MODELLING THE TRANSMISSION OF VIRUS PARTICLES VIA AIRFLOW IN BUILDINGS WITH THE LATTICE BOLTZMANN METHOD

Erencan Tatar; Robbie Koevoets; Jeroen van den Berg
UvA `https://github.com/MessyAnswer/project-computational-science`

Introduction

To mitigate the spread of virus particles in the air, it is helpful to ensure a good flow of fresh air indoors. To research the physics behind this principle, we built a numerical simulation that simulates airflow and tracks virus particles in an indoor environment. Using this model, we researched the effects of opening and closing windows, the most basic type of ventilation, on the number of particles inside the space.

Research question

Keeping the windows open takes out as many particles as possible. On the other hand, this could lead to annoying gusts of wind indoors, and an uncomfortable temperature. This leads to our research question: *what is the relation between the fraction of time that windows are open, and the number of particles in the system after a certain number of iterations?*. This number of iterations can be estimated by looking at the number of iterations needed for a stable system where number of particles exiting convergences.

Method

We use the Lattice Boltzmann Method (LBM) to simulate airflow. The LBM simulates fluid on a square lattice, and in discrete time steps. In the LBM, a particle can be moving in one of 9 directions, as shown in figure 1. Every iteration, a particle first collides with other particles on the same point, and is then streamed according to its direction.

