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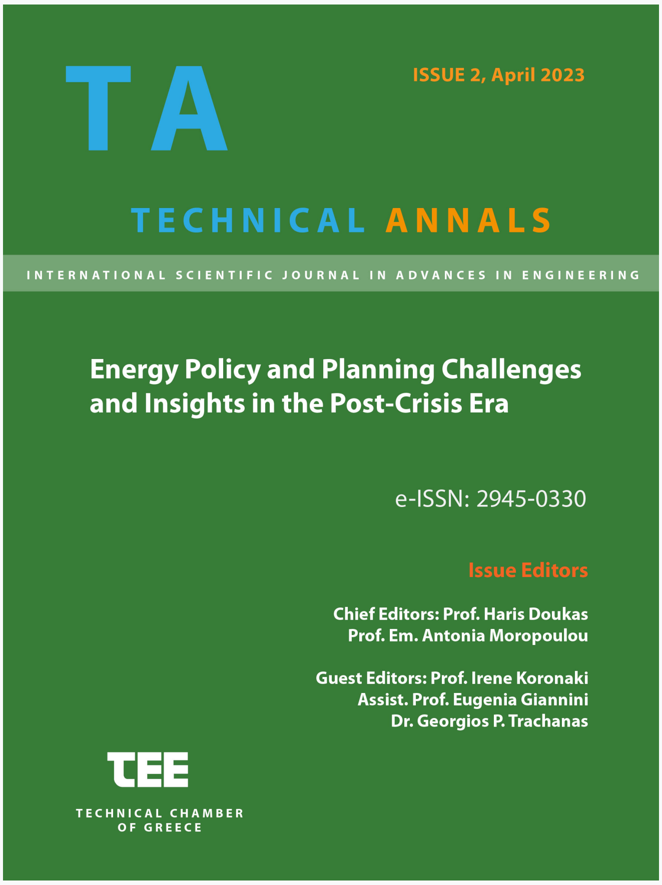

Climate-responsive opportunities and challenges in urban vernacular heritage.

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Climate-Responsive Opportunities and Challenges in Urban Vernacular Heritage

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Abstract. In response to today's contemporary challenge regarding how to tackle the effects of climate change in heritage environments, natural ventilation arises as a compatible, low-cost and environmentally friendly passive cooling strategy for the Mediterranean climate. However, an identified research gap concerns the lack of studies addressing data from both the urban and building scales. An innovative, multi-scale approach is introduced in this research, through the study of airflow on the neighbourhood, street canyon and building scales, which is then evaluated using field measurements. The effect of urban density and street-canyon geometry on indoor thermal comfort is discussed in the case of adobe buildings with pass-through spaces (*portico*), and timber projections with multiple openings (*sahnisi*). The originality of the presented research lies in the adopted multi-scale methodology. On the district level of study, analytical tools and urban-scale considerations in the development of vernacular buildings are discussed through the lens of environmental performance. Building ventilation is addressed as a function of in-street and rooftop airflow, demonstrating the airflow gradient across the scales under study. Furthermore, the impact of various window operation patterns is quantified, given the variability of the background wind and street geometry. The results indicate best practices for enhancing the cooling effect of natural ventilation, highlighting the role of occupant behaviour and night-time ventilation. Finally, key directions regarding conservation practices in urban contexts are discussed, bringing energy performance and comfort into cultural heritage studies.

Keywords: natural ventilation, thermal comfort, vernacular, urban canyon.

1 Introduction

Built vernacular heritage, as defined by the relevant International Council on Monuments and Sites (ICOMOS) Charter in 1999, refers to "*the traditional way by which communities house themselves*"[1]. Its importance lies not only in the singularity of each built artefact, but also expands to the context of urban and rural complexes. The benefits of having continuously inhabited and vibrant historic urban centres range from the intangible advantage that heritage has on society and cultural identity, to measurable economic and environmental benefits[2]. In this respect, accommodating contemporary standards of living and complying with thermal comfort requirements is a common

