Smart & Predictive Air Quality Solution

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ABSTRACT

Monitoring and regulating the air quality inside critical infrastructure is essential for protecting occupants from external and internal airborne threats, such as pollutants, toxic chemicals, and pathogens. The outdoor air can be contaminated with agents such as diesel and car exhaust or with more toxic agents like Toxic Industrial Chemicals (TICs). In case of a pandemic, there is a threat of viruses and bacteria which can spread in the building. These airborne agents can penetrate and disperse inside the building via windows and doors or via the ventilation system. This gives insights into the transportation of these agents through the building. A smart software suite was built (HAVAC) for calculating the air flow through the building, combined with agent mass balances per room. Furthermore, once combined with a range of sensor systems, the tool can use the output of these systems to fine-tune the prediction on the way the agent will disperse into the building. Future predictions of concentrations per room can be generated. In case of a calamity or incident, this system can indicate which areas in the building are or will be "hot zones" in terms of agent concentration. Furthermore, a companioning expert system (MORTAL AI) can use these future prediction calculations to determine expected toxicological effects on occupants and provide decision support on possible further actions, such as evacuation of people or the decontamination of specific rooms. When designing a building, it can also - based on a large number of iterations - help design evacuation routes based on a range of different scenarios and provide recommendations on the best locations in the building to deploy IAQ (Indoor Air Quality) sensors and air purification filters.

KEYWORDS

Airflow modelling, agent dispersion prediction, air quality, decision support

1 INTRODUCTION

Monitoring and regulating the air quality in indoor areas such as large (cruise) ships and critical infrastructure is important1. After an incident at – for instance – a nearby chemical plant, vapour or aerosol can escape into the surrounding area. The outdoor air can be contaminated with agents such as diesel and car exhaust or Toxic Industrial Chemicals (TICs). This pollution can have environmental effects and may have an effect on the health of persons in the polluted area. In case of a pandemic, there is a threat of viruses and bacteria which can spread in the building. These airborne agents can penetrate and disperse inside the building via windows and doors or via the ventilation system. To provide insight into these matters, there is a need for a holistic and comprehensive modelling and AI suite that takes into account indoor & outdoor air flow, agent dispersion, building information and human toxicology.

[1] See the EU Horizon ISOLA project for an example use-case (https://isola-project.eu/)

2 INDOOR AIR QUALITY & TOXICOLOGY MODELLING

For this reason, a software suite (HAVAC) was developed. It contains the necessary tools to safeguard occupants of critical infrastructure, by providing insight into current and future air quality issues and their potential impact on occupants of large structures. It includes an AI suite that specialises in a specific set of tasks related to the assessment and prediction of air quality and human comfortability / safety. It operates under a pre-defined range of contexts and is very good at handling these specific tasks. This approach is also known as Artificial Specialized Intelligence and can be integrated as a “smart” layer into new or existing air quality systems.

2.1 Air Quality

To model the indoor dispersion, a floor plan of a building is analysed in terms of rooms, windows, doors and the existence of a possible HVAC system. This 3 dimensional floor plan is used to calculate the airflow through the building, based on external factors, such as the outdoor wind velocity and temperature and also on the refresh rates of rooms, created by the HVAC system. If the exact structure of the HVAC is not known, the software tool is able to construct a virtual HVAC system for the building, depending on the required air refresh rate per room. This calculated air flow is used to predict the dispersion of possible contaminants through the building, which can originate from outdoors or from a source in the building.

In the HAVAC modelling suite a multi zonal approach is used, where every room in a building as well as every duct in the HVAC system is defined as a zone (Stuart Dols (2015), Feustel Helmut (2005), Brasser (2017a)). The outdoor environment is also defined as a zone. A zone can exchange air with a neighbouring zone via flow paths, which represent doors, windows and other leakages. The air flow through these flow paths can be present due to natural causes, such as outdoor wind pressure or as a result of ventilators, which are located in these flow paths (for instance in the HVAC system). The airflow through the entire building is then calculated by solving a set of equations, each describing the air mass balance per room (Brasser (2017b)). Outdoor wind pressures onto the building influence this air flow. Furthermore, an existing HVAC system also can supply fresh air into the building and suck away used air by incorporating an HVAC entrance and exhaust per room. In Figure 1, an example air flow and dispersion calculation for a single scenario is shown.

