

THE IMPORTANCE OF VENTILATING CLASSROOMS IN THE PREVENTION OF RESPIRATORY INFECTIONS AMONG STUDENTS: CURRENT CONCEPTS (A LITERATURE REVIEW)

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Abstract

The review examines the role of classroom ventilation in preventing respiratory infections among students and compares international evidence with the regulatory framework of Uzbekistan. Exhaled respiratory aerosol accumulates in poorly ventilated rooms, so the dose inhaled by occupants depends on how quickly indoor air is replaced with outdoor air. Observational studies in schools and workplaces link higher ventilation rates to less illness absence and a lower incidence of respiratory infection: in California classrooms each additional 1 L/s per person was associated with 1.6% lower illness absence, and in Italian schools mechanical ventilation above 10 L/s per student was associated with at least 80% lower risk of SARS-CoV-2 infection than natural ventilation. Carbon dioxide monitoring is a practical proxy for ventilation adequacy, although absolute CO₂ thresholds alone do not describe infection risk. Direct evidence for university classrooms is scarce; in a survey of four Russian universities, 32.1% of classrooms reached 1000 ppm CO₂ or more. The Uzbek sanitary rules for higher education institutions require natural ventilation with at least one air change per hour and airing during breaks; an illustrative calculation puts this at roughly 0.75–1.8 L/s per person, several times below the 10 L/s per person given in the WHO roadmap. The need for local measurements, CO₂ monitoring and revision of the norms is discussed. The review is based on 20 sources, including books, WHO guidance, scientific publications of 1955–2024 and Uzbek legal acts.

Keywords: Ventilation; classrooms; respiratory infections; students; airborne transmission; carbon dioxide; indoor air quality; sanitary rules; Uzbekistan.

Introduction

Upper respiratory infections are a major cause of morbidity among adults [1], and universities create many opportunities for their spread: students are brought together in lectures and small-group teaching, in accommodation and in social settings [2]. In a cohort study at the University of Minnesota, colds and influenza-like illnesses were common among students and were associated with substantial morbidity, impaired academic performance and increased use of health care [1].

Respiratory pathogens spread not only by contact and large droplets but also by droplet nuclei, small particles that stay airborne long enough to be inhaled by other people in the same room [3, 4]. Ventilation, the replacement of indoor air with outdoor air, dilutes these particles; according to the





Wells–Riley model, the probability of infection falls as the ventilation rate rises [4]. In practice, however, windows and doors often stay closed during lessons: in more than half of the university classrooms surveyed in Ufa, Russia, they were [5].

In Uzbekistan, sanitary rules, norms and hygienic standards are mandatory for educational institutions [6], and a separate SanPiN regulates the design and operation of higher education institutions [7]. It is therefore useful to compare these requirements with current evidence.

The aim of this review is to summarize current data on the role of classroom ventilation in the prevention of respiratory infections among students and to relate them to the regulatory framework of Uzbekistan. The objectives are: 1) to describe the general mechanisms by which ventilation affects airborne transmission; 2) to summarize epidemiological evidence from workplaces, schools and universities; 3) to consider ventilation strategies and methods for assessing ventilation; 4) to compare the Uzbek legal and sanitary requirements with international recommendations.

Materials and methods

Design. This work is a narrative review. It does not follow a systematic (PRISMA) protocol and does not claim to be exhaustive.

Search strategy. The literature was searched in October 2026 in open web sources, including publisher and journal websites, PubMed and PubMed Central, institutional repositories, library catalogues (for books) and the national legislation database Lex.uz (for laws). The bibliographic data of every included source (authors, title, journal or publisher, year, volume, pages, DOI where available) were checked against the publisher page, a PubMed or PubMed Central record, an institutional repository record or a library catalogue entry; legal and normative acts were checked against Lex.uz, policy and legal databases or the copy posted on the Uzbek government portal. The search terms were classroom ventilation, ventilation rate, airborne transmission, respiratory infections, illness absence, carbon dioxide, indoor air quality, university classrooms, students, sanitary rules and Uzbekistan, in English and Russian, used alone and in combination. The time frame was 1955–2025; priority was given to the last fifteen years and to classic works that laid the foundation of current concepts. Law No. ZRU-393 was read in the redaction published on Lex.uz (amendments up to 30 December 2025).

