Baby beds' sleep micro-environment in day care centres

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Abstract. Concerns are emerging about potential adverse effects of indoor air pollutants on children's health and development, since young babies are exceptionally more sensitive to chemical exposures than children and adults. Day care centres (DCCs) are the most important place besides their home as babies spend up to 11 hours inside the DCCs, of which half of the time in their beds during the first six months. Especially during the first year their developing lungs are highly sensitive to pollutions. Ventilation within the baby bed themselves is rarely studied however insufficient IAQ conditions at DCCs were unanimously confirmed in t previous studies. Therefore, the main aim of this paper is to state the importance of improving the indoor air quality at day-care centres, especially in sleep micro-environment of the baby beds. The paper presents an overview to emphasize the importance for the health of babies.

Keywords. Day-care centres, cribs, sleep micro-environment
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1. Introduction

The moment you are born you start breathing for the first time. Immediately the developments of your lungs continue in a new phase depending for the first time on the Indoor Air Quality. To date, air pollution, a world-recognized threat to human health, has been documented to be responsible for various health problems (e.g., respiratory diseases, asthma, cancer, etc.) and even shorten lifespans, both indoors and outdoors. Concerns are emerging about potential adverse effects of indoor air pollutants on children's health and development, since young babies are exceptionally more sensitive to chemical exposures than children and adults. Day care centres (DCCs), the first program for the social development of young children, is the most important place besides their home. Babies spend up to 11 hours inside DCCs and spend more than half of the time in their beds during the first six months. Especially during the first year their lungs are developing rapidly and therefor highly sensitive to the Indoor Air Quality. the needs for DCCs have increased considerably around the world 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%), (CBS 2020). There are more than 100.000 twin baby beds in the Netherlands, which means that on average daily around 120.000 babies spend half of their time with sleeping in one of these twin baby beds. These beds are close on 5 sides and only there is a front with bars that allow air to come in, see Fig. 1.

Fig. 1 – Most used baby bed in modern Dutch DCCs, fully closed on all sides only open at the from by bars

Adequate ventilation within the baby bed themselves has not been studied before however, it is extremely important for the babies and their healthy development. Especially within the sleep micro-environment, the source-proximity effect would become the most dominant, that is, pollutant concentrations above the crib mattress are greater than those in the bulk air of the sleeping room. When you also consider the layout of most of the modern DCCs, see Fig. 2, where they put as many beds in a room as possible it immediately becomes clear that there might be a problem with the adequate ventilation of these twin baby beds.

Fig. 2 – Most common set-up on modern day care centres; 2 rows of 6 baby beds, with just enough space between them

Therefore, the main aim of this study is to explore the air quality within the baby bed and determine influencing factors related to the indoor air quality. This especially for the position of the baby in the bed and the difference between lower and upper bunk bed in sleep microenvironment with the double baby bunk beds at DCCs. This article represents an overview of the research on baby beds over the last decades.

2. Health aspects and IAQ

2.1 Development of the lungs

To date, air quality, a world-recognized threat to human health, has been documented to be responsible for various health problems (e.g., respiratory diseases, asthma, cancer, etc.) and even shorten lifespans, both indoors and outdoors (EEA, 2017). Recently, World Health Organization (WHO) also stated that air pollutants, both indoor and outdoor, the biggest environmental threat to health, contribute to one-ninth of deaths annually in the world (WHO 2016).

DCCs are the most important place besides their home of young children (generally aged 0-4 years old). Concerns are emerging about potential adverse effects of indoor air pollutants in DCCs on children's health and development. Worse, available evidence (Zheng et al 2022) indicates young children's attendance in DCCs increases the risk of respiratory and gastrointestinal infections (Bradley 2003, Ferng and Lee 2002, Hagerhed-Engman et al. 2006, Koopman et al. 2001, Louhiala et al. 1995, Nafstad et al. 2005).

Young children are exceptionally more sensitive to chemical exposures than higher-grade children and adults (Ferguson and Solo-Gabriele 2016, Gabriel et al. 2020, WHO 2005). This is because of their developing organ systems (particularly lungs), incomplete metabolic systems, immature host defences, the higher inhalation rates per unit of body weight, and their greater surface-to-volume ratios (Brent and Weitzman 2004, Burtscher and Schüepp 2012, Oliveira et al 2019, WHO 2005). Baby's breath 10 times more air per body mass than adults and have skin surface area to body mass ratio three times greater than that of adults.

