University of Amsterdam

Modelling the transmission of virus particles via airflow in buildings with the Lattice Boltzmann Method

Project report

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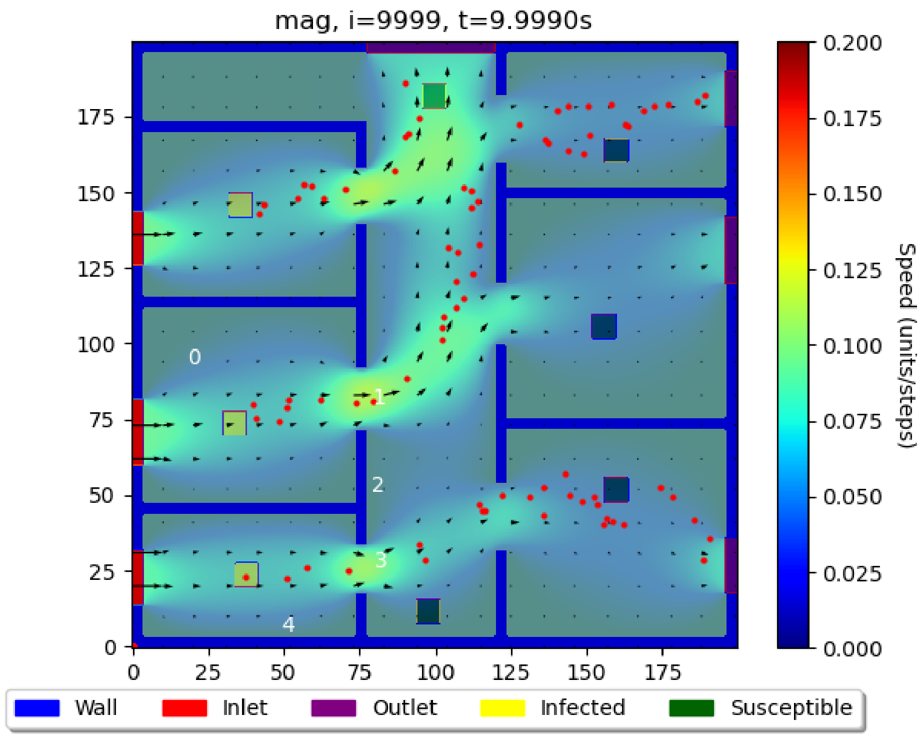


1 Summary

Part of the effort on mitigating the indoor spread of virus particles through aerosols consists of ventilation. To provide a clear picture of the movement of air through buildings and the effect that ventilation has on this, techniques from computational fluid mechanics can be employed. In this work, we consider the simplest type of measure that can be taken to provide a source of fresh air: the opening of windows. In particular, we study the effect on opening windows on the number of virus particles inside a building. To model the airflow in buildings, the Lattice-Boltzmann method was used. We hypothesize that having the windows opened more frequently corresponds to fewer particles that remain inside the building. Furthermore, we expect to see that the difference between having the windows opened for 0% and 10% of the time will be larger than the difference between 90% and 100%. The experiment done in this project confirms our initial hypothesis, although the accuracy of the results are questionable due to an artificially lowered Reynolds number.

2 Work and results

To simulate the airflow inside a building, the Lattice Boltzmann Method (LBM) was used. It is an iterative method, where every time step the next fluid density distribution is computed. Such an iteration consists of two steps. First, there is a collision step, where the particle densities on a lattice point are redistributed among the possible directions, see figure 1 In our case, this is done according to the BGK collision operator. After this step, the particles are streamed in their respective directions to other lattice points. Fluid-wall interaction is dealt with using the bounce-back boundary condition.

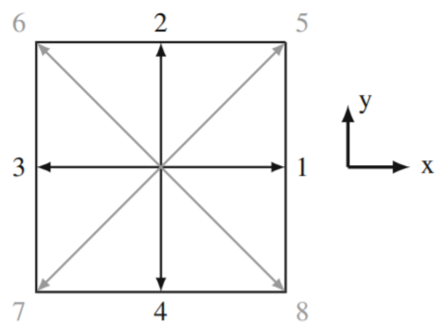


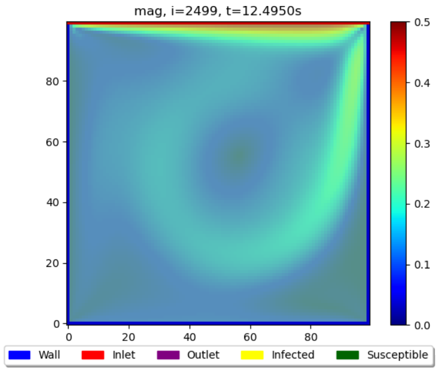
Figure 1: The D2Q9 grid (2 dimensions, 9 directions; the zero vector has index 0). This figure was taken from Krüger et al. 2017.

