Indoor and outdoor exposure to $PM_{2.5}$ during COVID-19 lockdown in suburban Malaysia

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During the COVID-19 pandemic, key policies aimed at reducing exposure to the virus from social distancing, restrictions on travel through to strongly enforced lockdowns. However, COVID-19 restrictions required people to spend more time at home so the exposure to air pollutants shifted to being derived from that of domestic interiors, rather than outdoors or the workplace environment. This study aims to characterise the influence of lockdown intervention on the balance of indoor and outdoor $PM_{2.5}$ exposure in a Malaysian suburb. We also calculate the potential health risk from exposure to both indoor and outdoor $PM_{2.5}$ to give context to personal exposure assessment in different microenvironments during the COVID-19 lockdown, known locally as *Movement Control Orders (MCO)*. The implementation of the MCOs slightly reduced daily average of outdoor $PM_{2.5}$ concentrations (median of 12.63 $\mu g\ m^{-3}$ before and 11.72 $\mu g\ m^{-3}$). In the Malaysian apartment considered here, cooking led to a substantial increase in exposure from increasing concentrations in $PM_{2.5}$ during a COVID-19 lockdown (maximum average concentration at 52.2 $\mu g\ m^{-3}$). The estimated excess risk to health was about 25% for lung cancer from staying indoor. Thus, there seems a potential for greater exposure to fine particles indoors under lockdown, so it is likely premature to suggest that more lives were saved through a reduction of outdoor pollutants than lost in the pandemic. Unfortunately, little is known about the toxicity of indoor particles and the types of exposures that result where people increase the amount of time they spend working from home or staying indoors, especially during periods of lockdown.

Keywords: Cancer, Cardio-respiratory diseases; Cooking; Indoor air quality; Lockdown

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INTRODUCTION

During the COVID-19 pandemic lower concentrations of ambient air pollutants were observed at many areas of the world due to widespread restrictions on travel, social activities and work. People spent much of their lives indoors, which further shifted human exposure to pollutants during periods of restricted activity. The pandemic infections were caused by a zoonotic virus of the SARS-CoV and MERS-CoV families (Mackenzie and Smith, 2020) first reported in Wuhan, China (Zhu et al., 2020). The COVID-19 crisis affected some six and a half million people worldwide with an 11% mortality rate through the first six months of 2020 (WHO, 2020). In the effort to prevent further outbreak, governments around the globe implemented restrictive measures as part of the COVID-19 containment.

Imposed changes to human activity led to a reduction in pollutant emissions, which was unprecedented on such a wide geographic scale. This provided a unique opportunity for researchers to assess the effect of the changes on air quality as measured from data monitored from satellite to ground measurements (Dutheil et al., 2020; Wang and Su, 2020; Xu et al. 2020; Yue et al., 2020; Sharma et al., 2020; Abdullah et al., 2020; Tobías et al., 2020; Muhammad, et al., 2020; Dantas et al., 2020; Nakada and Urban, 2020; Chauhan and Singh, 2020). Prior to the COVID-19 pandemic, transportation and the industrial sector were large and often growing sources of air pollution. The reduction of these sources during lockdown frequently improved air quality, with a notable decrease in NO_2 concentrations, although there have been increases in ozone concentrations e.g. across Northern China surface O_3 concentrations rose during the epidemic (Huang et al., 2020; Shi and Brasseur, 2020), with large increases in urban Beijing and Wuhan and more modest changes in Shanghai and Guangzhou (Zhao et al., 2020).

The strict lockdown in China limited human mobility, suspending intra city transport and closed factories. The air quality index improved 7.8% (Bao and Zhang, 2020), with the $PM_{2.5}$

concentration reduced by >30 μg m^{-3} in Wuhan (Wang et al., 2020), although SO_2 and CO were not greatly reduced during the COVID-19 lockdown as goods transport, coal-fired power plants and domestic heating were still needed in China. Overall these reductions may have been more subtle than often proposed in the media (Brimblecombe and Lai, 2020a; Cole et al. 2020; Silver, 2020), but they may have shifted the weekly and diurnal pattern of pollutants (Brimblecombe and Lai, 2020b). During lockdown in Malaysia there were decreases in concentrations of particulate matter in many locations, although there was evidence of illegal local biomass burning activities by individuals and private companies (Abdullah et al. 2020; Kanniah et al. 2020; Mohd Nadzir et al., 2020). Elsewhere increased outdoor burning activities of garden and household waste during lockdown in London came as people used the period at home to do spring cleaning (LFC, 2020). Increases in particulate matter may also come about through the production of secondary aerosol which arises from increased ozone and NO_3 radical formation at night when NO_2 concentrations were low (Huang et al., 2020a).

