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The impact of ventilation combining with moisture-buffering materials on selected parameters of environmental comfort in a nursery

Wpływ działania wentylacji w połączeniu z materiałami buforującymi wilgoć na wybrane parametry komfortu środowiskowego w żłobku

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Abstract. The article presents the results of simulations on the impact of ventilation systems combined with moisture buffering in partitions on air quality and thermal comfort in a nursery. The simulations were conducted using the WUFI Plus software. The performance of mechanical ventilation was compared with gravity ventilation. The analyses indicated that controlling CO_2 concentration is more favorable for local comfort, and moisture buffering in materials reduces the amplitude of humidity changes in the room.

Keywords: indoor climate; indoor air quality; moisture buffering; ventilation systems.

Streszczenie. W artykule przedstawiono wyniki symulacji wpływu działania systemów wentylacyjnych w połączeniu z buforowaniem wilgoci w przegrodach na jakość powietrza i komfort cieplny w żłobku. Symulacje przeprowadzono w programie WUFI Plus. Porównano działanie wentylacji mechanicznej z wentylacją grawitacyjną. Analizy wykazały, że sterowanie stężeniem CO_2 jest korzystniejsze w przypadku lokalnego komfortu, a buforowanie wilgoci w materiałach wpływa na zmniejszenie amplitudy zmian wilgotności w pomieszczeniu.

Słowa kluczowe: klimat wewnętrzny; jakość powietrza wewnętrznego; buforowanie wilgoci; systemy wentylacyjne.

The quality of the indoor environment is closely related to the proper airflow of ventilated air supplied to the room. Especially, childcare facilities require a high and consistent air exchange rate to ensure healthy and safe conditions conducive to children's development. Unfortunately, in most of these facilities, we deal with gravity ventilation, which does not provide sufficient air exchange in the rooms or, due to leaks in the building envelope, leads to increased, unjustified heat consumption through increased air exchange. Therefore, it becomes a challenge to ensure good air quality in childcare facilities.

Rooms designated for childcare have their own specifics. Typically, for several to a dozen hours during the day, they are occupied by a group of around 25 people, while they remain unused for the rest of the time. Additionally, childcare rooms do not have additional moisture gains from activities such as laundry or cooking; however, there are gains associated with the presence of occupants. Therefore, the appropriate ventilation design in such facilities should be based on Demand Controlled Ventilation (DCV) systems, which allow for intelligent adjustment of airflow to actual needs [1, 2]. By implementing DCV systems, ventilation in childcare facilities can be more flexible and efficient, dynamically adapting to changing operating conditions. Such a solution not only can reduce energy costs, but also significantly improve the indoor air quality in the room. Another solution may involve the use of moisture-buffering materials. In the literature, examples can be found of such additional passive solutions allowing for the regulation of relative humidity in the air in a room, through the use of appropriate finishing materials for internal surfaces [3 – 6]. However, there are few examples where the potential for moisture buffering has been studied in combination with various ventilation control methods. Woloszyn et al. [7] investigated the impact of combining a humidity-controlled ventilation system with moisture-buffering materials in rooms on indoor climate and building energy efficiency. The results of their research showed that humidity-controlled ventilation reduces the range between the minimum and maximum relative humidity values in the room and generates energy savings by maintaining relative humidity at the required

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level. However, a drawback of this type of ventilation is that other pollutants (such as CO_2) may exceed expected levels.

The authors of this publication, aiming to assess selected indoor comfort parameters in a nursery room, compared the performance of a CO_2 concentration-controlled DCV system with a gravity ventilation system using different interior finishing materials with moisture-buffering capabilities. To conduct a comprehensive evaluation of individual solutions, the study used WUFI Plus software [8], developed by the Fraunhofer Institute for Building Physics in Germany. The mathematical and physical models in WUFI Plus are based on assumptions outlined in Künzela's work [9], while the calculation method of WUFI complies with EN 15026 standard [10]. Model validation is presented in various studies [11 – 13].

Research

Building description. The simulation model was created for a nursery building designed and built in the 1970s, located in Warsaw (52.13°N and 21.00°E), with a typical structural layout typical for such facilities. Simulations were conducted for a room serving as a children's activity area.

The analyzed room is located on the second and last floor – it is an end room with a volume of 132 m³. The external wall with windows faces south. The analyses were performed on an existing building with thermal characteristics presented in Table 1.

