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IAQ Aspects of Daycare Centers: A Systematic Review of Exposure to Particular Matter

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ABSTRACT

When an infant is born, he or she begins independently breathing for the first time, meaning that immediately his or her lungs start becoming a principal interface between the outside air and the organism being considerably and continuously influenced by the Indoor Air Quality (IAQ). Daycare centers (DCCs) or early life educational institutions, the first program for the social development of young children (generally aged 0-5 years old), are the most important place besides their home. Young children, one of the most vulnerable population groups, spend most of their time at DCCs (up to 10 hours per day, 5 days per week, mostly indoors). Therefore, creating a healthy indoor environment for infants is important in DCCs. As one of the most health-relevant indoor air pollutants, the focus of this research is on the Particulate Matter (PM) that should be well-thought-out in DCCs. Thus, to characterize the status of PM exposure level at the most recent daycare centers worldwide, this work evaluated 35 peer-reviewed articles (2010-2020) on children's environmental exposure to PM, and major emission sources. Details about exposure to PM_{10}*,* $PM_{2.5}$*,* PM_1 *at DCCs were presented, analyzed, and compared based on continents, countries, seasonal variations, and urbanization. Among the reviewed studies, a total of 754-early-life educational institutions were involved in the measurement of PM levels worldwide. Most of the children were exposed to inadequate environmental conditions at daycare centers around the world, especially in Asian countries. Adequate evidence supports the statement that young children enrolled in daycare centers in urban areas, particularly near busy roads, are exposed to more concentrations of PM. There is a good trend in increasing monitoring of PM levels across the countries, especially in Asian regions, but, still, more particulate matter characterization and standardization of sampling techniques are needed. More attention should be placed at indoor air quality (IAQ) within the young children's breathing zone (e.g., sleeping micro-environment). There is a clear need to improve IAQ in daycare centers and to establish specific IAQ guidelines for exposure limits in these early-life educational environments.*

INTRODUCTION

Daycare centers (DCCs), the first program for the social development of young children (generally aged 0-5 years old), is the most important place besides their home. In contemporary society, parents of infants need to go back to work a few months after their infants were born. As a result, more than 90% of the small children (up to primary school age) are enrolled in DCCs, where children are gathered together generally with high densities. For example, in the Netherlands, most of the children aged from 3 months to 4 years spend as much as 11 hours per day, 5 days per week, in the daycare center. It should be mentioned that, obviously, the time young children spend indoor at the daycare center is dominantly more than the time high-grade children spend at school. A significant amount of time children spend at DCCs was also reported in other countries, such as Singapore (Zuraimi et al., 2007), Finland (Ruotsalainen et al., 1993), Latvia (Stankevica and Lesinskis, 2012), Korea (Shin et al., 2015; Yoon et al., 2011), and Germany (Sander et al., 2016). Apart from that, the needs for DCCs have increased considerably around the world

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over the last few years. For example, within the Netherlands, from 344,280 children in 2015 to 454,660 children in 2018 have registered at DCCs (increased by 32%), based on the latest data provided by the Dutch Central Bureau of Statistics (CBS, 2020).

Now, concerns are emerging about potential adverse effects of indoor air pollutants on children's health and development, since young children are exceptionally more sensitive to chemical exposures than higher-grade children and adults (Gabriel et al., 2020; WHO, 2005). This is because of their developing organ systems (particularly lungs), incomplete metabolic systems, immature host defenses, the higher inhalation rates per unit of body weight, and their greater surface-to-volume ratios (Oliveira et al., 2019; WHO, 2005).

Unfortunately, insufficient IAQ conditions at DCCs were unanimously confirmed in the previous studies (Amanda le Grand, 2010; Prussin et al., 2019; Zeiler, 2018). Apart from that, it's worth mentioning that the level of exposure to indoor air pollutants may be elevated due to the source-proximity effect specific to children's activity patterns (e.g., playing or crawling on the ground; sleeping in the crib; more mouth breathing; more oral ingestion via hands-to-mouth-transfer) (Boor et al., 2017; Liang and Xu, 2014). Especially within the sleep micro-environment, the source-proximity effect would become the most dominant, that is, pollutant concentrations within the crib mattress are greater than those in the bulk room air (Jr et al., 1996; Kim et al., 2015).