An initial study by Chen et al. (2020) found the reduction of $PM_{2.5}$ during this period can lead to a 73% reduction in mortality risk from $PM_{2.5}$ related deaths, but others said the pollution was not avoided (Wang et al., 2020). It is even suggested that health benefits related to cardiopulmonary disease can outweigh COVID-19 mortality under lockdown. Another health co-benefit from the 20% drop of air pollution levels is reduced asthma cases and risk of premature death (Venter et al., 2020). However, personal exposure to air pollution was quite different under the restrictions imposed to control COVID-19, as this often-involved urban populations spending almost all of their time indoors (Abouleish, 2020). Exposure in such microenvironments during COVID-19 have gone largely unreported, despite the enormous changes it imposed on daily lives. The preoccupation with outdoor air pollution (Huang et al., 2020b) may have distorted our views of how exposure might have changed. This is an especially distinct period when people spent so little time outdoors. A proper assessment of personal exposure during lockdown should account for the heterogeneity of relevant microenvironments, the number of occupants, housing conditions, activities and lifestyle in the indoor settings. All these are likely to influence both exposure to indoor and outdoor pollutants that resulted from stay-at-home policies mandated under COVID-19. Indoor outdoor ratios of $PM_{2.5}$ are often greater than unity in residential settings (Cao et al., 2005; Huang et al., 2007) and Thakur et al. (2020) have raised concern over increased rate of cooking and smoking activities, with particles in the kitchen potentially rather toxic with respect to their oxidative capacity (Shao et al., 2007).

Health may be of special consent among vulnerable groups such as pregnant women, children, the elderly and people with underlying respiratory disease and immunodeficiency. In crowded interiors where the range of daily activity is much restricted there was likely more cooking, household repairs and hobbies, so indoor air quality was likely more relevant to health during COVID-19 restrictions than normal. Additionally, there are other, perhaps more serious health problems under lockdown: lack of access to medical support, mental illness from isolation (Venkatesh and Edirappuli, 2020), increased alcohol consumption (Clay and Parker, 2020), domestic violence (Malathesh et al., 2020) etc.

This study reports $PM_{2.5}$ concentrations measured outdoors and indoors at an apartment building in suburban Malaysia, with those retrieved from a nearby campus mini monitoring station and an official fixed monitoring site. After more than 1000 confirmed positive cases in Malaysia, Movement Control Orders (MCOs) were introduced in mid-March. Such lockdowns offer an appealing opportunity for experimental studies of air pollution, and can provide a causal understanding relevant to improved air quality in line with studies of pollution reduction during the 2008 Beijing Olympics (Wang et al., 2010; He et al., 2016), street protests in Hong Kong (Brimblecombe and Ning, 2015; Brimblecombe, 2020) and driving restrictions in Tianjin and

Beijing (Zhang et al., 2020). This study aims to characterise the influence of MCO intervention on the balance of indoor and outdoor $PM_{2.5}$ exposure and likely potential changes in the risk to health, through increased times spent indoors under the lockdown restrictions.

METHODS

Study Period

Movement control in Malaysia was initially imposed from 18th March 2020 under the Prevention and Control of Infectious Diseases Act 1988 and the Police Act 1967 (MKN, 2020). Table 1 shows the different phases of MCO introduced by the Malaysian government in the fight to reduce COVID-19 infections. During the first phases of the MCOs (MCO1-MCO3), all Malaysians were advised to stay at home, maintain social distancing and stay within 10 km of their residential area when obtaining groceries or medication. Control was relaxed following advice by the Ministry of Health on 4th of May 2020, after the number of daily cases and active cases of COVID-19 declined. We compare $PM_{2.5}$ concentrations retrieved before MCO imposition (n<MCO=38 days) and after MCO periods that ran from MCO1 through to MCO5 (nMCO1-5=51 days) measured at the outdoor campus monitoring equipment (UPM) and the site at Putrajaya. These are compared with the separate set of measurements made as part of the indoor-outdoor apartment monitoring between MCO3 and MCO5 from 09:00 to 19:00 (n=13 days).

Study Area

The sampling sites in this study were (i) a mini monitoring platform in a university campus, (ii) an official measurement site of the Malaysia Department of Environment and (iii) inside and outside at an apartment located in suburban areas of Selangor, a state in the central region of Peninsular Malaysia (Fig. 1). Selangor covers an area of 7957 km^2 and has a population of over 6.3 million. It consists of residential neighbourhoods and is home to a number of universities. The university campus of Universiti Putra Malaysia is ~28 km southeast from the centre of Kuala Lumpur (Fig.1). The main outdoor sources of $PM_{2.5}$ at the UPM site is traffic on campus roads and nearby residential areas (~500 m distant). The apartment is located 11 km southwest from the campus and approximately 2 km from the highway. Our campus observations were made between February (before MCO) through May 2020 (during MCO), which spans the inter-monsoons from April to May in Malaysia.

Ambient Measurements

Ambient particulate matter measurements from the campus are taken over 85 days; before (9 February-17 March 2020) and during (18 March-7 May 2020) the implementation of partial lockdown MCOs. This mini monitoring station was installed and managed by Enviro ExcelTech Sdn Bhd. We retrieved $PM_{2.5}$ data from the Aeroqual AQY-1 (Aeroqual, Auckland NZ), which is equipped with particulate ($PM_{2.5}$), gaseous (NO_2 and O_3), external temperature and humidity sensors. This $PM_{2.5}$ light-scattering optical particle sensor with RH correction ranges between 0 to 1000 $\mu g\ m^{-3}$ and uses wireless technology to communicate its readings. The AQY-1 was housed in a sampling enclosure, mounted on a poll at 2-metre height with power supply via solar panels, with back up electricity and provides minute-by-minute $PM_{2.5}$ measurements. The AQY-1 has shown very good agreement (Karagulian *et al.*, 2019) with a reference system ($R > 0.85$; $0.8 < \text{slope} < 1.2$). The values for Putrajaya come from a government monitoring site, which is located approximately 14 km from the campus site. $PM_{2.5}$ measurements were made using the Thermo Scientific TEOM 1405-DF, under maintenance by a private company, Transwater Sdn Bhd, which have been granted a 15 year concession to operate the site.

