PASSIVE VENTILATION SYSTEMS IN HISTORIC TOGH

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Abstract: *This study investigates the natural ventilation systems integrated into the historical architectural structures of Togh village in the historical province of Dizak in Artsakh. The village is situated on the eastern slope of Mount Togh and has been inhabited since ancient times. At its center stands the eighteenth-century Melik Yegan Palace. The study aims to identify the design principles of the natural ventilation systems, analyze their spatial and structural characteristics, and evaluate their functional significance. The relevance of the research is driven by the need to study and preserve traditional engineering solutions in historical architecture, while its scientific novelty lies in the comprehensive analysis of the ventilation systems preserved in Togh's historical buildings. The research employs architectural analysis, field observations, and comparative methods. The results demonstrate that passive ventilation operated not only in residential spaces but also in basements, including rooms without direct external openings. The study identifies the structural characteristics and spatial organization of these systems and highlights their role in regulating the indoor microclimate. The findings have practical significance for the conservation and restoration of historical buildings and may also contribute to the development of contemporary sustainable architectural design.*

Keywords: *Togh, Melik Yegan, historical structure, microclimatic conditions, passive ventilation, green buildings.*

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Received: 03.06.2026
Revised: 28.06.2026
Accepted: 23.07.2026

Introduction

Vernacular architecture represents the accumulated knowledge of generations that adapted the built environment to local climatic, geographical, and socio-cultural conditions. The use of locally available materials, passive environmental strategies, and construction techniques refined over centuries suggests that traditional buildings incorporated passive environmental strategies that may have contributed to effective environmental control. As noted by previous studies, vernacular dwellings provide valuable evidence of environmentally responsive design and demonstrate how human needs were satisfied through simple but highly efficient architectural solutions [1].

Togh village is located in the historical province of Dizak in Artsakh, on the eastern slope of Mount Toghasar (Fig. 1). The settlement has been continuously inhabited since ancient times. It is first documented as a monastic village in a 1246 inscription from Gtchavank [2]. Melik Yegan (Avan), the founder of the Togh Melik dynasty, was officially recognized as a melik by Shah Tahmasp II of Persia. Togh subsequently became the administrative center of the Dizak Melikdom. Melik Yegan later received the title of *Beklarbeg* of Artsakh from Nader Shah, as confirmed by an inscription on the Melik Palace [3]. Historical information on the settlement's structure, economy, and patterns of occupation is further documented by Arakel Vardapet [4]. The architectural heritage of the settlement includes ecclesiastical buildings, khachkars, defensive complexes, bridges, and funerary monuments [5].

Heritage represents an important component of a nation's cultural identity and plays a significant role in its historical and political continuity. The historic center of Togh began to develop in the eighteenth century. It continued to evolve until the early twentieth century (Fig. 2). The settlement developed as a unified urban organism, characterized by planning features typical of steep-slope settlements, including a road network, small public squares, and a natural spring. Buildings were constructed using locally quarried, roughly hewn tuff sandstone, ensuring a consistent material palette, scale, and construction technique throughout the village.

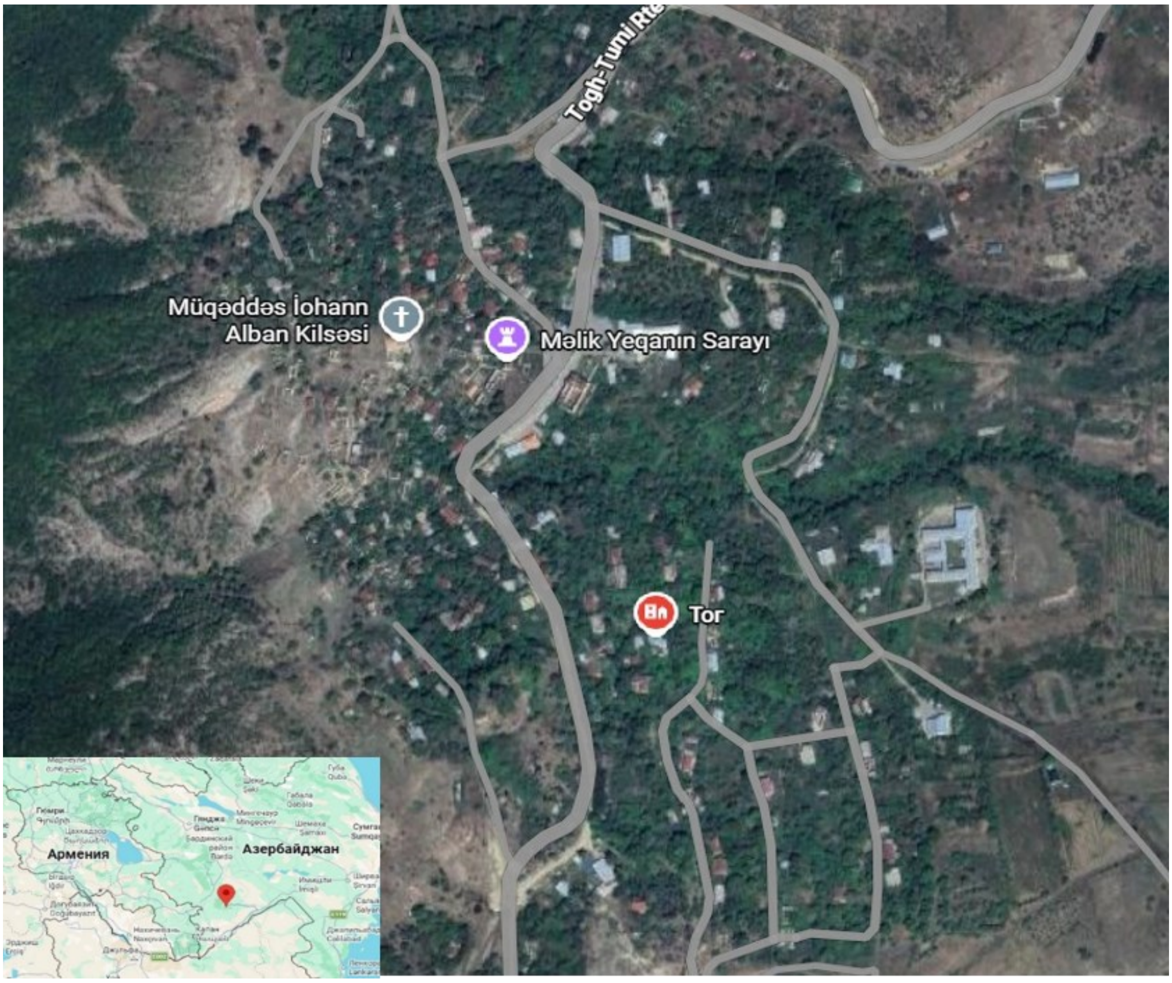

Fig. 1. *Satellite image (Google Earth) of the geographical location of Togh village*

