European International Journal of Multidisciplinary Research and Management Studies
(ISSN: 2750-8587)

Received: 20 April 2026 | Accepted: 24 May 2026 | Published: 09 June 2026

**DOI:** 10.55640/eijmrms-06-06-06

**RESEARCH ARTICLE**

# Analysis of The Efficiency of Energy-Efficient Natural Ventilation Systems in General Education School Buildings

**Sh. Xoltursunov**

Master's Student, Tashkent University of Architecture and Civil Engineering, Uzbekistan

**VOLUME:** Vol.06 Issue06 2026

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## Abstract

This article presents information on natural ventilation in general education school buildings. In addition, the article discusses international experience in improving the energy efficiency of school buildings through natural ventilation methods, as well as the regulatory requirements for the design of general education school buildings.

**KEYWORDS**

Energy efficiency, microclimate, relative humidity, energy balance, mechanical ventilation, orientation, environmental sustainability, airflow, stack effect, cross ventilation, vertical ducts, single-sided ventilation, vertical ventilation, passive building, information and communication technologies, free word combination, affixation.

## INTRODUCTION

At present, the rational use of energy resources, the improvement of building energy efficiency, and the mitigation of the adverse consequences of climate change are among the most pressing issues worldwide. In particular, buildings and structures account for approximately 30-40 percent of global energy consumption, and their operation requires substantial amounts of thermal and electrical energy. This makes it necessary to intensify scientific research in this field.

General education school buildings belong to socially significant facilities. They are characterized by their large number, long daily operating periods, and the fact that most of their users are children. Ensuring a healthy microclimate in school buildings - in particular, adequate air exchange, temperature, relative humidity, and air cleanliness - has a direct impact on students' health, the effectiveness of the educational process, and overall productivity.

Practice shows that in most general education schools, ventilation is mainly provided by opening windows or by relying on mechanical ventilation systems with high energy consumption. Mechanical ventilation systems are characterized by significant energy demand, high operating costs, and complex maintenance requirements. Therefore, in modern architectural and construction practice, the use of natural ventilation systems is becoming increasingly important as an energy-efficient and environmentally acceptable solution. In the sharply continental climate of the Republic of Uzbekistan, high summer temperatures and cold winter airflows further increase the role of ventilation systems in shaping the energy balance of school buildings. Poorly organized natural ventilation can increase heat losses or lead to excessive overheating during the summer period. For this reason, the scientific calculation and modelling of natural ventilation processes and the determination of their impact on the energy balance are among the current research priorities.

Energy balance is an indicator that expresses the equilibrium between all energy flows entering and leaving a building. Maintaining this balance determines the energy efficiency of the building. The main components of the energy balance include the following:

Heat gains - heat entering through solar radiation, as well as heat released from internal sources, namely people, lighting systems, electrical equipment, and technical devices.

Heat losses - the transfer of heat to the exterior through external walls, the roof, floors, and window structures. This process depends on the thermal conductivity of the building envelope and the level of insulation.

Heat exchange through ventilation - heat loss or heat gain resulting from the inflow of outdoor air and the removal of indoor air.

Energy consumption by engineering systems - the amount of energy consumed by heating, cooling, ventilation, and lighting systems.

Ventilation systems in educational buildings are divided into three main types: natural, mechanical, and mixed (hybrid) systems. Natural ventilation is achieved through windows, doors, ventilation ducts, and internal courtyards, and is distinguished by the fact that it does not require energy consumption. Mechanical ventilation is controlled by fans and air-conditioning systems and provides stable air exchange. Hybrid systems combine the advantages of these two approaches. In the conditions of Uzbekistan, many general education schools still widely use natural ventilation, that is, air exchange by opening windows. However, this method has several disadvantages. Opening windows in winter sharply increases heat losses and imposes an additional load on heating systems. In summer, the inflow of hot outdoor air causes the indoor environment to overheat. In addition, on days with low wind speed or due to improper building orientation, air exchange may not be provided at the required level. Therefore, in order to organize natural ventilation effectively, it must be designed on a scientific basis. In this process, the location of the building, wind direction, facade orientation, and the dimensions and placement of windows and openings should be taken into account. Moreover, internal planning solutions - for example, directing airflows properly through corridors and internal courtyards - are of great importance. In modern approaches, natural ventilation systems are considered a means of improving energy efficiency. A properly designed ventilation system can reduce the need for artificial cooling and mechanical ventilation. This improves the overall energy balance of the building, reduces operating costs, and supports environmental sustainability.