Apartment Measurements

The concentrations of $PM_{2.5}$ at the apartment building were measured using two units of TSI DustTrak II (Model 8532, TSI Inc., Shoreview, MN) and logged at a 1-minute time resolution. These light-scattering laser photometers were calibrated and validated by the manufacturer. The monitors were placed at the kitchen (indoor) and near the window (outdoor) in a vacant bedroom. Indoor and outdoor measurements were made simultaneously on 12 days during MCO3 (22 April-28 April 2020), MCO4 (1 May-3 May 2020) to MCO5 (4 May-7 May 2020) from 09:00 to 19:00 (total sampling time 84 h). The newly constructed apartment unit covers an area of 787 square feet (i.e. 73 m^2) and was built four years ago. The kitchen is equipped with a natural gas stove, hood exhaust duct and located within an open floor plan near the living area. All windows were opened in both kitchen and bedroom areas to maintain smooth air supply from outdoor and simulate normal conditions for a house in Malaysia where most use natural ventilation, although during cooking a fan with 1310 $m^3 h^{-1}$ suction could reduce the pollutant concentrations, as this flow would mean an air change rate 5 h^{-1} for the entire apartment (242 m^3).

Traffic Data

Daily traffic flow data were obtained from the exit toll stations near the UPM campus. The toll data was captured by site-based traffic sensors installed at each toll plaza and operated by the highway toll concessionaire or build-operate-transfer operator company, PLUS Malaysia Berhad.

Estimation of Health Outcomes

The relative risk (*RR*) is derived from the concentration of $PM_{2.5}$ measured at the campus and Putrajaya monitoring site and from the indoor apartment measurements and then applied to make the epidemiology-based excess risk (*ER*) calculations as shown in Eq. 2 (Kumar *et al.* 2020). The annual WHO standard of 10 μg m^{-3} is used for the baseline $PM_{2.5}$ concentrations.

$$RR = \exp [\beta(C-Co)],\ C>Co \qquad (1)$$

$$ER = RR - 1 \qquad (2)$$

where *ß*, the exposure-response coefficient was adopted from a linear dose response relationship used to estimate the health burden from acute respiratory diseases (age < 5), cardio-respiratory diseases (age > 30) and lung cancer (age > 30) as given by Ostro (2004) and Kwan *et al.* (2017). Here *C* is the average concentration that is measured from the site and *C*o is the WHO threshold concentrations for $PM_{2.5}$.

RESULTS AND DISCUSSION

Ambient $PM_{2.5}$ before and during MCO

The daily change in ambient $PM_{2.5}$ concentrations are shown in Fig. 2a, which depicts the daily average $PM_{2.5}$ concentrations before MCO (9 February-17 March 2020) and during MCO (18 March-7 May 2020). The implementation of the MCOs slightly reduced daily average $PM_{2.5}$ concentrations at UPM, which had a median of 12.63 µg m^{-3} before and 11.72 µg m^{-3} under the MCOs (significant in Mann-Whitney test: U=1237; p_1~0.013), while for Putrajaya the differences were less distinctive 17.39 µg m^{-3} before and 16.25 µg m^{-3} during (Mann-Whitney test: U=1107; p_1~0.13). With the exception of the first day of the record, the average concentrations of $PM_{2.5}$ did not exceed the standard of daily 24-h $PM_{2.5}$ of *The New Malaysia Ambient Air Quality Standard* of 35 µg m^{-3}, and the more stringent limit of *WHO Air Quality Guideline* of 25 µg m^{-3}. Similarly, Ash'aari *et al*. (2020) observed the reduction of $PM_{2.5}$ at the sub-urban areas and did not exceed the guidelines during the different phases of MCO lockdown. A study by Kanniah *et al*. (2020) also revealed that $PM_{2.5}$ was higher than the guidelines in 2019 compared with those in 2020 between March and April. The reduction of transport, and closure of educational institutions, government, and private agencies is generally believed to have caused the lowered $PM_{2.5}$

concentrations during movement control (Mohd Nadzir *et al.*, 2020), although during the early part of lockdown pollutant concentrations were not greatly reduced (Abdullah *et al*., 2020).