Inclusion criteria. (1) Peer-reviewed reviews, observational and experimental studies, WHO guidance documents, books, and official texts of laws and sanitary rules of Uzbekistan; (2) publications in English or Russian; (3) data on ventilation, indoor air quality or respiratory infection in schools, universities or comparable indoor settings.

Exclusion criteria. Conference abstracts and theses; preprints and other non-peer-reviewed material, including news and popular-science pages; publications in other languages; publications for which neither the full text nor a detailed abstract could be accessed.

Data synthesis. The data were summarized narratively and grouped by topic (mechanisms, evidence, strategies, assessment, regulation). Basic concepts are referenced to books and guidance documents,



mechanisms to reviews, key findings to primary studies and regulatory statements to the official texts. Twenty sources were included in the final review.

1. General mechanisms: airborne transmission and the role of ventilation

Wells showed that the nuclei of evaporated respiratory droplets can remain airborne long enough to be inhaled by other people and cause infection [3]. The WHO guideline on natural ventilation, which applies to diseases transmitted through fine droplets or droplet nuclei, states that lack of ventilation or low ventilation rates are associated with increased infection rates or outbreaks of airborne diseases, whereas high ventilation rates could decrease the risk of infection; it also notes that after more than a century of study the information remains sparse and incomplete [4].

A multidisciplinary systematic review of 40 studies, ten of which were conclusive, found strong and sufficient evidence of an association between ventilation, air movement in buildings and the spread of measles, tuberculosis, chickenpox, influenza, smallpox and SARS; the data were insufficient to specify minimum ventilation requirements for hospitals, schools, offices and homes [8].

The quantitative basis is the Wells–Riley equation, in which the probability of infection through droplet nuclei is inversely related to the ventilation rate [4]. Rudnick and Milton proposed using indoor CO₂ as a marker of the fraction of inhaled air that has been exhaled by others (the rebreathed fraction) and concluded that there is likely an achievable critical rebreathed fraction below which airborne propagation of common respiratory infections and influenza will not occur [9]. Basic non-pharmaceutical measures do not eliminate the airborne route, and there is wide consensus that improved ventilation, mechanical or by manual airing, is needed in schools [10]. These relationships are shown schematically in Fig. 1.

Fig. 1. General scheme of the effect of classroom ventilation on the risk of respiratory infection (scheme compiled by the authors from the sources [4, 8–10]). Ventilation, airing and CO₂-guided control act on the second step by diluting exhaled air.

Drivers	Indoor air	Exposure	Outcome
High occupancy; closed windows and doors; low outdoor-air supply	Exhaled aerosol and CO ₂ accumulate; rebreathed fraction rises	Higher inhaled dose of airborne pathogens	More respiratory infections and illness absence

2. Evidence from workplaces, schools and universities

Workplaces. A multidisciplinary review of the literature through 2005 judged 27 papers informative and concluded that, according to the limited available data, respiratory infections and short-term sick leave increase at lower ventilation rates; it called for more studies in diverse climates, in locations with polluted outdoor air and in buildings other than offices [11]. In a study of about 3,700 hourly employees of a manufacturer, the relative risk of short-term sick leave among office workers was 1.53 (95% CI 1.22–1.92) in areas with lower ventilation (about 12 L/s per person) compared with areas with higher ventilation (about 24 L/s per person) [12].