Particulate matter (PM) is one of the most health-relevant indoor air pollutants selected as crucial to verify indoor air quality by the World Health Organization (WHO, 2010, 2016). PM is a heterogeneous mixture of solid and/or liquid particles suspended in air, with a wide array of variations in size, shape, composition, and physical nature (Oliveira et al., 2019; U.S.EPA, 2020; WHO, 2013). Generally, concentrations of PM in the air can be characterized in two manners: one in particle number concentrations (e.g., in number/particles per cm^3, L/dm^3, or m^3); another one in particle mass concentrations (e.g., in $\mu g/m^3$, mg/m^3 or ng/m^3) (Winkel et al., 2014). Although the mechanism of injury posed by PM on children's health is not fully clear at present, a significant body of evidence supports the explanation that PM can pose various adverse health problems including irritations of eye, nose, and throat; aggravation of coronary and respiratory disease symptoms such as bronchitis, asthma, cough, dyspnea, and pneumonia; premature death in people with heart or lung disease; childhood mortality; increased risk of cardiovascular pathologies; harmful effects on neurodevelopment (Cadelis et al., 2014; U.S.EPA, 2020; WHO, 2005). Especially, in one study (McCormack et al., 2011), the authors studied a cohort of 150 children (aged 2 to 6 years) with asthma, and their results suggested that there were statistically significant relationships between both $PM_{2.5}$ and $PM_{2.5\text{-}10}$ levels and asthma symptoms in both atopic and nonatopic asthmatic children.

Overall, based on the explanations above, there are various defining properties of this indoor environment at DCCs that make it unique and critical from both an indoor air quality (especially PM) and exposure/health aspects in young children, such as:

- the significant amount of time children spent at DCCs and with high densities of children;
- the diversities of pollutants and pollutant emission sources;
- the higher susceptibility of occupant group (children) to air pollution due to their bodies under development;
- the insufficient IAQ at DCCs according to the current scientific survey/findings.

Therefore, in this study, a systematic review with a focus on assessment and comparison of children's exposures to PM levels at daycare center environments worldwide is conducted, and the gathered knowledge is discussed.

METHODOLOGY

A literature search was carried out in four scientific databases including PubMed, Scopus, Web of Science, and ScienceDirect covering studies published from 2010 to 2020, using the following keywords (combining at least two of the following terms): *building types* (daycare center/ childcare facility/ kindergarten/ preschool/ day nursery); *environment* (indoor air quality/particulate matter (PM)/ pollution); *human* (infant/ toddler/ baby/preschool/baby) and *health*. Basic settings by using filters include that search results for all databases are sorted by relevance; article type: journal article only; language: English only. It should be mentioned that all selected articles are required to contain an in-situ measurement survey for PM values inside the daycare centers, without restrictions on those whether measuring PM levels outdoor. The preliminary searches totally yielded 34,743 articles in all the four databases, which were provided for consideration. After following eligibility criteria and scientific judgment to titles, abstracts, and even the full text (including their references), a total of 35 selected studies were included in this review.

In terms of research subjects, in this work, the information should be supplemented and explained that: firstly, all building scenarios functionally similar to daycare centers, such as childcare facilities, nurseries, kindergartens, and preschools were included, considering these functionally educational institutions are dedicated for the children in the typical age range of 0-5 years old across the world. In the following text, the term "daycare center" can mean any building scenarios, including childcare facilities, nurseries, kindergartens, and preschools. Secondly, concerning age groups, there are several English terms for young children aged 0-5 years old who attend daycare centers, including infants, babies, toddlers, and preschoolers, etc., defined by the different official organizations worldwide (Encyclopedia-Britannica, 2020; EPA, 2017; U.S.AAP, 2020; U.S.CDC, 2020; WHO, 2020; Wikipedia, 2020); Refer to the above regulations, in this article children groups are thus considered as infants/babies (0-1-year-old); toddlers (1-3 years old); preschoolers (3-5 years old); young children (0-5 years old).

RESULTS

Based on the selected 35 papers, there were four continents (Africa, North America, Asia, and Europe) that were involved in the determination of PM levels in the indoor environment at daycare centers worldwide. A total of 754 building scenarios were involved in the measurement of PM levels in the world among the 35 available studies, including 531 daycare center (DCC), 69 preschools (PS), 22 kindergartens (KG), 39 nursery school (NS), 97 childcare facilities (CF). As noted in section "Methodology" before, since these similar educational buildings are dedicated for 0-5-year-old children up to the primary school throughout the world, all the building scenarios will be directly inter-compared together instead of separating them.

