BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iaşi
Volumul 69 (73), Numărul 1, 2023
Secţia
CONSTRUCŢII. ARHITECTURĂ
DOI: 10.2478/bipca-2023-0003

Reinterpreting ancient typologies of natural ventilation: a climatic and cfd-based analysis

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Received: September 20, 2025
Accepted for publication: October 6, 2025

Abstract

Ensuring indoor environmental comfort parameters in relation to indoor air quality requirements necessitates the identification of methods that allow for the development of tools to validate the natural ventilation efficiency in relation to factors that can influence system performance. Analysing the historical evolution of natural ventilation, it is observed that the main identified natural physical phenomena by researchers and design specialists in the field are primarily based on the natural forces that generate the exchange of air between the constructed interior environment and the natural exterior environment. The difference in air pressure on either side of the envelope can be generated by two natural factors, either independently or cumulatively, through the action of the wind and temperature difference.

Keywords: Architecture, Collaboration, Trust, Convergence, natural ventilation, energy effiency

Introduction

This paper studies the way ancient society addressed the issue of fresh air supply in residential buildings through architectural systems, in correlation with meeting comfort requirements. Since the early days of building constructions, especially those intended for habitation, it has been observed that, although involuntarily, a strong connection was established between ensuring thermal comfort and providing the fresh air necessary for the occupants' survival. The aim is to identify passive, natural construction methods that could be successfully integrated into contemporary architecture. In general, three major geometric morphologies can be identified that contribute to the manner of air exchange between the interior and exterior, depending on the location in relation to the major climatic zones: warm, temperate, and cold. Buildings located in the northern regions with a temperate continental and cold climate have led to the placement of the heat source at the centre of the function. For buildings located in areas with a warmer winter climate, such as the subtropical zone, one of the identified characteristics is the appearance of the atrium or inner courtyard, which facilitates the opening of spaces to a sheltered, shaded area, allowing for controlled cooling of the spaces. In tropical, subequatorial, and equatorial climate zones, a specific characteristic is identified from the constructive use for the purpose of utilizing the chimney effect. The external climatic factor, today, has become just a coefficient in the equation for sizing ventilation systems, as the adjustment of air supply parameters has turned into a complex technological process accompanied by various mechanisms and technologies, tailored to the requirements. The variety of types of equipment intended for controlling the quantity and quality of fresh air introduced into buildings has led over time to a decrease in production, acquisition, and installation costs for these types of complex systems. However, to meet high energy efficiency requirements, re-evaluation is necessary.

Literature Review

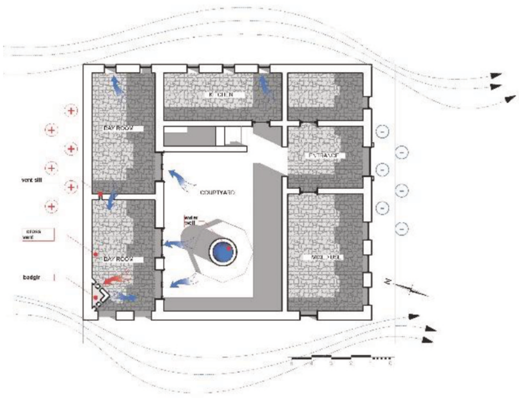
From the very beginning, it is possible to observe characteristics dependent on the climatic zones in which the study buildings are located, and specific features can be preliminarily identified. Historical residential architecture often relied on passive design strategies to regulate indoor climate. These include: Wind catchers (badgirs): Used in Middle Eastern architecture to funnel cool air indoors and expel warm air; Courtyards: Central open spaces that promote air circulation and thermal buffering; Stack ventilation: Leveraging vertical air movement through high and low openings; Thick walls and high ceilings: For thermal mass and air stratification. For the evaluation and retrieval of the necessary input data, namely monthly average outdoor temperatures and average wind speeds, the climatic zoning classification system developed by Wladimir Köppen (Arnfield, A.J.,2025) was used. Group B: arid climate; hot desert subgroup (Bwh) In regions with a hot and dry climate, such as the Middle East, northern Africa, or parts of India and Australia, the main purpose of natural ventilation is to cool indoor spaces and maintain a comfortable microclimate. Ancient Mesopotamian architecture utilized wind catchers and atriums to enhance airflow in hot, dry climates. These elements were integrated to achieve efficient ventilation systems, increasing airflow speed and thermal comfort in buildings (Alshakir, 2025). Wind catchers, particularly in Middle Eastern architecture, have been shown to optimize wind capture and air circulation. Studies on their configurations, such as the angle of upper wing walls, revealed that a 30° angle provides optimal ventilation performance (Nejat, 2024). Courtyards were a common passive cooling strategy in ancient buildings. Research indicates that reducing the windward side length and elongating the courtyard in the wind direction improves airflow patterns and ventilation efficiency (Saadatjoo, 2016).

