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Assessment of mechanical ventilation performance in Finnish daycare buildings

Natalia Lastovets [a], Anni Luoto [b], Piia Sormunen [a], Mohamed Elsayed [a], Antti Mäkinen [c], Jussi-Pekka Juvela [c], Sakari Uusitalo[c], Enni Sanmark [d]

[a] Faculty of Built Environment, Tampere University, Tampere, Finland, natalia.lastovets@tuni.fi

[b] Department of Construction and Property Development, Granlund Ltd, Helsinki, Finland.

[c] School of Built Environment and Bioeconomy, Tampere University of Applied Sciences, Finland.

[d] Department of Otorhinolaryngology and Phoniatrics, Head and Neck Surgery, Helsinki University Hospital, University of Helsinki, Helsinki, Finland.

Abstract. Ventilation performance is critical in daycare buildings since they are often designed for high occupancy density and longer occupant periods. During the past decades, broad research and detailed guidance on ventilation design to provide good indoor air quality have been developed in Finland. However, the Covid-19 pandemic revealed the significance of ventilation in preventing airborne transmission within enclosed spaces. Therefore, ventilation strategies are currently being reconsidered for the health emergency arising from the pandemic. Moreover, even in retrofitted educational buildings, the effect of the intervention showed some differences from what was expected at the design stage. Thus, ventilation performance analysis and detailed ventilation system inspection are required to provide healthy and safe indoor spaces.

This study presents measurement results for assessing mechanical ventilation performance and indoor air quality in several Finnish daycare buildings. Indoor air quality in daycare premises was evaluated by measuring CO2 and indoor temperature. In addition, the mechanical and electrical components of ventilation systems were expected using the Finnish guideline for inspecting ventilation systems. The study revealed differences between the expected and measured ventilation performances. The findings of this study will contribute to understanding ventilation performance and potential measures to improve indoor air quality for daycare premises.

Keywords. Indoor air quality, mechanical ventilation performance, daycare buildings, ventilation strategies

1. Introduction

Indoor air quality in daycare premises is critical. Ventilation systems play a significant role in providing proper IAQ on the premises. The significance of ventilation systems increased during the Covid pandemic after it was revealed that the infection was airborne (Morawska et al., 2021). The ventilation system used to create the indoor environment would facilitate the transmission of airborne infectious diseases.

Ventilation systems in Finland are considered to be developed. According to buildings' requirements, mechanical supply and exhaust ventilation with heat recovery are installed in Finland's non-residential premises and daycare buildings (Arvela, 2014). At the same time, the low IAQ reported in many daycare centres in Finland is reported as non-sufficient (Haverinen-Shaughnessy et al., 2015). The problems with ventilation performance in daycare buildings got special attention during the Covid-19 pandemic spread (Lastinen et al., 2021).

While monitoring virus transmission is generally complicated and highly case-specific, the first step to reducing the risk is considering improving ventilation performance. There are several factors in terms of the ventilation system: the ventilation should be designed and meet the national standard, and the mechanical and electronic components of the system should be calibrated to work correctly. In addition, the requirements of the design values for ventilation systems are getting stricter: the design airflow rate is suggested to get higher, and the schedule of ventilation systems is more extended (REHVA, 2021).

In addition, it is important to consider the use of the premises. Regarding virus spread, the general human density should be reduced, and the time for the high density should also be reduced (Morawska et al., 2021).

The present study analyses the ventilation performance in two daycare premises and a set of indoor air quality parameters. The study is a part of Business Finland financed research project E3 Excellence in Pandemic Response and Enterprise Solutions. The project will study the different pathways of pathogens and viruses, virus control and detection methods that can be used to find solutions to keep indoor air clean and safe in hospitals, offices, schools, daycare buildings and public spaces.

The daycare use case is one of the three use cases in the E3 project. The main objective of the daycare use case is to determine if the use of air purification systems can reduce the morbidity of kindergarten children and staff from circulating infectious diseases such as upper respiratory infections and stomach diseases. The use case is executed as intervention research in several day care buildings over two years period. This study is prestudy before interventions to ensure that the ventilation systems function as designed and constructed.