Concerning the measurement location levels of daycare centers, most of the studies were focused on PM measurement in classrooms or playrooms in 30 out of 35 articles. Only three studies were involved in the determination of PM concentrations in bedrooms at DCCs (Basinska et al., 2019; Branco et al., 2019; Clausen et al., 2012). No measurement of PM concentrations has been conducted at the bed level at the daycare center. On the other hand, it is worth mentioning that, there have been emerging studies on investigation of air pollutants at bed level (also referred as "sleep micro-environment"), such as volatile organic compounds (VOC) experimented at beds within a chamber (Boor et al., 2014; Boor et al., 2015; Kim et al., 2015; Laverge et al., 2013; Liang and Xu, 2014; Oz et al., 2019), CO_2 at bed level in real daycare centers (Braun and Zeiler, 2019a; Braun and Zeiler, 2019b; de Waard and Zeiler, 2014; de Waard and Zeiler, 2015; de Waard, 2014; Kruisselbrink et al., 2016; Zeiler, 2018).

Mass concentrations were mainly expressed in 93% of the selected articles; only a very small fraction of studies employed particle number concentrations (i.e., in 4 out of 35 studies) (Basinska et al., 2019; Clausen et al., 2012; Fonseca et al., 2014; Gaspar et al., 2018). Regarding PM fractions, PM_{10} and $PM_{2.5}$ were the most commonly investigated inside the daycare centers and were recorded in 63% and 66% of the available studies, respectively; Only about one-third of the available studies (n=11) on PM levels at daycare centers included the environmental monitoring of PM_1, being those studies restricted to three Asian (Abdullah et al., 2019; Harbizadeh et al., 2019; Yu et al., 2019) and eight European (Branco et al., 2014; Branco et al., 2019; Clausen et al., 2012; Fonseca et al., 2014; Mainka et al., 2015; Mainka and Zajusz-Zubek, 2015; Nunes et al., 2015; Oliveira et al., 2015) countries.

Exposure levels of PM at the daycare center environment

Figure 1 pools all the indoor PM_{10} concentrations (mean and median value) extracted from the available selected studies. The horizontal axis only states the presentation order of studies' results (It should be mentioned that some of the selected studies reported more than one group of sample results). In general, among 22 studies which reported indoor PM_{10} concentrations, a total of 55% of the studies (6 Asian and 6 European for PM_{10}) reported indoor PM_{10} that are higher than the exposure guidelines by the World Health Organization (WHO). The highest exceedances were observed in Asian daycare centers (Harbizadeh et al., 2019), with an overall mean value of 240 μg/m³ for PM_{10}, which is 3.8 times higher than the WHO guidelines (WHO, 2006, 2010, 2016).

Figure 2 pools all the indoor $PM_{2.5}$ concentrations (mean and median value) extracted from the available studies. Similarly, it should be mentioned that some of the studies presented more than one group of sample results. In general, among 23 studies which reported indoor $PM_{2.5}$ concentrations, a total of 74% of the studies (one African, nine Asian and seven European studies) reported indoor $PM_{2.5}$ that is higher than the exposure guidelines by the

WHO which is 25 µg/m³ (24 h mean). Only five studies (1 America, 2 Asia, 2 Europe) reported $PM_{2.5}$ concentrations lower than the WHO exposure limit value (Deng et al., 2018; Gaspar et al., 2018; Oliveira et al., 2016; Oliveira et al., 2017; Rim et al., 2017). Also, the highest exceedances were observed in Asian daycare centers (Zhang et al., 2018), which has an overall mean value of 267 µg/m³ (at 10 DCCs in China), which is 9.7 times higher than the WHO guidelines. Meanwhile, the only African study (Awad et al., 2018) also reported comparatively high concentrations for $PM_{2.5}$ with an overall mean value of 258 µg/m³ at two DCCs in Egypt.