Methodology

Based on Computational Fluid Dynamics (CFD) has been used to analyze airflow in historical buildings, such as the Pitti Palace in

Florence (Balocco, 2008) and similar CFD studies on Xingguo Temple that demonstrated the benefits of integrating computer simulations in planning and protecting ancient buildings while improving their natural ventilation (Li, 2023) the use of ANSYS Discovery, a powerful simulation-driven design tool that blends real-time physics simulation, high-fidelity analysis, and interactive 3D modelling into a single, intuitive platform was chosen. This helps visualize pressure distributions, temperature gradients, and ventilation effectiveness—offering insights into the sustainability and ingenuity of traditional design, long before the advent of modern HVAC systems. Workflow in Ansys Discovery is a straightforward process that involves the following key steps: Import Geometry designed in Archicad straight in Discovery's built-in modelling panel where optimisation of flow volume and meshing was performed. A crucial step is defining key architectural features: windows, doors, vents, and internal partitions. Definition of Fluid Domain that consists of identifying the air volume inside and around the structure. The use the Enclosure tool to create a fluid domain that surrounds your geometry is the next step in the process. In the scope of the research the next stage consists in assigning the specific materials and setting the fluid properties of internal/external volume material to air, solid materials to walls, furniture, or other elements if needed for thermal interaction. After the previous stage the setting of Boundary Conditions such as Inlets/Outlets, setting the definitions for openings like windows or vents as pressure outlets or velocity inlets, Walls Set as no-slip boundaries is performed. The specific independent variables such as Ambient Conditions: temperature, pressure, and gravity to simulate buoyancy-driven flow is the key step in obtaining valid results for the simulation. In this simulation Gravity and Buoyancy Effects were enabled and the Boussinesq approximation if simulating temperature-driven ventilation (stack effect) was used. A refined mesh near walls and openings for better accuracy was preferred. Simulation was performed in the Steady-State that suited study goals for observing the effects of a windcatcher and the potential in modern passive systems. The Post-Processing offers valuable tools that helps the user to visualize airflow using streamlines to show direction and velocity, temperature contours to assess thermal comfort, velocity vectors to identify stagnant zones or high-speed jets. Considering the current climatic evolution, namely the increase in average annual temperatures and the desertification of geographical areas traditionally classified as belonging to class Dfa towards class BSk and Bwh in some cases, it is considered useful to study specific constructive typologies of the Middle East, such as residences that include an interior courtyard, often featuring a water well and a badgir tower, orientation of buildings and their openings towards the prevailing winds, usually from the north.

Natural ventilation was not just a matter of thermal comfort, but also of public health. In the hot and dry regions of the Middle East, where water was often a rare and precious resource, the efficient use of air and wind was essential to prevent the risks associated with stagnant air, which contributes to the emergence of respiratory diseases and infections. The combination of natural ventilation with the use of Persian wind catchers represents a fascinating example of architectural adaptation to local conditions, demonstrating the importance of utilizing natural resources for a more sustainable and efficient living. It constitutes a positive example of how the principles of natural ventilation and the way these traditional solutions can be integrated into modern architecture can contribute to the creation of eco-friendly and energy-efficient buildings.