Decreased pollutant concentrations gain support from recorded traffic flow at the UPM road exit displayed over the period 9 February to 7 May 2020 (Fig. 2b) as it suggests that after lockdown traffic flows decreased rapidly and at least in terms of use of major highways citizens were compliant, and rapidly adapted to the new regime, despite widely held views that many took a long time to follow the regulation (Lim, 2020; Yusof, 2020). Even as lockdown, ended the return to normal was rather slow and as late as the end of June traffic was some 10% lower than before the MCOs had been imposed. Again, the media drew attention to rapid increases in traffic flow after the MCOs ended after May 3rd (TheStar, 2020), although there was a rise, it was clearly to nothing like the level typical before COVID-19. The dramatic changes in traffic flow are not well mirrored by the changes in $PM_{2.5}$. This reminds us that there are many sources of pollution apart from highway traffic, and of course changing weather undoubtedly affected the concentrations during the MCOs. For example, high relative humidity levels were recorded during the MCO that may related to the rain events that can reduce $PM_{2.5}$ (Ash'aari *et al*. 2020). Any meteorological parameters do not influence the $PM_{2.5}$ levels before MCO.

Superficially the end of lockdown (MCO4 and MCO5) looks to have the lowest concentrations of $PM_{2.5}$, despite the gradual increase in traffic, although the very last days of MCO5 showed increases in concentrations, though still less than 20 μg m^{-3}. An ANOVA test revealed little difference in concentration between the various MCO periods. There were slightly higher concentrations, though statistically non-significant, during the weekends during the MCOs. This is rather the reverse of the normal situations where weekends typically have lower $PM_{2.5}$ concentrations. Such an outcome would be expected from lower weekend activity, such as the traffic flow illustrated by Fig. 2b, where the pairs of weekend days show lower flows across the entire period, and there is no particular increase in traffic flow at the UPM exit due to people undertaking weekend shopping. It is possible that shopping under the MCOs was very localized, but this in itself would have in effect reduced the total burden of emissions. It should be noted that a wide variety of sources other than traffic exhaust may also contribute to the reduction of $PM_{2.5}$ including local biomass-burning activities. Ash'aari *et al*. (2020) suggest that the decreased level of $PM_{2.5}$ began during MCO4 due to reduction of fire emissions monitored from MODIS-derived hotspots and fire locations in Malaysia.

Indoor-outdoor Measurements of $PM_{2.5}$ in the Apartment

The $PM_{2.5}$ concentrations measured in the kitchen (indoor) and window (outdoor) during MCO3-MCO5, between 22 April until 8 May (n =13 days), are shown as points in Fig. 3. The amount of $PM_{2.5}$ steadily increased during the afternoons and constantly higher in the kitchen compared to the vacant room. Accounting for a typical daily meal preparation, the average modern adult spends over 10% of his or her during the day on a daily basis in the kitchen which may include eating and cleaning up from meals (Marć *et al*., 2018). However, considering the lower frequency of cooking before the lockdown for one person living in the apartment, the addition of extra cooking time each day during lockdown (approximately 20% of the day during meal preparation on food preparation, cooking, and cleaning) may represent an important source of indoor particles, and multiple exposures if the whole family is home. The distribution of $PM_{2.5}$ was higher during lunch time and gradually increased during preparation of the evening meal. It is noted that most cooking styles involved pan-frying and stir-frying for evening meal preparation, therefore showing a distinctive high peak between 17:30 to 18:30. Elevated concentrations were especially noted during MCO where a maximum concentration was observed in the evening at 52.2 $\mu g\ m^{-3}$. Other cooking activities using the kitchen during the MCO involved boiling egg and chicken and baking.

The usage of gas stove either propane or natural gas has been suggested to contribute to the airborne particles related to the cooking method. The process of coagulation, condensation and evaporation will take place during cooking and influence the temporal variability in emissions (Huboyo *et al*., 2011). The emissions from cooking activities would be higher when the majority of people stayed at home the whole day so they may have been exposed to increased indoor air pollutants during the lockdown. Wan *et al*. (2011) have established the extent to which the average indoor particles of $PM_{2.5}$ and ultrafine concentrations were found higher than the background level in the living room. The dispersion of particles from the kitchen to the living room indicates that the health impact is not limited to occupants in the kitchen. In their study, the particulate emissions were found to disperse rapidly through the apartment and the particle number concentration can remain elevated for up to 90 minutes and as much as an hour in adjacent spaces after cooking in the kitchen. The average indoor-outdoor (I/O) ratio also shows consistently higher than 1 in our study. This may give indication on the elevation of indoor particles compared to outdoor. Other sources of indoor particles during stay at home are household dust, smoke from candles and cigarettes (DEFRA, 2020).

Exposure to $PM_{2.5}$ and Risk

The average excess risk (ER) is shown in Fig. 4 where, ER (%) of the health burden from acute respiratory diseases (age < 5), cardio-respiratory diseases (age > 30) and lung cancer (age > 30) estimated from average $PM_{2.5}$ concentrations measured at indoor apartment, UPM (campus) and Putrajaya monitoring station during the lockdown under the MCOs. Estimated health burden before the MCO lockdown from UPM and Putrajaya measurements are also shown. Greater reduction in ER during lockdown as compared before lockdown is observed at UPM (3.4%) and Putrajaya (2.5%) for adult lung cancer risk compared to acute respiratory infection among children. These results demonstrate that a lower excess risk was obtained during lockdown MCOs for long-term positive health impact. Children below than 5 years old living within UPM and Putrajaya is more likely to present acute health effects than in a group that is exposed to outdoor concentration of 10 $\mu g/m^3$, but people were of course indoors over the period of lockdown. Recent estimates by Giani *et al*. (2020) found that 10, 000 of premature deaths from air pollution exposure were avoided in China and Europe due to the reduction of $PM_{2.5}$ during lockdown interventions. Other study that investigated the health and economic impact of lockdown across a few cities in India also found health and economic co-benefit due to lockdown across five Indian cities with decrease 30 to 50% in ER and avoided 630 premature deaths that cost 0.69 billion USD (Kumar *et al*. 2020).

