DYNAMICS OF MENTAL PERFORMANCE IN SCHOOLCHILDREN UNDER POOR INDOOR CLIMATE CONDITIONS AND ELEVATED CARBON DIOXIDE LEVELS

Lobkis MA, Novikova II, Romanenko SP ✉, Sorokina AV

Novosibirsk Research Institute of Hygiene of Rospotrebnadzor, Novosibirsk, Russia

One of the pressing current issues requiring investigation is the adverse effect of prolonged exposure of schoolchildren to substandard indoor climates and elevated CO_2 levels, which can impair their well-being, hinder cognitive performance, and disrupt the body's adaptive capabilities. This study aimed to assess the dynamics of mental performance of students depending on the said parameters, the indoor climate and CO_2 levels. The temperature, humidity, and CO_2 datapoints ($n = 673$) were recorded using an Engineering Technical Module in two rooms. Mental performance was assessed by the performance quotient and indicators of short-term memory and attention ($n = 352$); for this purpose, we used an NS-Psychotest hardware and software complex. In statistical processing, the threshold of significance was set at $p < 0.05$. We registered an increase of temperature up to 25.7 °C, a decrease of humidity to 31.3%, and a steady growth of the concentration of CO_2 from the normal 1000 ppm to substandard 2586 ppm. By the end of the day, the proportion of schoolchildren capable of high-level mental performance had dropped by 30%. We identified significant, moderately strong inverse correlations between performance level and CO_2 concentrations ($r = –0.464$, $p < 0.001$), as well as weak inverse correlations with temperature ($r = –0.327$, $p < 0.001$). A strong inverse relationship was found between fatigue and CO_2 levels ($r = –0.599$, $p < 0.001$); schoolchildren's functional state was poorest when the CO_2 concentration was highest. The study identified a correlation between the deterioration of air quality parameters and reduced mental performance among students, highlighting the necessity for monitoring and preventive interventions.

Keywords: educational institutions, schoolchildren, hygienic learning conditions, microclimate, carbon dioxide, mental performance, fatigue, health risks, prevention

Author contribution: Novikova II, Lobkis MA — concept and design of the study; Lobkis MA, Romanenko SP, Sorokina AV — collection and processing of the material; Lobkis MA, Romanenko SP — statistical processing of the material; Lobkis MA, Sorokina AV — article authoring; Novikova II, Romanenko SP — editing.

Compliance with ethical standards: the study design was previously reviewed by the Local Ethics Committee of the Novosibirsk Research Institute of Hygiene of Rospotrebnadzor (Minutes No. 2 of February 1, 2024). The parents/legal representatives have filled the informed consent forms for the children's participation in the study.

✉ **Correspondence should be addressed:** Sergey P. Romanenko
Parkhomenko, 7, Novosibirsk, 630108, Russia; romanenko_sp@niig.su

Received: 25.06.2025 **Accepted:** 26.12.2025 **Published online:** 31.12.2025

DOI: 10.24075/rbh.2025.149

ДИНАМИКА УМСТВЕННОЙ РАБОТОСПОСОБНОСТИ ШКОЛЬНИКОВ В УСЛОВИЯХ НЕБЛАГОПРИЯТНЫХ ПОКАЗАТЕЛЕЙ МИКРОКЛИМАТА И УГЛЕКИСЛОГО ГАЗА В ПОМЕЩЕНИЯХ

М. А. Лобкис, И. И. Новикова, С. П. Романенко, А. В. Сорокина ✉

Новосибирский научно-исследовательский институт гигиены Роспотребнадзора, Новосибирск, Россия

В настоящее время актуальным является изучение неблагоприятного воздействия длительного пребывания обучающихся в условиях, не отвечающих требованиям нормативов по показателям микроклимата и концентрации CO_2, способного вызывать нарушение самочувствия, снижение показателей умственной деятельности, нарушение адаптационных возможностей организма. Целью работы было оценить динамику умственной работоспособности обучающихся в зависимости от указанных параметров. Показатели температуры, влажности и CO_2 ($n = 673$) регистрировали с помощью «Инженерно-технического модуля» в двух классах. Умственную работоспособность оценивали по коэффициенту работоспособности, показателям кратковременной памяти и внимания ($n = 352$) с использованием аппаратно-программного комплекса «НС-ПсихоТест». Статистическую обработку данных выполняли при уровне значимости $p < 0{,}05$. Зарегистрированы повышенная температура (до 25,7 °C) и низкая влажность (до 31,3%), а также устойчивое повышение концентрации CO_2 по сравнению с нормой (1000 ppm) до 2586 ppm. Установлено снижение доли учащихся с высокой работоспособностью на 30% к концу дня. Выявлены значимые обратные корреляции умеренной силы между работоспособностью и концентрацией CO_2 ($r = –0{,}464$, $p < 0{,}001$), а также слабые — с температурой ($r = –0{,}327$, $p < 0{,}001$). Обнаружена сильная обратная связь между утомлением и уровнем CO_2 ($r = –0{,}599$, $p < 0{,}001$). Наиболее выраженное ухудшение функционального состояния наблюдалось в периоды максимальных концентраций CO_2. Исследование выявило взаимосвязь между ухудшением параметров воздушной среды и снижением умственной работоспособности школьников, что обосновывает необходимость мониторинга и профилактических мероприятий.

Ключевые слова: общеобразовательные организации, обучающиеся, гигиенические условия обучения, микроклимат, диоксид углерода, умственная работоспособность, утомление, риски здоровью, профилактика

Вклад авторов: И. И. Новикова, М. А. Лобкис — концепция и дизайн исследования; М. А. Лобкис, С. П. Романенко, А. В. Сорокина — сбор и обработка материала; М. А. Лобкис, С. П. Романенко — статистическая обработка материала; М. А. Лобкис, А. В. Сорокина — написание текста; И. И. Новикова, С. П. Романенко — научное редактирование.

Соблюдение этических стандартов: дизайн исследования предварительно прошел экспертизу в Локальном этическом комитете ФБУН «Новосибирский НИИ гигиены» Роспотребнадзора (протокол № 2 от 1 февраля 2024 г.). Получено предварительное письменное информированное согласие родителей/законных представителей на участие детей в исследовании.

✉ **Для корреспонденции:** Сергей Павлович Романенко
ул. Пархоменко, д. 7, г. Новосибирск, 630108, Россия; romanenko_sp@niig.su

Статья получена: 25.06.2025 **Статья принята к печати:** 26.12.2025 **Опубликована онлайн:** 31.12.2025

DOI: 10.24075/rbh.2025.149

During the school years, the mental and physical health of students is influenced by various factors, including how well classroom conditions meet hygienic standards. Against the background of an increasing academic workload, a compromised environment depletes the body's reserves, leading to functional abnormalities and disorders of both mental and physical health [1, 2]. One of the most important tasks in creating favorable conditions for education is to monitor and improve classroom air quality, which depends in particular on microclimate parameters and carbon dioxide (CO_2) concentration [3].