**Natural Ventilation Methods and Operating Principles**. Natural ventilation is the process of air exchange that occurs under the influence of natural forces, namely wind and temperature differences, without mechanical devices. In natural ventilation, wind pressure increases on the windward side of the building, while a zone of lower pressure forms on the opposite side, resulting in airflow. Natural ventilation systems are based on organizing air exchange in a building without mechanical devices and mainly arise under the influence of pressure differences and temperature variations between the outdoor and indoor environments. These processes are based on fundamental physical principles such as the stack effect and cross ventilation (Figure 1). The stack effect is a natural air movement mechanism that occurs as a result of differences in air temperature and density inside and outside a building. This phenomenon is based on the process of convection: warm air rises because its density is lower, while colder and denser air moves downward. As a result, fresh air enters from the lower part of the building, while polluted air is discharged from the upper part. Cross ventilation is a natural air exchange method that occurs under the influence of wind pressure through openings such as windows and doors located on opposite or intersecting facades. This process is based on the entry of outdoor wind flow into the building, its passage through the interior space, and its exit from the opposite side.

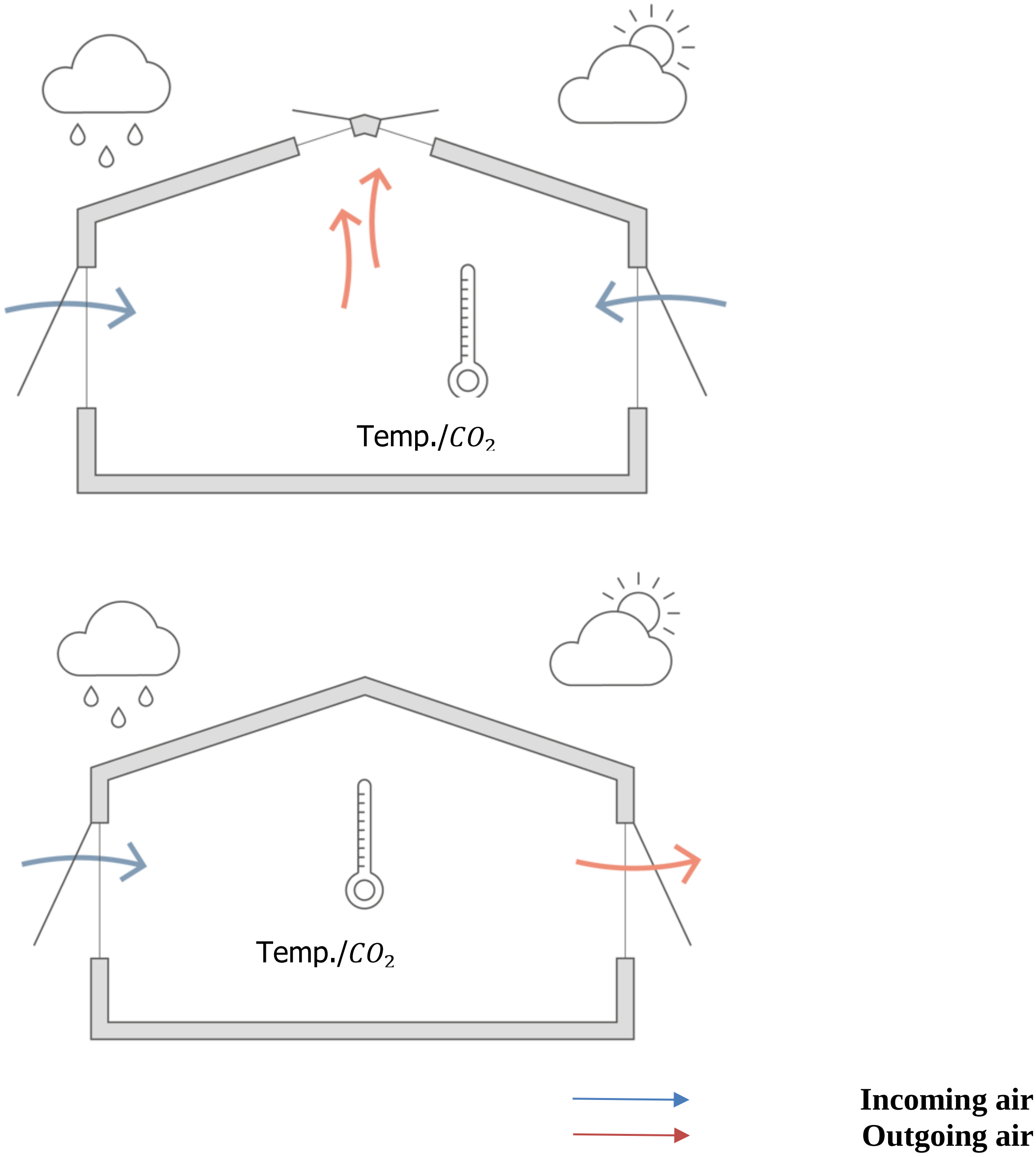


**Figure 1. Stack effect and cross ventilation**

Natural ventilation systems are implemented through various architectural and planning solutions. In particular, cross ventilation is organized through windows and openings located in single-sided and opposite walls, while vertical ventilation is formed through vertical ducts, shafts, or atria based on the upward movement of air (Figure 2). In addition, internal courtyards, roof lights, wind towers, and adaptive facade elements are important structural tools that improve the efficiency of natural ventilation. These solutions are designed in close connection with the volumetric and planning structure of the building, number of storeys, orientation, and environmental conditions.