challenge;especially in light of climate change and unprecedented transformations in the social and urban context of historic centres[3].
Placing urban morphology in the climate context of its environment plays a key role in the liveability and continuous use of urban heritage. Historic Urban Landscapes (HUL), especially in hot, arid climates around the Mediterranean, are characterised by narrow, winding streets and wide courtyards in a continuous building system[4]. The airflow and thermal characteristics at street canyon level determine the heat flux and air quality of the city, thus, playing a crucial role in the energy demand of buildings[5]. Building density creates rather ambivalent microclimatic conditions. Narrow and winding streets contribute to the decrease of solar radiation and provide shading; however, they suffer from reduced cooling potential due to reduced outgoing long-wave radiation. Also, an increase in urban compactness entails a decrease of solar energy availability within the urban texture and an increase of heat island intensity in the urban area, especially at night. Thus, urban compactness may have contrasting outcomes in a building's energy performance, especially in the Mediterranean climate, where cooling and heating demand is equally significant[6].
Respectively, airflow within the urban canopy layer (UCL), which reaches the average building height, can be a far lower fraction of the free-stream wind speed that is developed at the top of the urban boundary layer (UBL). This has an impact on indoor ventilation and the provision of comfort ventilation, which is based on elevated air speed. Furthermore, air and heat exchange processes between the in-street and above-canopy region, define the ability of heat and pollutant removal, which in turn, define the boundary conditions for building ventilation[7]. The building density, as well as the degree of asymmetry and the variation of the building height are highlighted as beneficial in generating more turbulence at the top of the canyon, thus increasing the air exchange process between the air in the street canyon and the atmosphere. This capacity of an urban environment to 'ventilate' itself, termed as *breathability*, is often underestimated, as most numerical or laboratory studies focus on idealised geometries[8,9]. This highlights the need for further field studies in real urban settings and especially in historic urban centres with substantial heterogeneity that have been organically developed[10].
In turn, the built environment of the HUL incorporates several opportunities, as well as challenges, in terms of environmental performance. The climatic adaptability of vernacular buildings and settings has been confirmed by various studies highlighting the role of the building form and typology, the selection of building materials and the use of open and semi-open spaces[11–15]. However, several studies also address the potential of energy savings and emissions' reduction by retrofitting vernacular buildings[16–20]. Prior to exploring the potential of integrating innovative materials and renewable energy systems in a compatible way, it is imperative to cater for the protection and enhancement of the passive design strategies employed through the building envelope and its surroundings[21]. Particularly in the Mediterranean climate, natural ventilation emerges as a significant passive cooling strategy[22,23]. Especially in heavyweight buildings, night ventilation techniques are particularly effective in order to delay heat transmission and decrease the temperature amplitude of the outdoor environment[24–26]. As a non-invasive technique, natural ventilation constitutes a considerable advantage in the case of retrofit projects, given the delicate protective legislation schemes for heritage

buildings. Also, this strategy has minimal operational costs and is considered an environmentally friendly alternative to relying on mechanical heating, ventilation, and air conditioning (HVAC) systems for comfort. Cross-ventilation and buoyancy-driven ventilation are enhanced by numerous building elements (e.g., pass-through semi-open spaces, courtyards, interior stairwells, windcatchers etc.), yet their effectiveness relies on both occupant behaviour and urban morphology[27,28]. The question that arises and has been investigated in this research, is the degree to which we can rely on natural ventilation as a cooling strategy in heavyweight vernacular buildings located in dense urban contexts.

2 Methodology

2.1 An overview of the research objectives, scales of study and tools

When it comes to the environmental assessment of vernacular heritage and the role of natural ventilation, an identified research gap concerns the lack of studies addressing data from both the urban and building scales. In this context, the research presented in this paper investigates the role of natural ventilation as a passive cooling strategy, to highlight the environmental challenges and opportunities that arise in urban vernacular heritage. One of the main research objectives and innovations of this research is to address building ventilation as a function of in-street and rooftop ventilation, as well as to decipher the role of urban geometry in determining any possible variation in indoor and urban ventilation. An innovative methodology is adopted for the consideration of the multi-scale nature of airflow on, a) neighbourhood, b) street canyon, and c) building scale, highlighting the airflow gradient across the different scales under study, in real field conditions. Analytical tools are employed on the district scale of study, which corresponds to the walled city of Nicosia, Cyprus. Respectively, environmental field monitoring is conducted in the selected neighbourhoods, street canyons and buildings (see Fig. **1**).