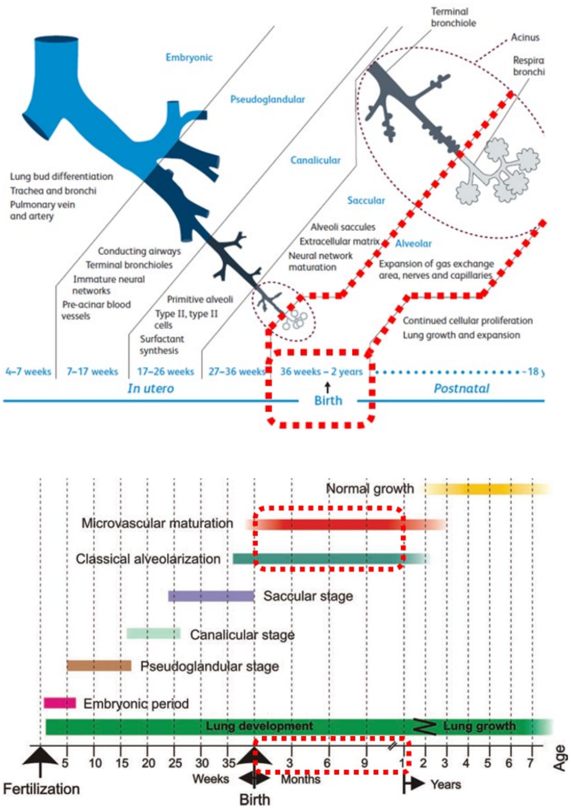


Fig. 3. Top Principal stages of lung development in humans [Holgate 2016] and timing [Schittny and Burri 2008].

2.2 IAQ within DCCs

On a global scale, there has been a certain body of studies about IAQ investigations at DCCs over the last decade. More specifically, a total of 122 IAQ-related studies were performed at DCCs from 2010 to 2020(Zheng et al. 2022). Measured types of indoor air pollutants covered physical parameters (temperature and relative humidity), chemical (VOC, SVOC, O_3, CO_2, CO, NO_2, SO_2, Radon, PM), biological contaminants (bacteria, fungi/moulds, allergens, pollen, pet dander).

There are significant space-related contaminants, including diapers, arts-and-crafts supplies, and cleaning agents (ANSI/ASHRAE, 2019). 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. 2014, Boor et al. 2017, Liang and Xu 2014). Especially, within the sleep micro-environment, the source-proximity effect would become the most dominant. Pollutant concentrations within the crib mattress are greater than those in the bulk room air (Furtaw et al. 1996, Laverge et al. 2013, Spilak et al. 2014, Boor et al. 2014, Boor et al. 2015, Kim et al., 2015, Zheng et al. 2022), which may also be a significant influence on exposures to the sleep micro-environment at DCCs.

2.3 Micro-climate DCCs' Baby beds

Mattress dust is found to contain a diverse spectrum of biological particles and particle-bound chemical contaminants and their concentrations in dust can span many orders of magnitude among bed samples (Boor et al 2014). Furthermore, mattress foam and covers, pillows, and bed frames can emit a variety of volatile and semi volatile organic compounds, and emission rates can increase due to localized elevations in surface temperature and moisture near the bed due to close contact with the human body (Boor et al 2014). Emissions can emit more organic compounds (VOCs) due to the increase in surface temperature by the baby's body and humidity (leaking diapers). This is specifically in the places where the material is in contact with the body. Therefore, good ventilation levels inside the baby beds are of extreme importance to remove the pollutants and create a healthy sleep microenvironment for the babies. Crib mattresses have also been indicated as a major source of VOC concentrations in a room. The emission rates of mattresses are comparable to those of flowing materials, wallcoverings, and plastic toys. (Boor et al 2015) This is a concern as the source of VOCs is within the breathing zone of the babies when put in bed.