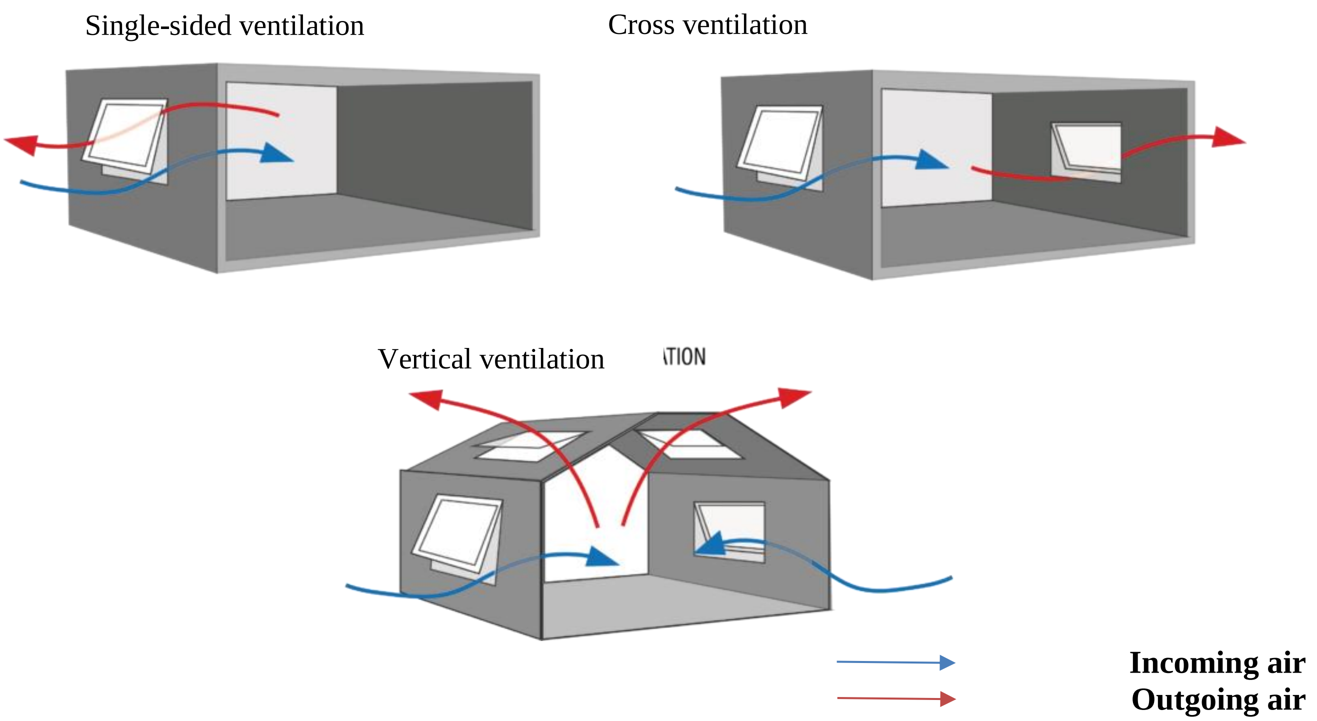


**Figure 2. Natural ventilation systems**

The efficiency of natural ventilation systems depends on many factors, including outdoor climatic conditions, wind speed and direction, solar radiation, the thermophysical properties of the building structure, and the size and location of openings. In the sharply continental climate of Uzbekistan, the effective use of natural ventilation is especially important for removing excess heat during the hot summer period and maintaining a comfortable microclimate during transitional seasons. In modern construction practice, natural ventilation systems are distinguished by their energy-saving potential, environmental friendliness, and low operating costs. They reduce the need for mechanical cooling and ventilation systems, thereby decreasing the overall energy consumption of a building. At the same time, natural ventilation has a positive effect on human health by improving indoor air quality and creating comfortable conditions for occupants. Therefore, the scientific study of natural ventilation systems, their improvement in accordance with local climatic conditions, and their integration with traditional and modern architectural solutions represent an important scientific and practical task. In the conditions of Uzbekistan, the most effective solutions include planning that enables two-sided ventilation of classrooms, intensifying air circulation through high- and low-level openings, and organizing ventilation in combination with solar-shading elements.

**International Experience**. Natural ventilation is recognized in modern architecture and construction practice as one of the most important tools for improving energy efficiency. International experience shows that the proper organization of natural ventilation in schools and other educational institutions not only significantly reduces energy consumption but also makes it possible to maintain the indoor microclimate at normative levels.

Germany: School buildings are designed on the basis of the passive building concept. In such buildings, natural ventilation and hybrid ventilation systems are used in combination. For example, air exchange is provided through operable windows, atria, wind ducts, and roof lights. As a result, the energy consumed for heating and cooling can be reduced by up to 80-90%. According to studies conducted in Germany in 2020, when passive school buildings were compared with conventional buildings, energy consumption was on average 60-70% lower in terms of kWh/m²/year. A passive building is a building in which the specific energy consumption for heating does not exceed an average of 15 kWh per square metre per year, whose negative environmental impact is minimized, and whose heating, ventilation, and air-conditioning systems operate through the use of renewable energy sources, including solar energy, as well as energy-efficient and energy-saving technologies. m^2

