🏆 *reviewed paper*

Optimization of Cities through Green Spaces

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1 ABSTRACT

In general, the trend prevailed in recent years that the effects of civilization's interventions in environmental conditions have not been as prominent in publications as they were before the outbreak of the Corona pandemic. The Corona pandemic has focused attention on the most pressing problems in recent years, such as, in metrological terms, the dispersion of liquid aerosols. Although incidences due to Corona are still extremely high, and the number of days of illness has a massive impact on industrial and societal processes, Corona is no longer considered the No. 1 issue. This is due in particular to the lower mortality that has resulted from the immunization of the population and the attenuation of the dangerousness of the new generations of the pathogen. By pushing the topic of Corona off the front pages of journals, previously discussed priorities are increasingly resurfacing.

Against this backdrop, the long ‘dead’ discussion about the occurrence and effects of particulate matter is gaining momentum again. This paper revisits a previous Real Corp conference paper (Westphal et al., 2022), in which the authors suggest and explain the contributions of an innovative measurement device (ProxiCube) developed by the City of Mannheim’s ecosystem addressing the key success factors for awarded Smart Cities and the various factors of an urban management model. This paper exemplifies the cube’s contribution by a specifically designed and conducted research experiment.

In the research setting of the City of Mannheim, a city in the forefront of the Smart City movement in Germany, the empirical part of the paper comprises the parameters of liquid aerosol, dry particulate matter, CO2, humidity, temperature, pressure and light conditions which were measured by innovative and internationally awarded air quality measurement devices (ProxiCube) (see Westphal et al., 2022) simultaneously at five parallel measurement points of the city at a high data rate. With the measurement constellation, influences can be visualized such as the daily course of all these measured variables at a busy street juxtaposed to the backyard of adjacent buildings or to the building itself implying a crucial impact for the citizens’ life quality.

Keywords: carbon dioxide, environment, green spaces, ventilation, air quality

2 INTRODUCTION

The term particulate matter covers airborne particles up to 2.5 µm in diameter and is an important factor in the air quality index. Both, directly emitted particles and particles generated by secondary particles are included in this category. Tucker lists as PM 2.5 particles sources combustion processes and high temperature metallurgy, secondary particles from atmospheric reactions, and fine particles deposited and resuspended by wind or human activities, and adds that it is difficult to identify the main sources of the particles because of the interaction of numerous emission sources (Tucker, 2000). The Federal Environment Agency lists combustion processes in the home, from road traffic and from agriculture as sources of particulate matter 2.5 (Umweltbundesamt, 2023).

The results of the study shed light on the following research questions: does living in a high-rise building at a great height offer environmental advantages or how densely planted and how large must green areas be in order to filter fine dust? This leads to further implications of deep penetration of particulate matter into green strips within urban facilities. The building implications of the findings derived via the data, furthermore, allow conclusions to be drawn about optimal ventilation behavior, hereby assessing how CO2 and particulate matter accumulate kinetically during the time of the ventilation process of shock ventilation. Summarizing, the environmental loads of humans exposed to the given measured variables are measured and presented graphically.

3 MATERIAL AND METHODS

The measuring device used as basic hardware, called ProxiCube NX3, is a cube-shaped multi-sensor system with an edge length of approx. 8 cm (Figure 1). It simultaneously measures various environmental data such as CO2, TVOC, temperature, pressure, humidity, but also fine dust and liquid particles (Westphal et al., 2021). The device categorises the fine dust into different size classes and enables the exact identification of the respirable load. The instrument is capable of producing the same readings as highly complex reference instruments and can enable the correlation between different environmental influences on indoor and outdoor conditions, as confirmed by recent publications (Westphal et al., 2022). Depending on the test set-up, several Proxicube NX3s, with or without additional GPS trackers, are used at specific points or distributed over longer distances. The basic ProxiCube is modified for the shown measurements to increase the measurement frequency rate. All data are transmitted via the mobile network to the cloud storage, where they are retrieved from the database, displayed, compared and further processed.

Figure 1: ProxiCube NX3 multi-sensor system

The measurement data for the fine dust class PM2.5 are presented and compared with the official air measurement values of the two measuring stations (identifier DEBW098 and DEBW005) of the Federal Environment Agency in Mannheim.

4 RESULTS AND DISCUSSION

Six series of measurements were planned and carried out to determine the local particle concentrations in green, rural, industrial and built-up areas in the city of Mannheim and the concentrations to which cyclists, for example, are exposed.