The ventilation system components are inspected using the corresponding Finnish guideline (Holopainen et al., 2022). The indoor air quality paraments, such as carbon dioxide and volatile organic components, are continuously monitored during the study. The research aims to give an easily implemented methodology to reveal the potentially risky premises and recommend further analysis and measures to reduce the risk.

2. Case Studies

This section presents information on studied daycare centres 1 and 2, the use of premises and the main parameters of the ventilation systems. Both daycare centres provide supervision and care of young children aged 2-7 years. The case studies focused on the occupied premises, group rooms and common spaces occupied by both children and personnel.

2.1 Daycare centre 1

The daycare centre has group rooms, small group rooms, meeting and dining rooms, dressing rooms and a multipurpose hall. Children and personnel spend most of the time in their group spaces. There are 7 preschool children's groups in the daycare centre: 4 groups for 3-7-year-old children and three groups of younger 2-3-year-olds. The main activities of the elder children's group rooms are playing, crafting and learning. Younger group activities also include 2-3-hour day naps. Also, there is a kitchen and food preparation area, and the dining area where the children and teachers have their meals. In addition, the children have intense activities in the multipurpose hall, such as physically active playing, games and singing.

Table 1

General information about the Daycare centre 1

Daycare centre 1	
Construction year	2013
Number of children	107
Number of personnel	17
Opening hours	06:15-17:30
Number of groups	7 groups
Common spaces	dining room, lobby, multi-purpose hall, small group rooms and dressing rooms

The daycare centre building has mechanical supply and exhaust ventilation systems with heat recovery.

Table 2

Parameters of room ventilation systems

Parameters of the ventilation system		Room names		
		111 Dressing room	155 Group room	133 Dining room
Airflow rate l/s	sup.	70	96	200
	exh.	–	96	200
ACH		–	2.8	6.4
AHU		202	201	201

The spaces of interest (Table 3) are served by mechanical supply and exhaust air handling units (AHU) 201 and 202. Both air handling units operate during the working days (Mon-Fri) from 4:00 to 18:00. The AHU 201 mainly serves the general spaces such as halls and small group rooms. Most group rooms are operated by the bigger AHU 202. The properties of the AHU elements are shown in Table 3.

Table 3

Content and properties of air handling units

AHU		201	202
Supply line	Airflow rate, l/s	810	2130
	Filter class	EU3 and EU7	EU3 and EU7
Exhaust line	Airflow rate, l/s	850	2150
	Filter class	EU5	EU5
	Heat recovery type	Crossflow	Rotary

2.1 Daycare centre 2

Daycare centre 2 (Table 4) has group rooms, small group rooms, meeting and dining rooms, dressing rooms and a multipurpose hall. Children and personnel spend most of the time in their group spaces. The resting rooms are used for day napping, sleeping and quiet activities. Before the dressing rooms, there are wet entryways with drying cabinets and shelves where children leave their wet clothes and shoes.

Table 4

General information of the case study Daycare centre 2

Daycare centre 2	
Construction year	2009
Number of children	122
Number of personnel	27-28
Opening hours	06:15-17:30
Number of groups	6
Common spaces	multi-purpose hall, dining room, small group rooms, dressing rooms, wet hallways and lobby

The spaces of interest (Table 4) are served by the mechanical supply and exhaust air handling unit (AHU) 201 that operates during the working days (Mon-Fri) from 6:00 to 17:00. The properties of the AHU elements are shown in Table 5.

Table 5

Content and properties of air handling units

AHU		201
Supply	Airflow rate, l/s	2900
	Filter class	EU5
Exhaust	Airflow rate, l/s	2400
	Filter class	EU3 and EU7
	Heat recovery type	Rotary

Table 6

Parameters of room ventilation systems

Parameters of the ventilation system		Room names		
		111 Dressing room	155 Group room	133 Dining room
Airflow rate l/s	sup.	70	96	200
	exh.	–	96	200
ACH		–	2.8	6.4
AHU		202	201	201

3 Methods

This section presents the ventilation system inspection methodology, airflow measurements process and indoor air quality measurements set-up.

