explosive hazards in residential buildings.

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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 hazard. What is the risk of a gas leak in such a home? To find out, we simulated a demo house with a gas leak using Computational Fluid Dynamics. The goal is to find the potential hazards of gas leaks and to consult in the building of houses, installation of vents and placing gas detectors.

In this example, a fictitious house is simulated consisting of two rooms at 2 different levels. The gas leakage is positioned on the ground level. In the house, a ventilation duct ventilates air from both of grouds.

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. This effect is taken into account in the simulation. 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.

The goal of the current study is to see how long it takes for this gas leak to result in dangerous situations – that is: a gas concentration above the Lower Explosive Limit.

Approach

The geometry and setup of the house is shown in Figure 1. For this simulation, we used a ventilation flowrate of $50 m^3/hr$ 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 averagely 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 fluid field is for a steady state situation.
2. Steady state gas leak: The leak is a natural gas leak, but time dependent effects still are not taken into account. Next to the velocity and pressure fields, we solve the concentration through the entire numerical domain

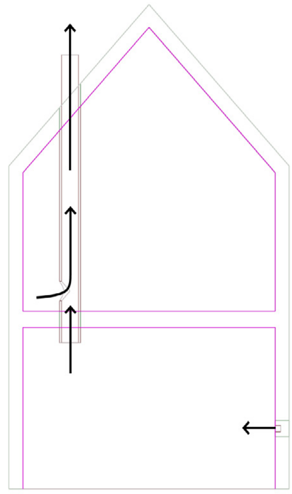

Fig 1. Geometry of residential building

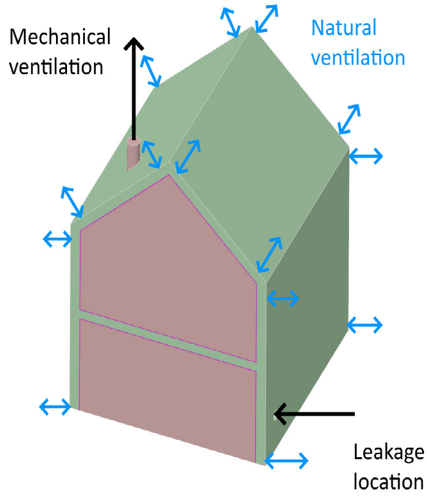

Fig 2. Position of ventilation shaft in building

3. Time-dependent gas leak: In this step the time dependent steps are calculated. The velocity field from step 2 is used as an initial condition and will not be recalculated. The initial natural gas concentration is zero everywhere.

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 through the air duct (Figure 4), it can be seen that the ventilation system is working and that the velocities inside the air duct are relatively high.

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 by the venting system.

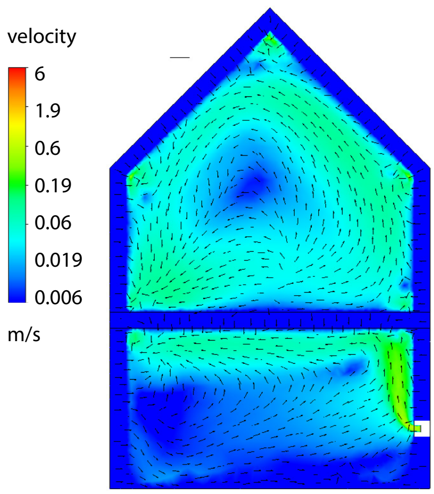

Fig 3. Flow velocities of cross-sectional plane at leakage inlet

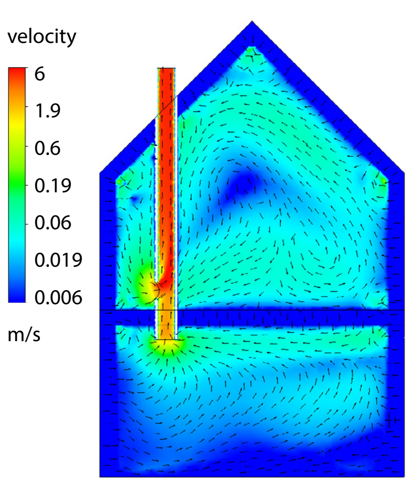

Fig 4. Flow velocity at cross-section of ventilation shaft

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 in 8-16 seconds. It takes roughly a 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 becomes a dangerous mixture. Only at the side of the leak and close to the ceiling the mixture could ignite. 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 exist.

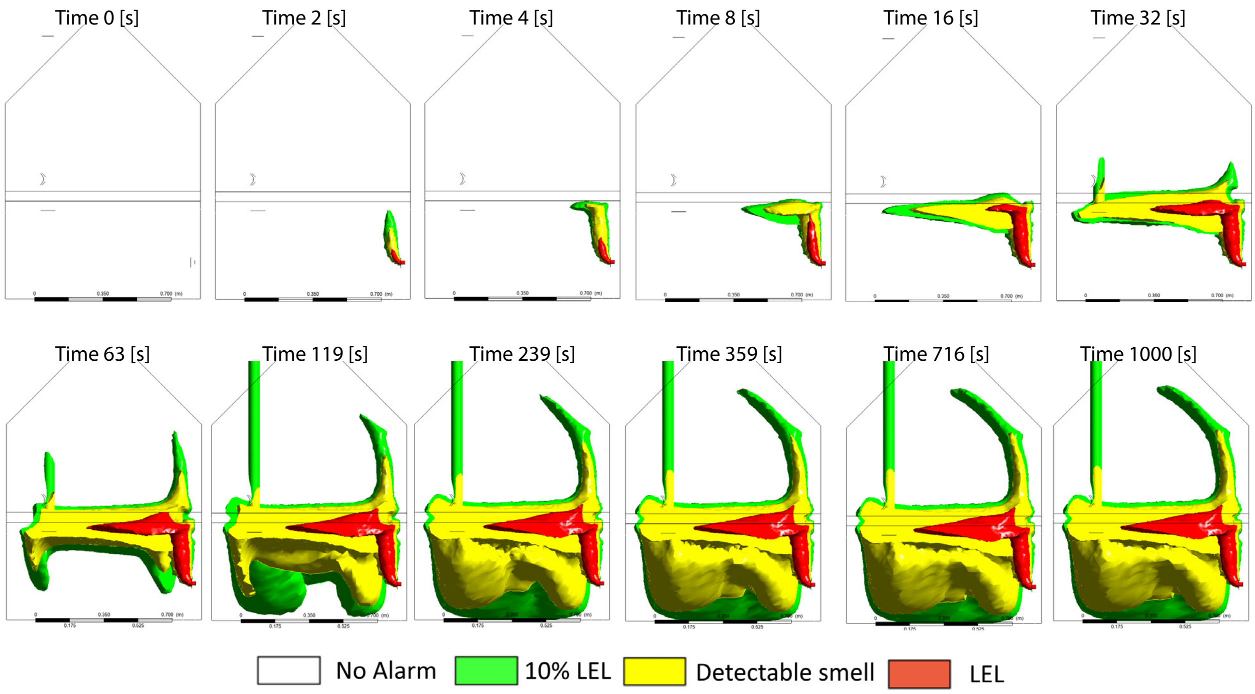

Fig 5. Concentration of natural gas as a function of time