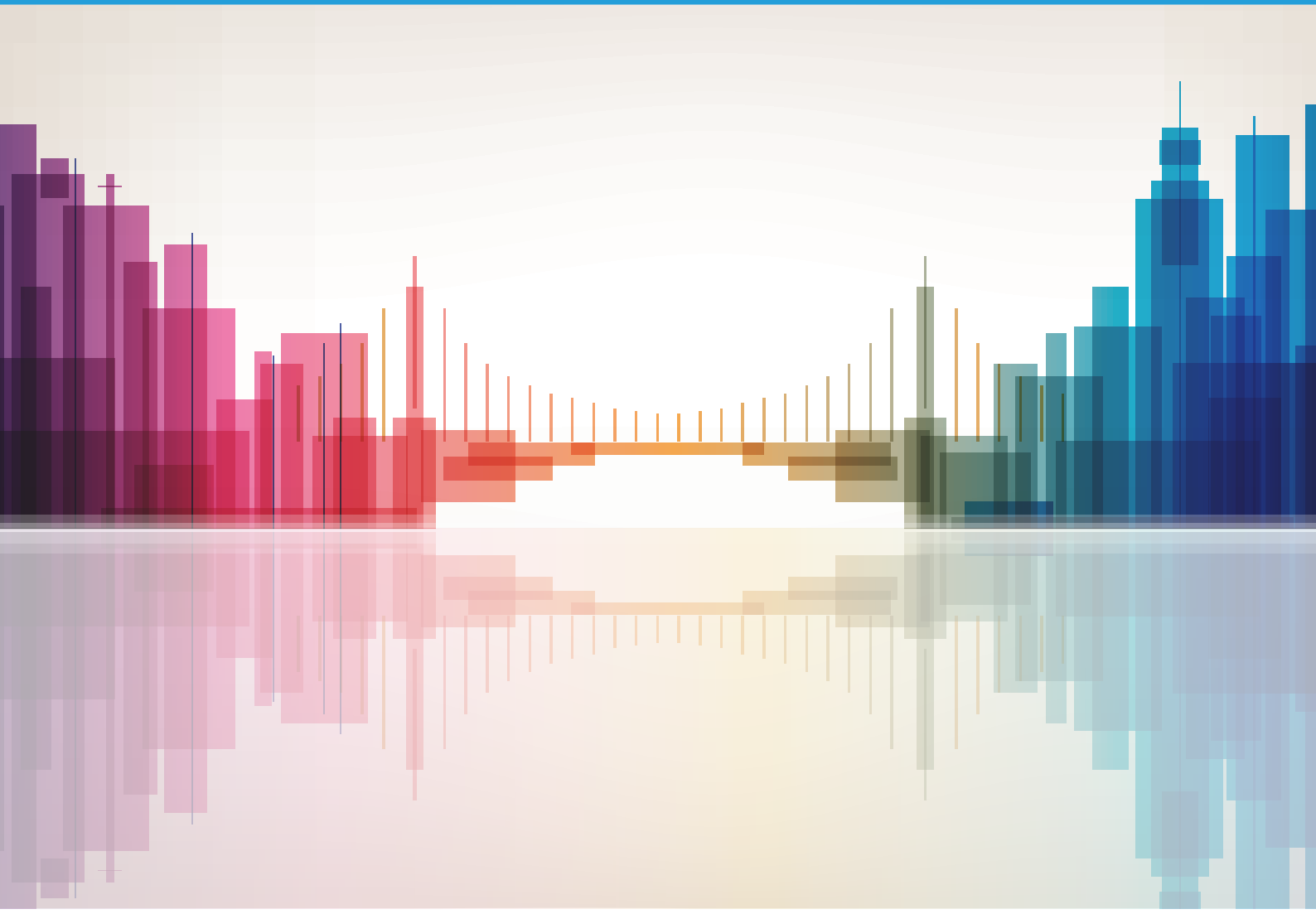
United 4 Smart Sustainable Cities

Fine dust filtration in Stuttgart, Germany

Case study of the U4SSC City Science Application Framework



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Case study: Fine dust filtration

