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Field-based evidence of changes in household PM$_{2.5}$ and exposure during the 2020 national quarantine in China

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Abstract

Air pollution exposure depends not only on outdoor but also on indoor air quality and human activities. The outbreak of coronavirus in 2019 occurred close to the Spring Festival in China, when many rural-to-urban workers moved to their hometowns, resulting in increased household (HH) consumption of solid fuels for space heating in the rural north. In this study, field measurements of HH PM$_{2.5}$ (particulate matter with an aerodynamic size $\leqslant 2.5$ μm) from a rural village were performed to evaluate changes in indoor, outdoor, and total exposure during the quarantine. Both indoor and outdoor PM$_{2.5}$ were, as expected, higher during the heating period than during the non-heating period, resulting in much more exposure during the heating season. Indoor exposure accounted for up to 87% and 95% of the total PM$_{2.5}$ exposure during the non-heating and heating periods, respectively. The contributions of indoor exposure associated with internal sources were 46% and 66%, respectively. Indoor coal combustion resulted in an increment of about 62 $\pm$ 12 μg m^{-3} in indoor PM$_{2.5}$ exposure. Due to the quarantine, the indoor-originated PM$_{2.5}$ exposure increased by 4 μg m^{-3} compared to that during the heating period before the lockdown. In comparison with the exposure before the quarantine during the heating period, the outdoor exposure decreased by 5 μg m^{-3} during the quarantine, which was mainly attributable to much less time spent outdoors, although the outdoor PM$_{2.5}$ levels increased from 86 $\pm$ 49 μg m^{-3} to 104 $\pm$ 85 μg m^{-3}. However, the overall exposure increased by 13 μg m^{-3} during the quarantine, resulting from the changes in outdoor exposure (-5 μg m^{-3}), outdoor-originated indoor PM$_{2.5}$ exposure ($+9$ μg m^{-3}), PM$_{2.5}$ from indoor sources before the quarantine ($+5$ μg m^{-3}), and quarantine-induced indoor PM$_{2.5}$ increments ($+4$ μg m^{-3}). The increase in air pollution exposure during quarantine deepened concerns about the issue of HH air pollution and the clean HH energy transition actions required to eliminate traditional solid fuels.

1. Introduction

The adverse impacts of using solid household (HH) fuels have been widely documented; however, this issue continues to undergo an all-time increase in many countries, in comparison with other air pollution sources, such as industrial and vehicular emissions. Coal is frequently used for HH space heating in rural homes in northern China, contributing significantly to ambient air pollution in the winter (Liu *et al* 2016, Du *et al* 2018), and severe indoor air pollution due to fugitive emissions and the re-infiltration of outdoor air pollution (Shen *et al* 2020, Luo *et al* 2021b). HH air pollution causes millions of premature deaths associated with PM$_{2.5}$ (particulate matter with an aerodynamic size $\leqslant 2.5$ μm), and recent

research has revealed that the contributions due to the residential consumption of solid fuels to energy consumption, air pollutant emissions, pollution exposure, and $PM_{2.5}$-associated premature deaths have been magnified from less than 10% to about 70% (Yun *et al* 2020).

In rural areas, residents of low socioeconomic status burn solid fuels for heating and cooking, which emit large amounts of $PM_{2.5}$ and other pollutants into the indoor and outdoor environments, leading to enhanced exposure of rural residents to air pollution (Hajat *et al* 2015). In the early 2020s, the outbreak of coronavirus disease 2019 (COVID-19) significantly affected the world, and the impacts are continuing. High death rates attributed to COVID-19 were recorded in some low-socioeconomic-status areas (Nazroo and Becares 2020, Sun *et al* 2021), deepening environmental inequality (Frontera *et al* 2020, Chen *et al* 2021). In response to the pandemic, China activated the First-Level Public Health Emergency Response (quarantine) and imposed strict restrictions on population migration. Obvious changes in ambient air pollution were observed, especially for NOx, for which vehicle emission is a major source (Lv *et al* 2020, Venter *et al* 2020). Changes in other air pollutants, such as $PM_{2.5}$, volatile organic compounds, and O_3 were site- and time-dependent because of the impacts of emission source changes, meteorological conditions, and atmospheric chemical reactions (Kumari and Toshniwal 2020, Zhao *et al* 2020). While ambient air pollution was reduced during quarantine, Shen *et al* (2021) noted that the overall exposure depended on indoor air quality and time activities. Since rural areas rely heavily on solid fuels, factors influencing this exposure include the number of people in the home, time spent indoors, and the type of HH energy used for space heating. A modeling study revealed that the overall $PM_{2.5}$ exposure increased by $\sim$5.7 μg m^{-3}, although the ambient air pollution decreased by 10.5 μg m^{-3}, considering indoor air quality and changes in human activities (Shen *et al* 2021). Other studies have identified an increase in indoor air pollution and the longer time spent indoors during quarantine as major contributors to higher exposure (Gao *et al* 2020, Jiang *et al* 2020). Although this modeling study highlighted an important issue in air pollution exposure associated with indoor solid-fuel use, only a few field observations have been made so far to evaluate HH air pollution and exposure changes during quarantine.

As part of this work, a field study of HH $PM_{2.5}$ in rural homes using coal for heating in northern China was performed for about five months using low-cost sensors. The fast development of sensor-based $PM_{2.5}$ measurements has made highly temporally resolved indoor monitoring more convenient and caused less interference to residents' lives. Pollution levels and differences in exposure before, during, and after the quarantine are discussed.