Studies have shown that prolonged exposure to elevated concentrations of CO_2 (1000–1500 ppm or higher) has both immediate and delayed negative effects on students' well-being. Such exposure disrupts the metabolic processes of the circulatory, central, and respiratory systems, leading to deteriorated performance and mental activity, increased fatigue, lower resistance to infectious and non-infectious agents, and a higher incidence of upper respiratory tract diseases [4–7].

Children studying in classes with high concentrations of CO_2 often experience heavy breathing, shortness of breath, dry cough, and rhinitis. Students with asthma may have attacks [8]. Higher CO_2 levels in schools are associated with an increase in illness-related absences; respiratory infections and asthma are the main diseases in such conditions. An increase in the concentration of CO_2 in a classroom negatively affects the academic performance and general productivity of schoolchildren. It is considered a risk factor for chronic fatigue syndrome and higher incidence of upper respiratory tract diseases [9–11].

A study involving more than 400 schools in the United States found that an increase in classroom CO_2 concentration to 1,000 ppm was associated with a 10–20% drop in attendance, and that each additional 100 ppm of CO_2 corresponded to a further 0.2% decrease in yearly attendance [12]. Studies focusing on preschool establishments have shown that increasing the frequency of air exchange has a positive effect on kindergarten attendance: morbidity decreases by 12% with each additional hourly increase in the air exchange rate [13].

In Belarus, researchers reported that carbon dioxide concentrations above 1500 ppm in classrooms are associated with more complaints of rapid fatigue and headaches, affecting about one-third of primary school students [14, 15]. There is evidence of a 30.0% decrease in concentration of attention at CO_2 levels above 600–800 ppm; when these exceed 1500 ppm, about 80.0% of students experience fatigue [16]. Substandard microclimate indicators can worsen people's well-being by causing physiological changes in the functional state of organs and systems [17, 18]. In educational settings, failure to meet regulated indoor climate parameters can also disrupt children's adaptation processes [19].

Thus, numerous studies support the importance of examining how indoor air quality affects the functional state and health of individuals, particularly children, taking into account microclimate parameters and carbon dioxide levels.

It is important to note that in educational establishments, an increase in CO_2 concentration correlates with the accumulation of a wide range of other anthropotoxins released by humans as well as substances emitted by finishing materials, furniture, and educational supplies. Thus, CO_2 in this context can be considered as a convenient integral indicator (surrogate marker) of the overall level of anthropogenic load on the indoor air environment. Consequently, the observed effects on performance and well-being are highly likely caused by the combination of contaminants, and the concentration of CO_2 is an indirect indicator of this combination.

This study aimed to investigate variations in schoolchildren's mental performance across the school day, relative to classroom microclimate conditions and CO_2 concentration

METHODS

Hygienic, physiological, and analytical research methods were used in the work.

The indoor climate parameters were measured with the Engineering Technical Module (measuring instrument pattern approval certificate 89313-23) in the automatic continuous mode over the course of one week. The module recorded values of individual microclimate indicators (temperature, relative humidity) and carbon dioxide concentration around the clock, generated summary reports covering current and past data, and compared the measurements to the given regulated value ranges, visualizing the monitoring results.

The module worked for a week in two elementary school classrooms used by 3rd- and 4th-grade classes. The 4th-grade class studied during the first shift in Room 1, and the 3rd-grade class had the second shift in Room 2. The total number of observations was 673. The indoor climate was evaluated against the regulated parameters stipulated in SP 2.4.3648-20 "Sanitary and epidemiological requirements for educational organizations, recreational establishments for children and youth"; SanPiN 1.2.3685-21 "Hygienic standards and requirements for safety and (or) harmlessness to humans." As for carbon dioxide, its values were compared to those given in GOST 30494—2011 "Residential and public buildings. Indoor climate parameters"; GOST R EN 13779—2007 "Ventilation in non-residential buildings. Technical requirements for ventilation and air conditioning systems"; EN 13779:2004 "Ventilation for non-residential buildings — performance requirements for ventilation and room-conditioning systems." The rooms were similar in their architectural, planning, and sanitary specifications: each had an area of 54 m^2 and a ceiling height of 3.2 m. The design occupancy met sanitary standards and was set at 25 people, providing a minimum of 6.9 m^3 of air per student. The heating carrier (water) came from the centralized town system to the radiators in the rooms. The temperature of the carrier could not be adjusted during the school day. The ventilation was natural, enabled by window transoms and exhaust ducts, with no forced elements. In accordance with the relevant regulations, the teachers fully aired the rooms for five minutes during breaks according to the general school schedule; we did not monitor compliance with the established airing routine. Wet cleaning was performed twice a day — at the end of the first and second shifts. It is important to note how the classrooms were used differently: Room 1 was reserved for 4th-grade classes in the first shift, while Room 2, used by the 3rd grade in the second shift, served for part-time activities (up to 12 people) in the first shift.

The students' mental performance was assessed using indicators of the working capacity coefficient, short-term memory dynamics, attention span, concentration, and stability. The assessment was conducted with the NS-PsychoTest hardware and software complex, and measurements were taken three times a day — at the beginning, middle, and end of the school day — over the course of a week (total number of observations: 352).

The following techniques were used to measure mental performance:

1. Kraepelin tables [20], designed for assessment of the dynamics of mental performance and detection of fatigue, completed three times during the school day (n = 132). Each table consists

Table. Mean microclimate parameters and CO_2 concentration during the school day over a week

Indicators M ± SD	First shift (Room 1)		
	Lessons		
	1	2	3
Temperature, C°	22.2 ± 0.5	23.3 ± 0.4	23.3 ± 0.8
Relative humidity, %	46.5 ± 2.7	52.4 ± 4.3	50.5 ± 6.0
CO_2 concentration, ppm	1312.2 ± 485.4	2586 ± 543.7	2039 ± 823.8
Indicators M ± SD	Second shift (Room 2)		
	Lessons		
	1	2	3
Temperature, C°	25.7 ± 0.2	25.7 ± 0.9	25.7 ± 0.2
Relative humidity, %	31.3 ± 2.5	32.5 ± 5.0	33.5 ± 2.5
CO_2 concentration, ppm	1443.3 ± 482.7	2097.1 ± 425.1	2097.6 ± 500.6

of eight pairs of rows of single-digit numbers, with the numbers arranged vertically one above the other. The performance coefficient C_{per} is calculated as S2/S1, where S2 is the sum of correctly performed additions of the last four rows (S2), and S1 is the sum of correctly performed additions of the first four rows (S1).

2. Memory for numbers [21], designed to assess the dynamics of short-term memory, completed twice during the school day ($n = 88$). The mnemonic performance is evaluated by the number of correctly found numbers: 2 points — low efficiency, 3 points — satisfactory, 4 points — average, 5 points — high.