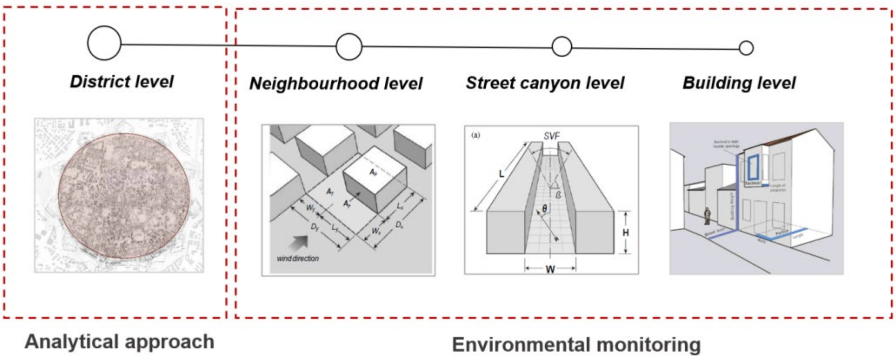

Fig. 1. Scales of study and main methodological tools employed.

An additional objective is to address the effect of various window operation patterns (applied by the occupants or under controlled conditions) on indoor thermal comfort. The focus is on heavyweight buildings with tripartite arrangement (*trimeres*), featuring two elements which both play key roles in natural ventilation[29]. The first is the pass-through space called *portico* that connects the street and the interior courtyard and the second is the timber projecting volume *sahnisi* (see Fig. 2). Furthermore, through this research, the role of the sahnisias a wind-capture element in a dense urban canopy is quantified under real field conditions.

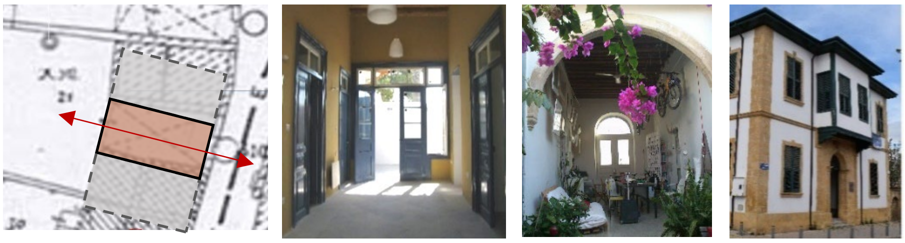

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Fig. 2. a) Typical tripartite arrangement of houses with portico (highlighted in colour); b) View of a pass-through portico space – towards the courtyard; c)A portico space in the original, semi-open form – view towards the street; d) Two-storey building with tripartite arrangement and sahnisi projecting volume on the first floor.

2.2 Analytical tools employed on the district scale of study.

An analytical approach was adopted for the investigation on the district level of study. The aim was to identify the main typological and morphological features that play a key role in the effectiveness of natural ventilation on a building or urban scale. Additional goals were to investigate the interdependence of urban morphology and environmental parameters, such as insolation and ventilation. And finally, to select case study neighbourhoods, street canyons and buildings for further environmental monitoring. An innovative, multi-dimensional and multi-scale approach was applied to reading the historical process of defining the urban tissue and building typology. This was achieved through a holistic reinterpretation of historic, cultural and environmental factors, in order to interrelate these attributes to each other in a meaningful way. The tools used in this process involved historic references, maps, chronicles, in situ documentation and mapping of particular vernacular design elements in the wider district of the walled city of Nicosia.

2.3 Environmental monitoring on the neighbourhood, street canyon and building scales of study.

Environmental measurements (focusing on temperature, relative humidity and air velocity) were conducted in, a) two neighbourhoods with distinctive building density, mean building height and street pattern; b) three street canyons with variable aspect ratio (two narrow canyons and one square shaped canyon); and c) three heavyweight adobe buildings with pass-through portico spaces (single-storey, double-storey and double-storey with sahnisi). Measurements were taken at the reference height of 2.5H, the mid-height and the top of the canyons, as well as in the portico spaces of the buildings. The cross-scale nature of ventilation is characterised through the normalised ratios of indoor velocity to canyon wind speed, U_{in}/U_c, as well as the ratio of canyon to reference wind speed, U_C/U_{ref}. Finally, the breathability capacity – which demonstrates the rate of air and heat exchange between the UCL and the RSL (laying above) – is quantified through the ratio of the non-dimensional exchange velocity, U_E, to reference wind speed, U_{ref}. A schematic representation of the cross-scale approach adopted in the environmental monitoring is presented in see Fig. 3.