Fig. 2. *The general view of Togh village*[1]

[1] https://www.flickr.com/photos/danielyans/14970234110/in/photostream/

At the center of the settlement stands the Melik Palace complex, while multi-story residential buildings were subsequently constructed in the surrounding areas. This historically developed architectural environment reflects the social organization, domestic life, and security requirements of the eighteenth and nineteenth centuries. Despite chronological differences, the buildings exhibit a shared tradition of advanced construction techniques, demonstrating continuity in local architectural practice and the high level of engineering knowledge of their builders.

The Melik Yegan Palace is a significant example of late medieval Armenian architecture. Its historical background, architectural characteristics, and spatial composition have been examined by M. Sargsyan [6] and A. Ghulyan [7]. In 2010, a restoration project for the monument was prepared by "VEM" LLC**,** and the restoration works were completed in 2016[2].

This study aims to investigate the integrated passive ventilation systems incorporated into the historical buildings of Togh and to evaluate their architectural configuration, engineering principles, and functional performance. The study addresses the following research questions:

- What architectural and structural characteristics define the passive ventilation systems preserved in the historical buildings of Togh?
- How do these ventilation systems operate with respect to airflow organization and regulation of the indoor microclimate?
- What is the engineering and functional significance of these passive ventilation systems for the conservation of historical buildings and contemporary architectural practice?

This article examines the integrated passive ventilation systems incorporated into the historical buildings of Togh, particularly in spaces with limited or no window openings. Field investigations and architectural surveys indicate that these systems played a crucial role in maintaining favorable indoor microclimatic conditions in buildings of various functions. The specially designed openings served not only as sources of natural light but primarily as passive ventilation and cooling elements. Their geometric configuration and interconnected air passages reflect a sophisticated understanding of environmental behavior by traditional builders. The architectural evidence suggests that empirical knowledge of local climatic conditions was effectively incorporated into the design of these systems. The arrangement of ventilation openings and airflow channels suggests careful consideration of prevailing wind directions, solar exposure, and thermal gradients. The identified systems regulated airflow via pressure differentials and buoyancy-driven mechanisms, ensuring continuous air exchange and helping control indoor temperature and humidity. These engineering solutions illustrate a high degree of environmental adaptation achieved through accumulated construction experience. Overall, Armenian builders successfully integrated passive ventilation principles into masonry structures, creating thermally efficient systems that are consistent with the fundamental concepts of passive environmental design.

Preserved examples of these passive ventilation systems have been documented in the basement and first-floor levels of the Melik Yegan Palace reception hall, as well as in the basement of later multi-story residential buildings. These features represent a relatively underexplored category of passive environmental control systems within Armenian architectural heritage and provide valuable evidence of the engineering knowledge embedded in traditional construction practices.

Scientific Novelty

The scientific novelty of this research lies in the first systematic architectural and engineering investigation of integrated passive ventilation systems preserved in the historic buildings of Togh. The principal original contributions of the study are as follows:

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- the identification and documentation of previously undocumented passive ventilation elements integrated into the masonry structures of the Melik Yegan Palace and adjacent historic residential buildings,
- the architectural and functional interpretation of these systems based on field investigations, measured drawings, and comparative analysis,
- the preliminary engineering assessment of their ventilation performance through airflow calculations based on measured geometric characteristics,
- the demonstration that these ventilation systems represent an indigenous environmental strategy adapted to the climatic conditions, topography, and construction traditions of historic Armenian architecture, differing from the better-known Middle Eastern wind towers,
- the establishment of a scientific basis for the conservation of these engineering features and for their consideration as a source of knowledge for contemporary architectural design.

Beyond its engineering significance, the study preserves architectural documentation of historic structures that are currently inaccessible for further field investigation, thereby contributing to the long-term documentation and safeguarding of Armenian architectural heritage.

Materials and Methods

This research is based on a combination of field investigation, architectural analysis, environmental assessment, and comparative study methods to identify and evaluate natural ventilation systems in the historical structures of Togh village (Table 1).

Table 1. Research Framework: Stages, Methods, and Expected Outputs

N	Research Stage	Method	Expected Output
1.	Literature review	Review of traditional ventilation and vernacular architecture	Research gap framework and knowledge gap
2.	Selection of case studies	Selection of representative historical buildings based on preservation, authenticity, accessibility, and presence of ventilation elements	Representative sample of investigated buildings
3.	Field survey and documentation	On-site investigation, measurements organization and building organization	Architectural documentation and measured drawings
4.	Architectural and spatial analysis	Analysis of ventilation channels, spatial organization and building orientation	Identification of passive ventilation systems
5.	Environmental assessment	Analysis of climatic conditions, geology and natural resources	Environmental context and engineering parameters
6.	Comparative analysis	Comparison with Persian Badgirs and Egyptian Wind Towers	Functional and Typological assessment
7.	Interpretation and Conservation Implications	Evaluation of ventilation performance and heritage significance	Conclusions and conservation recommendations

Literature Review

Recent international research often reflects a gradual shift from descriptive studies of national architecture to interdisciplinary research that integrates heritage conservation, building physics, and environmental engineering. Studies by E. Lucchi and F. Ascione highlight the importance of building performance modeling for understanding the environmental behavior of historic buildings, while acknowledging the methodological limitations associated with heritage structures [8, 9]. They argue that successful conservation requires a balance among historical authenticity, environmental performance, and energy efficiency. These studies provide advanced analytical frameworks for assessing historic buildings, focusing primarily on European stone heritage that has undergone renovation. In contrast, passive ventilation systems embedded in traditional Armenian stone architecture have largely gone undocumented in the international literature. Therefore, the current study addresses this research gap by providing architectural documentation and a preliminary engineering interpretation of a previously unexplored passive ventilation strategy preserved in Togh's historic buildings.