Excess risk to health is found highest for lung cancer estimation when staying indoor (25.8%) during lockdown. This suggested that an individual in a group living in the indoor environment that is exposed to the corresponding $PM_{2.5}$ concentration will encounter a raised health risk for mortality from lung cancer. It is important to note that the excess risk for cardiorespiratory mortality is also higher for indoor $PM_{2.5}$ exposure (17.5%) during period of lockdown. Nonetheless, we noted that we only estimated the indoor exposure during lockdown period, therefore a comprehensive intervention of short and long-term health impacts should be accounted in the future study. The impact of particles in the indoor environment deserves further investigation.

Policy relevance

Much has been made of the declining concentrations of some primary pollutants observed under lockdown with thoughts that this may provide guidance for future policies. Previous experiences suggest that the public are aware that air pollution returns once consumption activities resume and short-term restrictions are relaxed (Brimblecombe and Zong, 2019). A number of potential future pathways have been suggested (Bergman, 2020), but it is not clear how the patterns of human life will change when the pandemic is over. Suggestions that lockdown decreases in traffic might be replicated in a post COVID-19 world may be difficult to achieve, and as observed here decreases in traffic were not paralleled by equivalent decreases in $PM_{2.5}$ concentrations. It has been argued that the experience of lockdown will encourage people to increasingly work from home in the future. However, this should raise concerns about the enhanced potential for indoor exposures and concomitant health risks. While there is some knowledge of a range of indoor microenvironments, our knowledge is often limited to simple concentration measurements, so much less is known of the health risk imposed by a range of different types of indoor particulate material.

CONCLUSIONS

Our study characterised the influence of MCOs lockdown intervention on the balance of indoor and outdoor $PM_{2.5}$ exposure and likely potential changes in the risk to health. The reduction in human movement and changed work patterns led to reduced pollutant emissions widely observed as a reduction in air pollutant concentrations. The daily median outdoor concentrations of $PM_{2.5}$ were reduced during the lockdown of 12.63 µg m^{-3} before and 11.72 µg m^{-3} under the MCOs at UPM (campus site) (Mann-Whitney test: U=1237; p1~0.013). Meanwhile, the reduction for Putrajaya was less distinctive 17.39 µg m^{-3} before and 16.25 µg m^{-3} during (Mann-Whitney test: U=1107; p1~0.13). Our study suggested that cooking activities led to a substantial increase in $PM_{2.5}$ exposure during COVID-19 lockdown (maximum average concentration at 52.2 µg m^{-3}). Our estimation from health risk calculation has highlighted the relevance of staying indoor during lockdown with regard to health of the population. The excess risk to health is found at 25.8% for lung cancer estimation when staying indoor. Traditionally it maybe that only a few of the family were at home during cooking, but under MCOs it would mean exposure for the whole family. Indoor pollutants are often found at higher concentrations than outdoors (I/O ratio > 1) in our apartment observation, so it is hardly surprising if extended periods spent indoors under lockdown increases exposure to particulate material. The widespread belief that exposures to air pollutants during COVID-19 were lower or that they drove susceptibility to infections seem unconvincing if these depend on only outdoor observations of concentrations. The simple set of measurements presented here would suggest that exposures in crowded interiors occupied for long periods was likely higher in terms of particulate concentrations. Little research has been done on examining the way people spent their lives under lockdown and to explore social disparities perhaps crucial in the way crowded living environments were utilised. Also, exposure would likely have been higher than outdoors, though it is far from certain whether the types of particles indoors under lockdown represented an enhanced risk to short term health. The toxicology of indoor particles is uncertain, so it is difficult to formulate the real risk when using indoor concentrations of particles. It is probably important to learn more about the reactive oxygen species and other toxicological properties of indoor particles. This is particularly true if in a post COVID-world people work from home and spend more time in domestic settings.

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Table

Table 1 Dates of different MCO periods in Malaysia

MCO phase	Dates	Summary
MCO 1	18th March 2020 – 31st March 2020	The prohibition of movement within 10 km of the residence and mass assembly
MCO 2	1st April 2020 – 14th April 2020	The Malaysian government announced a stricter MCO and minimize numbers of essential services
MCO 3	15th April 2020 – 28th April 2020	More roadblocks by police and soldiers
MCO 4	29th April 2020 – 3rd May 2020	Only selected industries are allowed to run full capacity and some movement restrictions were slowly eased
MCO 5	4th May 2020 – 12th May 2020	This phase is known as Conditional Movement Control Order (CMCO). The Government started to ease restrictions on Movement (i.e travelling more than 10 km from residential area is allowed

Figure Captions

Fig. 1. Map of the study area with monitoring sites marked +.

