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Major Article

Indoor air quality and symptoms of acute respiratory infections and gastrointestinal issues in children and employees in day-care nurseries

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Background: Children attending day-care centers (DCCs) experience more infections than those cared for at home and DCC employees have high sickness absence rates. This study aimed to investigate the association between indoor air quality and absenteeism among children and staff in DCCs.

Methods: CO_2 levels, relative humidity (RH), and temperature were continuously measured in 22 DCCs over 3 winter months. Simultaneously, absenteeism due to sickness was recorded for 721 children and 213 employees. In 11 DCCs, staff received training to improve ventilation.

Results: The median CO_2 concentration, RH, and temperature were 818 ppm, 38.7%, and 20.8 °C, respectively. Acute respiratory infections (ARIs) accounted for 42% of child absenteeism and 53% of staff absenteeism, while gastrointestinal symptoms (GI) were responsible for 24.7% and 27.3% of absenteeism in children and staff, respectively. No significant association was found between ARI absenteeism and CO_2 concentration, RH, or temperature. However, a significant association was observed between GI and room temperature ($P < .05$). No significant differences in CO_2 concentration or absenteeism were observed between intervention and control groups.

Conclusions: No statistical evidence was found that ARI absenteeism was associated with the measured indoor air quality parameters. GI for staff and children was significantly associated with room temperature. Absenteeism was not associated significantly with targeted interventions.

BACKGROUND

Children starting in day-care experience 2 to 3 times as many infections in the first year compared with those cared for at home, particularly among those commencing day-care at a young age.[1] In addition, 10% to 15% of preschool children have at least 12 infections per year.[2] In Denmark, about 90% of 1-year-old children attend day-care centers (DCCs).[3] Furthermore, employees in DCCs exhibit some of the highest rates of absenteeism in Denmark.[4] A review study finds that the primary cause of absenteeism for both children and staff is acute respiratory infections (ARIs), constituting over 60% of absenteeism and incurring significant personal and societal costs.[5]

Extensive research during the Coronavirus Disease 2019 (COVID-19) pandemic has documented that the primary mode of transmission for not only Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) but also for key respiratory viruses occurs through small and large aerosols released during breathing, talking, singing, coughing,

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and sneezing.[6-8] Transmission predominantly occurs indoors; therefore, it is logical to examine preventive measures targeting indoor transmission. Ventilation and airing out play central roles.[5]

For many years, CO_2 has been used as a proxy for indoor air quality (IAQ),[9] and in recent years, it has been directly linked to the risk of respiratory infections.[10,11] This is because CO_2 concentrations rise with increasing person density but decrease with air exchange rate. Several studies have indicated that high CO_2 levels can impact cognitive functions (for an overview, see the work of Fisk et al[12]). Additionally, numerous studies underscore the impact of humidity in preventing the spread of infections.[13] Several membrane-bearing viruses, including SARS-CoV-2, influenza, and respiratory syncytial virus, display enhanced survival and transmission in low-humidity conditions. There is evidence that aerosols will rapidly evaporate in dry air, resulting in reduced particle size, enabling them to penetrate deeper into the respiratory tract and remain airborne for longer periods. Additionally, there are indications that low-humidity levels lead to increased stress on the mucous membranes in the airways and heightened infection risks.[14]

Studies have been conducted on the impact of adequate ventilation on the occurrence of COVID-19 in schools in Italy and in dormitories in the United States.[15-17] To our knowledge, only a few studies have focused on respiratory infections in children and staff in DCCs with concurrent assessments of air quality. In a Danish study, Kolarik et al[18] observed a 12% reduction in the total number of respiratory infections for every one increase in air changes/h. A Finnish study reported a significant decrease in otitis media among young children in DCCs equipped with mechanical ventilation, compared with those with only natural ventilation.[19] In the Finnish study, the ventilation was only assessed qualitatively, and the air changes/h was not measured. Although airborne transmission is now considered the primary route of infection for respiratory viruses, there is substantial evidence that they can also spread through fresh mucus and hands, as demonstrated for rhinovirus.[20]

The aim of the present study was to identify which illnesses are causing sickness absence and to investigate whether IAQ is associated with sickness absence rates among both children and staff. Furthermore, we aimed to determine if targeted interventions could reduce sickness absence.