2. Methods
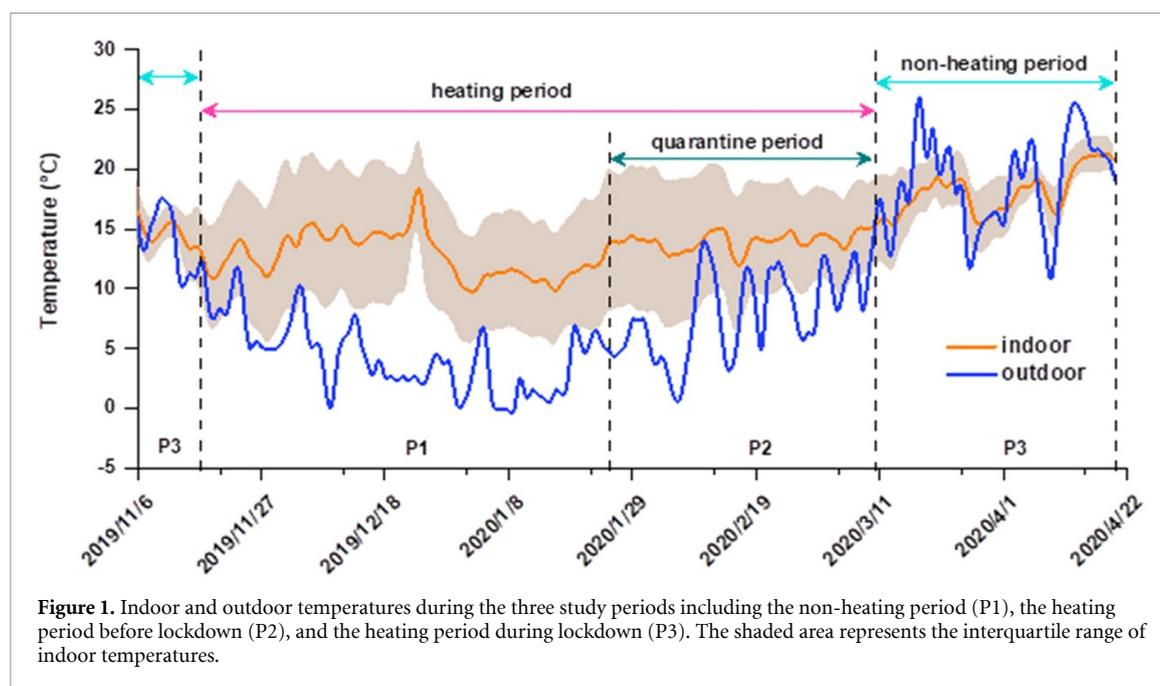
2.1. Study area and period

In-home measurements were carried out at 70 randomly selected rural HHs in a typical village (about 120 HHs) in the Hebei province of northern China. This village is located in one of China's economically strategic core regions (i.e. the Beijing-Tianjin-Hebei region) with the most severe air pollution. The Chinese government has been under enormous pressure to improve air quality in this region, and several measures have recently been put in place to deal with its air pollution issues, including the transition of HH energy away from conventional coal combustion. Most homes usually have one living room and $1 \sim 3$ bedrooms, and one kitchen using gas or electricity for cooking and a coal briquette burner for heating. Informed consent was obtained from all the HHs recruited, and a questionnaire was completed for each HH during a face-to-face interview to collect information on family size, the energy mix used for cooking and heating, smoking behavior, types and locations of the cooking and heating stoves, home cleaning activity, number of windows/doors, etc.

The entire study period lasted from 6 November 2019 to 20 April 2020. Unlike urban areas, where centralized space heating is available and the heating period usually lasts from 24 November to 10 March in the next year, rural people heat their homes using in-home heating stoves with a shorter heating duration, as a way to save costs. Figure 1 shows the average indoor and outdoor temperatures during the study period. The COVID-19 lockdown period in the study area was from 25 January 2020 to early March. The entire study period was classified into the non-heating period (Period 1), the heating period before quarantine (Period 2), and the heating period that overlapped with the lockdown (Period 3).

2.2. $PM_{2.5}$ measurements and validation

The HH $PM_{2.5}$ concentration was continuously monitored using low-cost sensors that have been successfully applied in several recent studies (Han *et al* 2015, Qi *et al* 2019, Lu *et al* 2020). The equipment includes an online particle counter (Green Built EnvMent, Beijing, China) with a laser scattering sensor (Plantower PMS3003, Beijing, China) to measure $PM_{2.5}$ concentration every 5 s and a temperature/humidity module to measure indoor temperature and moisture. The $PM_{2.5}$ sensors were calibrated against a standard $PM_{2.5}$ instrument (Model 5030 Synchronized Hybrid Ambient Realtime Particulate Monitor, SHARP, United States) before being deployed in the field. The instrument was placed at a height of 1.5 m, $1 \sim 2$ m from the heating stove, at least 50 cm from the walls, and away from windows/doors (Lu *et al* 2020).