United Kingdom: Automated window systems are used in school buildings. These systems monitor $CO_2$ concentration and air temperature through sensors and automatically open and close windows. As a result, energy consumption is reduced and indoor air quality is maintained at a stable level. Studies indicate that in schools equipped with automated ventilation systems, students' concentration and work productivity increase by 15-20%.

Japan and South Korea: In these countries, passive cooling and ventilation shafts are widely used together with natural ventilation. For example, in Japanese school buildings, special ventilation ducts are installed in ceilings; they remove

warm air upward and bring in cooler air from below. As a result, the room temperature is maintained at a comfortable level during summer, and the need for air conditioning is reduced.

**Regulatory Requirements for Energy Consumption and Ventilation Systems in School Buildings**. In the Republic of Uzbekistan, strict regulatory requirements exist for ensuring energy efficiency and indoor microclimate conditions in general education school buildings. These requirements are regulated through a number of normative documents covering the fields of construction, sanitation and hygiene, and energy. According to Appendix 9 of the normative document Sh.N.Q 2.08.06-23 "Educational institutions. Design requirements", the optimal indoor air temperature should be 21-23°C in classrooms, 17-18°C in training workshops, 19-21°C in assembly halls, 19-21°C in club and extracurricular rooms, and 18°C in libraries, while the air exchange rate must be at least 20 $m^3$/hour per person. In practice, insufficient air exchange may lead to fatigue, headaches, and reduced concentration among students. Therefore, the integration of energy efficiency and ventilation systems is important in modern school design.

## CONCLUSION

In conclusion, the effective application of natural ventilation systems in general education school buildings is one of the key factors not only in the rational use of energy resources but also in the fundamental improvement of the quality of the educational environment. This approach should not be limited to the application of individual technical solutions; rather, it must be considered in close connection with the building's overall architectural and planning concept, climatic adaptability, and functional organization. In the future, more advanced results can be achieved by widely introducing innovative and adaptable ventilation solutions into the design and reconstruction of school buildings, optimizing them on the basis of local climatic conditions, and using digital modelling methods. As a result, a strong scientific and practical foundation will be created for the formation of an energy-efficient, environmentally sustainable, and healthy educational environment.

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