GENERAL AUTHOR COMMENT:

We added supplementary information including Heat Maps for ambient temperature, pressure, relative humidity and $PM_{2.5}$. We also evaluated scatterplots to show the correlation with UFP for these parameters. The conclusions drawn from this investigation do not impact the main findings of the manuscript and only provide further context.

Referees can check the specific changes in the manuscript via the "Track-changes" mode.

REFEREE 1

REFEREE COMMENT:

This manuscript presents the results of UFP measurements taken on a balcony in a residential area near Karlsruhe. A high-resolution data set is available for the winter months of 2024/25. The UFP data is compared with wind data from the same location. The influence of wind speed on the dispersion of UFP is examined in detail, and the observed concentrations are compared with the new WHO recommendations. Source apportionment is performed by comparing the UFP data with the BC concentrations and taking into account the concentration as a function of time. The conclusion is that wood stoves are the main source. This conclusion is likely, but the influence of traffic cannot be completely ruled out. An analysis of the BC filter samples for a wood combustion tracer could be helpful.

Since most ambient air data currently available is for mass (PM10, PM2.5), UFP data is valuable. Nevertheless, the authors could perhaps state more clearly what is really new about their results.

The manuscript is mostly clearly written and easy to read.

Here are a few comments that point out minor errors or will hopefully help the reader:

AUTHOR RESPONSE:

We agree that – of course – a more elaborate source apportionment (e.g. looking for wood combustion tracers) would be most helpful to remove any existing doubts regarding the origin of the air pollution. Within the framework of our measurement campaign it was sadly not possible to analyze the BC filters regarding the composition of the deposited particles. We hope that the argument made in section 3.1 is sufficient to identify wood-smoke as the main source. Within the scope of another comment we provided raw-data for all days where the mean hourly concentration of 20 000 cm^{-3} was exceeded (Figure R1) – there it is clearly visible that concentration spikes also commonly occur outside of rush hours (e.g. after 20:00 in the evening). In combination with low wind speeds that are a prerequisite for higher concentration measurements – it is impossible that local traffic is a significant source in these cases since the measurement position is in a traffic-calmed residential area and traffic emissions would have to occur close to the measurements to affect the concentration readings.

No changes were made to the manuscript based on your overarching comment, but we do hope to have offered some additional context that readers can later access within the discussion section of the article.

Regarding new aspects of our research, we of course agree that the application of established aerosol measurement technology (especially in the context of conventionally monitored pollutants like PM2.5 that is also featured in the manuscript) is nothing special or "new". This paper combines temporally resolved measurements of pollutants of emerging concern (UFP & BC) that are increasingly relevant within the scope of the revision of the Ambient Air Quality Directive, at a measurement location that is rarely featured in literature (residential area with wood-smoke as a main source) compared to sites where other sources (e.g. traffic, air traffic, etc.) are the main pollutants. A key aspect highlighted in the paper is, that due to the pollution dynamic it is especially important to consider peak concentrations at shorter timeframes (as is e.g. specified in the WHO good-practice statements for UFP maximum 1-hour concentrations). As such we hope our article remains of interest for publication.

REFEREE COMMENT:

2.2: A reference with further information on the UFP monitor would be helpful

AUTHOR RESPONSE:

We added a source (Palas, 2025) to the table headline that leads to a link to the manufacturers product page for further information. The main specifications are already summarized in the table.

REFEREE COMMENT:

Line 164: Is the inlet sample actually dried (if so, how) or only heated?

AUTHOR RESPONSE:

The unipolar corona discharge and ejector-dilutor system at the inlet are both heated. There is no actual drying, as in removing the absolute water content, involved. We corrected this error in the manuscript and clarified that the inlet aerosol is merely heated.

REFEREE COMMENT:

Fig. 2: Wind speed ranges specified for the wind rose: 1.5 m/s-2 km/h Always use m/s or km/h, explain the scale from 0% to 25% shown in the wind rose.

AUTHOR RESPONSE:

Thank you for this remark. All wind speeds are in unit km/h. Fig 2 was corrected accordingly. We also added an explanation of the wind rose in section 2.3:

"The wind rose shows the probability / fraction of the dataset of different wind speeds (above zero) coming from a corresponding wind direction in %."

REFEREE COMMENT:

Fig. 3: Instead of simply specifying the concentrations for three colors, a more detailed scale would be helpful. In the second half of December, concentrations tend to be low. Can this be explained (e.g., by higher temperatures, more wind)?