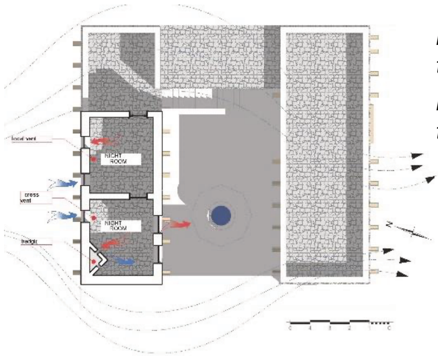


Fig. 1 Ground plan traditional house

Fig. 2 First floor plan traditional house

Results

Using ANSYS Discovery, the principles of physical phenomena occurring in the operation of construction systems were simulated and observed. Seasonal averages of external temperatures specific to the climatic zone, predominant directions of air mass movement, and average wind speeds were used. The simulation aims to obtain valid data that will contribute to identifying the potential for the reinterpretation and contemporary use of constructive concepts from antiquity. A basic volumetric model was generated, including the specific elements of the houses in the studied climatic zone. Stone masonry with mortar was set as property for all walls. To observe and analyse a set of conclusive variables, it is necessary to develop a simulation as close as possible to natural conditions that involve the seasonal variation of temperature ranges. The relevant output indicators chosen to refer the values of the pressure domain, the speeds of air mass movement, and the interior and exterior temperatures for the analysed building. Type B climate in the Köppen-Geiger climate classification represents arid climates. These are characterized by low rainfall, insufficient to compensate for evaporation, which gives them a dry landscape. The following tables aggregate public data on average monthly precipitation amounts, minimum, median, and maximum temperatures for the period 1991-2022, according to publicly available resources published by the World Bank Group and include statistical values. The selected data is based on average values and includes specific anomalies, historical values, and offers global coverage. To be relevant in the context of the research, minimum, average, and maximum monthly temperature values processed by arithmetically averaging historical values collected from measurement stations will be used.

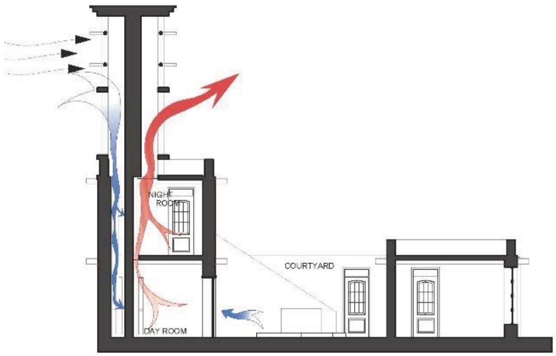


Fig. 3 Schematic section traditional house

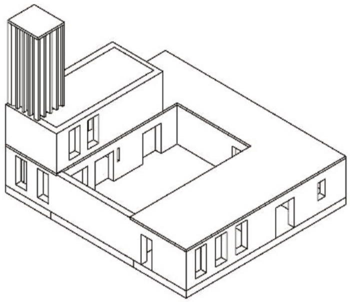


Fig. 4 Axonometric view of proposed building for study

Table 1 Average monthly temperatures and precipitation

Month	Average minimum temperature	Average median temperature	Average maximum temperature	The amount of precipitation
Jan	6,82	13,72	20,67	3,89
Feb	7,85	15,21	22,62	3,30
Mar	11,21	18,74	26,31	1,97
Apr	15,26	23,23	31,25	1,37
May	19,32	27,10	34,93	0,92
Jun	21,99	29,63	37,33	0,31
Jul	23,39	30,53	37,72	0,53
Aug	23,43	30,58	37,78	0,73
Sep	21,67	28,67	35,71	0,22
Oct	18,10	25,13	32,20	1,18
Nov	12,66	19,53	26,46	2,04
Dec	8,27	15,13	22,05	3,14

Other required data for input independent variables consists of specific monthly average wind speeds in the studied area.