Schools. In a two-year prospective study of 162 classrooms in 28 California elementary schools, with ventilation rates estimated from CO₂ sensors, each additional 1 L/s per person was associated with 1.6% lower illness absence; raising classrooms from the California average of 4 L/s per person to the





state standard of 7.1 L/s per person would, if the association is causal, reduce illness absence by 3.4% [13]. Among 169 elementary schools in Georgia, COVID-19 incidence adjusted for county incidence was 37% lower where staff were required to wear masks and 39% lower where ventilation was improved; dilution strategies (open windows and doors, fans) were associated with 35% lower incidence and their combination with filtration with 48% lower incidence, although the strategies were self-reported and may have coincided [14]. In more than 10,000 classrooms of Italy's Marche region, the relative risk of SARS-CoV-2 infection among students was at least 74% lower in the 316 mechanically ventilated classrooms than in naturally ventilated ones, and at least 80% lower at rates above 10 L/s per student [15].

Universities. Direct evidence on ventilation and infection in university classrooms is scarce; a survey in Cambridge described itself as one of few recent detailed datasets of influenza-like infection in a university context [2]. A hygienic survey of four universities in Ufa, Russia (486 CO₂ measurements in the cold season), found high air quality (400 ppm or less) in only 9.8% of classrooms and low quality (1000 ppm or more) in 32.1%; in 24.7% of classrooms the air was already of low quality before lessons began [5]. In Uzbekistan, a hygienic study of a military higher school reported CO₂ above the norm because of poor air exchange in the cadets' study and living rooms [16].

3. Ventilation strategies in classrooms

Ventilation can be natural (windows, doors and vents), mechanical or combined, and air filtration can supplement dilution [4, 14]. The WHO guideline notes that a major disadvantage of natural ventilation is the difficulty of achieving a consistent airflow direction, with major fluctuations possible [4]. For non-residential settings, the WHO roadmap on indoor ventilation in the context of COVID-19 gives a minimum ventilation rate of 10 L/s per person [17]; the Italian school data suggest that protection is greater at rates above this value [15]. At the same time, no minimum ventilation rate for infection control against droplet nuclei has been established [4, 8], so such figures are pragmatic benchmarks, not thresholds.

In naturally ventilated classrooms the way windows are used matters. In the Ufa survey the mean CO₂ during lessons was 1255.9 ppm with windows and doors closed (55.6% of rooms), 746.8 ppm with a tilted window (17.8%), 791.3 ppm with closed windows but an open door (12.3%) and 1058 ppm with windows in a micro-ventilation mode (14.3%) [5]. A mass-balance modelling study quantified the ability of both mechanical ventilation and ad hoc airing to mitigate airborne transmission in classrooms and proposed a feedback strategy in which airing is adjusted to measured CO₂ [10].

4. Methods for assessing ventilation and infection risk

Indoor CO₂, produced by the occupants, is the most accessible indicator: its excess over the outdoor level reflects the fraction of rebreathed air [9], and continuous CO₂ records were used to estimate ventilation rates in a large school study [13]. In the Ufa survey CO₂ was measured at the centre of the room at a height of 1.5 m before lessons and at the end of the day, and rooms were graded from high quality (400 ppm or less) to low quality (1000 ppm or more); the authors refer to 0.1% (1000 ppm) as the limit value for indoor air [5].



Absolute CO₂ thresholds are, however, inadequate as the sole indicator of airborne transmission risk [10]. Health outcomes can be assessed from illness absence records [13] and reported case counts [14]; bacterial contamination of air can be quantified by air sampling [5]; and infection risk can be modelled with the Wells–Riley approach [4, 9, 10].

5. Regulatory framework of Uzbekistan

The basic act is Law No. ZRU-393 of 26 August 2015 “On sanitary and epidemiological well-being of the population” [6]. It makes sanitary rules, norms and hygienic standards (SanPiN) mandatory and requires educational institutions to observe them, but it does not set ventilation parameters itself; these are contained in sanitary and construction norms. For higher education the key document is the SanPiN “Hygienic requirements for the design, development, equipment and operation of higher educational institutions” (Tashkent, 2016), developed by the Tashkent Medical Academy [7]. The documents are summarized in Table 2.