3. Munsterberg's method [22], designed to assess the attention concentration and stability, completed three times during the school day ($n = 132$). The testing involves finding words in rows random letters, duration — 2 minutes. The measured results are the number of incorrectly highlighted words and the number of missed words. The level of stability and concentration of attention can be low, below average, average, above average, and high.

Statistical data processing was performed using the methods of parametric and nonparametric analysis. The distribution of quantitative variables was assessed using the Shapiro–Wilk test when number of indicators was below 50 and the Kolmogorov–Smirnov test when it exceeded 50.

We used the standard methods of descriptive statistics: calculated means, standard deviations, medians, ranges (minimum and maximum), 25^{th}–75^{th} percentiles, and coefficients of variation.

For the comparative assessment of changes in quantitative indicators, we used the parametric Student's *t*-test for normally distributed data. In the case of a non-normal distribution, the Mann–Whitney test was applied for two independent groups, the Wilcoxon test for two dependent groups, and the Kruskal–Wallis test for several independent groups.

To study the relationship, we used the correlation analysis methods. The Pearson correlation coefficient was used to assess the strength of the relationship between quantitative indicators with a normal distribution, and the Spearman rank correlation — for variables with non-normal distributions. Correlation coefficients were interpreted using the Chaddock scale: weak (0.1–0.3), moderate (0.3–0.5), strong (0.5–0.7), high (0.7–0.9), very high (0.9–0.99). The significance of the relationship was assessed using the Student's *t*-test, and the relationship was considered significant at $p < 0.05$.

Statistical processing was performed in STATISTICA 10 (StatSoft; USA) and MS Office Excel 2016 (Microsoft; USA).

RESULTS

The assessment of the actual dynamics of temperature, relative humidity, and CO_2 concentration was performed to determine the cause-effect relationship of these parameters and the functional state of students. The recorded values of the indicators generally varied highly. During the first shift, the mean air temperature was within acceptable limits. In the second shift, we registered values exceeding the norm: the temperature in Room 2 was significantly higher than that recorded earlier in Room 1 through all three lessons ($p < 0.001$ for each comparison). The relative humidity in Room 1 was significantly higher than in Room 2 during all lessons ($p < 0.001$). The CO_2 concentration varied greatly during the school day in both classrooms, reaching values significantly exceeding those recommended in the hygienic standard (800–1000 ppm, GOST R EN 13779—2007 "Ventilation in non-residential buildings. Technical requirements for ventilation and air conditioning systems"). Significant differences in CO_2 concentration between shifts were observed only in the second lesson ($p = 0.049$); in the first and third lessons, the values of this parameter did not differ significantly ($p > 0.05$). The dynamics of indicators within each shift also deserves attention. In Room 1, the CO_2 concentration increased from the first to the second lesson (from an average of 1312 to 2586 ppm), and decreased by the third lesson (2039 ppm), remaining high. In Room 2, the CO_2 concentration increased from the first to the second lesson (from 1443 to 2097 ppm) and remained almost unchanged in the third lesson (2098 ppm). Thus, we identified stable differences in temperature and humidity between shifts, while the differences in CO_2 concentration were unsystematic (Table).

It should be noted that although the ventilation and heating systems are in working condition and hygienic requirements for classroom cleaning and airing are met, the microclimate parameters and carbon dioxide concentration indicate that the current preventive measures are not sufficiently effective. This highlights the need for new engineering solutions to ensure optimal air quality in classrooms.

Over the course the school day, the classroom microclimate indicators, including carbon dioxide concentration, generally increased from the 1^{st} to the 6th lesson. This increase was associated with the growth of proportion of schoolchildren whose performance dropped significantly — by more than 30% ($p < 0.05$; Fig. 1A). "At the same time, we observed a more drastic drop in the share of well-performing students during the first shift — by more than 40% ($p < 0.01$ for the pairwise comparison of proportions between the 1^{st} and 6^{th} lessons). By the end of the school day (second shift), there were no schoolchildren showing a high level of performance, and the differences in the distribution of the performance indicators between the beginning and the end of the school day were significant ($p < 0.001$). These changes, together with the influence of the studied factors, may result from the natural buildup of fatigue by the end of the second shift (Fig. 1B).

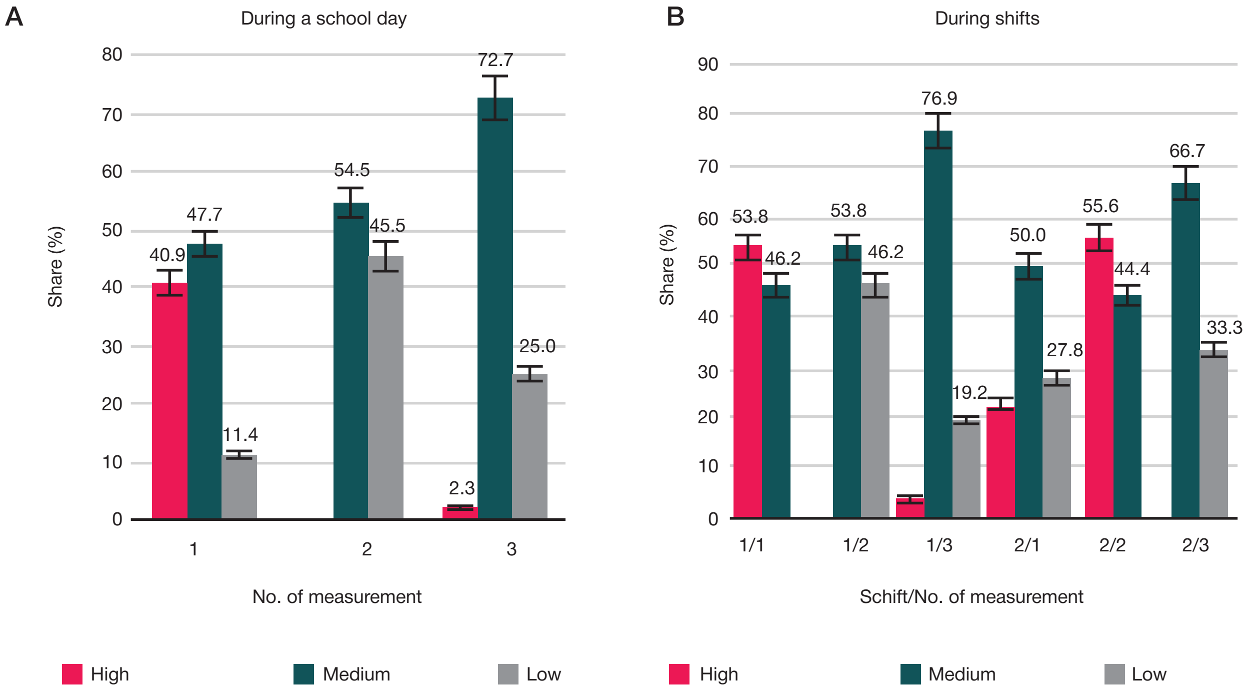

Fig. 1. Characteristics of schoolchildren by performance, %

The characteristic of the performance coefficient depending on the actual dynamics of the microclimate and carbon dioxide concentration is shown in Fig. 2. Using the Spearman's rank correlation coefficient, we found significant inverse moderately strong relationships between the performance coefficient and CO_2 concentration (r = –0.464, r^2 = –0.198, p = –0.0000), as well as weak ones between the performance coefficient and air temperature (r = –0.327, r^2 = –0.118, p = –0,000). As for humidity, it did not affect the said coefficient significantly (r = –0.056, r^2 = –0.003, p = –0.821).

