrxiv.org/content/10.1101/2020.04.12.20059972v2.

Qian G, Yang N, Ma AH, Wang L, Li G, Chen X, et al. COVID-19 transmission within a family cluster by presymptomatic carriers in China. Clin Infect Dis 2020;71(July (15)):861–2.

Vynnycky E, White R. An Introduction to Infectious Disease Modelling. Oxford: OUP; 2010. p. 63–82.

Wang B, Li R, Lu Z, Huang Y. Does comorbidity increase the risk of patients with COVID-19: evidence from meta-analysis. Aging (Albany NY) 2020;12(April (7)):6049–57.

World Health Organization. GO Training—Pillars of the Global Ebola Response. [internet]. Available from. Geneva: World Health Organization; 2015. https://www.who.int/csr/disease/ebola/training/go-video-lectures-module-4/en/.