Table 1. Description of the building components
Tabela 1. Opis przegród budowlanych

Type of partition	Total thickness [mm]	Thermal transmittance [W/(m²K)]
External wall (west and south orientation)	397.5	1.04
Flat roof	263.5	0.42
Internal wall	263.5	2.06
Intermediate floor slab	310.5	0.89
Window		2.53

To analyze the influence of the buffering effect of finishing materials on the indoor climate in the room, two types of internal finishing materials were considered for analysis: gypsum plasterboard marked as A1 and cement-lime plaster marked as A2, with thermal and moisture properties presented in Table 2. Two painting variants of the internal surface of the finishing material were assumed: unpainted (variant -a) and painted with acrylic surface paint defined by a diffusion resistance coefficient value of S_d = 0.5 m (variant -b).

Table 2. Properties of internal coverings
Tabela 2. Właściwości cieplno-wilgotnościowe materiałów wykończeniowych

Parameter	A1 gypsum plasterboard	A2 cement-lime plaster
λ [W/(mK)]	0.20	0.80
μ [-]	6.1	19.0

The thermal and moisture properties of the materials used were taken from the database of the WUFI Plus program. The following initial conditions were assumed: indoor temperature of 20°C, relative humidity of 50%, and CO_2 concentration of 400 ppm. The simulation analyses were conducted for climatic data from September 1, 2022, to August 31, 2023, with a time step corresponding to 1 hour.

Functional characteristics of the room. The nursery usage profile was based on information obtained from nursery staff. According to them, the room is used between the hours of 6:00 and 17:00 on weekdays, Monday to Friday. In the morning, children gather from 6:00 to 7:00, and in the afternoon, they are picked up by parents from 15:00 onwards. Therefore, the following assumptions were made: from 6:00 to 7:00, there are 1 caregiver and 2 children present; from 7:00 to 8:00, there is 1 caregiver and 10 children present; from 8:00 to 16:00, there are 2 caregivers and 15 children present, and from 16:00 to 17:00, there are 1 caregiver and 5 children present.

The daily and hourly profiles of heat emission through convection and radiation, humidity, and CO_2 production used for calculations are presented in Table 3, which was developed using data obtained from the WUFI Plus simulation program. According to the program description, the values were determined based on: ASHRAE 55 standard [14] for heat emission, IEA ANNEX 41 [15] for moisture gains, and ASHRAE 62 standard [16] for CO_2 emissions.

Characteristics of the ventilation system. Regarding the ventilation system solution, two scenarios were assumed:

● V1: Gravity ventilation with air exchange through infiltration at a rate of ACH = 0.5 1/h and with windows opening four times a day for 10 minutes each time during the hours of 6:00 to 6:10, 8:00 to 8:10, 11:00 to 11:10, 14:00

Table 3. Utility profile of the nursery with heat and moisture generation and emission of CO_2
Tabela 3. Profil użytkowy żłobka wraz z zyskiem ciepła i wilgoci oraz emisją CO_2

Room occupancy hours	Sensible gains (convection) [W]	Sensible gains (radiation) [W]	Latent gains (humidity) [g/h]	CO_2 emission [g/h]
6.00 – 7.00	168	84	161	81
7.00 – 8.00	552	276	529	265
8.00 – 9.00	864	432	828	415
9.00 – 11.00	1656	828	2215	754
11.00 – 12.00	864	432	828	415
12.00 – 14.00	624	312	483	340
14.00 – 15.00	864	432	828	415
15.00 – 16.00	1656	828	2215	754
16.00 – 17.00	312	156	299	150

to 14:10, and 16:30 to 17:00, assuming an air exchange rate in the room of 4 1/h (in accordance with the Regulation on local and sanitary requirements for the premises in which a nursery or children's club is to be operated [17]);

● V2 • V2: Demand-controlled ventilation prioritizing CO_2 concentration levels not exceeding 1500 ppm according to the German standard DIN 1946-2 [18]. The supply airflow rate is determined based on individual airflow rates per person according to the room occupancy profile, at a level of 285 m^3/h. During the summer period, the system additionally limits the room temperature to a maximum of 26°C. The system operates during hours when people are present in the room. During other hours, it is assumed that only air infiltration occurs through building leaks, at a rate of ACH = 0.5 1/h.