Two sensors were placed outdoors near the HHs to measure outdoor $PM_{2.5}$. However, some data were missing because of their poor efficiency in low

Figure 1. Indoor and outdoor temperatures during the three study periods including the non-heating period (P1), the heating period before lockdown (P2), and the heating period during lockdown (P3). The shaded area represents the interquartile range of indoor temperatures.

temperatures and the unstable power supply in rural fields. Therefore, the outdoor $PM_{2.5}$ reading from the nearest local environmental monitoring station in the county ($\sim$10 km from the village) was adopted to evaluate outdoor pollution during the whole study period. On days when the outdoor sensors worked, the measured concentrations correlated well with those from the official monitoring station ($r = 0.81$, $p < 0.01$) (figure S1 (available online at stacks.iop.org/ERL/16/094020/mmedia)). Potential differences exist in the ambient $PM_{2.5}$ levels between the village and the county, causing biases in the analysis of the indoor–outdoor relationship and the overall exposure. Given the homogeneous characteristics of outdoor fine $PM_{2.5}$, the official outdoor data can be used for outdoor air pollution analysis and interpretation. The outdoor temperatures (maximum daily temperatures here) were derived from a weather forecast website (www.tianqi.com).

2.3. Exposure assessment and uncertainty

The overall exposure to $PM_{2.5}$ was calculated for male adults, female adults, male children, and female children from the $PM_{2.5}$ concentrations in different microenvironments and the time spent indoors and outdoors. The time-activity data of the population in the study area were taken from the Chinese Exposure Handbook, and the activity pattern of residents from the rural area during the lockdown was taken from Gao *et al* (2020)'s online survey of exposure parameters during the quarantine. The survey showed that the more severe the epidemic, the lower the frequency of people going out each day. The frequency data were translated into the time lengths of the outdoor stays by multiplying the average outdoor event duration by the frequency of going outdoors (Gao *et al* 2020,

Jiang *et al* 2020, Shen *et al* 2021). The contributions of the time-weighted exposures to different sources/processes during the three periods were decomposed using an adjoint analysis (see details in supplementary method and table S2).

The software SPSS Statistics 24 (IBM Corp., NY, USA) was used for descriptive statistical derivation and significance analyses at a significance level of 0.05. Monte Carlo simulations (100 000 runs) were conducted using MATLAB software (MathWorks, MA) to address the uncertainties in exposure estimation, and the results are presented in terms of changes in exposure levels with a 90% confidence interval.