METHODS

Study population

At a meeting attended by all leaders of DCCs in a municipality, Gentofte Kommune, north of Copenhagen, the project was presented, and institutions were invited to participate. Subsequently, 22 institutions agreed to participate with a total of 671 children under 3 years old and 219 staff members, excluding managers, administrative staff, and service personnel. Each institution had up to 4 child groups, each having 1 or 2 rooms where children spend approximately 80% of their time while in the institution. Children may begin attending DCC from the age of 6 months, although they typically start between 7 and 12 months of age. Table 1 provides an overview of the participating DCCs along with basic information. Supplementary Table S1 includes additional details, such as building type, year of construction, the number and total area of operable windows, as well as the placement of any mechanical supply and exhaust ventilation systems. Furthermore, it specifies whether the children nap indoors, outdoors, under a canopy, or in a shed. There is no major difference in the amount of time children spend on outdoor playgrounds or excursions across the different DCCs.

Measurements of ventilation and other variables

Two groups with children under 3 years of age in each institution were chosen for the measurements. If the institution had more than 2 groups, those with the most diverse types of rooms were selected. The IAQ measurements were conducted by means of carbon dioxide monitors (HT-501, hti-instrument), which measure the concentration of CO_2 (0-10,000 ppm, ± 3%), relative humidity (RH) (0.1%-99.9% RH, ± 3%), and temperature (T) (−10 to + 70 °C, ± 0.3 °C). A monitor was placed in each room, and efforts were made to position it at a height of 1.5 to 2 m and as far away from doors, windows, and ventilation channels as possible. The measurements were recorded every 10 minutes from December 1, 2023 to February 29, 2024. All CO_2 monitors were tested at low and high CO_2 levels prior to the study, to ensure that no instruments deviated by more than 3% from the average. Data from 7 AM to 5 PM on weekdays, excluding holidays, were used. For concentrations of CO_2, temperature, and RH, we calculated medians for occupied hours for each of the 2 measured rooms and then took the average of the 2 values. Area per child was calculated by dividing the number of square meters in the central rooms by the number of children. IAQ measurement data were collected at the end of each month. The number of airing-out events was counted by reviewing the continuous CO_2 measurements and recording each instance where the CO_2 concentration decreased by at least 20% (minor and major ventilation events) or at least 30% (major ventilation events) over 10 minutes during daytime hours.

The volume and area of the rooms were measured and area per child was calculated as a proxy for density. The institution's leader provided information on the number of children, their average age, and how they were organized (eg, the number of children's groups, the time they spend in shared spaces, outdoor time, and the time spent with children from other groups). Eleven of the institutions had mechanical exhaust in the restroom or kitchen, while 1 institution had natural ventilation only. Ten DDCs were equipped with balanced mechanical ventilation systems. Information on the type of ventilation system was collected from the municipality's technical department.

Sick leave registration

During the monitoring period, instances of absenteeism (sick leave events) among children and staff were recorded anonymously through *postcards* with checkboxes for the following symptoms: fever, runny or blocked nose, earache, cough, sore throat, general discomfort, headache, diarrhea/vomiting/upset stomach, conjunctivitis, other illness, and absence not due to illness. We tested this anonymous method for recording sickness absence in a pilot study in another municipality outside Copenhagen in February 2023, and subsequently, the postcard was slightly adjusted (postcard available upon request). The pilot study also provided an expected level of the different symptom groups. The postcards were filled out by the staff themselves when it concerned their own illness and by parents or staff on the first day after sickness when it concerned the children's illness. The postcards were placed in a sealed box until the end of the registration period. ARIs were defined as the presence of at least 2 of the first 7 symptoms listed above. Another category was fever without other symptoms, and a third category was gastrointestinal symptoms (GIs), indicated by checking either vomiting or diarrhea. Both individual postcards and institutions were anonymous to the individuals compiling the data. Throughout the project, all DCCs were visited approximately every 2 weeks to check CO_2 monitors and maintain a focus on sick leave registration. The municipality has an electronic registration system where all parents report their children's illnesses. However, this system does not include information on the reasons/symptoms for absence but can be used to evaluate the effectiveness of the institutions in filling out symptom postcards for the children. When the number of sick leave episodes was calculated, it was adjusted for each institution's registration efficiency by comparing the number of completed postcards with the total number of sick leaves recorded through the municipality's electronic system.