Table 2 Average monthly wind speed data

Month	Average wind speed (m/s)
Jan	4,011723
Feb	4,201306
Mar	4,156168
Apr	4,095612
May	4,157945
Jun	4,061279
Jul	4,098556
Aug	3,920779
Sep	3,749251
Oct	3,819779
Nov	4,025140
Dec	4,139584

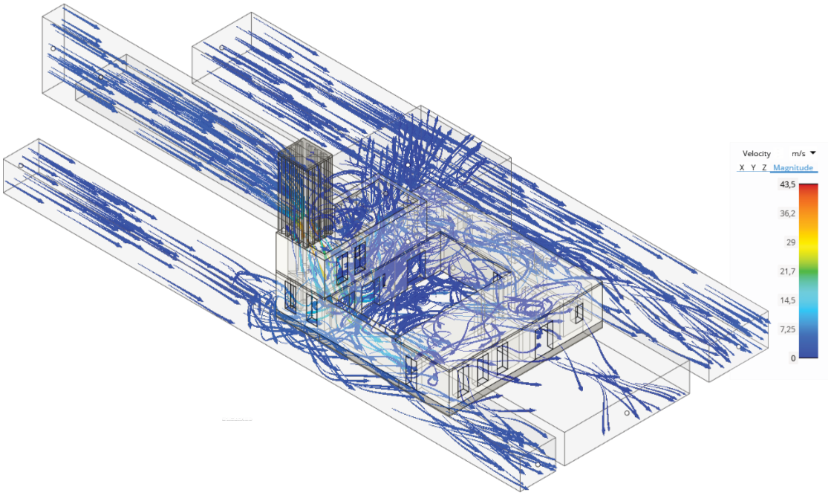


Fig. 5 Simulated results for velocity vectors

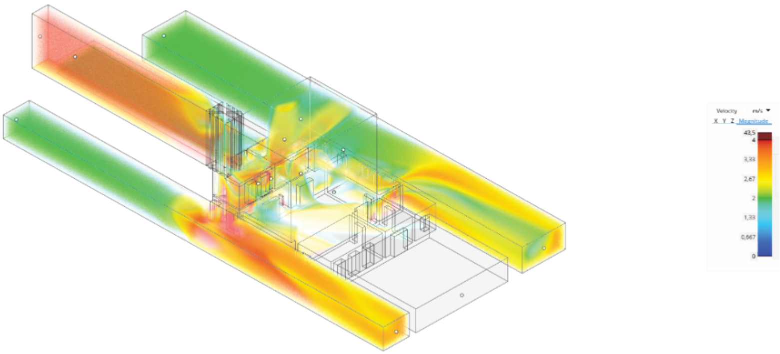


Fig. 6 Simulated results for velocity volume

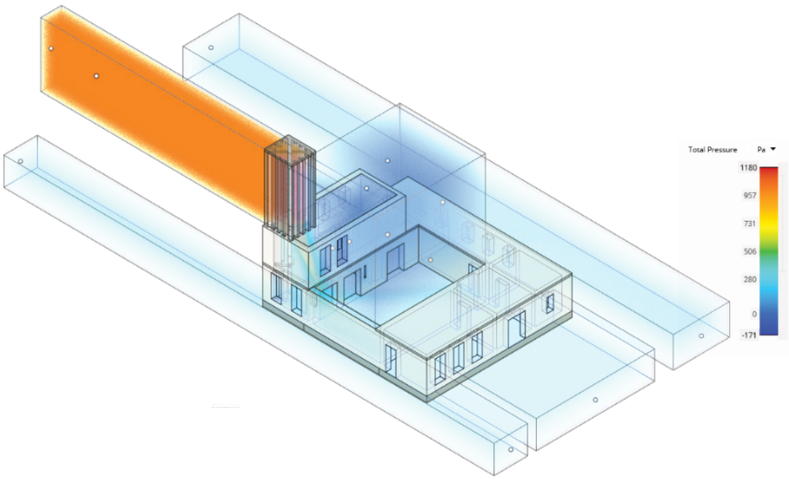


Fig. 7 Simulated results for pressure uniformity distribution

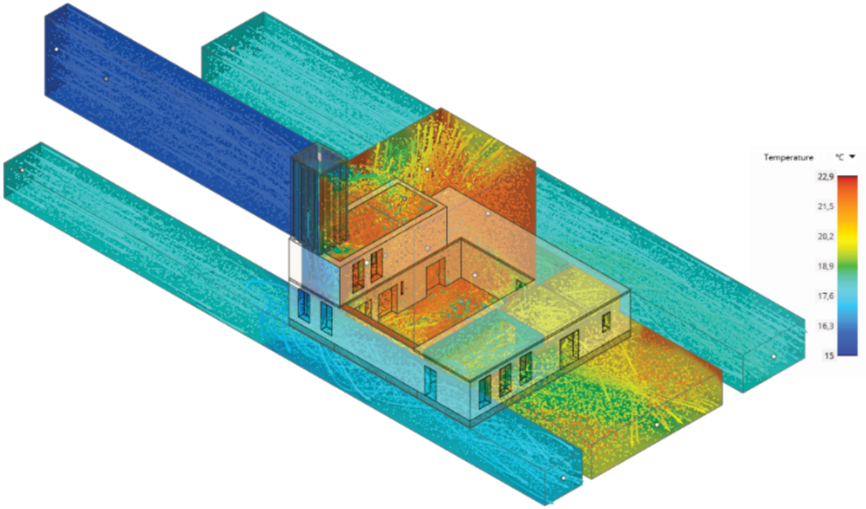


Fig. 8 Simulated results for temperature direction

Discussion

The study of ancient structural compositions using modern simulation and analysis technologies can offer specialists, interdisciplinary teams of architects and engineers, a new perspective on the potential inclusion of these in the design process. This process can offer the possibility of integrating old passive solutions into a hybrid system with new automated monitoring and control technologies. Selection of courtyards, wind catchers, or lattice systems according to local wind regimes and humidity patterns validated via CFD, not by stylistic similarity alone is the most important thing to consider when adopting this approach.

Conclusion

Although the present study provides a brief analysis of an isolated case study regarding the potential for integrating methods used in the past into optimized passive solutions, it can become a model for a systemic and integrated approach toward developing the necessary tools for designers. This type of study can be adapted