COBWEB

Modelling the effect of higher density living areas on transmission of COVID-19 in a university residence

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Introduction

COVID-19 is an infectious respiratory disease caused by the most recently discovered novel coronavirus found in Wuhan, China in late 2019. Coronaviruses are a family of viruses causing illnesses in animals and humans including the common cold, Severe Acute Respiratory Syndrome (SARS), and Middle East Respiratory Syndrome (MERS)[1,7]. The World Health Organization (WHO) classified COVID-19 as a pandemic on March 11, 2020[1] and the outbreak is still ongoing in countries around the world. COVID-19 is transmitted through respiratory droplets from an infected person's nose or mouth, which are expelled when they cough, sneeze, or talk. People can become infected by breathing in these droplets or touching contaminated surfaces and then touching their eyes, nose, or mouth[7]. COVID-19 has a high basic reproduction number (R0) of around 3, meaning, on average, one infected person will infect 3 other people[5].

Shortly after COVID-19 was declared a pandemic and cases began growing in Canada, Canadian universities shut down their facilities and on-campus learning. The large number of students living in high density residences on university campuses means that universities are susceptible to a serious outbreak of COVID-19.

This report explores the effect of higher density living areas on the transmission of COVID-19 in a university residence using COBWEB simulation software. Higher density living areas can be defined as locations where people spend part of their time with others. Examples of higher density living areas are university dorm rooms and common areas such as study spaces and dining halls. It is hypothesized that the introduction of higher density regions in a constant overall population density will lead to increased risk of infection and quicker spread of COVID-19 because having more agents in a smaller space will increase how often they come in contact with each other.

Methods

COBWEB (Complexity and Organized Behaviour Within Environmental Bounds) is a simulation software application that has two main components: agents and resources. These are displayed on a 2D grid where agents are represented by triangles that can move, eat, and reproduce, and resources are represented by squares that can be consumed by agents for energy. Stones are another component represented by grey squares that act as barriers for agents. Ticks count time, with one tick being the amount of time it takes an agent to move one grid square. COBWEB is also able to represent the transmission of a disease among agents[5,6].

The model used agents to represent students living in a university residence. A simulation was started with one infected individual and was run until all agents were infected and the total number of ticks were recorded. Two different test scenarios were considered: one scenario with higher density living areas and another scenario, the control, without. The total number of ticks for each scenario were compared.

The Clare Hall residence at Brescia University College was used as a reference for the residence building in the model. Clare Hall includes a population of 300 students, dorm rooms, and a common area[3]. The size of a dorm room was 21 square metres[2] and the common area was estimated to be 400 square metres based on the dimensions of an elementary school gym[4] (see Appendix for calculations). An area of 900 grid squares was chosen for the size of the common area because of the best balance for size in the COBWEB grid and proportion to the agents inside. Dorm room size was represented by 45 grid squares. Twenty-five dorm rooms and a common area were drawn with stones on the COBWEB grid (see Appendix Fig. 5-7). This number of dorm rooms was chosen because of limitations in the COBWEB grid size and because the population of agents could be divided evenly between them. Only the scenario with higher density living areas used the dorm rooms and common area. The control scenario used the total area of the residence, 20205 grid squares, without any rooms.

Since this model was being manually tested, a population of 100 agents was chosen for the best balance between feasibility of testing and having enough agents for lower error and less necessary trials. One day or night was represented by 25 ticks, chosen for its reasonable scale and being the optimal amount of time for agents to interact without unrealistic encounters.

This model was only looking at the transmission of COVID-19 and not its effects, so the population was kept constant and agents were prevented from dying. Agents were given a high initial energy, sufficient resources, and aging was turned off. In the disease tab, healing was turned off to focus on transmission and the step energy factor was set to one so infected agents could move as easily as uninfected agents. A contact transmission rate of one was chosen based on Lin & Shen's model[5].

Seven trials were done for both scenarios. The model was set up with one initially infected agent out of the 100. For the control scenario, agents roamed around the entire area with no restrictions and the simulation was paused every 25 ticks to count the infected agents. For the higher density living areas scenario, all agents were placed in the common area during the day to simulate real life student schedules. At night, the infected and non-infected agents were divided as evenly as possible among the dorm rooms with 4 agents per dorm room. After each day or night, the number of infected agents was counted and recorded. Agents were moved by deleting them and drawing in the corresponding number of infected and non-infected agents. For both scenarios, the process was repeated until all agents were infected.