3. Results and discussion

3.1. HH and ambient pollution levels

During the study period, the overall average outdoor daily $PM_{2.5}$ was 72 μg m^{-3}, ranging from 13 to 372 μg m^{-3}. There were 34% days outdoor exceeding the Chinese national standard of 75 μg m^{-3} which is also the WHO Interim Target-1 limit and compared with the WHO guideline of 25 μg m^{-3}, the exceedance was 86%. High pollution levels were observed in January 2020 (figure 2) followed by those of February 2020, with a monthly average of 133 μg m^{-3}. The average concentration during the heating period was 92 μg m^{-3}. The high outdoor pollution levels during the heating period have been examined in many past studies and attributed to increased emissions from solid fuel combustion for HH space heating, especially in rural HHs in the northern area (Liao *et al* 2017, Zhang *et al* 2017, 2021) but also associated with unfavorable meteorological conditions during the winter.
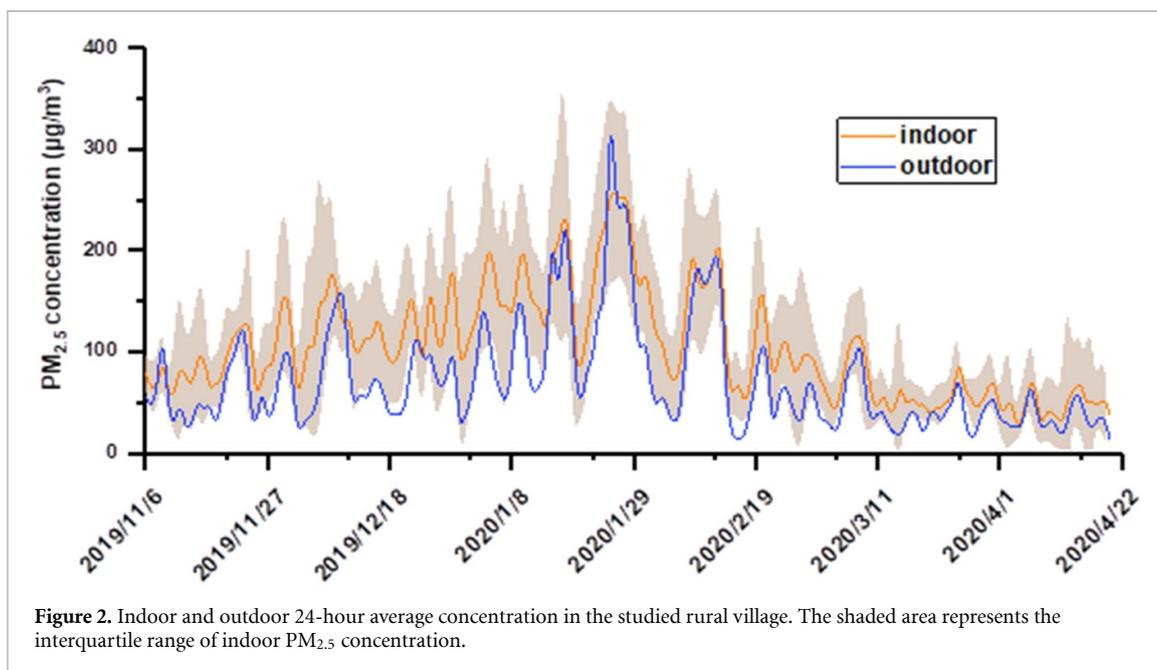
Figure 2. Indoor and outdoor 24-hour average concentration in the studied rural village. The shaded area represents the interquartile range of indoor PM$_{2.5}$ concentration.
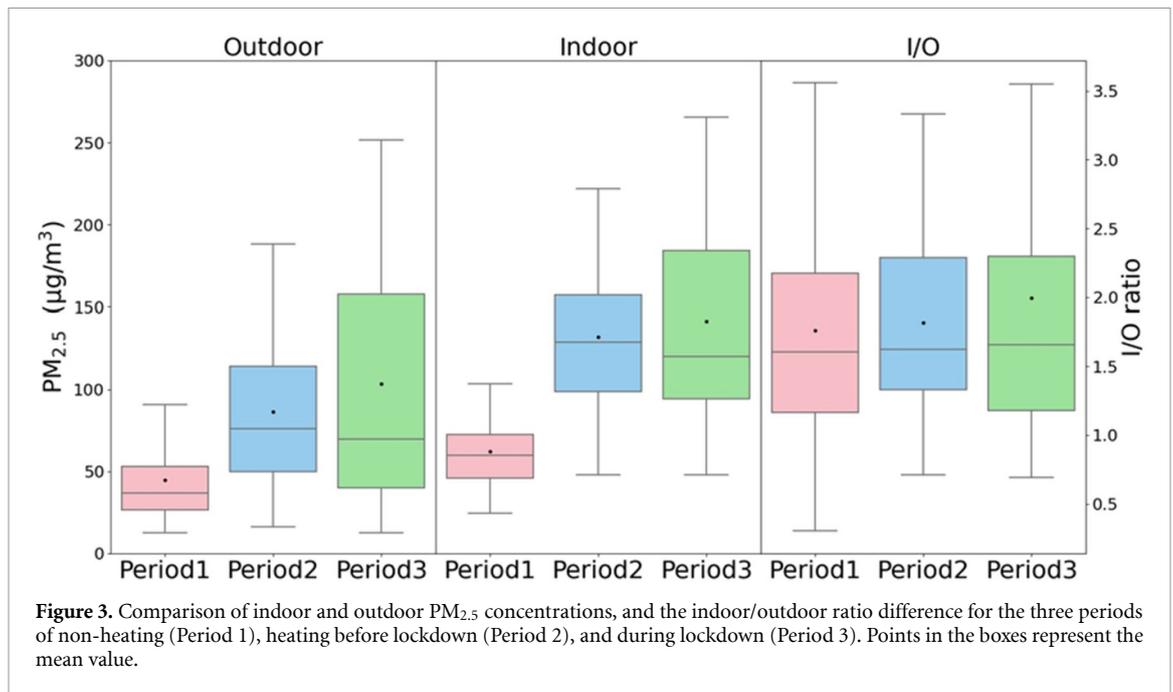
The overall mean indoor PM$_{2.5}$ concentration during the study period was 107 μg m^{-3}. Recognizing that the dose–response relationship between adverse health outcomes and the PM$_{2.5}$ pollution level does not take account of whether the exposure occurs indoors or outdoors, the ambient PM$_{2.5}$ standard is adopted in the development of indoor air quality guidelines (WHO 2014). In a comparison with the standard of 75 μg m^{-3}, on 65% of the days, indoor PM$_{2.5}$ concentrations exceeded the standard, and the exceedance rate was 99% when compared to the 25 μg m^{-3} level. High indoor air pollution was also observed in January 2020, the coldest month in northern China. Severe indoor pollution levels, as observed in this study, are associated with the re-infiltration of increased outdoor air pollution into the indoor air, and more importantly, combustion emission smoke being leaked into indoor rooms during the combustion process, which is considered to be a fugitive emission (Johnson *et al* 2011, Shen *et al* 2020, Luo *et al* 2021b). Field studies have revealed that the fugitive emission fraction of PM$_{2.5}$ from indoor biomass burning can be as high as 25% (Shen *et al* 2020). In this study, a moderately positive relationship ($r = 0.45$, $p < 0.01$) between the indoor–outdoor temperature difference and the indoor–outdoor PM$_{2.5}$ difference indicated that increased fuel consumption was required to warm the HH in cold periods, consequently resulting in higher increments in the indoor PM$_{2.5}$.

Indoor PM$_{2.5}$ levels were significantly higher than the outdoor pollution ($p < 0.01$), and the difference between the kitchen and the living room was not statistically significant. However, the living room PM$_{2.5}$ had much larger ranges and higher variations compared to that in the kitchen, even though, statistically, the difference between the kitchen and living room was insignificant. Some residents went outdoors for field work or visited neighbors, resulting in some being in the living room and some, but not all and not always, smoked in the living room, as indicated from the results of the face-to-face HH interview. This resulted in much more variability in the living room PM$_{2.5}$.

The daily indoor PM$_{2.5}$ concentration varied greatly among different HHs. The coefficient of variation (CV) in the indoor PM$_{2.5}$ concentration on different days was relatively higher during the non-heating season (58% on average) than the CV during the heating season (46%). This was because a major source of indoor air pollution during the heating season was indoor coal combustion for space heating, although it varied between different homes. However, during the non-heating seasons, indoor pollution levels were influenced by a variety of internal sources, such as cooking activities, smoking, and HH cleaning, which did not predominantly affect indoor air pollution in the same way as the heating process. Therefore, larger variations were noted in indoor PM$_{2.5}$ concentrations from different homes during the non-heating season.

The PM$_{2.5}$ level follows a log-normal distribution, rather than a normal distribution. Therefore, although arithmetic means are often reported and compared in the literature, geometric means are preferable to characterize data with a log-normal distribution. The geometric mean of the outdoor PM$_{2.5}$ during the study period was 57 μg m^{-3}, and for the indoor PM$_{2.5}$, the geometric mean was 97 μg m^{-3}. The variability in indoor PM$_{2.5}$ across different days, as indicated by the CV value, was 51% and was lower than the outdoor value, which was about 80%.