This model was extended with in- and outlets in order to mimic real-world mechanics like windows and ventilation. Particles were also added in order to research how aerosols like Corona virus particles move in buildings. In the experiments, the outlets would open and close periodically to measure how this influences the presence of particles in the system. One could hypothesize that removing all airflow by removing inlets and outlets, susceptible persons would be the safest, However over time movement of people will inevitably cause infection and thus removing particles from the whole system should be preferred.

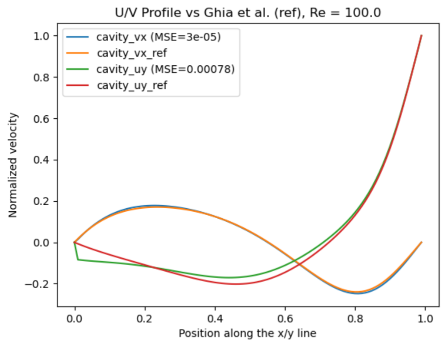
Finally, to build the environments, a map creator tool was used that made it possible to place walls, inlets, outlets, infected and susceptible people.

2.1 Model validation

To validate the model, the lid driven cavity benchmark was used. The setup is a square where the top is made of an inlet that produces a flow to the right (2a). The values that this model produces were then compared to the values of a correctly working model in order to measure the accuracy of the model. To compare the values, we used U. Ghia, K. Ghia, and Shin 1982.



(a) The lid-driven cavity benchmark



(b) Compared against *Ghia et al.* data

2.2 Simulation

We design our environment such that infected people were placed near inlets (an air ventilation system or a open windows blowing air inside). We then measured the effect of opening and closing windows for a certain duration see Figure. 3).

For both inlets and outlets we use the equilibrium function with a given density and velocity an these lattice points. For the inlets we alter the velocity and for the outlets we lower the pressure compared to the room, creating a suction effect. Every 5 iterations 25 particle are produced at infected cells.

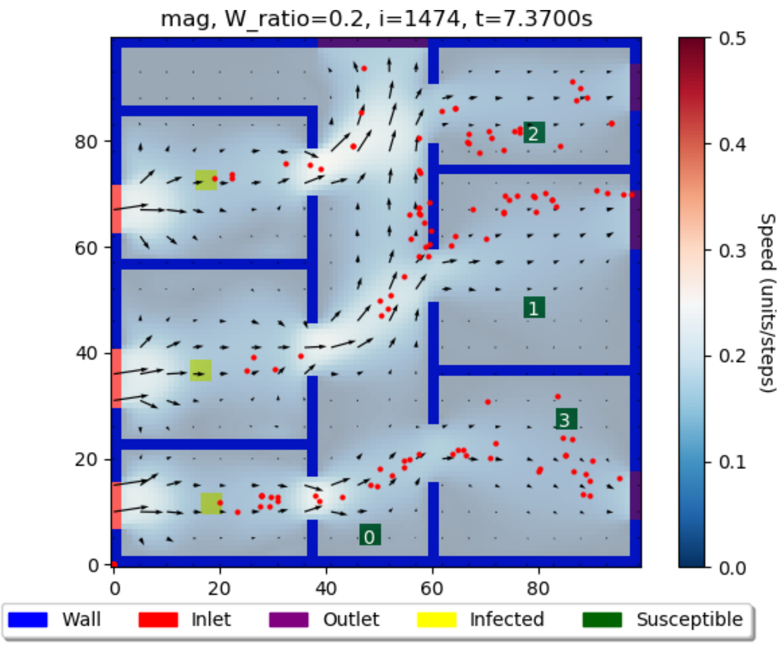


Figure 3: The simulation environment.

2.3 Unit conversion

The physical scenario we modelled is a room of 30×30m. The geometry is meant to represent a section of a hospital, see figure 3. Airflow is coming in from the open window at a speed of $0.1\mathrm{m\,s^{-1}}$, and the kinematic viscosity of air is $1.48 \cdot 10^{-5}\mathrm{m^2\,s^{-1}}$. This gives a Reynolds number of

$$\mathrm{Re} = \frac{lU}{\nu} = \frac{30 \cdot 0.1}{1.48 \cdot 10^{-5}} = 202702.$$

The Reynolds number is an indication of how many calculations need to be performed in the simulation. Unfortunately, we found that it was not feasible to run the simulation with this Reynolds number. Instead, we forced Re = 300, which made our system stable, at the cost of realism.