The evaluation of the dependence of mnemonic processes on the dynamics of microclimate and carbon dioxide concentration (using Spearman's rank correlation coefficient) revealed significant inverse relationships of moderate strength between memory performance and CO_2 concentration (r = –0.500, r^2 = 0.254, p = 0.001), as well as between memory performance and air temperature (r = –0.384, r^2 = 0.141, p = 0.002). The relationship between memory performance and relative humidity was insignificant (r = –0.060,r^2 = –0.002, p = –0.577).

A comparative assessment of short-term memory showed that, over the study period, the proportion of students whose short-term memory remained highly effective by the end of the school day decreased from 22.7% to 9.1%, while the proportion of those who demonstrated low accuracy and poor short-term memory efficiency increased from 6.8% to 18.2% (Fig. 3A). This finding is relevant to both shifts: in the first shift,

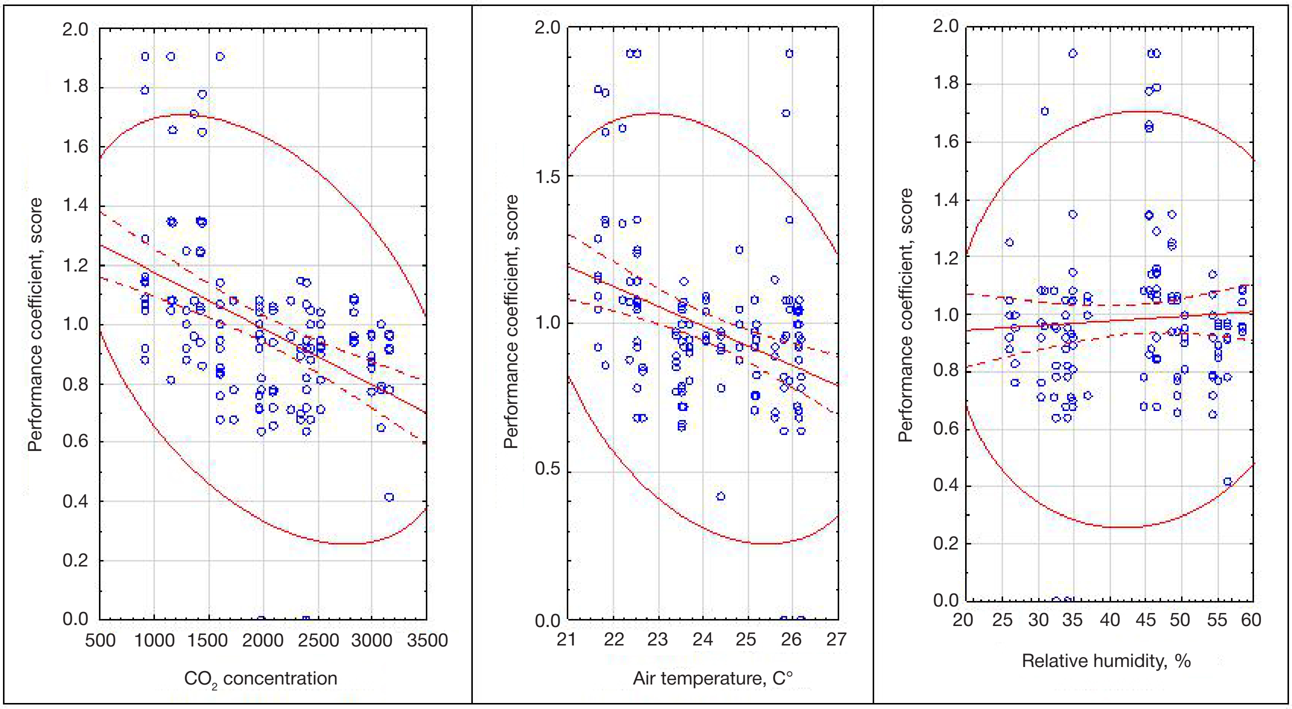

Fig. 2. Dispersion diagram of correlations between CO_2 concentration, temperature, relative humidity, and the performance coefficient

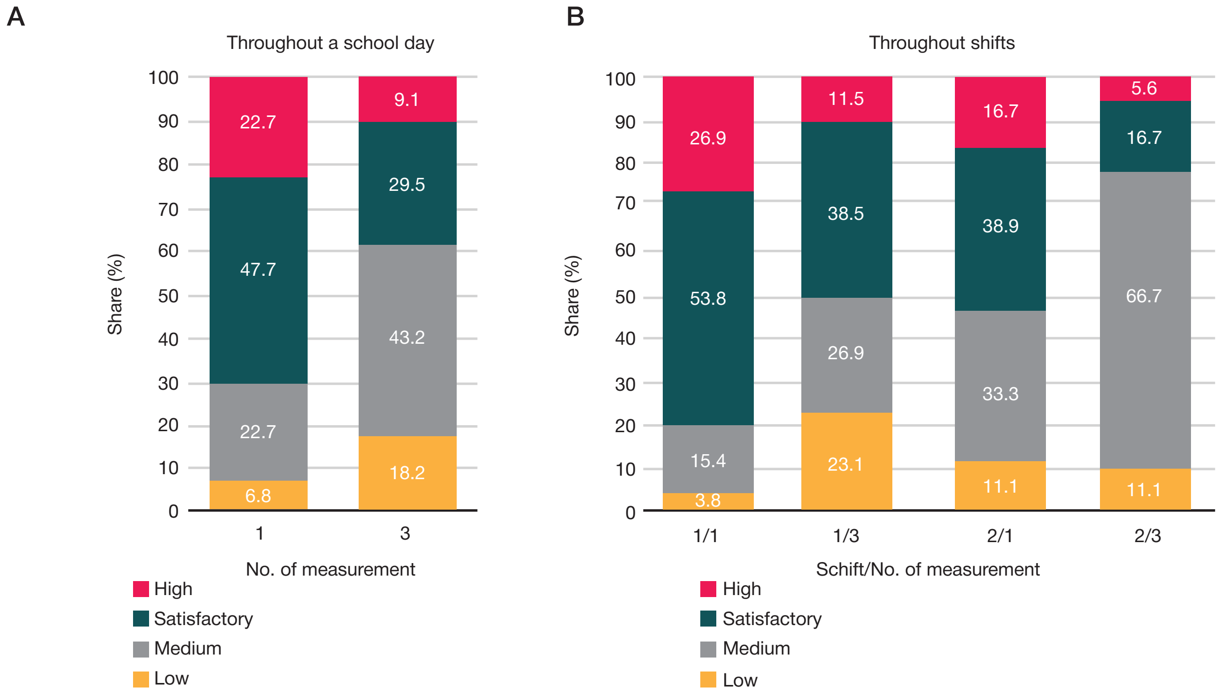

Fig. 3. Effectiveness of mnemonic processes among students throughout the school day, %

the considered indicator dropped by 15.4%, in the second shift — by 10.9% (Fig. 3B).