In both cases, the temperature is maintained at 20°C throughout the period from September 1, 2022, to May 31, 2023, by the heating system.

Results and Discussion

The impact of the ventilation system combined with the selected interior surface finish on maintaining thermal comfort in the room was evaluated. This effect was assessed by analyzing the variability in the number of hours during which the indoor air quality parameters remained within acceptable ranges during the room's usage hours from 6:00 to 17:00 on weekdays, from Monday to Friday (3132 hours). The acceptable ranges were set as follows:

■ Temperature: 20 – 26°C;

■ Relative humidity: 40 – 60%;

■ Carbon dioxide concentration: not exceeding 1500 ppm.

The evaluation was carried out for the following variants of the interior surface finish of the building partitions:

● A1-a: Unpainted gypsum plaster board;

● A1-b: Gypsum plaster board painted;

● A2-a: Unpainted cement-lime plaster;

● A2-b: Cement-lime plaster painted.

Figure 1 illustrates the number of comfortable hours in relation to temperature, humidity, and carbon dioxide (CO_2) concentration for all analyzed variants.

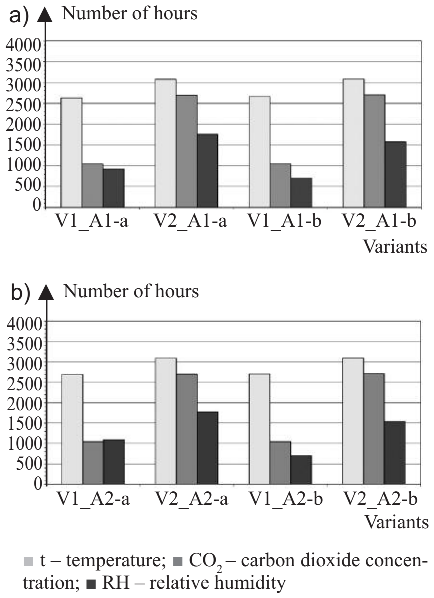


Fig. 1. The number of comfort hours for temperature, relative humidity and CO_2 for materials: a) A1 (gypsum board); b) A2 (cement-lime plaster) with paint internal surfaces of building partitions (-b) and no paint (-a), depending on the ventilation system V1 and V2

Rys. 1. Liczba godzin komfortu cieplnego w odniesieniu do temperatury, wilgotności i CO_2 w przypadku materiału: a) A1 (płyta gipsowo-kartonowa); b) A2 (tynk cementowo-wapienny) – warianty z malowaniem powierzchni wewnętrznych przegród budowlanych (-b) i bez malowania (-a), w zależności od systemu wentylacyjnego V1 i V2

For scenario V1 (gravity ventilation), the number of comfortable hours for room temperature in all analyzed material variants remains at a comparable level, approximately 2672 hours out of 3132 hours of room use, which constitutes 85% of the hours. On the other hand, with controlled supply air flow resulting from the composite maximum allowed level of CO_2 concentration (scenario V2), the number of comfortable hours averages 3087 hours, which is 95% of the hours. The higher number of comfortable hours in the case of the DCV system results from the adopted control method, which influences lowering the room temperature during the summer period. This prevents significant overheating of the room, which unfortunately is unavoidable with gravity ventilation.

The most significant difference between scenarios V1 (gravity ventilation) and V2 (ventilation with CO_2 concentration control priority) in terms of the number of comfortable hours during the room's usage period (3132 hours) is noticeable concerning CO_2 concentration. For scenario V1, the number of comfortable hours for all analyzed material solutions is 1044 hours, which constitutes 33.3% of the hours. In contrast, for scenario V2, the number of comfortable hours is 2704 hours, which represents 86.3% of the hours. This is evident due to the adopted ventilation system control method.