Fig. 2. (a) Measured $PM_{2.5}$ concentrations as daily averages for the ambient monitoring sites at the university campus (UPM) and Putrajaya from 9 February to 7 May 2020 (during MCOs phases – as noted in the Table 1). The open circles denote daytime measurements inside the apartment (averaged 09:00-19:00) and outdoors as dots. (b) The daily traffic flow at the exit near UPM.

Fig. 3. Average diurnal change (as an 11-point running mean) in the apartment (dark line) and outdoors (dotted line) averaged over 13 daytime periods. The grey area denotes the standard deviation.

Fig. 4. The average excess risk of the health burden from acute respiratory diseases (age< 5), cardio-respiratory diseases (age> 30) and lung cancer (age> 30) estimated for campus and Putrajaya monitoring station before and during lockdown MCO. The excess risk inside the apartment assuming concentrations were maintained for 24 hours and 50% assuming they were almost zero at night.

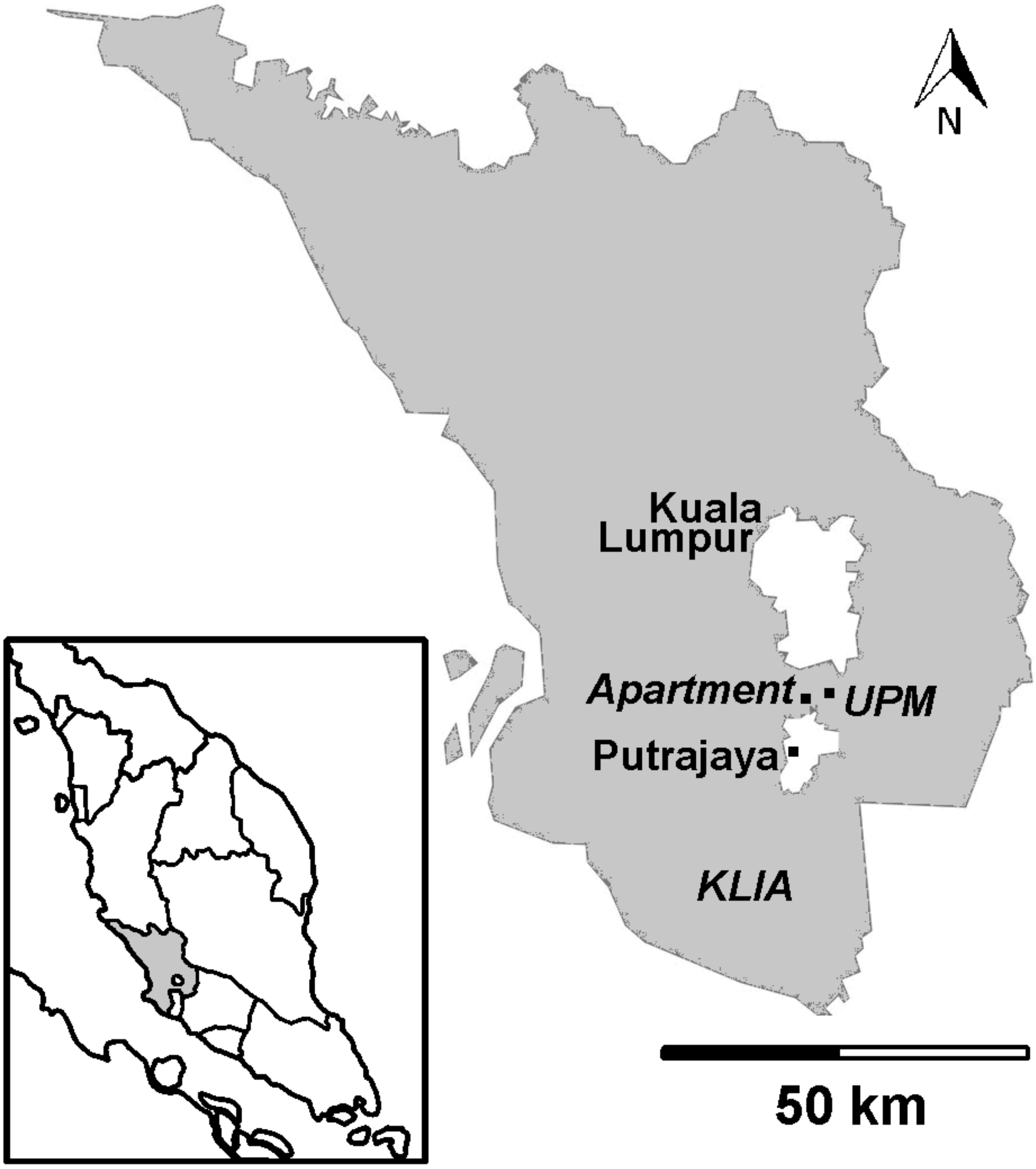

Fig. 1.