The independent variable was the existence of higher density living areas, which depended on the scenario chosen. The dependent variable was how long it took for all agents to be infected.

Results

For the control scenario, it took an average of 450 ticks for all agents to be infected. The agents in the control group had access to the entire residence building and a density of 0.05 agents/grid square.

In the scenario with the higher density living areas, it took an average of 242 ticks for all agents to be infected. In the common area there was a density of 0.11 agents/grid square and each dorm room with 4 agents had a density of 0.089 agents/grid square.

My results validate my hypothesis because when there were no higher density areas in the control scenario, it took 208 more ticks for all agents to be infected compared to the scenario with the higher density living areas. This means that a higher household density leads to quicker transmission of COVID-19.

Incidence rate is the number of new cases in a specific period of time. When the average incidence rate graphs for the control scenario (see Figure 1) and the scenario with higher density living areas (see Figure 2) are compared, you can see that in the control scenario there are less new cases per day and cases are more spread out compared to the scenario with higher density living areas.

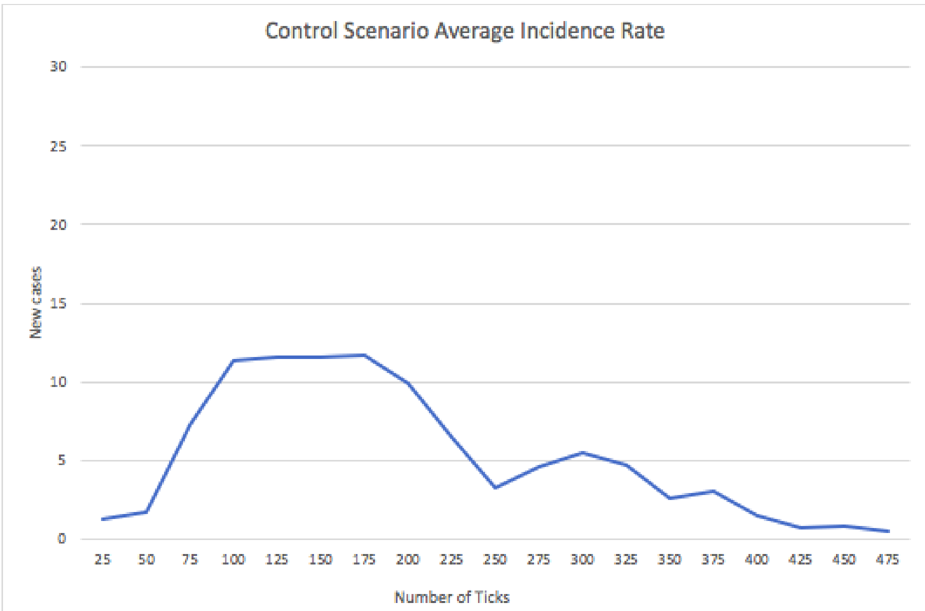


Figure 1: Average incidence rate for the control scenario

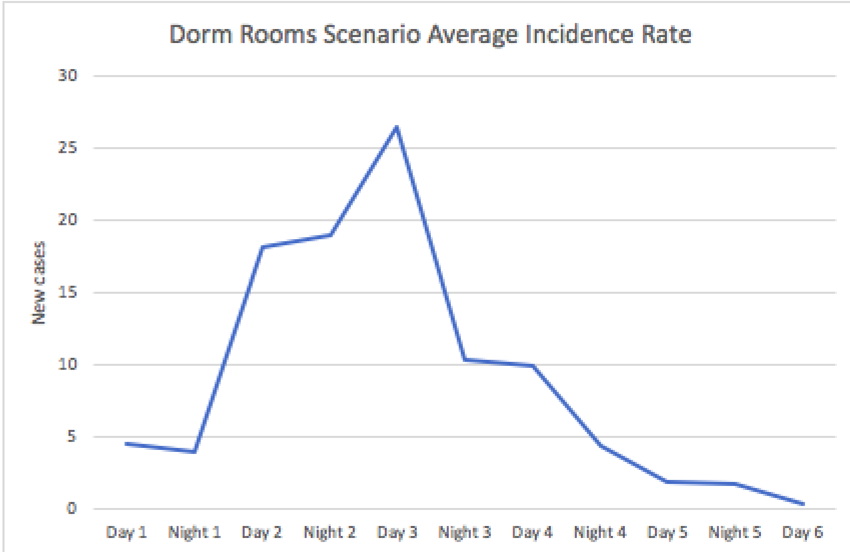


Figure 2: Average incidence rate for the scenario with higher density living areas