Since antiquity, natural ventilation techniques have been employed to improve indoor air quality and thermal comfort in built environments. Among these, wind towers (*wind catchers* or *badgirs*) are among the most effective passive environmental control systems. Designed to capture cooler outdoor air and channel it into interior spaces while exhausting warmer air through vertical shafts or openings, these systems have been documented in the architectural traditions of Egypt, Persia, and other regions of the Middle East [10]. Their effectiveness has been widely recognized in the scientific literature, where they continue to serve as important references for contemporary passive cooling strategies.

A substantial body of research has been devoted to the engineering analysis of historical buildings and passive environmental control technologies [11]. In addition to ventilation, studies have highlighted the importance of moisture management in preserving historic masonry structures, identifying rising damp caused by capillary water transport as one of the principal mechanisms of material deterioration [12]. These investigations demonstrate that environmental performance is an essential aspect of both the conservation and functional assessment of architectural heritage.

Research conducted in regions with climatic conditions comparable to those of Armenia has further demonstrated the effectiveness of traditional passive design strategies. Alwetaishi *et al.* investigated thermal comfort in historic buildings in Saudi Arabia and showed that thermal mass and appropriate building orientation significantly improve indoor thermal conditions without mechanical systems [13]. Similarly, Nassim *et al.* analyzed traditional wind towers (*badgirs*) as an effective passive cooling technology that operates through pressure differences and thermal buoyancy. Their study confirmed the ability of these systems to provide continuous natural ventilation and improve indoor environmental conditions in hot climates [14] (Fig. 3).

Fig. 3. *The historical town of Yazd in Persia and the wind towers. Photo by M. Titanyan*

The accumulated research suggests that traditional passive environmental systems incorporate engineering principles that remain highly relevant to contemporary sustainable and energy-efficient architecture. The environmental logic embedded in these historical solutions provides valuable guidance for reducing energy consumption and improving indoor environmental performance in modern buildings [14].

Despite the growing body of research on passive environmental systems in historical architecture, comparable studies of Armenian architectural heritage remain limited. Previous investigations have primarily focused on the historical and architectural significance of monuments, while the integrated passive ventilation systems preserved in traditional Armenian masonry buildings have received little scientific attention. Consequently, their architectural configuration, engineering principles, and environmental performance remain insufficiently documented and evaluated. The present study addresses this research gap by providing a systematic architectural and engineering analysis of the passive ventilation systems preserved in the historical buildings of Togh village.

Selection of case studies

The study focuses on the historical buildings of Togh village, with particular emphasis on the palace of Melik Yegan and adjacent multi-story residential structures dating from the eighteenth and nineteenth centuries. The investigated buildings were selected according to the following criteria:

- preservation of their historical authenticity,
- presence of identifiable passive ventilation elements,
- accessibility for field documentation and architectural measurements at the time of the survey,
- representativeness of the traditional residential architecture of Togh.

The selected buildings are the surviving historic structures accessible during the field investigations. Consequently, the present study is based on the complete set of field documentation collected during the accessible period, which constitutes the primary empirical dataset for the research.

Field Survey and Documentation

Fieldwork was conducted through on-site surveys, visual inspections, photographic documentation, and measurements of preserved architectural elements, including ventilation openings, wall thicknesses, and spatial configurations. The documentation focused on identifying the location, geometry, and connectivity of air channels within the masonry structures.

Architectural and Spatial Analysis

The documented data were analyzed to determine the spatial organization and structural integration of ventilation systems. Particular attention was given to the relationship between ventilation openings and building orientation, floor levels, wall construction, and the functional organization of interior spaces. The analysis also examined the operation of the ventilation systems in rooms lacking direct external openings.

Environmental and Functional Assessment

The study evaluates the performance of the identified systems based on passive ventilation principles, including airflow driven by pressure differentials and thermal gradients. The analysis considers local climatic conditions, solar exposure, and prevailing wind directions to interpret the effectiveness of these systems in regulating indoor microclimate (temperature and humidity).

Comparative Analysis

A comparative analysis was conducted using published studies on traditional passive ventilation systems from regions with climatic conditions comparable to those in Armenia. The calculated ventilation performance of the investigated systems was also compared with contemporary normative ventilation requirements for buildings of similar function.

For the environmental assessment, the climatic conditions of Togh were analyzed based on long-term meteorological data. As the study focuses on the functional principles of passive ventilation rather than precise historical climate reconstruction, contemporary climatic data are considered an appropriate basis for evaluating the environmental performance of the identified ventilation systems. Long-term averaged data from the Varanda (Fizuli) and Hadrut meteorological stations, located near Togh, were used to calculate key values of outdoor air temperature for both summer and winter conditions (Table 2). These data form the basis for evaluating the environmental performance of the observed ventilation systems. The analysis indicates that the climate of Togh is mild and temperate, with characteristics closely resembling a dry subtropical climate, which is particularly relevant for the application of passive ventilation strategies.

Table 2. Outdoor air design values of Togh. By A. Karamyan

Name of the settlement	Altitude, m	Atmospheric pressure, Pa	The season	Air temperature,° C	Relative air humidity, %	Wind speed, km/h	Wind Frequency Direction
TOGH	800	888.8	Summer	26.8	57	2.3	S
			Winter	-14	64	2.6	SW

Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the investigation is based on a limited number of well-preserved historical buildings in Togh that retained identifiable passive ventilation elements and were accessible for detailed architectural documentation during the field survey. Following the loss of physical access to the study area after 2023, no additional field investigations, repeated measurements, or verification of the documented structures have been possible.