3.1 Finnish guideline for inspecting ventilation systems

Buildings' ventilation systems have many mechanical and electrical components that require inspection and maintenance. The system must perform properly, as faults in the functioning of a ventilation system affect indoor air quality. Periodic inspections are essential to ensure the ventilation system's proper functioning. (EU, 2020). In Finland, the performance of new ventilation systems must be measured before handing it over to the building owner (ME 1009/2017). Measurements must be taken of the ductwork air tightness, the airflow rate of the system and spaces, the airflow balance, the air velocity in the occupied zone, and the specific fan power (SFP) of the ventilation system. The cleanliness of the ventilation system is inspected visually. Periodic inspections are not mandatory after commissioning. The request for a new ventilation inspection method came from the Ministry of the Environment in Finland (FINVAC 2021). The previously published guides, such as

CEN/TR 16798-18 (2017), were considered too expensive to implement for a quick inspection. The project aimed to develop a simple and low-cost method for the periodic inspections of ventilation systems. In 2022 the first version of the ventilation inspection guideline was published. The ventilation inspection guideline is intended for use in public buildings, such as educational buildings owned by municipalities and cities, kindergartens and in inspections of office buildings, ventilation.

The developed method is intended to be used as the first step in assessing the performance and cleanliness of ventilation systems.

3.1.1 Inspection stages

Figure 2 presents the stages of ventilation system inspection. The inspection process begins with selecting a qualified inspector and ordering an inspection. The building owner or its representative collects and submits the necessary documents and information to the inspector before the initial meeting. Next, the ventilation system is examined in a structured walk-through inspection with the service and operational personnel of the building. The condition of the ventilation system is recorded with photos during the inspection. The inspection ends with a final meeting and the presentation of the results to the building owner. The inspection report and certificate are saved in the building’s maintenance book.

The walk-through inspection covers the following items: design, operation and maintenance documents of the ventilation system; condition and functioning of the system and its components; air flows in the ductwork and to the rooms; the balance of the air flows; operation and maintenance of the system and its components, cleanliness and hygiene, fire safety, performance and schedules of building automation system, perceived indoor air quality and environment, and energy efficiency.

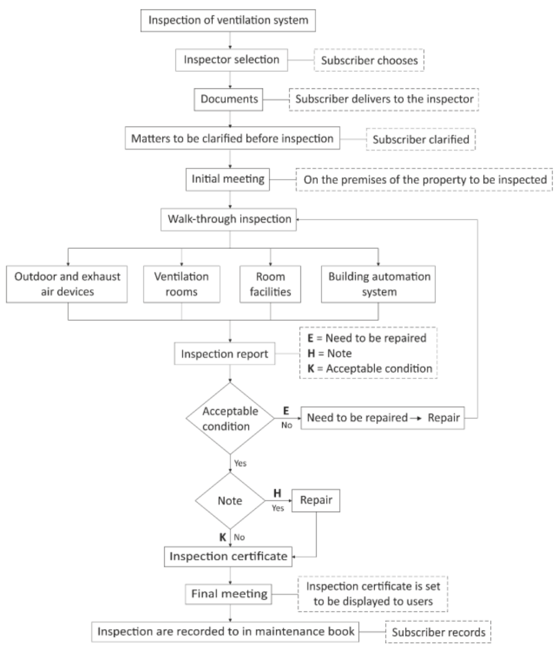
During the walk-through inspection, the ventilation inspector checks the condition, operation and need for cleaning the ventilation system components, mainly step-by-step. The inspector takes photos of the deviations he observes and records the deviations system-specific in the inspection report.

The condition, operation and need for cleaning of the ventilation system are evaluated with the letters E = condition not acceptable (needs to be repaired), H = weak condition (note) and K = acceptable condition (functions as intended). The need for additional research = L is added to the repair request if the investigation of the defect found during the inspection requires measurements made during the ventilation inspection. When evaluating the condition, the inspection interval must be taken into account. The ventilation must remain functional during the inspection interval. The number of inspections performed during the inspection and inspection costs can be reduced with trend monitoring available from building automation. Therefore, it is recommended that the person responsible for building automation in the property conducts trend monitoring of the operation of the ventilation systems.