Figure 3. Comparison of indoor and outdoor PM$_{2.5}$ concentrations, and the indoor/outdoor ratio difference for the three periods of non-heating (Period 1), heating before lockdown (Period 2), and during lockdown (Period 3). Points in the boxes represent the mean value.

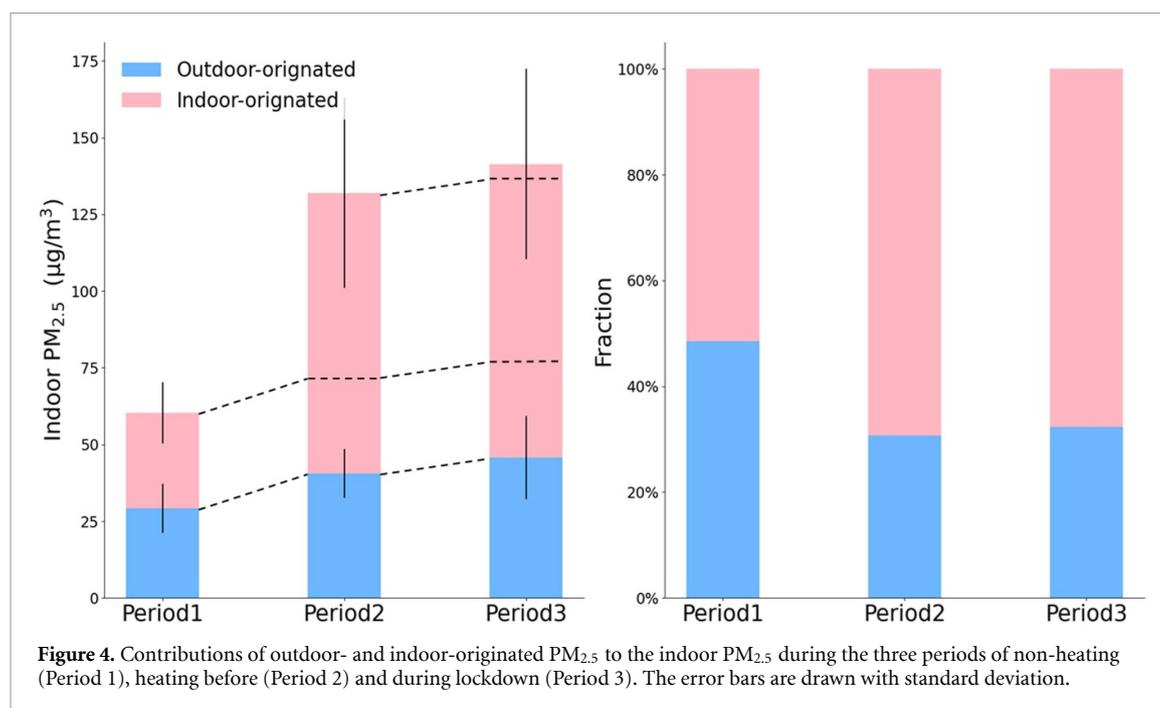### 3.2. PM$_{2.5}$ difference across different periods

As mentioned above, the entire study period is classified into three periods. The period-averaged indoor and outdoor concentrations for these three periods are compared in figure 3. The lowest outdoor PM$_{2.5}$ levels, with a statistical significance of $p < 0.05$, were, as expected, found in Period 3, which was a non-heating period in the study area. The period average concentration was 45 ± 27 μg m^{-3}, which was about half of the concentrations in heating Period 2 (86.3 ± 49.1 μg m^{-3}) and Period 3 (104 ± 85 μg m^{-3}). The outdoor temperature during Period 1 was 16.5 ± 5.3 °C, which was much higher than the outdoor temperatures of 4.1 ± 3.2 and 7.0 ± 3.9 °C during Period 2 and Period 3, respectively ($p < 0.05$).

The outdoor PM$_{2.5}$ pollution in lockdown Period 3 was higher than that in Period 2 before lockdown. During the quarantine, although the lockdown reduced the emissions from vehicles and some industrial factories, resulting in a significant decline in NOx, emissions from sources such as power plants and residential sectors were not simultaneously reduced and some even possibly increased because of heating demands and unfavorable meteorological conditions in north China (Le *et al* 2020, Marlier *et al* 2020, Wang *et al* 2020, Zhao *et al* 2020). The impacts and relative contributions of emission changes and meteorological variations were site- and time-dependent. By comparing the air pollution status one week before and one week after the activation of the first-level public health emergency response, it was estimated that 80% of the Chinese cities had lower PM$_{2.5}$ levels shortly after the lockdown, which largely rebounded due to meteorological impacts (Zhao *et al* 2020). Huang *et al* (2021)

estimated provincial emission changes during the lockdown and using comprehensive measurements and modeling found that enhanced secondary formation offset emission reductions, resulting in haze formation during the lockdown. Le *et al* (2020) highlighted that, by contrast to those in southern and central China, ambient PM$_{2.5}$ levels in northern China increased substantially during the COVID-19 outbreak and explained the unexpected high pollution by stagnant airflow, uninterrupted emissions from sources such as power plants and petrochemical facilities, and high humidity that promoted aerosol heterogeneous chemistry.