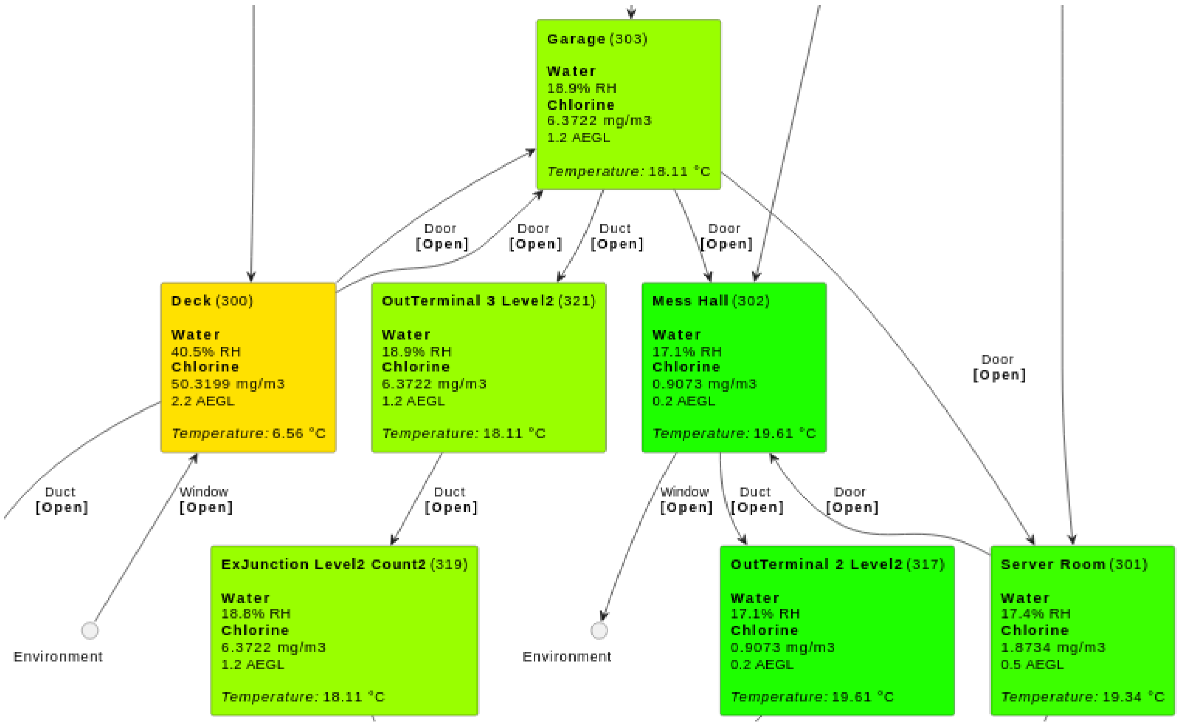

Figure 1: Example air flow and dispersion calculation for a single scenario

Temperature effects of airflow are also taken into account. For instance hot air will rise, resulting in a vertical air flow. Once this air flow through the building is known, it is also possible to calculate agent transport through the building. If an agent source is suspected or known (indoor or outdoor), this can be added into the software as well, resulting in the calculation of a dispersion of the agent through the building over time.

On top of that, the software tool is also able to incorporate sensory data of agent concentrations to fine tune the predicted agent dispersion through the building.