Despite the severity of the situation inside the baby beds, only a few studies were performed to focus on the air quality of sleep microenvironment within the beds at DCCs (Da Silva et al. 2005). These studies only investigated CO_2 levels or mite levels, which would be far insufficient to characterize the overall IAQ since other air pollutants can be dominant. Unfortunately, insufficient IAQ conditions, based on CO_2 measurements at DCCs were unanimously confirmed in the previous studies (Ferng and Lee 2002, Versteeg 2009, Mendes et al 2014, le Grand and Duijm 2017, Prussin et al. 2019). Similar to a home, various indoor pollutant sources exist in the DCCs (Junaidi et al. 2019, Lee et al. 2018, Yu et al., 2019, Zheng et al. 2022). The air quality might not be the same throughout a ventilated space. What really counts for the occupants is the air quality in the breathing zone. Such an inhomogeneity of the air quality in space has an impact on the ventilation requirement, especially in the case of the sleep microenvironment within baby bunk beds at DCCs. So clearly, more interesting are the conditions inside the baby beds, they only measurements we could find beside our own measurements [Offermans 2020], were by le Grand and Duijm (2017). To determine whether our results were in line with their results we compared them, see Fig. 4. Both trendlines have a factor of slightly more than 1.2, meaning that on average the CO_2 concentration in the baby bed is around 20% more than in the sleeping room itself. However, there is a weaker correlation in the measurements in the Eindhoven DCC compared to that of the results by le Grand and Duijm [2017]. This probably because of more different occupancy rates of babies in the sleeping room in Eindhoven.

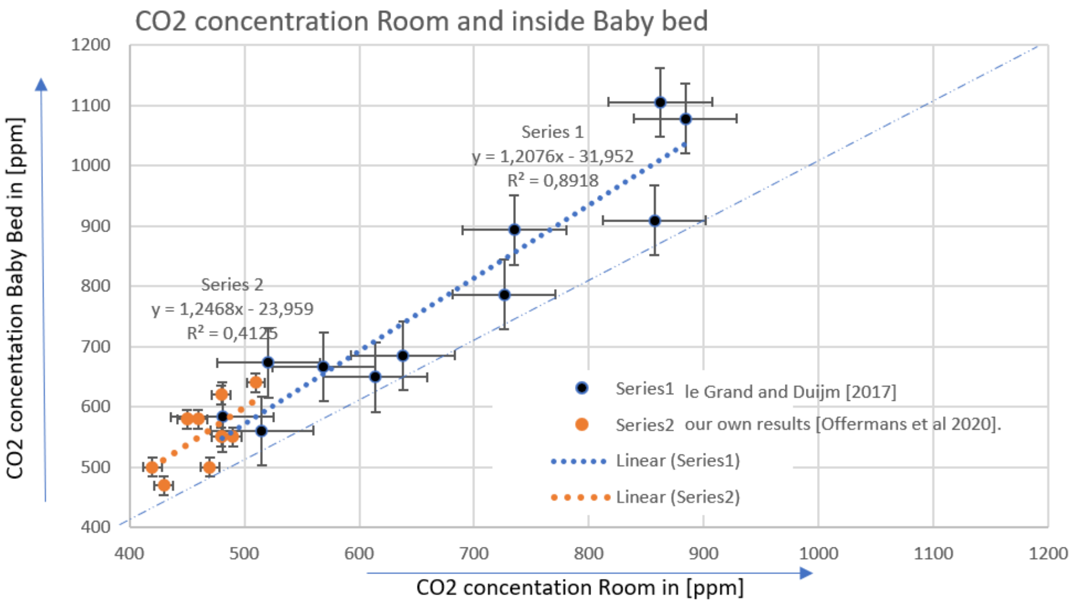


Fig. 4 -Results measurements within the baby beds

3. Methodology measurements

It is clearly necessary to get more and detailed insight in the IAQ in sleep microenvironment with the baby bunk beds at DCCs.

3.1 Influence of the position of the bed

Especially, interesting is to see whether there is a significance difference in IAQ between the upper and lower bed of a baby bed bunk. Therefore, the CO2 concentration were measured in the upper baby bed as well as in the lower baby bed in the real situation of a DCC, see Fig. 5.