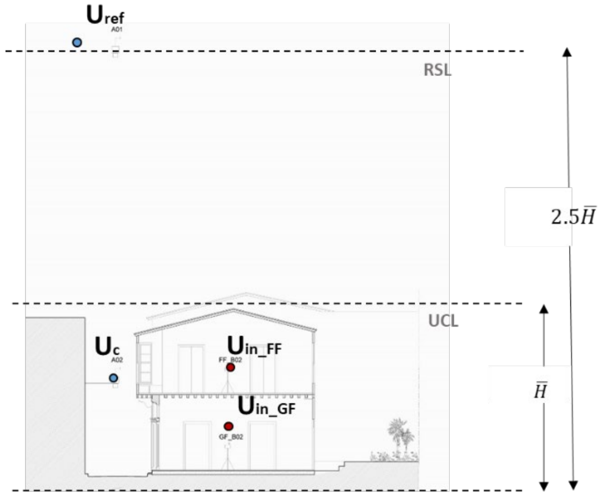

Fig. 3. Schematic representation of the cross-scale approach in the environmental monitoring.

Urban scale: A set of morphometric variables were adopted to describe urban morphology: the Sky View Factor (SVF), planar and frontal packing density (λp, λf) and mean building height. Area 1 is mainly comprised of two-storey buildings, whereas Area 2 is covered mainly by ground-floor residences with large courtyards, settled in a more organic and irregular street pattern. For this reason, Area 2 presents a higher SVF and a lower packing density than Area 1, i.e., SVF2=0.39±0.24, λp2=0.49, whereas SVF1=0.26±0.22 and λp1=0.60. Two narrow street canyons with aspect ratio H/W=2 (where H the building height and W the street width), located in Area 1 (i.e. Perikleous and P.P.Germanou str.), and one square cavity canyon (H/W=1) in Area 2 (i.e. Antigonou str.), were selected. The streets have the same orientation, i.e., 20° from north, and the monitoring points were located approximately at a height of 5m above street level, centred in the middle of the street width.

Building scale: Three adobe buildings with tripartite arrangement and central portico spaces were selected for environmental monitoring, located on the aforementioned-street canyons, as shown in Fig. 4**.** Specifically, the building located on Perikleous street in Area 1, is a characteristic double-storey building with a portico and a timber projecting volume sahnisi on the first floor, covering approximately 210m^2 of indoor space. The double-storey building on P.P. Germanou street in Area 1, and the single-storey building on Antigonou street in Area 2, cover indoor spaces of approximately 120m^2.

Furthermore, the impact of various window operation patterns was quantified, given the variability of the background wind and the street geometry.Each ventilation scenario comprises variable time of opening, namely: all-day, daytime, night-time ventilation or no ventilation, as well as different percentages of opening (described through the indicator Window-to-Floor percentage – WTF) in cross-ventilation or single ventilation mode.It is noted that applying cross-ventilation in the ground-floor porticos was not always an option as either, a) the opening above the main entrance door (locally called *arsera* or *phengitis*) was not operable, or b) the glazed surfaces incorporated on the main entrance door remained closed due to safety reasons. Finally, indoor thermal comfort was assessed through the adaptive comfort theory[30]. Additional parameters of relative humidity and air velocity were also taken into consideration.

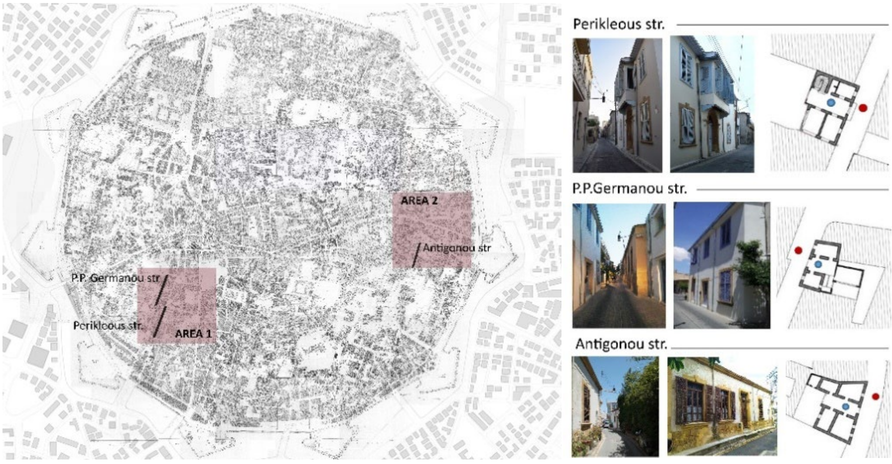

Fig. 4. Case study urban buildings and urban canyons.