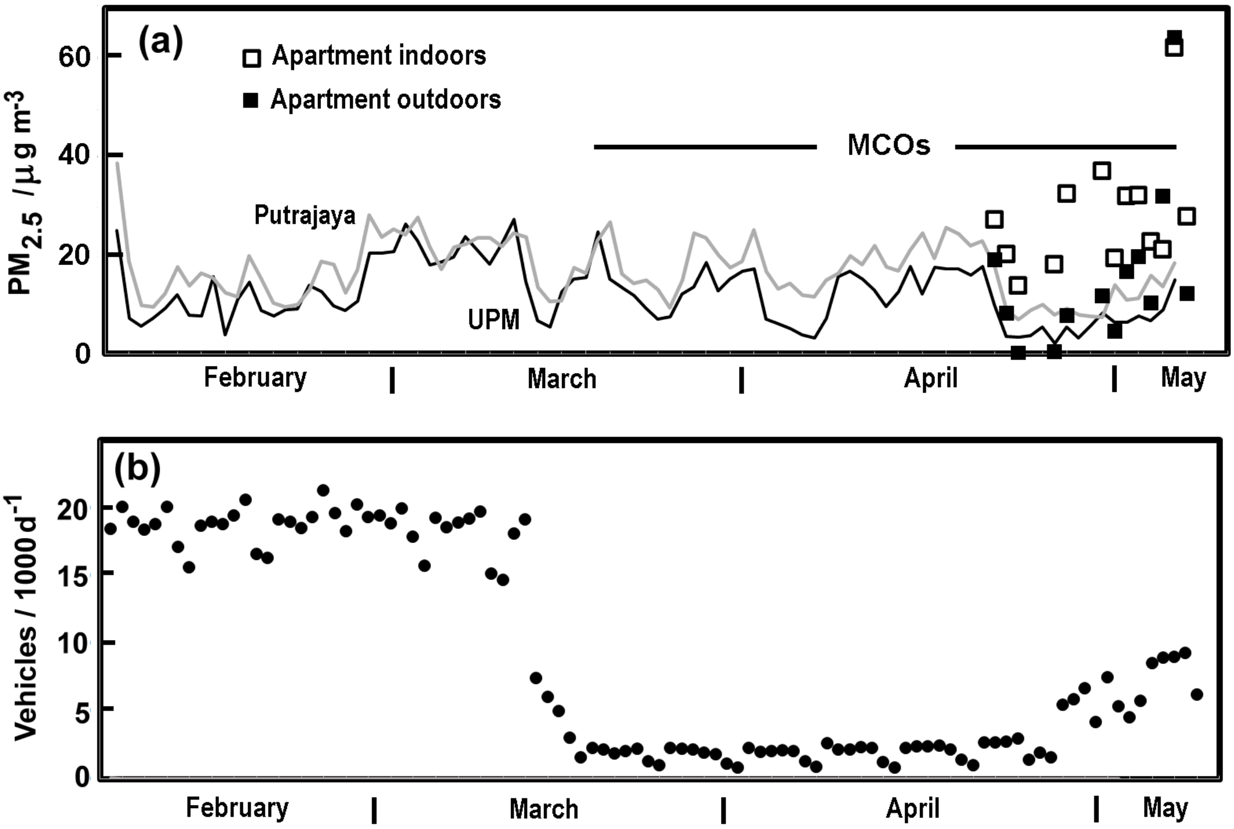
(a)
Apartment indoors
Apartment outdoors
MCOs
Putrajaya
UPM
PM$_{2.5}$ /µg m^{-3}
0
20
40
60
February
March
April
May
(b)
Vehicles / 1000 d^{-1}
0
5
10
15
20
February
March
April
May

Fig. 2.

