Ventilation Strategy for Proper IAQ in Existing Nurseries Buildings -Lesson learned from the research during COVID-19 pandemic

Katarzyna Ratajczak[1]

[1]Institute of Environmental Engineering and Building Installations, Poznan University of Technology, Pl. M. Sklodowskiej-Curie 5, 60-965 Poznan, Poland;
* Corresponding *author. Tel: 00-48-665-58-23*

E-*mail address*: *katarzyna.m.ratajczak@put.poznan.pl*

Supplementary Material

S1. Location of facilities and climate parameters

The location of the buildings and its climate are important for indoor air quality. This is especially important when the outside air is used to directly ventilate the rooms. The monthly average outdoor air temperatures in 2018 are presented in Figure S1. From January to April and from October to December, the outside air temperature is lower than 16°C. Assuming that the temperature of the indoor air in the nursery should be around 21°C, the temperature of the outside air is within this limit for June, July, and August. It can be assumed that in May and September, during the daytime, the temperature of the outside air is similar to the temperature of the air indoors. Due to the measured monthly concentration of PM and its direct seasonal relationship, it was assumed that in the heating season, the quality of the outside air is poor i.e., the concentrations of PM are above the recommended values (Environmental Protection Inspection., 2010). As such, in place of airing, alternative ventilation strategies should be used.

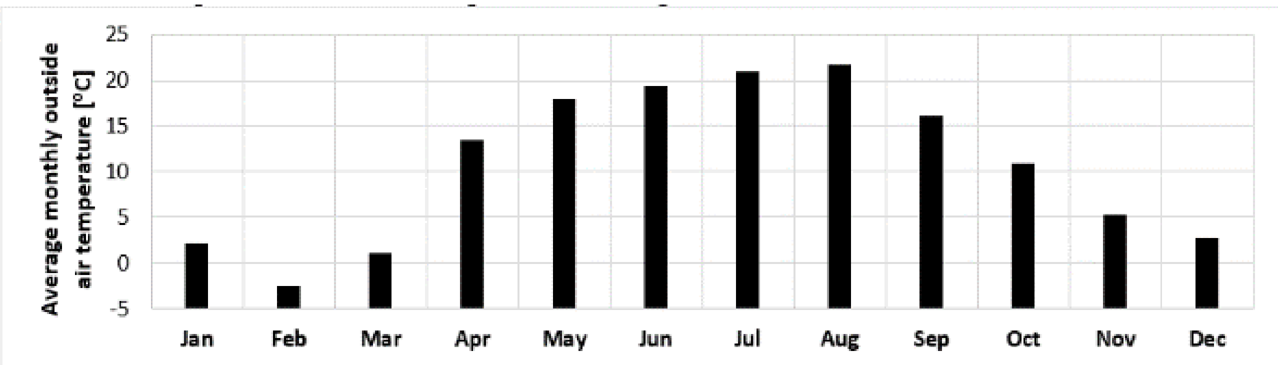

Figure S1 **Average monthly outside air temperature in Poznań** (Statistical Office in Poznań, 2019)

S2. Simulation of CO_2 concentration in nursery rooms.

Step 1: The appropriate ventilation airstream should be designed in such a way as to maintain the specified air quality in a room. For the calculation, the concentration of outside air will be adopted as 420 ppm.

The simulations will show how CO_2 concentration in the room changes during the use of the room and how CO_2 emission is related to the breathing of children and sitters. Based on previously published work, it was assumed that CO_2 emission for a child under 3 years old and a babysitter is 7.56 L/h and 18 L/h, respectively (Persily and de Jonge, 2017).

It was decided to analyze a wide range of airflows to select the smallest possible airflow that would facilitate appropriate average CO_2 concentration. From the recommendations indicated in various European countries, the following airflows were adopted: 30 m^3/h/person, 15 m^3/h/person, 10 m^3/h/person (Basińska et al., 2019; Ratajczak and Basińska, 2021).

Step 2: To calculate the variability of CO_2 concentration, equations (1) and (2) will be used. Equation (1) models CO_2 emission in response to the presence of children. Equation (2) models the situation where there are no emissions i.e., no children present.

Regarding the playroom, i.e., the room in which the children stay in the morning, vacate it for nap time, and then return to it later in the day, two equations will be used. Equation (1) will be used for calculations where the children are present in the room (morning and afternoon), and equation (2) will be used when the children are in the bedroom (nap time) and CO_2 emission does not occur. For the sleeping room, only equation (1) will be used because the bedroom is used during the sleeping time only. Further, as the children only use the bedroom once per day and do not return to it, it is sufficient to ventilate this room only during nap time. This strategy will allow for the conservation of energy relating to fan operation and a reduction in costs.

Step 3: Average CO_2 concentration seems to be the good indicator because it shows the values over the entire period of children's stay in the room, i.e., on average, it reflects what concentration of CO_2 the children are exposed to throughout the day. For the playroom, the average CO_2 concentration will be calculated over two periods of time. Additionally, the average CO_2 concentration during nap time will be determined for the bedroom.

This approach is justified by the need to find a small enough airstream to keep the average CO_2 concentration in an appropriate range. This should be done in new buildings. In existing buildings, where the CO_2 concentration limit is exceeded by up to 4 times (Basińska et al., 2019), each improvement will make it easier to achieve better parameters. Therefore, it is important that the mean concentration be acceptably low, and that the maximum concentration not be higher than 10% of this value.