Second, the engineering assessment is based on measured architectural parameters and theoretical assumptions regarding airflow characteristics. Since direct measurements of historical airflow velocities under their original operating conditions are not possible, typical air velocity ranges for natural ventilation systems were adopted as reference values. Consequently, the presented calculations should be regarded as a preliminary engineering assessment based on theoretical assumptions rather than experimentally verified performance values**.** Computational Fluid Dynamics (CFD) simulations, smoke visualization tests, tracer-gas experiments, and long-term in-situ environmental monitoring were beyond the scope of the present research.

Despite these limitations, the integration of field measurements, architectural documentation, comparative analysis, and engineering interpretation provides a reliable basis for identifying the passive ventilation principles incorporated into the historic buildings of Togh. The findings establish a foundation for future interdisciplinary investigations employing advanced environmental simulation and monitoring techniques.

Results and Discussion

The Melik Yegan Palace reception hall occupies a central position within the architectural complex (Fig. 4). According to the inscription engraved on the entire facade of the second-floor entrance, the palace was constructed in 1737 by Melik Yegan, the founder of the Dizak estate and a prominent political figure in eighteenth-century Armenia [4]. The building is a slightly irregular rectangular, two-story structure oriented along the north–south axis. Its spatial organization and structural configuration provided favorable conditions for integrating airflow systems, making it an appropriate case study for investigating traditional environmental control strategies.

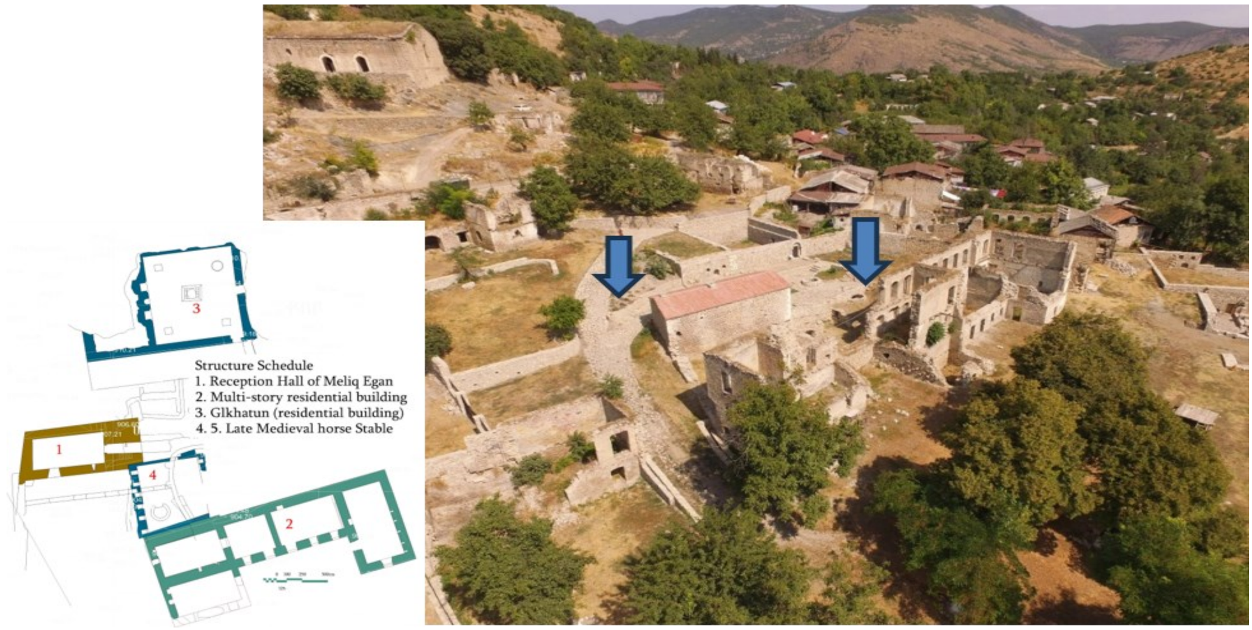

Fig. 4. *Melik Yegan's Palace view from above. The tiled structure in the center is the restored reception hall building. On the right is the multi-story residential house built in the XVIII-XIX centuries. Photo by A.Mkrtchyan*[3]

The basement level consists of a vaulted hall devoid of natural lighting (Fig. 5)[4]. The only external opening is the entrance door, which opens outward. Based on this feature, M. Sargsyan suggested that the basement may have functioned as a prison cell [6]. However, the architectural evidence documented during the present investigation suggests an alternative interpretation. The integrated ventilation mechanism and the absence of internal locking provisions indicate that the space was more likely used as a storage or utility area rather than a detention facility. Buildings intended for economic purposes, rather than for habitation, generally did not require internal locking mechanisms, whereas controlled ventilation was essential to preserve stored goods and maintain a stable indoor microclimate.

Within the mass of the southeastern wall, which has a thickness of 103 cm, two openings (41×66 cm and 67 cm deep) are embedded (Fig. 6a)[5].

These connect to a horizontal ventilation duct with a cross-section of 22×22 cm (Fig. 6b, c). The vents are positioned approximately 0.70 m above the basement floor level. The horizontal duct extends through the wall and opens onto the exterior façade at a height of 2.76 m above the basement floor, forming a rectangular outlet measuring 36×40 cm (Fig. 7). The remaining walls are solid, emphasizing the intentional, localized design of the ventilation system.