The share of students with low mnemonic efficiency is greatest at the highest carbon dioxide levels (Fig. 4).

Using the Munsterberg test [22], we assessed the selectivity and volume of attention in the dynamics of the school day. This test allows determining the degree of fatigue depending on the actual indicators of the microclimate and CO_2 concentration.

The results of the test, which reflect the dependence of the number of correct answers on the parameters of the microclimate and CO_2 concentration in the classrooms, are shown in Fig. 5.

In the dynamics of the school day, the assessment of fatigue levels based on actual microclimate indicators and carbon dioxide concentration revealed a strong inverse correlation between CO_2 concentration and the number of correct answers, both over the entire monitoring period and across study shifts ($r = –0.599$, $r^2 = 0.359$, $p < 0.0001$) There was also a weak significant inverse relationship between fatigue indicators and air temperature ($r = –0.303$, $r^2 = –0.092$, $p = –0.0004$), as well as relative humidity ($r = –0.244$, $r^2 = –0.059$, $p = –0.005$).

The largest proportion of respondents with the highest levels of fatigue was registered during periods when the optimal concentrations of carbon dioxide in the classroom air were exceeded (Fig. 6).

The distribution of students by attention span and selectivity also indicates that fatigue becomes more prevalent as the school day progresses. Over the entire observation period, the share of children with high fatigue levels increased by 70.4%: from 2.3% at the beginning to 72.7% by the end of lessons. Specifically, in the first shift, the proportion rose from 3.8% to 65.4%, and in the second shift — from 0% to 77.8%. In the background of this process, there is a progressive deterioration in the parameters of the air environment: carbon dioxide concentration, elevated from the outset (Table), increased by 1.5–2 times by the middle of the school day, significantly exceeding hygiene standards. In addition, during the second shift (Room 2), the air temperature was consistently above the permissible values, and the relative humidity decreased.

DISCUSSION

The importance of maintaining good air quality in classrooms and other educational spaces is beyond doubt. Back in the 1980s, Russian scientists observed a direct relationship between air quality and the well-being, performance, and other functional indicators of students, as well as significant variability in the indoor microclimate under conditions of insufficient or imperfect air exchange [23, 24]. According to current interstate standards (GOST 30494—2011 "Residential and public buildings. Indoor climate parameters"; GOST R EN 13779—2007 "Ventilation in non-residential buildings. Technical requirements for ventilation and air conditioning systems"), carbon dioxide concentration is the main indicator of indoor air quality, serving both as an independent factor and as an integral marker of human-related air pollution.

In this study, assessing the relationship between the parameters of the microclimate, CO_2 concentration, and mental performance

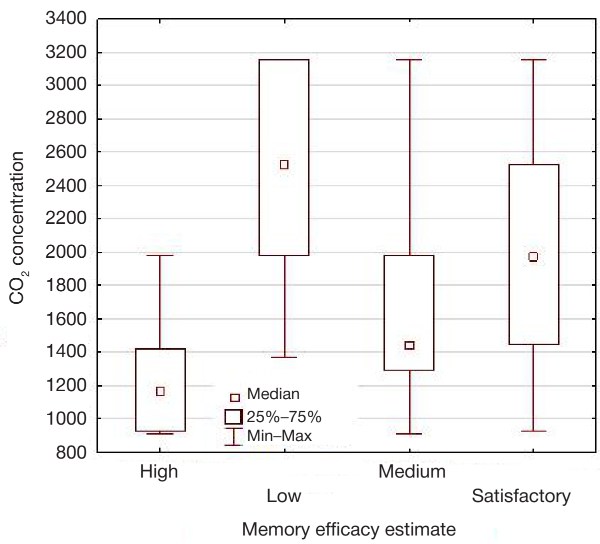

Fig. 4. Distribution of students' short-term memory efficiency depending on the actual carbon dioxide concentrations over the entire monitoring period

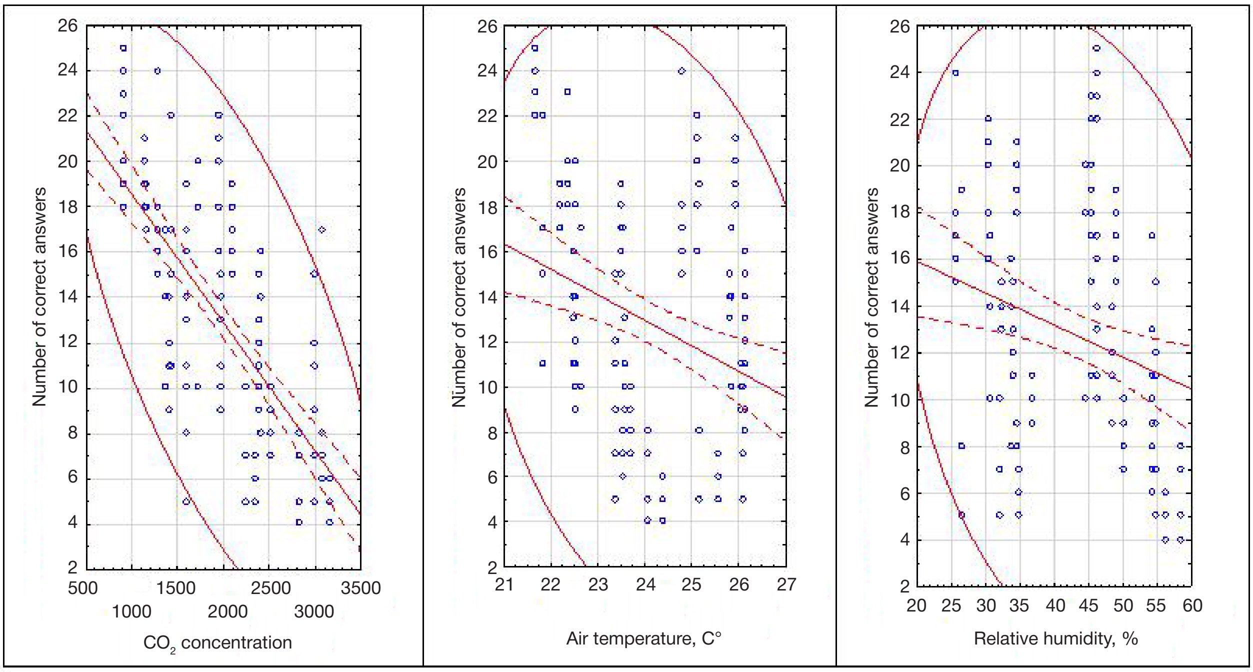

Fig. 5. Dispersion diagram of correlations between microclimate indicators and CO_2 concentration and the number of correct answers

of students, we registered a progressive deterioration in their functional state during the day. In Room 1, the number of students capable of high performance by the end of the first shift decreased by 30%, and in Room 2, there were no such students by the end of the second shift. The lack of high-performing schoolchildren by the end of the second shift deserves a special mention. There was a combination of factors behind this phenomenon: consistently increased air temperature throughout the day (exceeding the regulatory values) and a significant increase in the initially high concentration of CO_2. Such a combination could have a negative effect.