AUTHOR RESPONSE:

The scales for the Heat Maps in Fig. 3 and Fig. 5 have been extended.

We also added temperature, ambient pressure, relative humidity and wind-speed Heat Maps for the entire measurement period in the appendix to provide further data. References to these Heat Maps in the appendix were added in the manuscript (mainly section 2.1, 2.3 and 3.3).

Overall, we identified the dispersion conditions as the main (measurable) impact on ambient UFP concentration levels.

Regarding your remark on the lower concentrations in December, there is indeed a period with higher wind speeds in mid-to-late December where UFP concentrations are lower. Temperatures are likely not the reason behind lower concentrations, as similar temperatures were measured throughout the measurement period.

Considering the entire dataset, temperature, ambient pressure and relative humidity show no unambiguous correlation with UFP-concentrations. We added an evaluation of scatterplots of the 15-minute average concentrations (similar to figure 8 in the main manuscript) to the appendix to show this lack of a proper correlation between UFP-concentrations and the specified ambient conditions.

REFEREE COMMENT:

Fig. 4, right: It is surprising that on days when the 1-hour average exceeded 20,000cm^{-3}, the 15-minute average never exceeded 20,000cm^{-3}.

AUTHOR RESPONSE:

Of course it would be, as you correctly mentioned, impossible for days where the 1-hour average of 20,000 cm^{-3} was exceeded to not also have 15-minute average UFP-concentrations above 20,000 cm^{-3}. In that sense Fig. 4 might be a little misleading. To facilitate understanding the evaluation behind Fig. 4, the corresponding explanations were extended:

Here [in Fig. 4] the overall average 15-minute mean concentration in a fixed time interval e.g. from 09:00 to 09:15 is calculated for either the entire measurement period (left) or only the days where the 1-hour average concentration of 20,000 cm^{-3} was exceeded (right). E.g. for Fig. 4 left: the average concentration for an entire row of the Heat Map is calculated for each time interval to gain a "mean" diurnal pattern for the entire measurement period."

To further address your comment, I plotted the underlying daily UFP-data for Fig 4 to give more context regarding the raw-data behind the "average" diurnal patterns (figure R1).

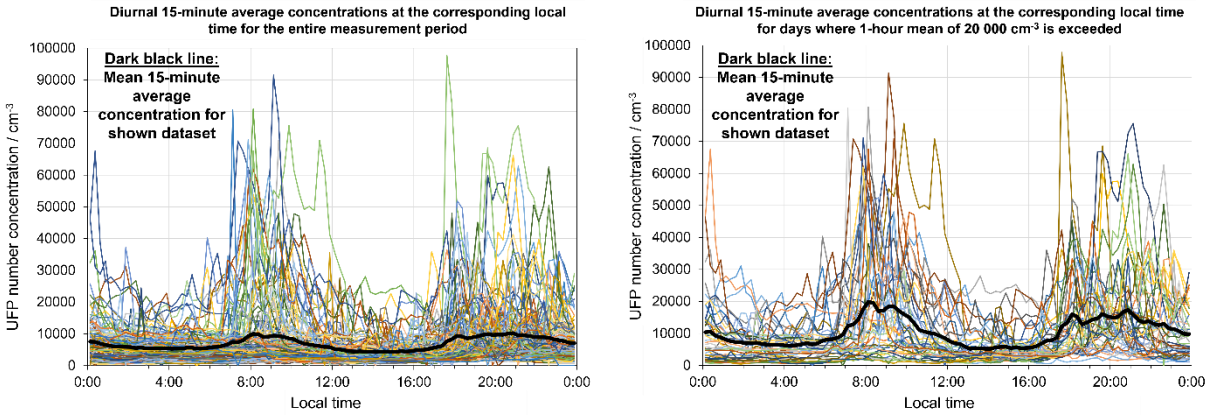

Figure R1: Raw-data for the calculation of the diurnal patterns in Figure 4 of the main manuscript

There are significant fluctuating concentration spikes for the entire measurement period during varying times of the day (focusing on the morning and evening hours). The resulting "mean" diurnal pattern shown in Fig. 4 is thus skewed towards a longer period of "moderately increased" average concentrations compared to the significant spikes that can occur on the actual daily basis. Here, the 15-minute average concentrations significantly exceed a concentration level above 20,000 cm^{-3} resulting in the corresponding exceedance of the hourly maximum concentration specified by the WHO. Since our comment would be available on the Discussion Section of the article upon publication, we did not separately include Figure R1 in the manuscript.