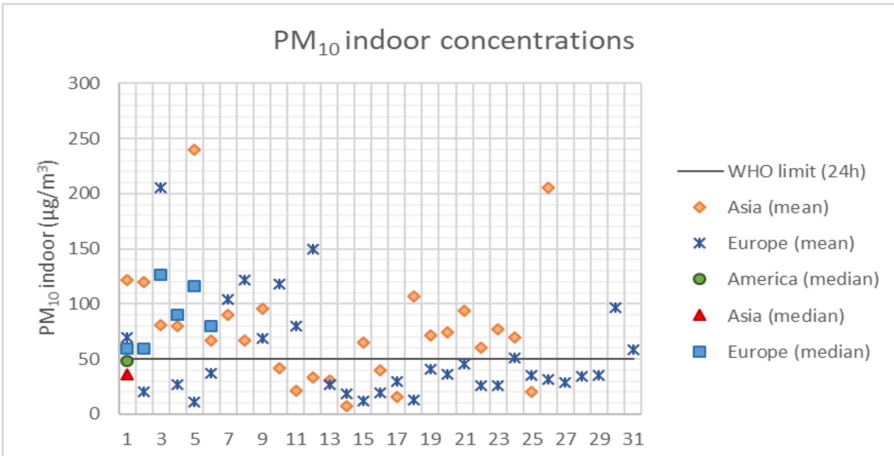

Figure 1 Inter-continent comparison of PM10 indoor concentrations (mean and median value) extracted from the available studies (note: the horizontal axis only represents a presentation order of studies' results).

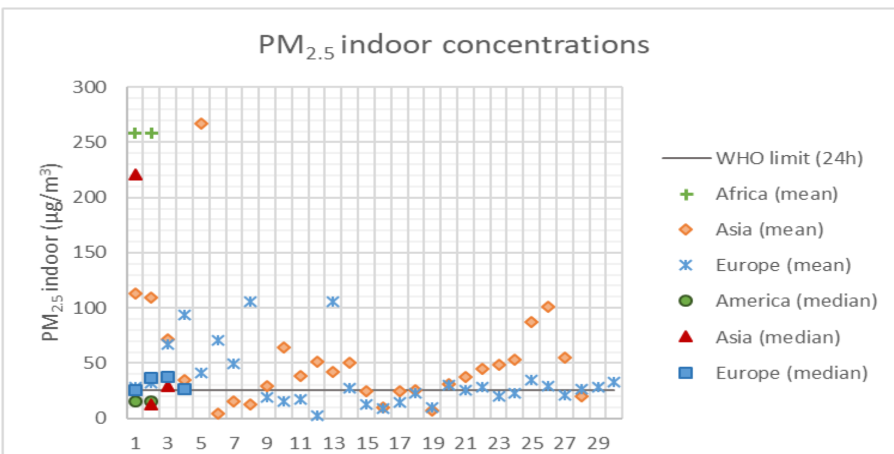

Figure 2 Inter-continent comparison of PM2.5 indoor concentrations (mean and median value) extracted from the available studies (note: the horizontal axis only represents a presentation order of studies' results).

Apart from $PM_{2.5}$ and PM_{10}, ultrafine particles (PM_1) have recently attracted substantial attention from both the scientific and medical areas. Generally, PM_1 is measured as number concentrations, whilst among 11 available articles, there are only two articles that employed number concentrations (Clausen et al., 2012; Fonseca et al., 2014). One study (Branco et al., 2019) found extremely high $PM_1/PM_{2.5}$ ratios by continuously monitoring PM concentrations inside 17 daycare centers, revealing that most of the $PM_{2.5}$ particles were finer, with less than one µm diameter. Meanwhile, according to a statement by WHO, even though there is substantially toxicological evidence of potential adverse effects of PM_1 on human health, the current epidemiological evidence is insufficient to conclude the exposure-response relationship to PM_1. Therefore, the WHO has not set the limit value of ultrafine particles (WHO, 2010). From the standpoint of safety, it is wise and expedient to reduce indoor PM_1 exposure levels as low as possible. As shown in **Error! Reference source not found.**Figure 3, European countries were mostly involved in the measurement of PM_1.