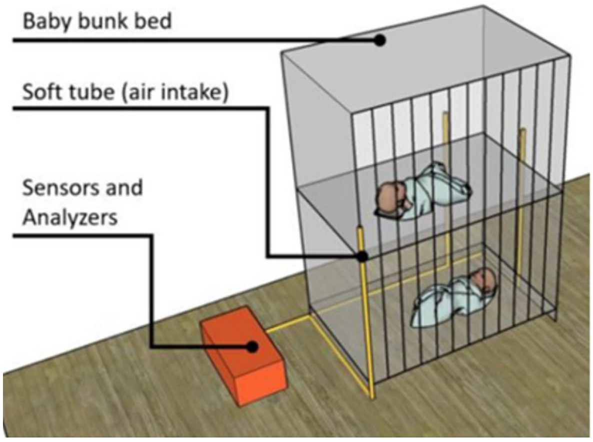
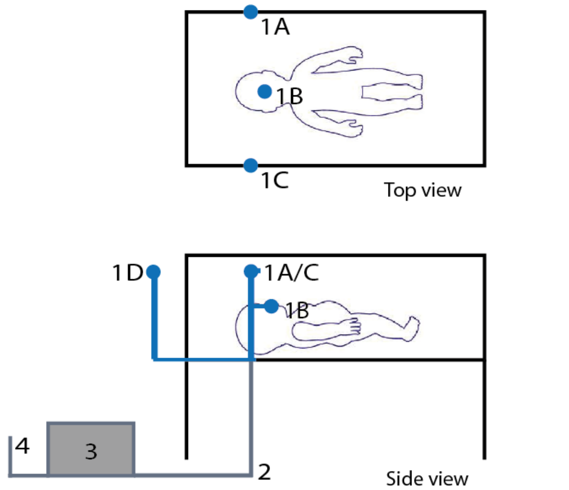


Fig. 5 - Measurement setup indoor air quality in the upper and lower baby bunk beds (Offermans et al 2020)

Also, interesting is whether the position of the baby within the bed itself would have a large influence on the CO2 concentrations inside the bed. However, due to privacy reason it was not allowed to monitor the positions of real babies in their beds, therefore an experimental set-up was built. A baby doll was used, in which the breathing of a baby was simulated by a ventilator and valve mechanism. In this way a mixture of air and CO2, just like the breathing of a baby, was generated, see Fig. 6-8. Experiments were performed representing a bottom bunk bed and a bedstead.



1. Four CO_2 sensors 2. Cable bundler 3. Central box 4. Main's supply

Fig. 6 - Experimental measurement to simulate different positions for the baby doll inside the baby beds(Braun and Zeiler 2019)

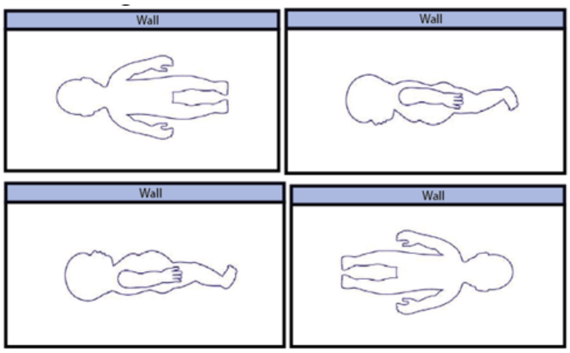


Fig. 7 - Measurement positions for the baby doll inside the baby beds: supine, lateral facing room, lateral facing wall and prone (Braun and Zeiler 2019)