Table 1
Overview of day-care centers and indoor air quality measurements

Day-care	Number of children	Mean age (months)	Number of employees	Area per child (m^2)	Ventilation*	Intervention	Median CO_2, ppm (min, max)	Median relative humidity (min, max)	Median temp (min, max)	Large ventilation events per day†	Large and smaller ventilation events per day‡
1	44	20.2	13	2.20	Nat	Yes	837 (389, 2,311)	38.5 (22.2, 59.3)	20.9 (14.2, 22.9)	0.60	1.58
2	28	27.6	10	3.21	Bal	No	630 (389, 2,256)	31.7 (17.7, 55.6)	21.4 (16.1, 27.0)	0.82	2.18
3	33	22.8	9	4.83	Nat	No	655 (388, 1,439)	36.1 (20.8, 49.3)	21.4 (15.2, 25.3)	0.62	1.84
4	15	22.3	5	4.34	Nat	Yes	906 (383, 2,599)	40.5 (23.5, 58.8)	20.0 (13.7, 26.5)	1.44	2.63
5	27	24.4	9	3.71	Bal	No	652 (382, 1,702)	34.2 (19.4, 50.9)	21.1 (18.8, 23.1)	0.16	0.74
6	26	19.0	10	3.60	Nat	Yes	1,105 (392, 3,362)	43.5 (23.7, 63.3)	20.4 (14.7, 23.4)	1.58	3.02
7	42	23.6	12	2.65	Nat	Yes	941 (393, 2,618)	41.0 (24.7, 64.7)	20.2 (14.9, 23.0)	0.96	2.55
8	26	18.0	7	3.46	Bal	No	497 (387, 1,046)	33.9 (20.5, 51.1)	22.1 (17.6, 24.9)	0.04	0.39
9	29	23.6	8	3.89	Bal	No	508 (382, 921)	33.4 (11.8, 54.6)	21.6 (13.9, 44.5)	0.09	0.50
10	21	20.3	8	3.51	Nat	No	946 (396, 3,129)	42.4 (27.3, 58.7)	20.6 (15.7, 23.6)	0.70	2.01
11	33	21.7	12	3.94	Bal	No	601 (389, 2,020)	34.0 (22.3, 66.5)	21.8 (8.6, 24.5)	0.11	0.64
12	46	20.4	14	3.03	Nat	Yes	1,062 (384, 2,674)	44.8 (27.6, 62.0)	19.0 (15.1, 22.2)	0.31	1.06
13	30	16.5	14	3.87	Bal	Yes	680 (385, 1,622)	38.5 (21.8, 82.2)	19.8 (15.4, 22.2)	0.26	1.11
14	26	20.8	8	2.77	Bal	Yes	813 (384, 2,222)	40.2 (26.6, 44.4)	21.4 (17.6, 24.8)	0.17	0.52
15	28	23.8	8	3.54	Mech	No	751 (384, 1,757)	36.3 (22.6, 57.9)	21.1 (17.3, 27.5)	0.25	1.16
16	33	23.0	11	4.42	Bal	Yes	562 (380, 1,701)	33.7 (19.6, 46.6)	22.3 (19.9, 25.5)	0.04	0.15
17	30	23.2	10	3.79	Nat	Yes	1,282 (392, 4,017)	46.7 (28.2, 61.1)	20.2 (16.9, 22.2)	0.20	0.95
18	32	23.0	13	2.80	Nat	No	1,347 (387, 3,928)	45.7 (30.1, 66.5)	21.0 (15.7, 24.7)	0.81	2.36
19	24	20.8	7	3.36	Bal	No	770 (388, 4,340)	39.5 (22.5, 64.9)	21.1 (18.0, 24.1)	0.32	0.84
20	22	21.2	7	4.13	Bal	No	653 (383, 1,676)	37.9 (23.3, 56.6)	19.4 (15.0, 22.3)	0.17	0.97
21	42	20.8	13	3.06	Nat	Yes	841 (395, 2,233)	39.7 (22.7, 54.1)	20.6 (14.5, 23.7)	0.56	1.72
22	34	23.1	11	3.04	Nat	Yes	958 (382, 2,272)	39.5 (24.5, 64.6)	21.4 (16.4, 24.4)	0.85	2.34
Total	671		219								
Intervention (mean)	33.4	21.2	11.0	3.34			907	40.8§	20.5	0.63	1.60
Control (mean)	27.5	22.4	8.91	3.67			728	36.8	21.1	0.37	1.24
Mean total	30.5	21.8	9.95	3.51			818	38.7	20.8	0.50	1.42

Bal, balanced mechanical ventilation systems; *Nat*, only natural ventilation through doors and windows; *Mech*, mechanical exhaust.
*Type of ventilation in the central rooms where children spend approximately 80% of their time.
†Defined as a decrease in CO_2 concentration of at least 30% over 10 minutes.
‡Defined as a decrease in CO_2 concentration of at least 20% over 10 minutes.
§Significant difference between the intervention group and the control group.