The indoor PM$_{2.5}$ levels were also lower during the non-heating Period 1 (62 ± 22 μg m^{-3}), compared to the indoor levels during heating Periods 2 and 3 ($p < 0.01$). While indoor temperatures during Period 1 (17.0 ± 2.5 °C) were close to those outdoors (16.5 ± 5.3 °C), the indoor temperatures during the heating period (12.4 ± 1.6 °C and 13.6 ± 1.1 °C before lockdown (Period 2) and under lockdown (Period 3)) were significantly higher than those outdoors (4.1 ± 3.2 and 7.0 ± 3.9 °C during Periods 2 and 3). Thus, the relatively lower indoor levels during the non-heating period were attributed to lower outdoor pollution levels and significant reductions in indoor-originated pollution, as indoor coal combustion for space heating was absent. The outdoor-originated PM$_{2.5}$ accounted for up to nearly half of the indoor PM$_{2.5}$ during the non-heating period, while during the heating period, the outdoor-originated PM$_{2.5}$ comprised much less, at $\sim$30% (figure 4).

Relatively higher indoor PM$_{2.5}$ levels were found during quarantine (Period 3, 142 ± 63 μg m^{-3}) than before quarantine (Period 2, 132 ± 44 μg m^{-3}) ($p < 0.05$, figure 4). As mentioned above, the outdoor

Figure 4. Contributions of outdoor- and indoor-originated $PM_{2.5}$ to the indoor $PM_{2.5}$ during the three periods of non-heating (Period 1), heating before (Period 2) and during lockdown (Period 3). The error bars are drawn with standard deviation.

$PM_{2.5}$ was also higher in Period 3 (104 ± 85 μg m^{-3}) than in Period 2 (86 ± 49 μg m^{-3}), which was explained by the unfavorable meteorological impacts, insignificant emission changes from primary sources except for transportation and some industries, and enhanced atmospheric reactions contributing to secondary aerosols (Le *et al* 2020, Zhao *et al* 2020, Huang *et al* 2021). The higher outdoor $PM_{2.5}$ in Period 3 led to higher outdoor-originated indoor $PM_{2.5}$. Additionally, during quarantine, the increased number of residents staying at home produced more indoor-originated pollutants from sources such as fuel combustion and smoking. After subtracting the outdoor-originated $PM_{2.5}$ (Shi *et al* 2017, Hu *et al* 2020), the indoor-originated $PM_{2.5}$ levels during the non-heating Period 1, the heating period before lockdown (Period 2), and the heating period during lockdown (Period 3) were 31 ± 25, 92 ± 31, and 96 ± 32 μg m^{-3}, respectively (figure 5). Thus, the burning of coal for space heating increased the indoor $PM_{2.5}$ level by $\sim$60 μg m^{-3} in the rural HHs ($p < 0.05$), and the overlap of lockdown with the Spring Festival holiday additionally increased the indoor $PM_{2.5}$ by $\sim$4 μg m^{-3}. The HH fuel consumption is positively correlated with the number of family members (Chen *et al* 2016, Luo *et al* 2021a). When residents returned to their hometowns for the holiday before the lockdown, they were restricted to staying at home, which resulted in increased fuel consumption for space heating. A recent study in rural Hunan, southern China (Du *et al* 2021), showed that daily $PM_{2.5}$ concentrations in the kitchen and living room during the Spring Festival were 180 ± 97 and 150 ± 82 μg m^{-3} and were significantly higher than their levels before the Spring Festival ($p < 0.05$).

3.3. Exposure estimates and quarantine impacts

The time-weighted exposure level during the non-heating Period 1 was 59 ± 6 μg m^{-3}. Since the indoor pollution level was higher than that outdoors, and people spent more time indoors, the indoor exposure dominated the overall exposure, contributing to about 86% of the total exposure. Several previous studies of homes using solid fuels also confirmed the high contribution of indoor exposure to the total exposure (Li *et al* 2016, Huang *et al* 2017). As part of the indoor $PM_{2.5}$ was from outdoors, the contribution of indoor-originated pollution comprised about 46% of the total exposure (figure 6).