Indoor/outdoor air measurement Institute kitchen

Figure 2 shows the PM2.5 fine dust pollution on 12 May 2023 from 9:00 to 14:00. The PM2.5 measurement values of the measuring stations DEBW098 and DEBW005 in Mannheim as well as the measurement values of three Proxicube measuring devices are plotted. The values of the measuring stations of the Federal Environment Agency are plotted as hourly moving averages. One Proxicube is located outside on the windowsill facing NW, another Proxicube is located in the middle of the kitchen on a table. The third sensor is located in the hallway leading to the kitchen. The outdoor air readings largely correspond to the air measurement of DEBW098 with a slight tendency towards slightly higher particle densities. At the beginning of the experiment, the sensors inside the building show significantly lower particulate matter levels of about 3-4 µg*m-3. In the period from 10:20 a.m. to 10:30 a.m., the window of the room is completely open (shaded grey area in the figure). During this period, a clear increase in the fine dust particle density in the room can be observed. After closing the window, the concentration drops back to the initial value. In the period from 11:20 to 11:30 a.m. the window is fully opened again, with identical results. From 12 to 14 o'clock the window is tilted (shaded area in grey in the figure). The fine dust concentration rises to the level of the outside air - and remains at this high level. The measurement in the corridor to the kitchen shows an increase in the fine dust concentration at 11:30 and 13:00. This can be attributed to the fact that the door to the kitchen was repeatedly opened and closed from 11:30 to 12:00 and is permanently open from 13:00.