Intervention

Institutions were divided into 2 groups with an equal distribution of balanced mechanical ventilation system and natural ventilation through strategic randomization. The intervention comprised 30 to 45 minutes of background education for the leaders and selected educators on how respiratory infections spread, emphasizing the importance of ventilation, outdoor activities, and airing out as preventive measures. Furthermore, illustrative posters encouraging the opening of windows were displayed in central areas. All institutions were equipped with carbon dioxide monitors, but in the intervention DCCs, the display was made visible, and the staff were instructed to monitor the CO_2 levels and open windows if the concentration exceeded 1,000 ppm. This was accompanied by small descriptive posters placed next to the carbon dioxide detectors. All DCCs were visited approximately every 14 days, and in the intervention institutions, the staff were reminded of the importance of fresh air and opening windows to reduce the risk of infection transmission. Dialogs regarding sick leave and prevention were also encouraged.

Statistical analysis

We analyzed the association between different proxies of ventilation and sick leave events for the 22 DCCs. We used the following proxies of ventilation: (i) median concentration of CO_2 in the opening hours during the measuring period (3 months), (ii) percent of time where CO_2 concentration was above 1,000 ppm in the period as well as (iii) number of airing out events per day with minimum 20% drop of CO_2 concentration over 10 minutes, and (iv) number of airing out events per day with minimum 30% drop over 10 minutes in CO_2 concentration. The analysis was made for 3 categories of sick leave events: (j) sick leave due to ARI, (jj) sick leave due to ARI and "just fever" and "unknown," and (jjj) sick leave due to gastrointestinal infections. The analyses were performed separately for children and employees.

We used a linear regression model with a number of sick day events (j, jj, or jjj) as the dependent variable. Separate analyses were conducted for the above-described 4 proxies of ventilation (i, ii, iii, or iv) as the main explanatory variable. Multivariate analyses (model 1) with backward elimination (model 2) were conducted, with adjustment for mean age of children and density expressed as m^2/child. Median temperature and median RH were included in the models as well. We conducted supplementary analysis for (i) median concentration of CO_2 in an extended model where sleeping location, possibility of cross-ventilation, and type of ventilation were included.

The significance threshold was $P < .05$ and all analyses were performed in SPSS (IBM SPSS Statistics 29.0.2.0 for Windows). The sick leave data showed skewed distribution; therefore, all regression analyses were performed using the logarithm of the number of sick days. The association between sick days caused by symptoms of infectious disease and each of the ventilation proxies was calculated by the exponential transformation of the regression estimate and expressed as a percentage change.

RESULTS

During the monitoring period, 6 out of the total 44 CO_2 monitors in 4 different DCCs had unintentionally been turned off for up to 10 days. After filtering the measurements for daytime hours (from 7 AM to 5 PM) on weekdays, an average of 6,992 measurements (ranging from 5,088 to 8,041) of CO_2, temperature, and RH were collected for each DCC.

IAQ

Table 1 provides an overview of the 22 DDCs, including the number of children and staff, area per child, as well as the results of the IAQ measurements. The calculated volume per child ranged from 6.54 to 15.26 m^3 (median 9.37 m^3). As shown in Table 1, we measured a wide variation in indoor CO_2 concentrations across the different institutions, ranging from below 500 ppm (median daytime) to over 1,300 ppm (median daytime). Institutions equipped with balanced ventilation systems had significantly lower CO_2 concentrations and lower RH ($P < .05$).

Sick leave

We collected 895 sick leave postcards for children (some reported symptoms encompassed both ARI and other categories) and 234 for staff over the course of 3 months (Table 2). Using the municipality's electronic registration system, as described in the "Methods" section, we found a total of 1,684 cases of sick leave among the children giving an average overall registration efficiency of 52% using the postcards with symptoms. The registration efficiency varied among the different DCCs, from < 40% to 100%. We used the calculated registration efficiency of each DCC as a correction factor in estimating the total number of sick leave.