REFEREE COMMENT:

Line 235: "So not only are the major sources likely not active during the lunch hours, pollutant dispersion has positive impacts on the particle concentration level." How can a distinction be made between low activity and dispersion by wind?

AUTHOR RESPONSE:

It is difficult to make such a distinction based on the presented dataset. I am currently evaluating the "signal noise", respectively concentration peaks, during periods with increased wind speeds to enable some sort of identification of source activity for a follow-up publication. These conclusions on source activity are not necessarily reflected by the 15-minute average concentrations shown in this publication. I am therefore not able to completely address your comment but can offer some context on the idea behind the current work. This relies on a temporally resolved evaluation of the pollutant concentrations on a shorter timescale, which is 1 minute for the used measurement devices as shown in figure R2.

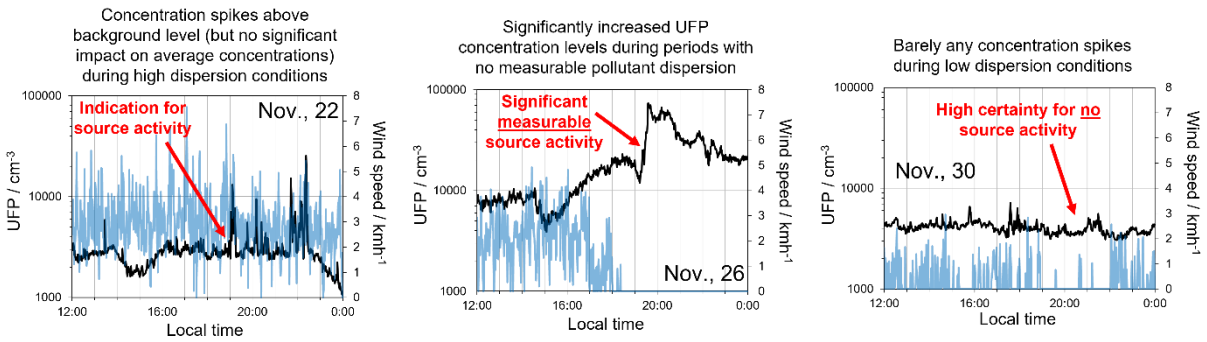

Figure R2: UFP-concentrations in the context of wind speed for three exemplary days during the measurement period

In Figure R2, the UFP-concentrations and wind speeds are plotted for three exemplary days (1-minute time resolution of data). On Nov. 22, concentrations are comparably low and approx. around the background level. During the evening hours, short concentration spikes are measured that may exceed 10 000 cm^{-3} but have no significant impact on average concentrations (compare Heat Map in Fig. 3). This "signal noise" serves as an indication on source activity. As wind speeds are comparably high during this period, it is likely that emitted pollutants are affected by dispersion.

The other two images serve as examples for low wind speeds / no significant pollutant dispersion where either a measurable effect on UFP-concentration levels is unambiguously detected (source activity) or concentrations remain on the background level with no significant concentration spikes (high certainty of no source activity).

Summarizing, based on the presence of concentration fluctuations it might be possible to determine if pollution sources were active (without affecting average concentrations, respectively having little impact) or if no sources were active that could potentially impact the measurements for the given dispersion conditions. This is just an initial approach on how source activity could be identified based on temporally resolved data. These conclusions are also linked to section 3.1 (source apportionment).

Therefore, I added a comment behind the corresponding sentence in line 235 to address the difficulties surrounding the identification of source activity:

"Identifying pollutant sources is not possible based on concentration data alone, however section 3.1 offers some insights regarding the corresponding source apportionment for the conclusions drawn from Fig. 3 and Fig. 4."

REFEREE COMMENT:

Fig. 5: same comment as for Fig. 3

AUTHOR RESPONSE:

The scale for the Heat Map has been extended.

REFEREE COMMENT:

Fig. 6 and 7: midnight is either 12 PM or 0 AM

AUTHOR RESPONSE:

As far as I know, the convention is that 12 AM is used to denote "midnight". (See e.g. in the American Heritage Dictionary: https://ahdictionary.com/word/search.html?q=AM where it is spelled out that: "By convention, *12 AM* denotes midnight and *12 PM* denotes noon. Because of the potential for confusion, it is advisable to use *12 noon* and *12 midnight."*.)