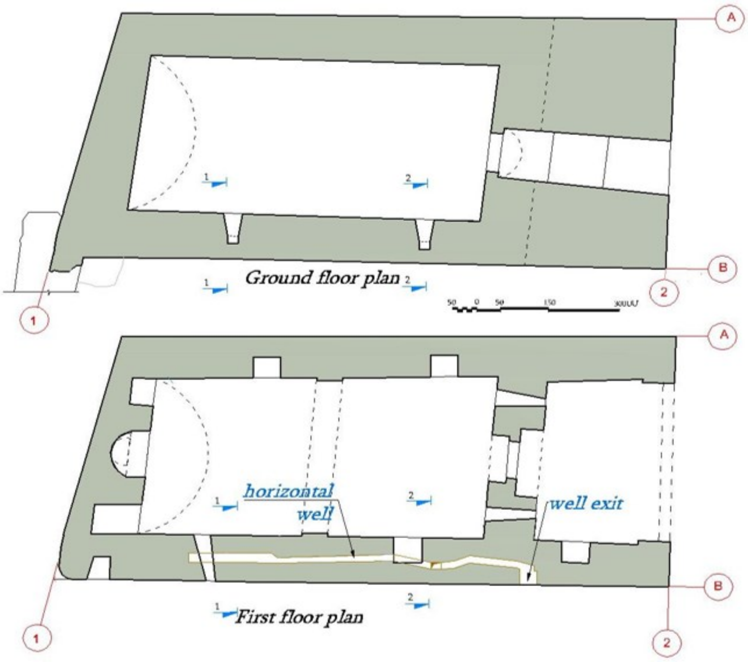

Fig. 5. *Melik Yegan's reception hall, basement, and first-floor plans by M. Sargsyan, R. Kharazyan*

[3] https://monumentwatch.org/wp-content/uploads/2023/12/001-2-1-1-2048x1536.jpg
[4] Measurements and photos made by the authors
[5] The photos were taken during the measurement phase before restoration

Fig. 6. *The nipple opening* (a) *and the horizontal wells* (b, c*) are embedded within the mass of the southeastern wall. Photo by M. Titanyan*

The first floor functioned as the reception area. It consists of a vaulted hall connected to a vaulted corridor on the northeastern side. Beneath this corridor, a narrow, sloping vaulted passage provides access to the basement (Fig. 8a). The entrance to the reception hall is architecturally emphasized. The façade contains two small windows (17×35 cm and 18×25 cm) with deeply splayed internal reveals (Fig. 8b), while a third opening (20×16 cm) is located on the southeastern façade. The limited dimensions of these openings indicate that they were not designed primarily to provide daylight. Instead, natural illumination was supplemented by a skylight incorporated into the vault (Fig. 9). The configuration of the openings suggests that their primary function was to promote natural air circulation while minimizing direct solar gain, thereby helping regulate the indoor microclimate.

Adjacent to the reception hall stands a multi-story residential building that was documented and surveyed by VEM LLC during the preparation of restoration and adaptive-reuse projects. The structure is predominantly three stories high, with a four-story section on its southeastern side, and exhibits clear evidence of several reconstruction phases.

Despite these later modifications, the building preserves its original basement spaces with integrated passive ventilation elements, making it an important subject of the present architectural and engineering investigation[6].

Fig. 7. *The first-floor window (left) and the exit of the horizontal well (right) in the southeastern facade. Photo by M. Titanyan*

[6] Author: M.Titanyan

a.

b.

Fig. 8. *The northeast facade of the reception area* (a): *The basement level is accessed through a narrow vaulted corridor. Photo by G.Budaghyan*[7]*. The small opening of the window* (b) *expands at a steep angle as it progresses inward. Photo B by M.Titanyan*

Fig. 9. *The view of the skylight from the roof and from the hall. Photo by M. Sargsyan*

Of particular interest is the southwestern room at the semi-basement level (Fig. 10). This space features a vaulted ceiling and exceptionally thick masonry walls measuring 137 cm, approximately 35 cm thicker than those of adjacent rooms. Two niches (31×54 cm and 31×36 cm, each 50 cm deep) are integrated into the southeastern wall. These niches are connected to a horizontal ventilation duct embedded within the same wall structure. The duct terminates through a 12×12 cm opening leading into an adjacent room.