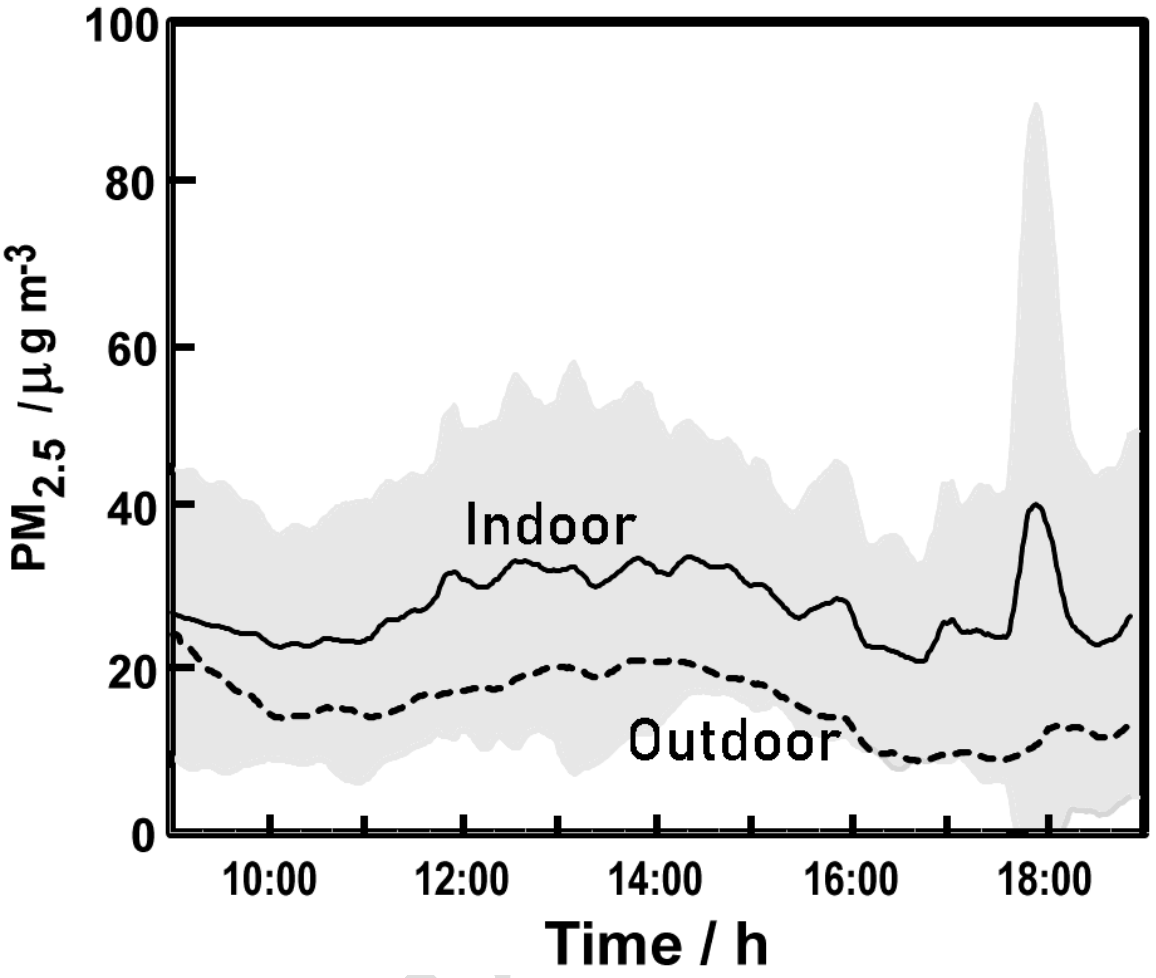
100
80
60
40
20
0
$PM_{2.5}$ /µg m^{-3}
Indoor
Outdoor
10:00
12:00
14:00
16:00
18:00
Time / h

Fig. 3.

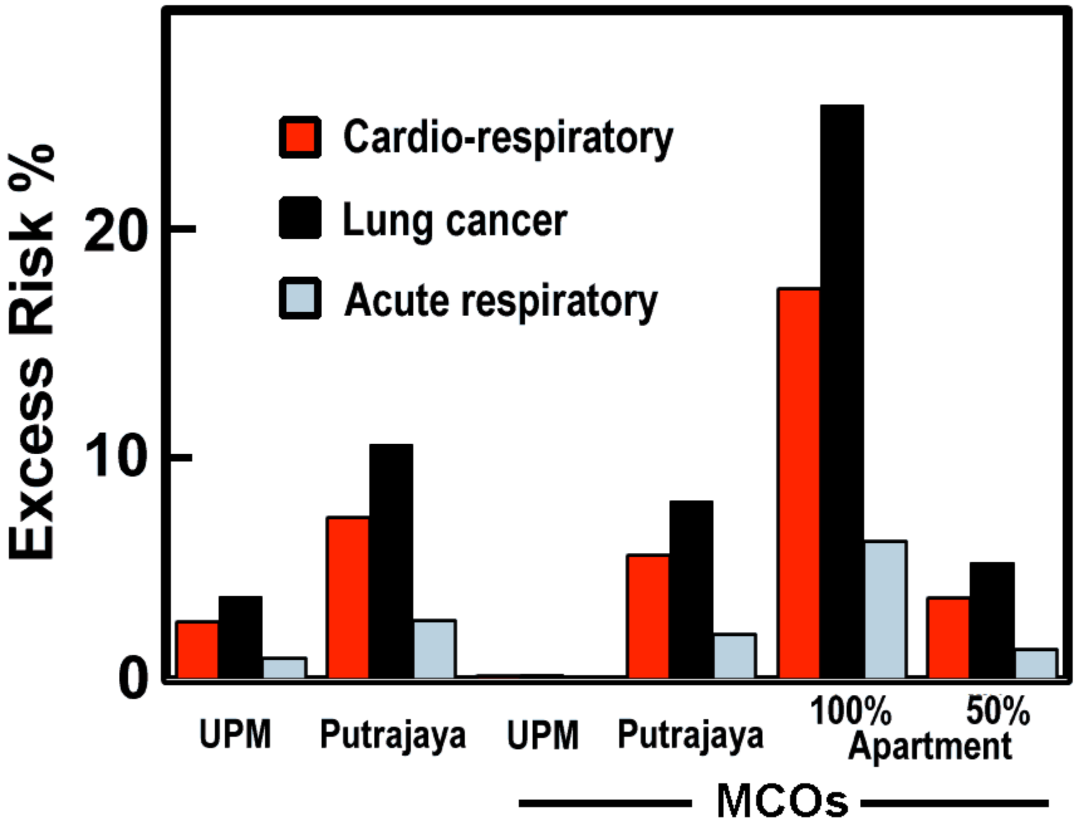
Excess Risk %
0
10
20
Cardio-respiratory
Lung cancer
Acute respiratory
UPM
Putrajaya
UPM
Putrajaya
100%
50%
Apartment
MCOs

Fig. 4.