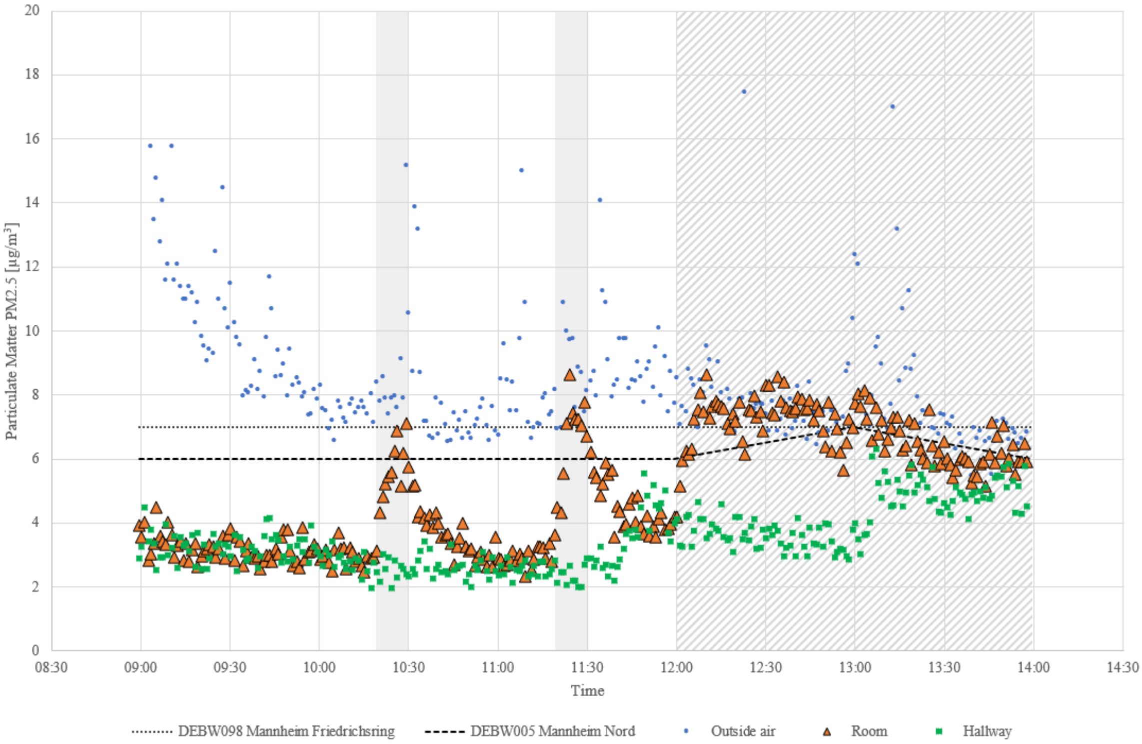

Figure 2: Indoor outdoor comparison in office kitchen, PM 2.5

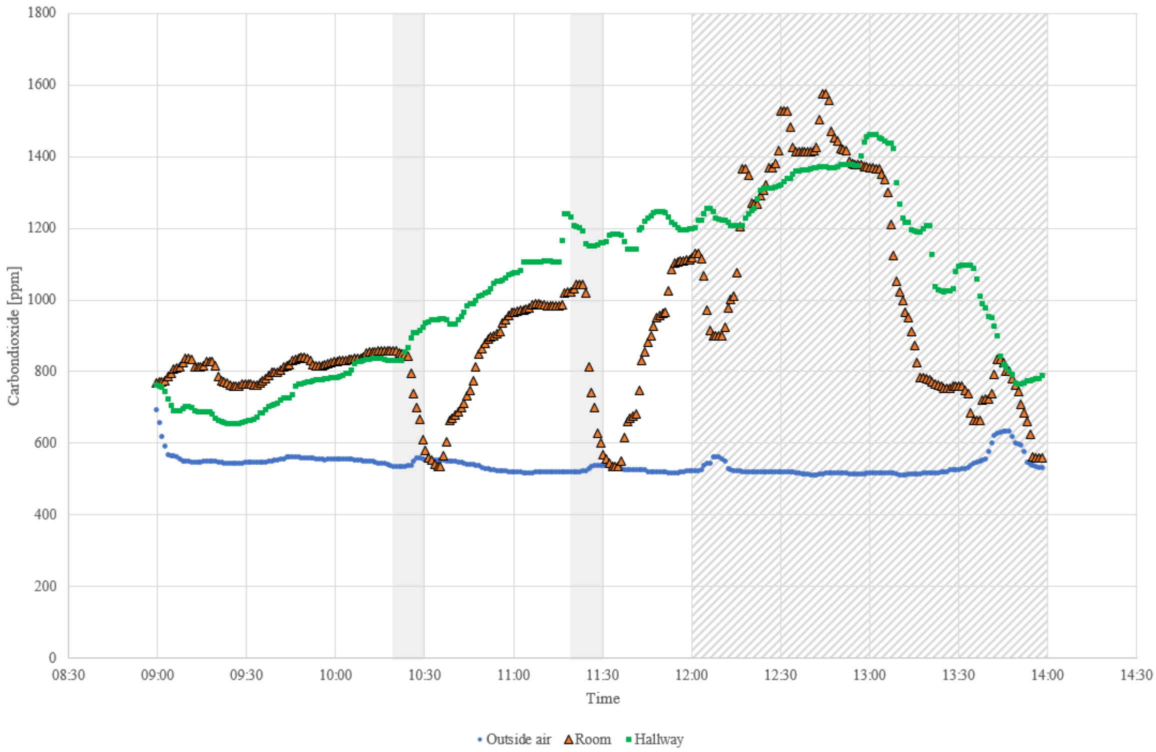

Figure 3: Indoor outdoor comparison in office kitchen; carbon dioxide concentrations

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In Figure 3, the carbon dioxide concentrations are plotted for the same period as in Figure 2. With the windows open and tilted (10:20 - 10:30, 11:20 - 11:30 and from 12:00), the carbon dioxide concentration drops significantly, followed by an increase with the windows closed (from 10:30 and 11:30). From 12:00 - 13:00 there are about 5 people in the room. The tilted window is not sufficient to remove the carbon dioxide, so the concentration rises again. At the same time, however, fine dust enters the room, as already shown in Figure 3. The carbon dioxide concentration in the hallway increases continuously throughout the day. The concentration only decreases after the door is permanently opened.

Based on these results, short-time shock ventilation is preferable to permanent tilt ventilation in order to achieve a more efficient air exchange and a temporally lower exposure to fine dust.