[7] https://monumentwatch.org/wp-content/uploads/2023/12/002-2-1-1.jpg

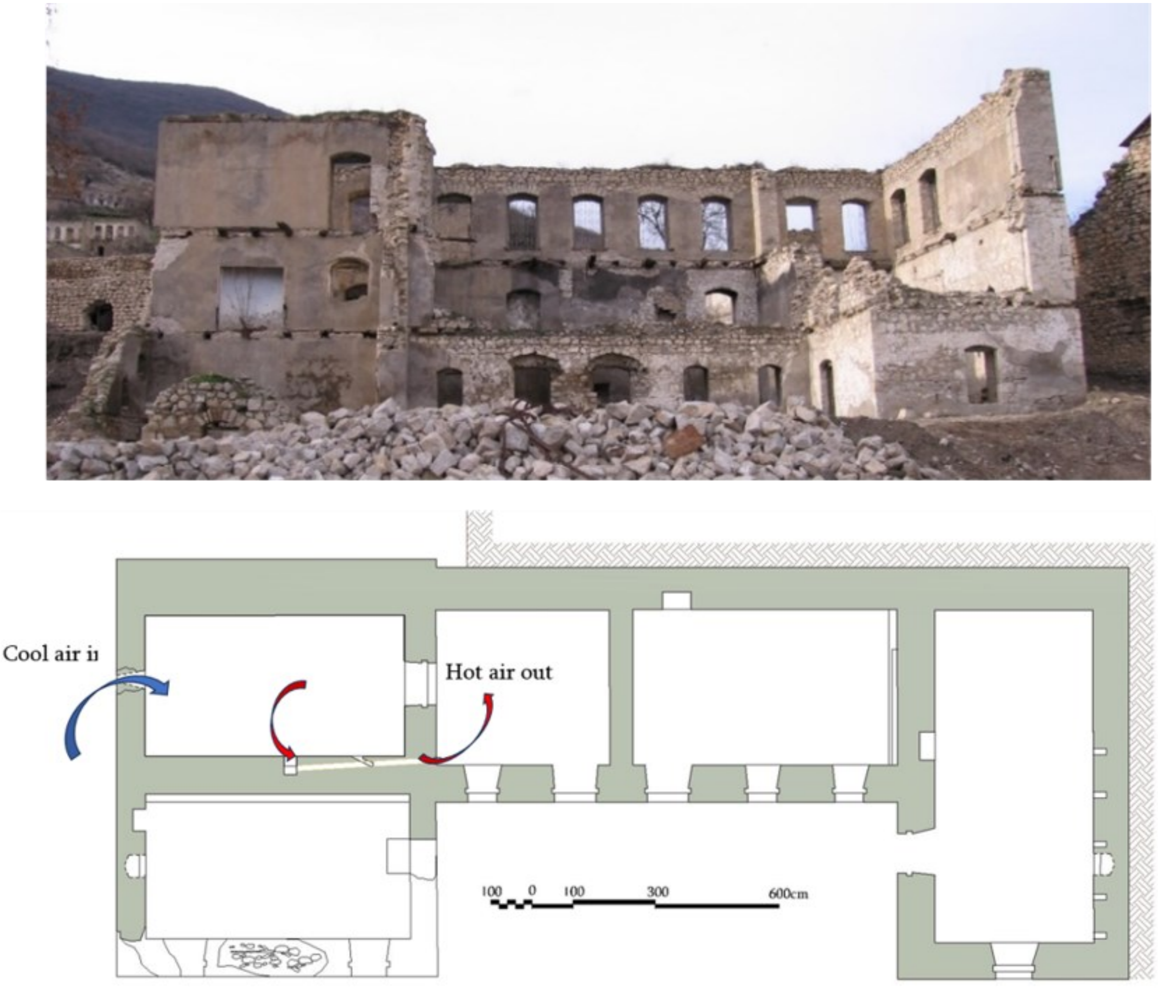

Fig. 10. *Multi-story residential building, facade, first-floor plan. Photo and plan by M.Titanyan*

The configuration of these elements suggests that the ventilation channel was originally designed as part of a passive air circulation system. Although subsequent reconstruction phases appear to have enclosed the duct's external connection and sealed it with oak (Fig. 11), the preserved architectural elements may be interpreted as evidence of an earlier integrated passive ventilation system. Based on the available architectural evidence, it is likely that the room belonged to the eighteenth–nineteenth-century construction phase; however, this interpretation cannot be verified through direct archaeological investigation. The preserved elements provide evidence of an earlier integrated ventilation solution. This indicates that the room likely belongs to the eighteenth–nineteenth-century construction phase and was later incorporated into a modified structural system. Notably, it represents the only preserved stone-vaulted space within a building that was otherwise reconstructed with wooden intermediate floors.

A partially preserved window opening is visible on the transverse façade of the room, with original dressed stone elements preserved on one side. The opening appears to have been relatively small and positioned at a higher external level, which may explain its limited visibility in the present condition. Given its location and connection to the internal ventilation duct system, this opening likely served as a wind-catching element, facilitating the introduction of external air into the interior space (Fig. 12).

Examination of the historical structures of the Togh Melik Palace indicates that rooms with limited window openings employed a similar environmental control strategy. The spatial arrangement of openings and internal air channels suggests that cooler external air entered the rooms through small façade openings and downward-oriented vents, while warmer air was directed through internal vaulted niches, collected within horizontal ducts, and discharged through higher-level outlets. On the upper floor, a roof opening appears to have functioned as an exhaust element, supporting vertical air circulation within the building (Fig. 13).


Fig. 11. *The niches of the vaulted room in the semi-basement, the exit of the horizontal vault extending from the room. Photo by M. Titanyan*


Fig. 12. *General view of the "wind-catching" window in the half-floor vaulted room, including the preserved shingle stones. Photo by M. Titanyan*

This configuration indicates a deliberate application of passive ventilation principles based on thermal buoyancy and pressure differentials. The presence of an organized ventilation system suggests that the basement space may have been used for storage, particularly to maintain conditions suitable for preserving food products, as continuous air exchange would have helped maintain thermal stability and humidity control.

Since direct measurements of historical airflow velocities are not possible, typical air velocity ranges for natural ventilation systems (0.5–1.5 m/s) were adopted as reference values for the preliminary assessment of airflow through the identified openings and horizontal ducts. Based on these assumptions, a simplified engineering calculation was performed to estimate the ventilation performance and develop a schematic representation of air movement within the basement space (Fig. 13).