The site tour covers all ventilation machine rooms, the water roof and the yard area if the inspection of ventilation and outdoor air and exhaust devices requires it and their inspection can be done safely. About 20% of the rooms in the service area of each ventilation machine should be inspected. In small properties with an area of less than 300 m^2, all rooms are inspected. The rooms are selected so that the inspection focuses on each floor of the ventilation unit's service area. For the target tour, rooms are chosen that represent the standard rooms in the service area of the ventilation machine. In addition, facilities with a high density of people and facilities from which users have received service requests regarding the operation of the ventilation or the quality of the indoor air are also selected for the target tour.

Figure 2

Stages of the walk-through inspection (Holopainen et al., 2022)



3.2 Airflow measurement process

The air flows were measured from the spaces where the intervention of clean air production was planned to be established after prestudy. The measurements were performed in 7 spaces in Daycare centre 1 and 7 spaces in Daycare centre 2 in a two-day time period 04-05.10.2022.

A VelociCalc air velocity manometer measured flow rates from individual diffusers. The accuracy of pressure velocity measurements is a function of covering pressure to velocity. Table 7 shows the technical parameters of the differential pressure meter.

The way to determine the volume flow from the terminal is based on the measurement of the local pressure difference. This happens with a purpose-made measuring probe, which is placed inside the valve in a prescribed manner. The manometer connected to the probe gives the result of the valve's local pressure difference, which can be used to determine the corresponding volume flow from the manufacturer's measurement curve. The method is adjustable with the help of a threaded shaft. With the right equipment and correctly performed, the inaccuracy of such a method can, at best, be ±5% of the measured value.

Table 7

Static/Differential Pressure Meter VelociCalc *Model 9555*

Parameter	Value
Range	-3735 to +3735 Pa
Accuracy	±1% of reading, ±1 Pa
Resolution	0.1 Pa
text	text

3.3 Indoor air quality set-up

The indoor air temperatures and carbon dioxide levels were measured in the studied spaces with the cloud-based indoor air quality (IAQ) monitoring service Smartwatcher. The Smartwatcher IAQ Monitoring Service is a cloud-based indoor air quality monitoring service showing real-time values for the investigated parameters.. The portable device collects air quality data every 10 minutes. Table 8 shows the technical parameters of the temperature and carbon dioxide sensors of the Smartwatcher device. The outdoor air measurements were taken from the open data given by the Finnish Meteorological Institute (FMI) (https://en.ilmatieteenlaitos.fi/)

Table 8

Technical data of Smartwatcher air temperature and CO_2 meters

Parameter		Value
Air temperature	Range	-10 to 50 °C
	Accuracy	±0.1 °C
	Resolution	0.1 °C
CO_2	Range	0 – 10000 ppm
	Accuracy	±3% of reading, ±30 ppm
	Resolution	1 ppm

4. Results

This section presents the inspection results of ventilation systems and measuring results of airflow rates, indoor air temperatures and carbon dioxide in the selected cases.

4.1 Inspection results of ventilation systems

This section presents the main results from the inspection report for both case studies (Tables 9 and 10). In general, the inspection revealed the accepted conditions of the ventilation systems. However, there were noticed problems with the cleanness of ventilation system elements (ducts, AHU room and some AHU elements). Almost all air filters in the systems were dirty and had to be replaced.

Table 9

Inspection results of ventilation systems in the Daycare centre 1

Date	04.10.2022
Parameters	Notes
Outdoor and exhaust air devices	It is recommended to clean the roof.
AHU	All filters are dirty and dusty and need replacement.
	Moisture corrosion damage of the metal between the front and side filters
	Dust under the rotary heat recovery
	The manual actuator of the damper motor prevented the operation of the damper.

	Repaired during the inspection.
Cleanliness and hygiene	The attachment of the damper motor of the grease removal channel to the damper must be checked. The damper motor does not close or open properly.
	Cleaning of the canals is planned for the summer of 2023.
Building automation system	There is no pressure difference measurement at the front filter.
	The differential pressure monitor is wrong installed; the filter monitor is on the front filter.
	The automatic selection switch is missing (0.1 switch)
	In AHU runs automation control Siemens Design, 0.1 automatic switch point is missing

Table 10

Inspection results of ventilation systems in Daycare centre 2

Date	05.10.2022
Parameters	Notes
Outdoor and exhaust air devices	The waste air damper is in the wrong place.
	The condition of the drainage is acceptable except for the pipe outlet
AHU	Dust in the exhaust fan
	The shut-off valve of the heating coil pump is leaking.
	Filters require replacement, garbage between fresh air damper and filter, and dirt stuck under the filters.
	The shut-off valve of the heating coil is leaking.
	Dirt on the bottom of the intake air chamber.
Cleanliness and hygiene	The exhaust duct is dirty/dusty.
	Scattered stuff near the AHU 202 and on it.