When analyzing the variability of relative humidity in the room for scenario V2 and unpainted gypsum plasterboard (V2_A1-a), the number of comfortable hours is 1757 hours, while for unpainted cement-lime plaster (V2_A2-a), it is 1771 hours. However, for painted variants, the numbers are as follows: V2_A1-b – 1576 hours and V2_A2-b – 1542 hours. For scenario V1, a deterioration in air quality regarding relative humidity can be observed, reflected in a lower number of comfortable hours during the room's usage period compared to scenario V2. Analyzing scenario V1, we can see that for material A1 without painting (V1_A1-a), the number of comfortable hours is 924 hours, and for material A2 also without painting (V1_A2-a), it is 1090 hours. Meanwhile, for painted variants, we have respectively: V1_A1-b – 704 hours, V1_A2-b – 703 hours. Therefore, when comparing painted and unpainted solutions, both for materials A1 and A2, the number of comfortable hours is higher in the case of unpainted variants. The differences described in terms of individual material solutions were influenced by their diverse hygroscopic properties, translating into their moisture buffering capacity. The use of a material characterized by a higher moisture buffering capacity (material A2) allows for a reduction in the time users spend in extreme conditions. On the other hand, painting interior surfaces with paint with an additional diffusion resistance significantly reduces the moisture buffering ability of the individual materials, resulting in greater differences in terms of relative humidity amplitude in the room. Similar results were obtained in their studies by Latif et al. [19] and Shang and Tariku [20].

Regardless of the finishing material used, when implementing scenario V1, a deterioration in air quality regarding relative humidity can be observed, reflected in a lower number of comfortable hours during the room's usage period compared to scenario V2. In the case of gravity ventilation, several airings of the room were assumed. By opening the windows in the summer, warm and humid air enters the room, while in the winter, dry air enters, which, when heated, increases its humidity. This increase in humidity is absorbed by hygroscopic materials, which simultaneously lower the humidity in the room by absorbing moisture. On the other hand, in scenario V2, where CO_2 control with ventilation cooling was assumed, there are no distinct peaks in relative humidity in the room. Therefore, in this case, the differences between painted and unpainted materials are significantly smaller. This is evident in Figure 2, which shows the daily variability of

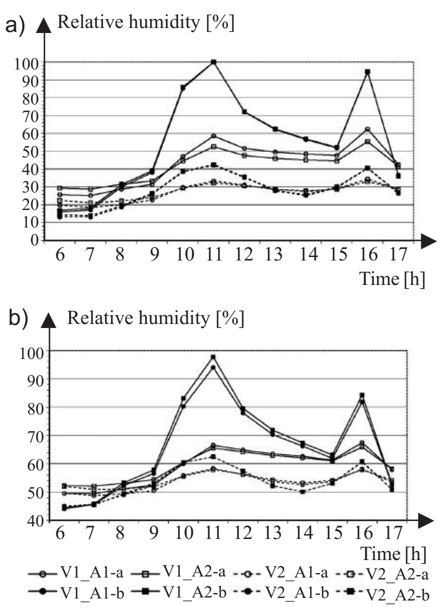


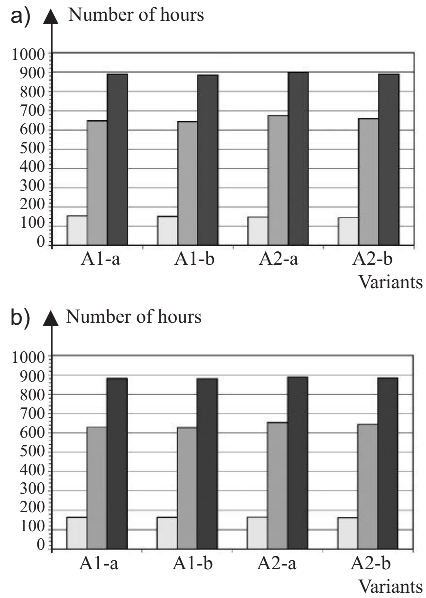
Fig. 2. The indoor relative humidity change on: a) 7 December 2022; b) 5 July 2023
Rys. 2. Zmiana wilgotności względnej w pomieszczeniu: a) 7 grudnia 2022 r.; b) 5 lipca 2023 r.

relative humidity for a selected day in the summer (July 5, 2023) and winter (December 7, 2022).

Therefore, comparing the relative humidity change in the room depending on the type of ventilation system and the applied finishing material of the interior partitions, it can be observed that the amplitude of changes for the unpainted variants (-a) is smaller compared to the painted variants (-b). The smallest amplitudes of relative humidity changes are observedwith the DCV system (scenario V2) for unpainted materials, where it is 7% RH for material A2 and 9% RH for material A1, respectively. On the other hand, for painted variants, this amplitude is 17% RH, regardless of the material type. In the case of material solutions with gravity ventilation (scenario V1), the differences between painted and unpainted materials are even more pronounced. For unpainted materials, the amplitude is 14% RH for material A2 and 18% RH for material A1. For painted materials, there is no difference in the amplitude value between material A1 and A2; it is always 50% RH. This also confirms that painting hygroscopic materials with paint reduces their hygroscopic properties.