2.2 Toxicology

Chemical agents can have a toxic effect on humans. Obviously the amount (the concentration or the dose) of the agent plays a huge role in this toxicity. To keep track of the effects people encounter when present in the infrastructure, the software tool stores all challenge concentrations a person (or an entity, for that matter) encounters every timestep, while present in the building. Based on these values, the toxicological effects of these agents onto these persons are calculated.

Several different models are present in literature to predict the toxic effect, based on certain agent parameters and the agent dose. Based on the amount of known toxicity data present of the agent, one of these models will be chosen for the toxicity calculations. All models make a distinction between the severity of the effect onto the human. Three levels of severity are defined:

- Mild effects: Myosis, small blisters etc.
- Severe effects: Problems with breathing, larger blisters etc.
- Lethal effect: Complete cessation of bodily functions

To calculate the severity of the effect, toxicological data is required for each severity level. Obtaining the required data often is the crucial part in the toxicological calculations. Results (effects) of toxicity tests on animals (and sometimes on humans) with the specific agent are required for toxicological calculations. In literature several different standards are present. For instance:

- AEGL: Acute Exposure Guideline Levels, see NRC (2001)
- ERPG: Emergency Response Planning Guidelines, see AIHA (2023)
- TEEL: Temporary Emergency Exposure Limits, see DOE (2008)
- NATO Publishes standards by NATO, see NATO (2003)
- PAC: Protective Action Criteria, see OEE HSS (2016)

Output from the air flow and agent dispersion modelling is used as input to this model current and future predicted toxicological effects on occupants of critical infrastructure.

3 APPLICATIONS

In critical infrastructure planning and operation, predictive air quality monitoring and smart air purification systems play a vital role in ensuring a healthy, safe, and efficient environment. Combining scenario-driven design in the planning phase of critical infrastructure design with real-time monitoring and response during its operational phase can significantly improve infrastructure resilience and sustainability.

During the scenario-driven design phase, predictive air quality modelling is used to simulate various scenarios which the infrastructure might encounter throughout its life (see Figure 2). This includes considering the dispersion of pollutants, variations in air pressure, temperature, and humidity (see Brasser (2017c), Brasser (2017d)). These simulations are essential for optimising the layout, materials, and systems of the infrastructure to various air quality scenarios. Smart air quality reporting tools, which incorporate AI-powered analytics, play a pivotal role here by providing detailed calculations, analyses, and targeted recommendations for various threat scenarios. For example, these tools can guide the optimal placement of indoor air quality sensors and filters, ensuring maximum detection coverage and filtration efficiency. Furthermore, they advise on the appropriate efficiency needed for air filters and provide insights into HVAC system design, to ensure harmony with the air purification strategy.