Measurement of the outside air at different heights

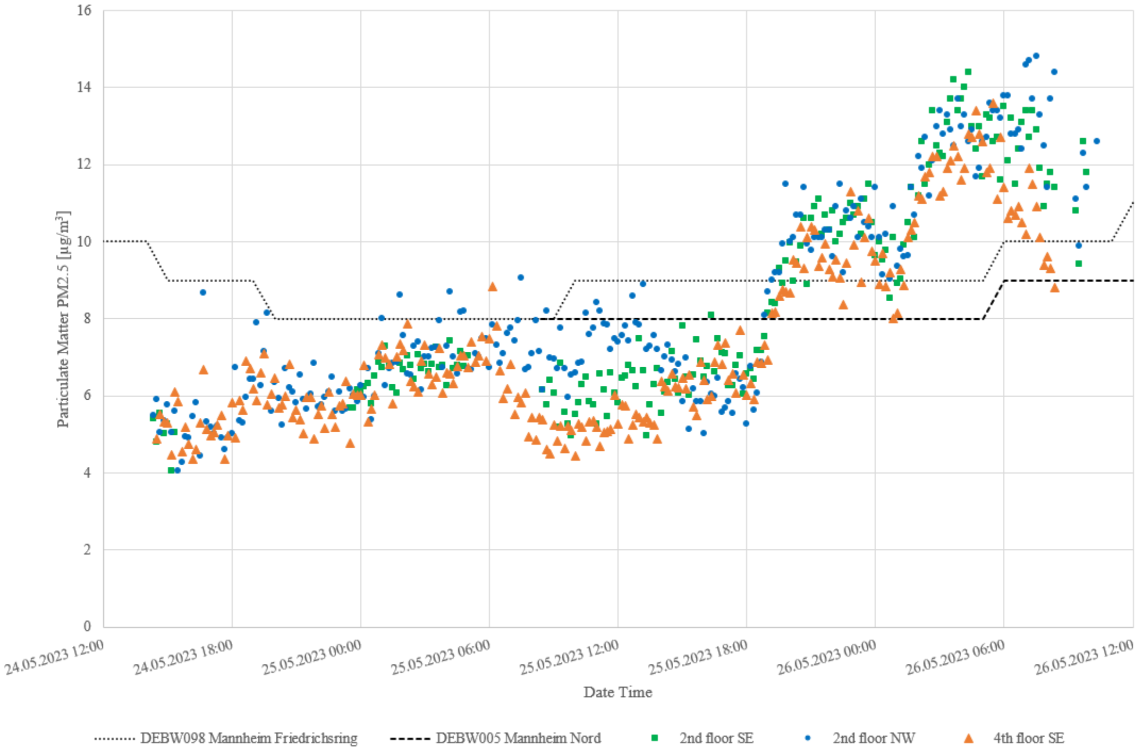

Figure 4: concentration in the outdoor air in different heights

Figure 4 shows the fine dust concentration in the outdoor air from 24.05.2023 to 26.05.2023. In addition to the official air measurement values for PM2.5, the measurement results of three Proxicube air sensors are entered. One sensor unit is located on the second floor facing southeast. Another Proxicube is located on the other side of the building, also on the second floor, facing northwest. The third Proxicube is located on the 4th floor facing south-east. All three sensor units are outside the building on window sills. The readings from the proxicubes are below the official air readings in the first half of the experiment from 24.05.23 14:00 to 25.05.23 18:00, in the second half above them. The official readings show an increasing trend, which is reflected in the readings of the proxicubes. Comparing the measured values of the proxicubes with each other by median formation shows that there is only a slight difference in concentration for PM2.5 between the sensors on the 2ndfloor. If one compares the measured values from the 2nd floor with those from the 4th floor, greater differences become apparent. Thus, the proxicube on the 4th floor has a median fine dust concentration that is 9 - 10 % lower than the proxicubes on the 2nd floor. This indicates that, for example, residents of attic flats are exposed to lower levels of particulate matter than their neighbours on the lower floor.

Air measurements around the coal-fired power plant Mannheim Grosskraftwerk

Figure 5 shows the results of the air measurements from 05.05.2023, 11:00 a.m. - 4:30 p.m., around the coal fired power plant Mannheim (GKM) in comparison with the measured values of the measuring stations DEBW098 and DEBW005. One Proxicube is located east of the GKM at the Stengelhofweiher, opposite the GKM on the banks of the Altrhein and west of the GKM, downstream on the flood embankment. The measured values of all three sensor units lie between the measured values of the Federal Environment Agency. Conspicuous or increased fine dust concentrations due to e.g. blown coal dust, fly ash or FGD gypsum are not detectable.

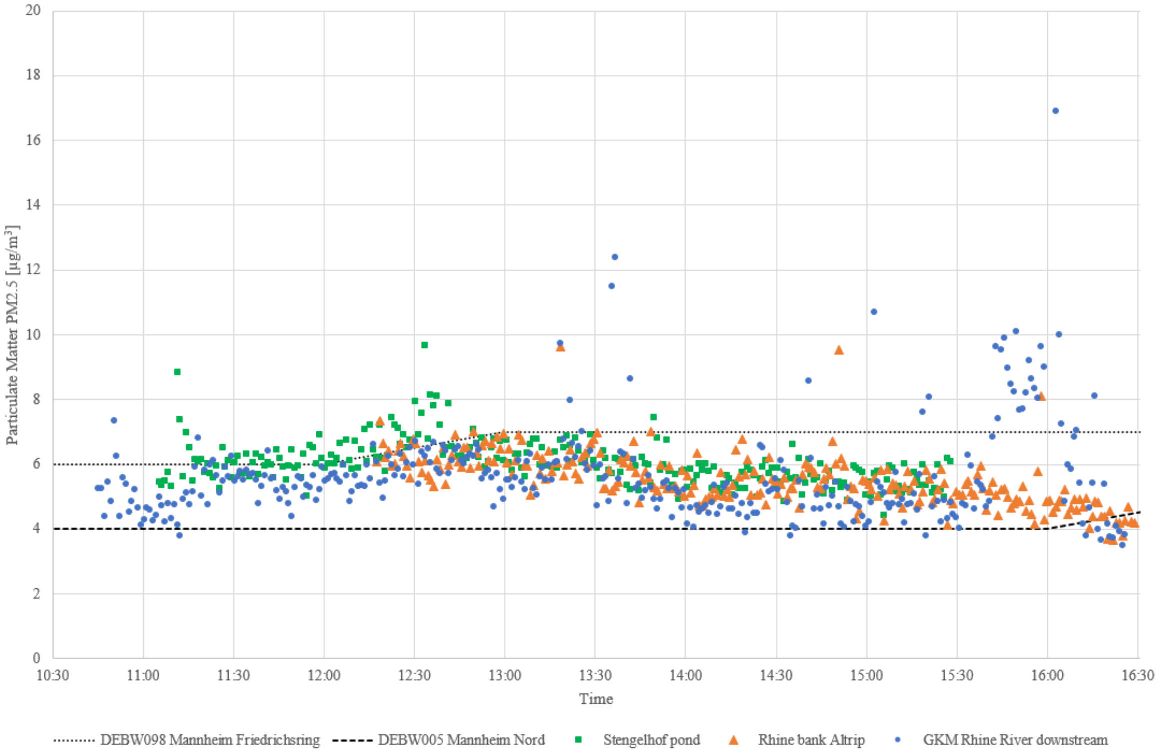

Figure 5: Air measurements around the coal-fired power plant Mannheim Grosskraftwerk