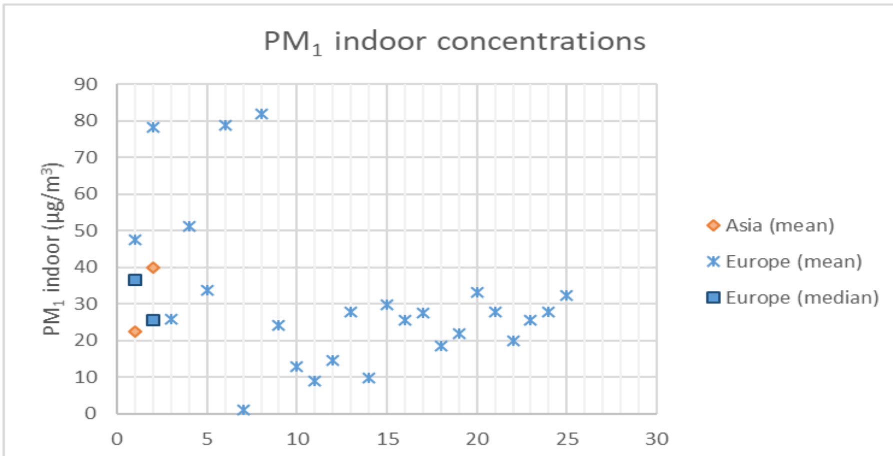

Figure 3 Inter-continent comparison of PM_1 indoor concentrations (mean and median value) extracted from the available studies (note: the horizontal axis only represents a presentation order of studies' results).

DISCUSSION

The results of data comparison clearly showed that the difference of PM concentrations was considerably apparent among the continents, which mainly resulted from the economic level and socio-cultural differences (Oliveira et al., 2019; WHO, 2010). On the other hand, other various aspects of factors such as geographic location (urbanization, climate, near traffic, or road), building characteristics, anthropogenic activities (indoor and outdoor), and seasonal variations can result in obvious divergence in indoor PM levels. In terms of urbanization, the available studies (n=9) unanimously indicated that substantially higher levels of a particulate matter in urban-traffic area than those in rural or suburb areas; including 4 Asian (Choo et al., 2015; Harbizadeh et al., 2019; Oh et al., 2014; Yoon et al., 2011) and 5 European (Branco et al., 2019; Fonseca et al., 2014; Mainka and Zajusz-Zubek, 2015; Nunes et al., 2015; Oliveira et al., 2015), except for two articles: one (Blaszczyk et al., 2017) which reported the higher PM levels in the rural area resulted from the use of coal stove in a daycare center kitchen; another one (Abdullah et al., 2019) which was not included due to the outliers. Meanwhile, most of the available studies reported the more than one ratio of the PM indoor to outdoor concentration value (I/O) (Alves et al., 2013; Deng et al., 2016; Mainka et al., 2015; Oh et al., 2019; Yoon et al., 2011; Yu et al., 2019); and only one study characterized the less than one I/O ratios (Yamamoto et al., 2010). These indicate the diverse contribution of both indoor and outdoor PM sources and influencing factors. These findings were consistent with the conclusions in WHO 2010 guidelines for indoor air quality: selected pollutants (WHO, 2010). Indoor particles are originated from the direct emission from indoor (primary sources), the infiltration of outdoor air (secondary sources), and particles formed indoors through reactions of gas-phase precursors (ammonia, sulfur dioxide, oxides of nitrogen and non-methane volatile organic compounds) (Morawska et al., 2013; Morawska et al., 2017; Oliveira et al., 2019; WHO, 2013). In the end, seasonal variation is also the main factor affecting PM indoor level. Several available articles (Blaszczyk et al., 2017; Mentese et al., 2012; Oh et al., 2019) revealed more aggravated pollutants of PM in winter (up to orders of magnitude) than those in spring or summer, because of lack of natural ventilation.

CONCLUSION

In conclusion, this review summarized the most recent scientific literature on early life (0-5 years old) exposure to PM pollutants at daycare centers worldwide (2010-2020). The available data extracted from all the 35 selected articles vary in geographical areas, sampling methodologies, sampling time, and durations, which may cause deviations and diversity among those data. The results showed that most of the children were exposed to inadequate environmental conditions at daycare centers in the world based on the fact that PM mean concentrations measured in more than half of the selected studies exceeded the international guideline (WHO) for PM_{10} or $PM_{2.5}$. Furthermore, enough evidence revealed that diverse sources were contributed to the PM concentrations inside the daycare centers. An emerging direction would be the investigation of IAQ at bed level, considering the importance of the sleeping micro-environment within the cribs. Notably, there is no PM investigation inside real cribs at daycare centers that could be found yet. Further research of this topic would be of great help to ensure a healthy microenvironment for young children at the daycare centers.

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