3 Results and discussion

3.1 District level of study

The holistic analysis of the district level of study revealed that the early drafting of the street network was on the north-south axis, favouring south orientation for the buildings. The city's fortification, unprecedented housing demand and multiple phases of land allotment, finally defined an urban canopy with both environmental virtues and limitations, e.g., narrow streets that provide shading during the summer, yet suffer from reduced potential for long-wave radiation during summer nights. Respectively, the building typology analysis highlighted the climatic adaptability of vernacular forms that is achieved through a series of elements, e.g., the courtyards, semi-open spaces adjacent to the main building volume, the cross arrangement of the windows and the sahnisi volumes that provide multiple window operation possibilities to the occupants. Based on the city's topographic map, approximately 40% of vernacular buildings in the walled city of Nicosia incorporate portico spaces in semi-open or closed form, that are widespread across the city (see Fig. 5). The majority of the porticos, specifically 78% of the identified cases, correspond to the central part of a three-bay arrangement, 22% correspond to double-bay buildings, while single-bay porticos are very rare.

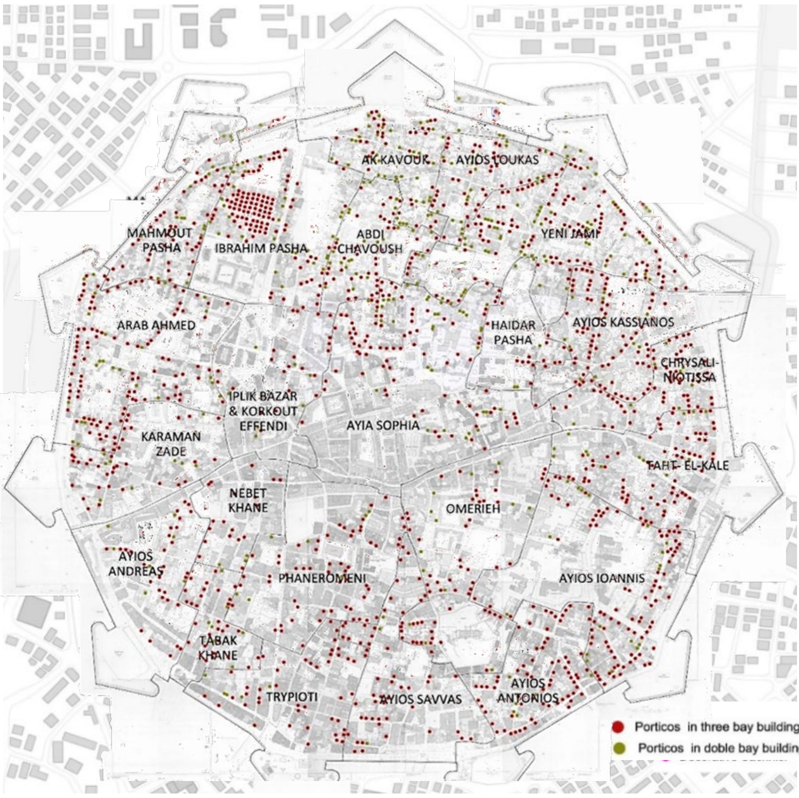

Fig. 5. Spatial distribution of porticos across the walled city of Nicosia.

The mapping process also identified 233 buildings with closed sahnisis and a total of 246 sahnisi projections. Most of the timber sahnisis are located in narrow canyons with aspect ratio $1 \leq H/W \leq 2$. The insolation analysis confirms the existing knowledge that direct light penetration in porticos located in narrow canyons is limited, while the first-floor portico and the sahnisi spaces are sunlit throughout the year[31]. It is deducted, that wide canyons with aspect ratio 1 could better accommodate the needs of deeper porticos. Respectively, a greater size of projection for the sahnisis would be preferable in wider canyons, for shading reasons. However, no significant correlation between the typical dimensions of the porticos or the sahnisis, with the street canyon geometry was found. Also, approximately 75% of the porticos are elongated spaces with $1 \leq L/W \leq 3$, which results in limited direct solar gains in ground-floor porticos. This demonstrates that the decisive parameters for the definition of the porticos' and sahnisis' morphology, were more associated with functional and structural aspects, rather than climatic ones. This finding is also pronounced when we look into the orientation of the main facade of the sahnisis. As observed, there is no correlation between the number of sahnisis' windows and the orientation, while window to wall percentage on the main facade did not differ significantly according to the canyons' aspect ratio. Detailed results regarding the interdependence of the urban and morphological aspects of buildings in the case study area are published in[32].