Traffic node

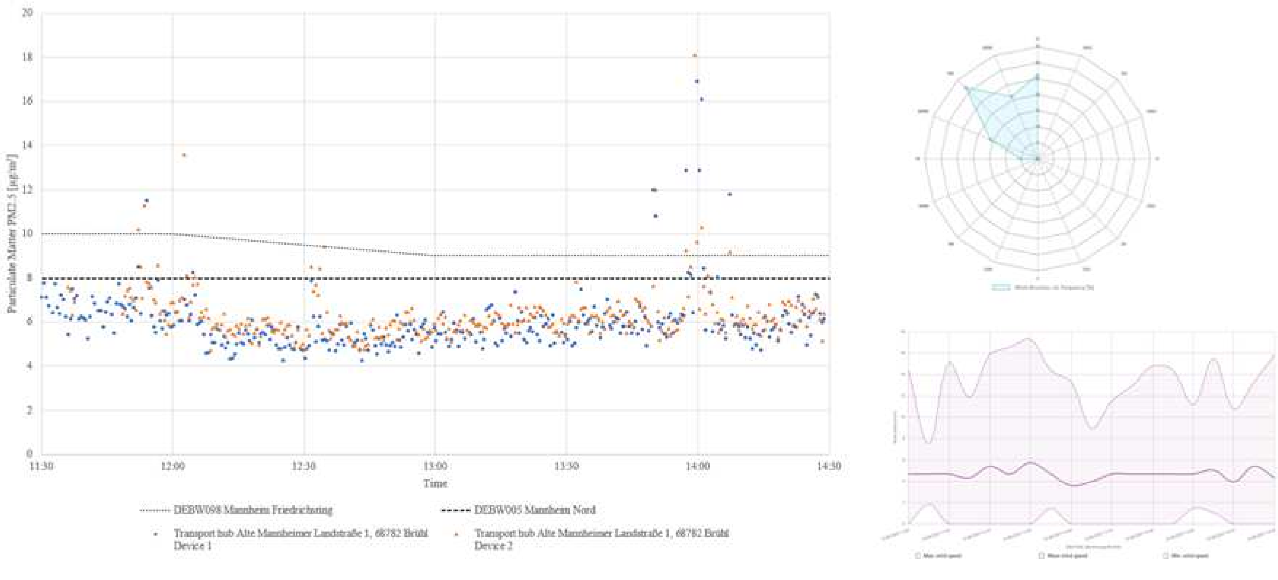

Figure 6: Traffic node and wind data

The two measurements in ABB ran in parallel at a traffic junction point in Mannheim. The measured PM2.5 values are somewhat lower than at the measuring points of the city of Mannheim. The fine dust pollution does not have the same effect at this well-traveled location as in a street surrounded by buildings. The wind speeds indicated by the city of Mannheim for this time period are 5 km/h on average. Here, the assumption can be made that the particle pollution caused by traffic is diluted continuously by the light wind. Locally recorded increased measured values can be attributed to the drive-in station in the vicinity.

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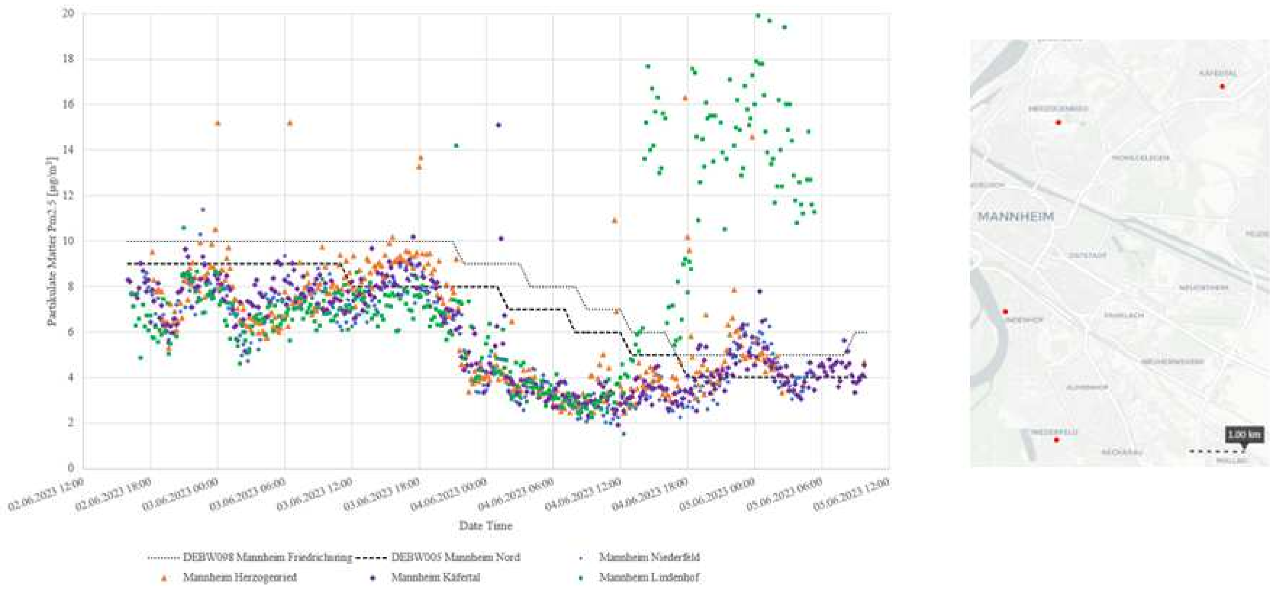