During the heating period, increased outdoor air pollution, increased indoor air pollution, and longer times spent indoors (Gao *et al* 2020) resulted in significant increases in the time-weighted daily exposure. The estimated daily exposure levels during the heating period before lockdown (Period 2) and under lockdown (Period 3) were 127 ± 14 and 140 ± 16 μg m^{-3}, respectively (figure 6). As people spent less time outdoors, the relative contribution of outdoor exposure during the heating period decreased by 8% compared with that during the non-heating period. Because windows were closed during the cold season, lower air exchange rates resulted in less infiltration of outdoor air pollution, consequently leading to a decreased outdoor-originated contribution to indoor $PM_{2.5}$ exposure. However, the contribution of indoor exposure to $PM_{2.5}$ from internal source emissions increased, and two-thirds of the indoor exposure to internal emissions was attributed to coal combustion in heating stoves.
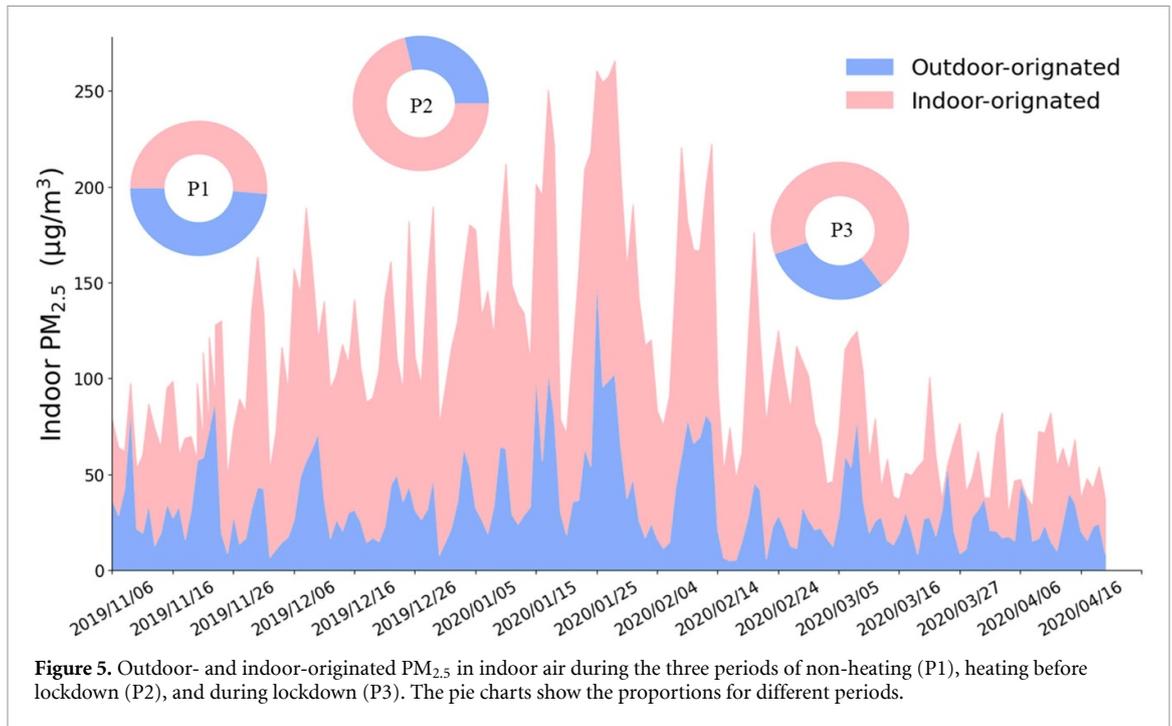
Figure 5. Outdoor- and indoor-originated PM$_{2.5}$ in indoor air during the three periods of non-heating (P1), heating before lockdown (P2), and during lockdown (P3). The pie charts show the proportions for different periods.
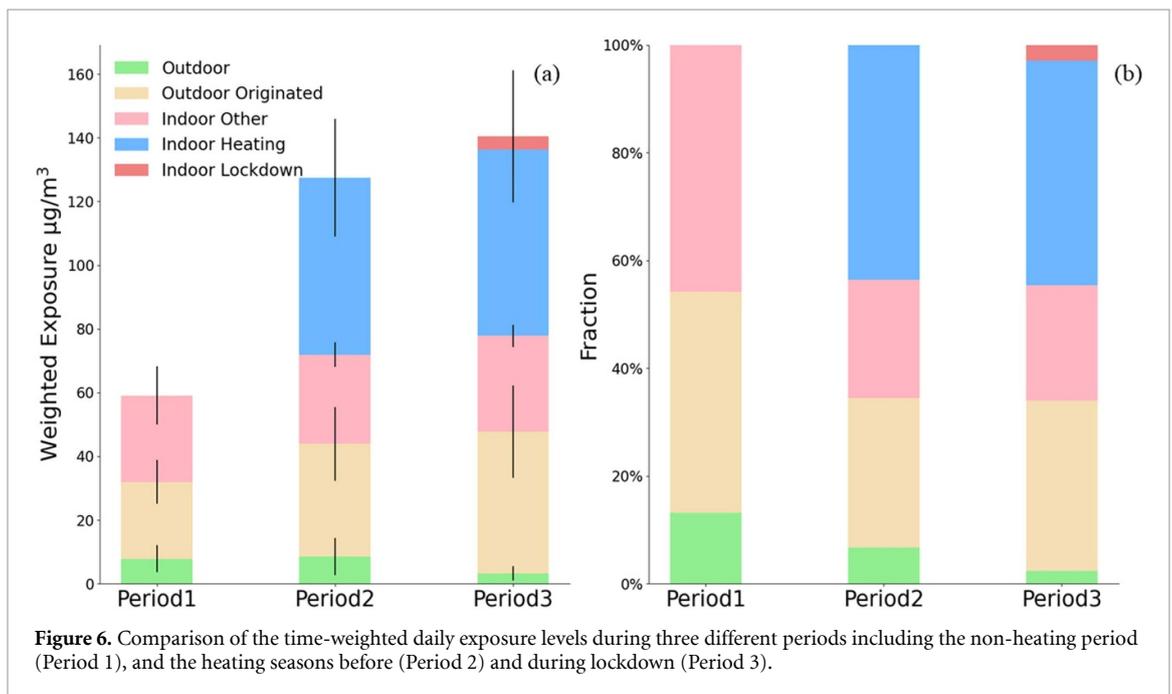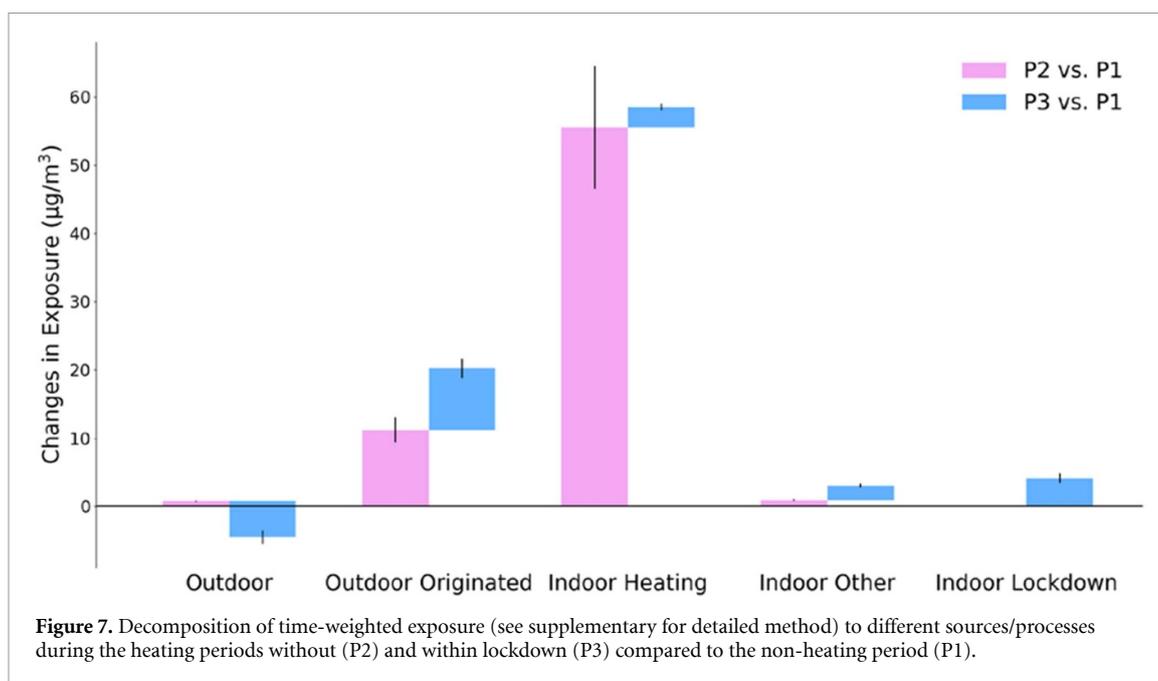