Finally, according to the mapping process, in approximately half of the cases of buildings with timber sahnisis, the porticos' axis is aligned with the prime wind direction in the summer i.e., orientated E-W or NW-SE, which leads to the enhancement of wind-induced ventilation. In the remaining sample of buildings with sahnisi and portico, the proper operation of the sahnisis' lateral openings for capturing the low-speed wind of street canyons is crucial. This highlights the role of occupant behaviour, and the importance of interacting with the envelope, in order to respond to urban constraints in the best possible way.

3.2 Neighbourhood and street canyon level of study

The outdoor field measurements demonstrate the daily variation of wind, which is in line with other field studies conducted in the area[33,34]. Peak wind speed in the afternoon (around 17:00) is substantially weaker during the night, while the main wind direction is W and WSW, i.e., perpendicular to the street canyons under study and aligned to the porticos' axis of the selected case study buildings. Moreover, wind speed in the street canyons is approximately one third of the reference wind speed, which is in line with other studies[35]. However, the dispersion of the field measurements that was recorded in this study highlights that flow in heterogeneous street canyons is much more complex than in simplified idealised street canyon models, as affected by the local asymmetry.

Regarding air temperature, it is observed that street canyons present systematically higher temperature levels than those occurring at the reference point, which depends on the canyon geometry. More specifically, mid-day temperatures in the square-cavity canyon reached up to 1.5°C higher than the reference temperature, while the corresponding temperature difference in the two narrow canyons reached up to 0.6°C[36]. Relative humidity levels in all the outdoor monitoring points did not differ significantly. In all, the observed thermal differentiations highlight the importance of considering the environmental conditions of the street canyons – rather than those recorded at a reference height – as more representative of the buildings' boundary conditions.

3.3 Building level of study

According to the airflow field measurements, long calm periods were monitored in the examined porticos. This indicates a limited potential for comfort ventilation due to insufficient air velocity to produce a cooling sensation. In fact, the percentage of air velocity measurements above the accuracy threshold of the equipment (which is 0.1m/s) in the ground-floor porticos were less than 11% (maximum air speed reached 0.2m/s), which is approximately one fifth of the canyon's wind speed. During the daytime ventilation experiment, the highest indoor air velocity was recorded in the first-floor portico of the building with sahnisi and reached up to 0.6m/s, which demonstrates the wind-capture potential of the sahnisi.

The potential for wind-driven ventilation rises during late afternoon (after 17:00), when winds are consistently stronger and outdoor temperatures cooler. Cross-ventilation in this case, is enabled through windows on the E-W facades, i.e., porticos' axis aligned to the prevailing wind direction. The location of the courtyard on the west side of the plot further promotes the cooling capacity of natural ventilation, as it drives fresh, cool air towards the indoor spaces. In cases of porticos with a N-S direction, i.e., street canyons along the E-W axis, the cross arrangement of the porticos' windows, along with the existence of the courtyard, play a fundamental role in directing west wind towards the interior spaces and enabling cross-ventilation. In this case, when a second-floor with a sahnisi projecting volume is present, the lateral openings of this element are crucial (perpendicular to the wind direction flowing along the canyon). Respectively, during the night, wind-driven ventilation is not effective as wind speed is minimum; yet, night-time ventilation is particularly beneficial in reducing indoor temperatures through convective heat exchange.

Reflecting on the observed occupant behaviour, when occupants were aware of the way thermal mass works and maintained greater ventilation rates at night, thermal comfort was achieved for the majority of the time. However, in some cases, occupants seemed to ignore an apt window operation pattern, or were unable to apply such due to practical reasons (e.g., their occupancy schedule, safety or difficulty in accessing upper windows). Finally, the results of the ventilation experiments (particular ventilation patterns applied by the researcher) indicated that a moderate percentage of opening is recommended to avoid overcooling and elevated relative humidity levels (especially in more humid regions of the Mediterranean, such as coastal areas). In the case of buildings with portico and sahnisi, the recommended WTF ratio on the ground floor is 9% and on the first floor, 13% (i.e., open windows and applied shutters)[37].

3.4 Open field for future research

Despite the intrinsic passive ventilation strategies incorporated in vernacular buildings, readjusting the research methodology in order to acquire neighbourhood scale morphometric variables is an open research direction. The results of this study offer a valuable background and starting point; however, a greater number of cases would be necessary to draw conclusions on potential correlations. Future studies could adopt this approach and create a database addressing building and urban scale morphometric characteristics, coupled with environmental monitoring data.