Since the above results confirm that mechanical ventilation systems such as DCV are capable of providing better temperature, relative humidity, and CO_2 concentration parameters, additional assessment of thermal comfort conditions was proposed for DCV mechanical ventilation (scenario V2) with reference to the alphabetical classification of rooms presented in standard PN-EN ISO 7730 [21]. This standard assigns indoor environments to letter categories A, B, C, depending on the values of thermal comfort parameters PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied):

- Category A – highest requirements, due to the presence of particularly sensitive users in the rooms, e.g., children, PMV index within <-0.2; +0.2> and PPD<6%;
- Category B – normal requirements for rooms in newly constructed or renovated buildings, with functions other than those mentioned in category A, PMV index within <-0.5; +0.5> and PPD<10%;
- Category C – conditions at a medium but still acceptable level; this category can be adopted in existing buildings, PMV index within <-0.7; +0.7> and PPD<15%.



Signs: ■ A; ■ B; ■ C

Fig. 3. Number of comfort hours in relation to the requirements set for a given category of buildings according to PN-EN 7730 [21] in relation to indicators: a) PMV; b) PPD
Rys. 3. Liczba godzin komfortu w odniesieniu do wymagań stawianych danej kategorii budynków wg PN-EN 7730 [21] w odniesieniu do wskaźników: a) PMV; b) PPD

Due to the analysis of the behavior of moisture-buffering materials, Figure 3 shows the number of hours for which the PPD and PMV indices, with respect to the analyzed interior surface finishes, meet the requirements for a given room category (A, B, C).

From the comparison presented, it is evident that the number of hours of comfort concerning users' perceptions expressed by the PMV index for the respective categories is similar across all analyzed interior surface finish solutions. A minimal, noticeable difference occurs only between materials A1 and A2 for categories B and C. Regarding category B, when using material A2, the number of hours of comfort increased by 4.2% for unpainted surfaces and by 2.5% for painted surfaces compared to material A1. Similarly, in category C, when using material A2, the number of hours of comfort increased by 1.0% for unpainted surfaces and by 0.5% for painted surfaces compared to material A1. A similar situation occurs with respect to the PPD index, where the number of hours for which the predicted percentage of dissatisfied individuals slightly increases in categories B and C. Specifically, for category B, when using material A2, it increases by 3.8% for unpainted material and by 2.7% for painted material, and for category C, it increases by 0.9% and 0.3%, respectively. From the above, it follows that using appropriate finishing materials in a room can contribute to improving indoor air quality.

Conclusions

The study conducted an assessment of selected environmental comfort parameters (temperature, relative humidity, carbon dioxide concentration) in a nursery room. The effectiveness of a Demand-Controlled Ventilation (DCV) system controlled by CO_2 concentration was compared with gravity ventilation using different finishing materials for interior surfaces in the room. The appropriate use of moisture-buffering materials can reduce the amplitude of air humidity fluctuations in the room, both in summer and winter. These materials limit daily fluctuations in relative humidity in the room, maintaining it at a stable level within acceptable ranges for user comfort. Their application reduces the time users spend in conditions with relative humidity above 60%. However, it should be noted that the use of an additional finishing layer with significant diffusion resistance, such as paint, significantly limits this effect. Regardless of the ventilation scenario adopted, buffering materials contribute to reducing room humidity, but this effect is less noticeable in mechanically ventilated rooms. This is because the use of ventilation with controlled air flow rate continuously limits the uncontrolled, rapid increase in air humidity in the room.

The chosen finishing material for the wall surfaces does not affect the number of comfort hours with respect to the indoor temperature. For scenario V2, the number of comfort hours only increases by 10% compared to scenario V1, reaching a level of 95%, influenced solely by the chosen control method.

Regarding comfort requirements for rooms intended for young children (category A), the number of comfort hours expressed by the PMV and PPD indices in all analyzed finishing material solutions for interior surfaces in the DCV mechanical ventilation system prioritizing CO_2 is similar.

The results of the simulations confirmed that regardless of the ventilation method used, the application of moisture-buffering materials increases the time users spend in acceptable environmental conditions

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