The average incidence rates for the days versus nights in the scenario with higher density living areas was also graphed (see Figure 3 and 4). Overall, both day and night cases drop off after Day 3, but the days have a higher number of new cases, with an average of 61.1 new cases compared to 39.6 new cases from the nights. The higher incidence rate during the day is because the density of agents in the common area is 0.11 agents/grid square, which is higher than the density of agents in a dorm room with 0.089 agents/grid square. This result still matches the hypothesis because even though the fastest spread was not exhibited in the dorm rooms, higher household density still correlates with faster disease spread.

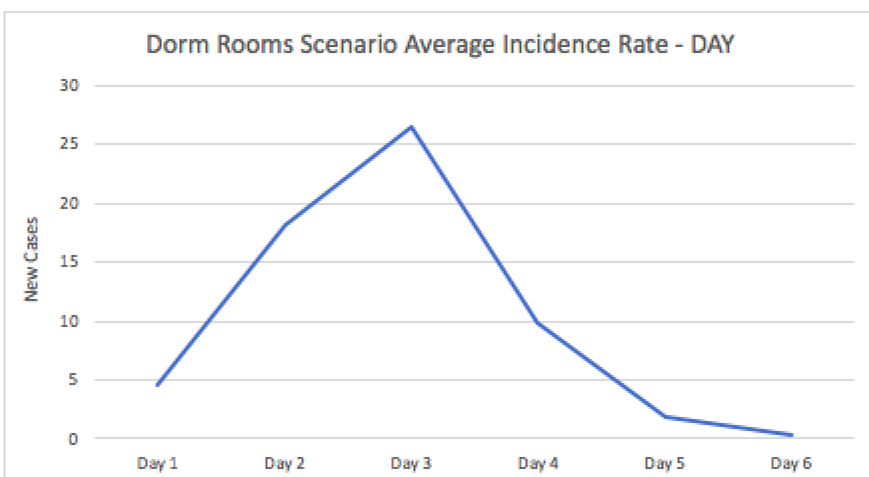


Figure 3: Average incidence rate for the days in the scenario with higher density living areas

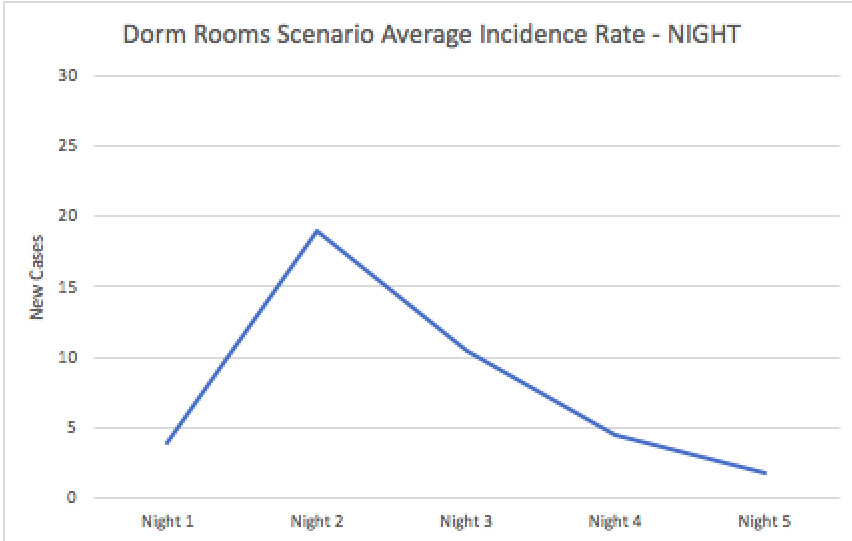


Figure 4: Average incidence rate for the nights in the scenario with higher density living areas

Discussion

The results of my model show that there is a relationship between higher density living areas and increased COVID-19 transmission. Individuals in higher density living areas are at higher risk of getting infected because of their closer contact with other agents. This simple model can lead to more detailed research on the effect of population or household density on the transmission of COVID-19 for many different scenarios and applications.