Figure 7: Measurements on four different parts of the city

The measurement cubes were positioned in four districts in Mannheim for three days and the measurement results were presented in Figure 7. At all four locations the basic course is the same and the changes of the particle concentrations are similar to the measured curves. Locally measured higher particle concentrations cannot be justified with certainty, but there are numerous sources in residential areas, such as cigarette smoke, barbecues, a running motor under the balcony, etc., which can lead to these measured values.

Bicycle tours

The measuring boxes are attached to the bicycle basket at a height of approx. 50 cm. Three people set off in the direction of the north-west, north-east and south-east of the city. The aim of the study is to identify zones with comparatively higher particulate matter pollution within the city and in the peripheral areas. Figure 1 shows the entire distance travelled with the measured PM 2.5 values.

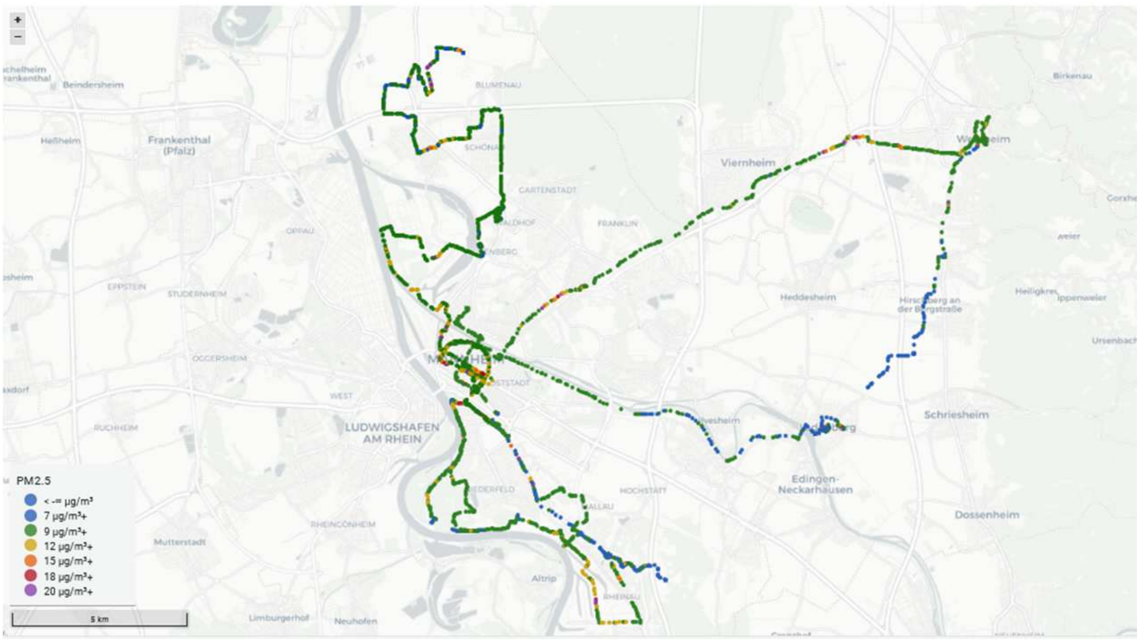

Figure 8: Bike route between 8:30 and 15:30

In the following, sections of the map are enlarged for a better overview and the hotspots are marked individually. The areas with special observations are noted in the legend.

Figure 9: Cycle route between 9:40-10:30 in city centre

In Figure 9, ten zones stand out. Most of the areas with comparatively higher readings have in common that they run along a busy major road or that many pedestrians are on their way. In the case of point 10, the higher readings could be attributed to the adjacent construction site. Here, the air circulation is lower than on an open road, which is probably why the swirled-up particles reach a higher concentration. The section at point 8 is located at a junction with traffic lights with higher traffic volume.