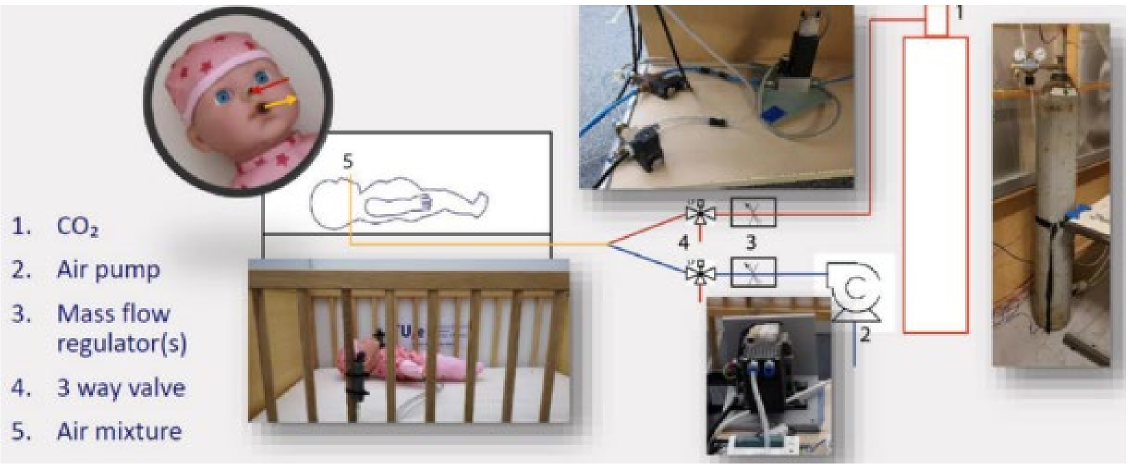


Fig. 8 - Breathing simulator and baby doll in a bedstead at TU/e (Braun and Zeiler 2019)

4. Results

The effects of the different location of the bed (upper or lower bed), as well as the different positions of the baby itself in the bed on the CO_2 concentrations are displayed in this paragraph.

4.1 Influence of the position of the bed

In the bottom bunk bed and upper bunk bed the average measured CO_2 concentration were determined. These are displayed in Table 1, where it can be seen that the CO_2 concentrations are higher for the position in the upper bunk bed and therefore lower in the lower bunk bed. Unfortunately, there were different occupancies in the sleeping room during our measurements.

Table 1. Difference between bottom and top position in baby bunk bed with 3 and 5 babies in the sleeping room (max. 6) in ppm CO_2

Bottom bunk bed - back of bed					Top bunk bed - back of bed			
min	average	max	P98	babys	min	average	max	P98
474	592	739	679	3	446	543	644	600
426	517	609	568	3	400	536	704	652
420	501	655	557	3				**µ = 626**
			µ = 601					
455	536	623	585	5	449	563	705	***635***
409	475	612	559	5				
			µ = 572					

As can be seen there is a significant difference, the top position is worse than the bottom position by 5 to 10 % CO_2 concentration.

4.2 Influence of the position of the baby

In the second series of experiments different fixed positions of a baby were simulated. It was found that the bottom bunk bed with more closed surroundings led to an average increase of around 220 percent relative to the background level compared to a bedstead where the increase was 160 percent, see Fig. 9. In both situations the increases are significant and even more significant for the measurements at the wall side, here the increase in the bottom bunk bed was on average around 270 percent and for the bedstead it was around 210 percent. Therefore, it can be concluded that the more closed the surroundings of a crib are, the higher the CO_2 concentrations will be.

The position of the baby doll also had a significant effect on the measurements. For example, with the bottom bunk bed when the baby is facing the wall the rise in the average CO2 concentrations was around 270 percent, however when the baby was facing the room (bars) the CO2 concentrations only rose by nearly 30 percent. Facing the roof led to an average increase of around 80 percent. Therefore, it is concluded that the position of the baby has a significant effect on the measured values. When the mouth of the baby is facing an open surrounding the average CO2 concentrations of the inhaled air decreased significantly compared to when a baby was facing a more closed surrounding. Thus, it is concluded that it is not sufficient to only measure the CO2 concentrations in the sleeping room as the conditions will significantly deviate from those in a bedstead.