Table 2. Uzbek legal and sanitary documents relevant to classroom ventilation (compiled by the authors from the sources in the last column)

Document	Provisions relevant to classroom ventilation and prevention of respiratory infections	Source
Law No. ZRU-393 of 26.08.2015 “On sanitary and epidemiological well-being of the population”	SanPiN are mandatory for state bodies, legal entities and individuals and are approved by the Chief State Sanitary Doctor (Art. 5); buildings of educational institutions must be maintained in line with them (Art. 20, 27); sanitary officials give conclusions on compliance of educational premises and senior officials may suspend their operation until violations are removed (Art. 12); anti-epidemic measures include isolation of suspected cases, observation of contacts, identification of transmission routes (Art. 30, 32), vaccination (Art. 33) and hygiene education (Art. 36); no ventilation parameters are set	[6]
SanPiN RUz “Hygienic requirements for the design, development, equipment and operation of higher educational institutions” (Tashkent, 2016)	Natural ventilation designed for at least 1 air change per hour; openable sashes, transoms or vents in the upper window zone (cl. 7.6); airing of educational rooms during breaks and servicing of ventilation and air-conditioning according to manufacturers’ recommendations (cl. 7.12); mechanical exhaust for laboratories, physics and chemistry classrooms, assembly halls and some other rooms (cl. 7.7); microclimate norms, e.g. classrooms in the cold season 20–21 °C (optimal), relative humidity 40–75%, air velocity 0.2–0.3 m/s (Table 5); floor area 0.9–2.2 m ² per seat in auditoria; no per-person ventilation rate or CO ₂ limit for lecture rooms and classrooms in the consulted copy	[7]
SanPiN RUz No. 0341-16 (general education schools), approved 22.12.2016	Classrooms are aired during breaks and recreation areas during lessons (the same principle as for higher education)	[18]
KMK 2.04.05-97 “Heating, ventilation and air conditioning”	Construction code to be followed when designing heating, ventilation and air conditioning of buildings; numerical requirements not analysed (full text not accessed)	[19]
Law No. ZRU-637 of 23.09.2020 “On Education”	Framework law for educational organizations; it replaced the 1997 Law on Education cited in the legal basis of [7]	[20]

Because the higher-education norm is expressed in air changes per hour, it can be converted into a per-person rate using the floor area per seat given in the same document (0.9–2.2 m² per seat) and an assumed ceiling height of 3 m: one air change per hour then corresponds to about 0.75–1.8 L/s per person (authors' illustrative calculation), i.e. roughly

5–13 times less than the 10 L/s per person given in the WHO roadmap [17]. Measured CO₂ in naturally ventilated university classrooms suggests that actual rates may be lower still when windows and doors stay closed [5].

6. Discussion

Comparison of the measures (Table 1) shows that the evidence is strongest for increasing the outdoor-air ventilation rate, and that natural ventilation, the dominant option in university buildings, depends on how windows and doors are actually used.

Table 1. Main measures related to classroom ventilation, evidence on their effect and limitations (compiled by the authors from the sources in the last column)

Measure	Mechanism	Evidence (setting)	Limitations	Sources
Higher outdoor-air ventilation rate (mechanical or hybrid)	Dilution of exhaled aerosol; lower rebreathed fraction	Offices: short-term sick leave RR 1.53 for lower (about 12) vs higher (about 24 L/s per person) ventilation. Elementary schools: 1.6% less illness absence per +1 L/s per person. Italy: mechanical ventilation above 10 L/s per student, at least 80% lower SARS-CoV-2 risk	Observational; schools and offices, not universities; energy costs	[11–13, 15]
Natural ventilation (window and door airing)	Dilution by wind- and temperature-driven flow	Ufa universities: mean CO ₂ 1256 ppm with windows and doors closed vs 747–791 ppm with a tilted window or open door; modelling supports CO ₂ -guided airing	Airflow variable and hard to control; weather; outdoor air quality	[4, 5, 10]
Dilution combined with filtration	Removal of particles from the air	Georgia schools: 35% lower incidence with dilution, 48% with dilution plus filtration	Self-reported strategies; confounding	[14]
CO ₂ monitoring with feedback	CO ₂ as a marker of rebreathed air	Used to estimate ventilation rates and to adjust airing; absolute thresholds not sufficient alone	Indirect measure of risk	[9, 10, 13]
Non-ventilation measures (masks, vaccination, hygiene education)	Source control; immunity; behaviour	Georgia: 37% lower incidence with a staff mask requirement; influenza vaccination emphasized for students	Effects overlap with ventilation	[1, 6, 14]