Given the social, cultural and financial assets of the free cooling potential of natural ventilation, as well as its environmental benefits quantified in this study, it can be argued that certain urban scale policies should promote the continuation of this practice. This would require action and research in the direction of improving air quality, lowering noise pollution, mitigating the effects of climate change and inspiring safety through means of governance in historic centres. Finally, in order to enhance cross or buoyancy driven ventilation, especially in ground-floor spaces, action should be taken in the direction of raising awareness amongst residents regarding efficient window opening behaviours in heavyweight buildings, as well as providing more practical, accessible and safe ways to operate windows, that explore the potential of smart opening mechanisms with the aid of technology.

4 Conclusions

As acknowledged, vernacular buildings encompass many environmental virtues, yet the roles of urban density, street orientation and geometry, as well as the variability of the background wind, are often neglected in relevant studies. The work presented in this paper addresses climate-responsive practices in urban vernacular heritage, emphasising the strategy of natural ventilation in the Mediterranean climate. The originality and significance of the presented research lies within the adopted methodology that investigates the climatic challenges and opportunities of vernacular dwellings on multiple scales. The district level of study corresponds to the wider historic centre under study, i.e., the walled city of Nicosia, where analytical tools were employed to, a) reinterpret the drafting of the city through an environmental lens, and b) decipher the role of urban morphology in the environmental performance of vernacular dwellings.

Through the employment of analytical tools at a wider scale (district level), it was made evident that besides the environmental factors, functional and morphological parameters have also emerged as decisive in the configuration of these architectural elements and their integration into the urban fabric. This is an important aspect to keep in mind when it comes to environmentally friendly conservation projects, so as to apply critical thinking on enhancing the environmental benefits of these features.

Environmental monitoring of the neighbourhood, street canyon and building levels highlighted the complexity of airflow in real inhomogeneous urban canopies. As demonstrated, air velocity level in the street canyons is approximately one third of the reference free-stream wind velocity, while indoor air velocity remains at minimum levels, reaching up to one fifth of the canyon's wind speed. This indicates the importance of considering the environmental conditions in the urban canyons, as they better describe the boundary conditions for building ventilation. Furthermore, the comparative analysis of the examined ventilation patterns revealed best practices for enhancing the cooling effect of natural ventilation, highlighting the benefits of night-time ventilation, as well as the importance of having energy-aware occupants. Moreover, through this research, the role of the sahnisi as a wind-capture element in dense urban canopies, was quantified under real field conditions. Finally, given the social, cultural and financial assets of natural ventilation, this research argues that urban scale policies should promote the continuation of this practice through means of governance in historic centres.

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References

1. ICOMOS. ICOMOS Charter on the Built Vernacular Heritage. (1999).
2. COE. Council of Europe Framework Convention on the Value of Cultural Heritage for Society (signed in Faro Convention). (2005).
3. Cantatore, E., De Fino, M. & Fatiguso, F. Energy Resilience of Historical Urban Districts: A State of Art Review Towards a New Approach. Energy Procedia111, 426–434 (2017).
4. Fathy, H. Natural Energy and Vernacular Architecture, Principles and Examples with Reference to Hot Arid Climates. (The United Nations University, 1986).
5. Allegrini, J., Dorer, V. & Carmeliet, J. Influence of the urban microclimate in street canyons on the energy demand for space cooling and heating of buildings. Energy Build.55, 823–832 (2012).
6. Salvati, A., Coch, H. & Morganti, M. Effects of urban compactness on the building energy performance in Mediterranean climate. Energy Procedia122, 499–504 (2017).
7. Mouzourides, P., Kyprianou, A., Neophytou, M. K.-A., Ching, J. & Choudhary, R. Linking the urban-scale building energy demands with city breathability and urban form characteristics. Sustain. Cities Soc.49, 101460 (2019).
8. Buccolieri, R., Salizzoni, P., Soulhac, L., Garbero, V. & Di Sabatino, S. The breathability of compact cities. Urban Clim.13, 73–93 (2015).
9. Chen, L. et al. The impacts of building height variations and building packing densities on flow adjustment and city breathability in idealized urban models. Build. Environ.118, 344–361 (2017).
10. Panagiotou, I., Neophytou, M. K.-A., Hamlyn, D. & Britter, R. E. City breathability as quantified by the exchange velocity and its spatial variation in real inhomogeneous urban geometries: An example from central London urban area. Sci. Total Environ.442, 466–477 (2013).
11. Coch, H. Chapter 4—Bioclimatism in vernacular architecture. Renew. Sustain. Energy Rev.2, 67–87 (1998).
12. Correia, M., Dipasquale, L. & Mecca, S. VERSUS. Heritage for Tomorrow: Vernacular Knowledge for Sustainable Architecture. (Firenze University Press, 2014).
13. From vernacular to world heritage. (Firenze University Press, 2020).
14. Lessons from vernacular architecture. (Routledge, 2014).
15. Philokyprou, M. & Michael, A. Environmental Sustainability in the Conservation of Vernacular Architecture. The Case of Rural and Urban Traditional Settlements in Cyprus. Int. J. Archit. Herit. 1–23 (2020) doi:10.1080/15583058.2020.1719235.
16. Historic England. Energy Efficiency and Historic Buildings, how to improve energy efficiency. (Historic England, 2018).
17. Gigliarelli, E. et al.Methodology for the energy renovation of heritage buildings using BIM. Guidelines for the development of an Energy Efficient Heritage Building Information Model (EE-HBIM). (Consiglio Nazionale delle Ricerche, 2022).
18. D'Ambrosio, F. R. et al. Energy Efficiency in Historic Buildings. (2018).
19. Troi, A. & Bastian, Z. Energy efficiency solutions for historic buildings. A handbook. (Birkhauser, 2015).
20. Martínez-Molina, A., Tort-Ausina, I., Cho, S. & Vivancos, J.-L. Energy efficiency and thermal comfort in historic buildings: A review. Renew. Sustain. Energy Rev.61, 70–85 (2016).
21. Eurac Research. Historic Building Energy Retrofit Atlas. https://www.hiberatlas.com/de/willkommen-bei-uns-1.html.