Stuttgart, Germany

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Foreword

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Umwelt
ZONE
Stuttgart
200 m
frei

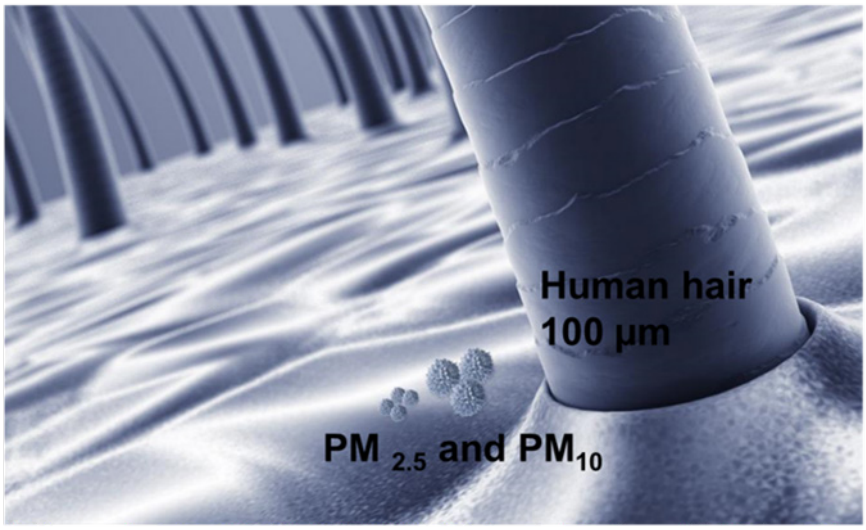
1. Introduction

1.1. Background

In recent years, there is a growing awareness of the high levels of air pollution in cities. Despite air quality in Germany improving over the years, 18 cities are still not in compliance with government-regulated limits for certain air-borne pollutants, with most lapses due to excessively high nitrogen dioxide (NO2) levels. NO2 is emitted from road traffic and can be dangerous in event of prolonged exposure. In addition, particulate matter from road traffic is especially harmful to human health. Small particulates (PM2.5) are able to penetrate deep into human lungs and may cause chronic lung and heart diseases. According to figures estimated by the World Health Organization, particulates are responsible for the death of around 47,000 people every year in Germany alone, and globally, more than 3.7 million deaths are attributed to outdoor air pollution.

In public debate, road traffic is blamed for a substantial part of both the NO2 and particulate matter in a city. Measures such as driving bans are repeatedly discussed and are met with resistance from the population. The non-governmental organization “Deutsche Umwelthilfe (DUH)” (The German Environmental Aid, which champions environmental and consumer protection) filed a lawsuit against several federal states in 2015, seeking to mandate NO2 levels and a ban on diesel vehicles. This affected not only Stuttgart, but also other major German cities including Cologne, Düsseldorf, Frankfurt, and Berlin. In addition, the European Union Commission has also decided to take legal action against Germany for non-compliance, hence there is a critical need for action.

Figure 1: Size of particulate matter (PM) compared to the thickness of human hair. PM2.5 can be lodged in the lungs, while PM10 can enter one’s bloodstream, and considered the most dangerous.



Stuttgart, the state capital of Baden-Württemberg, adopted its first air pollution control plan in 2005. While it contained more than 30 measures leading to significant improvements in air pollution in Stuttgart, it was not complied evenly at city-wide level. Subsequent updates of the air pollution

control plan were made in 2010 and 2014. Despite additional measures, short-term exposure to particulate matter (see fig.1) and short- and long-term exposure to NO2 often remain exceeding their limit values in Stuttgart. A road section at Neckartor has been particularly affected by rising levels of pollutants in recent years.