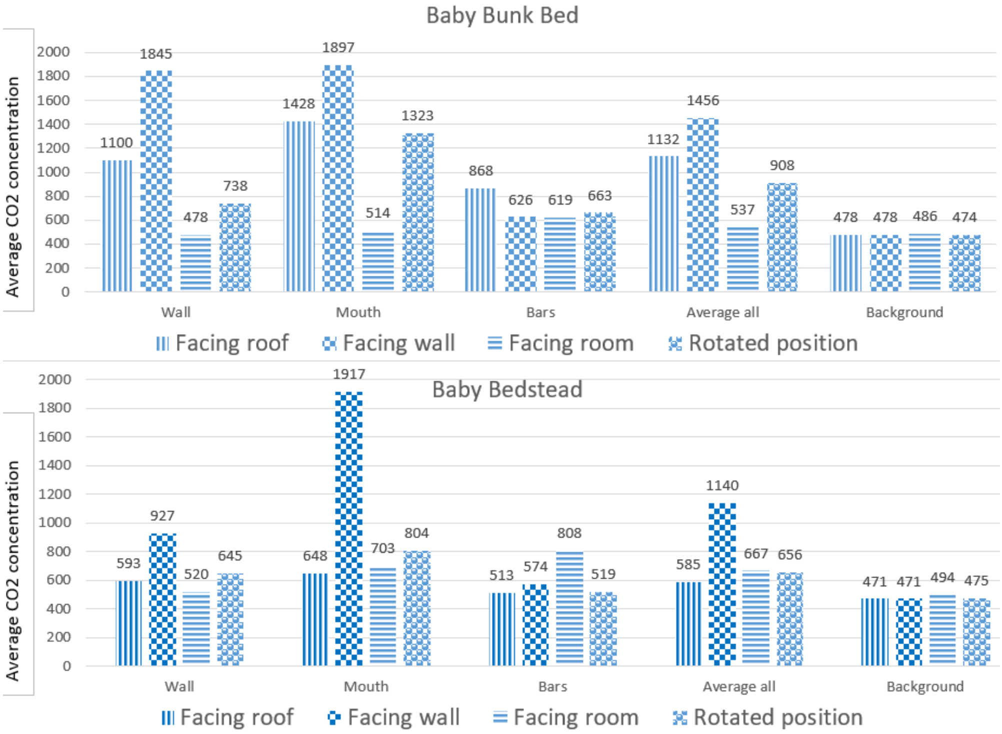


Fig. 9 – Bottum bunk bed versus bedstead average CO_2 concentration

5. Discussion

Concerning the measurements in relation to the position of the baby within the bed, it would be best to perform measurements in a real setting. However, this is not allowed due to privacy rules within the DCCs.

The research clearly showed the importance to monitor inside the baby bed and not take the average IAQ of sleeping room conditions of DCCs which as such is currently the common practice. Unfortunately, insufficient IAQ conditions at DCCs were unanimously confirmed in our studies. Especially within the sleep micro-environment, the source-proximity effect is most dominant, that is, pollutant concentrations within the crib mattress are greater than those in the bulk room air. The ventilation effectiveness inside the baby bed of the typical double baby bunk beds is considerable worse and it is therefore that more effort is necessary to come up with solutions to improve this.

The number of measurements which were done to determine the difference in IAQ between bottom and top position in the baby bunk bed is rather limited, so more measurements are needed to determine whether this is significant enough or not.

6. Conclusions

The main aim of this paper is to state the importance of improving the indoor air quality at DCCs especially inside the sleep microenvironment of the most used type of double baby bunk beds in the Netherlands.

The research on the indoor air quality at bed level and sleeping room level at DCCs ultimately can give a clear picture of the indoor air quality level at the bedroom and baby bunk bed in the Netherlands. It can lead to develop effective and efficient control strategies for the ventilation system to guarantee adequate indoor air quality at DCCs. Additionally, the result of this study should be used as a useful evidence base for the formulation and targeting of new standards, or guidelines for improving IAQ at DCCs.

Data access statement

The datasets generated during and/or analysed during the current study are not available because of privacy reasons but the authors will make every reasonable effort to publish them in near future.

References

ANSI/ASHRAE (2019) ANSI/ASHRAE Standard 62.1-2019 -- Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE).

Boor B.E., Järnström H., Novoselac A., Xu Y. (2014) Infant exposure to emissions of volatile organic compounds from crib mattresses. Environmental Science and Technology 48, 3541-3549.

Boor B.E., Spilak M.P., Corsi R.L., Novoselac A. (2015) Characterizing particle resuspension from mattresses: chamber study. Indoor Air 25, 441-456.

Boor B.E., Spilak M.P., Laverg, J., Novoselac A., Xu Y. (2017) Human exposure to indoor air pollutants in sleep microenvironments: A literature review. Building and Environment 125, 528-555.