The predominant reported causes of absenteeism for both children and staff in DCC were infections (Fig. 1). A higher proportion of staff reported symptoms consistent with ARIs compared with children, whereas children experienced more instances of "fever only." Notably, GIs account for approximately one-quarter of absenteeism in both children and staff. Of the total reasons for sick leave events, 42% and 54% were classified as ARI in children and staff, respectively. This results in an overall incidence of about 1.6 cases of ARI or just fever per child and 0.68 per staff member during the 3 winter months. The number of records in the different symptom groups in each DCC can be seen in Table 2.

Correlation of IAQ with sick leave

The sick leave events among children and staff (ARI or ARI+fever +unknown) were not associated significantly with any of the proxies of ventilation (Tables 3a and 3b and Supplementary Tables S2-S4). However, we found a significant association between sick leave events caused by GI, for both children and staff, and median temperature ($P = .044$ and $P = .010$, respectively) with up to 32% increase in sick leave events per degree Celsius increase in temperature (95% confidence interval for adults 10%-59%) (Tables 3a and 3b and Supplementary Tables S2-S4). Further, we observed that children napping in a shed had an 18% lower incidence of ARI compared with those napping under a canopy ($P = .045$). For the staff, the trend was reversed (Supplementary Tables S5a and S5b).

Intervention

We did not observe any statistically significant difference in either CO_2 concentration or absenteeism between the intervention and control groups. In the intervention group, the average number of major ventilation events was 0.63 times per day compared with 0.37 times per day in the control group. For major and minor ventilation events combined, the average was 1.60 times per day in the intervention group versus 1.24 times per day in the control group; however, this was not statistically significant ($P = .08$ and $P = .16$, respectively).

Table 2
Causes and number of reported sick leave periods at the day-care centers

	ARI		Fever only		GI		Other		Unknown	
Day care	Children	Staff	Children	Staff	Children	Staff	Children	Staff	Children	Staff
1	21	9	14	0	7	4	2	3	9	0
2	17	5	4	0	12	4	3	0	0	0
3	23	4	6	0	12	3	5	0	0	0
4	16	1	7	0	7	0	1	0	0	0
5	17	7	49	4	14	7	3	1	14	1
6	12	8	10	0	4	2	1	0	0	0
7	29	8	9	3	15	8	0	1	4	0
8	17	2	8	1	19	0	1	0	1	0
9	28	4	2	0	13	4	0	0	0	0
10	15	2	14	1	12	1	2	0	0	0
11	16	5	1	1	9	2	4	0	0	0
12	27	3	3	0	8	1	0	0	0	0
13	16	2	8	0	6	1	1	0	1	2
14	29	9	13	1	27	6	0	1	0	0
15	10	8	8	4	7	5	0	0	1	1
16	13	12	23	4	11	12	0	0	4	5
17	7	4	7	2	9	0	4	2	4	0
18	13	0	5	1	10	1	3	0	0	0
19	28	13	5	0	8	1	3	1	0	0
20	11	3	5	0	2	1	0	1	2	0
21	10	17	3	0	4	0	0	1	0	0
22	17	2	17	0	16	0	10	0	8	0
Total	392	128	221	22	232	63	43	11	48	9

ARI, symptoms of acute respiratory infection; *GI*, gastrointestinal symptoms.

DISCUSSION

There is no indication that having a large number of respiratory infections in childhood is beneficial in any way. On the contrary, extensive studies suggest that recurrent respiratory infections may increase the risk of asthma and other respiratory disorders later in life.[21,22] In Scandinavian countries, where it is a cultural norm for many children to attend DCCs and start early, it is of significant societal importance to attempt to reduce the number of respiratory infections. Therefore, this study has investigated whether IQA has an impact on children's or staff's sick leave.

Indoor air quality

We conducted a comprehensive mapping of the indoor climate parameters, including concentration of CO_2, RH, and temperature in 22 DCCs in Gentofte municipality, in the northern part of Copenhagen, with the aim of determining whether IAQ was associated with sickness absence. Some DCCs are located in old villas, whereas others are in modern buildings specifically designed for this purpose and equipped with ventilation systems in the day-care rooms. The mapping revealed large variations in median CO_2 concentration among the different DCCs, with median values ranging from around 500 ppm to over 1,300 ppm during daytime hours. As