1.2. Challenge and response

The Stuttgart “fine dust alarm”, unique to Germany, has significantly raised public awareness on the issue of air pollution. An alarm is triggered as soon as the German Weather Service forecasts that the atmosphere will have a severely limited ability to disperse particulate matter and NO2 on at least two consecutive days, indicating a risk that the limit might be exceeded. Car travel should be avoided, and the use of fireplaces, prohibited.

The local pollution is mainly due low wind conditions and pollution from power generation and agriculture around the region; as well as urban pollution caused by building sites, households, and small consumers. Furthermore, concentrated road traffic in Neckartor combined with poor air circulation added to the problem.

Despite various regulatory and behavioral measures taken by the city and its populace, long term, lasting change was still elusive. The key challenge was to clean up the air in Neckartor, for good.

Response, through innovative technologies

The work started off by asking, “What if we could improve the air quality along the road?”.

At MANN+HUMMEL, a filtration technology for particulate matter reduction was being developed. The impact of the technology was simulated based on current pollution levels and subsequently. With the support of the city of Stuttgart and the Ministry of Transport for Baden- Württemberg, the technology was piloted at a critical street junction at Neckartor. The technology was designed into modular cubes, code-named “Filter Cubes”. A further development of this filtration technology was to use the Filter Cubes to reduce NO2 on site as well, solving the two major issues raised above.

2. The smart project

2.1. Vision and content

Relation to city-wide vision and strategy

The city of Stuttgart is taking various measures to improve air quality in polluted areas and in the city as a whole in order to achieve their green vision. The pilot project from MANN+HUMMEL, sponsored by the Ministry of Transport in Baden-Württemberg and supported by Stuttgart, was implemented at the Neckartor road junction in Stuttgart at the end of 2018.

Key features and design

The pilot project is designed to investigate whether the technology can be used to reduce the local fine dust pollution and included 17 x 3 Filter Cubes measuring 3.6 meter in height, and these Filter Cubes were equipped with fine dust particle filters and energy-efficient fans.

It is assumed that the combination filter elements will have to be replaced approximately every 30 days during the pilot project. The exact replacement intervals will be determined within the project and defined on the basis of the requirements for proof of effectiveness.

On polluted days, a running time of 12 hours is planned. With a consumption of approximately 1.5 kW and an assumed electricity price of 20 cents per kWh, this results in energy costs of only 3.60 € per day and column.

Filtration Technology:

- Filter columns consist of a number of Filter Cubes stacked on top of each other (e.g. Figure 2 includes two columns each consisting of 3 cubes)
- A filter column with 3 Filter Cubes is able to clean 14,500 m^3 of air every hour.

  The technology was developed and integrated to a newly developed combifilter medium which has a filter layer that retains fine dust particles. This also includes additional activated carbon layers with large surface area to effectively adsorb NO2.

- For the particle filtration layer, an electrically charged filter medium, known as electret medium, was used for the particle filtration. The deposition of NO_2 on the activated carbon is carried out via the following parallel adsorption mechanisms at the surface of the activated carbon:
  - Physisorption: physical adsorption of NO_2
  - Chemisorption: chemical binding of NO_2 in the form of HNO_3
  - Catalytic reduction of NO_2 to NO and CO as well as to N_2 and CO_2.

Both NO2 and particle filtration technologies are characterized by a particularly low drop in pressure and therefore able to efficiently clean the air while using a low amount of energy.

Smart Technology:

- The filter column contains several sensors for monitoring ambient conditions such as e.g. temperature, humidity, and air quality. These measurement data are currently used to control how the system is used, but with more data and insights, there will be more applications that can emerge from data usage.

- The fans are controlled according to demand (i.e. concentration of pollutants in the air) in order to consume less energy.
- The data of all the filter columns are transmitted via a cloud connection where it is processed and evaluated. Each user (i.e. designated city officials and MANN+HUMMEL project team) will be able to upload his or her data and can access a combined database via web applications that provides accurate real-time data on pollution levels.
- In general, the intelligent systems will be able to provide a self-regulating swarm intelligence that can control the operation of the systems based on factors such as time of day, noise acceptance, weather, or actual levels of pollution. The prediction of maintenance and service requirements is also simplified by the use of intelligent technology, as it makes it easier to estimate when the filter element needs to be replaced.