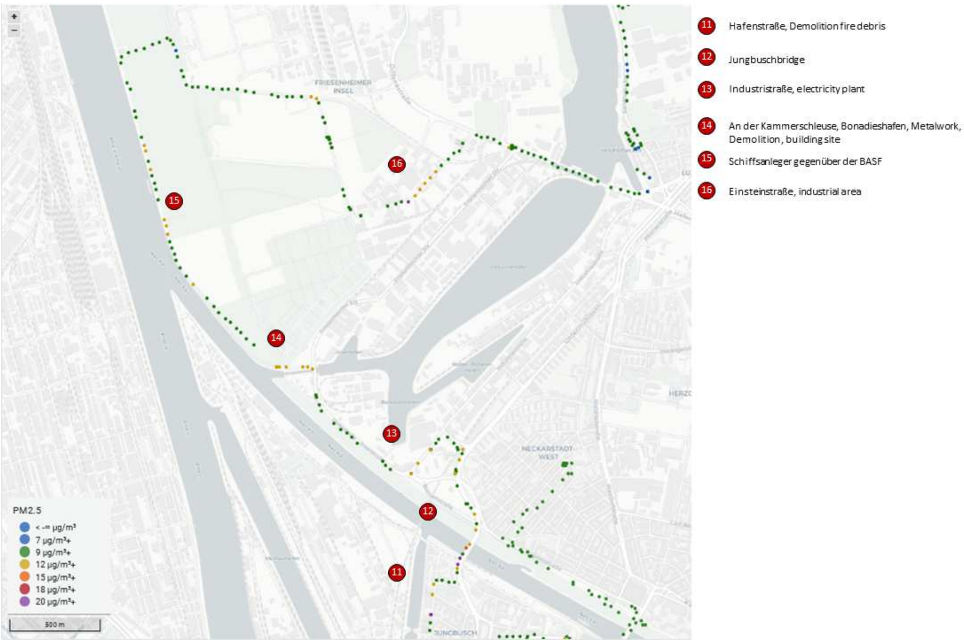

Figure 10: Cycle route between 11:00-12:30, north west route part 1

In Hafenstraße at hotspot 11, there is a burnt building in the route that is currently being dismantled. There is also a work site at 14. The other hotspots marked in Figure 10 are located near industrial facilities.

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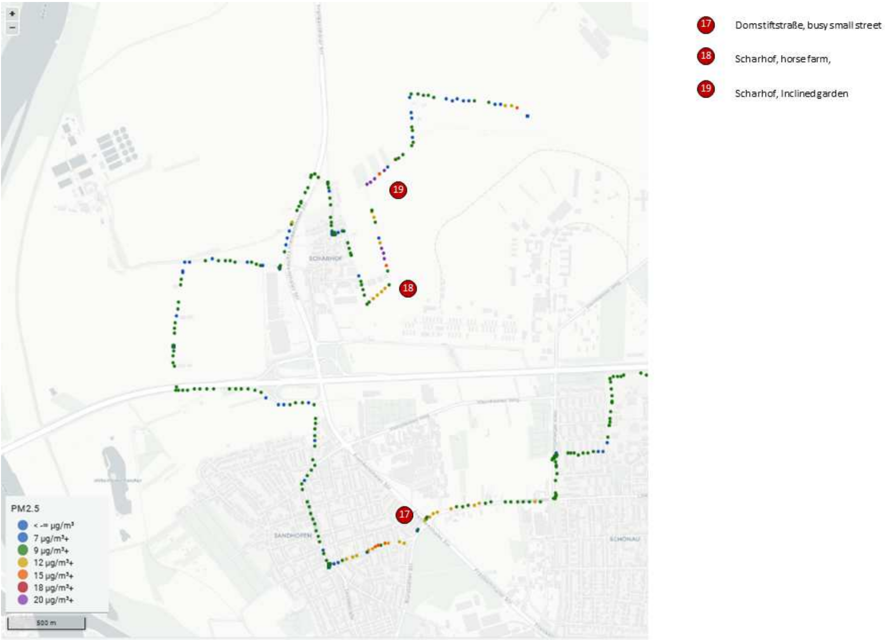

Figure 11: Cycle route between 12:30-13:30, north west route part 2

The track at point 17 is a small but busy road surrounded by buildings. The assumption here is that the particles are not blown away well enough and the concentration is higher than with open roads. The more rural stretches at 18 and 19 also show increased concentrations of particles, which could possibly be caused by the blowing of unpaved road sections, animal feed or similar bulk material.