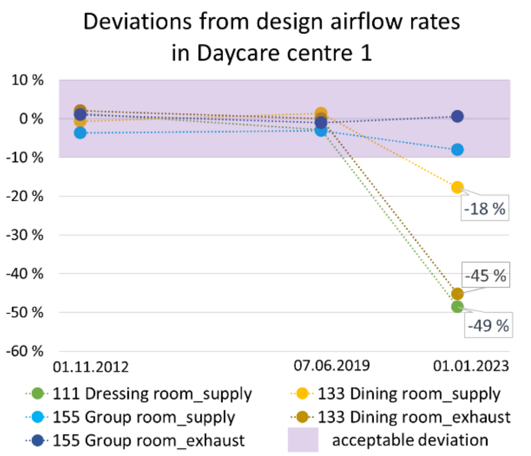
4.2 Airflow rate measurements

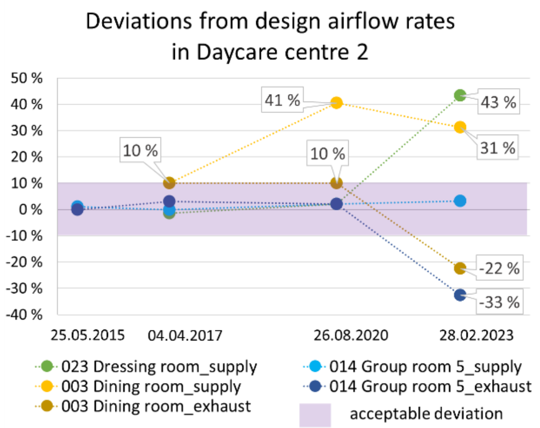
The deviations of the measured airflow rates from the design values in Daycare centres 1 and 2 are presented in Figure 3. The accepted deviation from the design airflow rates is ± 10%.

The measured results were also compared with the available measurement results in previous years. The comparison revealed that the deviation from the design values was the highest in the latest airflow measurements. In Daycare centre 1, one of two supply air terminals, and one of two exhaust grills were found to be closed in 133 Dining room, that resulted to lower air exchange in this space. In other room, the possible reasons for the deviations from the design airflow rate could be from unproper air balance and manual adjustments. The airflow rate measurements in Daycare centre 2 indicated, that the supply airflow rate was higher than exhaust airflow rate in nearly all the spaces.

Figure 3

Deviations from the design airflow rates





4.3 Indoor air quality measurements

Figures 4 and 5 represent the measurement results of the indoor and outdoor air temperatures and CO_2 levels.

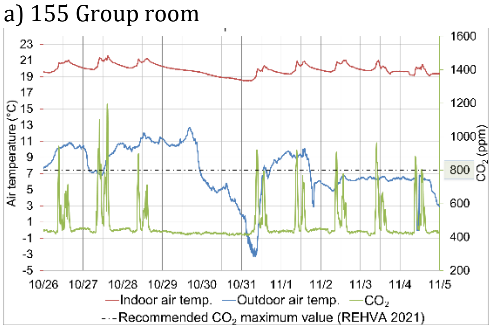
The CO_2 and indoor air temperature profiles in the selected rooms represent the occupancy times. The high level of indoor CO_2 in Group room 5 (Figure 5 b) was caused by the sensor location on the teacher's table. However, in some rooms, CO_2 levels higher than recommended 800 ppm were revealed. The cause of the increased CO_2 levels should be clarified in the future stages of the project, whether it is insufficient ventilation, exceeded occupancy or sensor location.

The indoor temperature measurements showed the proper work of the heating system in most of the rooms. The drops in the outdoor temperature did not cause the corresponding drops in indoor air temperature changes in Daycare centre 2, but there were slight changes in Daycare centre 1.

