explosion hazard in residential buildings.

A RISK ANALYSIS

CORE COMPETENCIES

1. Multi-component flow
2. Risk analysis
3. Porous media
4. Fluid dynamics

Goal

A large part of the Dutch houses are linked to the natural gas network. This means that in most households, a piping system is present, resulting in a potential explosion when a leak is present. What is the risk of such a gas leak causing an explosive concentration in a home? To find out, we simulated a demonstration house with a gas leak using Computational Fluid Dynamics (CFD). The goal is to find the potential hazards of gas leaks and to consult in the construction of houses, installation of vents and placing of gas detectors.

In this example, a fictitious house is simulated consisting of two rooms at two different levels. The gas leakage is positioned on the ground level. In the house, a ventilation duct ventilates air from both levels.

Every house also has a form of natural ventilation as the walls, doors and windows are never fully air-tight. The air is sucked into the house through these gaps and cracks. This effect is taken into account in the simulation as well. As a result of the gas leak, the concentration of natural gas increases over time. Eventually, the concentration might exceed the Lower Explosive Limit (LEL). Above this concentration, sufficient ignition energy will trigger a gas explosion.

With the current study we want to find out how long it takes for this gas leak to result in a dangerous situation – that is: a natural gas concentration above the Lower Explosive Limit.

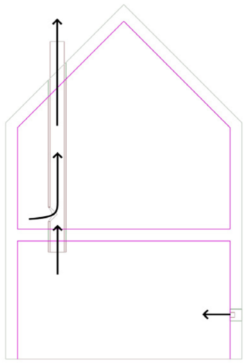

Figure 1 Geometry of the fictitious residential building

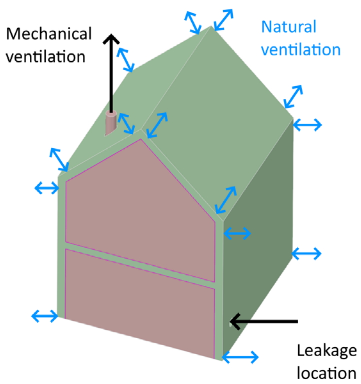

Figure 2 Location of ventilation and leakage point

Approach

The geometry and setup of the house is shown in Figure 1. For this simulation, we used a ventilation flowrate of 50m^3/hr and a leakage flowrate of 500 l/h. The air is sucked from both rooms through natural ventilation (Figure 2). The walls are simulated as being slightly permeable. The typical average permeability is a material property of the wall, which we derived from material data sheets.

The simulation is executed in three steps to ensure numerical convergence:

1. Steady state air only: In this simulation, no volume fractions of natural gas in air is present, air is the only present gas. With this, a first estimate can be made for the velocity and pressure fields, which are used as initial condition in step 2. Time dependent effects are not taken into account, which means that the flow field is for a fully developed situation.
2. Steady state gas leak: now the leak consists of natural gas instead of air. Time dependent effects are still not taken into account. Next to the velocity and pressure fields, we solve the concentration through the entire numerical domain.
3. Time-dependent gas leak: In this step the time dependent effects are calculated. The velocity field from step 2 is used as an initial condition and will not be recalculated for each timestep. The concentration of natural gas is determined for every timestep, where the initial concentration of natural gas is zero everywhere in the house.

Results

First, we show the velocity field inside the house. In Figure 3, we show that the velocity around the leak is pointing upwards. This is due to buoyancy effects, as the natural gas has a lower density than air. The velocity inside the walls is low due to the high flow resistance of the permeable walls. In the cut-through at the ventilation duct (Figure 4), it can be seen that the ventilation system is working and that the velocities inside the air duct are relatively high.

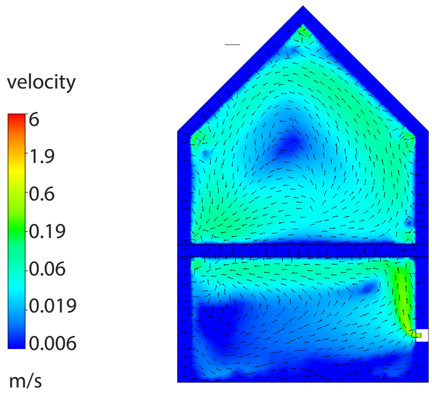

Figure 3 Flow velocity at cross-sectional plane at leakage point

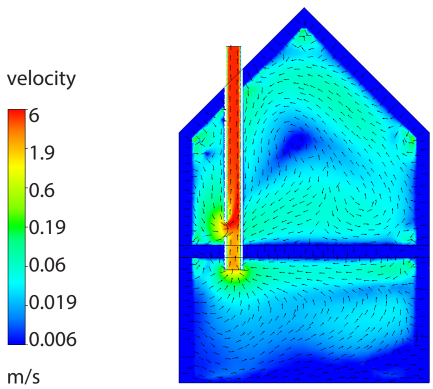

Figure 4 Flow velocity at cross-sectional plane at ventilation duct

Natural gas has different safety levels for different concentrations. Most gas sensors are tuned to 0.5% v, as this is 10% of the Lower Explosive Limit (LEL). At 1% v most humans can smell the gas. At 5.6% v the concentration becomes dangerous as the mixture reaches its LEL. For this reason it was chosen to display these safety levels in the colors green, yellow and red respectively. Every region below 0.5% v is not depicted at all.