Figure 6. Comparison of the time-weighted daily exposure levels during three different periods including the non-heating period (Period 1), and the heating seasons before (Period 2) and during lockdown (Period 3).

In comparison with the difference in the time-weighted daily exposure outside/within the lockdown (figure 7), although the outdoor PM$_{2.5}$ concentration during the lockdown heating Period 3 was higher than that during heating Period 2 outside lockdown (figure 3), because of the smaller amount of time spent outdoors, the outdoor exposure was smaller during Period3 (3 μg m^{-3}) than that in Period 2 (9 μg m^{-3}). Although the increase in outdoor-originated PM$_{2.5}$ indoors from higher outdoor PM$_{2.5}$ pollution was partly offset by a smaller infiltration fraction from the reduced frequency and short duration of window opening during the COVID-19

outbreak (Gao *et al* 2020), exposure to outdoor-originated indoor PM$_{2.5}$ increased during Period 3, compared with that in Period 2 because of the longer times spent indoors. With more people staying at home in Period 3, as shown by the face-to-face survey, the indoor PM$_{2.5}$ concentration associated with internal sources increased by 4 μg m^{-3} compared to that in Period 2, resulting in an incremental increase in exposure of 4 μg m^{-3}. The overall exposure to PM$_{2.5}$ in Period 3 increased by 13 μg m^{-3} compared to that in Period 2, due to the net impact of a 5 μg m^{-3} decrease in outdoor exposure and an 18 μg m^{-3} increase in indoor exposure, where

Figure 7. Decomposition of time-weighted exposure (see supplementary for detailed method) to different sources/processes during the heating periods without (P2) and within lockdown (P3) compared to the non-heating period (P1).

the latter included 9, 5, and 4 μg m^{-3} increases in the outdoor-originated exposure, exposures from internal sources outside lockdown, and increments due to the quarantine, respectively. A previous modeling study (Shen *et al* 2021) estimated that, on a national scale, despite a decrease of 10.5 μg m^{-3} in the outdoor air, the overall exposure increased by about 5.7 μg m^{-3}. The absolute values of concentration and exposure should not be compared, since there were extremely high variations in both indoor and outdoor pollution levels across the country during different periods, but both studies consistently identified that during the quarantine, the overall exposure increased, largely due to increased indoor $PM_{2.5}$ from internal sources, in particular, solid fuel combustion processes, and longer time spent indoors.

4. Conclusions

The overall exposure to air pollution depends on the outdoor air, the indoor air, and human activities. HH air pollution associated with solid fuels is a leading environmental risk factor in human health, causing millions of premature deaths globally, and the issue is more severe in developing countries. In early 2020, the outbreak of COVID-19 significantly affected the world. Although ambient air pollution was reduced during quarantine, there were potential increases in HH energy consumption as more people spent longer time indoors, resulting in increased household air pollution and higher exposure. While previous modeling work studied this issue on a national scale, this field study of rural HH $PM_{2.5}$ from homes burning coal revealed that indoor $PM_{2.5}$ from internal sources increased during quarantine, and consequently led to an increase in overall exposure, since people

stayed indoors for longer. Higher exposure to HH air pollution for the rural population increased potential health risks, and during the outbreak of COVID-19 this further deepened the environmental inequality linked with disparities in socioeconomic status, which should receive more attention in future research and pollution control measures.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

Competing financial interest

The authors declare no competing financial interest.

Appendix

Materials including the detailed calculation methods and the correlation of ambient $PM_{2.5}$ between the outdoor sensors and the nearest official monitoring station are provided and available via the internet.

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