Figure 2: Filter Cubes along a street in Neckartor

Data collection and analyses

Sensor data

The sensors on the filter cubes collect the following data:

- Presence of rain
- Temperature
- Relative humidity
- Particulate Matter size PM2.5, PM10

- Pressure loss
- Particle count

Simulations conducted and estimated PM10 reduction

Simulations were conducted by a certified simulation laboratory to predict the PM10 reduction for different wind directions and velocities, showing a strong influence of the wind direction. The design was optimized to provide the most effective filtration results for typical local conditions:

- Wind from 222° (South-West)
- Low wind speeds of 1 m/s (10 m above ground)
- High traffic emission modelling representing the peak hour

Predicted PM10 reduction, when 50 µg/m³ PM10 are measured at public measurement station, i.e.:

- ~5 µg/m³ at public measurement station
- 5-15 µg/m³ in Western area (walkways)
- 10-15 µg/m³ in Eastern area (walkways)
- >15 µg/m³ in the proximity of the columns

Evaluation filter columns' effectiveness at Neckartor

Concentration comparison was made between On and Off state, based on the following parameters:

- Baseline data: 30-minute average values by LUBW (note that this is preliminary, unpublished data)
- Concentration change achieved by columns in operation
- Public measurement data shows that the predicted 10% decrease of PM10 concentration is achieved.

2.2. Implementation

The following parties are involved in the project:

- The state capital of Baden-Württemberg, Stuttgart
- Ministry of Transport Baden-Württemberg
- MANN+HUMMEL

MANN+HUMMEL approached the state of Baden-Württemberg and presented its newly developed technology, the Filter Cubes, for the filtration of fine dust at the end of 2017. As a result, an independent engineering office carried out a simulation for the road section at the Neckartor, which included the performance of the filtration systems, traffic conditions, and environmental conditions. The Cubes promised a reduction in fine dust pollution on site. The state transport ministry then initiated the pilot project with MANN+HUMMEL and the city of Stuttgart in order to implement these Cubes.

The city of Stuttgart is a central partner for MANN+HUMMEL. The Municipal Civil Engineering office (part of the city of Stuttgart) was responsible for the planning and preparation of the infrastructure as well as the installation of the systems, which included:

- Consultation regarding the necessity of a building permit
- Coordination and definition of the locations of the systems
- Provision of the electrical cabling and supply
- Design and construction
- Road closure

The Municipal Office for Environmental Protection (part of the city of Stuttgart) and MANN+HUMMEL coordinated activities for the proof of concept. This includes:

- planning and implementation of the measurement campaigns
- selection and provision of measuring equipment

The costs of the project are shared by all three project partners. The project itself is scheduled to run for two years until the end of 2020. The first evaluation results have proven the effectiveness of the filtration technologies, and a final evaluation of the project will take place after the end of the two years.

Following the installation of the filter columns at the Neckartor in Stuttgart, MANN+HUMMEL has proved that the filter cubes can reduce both particulate matter and NO2 concentrations at polluted locations. The laboratory results from MANN+HUMMEL and the simulations carried out by an independent engineering office have proven that the effectiveness of the fine dust filters can be transferred to NO2 technology. It was agreed between the project partners that the filter systems already installed would be converted to this technology by summer 2019.

2.3. Results

Results of initial on-site measurement campaigns

The initial assessments of the project indicate that the Filter Cubes make a considerable contribution towards the reduction of local particle concentration by 10% to 30%, which corresponds to 40% of all fine dust particles caused by heavy traffic at the road junction. The positive initial results regarding the fine dust filtration are similar for the effectiveness of the technology to reduce NO_2 concentrations. This has been verified by the results of simulations carried out by an independent engineering office.