2.4 Results

Figure 4 shows the number of virus particles in the system as a function of the number of iterations. At multiples of 500 iterations, windows are closed. The time that passes until they are opened again depends on the percentage shown in the legend.

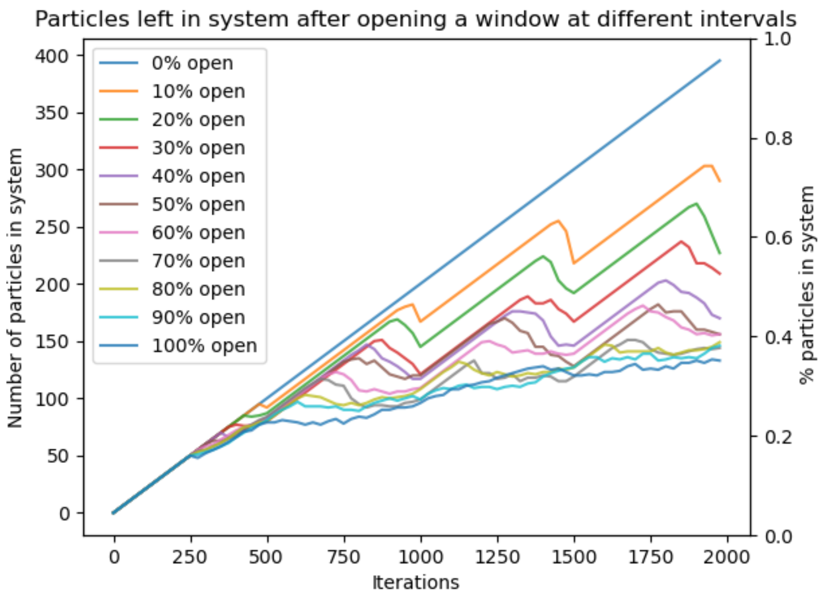


Figure 4: Particle over time in the room above

We found that opening a window 10% of the time relative to never opening a windows already results in a significant payoff.

We expect that, given enough time, each of the numbers of particles in the system in Figure 4 will converge (apart from the case with 0% windows opened, there it will clearly diverge to infinity). Furthermore, we suspect that larger percentages will correspond to lower values in the limit. Due to the limited number of iterations simulated, however, it is unclear how quickly they will converge, and what the values are they will converge to, if they converge at all.

3 Team contribution

Jeroen implemented the particle tracking code and map editor. He also wrote the majority of the LBM implementation, and a large part of the code for making visualisations such as in figure 3.

Robbie took care of unit conversion and parameter calculation, helped with implementing and bugfixing the LBM model, map resizing, did the code review, wrote one paragraph on the poster, and cleaned up and refactored code for submission.

Erencan worked on infection, susceptible persons and made the *particle in system* plots. Also worked on window opening and closing in the rooms, and did the model validation part.

The LBM code went through several iterations, with contributions from all team members throughout the process. Creating the poster and writing the feedback on another team's proposal were done together.

4 Code review (Team 2)

Reviewed team: Bas Zoeteman; Maksim Kolk; Roshan Baldewsing

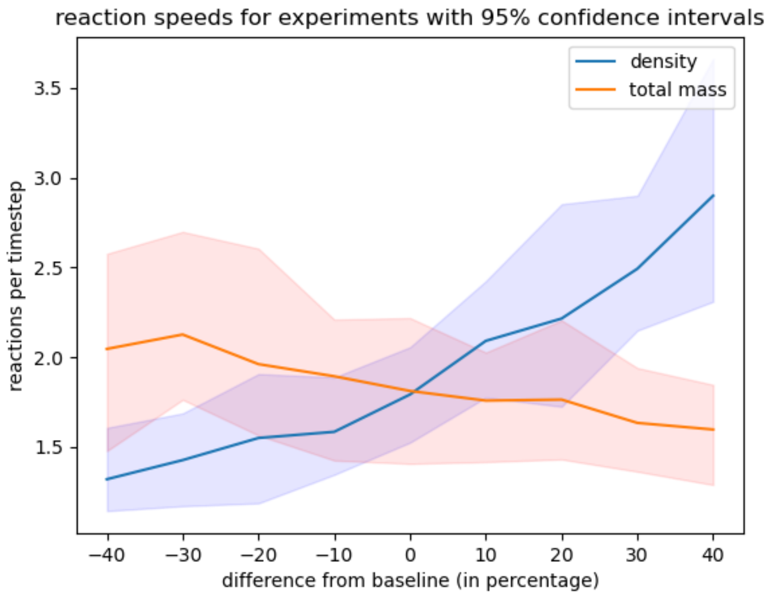


Figure 5: Figure from team 2's GitHub repository.