Correlation analysis confirmed significant inverse relationships, moderately strong and weak, between performance indicators, mnemonic processes, fatigue, and microclimate parameters (CO_2 concentration and air temperature). It is important to note that although the observed correlations are consistent with the hypothesis of the influence of environmental factors, they do not allow an unambiguous declaration of cause-and-effect relationships. The data obtained indicate that a decline in performance and deterioration of cognitive functions (such as memory and concentration) over the course of the school day occur in parallel with a progressive deterioration in the parameters of the air environment. This is consistent with literature data indicating a link between weakening cognitive capabilities and elevated CO_2 concentrations [25], as well as unfavorable microclimate parameters [26–29].

However, it is necessary to take into account the complex nature of the impact. The learning process itself is a burden, which naturally leads to fatigue. In the context of this observational study, it is impossible to fully isolate the contribution of the actual educational load and the contribution of the microclimate parameters to the observed deterioration of the functional state. Therefore, a more accurate conclusion is that when the learning process takes place under unfavorable air and thermal conditions (such as combined anthropogenic air pollution, high temperature, and low humidity), the development of fatigue and the deterioration of cognitive functions in students are more pronounced. The revealed relationships indicate the potential role of these environmental factors as aggravating components in the overall picture of learning fatigue.

Limitations and prospects of the study

The limitations of the study include its observational design, which does not allow full control of all related factors (person-specific variability of fatigue, pedagogical techniques, etc.), as well as measuring CO_2 concentration as the main, but not the only, marker of air quality. Further controlled intervention studies are needed to more accurately establish cause-and-effect relationships and assess the contribution of each factor. Such a study could include, for example, targeted adjustment of ventilation parameters and monitoring of a wider range of indoor air contaminants. The results of this work justify the need for continuous monitoring and the development of preventive measures to improve classroom air quality as an essential element of a healthy educational environment.

CONCLUSIONS

Continuous monitoring of temperature, relative humidity, and carbon dioxide concentration in educational facilities

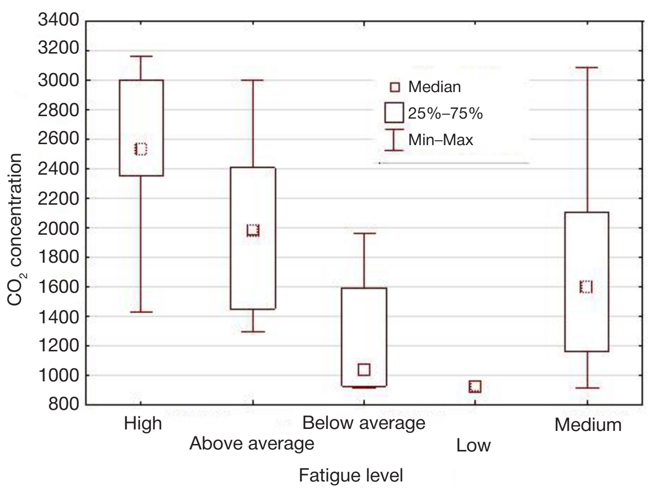

Fig. 6. Distribution of students' fatigue levels depending on the actual carbon dioxide concentrations over the entire monitoring period

revealed significant deviations from the regulated values of these parameters over the course of the school day. Room 2 (second shift) had a higher temperature because it was heated continuously throughout the day, used for part-time activities in the morning, and exposed to sunlight in the afternoon. In contrast, Room 1, which was occupied only during the first shift, lacked these sources of heat and prolonged exposure. The lower relative humidity in Room 2 is consistent with the hypothesis of increased temperature and possible insufficient ventilation efficiency. High and comparable levels of carbon dioxide concentration in both classrooms, reaching values significantly exceeding the hygienic standard, indicate that the natural ventilation, managed by a pattern, is insufficient to ensure the necessary air exchange given the actual occupancy of classrooms. The increase in CO_2 concentration by the second or third lesson reflects a typical accumulation of anthropogenic pollutants, and the absence of a systematic difference between classrooms suggests that the ventilation regime in place is ineffective at maintaining acceptable CO_2 levels, regardless of the time of classes. Thus, the presented parameters of the microclimate and carbon dioxide were formed in the conditions of typical classrooms with natural ventilation and a standard but insufficiently effective air exchange regime, and the differences in temperature and humidity are primarily related to the different times of use of classrooms during the day and the resulting differences in thermal balance. The correlation analysis confirmed that variations in classroom microclimate and carbon dioxide concentration were associated with changes in students' cognitive performance indicators. We have shown that elevated indoor carbon dioxide concentrations can reduce the effectiveness of mental performance, including shortterm memory, attention span, and concentration, and can significantly increase the proportion of students experiencing fatigue.

The results of this study make it possible to identify causal relationships within the system linking qualitative and quantitative indicators of air quality in educational institutions to the actual functional state of students. These relationships form the basis for developing a risk assessment system and a program to prevent adverse reactions in students' functional body systems in general education settings.