The filter removes 80% of fine dust from the surrounding air drawn in, with very low energy requirements. All 17 Filter Cubes together has reduced the local particle concentration by 10% to 30%, according to the results so far.

The Filter Cubes at the Neckartor junction will be adapted to include the new technology by the summer of 2019. In the future, they will be equipped with the newly developed combifilter medium which will enable the filters to retain particulate matter and also adsorb NO2 from the ambient air. With the updated combifilter mediums, it is expected that the local concentration of NO2 to be reduced by 10% to 30%. That in turn corresponds to 40% of all NO_2 and fine dust emissions caused by road traffic.

Results of additional on-site measurement campaigns

Procedure:

- 7 days of measurements under scientific supervision of Prof. Dittler, KIT, Karlsruhe.
- Utilization of high quality scattered light measurement devices

Main findings:

- Fine dust reduction was observed across the whole investigated area
- The reduction potential declined with increasing distance from the columns.
    - At the public measurement station, lower reduction values were measured than along the walkways. This is a consequence of the comparatively large gap in the net of columns stipulated by the contracting authority.
    - In the proximity of the filter columns, reductions of >30% were found

3. Conclusions

In the city of Stuttgart and elsewhere in Germany, the advocation for effective measures to improve air quality, including driving bans and other extreme measures, has been greatly discussed by the civil community. There has been repeated demonstrations from both sides on this issue. The use of the Filter Cubes could improve air pollution in the short term, contributing to human health protection, alleviating the social tension created by the debate, and creating a respite while a longer-term solution is sought.

The critical success factor of the project was the transition from a technical prototype with a limited range of effect to a large-scale project with an active filtration network of 17 columns along a 250m street in open atmospheric environment. An independent engineering office had previously simulated the effect of the technology under local conditions such as traffic volume and weather.

The main lesson learned was that proof of concept through large scale installation and measurements campaigns enables validation of internal development tests and simulations and provides a basis for further development. In the next step, the extension from particulate matter filtration to a combined filtration of particulate matter and NO2 requires an increase of filter size and a 50% increase in air flow.

Scaling up after prototype phase

MANN+HUMMEL is rolling out this technology in various countries around the world. The technology has already been transferred to a number of countries in Asia such as Japan, China, Korea and India for market investigation and prototype testing with local partners. The European market is mostly driven by maintaining legal limits and avoiding regulatory risks, while in Asia and other emerging markets have a much more intense challenge since these agile markets and their populations are growing at an astonishing speed. Due to the associated increase in manufacturing production, traffic, and resource consumption, air pollution and negative effects on human health are also increasing.

The current state of development of the Filter Cube technology has been made available in Germany, China, and India for medium scale volume in single batch production until demand necessitates large scale production. Furthermore, MANN+HUMMEL is extending the product portfolio for alternative applications by altering the system in shape and size, e.g. transfer to storage areas and subways.

In the short run, the Neckartor project will evolve over time by analyzing and comparing the external signals and the archived cleaning efficiency. The target is to optimize power consumption and filter efficiency together with the maximum usability of the filter, thereby reducing maintenance costs and downtime. The model needs to balance between optimal filtration efficiency over time for human protection, and lowest usage of resources in terms of energy, human resources, financial investment and material costs.

In the long run, MANN+HUMMEL is planning to install stationery and mobile solutions equipped with filtration and sensor units, working in an intelligent swarm to collect real-time data. This enables the team to draw an urban heat map of air quality and air pollution with potential applications such as:

- Identification of changing emission sources e.g. where are the pollutants coming from and whether there are new emission sources.
- Use of data to predict and redirect traffic flows depending on pollution levels
- Creating services that provide advice to sensitive or vulnerable groups to avoid unhealthy areas e.g. parents with young children, elderly or infirmed, joggers and cyclists.

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www.finedusteater.com

B. List of discussion partners/interviews

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