The sources of error in the scenario with higher density living areas was that it assumed all agents were in the common area at the same time, and did not try to model the movement in and out of the common area that would be found in real life. There was selection bias when infected and uninfected agents were divided between the dorm rooms, which affects the accuracy of results. In real life, infected and uninfected people would not be evenly divided between rooms. Another source of error came from drawing in agents by hand, which meant they were not spread out on the grid evenly.

Error was reduced by spacing out the agents as evenly as possible and not putting the initial infected agent too close or too far from the others. The 99 uninfected agents were allowed to roam around for 5 ticks so they were more evenly distributed before the infected agent was added and the simulation was run.

Conclusion

This model demonstrates how higher density living areas in a university residence can lead to faster transmission of COVID-19. Looking at two scenarios with the same overall population density, the scenario where agents were placed in higher density regions took less ticks for all 100 agents to be infected. This model used an R0 of 3 and a contact transmission rate of 1, but further trials could explore different R0 and transmission rate values as well as varying population sizes, household densities, and methods to reduce error.

Appendix

Calculations:

Average dorm room size[2] = 228 square feet
= 21.18 square metres
= 21 square metres

Common area size based on elementary school gym[4] = 471 square metres
= round down to 400 square metres because common area will not be as large as gym

21 square metres = dorm room is 5.25% of 400 square metres
= common area is 900 grid squares in COBWEB
5.25% of 900 = 47.25 grid squares
= round dorm room size to 45 grid squares

Table 1: Average Incidence Rate Control Scenario

Number of Ticks	New cases
25	1.29
50	1.71
75	7.29
100	11.3
125	11.6
150	11.6
175	11.7
200	9.86
225	6.43
250	3.29
275	4.57
300	5.43
325	4.71

350	2.57
375	3
400	1.43
425	0.71
450	0.86
475	0.43

Table 2: Average Incidence Rate Scenario with Higher Density Living Areas

Time	New Cases
Day 1	4.57
Night 1	4
Day 2	18.1
Night 2	19
Day 3	26.4
Night 3	10.4
Day 4	9.86
Night 4	4.43
Day 5	1.86
Night 5	*1.75*
Day 6	0.286

Table 3: Average Incidence Rate Scenario with Higher Density Living Areas during Day

Time	New Cases
Day 1	4.57
Day 2	18.1
Day 3	26.4
Day 4	9.86
Day 5	1.86
Day 6	0.286

Table 4: Average Incidence Rate Dorm Room Scenario with Higher Density Living Areas during Night