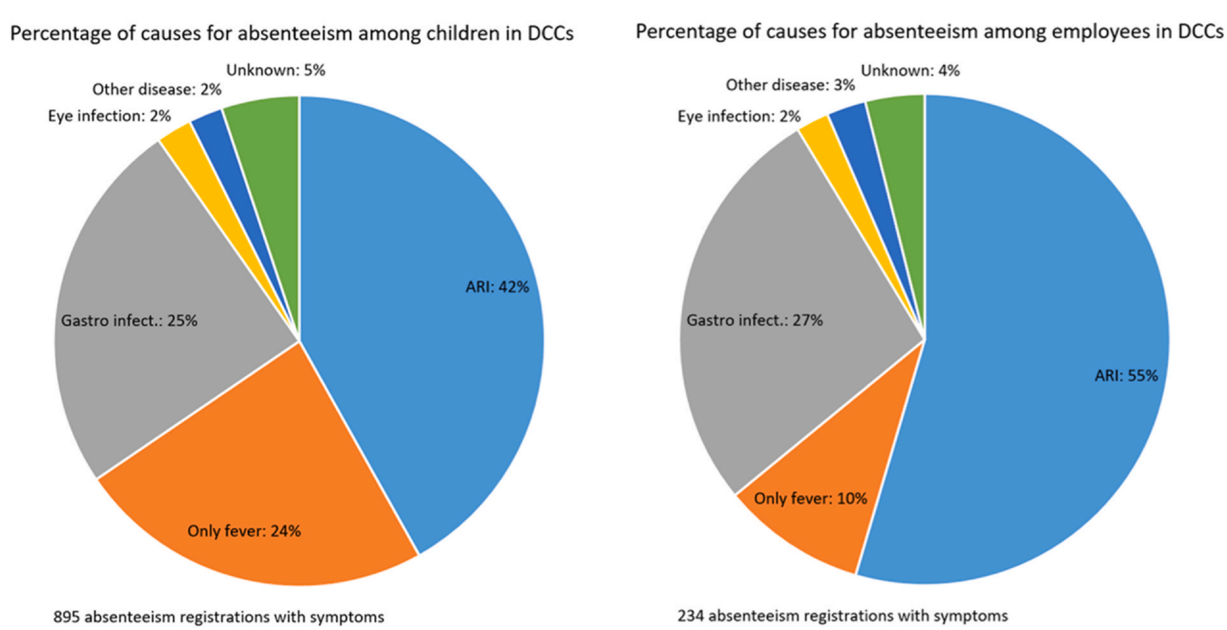

Fig. 1. Causes for absenteeism in day-care centers (DCCs) for children (left) and employees (right). *ARI*, symptoms of acute respiratory infection.

Table 3a
Associations between the number of sick leave events per child and median CO_2 concentration

	ARI				ARI+fever+unknown				GI			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value
Median CO_2	−0.2 (−0.38, 0.01)	.085	−0.02 (−0.06, 0.02)	.420	−0.1 (−0.26, 0.03)	.150	−0.01 (−0.04, 0.02)	.420	−0.2 (−0.36, 0.05)	.157		
m^2 per child	−11.7 (−25.72, 4.96)	.177			−7.8 (−18.97, 4.83)	.232			−9.7 (−24.61, 8.11)	.283		
Child age	4.5 (−2.03, 11.52)	.199			3.6 (−1.25, 8.76)	.166			6.1 (−0.80, 13.55)	.103		
Median RH	9.5 (−2.79, 23.39)	.154			5.7 (3.26, 15.54)	.237			10.7 (−2.24, 25.36)	.128		
Median temp	0.2 (−15.33, 18.59)	.982			1.3 (−10.64, 14.85)	.842			23.7 (3.76, 47.43)	.031	14.58 (1.24, 29.68)	**.044**

ARI, symptoms of acute respiratory infection; *GI*, symptoms of gastrointestinal infections; *RH*, relative humidity.
Significant values are marked in bold.