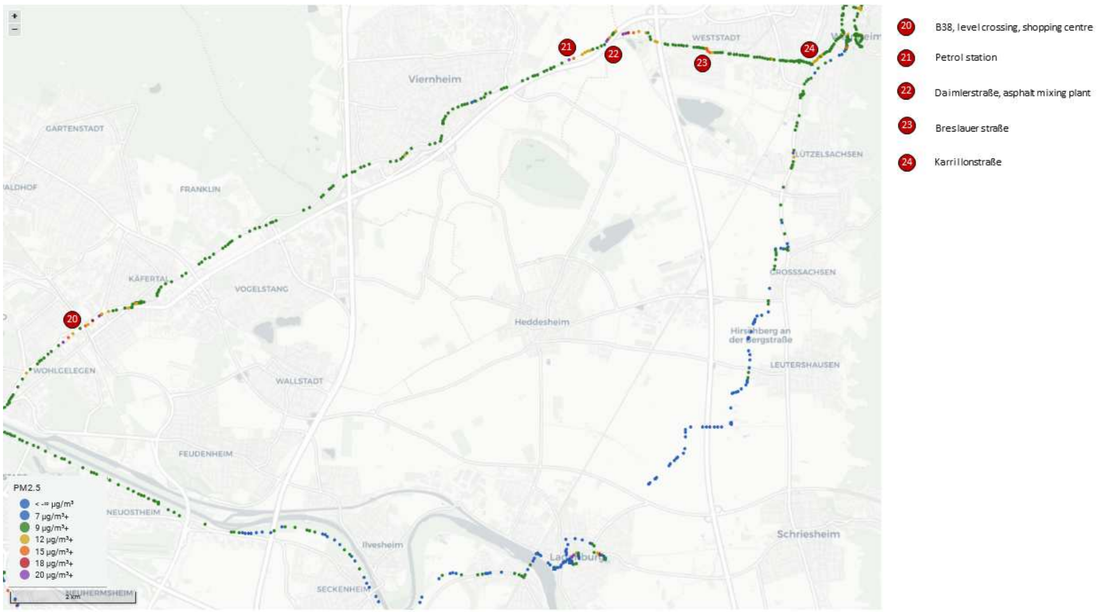

Figure 12: Cycle route between 10:15-15:30, north east route

Figure 12 also shows that higher values are measured in places close to industrial facilities and with heavy traffic or where cars have to stop and go and drive more slowly.

Increased values measured at points 25 and 26 in Figure 13 could be attributed to the football pitch. Dust stirred up by the wind and people is measurably distributed in the surroundings. The other hotspots are again routes with city traffic and industrial sites.

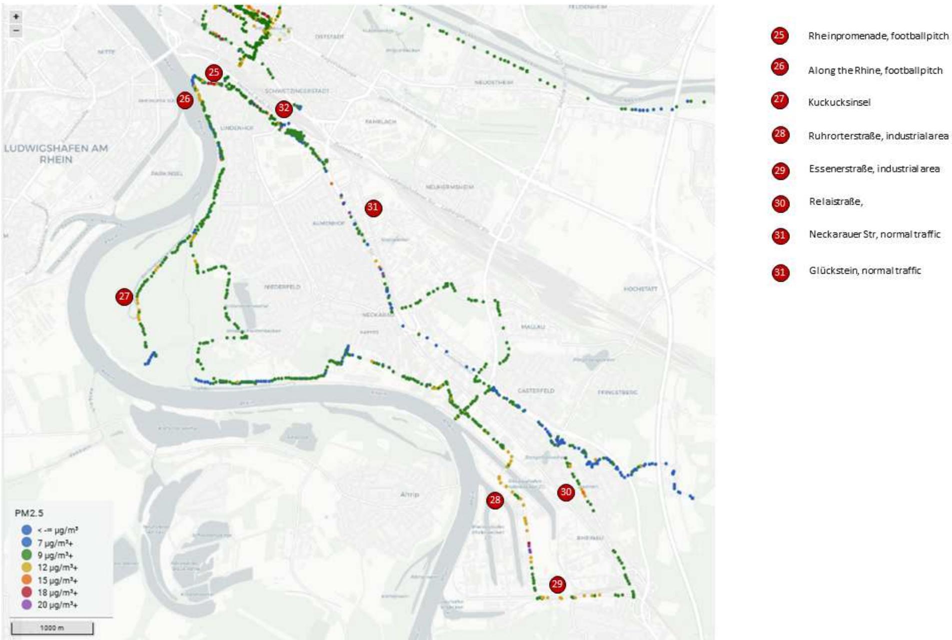

Figure 13: Cycle route between 9:40-16:10, south east route

5 CONCLUSION

The empirical experiment reflects the contribution of a measurement device (ProxiCube) to the key success factors of awarded smart cities highlighting the central importance of its citizens' health. It is an important ingredient of a smart city's technological infrastructure, informs the strategy for digital transformation i.e. in terms of planning the nexus between streets, factories, construction sites and residential areas evtl. via digital twins, providing the necessary skills, i.e. in terms of transversal (research), general or specific IT competences, informs the awareness and health education of citizens, and contributing to the authentic implementation of a Smart City's identity, i.e. in terms of a health orientated or life quality related identity. Furthermore, the experiment illuminates the interplay of the factors of an urban management model relating to competences, implicit SC domain priorities and the necessary collaboration of the SC ecosystem actors to achieve the SC objectives and outcomes (Westphal et al., 2022).

In more detail, the experiment determines the distribution of CO2 and particulate matter as a function of the height of the measuring point and the cross-influences of the other environmental parameters (temperature, humidity, dew point…). As to specific health orientated citizens' behavior, short-time shock ventilation is preferable to permanent tilt ventilation in order to achieve a more efficient air exchange and a temporally lower exposure to fine dust. Interestingly, residents of attic flats are exposed to lower levels of particulate matter than their neighbours on the lower floor. Numerous sources in residential areas, such as cigarette smoke, barbecues, a running motor under the balcony, etc., need to be taken into account to avoid excessive exposure.

In busy, major roads, the air circulation is lower than on an open road, which is probably why the swirled-up particles reach a higher concentration.

In general, it can be summarised that elevated PM 2.5 levels were measured on routes that run close to urban traffic or industrial facilities. In addition, construction sites with demolition work and unpaved roads or playgrounds could be sources of particulate matter.

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