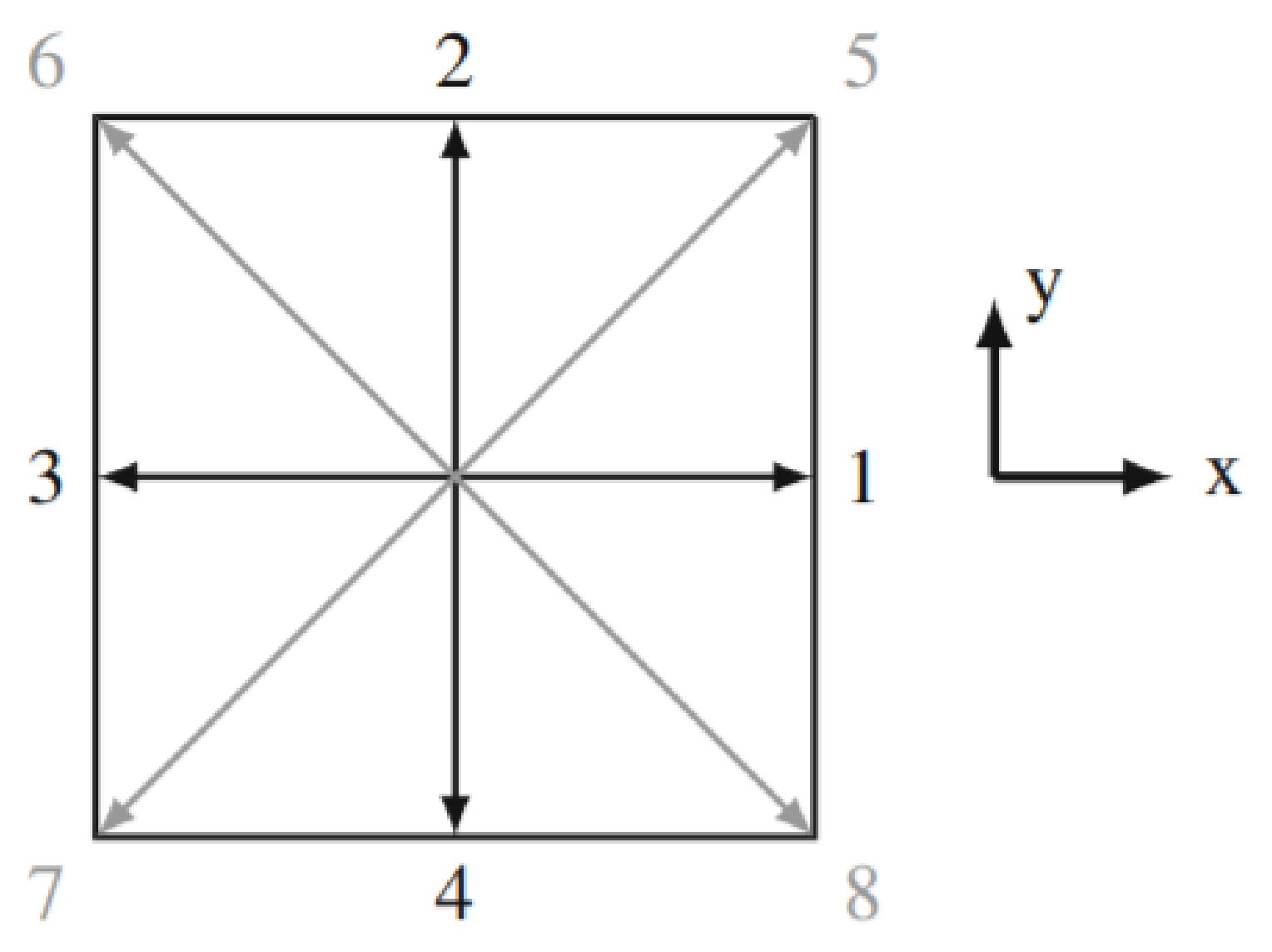


Fig. 1: The D2Q9 grid (2 dimensions, 9 directions, including the zero vector which has index 0).

To simulate the effect of windows on airflow, we designated some points on the lattice as *inlets* and some as *outlets*. At an inlet, the velocity is forced to be constant. At an outlet, pressure is forced to be constant. To perform experiments where windows open and close, we occasionally replace inlets and outlets by walls and revert them later.

Method validation

A common benchmark for fluid dynamic simulations is the lid driven cavity. In this test scenario, a moving lid slides at the top of a unit square. A paper by Ghia et. al provides values for the velocity along central axes after a large number of iterations [1]. A comparison of these reference values and the values calculated by our program is shown in figure 2.