Bradley R.H. (2003) Childcare and common communicable illnesses in children aged 37 to 54 months. Archives of pediatrics & adolescent medicine 157, 196-200.

Braun G.J., Zeiler W. (2019) CO_2-concentration of the surrounding air of sleeping infants inside a crib, Proceedings 40th AIVC Conference: From Energy crisis to sustainable indoor climate–40 years of AIVC. Air Infiltration and Ventilation Centre (AIVC), Gent, Belgium.

Brent R.L., Weitzman M. (2004) The Vulnerability, Sensitivity, and Resiliency of the Developing Embryo, Infant, Child, and Adolescent to the Effects of Environmental Chemicals, Drugs, and Physical Agents as Compared to the Adult: Preface. Pediatrics 113, 933-934.

Burtscher H., Schüepp K. (2012) The occurrence of ultrafine particles in the specific environment of children. Paediatric respiratory reviews 13, 89-94.

CBS, (2020) StatLine - Formele kinderopvang; kinderen, uren, soort opvang, vorm opvang, regio. Dutch Central Bureau of Statistics

Da Silva D.R., Binotti R.S., Da Silva C.M., De Oliveira, C.H., Condino-Neto, A., De Capitani, E.M. (2005) Mites in dust samples from mattress surfaces from single beds or cribs in the south Brazilian city of Londrina. Pediatric Allergy and Immunology 16, 132-136.

EEA (2017) National Emission Ceilings (NEC) Directive reporting status (2017): The need to reduce air pollution in Europe. European Environment Agency, Copenhagen, Denmark.

Ferguso, A., Solo-Gabriele H., (2016) Children's Exposure to Environmental Contaminants: An Editorial Reflection of Articles in the IJERPH Special Issue Entitled, "Children's Exposure to Environmental Contaminants". Multidisciplinary Digital Publishing Institute.

Ferng S.F., Lee L.W. (2002) Indoor air quality assessment of daycare facilities with carbon dioxide, temperature, and humidity as indicators.

Journal of Environmental Health 65, 14-18.

Gabriel M.F., Felgueiras F., Fernandes M., Ribeiro C., Ramos, E., Mourao Z., de Oliveira Fernandes, E. (2020) Assessment of indoor air conditions in households of Portuguese families with newborn children. Implementation of the HEALS IAQ checklist. Environ Res 182, 108966.

Grand A. le, Duijm F. (2017) Onderzoek binnenmilieu kinderdagverblijven, GGD Groningen, Groningen, Netherlands

Hagerhed-Engman L., Bornehag C.G., Sundell J., Aberg, N. (2006) Day-care attendance and increased risk for respiratory and allergic symptoms in preschool age. Allergy 61, 447-453.

Holgate S., Royal College of Physicians (2016) Every breath we take: the lifelong impact of air pollution. Report of a working party, London: RCP.

Furtaw Jr.J.F., Pandian M.D., Nelson D.R., Behar J.V. (1996) Modelling indoor air concentrations near emission sources in imperfectly mixed rooms. Journal of the Air & Waste Management Association 46, 861-868.

Junaidi E.S., Jalaludin J., Tualeka A.R. (2019) A Review on the Exposure to Benzene among Children in Schools, Preschools and Daycare Centres. Asian Journal of Atmospheric Environment 13, 151-160.

Kim K.-H., Pande, S.K., Kim Y.-H., Sohn J.R., Oh J. (2015) Emissions of amides (N, N-dimethylformamide and formamide) and other obnoxious volatile organic compounds from different mattress textile products. Ecotoxicology and Environmental Safety 114, 350-356.

Koopman, L.P., Smit H.A., Heijnen M.-L.A., Wijga A., van Strien R.T., Kerkhof M., Gerritsen J., Brunekreef B., de Jongste J.C., Neijens H.J. (2001) Respiratory infections in infants: interaction of parental allergy, childcare, and siblings-the PIAMA study. Pediatrics 108, 943-948.

Laverge J., Novoselac A., Corsi R., Janssens A. (2013) Experimental assessment of exposure to gaseous pollutants from mattresses and pillows while asleep. Building and Environment 59, 203-210.