The evidence agrees in direction: more outdoor air per person is associated with fewer respiratory infections and less illness absence, with the benefit in California schools continuing at least up to 15 L/s per person [13]. Several limitations restrict extrapolation to students. Most data come from primary schools and offices and from the COVID-19 period; the designs are observational [11–15];



a minimum ventilation rate for infection control has not been established [4, 8]; and data for university classrooms are scarce [2, 5, 16]. The figure of 10 L/s per person is therefore a pragmatic benchmark rather than a threshold.

Against this benchmark, the Uzbek design minimum for higher education institutions looks modest. It is also a design requirement without an operational criterion such as a CO₂ limit, so in daily use ventilation depends on how windows and doors are operated [5, 7]. The only local measurement identified reported higher-than-normal CO₂ owing to poor air exchange [16], and a survey in Russia found 1000 ppm or more in a third of university classrooms [5]; neither can replace measurements in Uzbek universities.

Practical measures consistent with current Uzbek requirements are available without changing the law: airing classrooms during every break (clause 7.12 of [7]), using the openable window sashes and transoms required by clause 7.6, opening doors for cross-ventilation, which was associated with lower CO₂ in the Ufa survey [5], and using CO₂ loggers to guide airing [10]. In the cold and hot seasons ventilation must be balanced against thermal comfort limits [7] and outdoor air quality, a recognized gap in the evidence [11]. Ventilation does not replace other measures: vaccination (Article 33 of the Law), hygiene education (Article 36) and, in outbreaks, the measures of Article 32 [6]; in Georgian schools mask requirements and ventilation were each associated with lower incidence [14], and efforts to prevent upper respiratory illnesses in students, especially influenza vaccination, are expected to improve their health [1].

The limitations of this review are its narrative nature, the small number of sources, the reliance on studies in schools and offices, and the use of a posted copy of the higher-education SanPiN whose registration number and date of approval are not shown; the current version should be checked in the national legislation database. Legal texts were read in Russian-language versions, and the official Uzbek texts should be used for citation. Priorities for research are seasonal CO₂ and ventilation-rate surveys in Uzbek university classrooms, their linkage with absenteeism and records of acute respiratory infections, and pilot interventions with airing protocols and CO₂ monitors.

Conclusions

1. Ventilation is a basic engineering measure against airborne respiratory infections: reviews demonstrate an association between ventilation and the transmission of several airborne infections, but a minimum ventilation rate for classrooms has not been established.
2. Observational data from schools and workplaces show a dose–response pattern: 1.6% less illness absence per additional 1 L/s per person, and at least 80% lower risk of SARS-CoV-2 infection with mechanical ventilation above 10 L/s per student than with natural ventilation; direct evidence for university classrooms is lacking.
3. CO₂ monitoring is a practical tool for assessing and managing ventilation, but absolute thresholds are not sufficient on their own; in naturally ventilated university classrooms the way windows and doors are used strongly influences CO₂.
4. In Uzbekistan compliance with sanitary rules in educational institutions is mandatory (Law No. ZRU-393); the SanPiN for higher education institutions requires natural ventilation with at least one air change per hour and airing during breaks but sets no per-person ventilation rate or CO₂ criterion, and an illustrative calculation places this design minimum several times below the WHO benchmark.





5. Practical steps are airing during every break, CO₂ monitors in classrooms, measurements of ventilation in Uzbek universities, combination of ventilation with vaccination and other preventive measures, and consideration of an update of the norm.

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