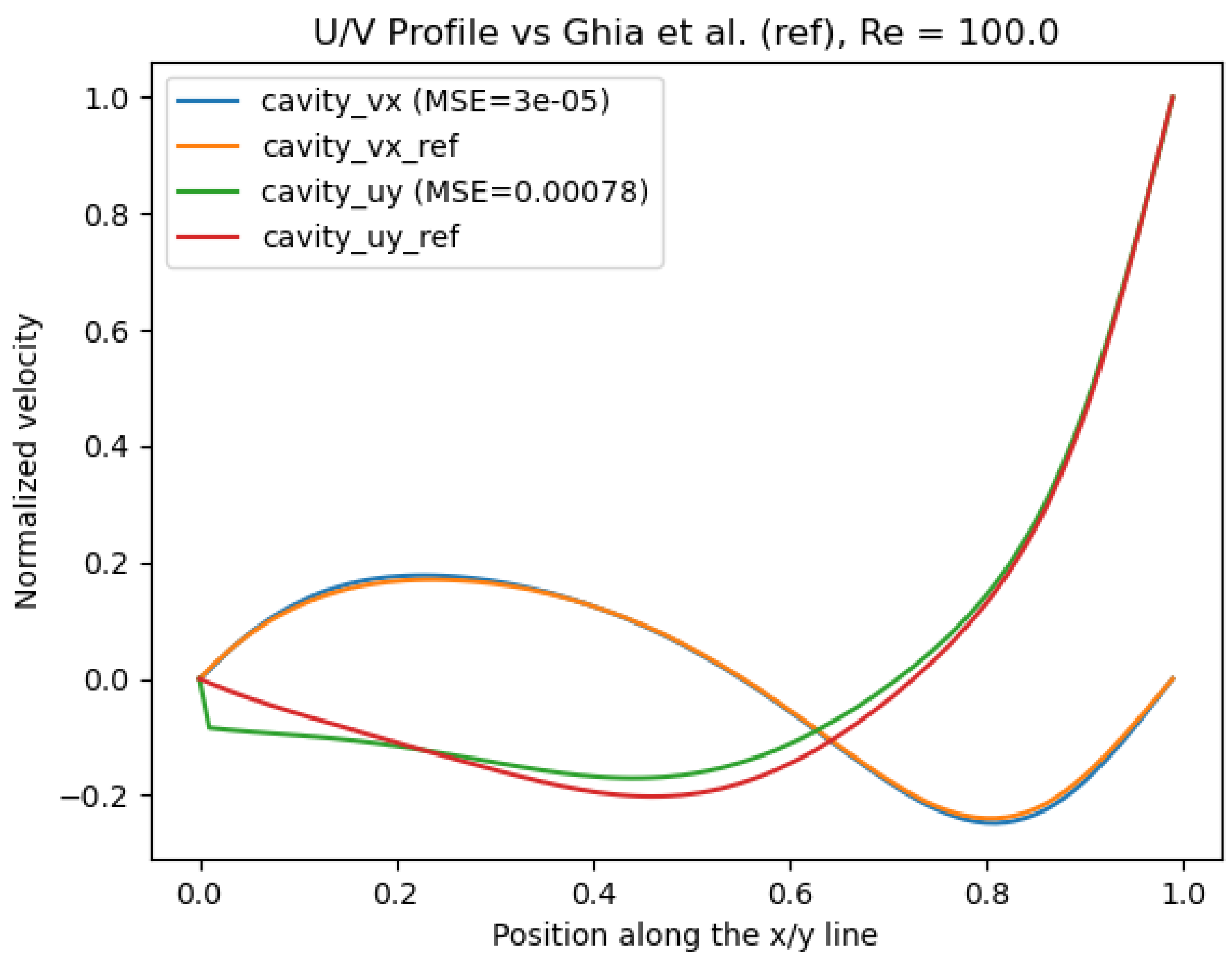


Fig. 2: The velocity values as calculated by our program, and as given by the benchmark in [1], for a Reynolds number of 100. The legend contains Mean Squared Error for our results.

Simulation

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 $\mathrm{Re} = 300$, which made it possible to create stable systems, at the cost of realism.