Nonetheless, the usage of the 12 hour clock might cause some confusion to some readers. I therefore changed all my diagrams to use the 24 hour clock instead and corrected time data throughout the manuscript.

REFEREE 2

The manuscript submitted by bächler et al. deals with the measurement of ultrafine particles using a diffusion charge-based UFP monitor, an aerosol spectrometer and a MA350. The measurements were conducted over a long period of time, focusing on identifying wood stove heating aerosol emissions.

Overall, the work is well written with easy-to-understand explanations, also with regard to WHO guidelines.

Nevertheless, I would like to have a few questions answered.

REFEREE COMMENT:

L 143 : The devices were installed on a balcony. Could you also provide information on possible wind shielding and surrounding vegetation?

AUTHOR RESPONSE:

Due to data protection, I cannot provide a detailed map of the surrounding building geometry. To give some context, the following rudimental drawing in figure R3 gives a rough outline of the closer proximity of the measurement location. There is some obstruction (e.g. wall on the east side) that influences the wind measurement to some degree, however no explicit wind-shielding was employed.

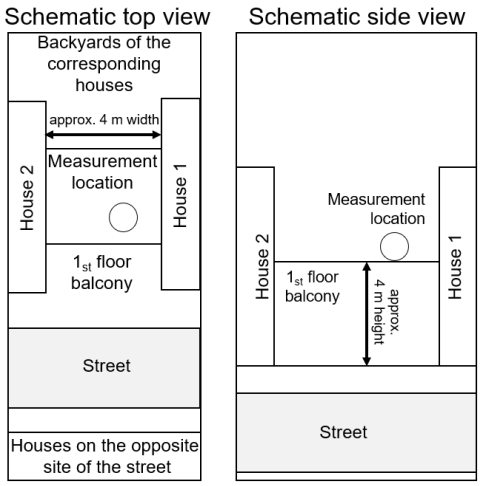

Figure R3: Schematic of measurement position

There is also no significant surrounding vegetation (e.g. larger treelines, etc.) in the residential area.

We slightly expanded the description of the setup to the corresponding paragraph.

REFEREE COMMENT:

L171 At the beginning, it was discussed that the 24-hour average does not cover smaller ufp events and is lost in the average. This could be clearly illustrated with the data collected.

AUTHOR RESPONSE:

Figure 3 and 4 show the temporally resolved diurnal pattern and the mean diurnal pattern based on the obtained data based on 15-minute mean concentrations to illustrate the effect of concentration spikes on shorter timeframes. In Figure 9 the mean 24-hour and 1-hour maximum mean concentrations are displayed, where a large difference can be identified. The 1-hour maximum concentration is, in many cases, multiple factors higher compared to the 24-hour mean concentration what can be an indication for significant short-term exposure.

Since this is already a significant part of the manuscript and the conclusions no changes were made based off this comment.

REFEREE COMMENT:

Figures: Please reconsider your colour scheme. There should be at least five colours in in the legend.

AUTHOR RESPONSE:

We adapted Fig. 3 and Fig. 5 and added a more detailed scale for the corresponding concentrations.

REFEREE COMMENT:

To emphasise the point that burning wood for heating causes ultra-fine particle (UFP) concentrations to increase dramatically, it would be useful to establish a correlation between UFP levels and outside temperature.

AUTHOR RESPONSE:

We added images in the appendix that illustrate the correlation of UFP with outside temperature as well as ambient pressure and relative humidity. There is no clear distinctive trend for these parameters, even though one would assume that e.g. for colder temperatures and a higher heating demand concentrations would be increased. The same goes for ambient pressure, where for temperature inversions / high pressure areas increased concentrations occur with higher frequency. This is not directly visible from the data, as these durations only span a comparatively small amount of the entire measurement period (though these periods can be identified for a $PM_{2.5}$ Heat Map we also added to the appendix. As such, the main parameter where we could determine a clear trend indicating the effect of local aerosol sources is wind speed. These additional images and the information are referenced in section 3.2.

REFEREE COMMENT:

L242: Please explain how the source was precisely identified.

High pollen counts or Saharan dust can cause PM2.5 levels to rise. Please also discuss this in relation to the UFP concentration and the long-term measurements.