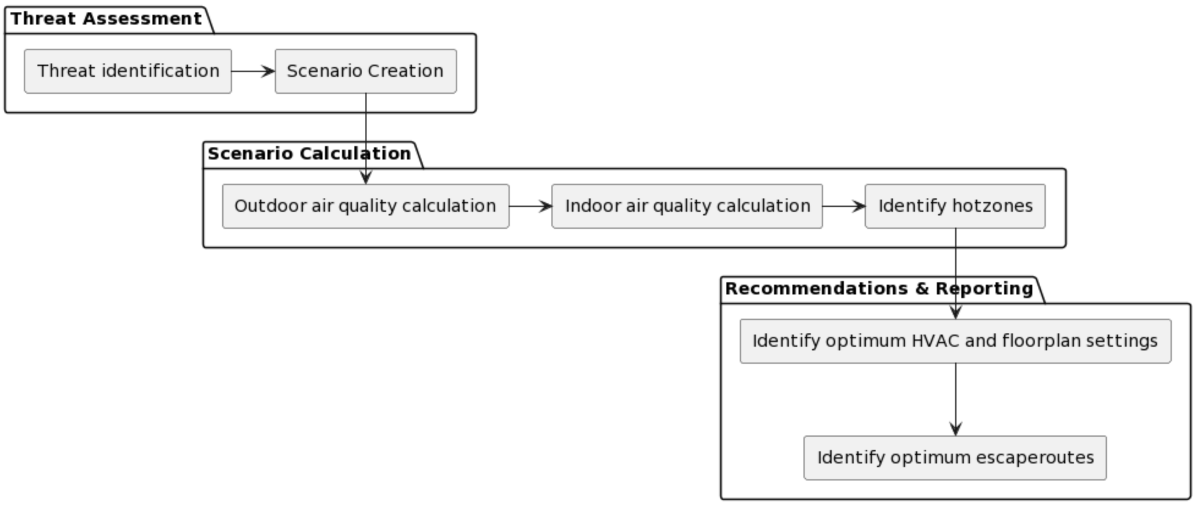

Figure 2: Flow of a scenario-driven design process

Similarly, during the operational phase, real-time air quality monitoring becomes crucial (see Figure 3). Here, smart air quality systems equipped with sensors continuously track air quality parameters, such as particulate matter, volatile organic compounds, and other pollutants. The HAVAC tool analyses the data and predicts trends in air quality, enabling operators to receive alerts when air quality levels cross predefined thresholds. It can also identify potential contaminated areas or hot zones and localise potential sources of contamination (see Brasser (2017e)). It, too, relies on AI-powered analytics, which leverage data from various internal and external sources to provide actionable insights.

In both phases, the challenges often arise from poor ventilation leading to an accumulation of indoor pollutants, the lack of data-driven support for the placement of sensors, and the absence of standard operating procedures for emergency response. Additionally, ensuring compliance with air quality regulations and standards is a concern common to both phases. In the scenario-driven design phase, adherence to regulations is achieved by incorporating predictions into the design process. In contrast, in the operational phase, compliance is ensured by real-time monitoring and dynamic adjustments to ventilation and filtration systems based on the data received.