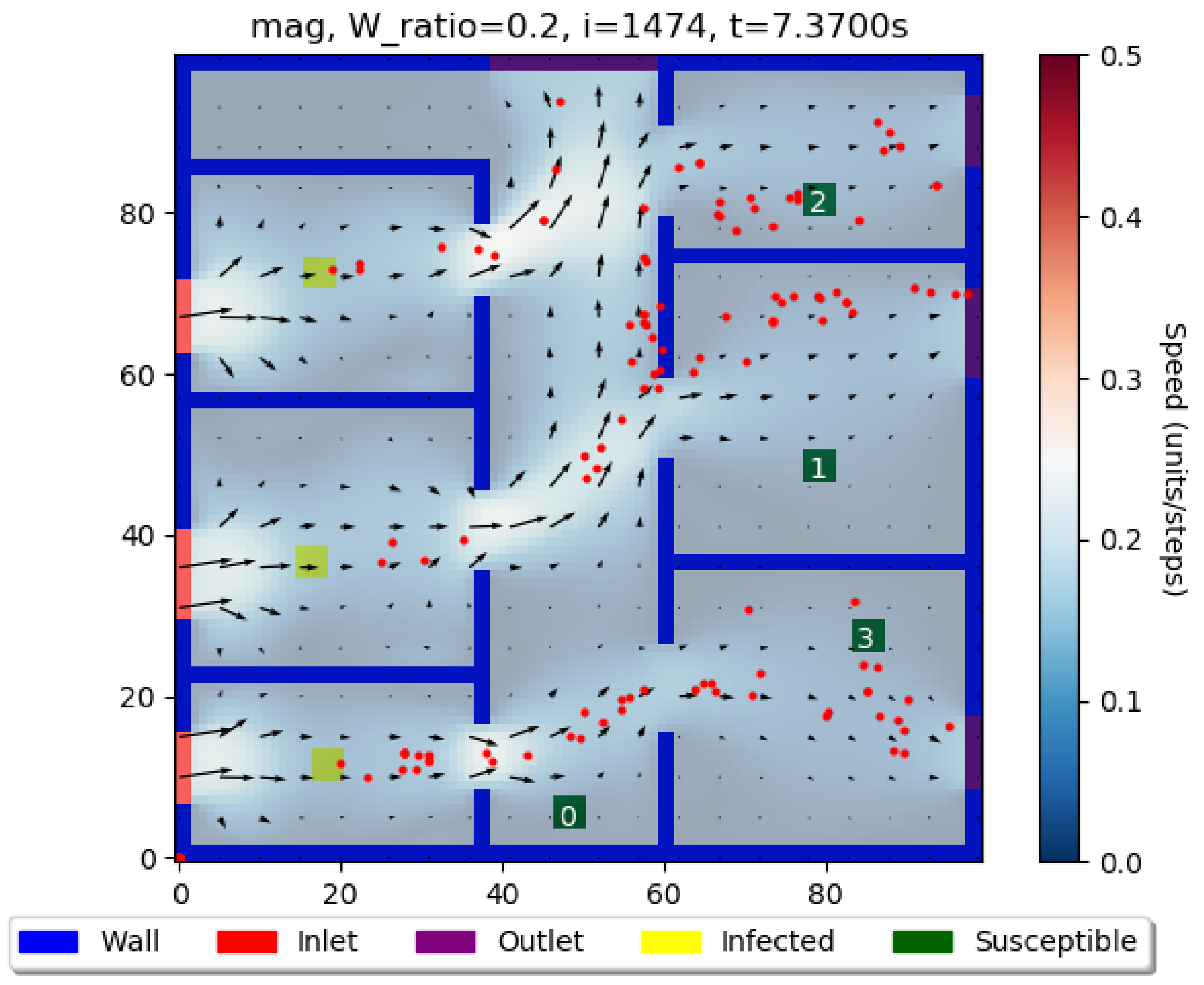
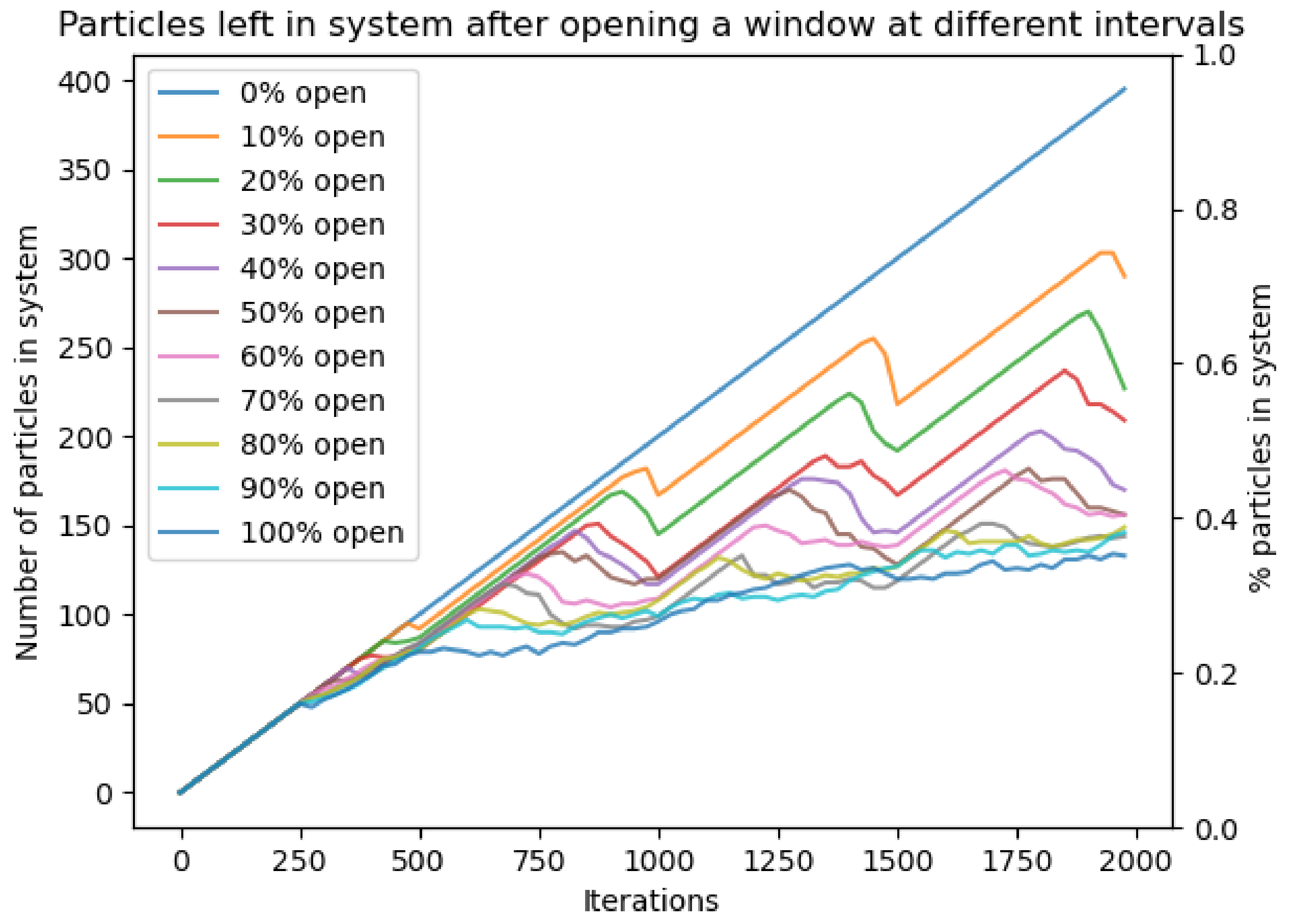


Fig. 3: The simulation environment.

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.



Discussion and future work

Further research could be done in implementing more factors that are present in the real world. For example, the temperature of the air also creates a pressure difference which leads to flow of air. Furthermore, air does not just move in two dimensions but in three in the real world. With these new additions to the model, one could more accurately research how particles move around within real buildings and how to particle spread by airflow.

References

[1] U Ghia, K.N Ghia, and C.T Shin. "High-Re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method". In: *Journal of Computational Physics* 48.3 (1982), 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`.