AUTHOR RESPONSE:

The source for the statement in line 242 was identified based off measurements with multiple devices according to the source from Dada et al. (https://ar.copernicus.org/articles/3/315/2025/ar-3-315-2025.html). We modified the sentence accordingly:

"The source was identified as domestic heating and aerosol transport from rush-hours based off intercomparisons of various different measurements (e.g. SMPS, CPC, Catalytic Stripper, NAIS, Trace-gas analysis, Aethalometer, etc.)."

We added a Heat-Map for 15-minute average $PM_{2.5}$ concentrations in the supplementary information to offer more context to the results reported in section 3.5. To address your comment, I looked up information on pollen and Saharan dust events. According to my internet research (sources in german language), the main pollen sources during winter months (starting in December and reaching into March) are from the alder and hazel trees, while other types of trees play a minor role (e.g. https://allergie.hexal.de/pollenflug/pollenflugkalender/). Here, the size of the pollen significantly exceeds 2.5 µm (e.g. https://allergiezentrum.org/allergien/allergenkunde/) and should not significantly impact $PM_{2.5}$ concentrations.

Considering Saharan dust events – I was only able to look into past news reports that reported events for Mar. 6, and Mar. 20-21. We measured increased $PM_{2.5}$ concentration from Mar.,9 -

11, as well as Mar., 13 and Mar., 26-27 according to the newly added $PM_{2.5}$ Heat Map. As these periods do not overlap it is not safe to say whether Saharan dust events had significant impact on PM concentrations. This especially holds true with long-term evaluations as there are only a couple of days each year where Saharan dust events become relevant.

What can clearly be identified in the $PM_{2.5}$ Heat Map is the temperature inversion period discussed in section 3.2.2. so that we added a reference to this section accordingly.

No further changes were made to the manuscript based off this comment.

REFEREE COMMENT:

L421: Most heating systems, including wood-burning ones, vent their exhaust air containing aerosols outside. Since most people are inside buildings during these events, this only has an indirect impact on health. Please do not mix ambient and indoor air quality

AUTHOR RESPONSE:

I have to admit that the statement in L421 {"Here [meaning during periods with outdoor wood-smoke pollution], it is highly likely that the particles from wood-smoke are especially hazardous and affect people when they are spending time at their homes."} was somewhat exaggerating. I changed this sentence and tried to make a balanced assessment:

"During these periods with increased wood-smoke pollution (morning and evening hours) people are more likely to spend time at their homes (indoors). Depending on ventilation / air exchange between interior and exterior, they may or may not be exposed to this outdoor air pollution. How much individual homes are affected can thus vary significantly."

Additional small notes

REFEREE COMMENT:

The title of the manuscript could be shortened without detracting from its meaning by deleting the time-resolved terms.

AUTHOR RESPONSE:

We complied with your comment and shortened the title of the manuscript. We added BC- and $PM_{2.5}$ measurements to the title.

REFEREE COMMENT:

L62 carried by wind and air flows : secondary organic aerosol formation and coagulation instead of air flow

AUTHOR RESPONSE:

We complied with your comment and changed the manuscript accordingly.

REFEREE COMMENT:

L98 Please address the composition of brake emissions, as these also contain heavy metals, which are even more harmful to health.

AUTHOR RESPONSE:

We added the reference [Neukirchen et al., 2025] to emphasise the composition of brake dusts which can indeed consist of toxic metal alloys.

REFEREE COMMENT:

L101 “the deadline can be postponed” – rephrasing

AUTHOR RESPONSE:

We rephrased the sentence: “– it is possible to postpone the deadline until compliance with the new limits becomes mandatory”

REFEREE COMMENT:

L119 I would recommend citing more articles on that topic that were not authored by the main author.

AUTHOR RESPONSE:

Additional references were cited: [Schiller & Schmid, 2015] [Matthes et al., 2016] [Mylläri et al., 2025]

REFEREE COMMENT:

Figure 4: could you add the date on this data?

AUTHOR RESPONSE:

We added additional explanations surrounding this image, as it is indeed an “average” diurnal pattern calculated from the entire dataset and days where 20 000 cm^{-3} hourly mean concentration are exceeded. As such there is no individual date for this diagram. See also a previous referee comment, where we provided further context and the underlying raw-data (Figure R1).