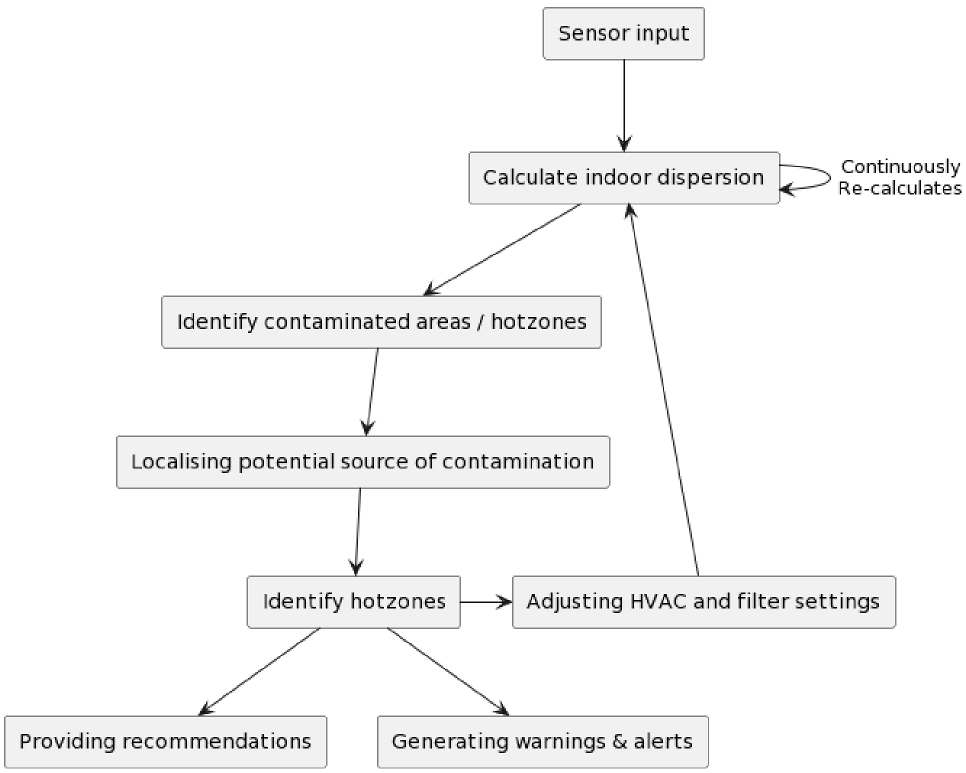

Figure 3: Real-time monitoring flow

A comprehensive solution to address these challenges in both phases involves integrating real-time air quality monitoring with data-driven insights, predictive modelling, and automation. This integrated approach offers facility managers an all-encompassing air quality management solution, empowering them to make rapid and informed adjustments in response to incidents or changes in air quality.

Additionally, situational awareness is critical in both phases. During the design phase, knowing potential threats and how they can impact the infrastructure is necessary for building a resilient system. In the operational phase, continuous awareness of the indoor air quality conditions is vital for timely interventions (see Figure 4). In both cases, the integration of advanced technologies, including AI and analytics with air quality systems, is key to providing a robust and efficient air quality management solution.

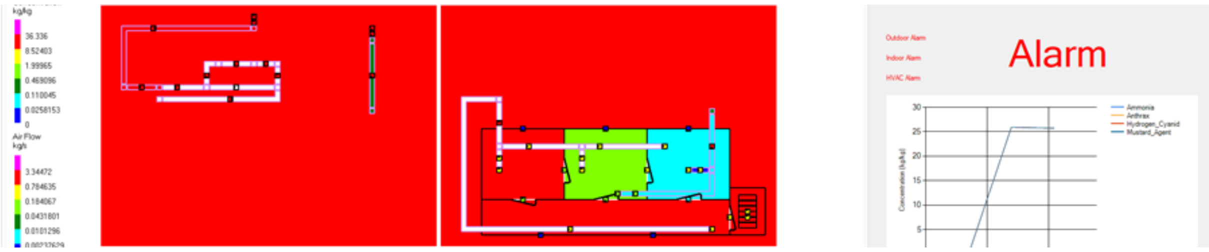

Figure 4: Example of agent concentrations in several rooms and floor levels in the floor plan of a building

In summary, by aligning the scenario-driven design process with real-time monitoring and response systems, critical infrastructure can be designed and operated with optimal efficiency and resilience to air quality challenges. This involves utilising predictive modelling in the design phase to anticipate and plan for various air quality scenarios, and implementing intelligent air quality monitoring systems during operation to ensure timely responses to changing conditions. Both phases necessitate the use of AI-powered analytics and integration with building management systems for a holistic and effective approach to air quality management.

4 CONCLUSION

A software suite was developed, which can be used to calculate the indoor airflow, dispersion of agents and toxicological effects. The tool predicts airflow by considering elements such as windows, doors, and the HVAC system. The tool quantifies the concentration of agents in each room over time and facilitates seamless incorporation of building structures, including rooms, corridors, and openings across various floor levels, effectively creating a digital twin for airflow analysis. Toxicological effects of existing contaminants are predicted.

Furthermore, escape routes can be generated in case of an incident, taking into account which rooms are least contaminated. It contains a decision support tool which is designed to provide a multifaceted simulation and analysis of air dynamics within buildings.

There are two major applications of the software suite: in the design phase of a building and during the operational phase of critical infrastructure. In the design phase of a building the smart air quality reporting tool generates detailed analyses and a plethora of recommendations, and serves as an invaluable resource for stakeholders in the design of critical infrastructure. During the operational phase of critical infrastructure, the primary value of the tool is to protect the health and well-being of occupants of the critical infrastructure, as autonomous response can save time (and therefore lives) in case of an emergency and help contain the possible threat.

All in all, this suite provides the necessary tools to safeguard the air quality within critical infrastructure, and therefore the health of its occupants.

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