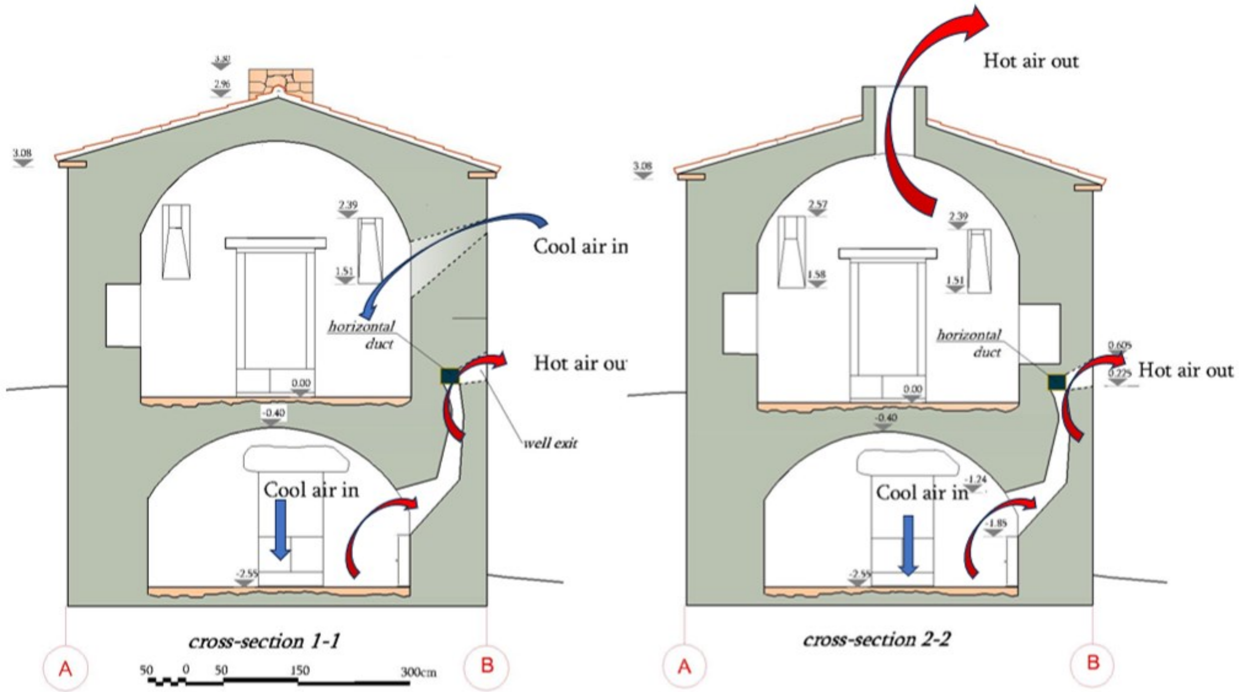

Fig. 13. *Cross-section of Melik Yegan reception hall, schematic diagram of air movement. By M.Titanyan*

Initial data for calculation

The assessment of the ventilation efficiency in the basement area is based on measurements and the geometric characteristics of the preserved ventilation elements.

According to the measurements, the total volume of the basement is approximately 63.5 m³. The ventilation system consists of inlet openings, horizontal pipes embedded in the stone walls, and an outlet opening located at a higher level on the facade.

The main geometric parameters are: the dimensions of the fresh air inlet opening are 0.41×0.66 m (S ≈ 0.27 m²), and the cross-section of the horizontal pipe is 0.22×0.22 m (S ≈ 0.048 m²). The dimensions of the exhaust air outlet opening are approximately 0.36×0.40 m (S ≈ 0.144 m²).

Since the system operates under natural conditions, i.e., without mechanical pressure, the dimensions of the ventilation shaft were selected based on values typical for natural ventilation systems. Lower velocities were assumed for the inlet openings, in the range of 0.2–0.3 m/s, while higher values of up to 1.0–1.5 m/s were taken into account for the ducts and outlet sections, reflecting the acceleration of the air flow due to pressure differences.

Calculation Approach and Results

To estimate the airflow rate, a standard relationship between airflow, velocity, and opening area was applied:

$$L = v \cdot 3600 \cdot S. \quad (1)$$

This equation allows the determination of airflow rate (m³/h) based on the cross-sectional area of the opening (S) and the average air velocity (v)[8].

By substituting the measured geometric parameters and applying aerodynamic assumptions, the airflow rates and velocities for different sections of the system were determined. The results are illustrated in the corresponding schematic diagram (Fig. 14).

[8] HHSHN IV-12.02.01-04, Jerrutsum, odapekhum yev odi lavorakum. Yerevan, 2004 (in Armenian). Available at: https://www.arlis.am/hy/acts/19533. Accessed on August 08, 2026.

First, the airflow through the inlet opening was estimated. Taking an average velocity of 0.23 m/s and an opening area of 0.27 m², the airflow rate is approximately: L ≈ 225 m³/h.

Given the presence of two similar inlet openings, the total inflow can be estimated at 440–450 m³/h. For the horizontal duct, where airflow is more confined, a higher velocity of about 1.3 m/s was assumed. With a cross-sectional area of 0.048 m², the corresponding airflow rate is approximately: L ≈ 225 m³/h. At the outlet section, where warm air is discharged, the velocity was assumed to be around 1.0–1.1 m/s. This results in an exhaust airflow rate close to: L ≈550 m³/h.

Taking into account all sections of the system, the overall airflow rate can be reasonably approximated as: L ≈ 550 m³/h.

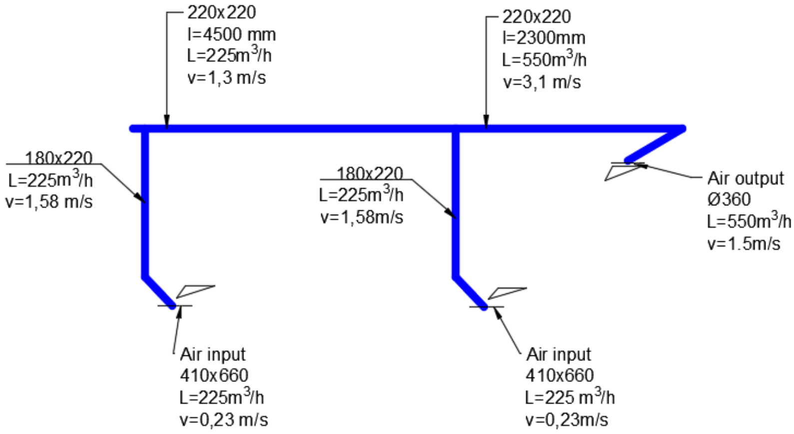

Fig. 14. *Diagram of the exhaust ventilation system. By A.Karamyan*

To evaluate the efficiency of the ventilation system, the air exchange rate (n) was calculated as follows: (air exchange rate reflects how many times per hour a given volume of space is ventilated):

$$n = \frac{L}{V} \ , \tag{2}$$

where L is the total air flow in (m^3/h), V is the volume of the space (m^3).

Substituting the obtained values:

$$n \approx 550 / 63.5 \approx 8.6 \text{ h}^{-1}.$$

This means that the air in the basement is renewed approximately 8–9 times per hour.

Comparison with Persian Badgirs and Egyptian Wind Towers

Wind towers are among the most studied airflow systems in traditional Middle Eastern architecture. These structures capture prevailing winds at roof level and direct fresh air through vertical shafts into interior spaces. Air circulation is driven by a combination of wind pressure, buoyancy, and thermal mass, enabling passive cooling without mechanical equipment[9]. Archaeological evidence suggests that wind-absorbing systems were used in ancient Egyptian architecture, in which raised openings directed cooler air into interior spaces, while warmer air was expelled through higher openings[10]. Similar principles were later developed throughout the Middle East.