References

1. Gricina OP, Trankovskaja LV, Semaniv EV, Liseckaja EA. Faktory, formirujushhie zdorov'e sovremennyh detej i podrostkov. Tihookeanskij medicinskij zhurnal. 2020; (3): 19–24 (in Rus.).
2. Fedotova IV, Troshin VV, Chernikova EF, Blinova TV, Potapova IA, et al. Aktual'nye problemy snizhenija riska shkol'no-obuslovlennyh narushenij zdorov'ja u sovremennyh shkol'nikov. V knige: Gerasimenko NF, Glybochko PV, Esaulenko IJe, Popov VI, Starodubov VI, Tuteljan VA, redaktory. Zdorov'e molodezhi: novye vyzovy i perspektivy. M.: Nauchnaja kniga, 2019; 48–67 (in Rus.).
3. Novikova II, Sorokina AV, Lobkis MA, Zubtsovskaya NA, Semenikhina MV, Shcheveleva VA, et al. Carbon dioxide: problems of standard setting, content control and prevention of adverse effects in educational institutions. Russian Bulletin of Hygiene. 2023; (4): 16–25.
4. Kutsyuruba B, Klinger DA, Hussain A. Relationships among school climate, school safety, and student achievement and well–being: a review of the literature. Rev Educ. 2015; 3 (2): 103–35. DOI: 10.1002/rev3.3043.
5. Babich F, Torriani G, Corona J, Ibeas IL. Comparison of indoor air quality and thermal comfort standards and variations in exceedance for school buildings. J Build Eng. 2023; (71): 1–19. DOI: 10.1016/j.jobe.2023.106405.
6. Jacobson TA, Kler JS, Hernke MT, Braun RK, Meyer KC, Funk WE. Direct human health risks of increased atmospheric carbon dioxide. Nat Sustain. 2019; 2 (8): 691–701. DOI: 10.1038/s41893-019-0323-1.
7. Agafonova VV. Ocenka kachestva vozduha v pomeshhenii ofisnogo zdanija. Vodosnabzhenie i sanitarnaja tehnika. 2019; (3): 61–4 (in Rus.).
8. Telcova LZ. Analiz sostojanija krovi detej doshkol'nogo vozrasta v zavisimosti ot mesta prozhivanija i urovnja CO2 v atmosfernom vozduhe. Jepoha nauki. 2024; (38): 368–72 (in Rus.).
9. Gubernskij JuD, Kalinina NV, Gaponova EB, Banin IM. Obosnovanie dopustimogo urovnja soderzhanija dioksida ugleroda v vozduhe pomeshhenij zhilyh i obshhestvennyh zdanij. Gigiena i sanitarija. 2014; (6): 37–41 (in Rus.).
10. Pitarma R, Marques G, Ferreira BR. Monitoring indoor air quality for enhanced occupational health. J Med Syst. 2017; 41 (2): 23. DOI: 10.1007/ s10916-016-0667-2.
11. Sadrizadeh S, Yao R, Yuan F, Awbi H, Bahnfleth W, Bi Y, et al. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. J Build Eng. 2022; (57): 104908. DOI: 10.1016/j.jobe.2022.104908.
12. Shendell DG, Prill R, Fisk WJ, Apte M. Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. Indoor Air. 2004; 14 (5): 333–41. DOI: 10.1111/j.1600-0668.2004.00251.x.
13. Kolarik B, Andersen ZJ, Ibfelt T, Engelund EH, Møller E, Bräuner EV. Ventilation in day care centers and sick leave among nursery children. Indoor Air. 2016; 26 (2): 157–67. DOI: 10.1111/ina.12202.
14. Agafonova VV, Panferova NV, Finogenova OE, Agafonova AR. Issledovanie vlijanija koncentracii uglekislogo gaza v pomeshhenii klassnoj komnaty na zdorov'e obuchajushhihsja. Jenergosberezhenie i vodopodgotovka. 2022; 1 (135): 76–8 (in Rus.).
15. Pronina TN, Karpovich NV, Poljanskaja JuN. Uroven' soderzhanija uglekislogo gaza v uchebnyh pomeshhenijah i stepen' komforta uchashhihsja. Voprosy shkol'noj i universitetskoj mediciny i zdorov'ja. 2015; (3): 32–5 (in Rus.).
16. Robertson DS. Health effects of increase in concentration of carbon dioxide in the atmosphere. Current Science. 2006; 90 (12): 1607–9.
17. Kapranov SV, Kapranova GV, Tarabcev DV, Solenaja ES. Vlijanie mikroklimata v pomeshhenijah prebyvanija shkol'nikov na ih samochuvstvie. Jekologicheskij vestnik Donbassa. 2022; (5): 5–14 (in Rus.).
18. Kulakov KJu, Egorova EM. Vlijanie izmenenij parametrov mikroklimata na samochuvstvie cheloveka i jekspluatacionnye harakteristiki stroitel'nyh konstrukcij. E-Scio. 2019; 5 (32): 248–54 (in Rus.).
19. Bannikova LP, Sebirzjanov MD. Kompleksnaja ocenka vlijanija faktorov okruzhajushhej sredy, uslovij vospitanija i obuchenija na techenie processov adaptacii, sostojanie zdorov'ja detej, poseshhajushhih doshkol'nye obrazovatel'nye uchrezhdenija goroda. Nepreryvnoe medicinskoe obrazovanie i nauka. 2022; 17 (1): 8–13 (in Rus.).
20. Vansovskaja LI, Gajda VK, Gerbachevskij VK. Praktikum po jeksperimental'noj i prikladnoj psihologii. L.: Izdatel'stvo Leningradskogo universiteta, 1990; 125 p. (in Rus.).
21. Shapar VB, Timchenko AV, Shvydchenko VN. Prakticheskaja psihologija. Instrumentarij. Rostov-na-Donu: Feniks, 2002; 287 p. (in Rus.).
22. Artjuhov AA. "Sistema uslovnyh ballov" kak priem ocenivanija znanij uchashhihsja v hode prepodavanija estestvennonauchnyh disciplin v obshheobrazovatel'noj srednej shkole na primere geografii. Mezhdunarodnyj nauchno-issledovatel'skij zhurnal. 2024; 6 (144). (In Rus.). Available from: https://research-journal.org/archive/6-144-2024-june/10.60797/IRJ.2024. DOI: 10.60797/IRJ.2024.144.87.
23. Korenevskaja EI, Rogachevskaja LG. Gigienicheskie voprosy stroitel'stva shkol'nyh zdanij. M.: Medicina, 1974; 224 p. (in Rus.).
24. Voronova BZ, Jelkovskaja EA. Izmenenie umstvennoj rabotosposobnosti i nekotoryh pokazatelej funkcional'nogo

sostojanija central'noj nervnoj sistemy mladshih shkol'nikov v razlichnyh uslovijah vozdushnoj sredy. Gigiena i sanitarija. 1982; (9): 44–7 (in Rus.).
25. Ikeda N, Takahashi H, Umetsu K, Suzuki T. The course of respiration and circulation in death by carbon dioxide poisoning. Forensic Sci Int. 1989; 41 (1): 93–9.
26. Kajtar L, Herczek L, Lang E. Examination of CO_2 by scientific methods in the laboratory. Healthy Buildings. 2003; (3): 176–81.
27. Kajtar L, Herczeg L, Lang E. Influence of carbon dioxide pollutant on human wellbeing and work intensity. Healthy Buildings. 2006; (I): 85–90.
28. Gurin IV. Problemy mikroklimata pomeshhenij. Santehnika, otoplenie, kondicionirovanie. 2011; (11): 72–5 (in Rus.).
29. Pang L, Zhang J, Cao X, Wang X, Liang J, Zhang L, et al. The effects of carbon dioxide exposure concentrations on human vigilance and sentiment in an enclosed workplace environment. Indoor Air. 2021; 31 (2): 467–79. DOI: 10.1111/ina.12746.