Step 4: Based on the average CO_2 concentration values obtained, the design ($V_{SU,ij}$), will be selected. The following possible single devices and their parameters are presented in Table S1.

Table S1: **Parameters of decentralized units for a single room in a nursery**

Airstream per unit [m³/h]	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**260**	**300**
Efficiency of heat recovery	74%	82%	75%	68%	67%	80%	76%	75%	74%
Fan power	20W	40W	39W	37W	87W	100W	115W	150W	200W
Filtration	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA	G4+F8 HEPA
Noise level	28dBA	30dBA	32dBA	33dBA	34dBA	31dBA	29dBA	34dBA	33dBA
The required diameter of the holes	Two holes in the external wall for one unit								
	2 x 100mm	2 x 100mm	2 x 100mm	2 x 160mm	2 x 160mm	2 x 160mm	2 x 200mm	2 x 200mm	2 x 200mm

The above efficiencies were determined based on an overview of commercially available equipment. Specifying devices is not preferred, and the data has been prepared based on catalog data from various manufacturers. The proposed devices have a supply and exhaust system located on the same external wall resulting in U-shaped airflow which has been highlighted as a good set-up, even in hospital rooms (Ren et al., 2021).

Step 5: Steps 1-4 takes into account the real attendance of children during the heating season. In the design process, human presence coefficients are used to determine the ventilation airflow. Additionally, these coefficients take into account that the maximum load rarely occurs in most rooms. Further, this design aims to prevent oversizing the installation by using smaller cross-sections of ducts or smaller devices.

A situation in which the selected airflow in Step 4 will work with a predetermined efficiency, and all children will be present was simulated. The rate of air quality deterioration and whether the average CO_2 concentration over a given period (morning, nap, and afternoon).

Step 6: For the selected ventilation airflow ($V_{SU,ij}$), the air quantity indicator per m^2 and m^3 of the room will be calculated. This will make it possible to compare rooms of different architecture and to select an optimal target airflow rate.

Step7: Based on the results of the modelled simulations, an appropriate strategy for ventilating nursery rooms will be determined. The final, proposed strategy will respond to literature recommendations and fill several gaps in the knowledge. The strategy will include:

a) Determining the appropriate size of the ventilation airflow.
b) Determining the maximum concentration of CO_2 that may occur in the room.
c) Field recommendations for mechanical ventilation efficiency and technical limitations of its installation.
d) Defining actions in a critical situation i.e., exceeding the maximum CO_2 concentration, or exceeding the density of children.

S3. Assessment of mechanical ventilation and airing – how much heat is necessary to warm ventilated air?

Formula (S1) models the amount of heat needed to warm up the air (Q_{AIRING}) from the average outdoor temperature for each month (Fig.S1) to room temperature. The air is supplied to the room by airing (without pre-heating) will be calculated by the symbol M (month):

$$Q_{AIRING,M} = 1.2 \cdot 1.005 \cdot V_{SU} \cdot (t_{ROOM} - t_{EX,AVE,M}) \cdot t \text{ [kWh/year]} \quad \text{(S1)}$$

It is assumed that the outside air supplied to the room will be heated each month from the average value for a given month ($t_{EX,AVE,M}$) to the temperature t_{ROOM} =21ºC. It will be assumed that ventilation of a given intensity for 8 hours a day in the playroom and 2 hours a day in the bedroom during the heating season (7-months) for 20-days a month. The time (t) (h/year) marked in the formula corresponds to the above assumptions.

Additionally, if the air supplied to the room is preheated by the heat recovery exchanger present in the ventilation units, this rate will then be compared with the mean value of 75% from Table S1. In this case, the air temperature after the heat recovery exchanger (t_{HE}) will be determined according to the formula (S2),

$$t_{HE,M} = t_{EX,AVE,M} + \eta_{HE} \cdot (t_{ROOM} - t_{EX,AVE,M}) \text{ [°C]} \quad \text{(S2)}$$

and the heating power will be calculated according to the formula (S3):

$$Q_{VENT,M} = 1.2 \cdot 1.005 \cdot V_{SU} \cdot (t_{ROOM} - t_{HE,M}) \cdot t \text{ [kWh/year]} \quad \text{(S3)}$$

To determine the final energy required to heat the air, the following parameters were used: the total efficiency of the heating system in the case of using district heating was assumed to be 80% and the cost of a heating unit based on data from the district heating network is PLN 3.00/kWh of heat (PLN 4.50/EUR).

References for Suplementrary Materials

Basińska, M., Michałkiewicz, M., Ratajczak, K. (2019). Impact of physical and microbiological parameters on proper indoor air quality in nursery. Environment International 132. https://doi.org/10.1016/j.envint.2019.105098

Environmental Protection Inspection. (2010). Voivodeship Inspectorate for environment protection. Air quality in Poznań .

Persily, A., de Jonge, L. (2017). Carbon dioxide generation rates for building occupants. Indoor Air 27. https://doi.org/10.1111/ina.12383

Ratajczak, K., Basińska, M. (2021). The Well-Being of Children in Nurseries Does Not Have to Be Expensive: The Real Costs of Maintaining Low Carbon Dioxide Concentrations in Nurseries. Energies 14. https://doi.org/10.3390/en14082035

Ren, J., Wang, Y., Liu, Q., Liu, Y. (2021). Numerical Study of Three Ventilation Strategies in a prefabricated COVID-19 inpatient ward. Building and Environment 188. https://doi.org/10.1016/j.buildenv.2020.107467

Statistical Office in Poznań (2019). Information about the city. Monthly air temperature.