In Figure 5, it can be seen that the natural gas immediately rises to the ceiling. Because the ceiling is simulated as slightly permeable, the gas leaks through the ceiling into the upper room. The building quality is a determining factor here: what happens in reality depends on the actual position of building materials, gaps and holes. It can be seen that a significant part of the gas is disposed of the ventilation system.

Figure 5 shows that the dangerous gas levels spread in a short time on the ground floor. If sensors would be installed on the ceiling, they would be triggered within 8-16 seconds. It takes roughly one minute before the explosive mixture spreads through the ground floor. After two minutes a sensor in the air duct would be triggered, whereas at this moment a dangerous mixture has already spread on the ground floor. Not the entire ground floor contains a dangerour gas mixture, the mixture could only ignite next to the leak and close to the ceiling. After a couple of minutes the gas mixture would also become smellable on the top floor, if gaps and holes were present in the ceiling.

To summarize, we made a fictitious house, in which a natural gas leakage is present. Using flow simulations (CFD), we calculated how natural gas transports through this residence, and whether concentrations exceeding the Lower Explosive Limit occur.

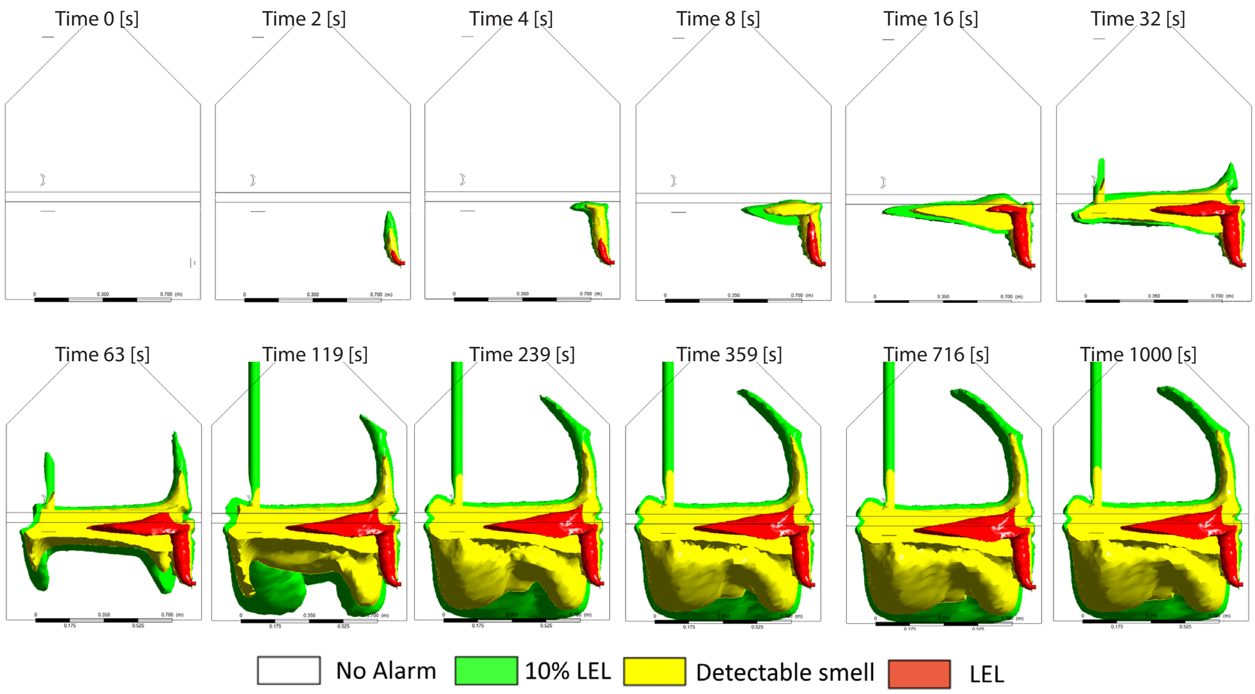

Figure 5 Concentration of natural gas over time