Figure 4

IAQ measurements in different rooms in Daycare centre 1

a) 155 Group room



b) 133 Dining room

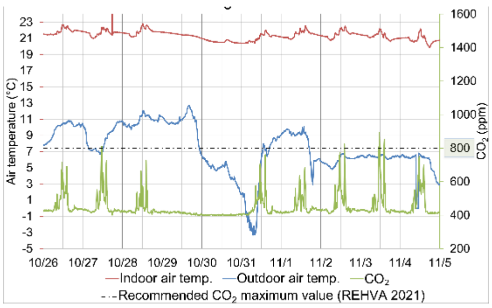
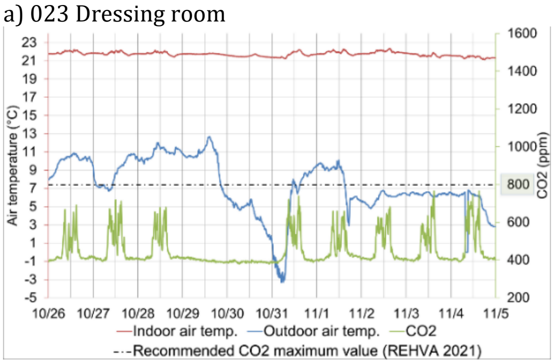


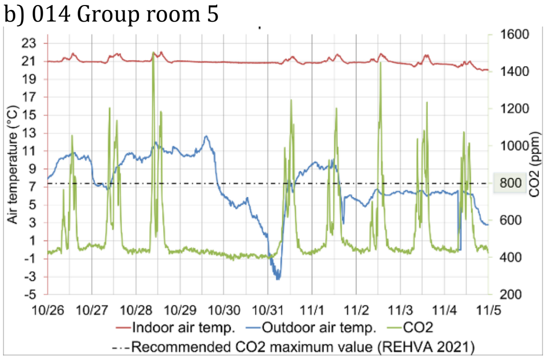
Figure 5

IAQ measurements in different rooms in Daycare centre 2

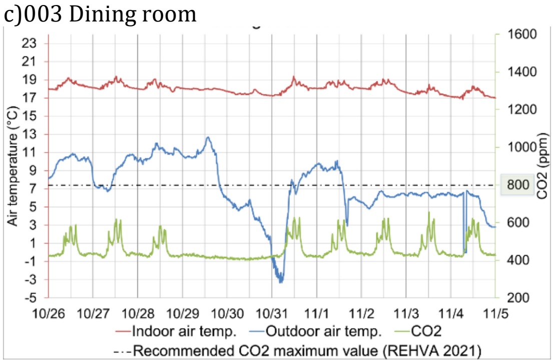
a) 023 Dressing room



b) 014 Group room 5



c)003 Dining room



5. Discussion

Ventilation system inspection is essential to ensure proper work of the system and indoor air quality. However, room airflow rate and IAQ measurements are not usually included in the inspection guidelines. At the same time, the current research results and other previous observations (Bask, 2019) indicate that there are reposted issues related to ventilation designs, balancing, sensors, and installation of ventilation. Even though an improperly functioning ventilation system does not always lead to bad room conditions, it significantly affects the room air flows, which makes it challenging to predict IAQ and virus spread. Furthermore, when new systems to improve air quality are added to the room, such as air purifiers, it is very important to check the ventilation system performance and air balances first.

6. Conclusion

The walk-through inspection is based on the inspector's sensory evaluation; therefore, it is a relatively simple and fast method to evaluate the ventilation system's performance. However, further examinations or measurements must be carried out if the reasons for the poor operation or conditions of the ventilation system cannot be specified in the sensory inspection. The inspection of ventilation systems in the presented case studies did not reveal significant faults in the ventilation systems. However, a high deviation of the measured airflow rate from the design values was observed in some rooms. Thus, the airflow rates should be rechecked in the further stages of the project. Since air imbalance is a widespread problem in ventilation systems, checking airflow rates during regular inspections of ventilation systems is generally recommended. The project research will continue with air purification studies to prevent the virus from spreading in daycare buildings.

7. Acknowledgements

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