Table 3b
Associations between the number of sick leave events per employee and median CO_2 concentration

	ARI				ARI+fever+unknown				GI			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value	% difference (95% CI)	*P* value
Median CO_2	−0.2 (−0.44, 0.13)	.301			−0.3 (−0.57, 0.05)	.121	−0.06 (−0.12, 0.01)	.104	−0.2 (−0.44, 0.10)	.232		
m^2 per child	−15.4 (−32.96, 6.72)	.178			−13.0 (−33.84, 14.51)	.336			−13.9 (−34.75, 13.55)	.311		
Child age	5.9 (−3.04, 15.65)	.222			6.1 (−4.25, 17.56)	.277			8.3 (−2.12, 19.78)	.151		
Median RH	10.1 (−6.58, 29.86)	.268			13.5 (−6.03, 37.18)	.207			7.1 (−9.19, 26.38)	.431		
Median temp	19.9 (−4.82, 50.97)	.144	12.12 (−4.07, 31.05)	.167	14.9 (−12.05, 50.09)	.324			22.8 (−3.77, 56.68)	.127	31.96 (9.58, 58.92)	**.010**

ARI, symptoms of acute respiratory infection; *GI*, symptoms of gastrointestinal infections; *RH*, relative humidity.
Significant values are marked in bold.

expected, the institutions equipped with balanced mechanical ventilation systems had significantly lower CO_2 concentrations ($P < .001$).

Mapping was conducted over 3 winter months when it is cold outside in Denmark (the average outdoor temperature in December, January, and February was 3.3, 1.1, and 4.4 °C, respectively). This implies that as outdoor air is drawn in and heated, the RH decreases, and we observed that DCCs with mechanical ventilation systems had significantly lower RH ($P = .002$). We identified high levels of CO_2 during daytime hours when children and staff were present in the rooms. With median CO_2 concentrations above the maximum allowed in Danish Government regulation (1,000 ppm) and US guidelines (1,000 ppm),[23] elevated CO_2 concentrations are not desirable, especially in spaces where young children spend a significant amount of time. Several studies have indicated that high CO_2 levels can impact cognitive functions (for an overview, see the work of Fisk et al[12]), and Satish et al[24] have compared exposure to high CO_2 concentrations to the effects of consuming alcoholic beverages. However, there are discussions and studies with conflicting results regarding the impact on cognitive functions and other health effects, and there are no studies yet on the effects of indoor CO_2 concentration on children.[12] A recent review finds that most guidelines for CO_2 in indoor environments recommend 1,000 ppm as the maximum value. However, they also note that the evidence regarding this threshold and its correlation with health effects is unclear.[23]

Respiratory infections and IAQ

We find that the vast majority of absenteeism is reported to be due to symptoms of respiratory infections. Fever without other symptoms is most often indicative of milder forms of viral respiratory infections.[25,26] In the new and comprehensive knowledge gained during the COVID-19 pandemic, it is now clear that the coronavirus and other respiratory viruses primarily spread through the air via aerosols in exhaled breath. Therefore, it has been suggested that CO_2 can serve as a proxy for the risk of transmission in workplaces, institutions, and schools where many people gather. Our mapping of sick leave events among children and staff in the 22 DCCs showed that the dominant reported cause of absenteeism was symptoms of respiratory infections, followed by those of gastrointestinal infections. However, this occurrence of sick leave was not associated with the CO_2 concentration in the respective institutions for either children or staff. Perhaps, the conditions in DCCs are such that transmission pathways are dominated by the short distance between individuals. In close proximity, there is potential for transmission through both larger aerosols (droplets) and smaller ones[27]; simultaneously, transmission via physical contact, nasal secretions, and other bodily fluids is likely more prevalent in the care of young children than in most other work environments. In a large study from Germany where the effect of air purifiers was tested in DCCs, no significant difference was found between institutions equipped with air purifiers and those that were not.[28] It is possible that the distance between individuals is so short that ventilation and air exchange must be substantial to exert an effect on the spread of infection. In schools and other nonday-care work environments, a reduction in transmission of SARS-CoV-2 and other respiratory virus has been found with increased ventilation and air exchange,[17,29-31] but here, one can imagine that the distance between individuals contributes to this effect. Finally, a recent study has shown that the number of potentially infectious aerosols does not necessarily correlate with CO_2 concentration but is highly dependent on the activities performed. For example, vocalization loudness significantly influences the relationship between CO_2 levels and respiratory emission of aerosols.[32]

It should be noted that airflow patterns can be influenced by ventilation systems. Specifically, it has been modeled that heating, ventilation, and air conditioning systems may contribute to the dissemination of potentially infectious aerosols by generating turbulent airflows.[33] In DCCs, children's active and dynamic behavior may potentially counteract this effect. However, since we were unable to document a consistently lower rate of illness-related absenteeism in DCCs with ventilation systems, this could be a contributing factor.