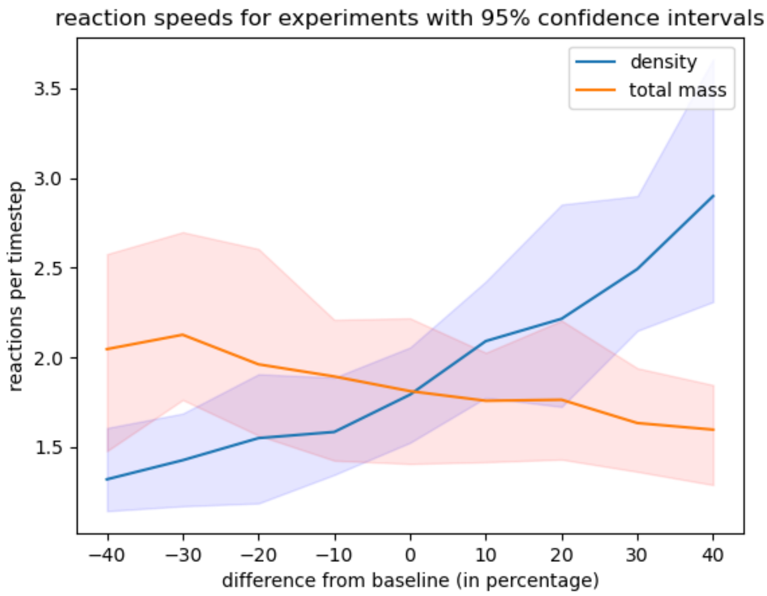


Figure 6: Reproduced figure

4.1 Code comments

Reproduced without problems (But we were not able to run the data acquisition because it would take too long to run. We were only able to reproduce it with the given data from the repository.).

Style A lot of warnings from pep8, all of them regarding line length and whitespaces. Rest of the code looks nice and readable. Also nicely separated into classes.

Documentation Some methods/functions have detailed docstrings, while other do not. Lots of small comments to explain specific lines which makes the code more clear.

Dependencies Dependent on popular modules such as numpy, pandas, csv and matplotlib. Which does not require additional installing for most people but a list would still be nice. But no non-trivial dependencies.

Testing There are a couple of assertions in the code. No unit tests.

Readme A figure in the readme that is supposed to be generated by the code would make it easier for people to see what the code does. There is an explanation of how to change the parameters. But it does not always work with the data analysis file.

References

Ghia, U, K.N Ghia, and C.T Shin (1982). “High-Re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method”. In: *Journal of Computational Physics* 48.3, pp. 387–411. ISSN: 0021-9991. DOI: `https://doi.org/10.1016/0021-9991(82)90058-4`. URL: `https://www.sciencedirect.com/science/article/pii/0021999182900584`.

Krüger, Timm et al. (2017). “The lattice Boltzmann method”. In: *Springer International Publishing* 10.978-3, pp. 4–15.

A Appendix

Peer review for team 2 by team 5

- The proposal talks about "possible environmental effects." However, the items in this list are not effects themselves, but rather environmental factors which could have an effect on the decaying process. It might be more fitting to replace "effects" by "influences" or "factors."
- We are somewhat confused by the phrase "without any environmental effects." The text mentions things like pressure and temperature as such effects; what would a situation look like in which these are not present? We would prefer a phrase such as "compared to a baseline environment."
- "Decay based on electron or neutron capture is probably more interesting to look at due to their higher dependency on environmental variables." Why is this true? If you write this in the final report, we would suggest to include the source.
- To simulate the decay, ordinary and partial differential equations will be used. We would suggest to include a detailed description in the final version of how you numerically solved these equations.
- The dependency of an impenetrable wall near or surrounding a decaying particle is not fully clear to us. Will the impenetrable wall cause radiation to reflection back to the particle and thus influence it? We propose to describe this in more detail.

Feedback for team 5/11 from team 2

We don't exactly know what is meant by "pollutant sources", as a result, it is not exactly clear what the difference between "eliminate or reduce pollutant sources" and "diluting the concentration of aerosols", these sound somewhat similar.

Also, if possible, it would be beneficial to your research to implement not only a system where particles are moved through airflow, but also include a source of aerosols to simulate the presence of people in a room and how much airflow is necessary to keep a safe environment.

The timeline looks very detailed and clear and the proposed plan sounds very interesting.