Time	New Cases
Night 1	4
Night 2	19
Night 3	10.4
Night 4	4.43
Night 5	1.75

Figure 5: Control scenario initial setup

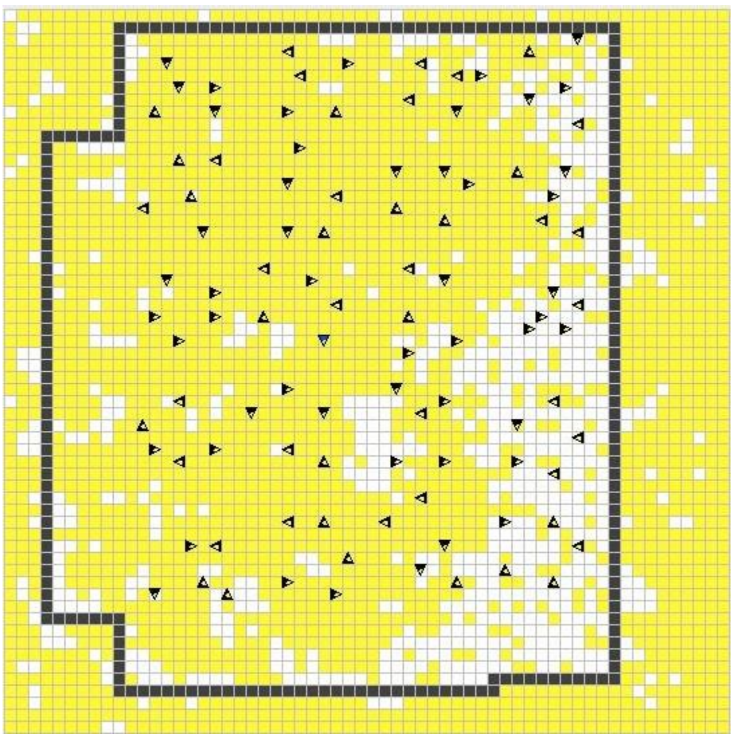


Figure 6: Scenario with Higher Density Living Areas - End of Day 1

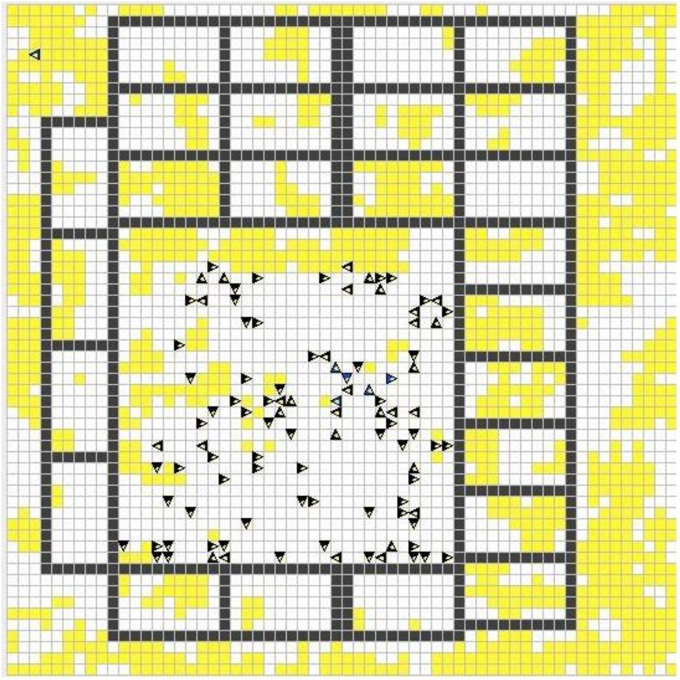
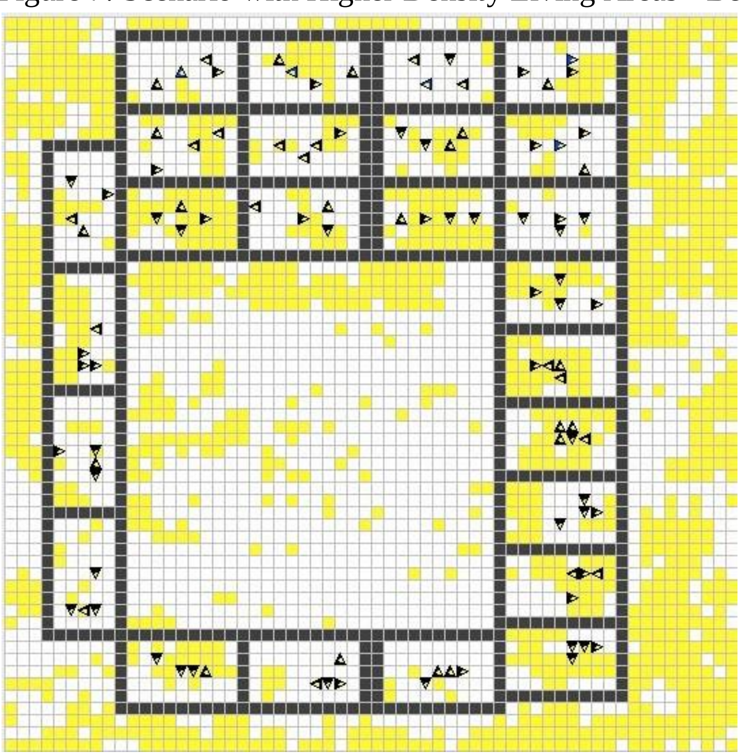


Figure 7: Scenario with Higher Density Living Areas - Beginning of Night 1



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