GI and temperature

Following respiratory infections, we observed that approximately a quarter of absenteeism was due to gastrointestinal (GI) issues, this frequency is comparable to findings in other studies.[34] Surprisingly, we observed a significant association between the room temperature and the incidence of GI. Norovirus is one of the primary causes of GI and frequently leads to outbreaks in DCCs.[35-37] Norovirus, along with rhinovirus, is nonenveloped and is among the viruses frequently found on surfaces in indoor environments.[38,39] It is resilient and capable of surviving for days, and temperature is known to influence survival and transmission of enteric viruses,[40] but we have not found studies comparing transmission rates and viability under typical indoor temperature variations.

Airing out

We observed a weak association between the number of ventilation events and absenteeism caused by ARI+fever+unknown among staff. However, we have no data or reason to assume there is a causal relationship between the frequency of ventilation and employee absenteeism. There may be a number of other explanations, such as that employees who frequently ventilate are also engaged in other infection prevention activities and are more focused on wellbeing and hygiene. We observed that children napping in a shed had an 18% lower incidence of ARI compared with those napping under a canopy. For the staff, the trend was reversed. Further studies are needed to verify or explain this observation.

RH

Another aspect is humidity. We find that, particularly in DCCs with balanced mechanical ventilation systems, the indoor air is dry, with RH often below 35%. Studies show that viruses with lipid membranes remain infectious for longer periods in dry air.[14] Furthermore, aerosols in dry air will quickly diminish due to evaporation, allowing for transmission over longer durations and distances, with smaller aerosols reaching deeper into the respiratory tract. Finally, RH will also affect mucous membranes and increase susceptibility in potential hosts[5] and may increase the risk of infectious transmission; at least with important viruses such as respiratory syncytial virus, coronaviruses, and influenza. In our study, institutions with balanced mechanical ventilation systems typically had significantly drier air. This effect pulls in the opposite direction than the suspected effect of air exchange rate and may, therefore, be one of the explanations for the lack of the effect between ventilation and sick leave.

Intervention

No significant improvements were found in either CO_2 concentration or sick leave for children or staff in the intervention group. In DCCs, there is often high staff turnover, with temporary employees being utilized. The environment is busy, and several institutions have limited opportunities to open windows or spend more time outdoors. These conditions make it difficult to maintain focus on the interventions. However, we find that the intervention group has a higher average number of ventilation events.

Limitations

Information on symptoms was gathered through simple anonymous questionnaires, which, for the children, in some institutions, were completed by staff and in others by parents. This can result in heterogeneous reporting, both qualitatively and quantitatively. Staff members themselves have completed questionnaires regarding their own reasons for absence, albeit anonymously; however, there may still be various reasons why this has not been done comprehensively. Nevertheless, we have no reason to believe that these inaccuracies are related to the indoor climate of the institutions. The study was conducted in a municipality in northern Copenhagen, primarily inhabited by the upper-middle class, and the results may not be representative of other socioeconomic groups and areas.

Absenteeism was recorded as the number of sick leave events and not the duration of absence. This may have led to a focus on less severe illnesses, and sometimes the same infection may have caused multiple sick periods. Furthermore, since absenteeism was recorded anonymously, it was not possible to adjust for age and gender at the individual level, factors that are known to be of importance. Additionally, the duration of time the children spent outdoors was not taken into account.

We did not measure other indoor environmental exposures, such as particles, microorganisms, and chemical substances, which may also influence the health of those occupying the buildings. Likewise, we did not account for individual factors such as the children's and employees' lifestyle habits, socioeconomic status, family size, and underlying health conditions.

CONCLUSIONS

Our mapping of IAQ has revealed significant variation among the 22 DCCs we have studied. CO_2 concentrations were too high in some facilities according to existing standards, and the RH of the air was lower than recommended, particularly in DCCs with balanced mechanical ventilation. We have observed that the reasons for sick leave are largely dominated by symptoms of infections, particularly respiratory infections, both for children and staff. We did not find a significant correlation between CO_2 concentration in DCCs and sick leave episodes; neither total sick leave nor specifically for respiratory infections. However, we have demonstrated a significant correlation between room temperature and the incidence of GI for both children and staff. On some IAQ factors, it appears that there are differences in the patterns of absenteeism between children and staff. This may be attributed to variations in susceptibility, transmission dynamics for different viruses, and distinct patterns of behavior. Further investigations are needed to establish a significant association between temperature and gastrointestinal issues.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at doi:10.1016/j.ajic.2024.12.006.

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