In contrast, the natural ventilation systems mentioned in Togh do not rely on tall wind-absorbing towers. Instead, ventilation appears to have been achieved through integrated horizontal stone ducts, combined with strategically placed inlet and outlet openings. The airflow path is embedded in the thick stone walls, where pressure differences and thermal buoyancy create continuous natural ventilation. These observations may indicate an alternative engineering solution adapted to the mountainous terrain and architectural features of Armenian stone construction.

While Persian wind towers require significant vertical structures above the roofline, Togh's system is fully integrated into the building envelope. These observations suggest that this configuration may reduce visual impact, improve structural protection, and allow the ventilation system to operate even in buildings with compact layouts and partially underground spaces.

[9] HHSHN IV-12.02.01-04, Jerrutsum, odapekhum yev odi lavorakum. Yerevan, 2004 (in Armenian). Available at: https://www.arlis.am/hy/acts/19533. Accessed on August 08, 2026.
[10] Ibid.

The ventilation method used in Togh is more akin to modern environmental control strategies, which aim to minimize building energy consumption while maintaining acceptable indoor environmental quality.

The ventilation systems described in Togh exhibit several characteristics that are consistent with modern passive ventilation principles. The arrangement of inlets at low levels and outlet openings at high elevations promotes buoyancy-based airflow. Thick stone walls provide thermal mass that moderates indoor temperature fluctuations, while embedded ducts create controlled air paths comparable to modern environmental engineering solutions.

Although the builders had no formal knowledge of air-movement mechanics, the architectural solutions considered demonstrate an empirical understanding of airflow behavior. Their design effectively exploited the interaction of thermal gradients, wind pressure, and building geometry to ensure continuous natural air exchange.

Comparing the Togh ventilation example with modern ventilation standards, we obtain a calculated ventilation rate of approximately 8.6 air changes per hour, indicating that such an airflow system could maintain a constant air renewal in the given area. The calculated air exchange rate coincides with the range recommended in modern ventilation practice for food storage, basements, and certain service areas[11]. It is especially noteworthy that such efficiency was achieved exclusively by natural means. The airflow is due to pressure and temperature differences caused by the wind, without any mechanical assistance.

Overall, comparative analysis indicates that Togh environmental engineering solutions reflect adaptation to local climatic conditions, mountainous topography, and building traditions. The engineering performance evaluated in this study indicates that these systems can provide effective natural ventilation comparable to modern passive ventilation objectives. Table 3 shows the structural and functional comparison of the studied ventilation systems.

Table 3. Comparison table of natural ventilation systems used in the past

Feature	Persian Badgir	Egyptian Wind Tower	Historic Togh System
Driving mechanism	Wind + stack effect	Wind + buoyancy	Buoyancy + wind pressure
Air channel	Vertical shaft	Vertical shaft	Horizontal masonry duct
Integration	Roof tower	Roof tower	Embedded in thick stone walls
Thermal mass	Moderate	Moderate	Very high
Main function	Cooling	Cooling	Ventilation, cooling, humidity control
Suitable climate	Hot-arid	Hot-arid	Mountainous temperate/subtropical
Mechanical energy	None	None	None

These past structures should be considered not only as examples of vernacular architecture but also as complex environmental engineering systems developed through centuries of accumulated experimental knowledge [15, 16].

Conclusion

This study investigated the natural ventilation systems integrated into the historical architectural structures of Togh village, with particular focus on the Melik Yegan Palace complex. The aim was to identify the design principles, spatial organization, and functional performance of these systems within the framework of passive environmental control.

The results suggest that traditional buildings in Togh incorporated effective environmental control strategies adapted to local climatic conditions, mountainous terrain, and the characteristics of stone masonry construction. The investigated ventilation systems were not limited to residential spaces but were also applied

[11] HHSHN IV-12.02.01-04, Jerrutsum, odapekhum yev odi lavorakum. Yerevan, 2004 (in Armenian). Available at: https://www.arlis.am/hy/acts/19533. Accessed on August 08, 2026.

in basement and semi-basement areas, including spaces with limited or no direct openings. The analysis revealed that these systems were based on the coordinated use of air inlets, horizontal wall-integrated ducts, and elevated outlets, enabling continuous air movement through thermal buoyancy and pressure differences.

The study suggests several important characteristics of the ventilation systems.

1. Stone-vaulted basement and semi-basement spaces were widely incorporated into eighteenth- and nineteenth-century structures, while rooms intended for storage and auxiliary functions achieved improved environmental stability through passive air exchange.
2. Rooms intended for economic purposes, despite lacking natural lighting, maintained stable internal conditions through effective ventilation.
3. The configuration appears to reflect the deliberate application of passive ventilation principles. Although direct evidence of the original design intentions is unavailable, the observed spatial arrangement is consistent with airflow mechanisms driven by thermal buoyancy and pressure differences.
4. The calculated air exchange rate of the investigated basement space suggests that a considerable ventilation capacity was achieved without mechanical assistance.
5. Roof openings in vaulted structures enhanced vertical airflow and improved indoor environmental regulation.
6. The volumetric and spatial configuration of the Melik Palace reception hall reflects a design that ensured both environmental control and functional resilience, including enhanced security and reduced fire risk.

The scientific novelty of this research lies in the systematic identification and functional interpretation of integrated passive ventilation systems within Armenian architectural heritage. Supported by field measurements, architectural documentation, and airflow calculations, the study goes beyond descriptive analysis to reveal the engineering principles underlying these historical solutions. Unlike widely studied wind towers of the Middle East, the Togh examples demonstrate a distinct approach in which ventilation mechanisms were incorporated directly into massive stone walls and adapted to local architectural and climatic conditions. The documentation and analysis of environmental engineering solutions, such as those identified in Togh, contribute to a more comprehensive understanding of heritage structures and support the development of informed conservation and adaptive reuse strategies. The findings contribute to the development of engineering thought within Armenian architectural heritage and open new directions for future research.

The identified passive ventilation systems demonstrate the continued relevance of vernacular environmental strategies for contemporary architectural practice [17]. Their adaptation to local climatic conditions provides valuable insights for heritage conservation, passive environmental design, and the development of energy-efficient and climate-responsive architecture.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research did not receive any financial support.

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