Литература

1. Грицина О. П., Транковская Л. В., Семанив Е. В., Лисецкая Е. А. Факторы, формирующие здоровье современных детей и подростков. Тихоокеанский медицинский журнал. 2020; (3): 19–24.
2. Федотова И. В., Трошин В. В., Черникова Е. Ф., Блинова Т. В., Потапова И. А. и др. Актуальные проблемы снижения риска школьно-обусловленных нарушений здоровья у современных школьников. В книге: Герасименко Н. Ф., Глыбочко П. В., Есауленко И. Э., Попов В. И., Стародубов В. И., Тутельян В. А., редакторы. Здоровье молодежи: новые вызовы и перспективы. М.: Научная книга, 2019; 48–67.
3. Новикова И. И., Сорокина В. А., Лобкис М. А., Зубцовская Н. А., Семенихина М. В., Щевелева В. А. и др. Углекислый газ: проблемы нормирования, контроля и профилактики неблагоприятного воздействия в образовательных организациях (обзор литературы). Российский вестник гигиены. 2023; (4): 18–28.
4. Kutsyuruba B, Klinger DA, Hussain A. Relationships among school climate, school safety, and student achievement and well-being: a review of the literature. Rev Educ. 2015; 3 (2): 103–35. DOI: 10.1002/rev3.3043.
5. Babich F, Torriani G, Corona J, Ibeas IL. Comparison of indoor air quality and thermal comfort standards and variations in exceedance for school buildings. J Build Eng. 2023; (71): 1–19. DOI: 10.1016/j.jobe.2023.106405.
6. Jacobson TA, Kler JS, Hernke MT, Braun RK, Meyer KC, Funk WE. Direct human health risks of increased atmospheric carbon dioxide. Nat Sustain. 2019; 2 (8): 691–701. DOI: 10.1038/s41893-019-0323-1.
7. Агафонова В. В. Оценка качества воздуха в помещении офисного здания. Водоснабжение и санитарная техника. 2019; (3): 61–4.
8. Тельцова Л. З. Анализ состояния крови детей дошкольного возраста в зависимости от места проживания и уровня CO_2 в атмосферном воздухе. Эпоха науки. 2024; (38): 368–72.
9. Губернский Ю. Д., Калинина Н. В., Гапонова Е. Б., Банин И. М. Обоснование допустимого уровня содержания диоксида углерода в воздухе помещений жилых и общественных зданий. Гигиена и санитария. 2014; (6): 37–41.
10. Pitarma R, Marques G, Ferreira BR. Monitoring indoor air quality for enhanced occupational health. J Med Syst. 2017; 41 (2): 23. DOI: 10.1007/ s10916-016-0667-2.
11. Sadrizadeh S, Yao R, Yuan F, Awbi H, Bahnfleth W, Bi Y, et al. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. J Build Eng. 2022; (57): 104908. DOI: 10.1016/j.jobe.2022.104908.
12. Shendell DG, Prill R, Fisk WJ, Apte M. Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. Indoor Air. 2004; 14 (5): 333–41. DOI: 10.1111/j.1600-0668.2004.00251.x.
13. Kolarik B, Andersen ZJ, Ibfelt T, Engelund EH, Møller E, Bräuner EV. Ventilation in day care centers and sick leave among nursery children. Indoor Air. 2016; 26 (2): 157–67. DOI: 10.1111/ina.12202.
14. Агафонова В. В., Панферова Н. В., Финогенова О. Е, Агафонова А. Р. Исследование влияния концентрации углекислого газа в помещении классной комнаты на здоровье обучающихся. Энергосбережение и водоподготовка. 2022; 1 (135): 76–8.
15. Пронина Т. Н., Карпович Н. В., Полянская Ю. Н. Уровень содержания углекислого газа в учебных помещениях и степень комфорта учащихся. Вопросы школьной и университетской медицины и здоровья. 2015; (3): 32–5.
16. Robertson DS. Health effects of increase in concentration of carbon dioxide in the atmosphere. Current Science. 2006; 90 (12): 1607–9.
17. Капранов С. В., Капранова Г. В., Тарабцев Д. В., Соленая Е. С. Влияние микроклимата в помещениях пребывания школьников на их самочувствие. Экологический вестник Донбасса. 2022; (5): 5–14.
18. Кулаков К. Ю., Егорова Е. М. Влияние изменений параметров микроклимата на самочувствие человека и эксплуатационные характеристики строительных конструкций. E-Scio. 2019; 5 (32): 248–54.
19. Банникова Л. П., Себирзянов М. Д. Комплексная оценка влияния факторов окружающей среды, условий воспитания и обучения на течение процессов адаптации, состояние здоровья детей, посещающих дошкольные образовательные учреждения города. Непрерывное медицинское образование и наука. 2022; 17 (1): 8–13.
20. Вансовская Л. И., Гайда В. К., Гербачевский В. К. Практикум по экспериментальной и прикладной психологии. Л.: Издательство Ленинградского университета, 1990; 125 с.
21. Шапарь В. Б., Тимченко А. В., Швыдченко В. Н. Практическая психология. Инструментарий. Ростов-на-Дону: Феникс, 2002; 287 с.
22. Артюхов А. А. «Система условных баллов» как прием оценивания знаний учащихся в ходе преподавания естественнонаучных дисциплин в общеобразовательной средней школе на примере географии. Международный научно-исследовательский журнал. 2024; 6 (144). URL: https://research-journal.org/archive/6-144-2024-june/10.60797/IRJ.2024. DOI: 10.60797/IRJ.2024.144.87.
23. Кореневская Е. И., Рогачевская Л. Г. Гигиенические вопросы строительства школьных зданий. М.: Медицина, 1974; 224 с.
24. Воронова Б. З., Эльковская Е. А. Изменение умственной работоспособности и некоторых показателей функционального состояния центральной нервной системы младших школьников в различных условиях воздушной среды. Гигиена и санитария. 1982; (9): 44–7.
25. Ikeda N, Takahashi H, Umetsu K, Suzuki T. The course of respiration and circulation in death by carbon dioxide poisoning. Forensic Sci Int. 1989; 41 (1): 93–9.
26. Kajtar L, Herczek L, Lang E. Examination of CO_2 by scientific methods in the laboratory. Healthy Buildings. 2003; (3): 176–81.
27. Kajtar L, Herczeg L, Lang E. Influence of carbon dioxide pollutant on human wellbeing and work intensity. Healthy Buildings. 2006; (I): 85–90.
28. Гурин И. В. Проблемы микроклимата помещений. Сантехника, отопление, кондиционирование. 2011; (11): 72–5.
29. Pang L, Zhang J, Cao X, Wang X, Liang J, Zhang L, et al. The effects of carbon dioxide exposure concentrations on human vigilance and sentiment in an enclosed workplace environment. Indoor Air. 2021; 31 (2): 467–79. DOI: 10.1111/ina.12746.