Lee J.Y., Kim C., Kim J., Ryu S.H., Bae G.N. (2018) Exposure assessments for children in homes and in daycare centers to NO2, PMs and black carbon. Asian Journal of Atmospheric Environment 12, 204-214.

Liang Y., Xu Y. (2014) Emission of phthalates and phthalate alternatives from vinyl flooring and crib mattress covers: The influence of temperature. Environmental Science and Technology 48, 14228-14237.

Louhiala P.J., Jaakkola N., Ruotsalainen R., Jaakkola J. (1995) Form of day care and respiratory infections among Finnish children. American Journal of Public Health 85, 1109-1112.

Mendes A., Aelenei D., Carreiro-Martins P., Agular L., Pereira C., Neves P., Azevedo S., Cano M., Prooenca C., Viegas J., Siva S., Mendes D., Neuperth N., Teixeira J.P. (2014) Environmental and ventilation assessment in Child Day Care Centres in Porto: the ENVIRH Project, J.Toxicol Environ Health A:77(14-16): 931-943

Nafstad P., Jaakkola J.J., Skrondal A., Magnus P. (2005) Day care center characteristics and children's respiratory health. Indoor Air 15, 69-75.

Offermans A., Zheng H., Zeiler W. (2020) Indoor Air Quality conditions within the baby bunk beds at Dutch daycare centers indicate the necessity for an improved ventilation ndesign, Proceedings 16th Conference of the International Society Indoor Air Quality & Climate, Indoor Air 2020, COEX, Seoul

Oliveira M., Slezakova K., Delerue-Matos C., Pereira M.C., Morais S. (2019) Children environmental exposure to particulate matter and polycyclic aromatic hydrocarbons and biomonitoring in school environments: A review on indoor and outdoor exposure levels, major sources and health impacts. Environment International 124, 180-204.

Pagliano L., Armani R., Sangalli A., Causone F., Pietrobon M. (2016) Analysis of ventilation strategies for nearly zero energy retrofit of a day care center, Proceedings Clima 2016, Aalborg, Denmark

Prussin A.J., Torres P.J., Shimashita J., Head S.R., Bibby K.J., Kelley S.T., Marr L.C. (2019) Seasonal dynamics of DNA and RNA viral bioaerosol communities in a daycare center. Microbiome 7.

Schittny J.C., Burri P.H. (2008) Development and growth of the lung. In: Fishman A.P., Elias J A , Fishman J.A., Grippi M.A., Kaiser L.R., Senior R.M. (eds) Fishman’s pulmonary diseases and disorders, vol 1. McGraw-Hill, New-York, pp 91–114

Spilak, M.P., Boor B.E., Novoselac A., Corsi R.L. (2014) Impact of bedding arrangements, pillows, and blankets on particle resuspension in the sleep microenvironment. Building and Environment 81, 60-68.

Versteeg H. (2009) Onderzoek binnenmilieu kindercentra, LBP|Lichtveld Buis & Partners

Wargocki P., Hviid C.A., Skupien A. (2016) Do New Renovated Schools and Kindergartens Secure Sufficient High Indoor Environmental Quality?, Proceedings Clima 2016, Aalborg, Denmark

WHO (2005) Effects of air pollution on children's health and development: a review of the evidence. World Health Organization, Regional Office for Europe, Copenhagen, Denmark (No. EUR/05/5046027).

WHO (2016) Ambient Air Pollution: A Global Assessment of Exposure and Burden of Disease. World Health Organization, Geneva, Switzerland 978-92-4-151135-3.

Yu K.P., Lee Y.C., Chen Y.C., Gong J.Y., Tsai M.H. (2019) Evaluation of PM1, PM2.5, and PM10 exposure and the resultant health risk of preschool children and their caregivers. Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering 54, 961-971.

Zeiler W. (2018) CO_2-concentration of the surrounding air of sleeping infants inside a crib, Proceedings Roomvent & Ventilation 2018, June 2-5, Aalto University, Espoo, Finland

Zheng H., Walker S., Zeiler W. (2022) IAQ aspects of Daycare Centers: Lungs and the Exposure to Particular Matter, ASHRAE and AIVC, submitted to IAQ 2020 conference, Athens, Greece