and extended to the specific analysis of other climatic zones that present challenges in adapting constructions to local environmental conditions. Validation evidence trough CFD simulations, when calibrated against on-site measurements, reproduce airflow patterns and metrics such as air change rates and indoor velocities, confirming the performance of many vernacular devices in their original climates. Where CFD challenges tradition Simulations show some elements perform poorly outside their climatic/design envelope or with changed openings/orientations, revealing limits to direct transplant of vernacular features without adaptation

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Reinterpretarea tipologiilor antice de ventilare naturală: o analiză bazată pe climat și modulul CFD

(rezumat)

Asigurarea parametrilor de confort al mediului interior în relație cu cerințele de calitate a aerului interior necesită identificarea metodelor care permit dezvoltarea unor instrumente pentru validarea eficienței ventilației naturale în funcție de factorii care pot influența performanța sistemului. Analizând evoluția istorică a ventilației naturale, se observă că principalele fenomene fizice naturale identificate de cercetători și specialiști din domeniu se bazează în principal pe forțele naturale care generează schimbul de aer între mediul interior construit și mediul exterior natural. Diferența de presiune a aerului de pe ambele părți ale anvelopei poate fi generată de doi factori naturali, fie independent, fie cumulativ, prin acțiunea vântului și a diferenței de temperatură..