22. Desogus, G., Felice Cannas, L. G. & Sanna, A. Bioclimatic lessons from Mediterranean vernacular architecture: The Sardinian case study. Energy Build.129, 574–588 (2016).
23. Michael, A., Demosthenous, D. & Philokyprou, M. Natural ventilation for cooling in mediterranean climate: A case study in vernacular architecture of Cyprus. Energy Build.144, 333–345 (2017).
24. Gagliano, A., Patania, F., Nocera, F. & Signorello, C. Assessment of the dynamic thermal performance of massive buildings. Energy Build.72, 361–370 (2014).
25. Thravalou, S., Philokyprou, M. & Michael, A. The impact of window control on thermal performance. Investigating adaptable interventions in vernacular Mediterranean heritage. J. Archit. Conserv.24, 41–59 (2018).
26. Artmann, N., Manz, H. & Heiselberg, P. Climatic potential for passive cooling of buildings by night-time ventilation in Europe. Appl. Energy84, 187–201 (2007).
27. Jomehzadeh, F., Hussen, H. M., Calautit, J. K., Nejat, P. & Ferwati, M. S. Natural ventilation by windcatcher (Badgir): A review on the impacts of geometry, microclimate and macroclimate. Energy Build.226, 110396 (2020).
28. Tablada, A., De Troyer, F., Blocken, B., Carmeliet, J. & Verschure, H. On natural ventilation and thermal comfort in compact urban environments – the Old Havana case. Build. Environ.44, 1943–1958 (2009).
29. Philokyprou, M., Michael, A., Thravalou, S. & Ioannou, I. Thermal performance assessment of vernacular residential semi-open spaces in Mediterranean climate. Indoor Built Environ.27, 1050–1068 (2018).
30. Carlucci, S., Bai, L., de Dear, R. & Yang, L. Review of adaptive thermal comfort models in built environmental regulatory documents. Build. Environ.137, 73–89 (2018).
31. Michael, A., Heracleous, C., Thravalou, S. & Philokyprou, M. Lighting performance of urban vernacular architecture in the East-Mediterranean area: Field study and simulation analysis. Indoor Built Environ.26, 471–487 (2017).
32. Thravalou, S. & Philokyprou, M. Urban design considerations in the environmental assessment of vernacular buildings with timber projections (sachnisi): The case of Nicosia's historic center. Front. Archit. Res.10, 176–189 (2021).
33. Karra, S., Malki-Epshtein, L. & Neophytou, M. K.-A. Air flow and pollution in a real, heterogeneous urban street canyon: A field and laboratory study. Atmos. Environ.165, 370–384 (2017).
34. Antoniou, N. et al. CFD and wind-tunnel analysis of outdoor ventilation in a real compact heterogeneous urban area: Evaluation using "air delay". Build. Environ.126, 355–372 (2017).
35. Neophytou, M. K.-A., Markides, C. N. & Fokaides, P. A. An experimental study of the flow through and over two dimensional rectangular roughness elements: Deductions for urban boundary layer parameterizations and exchange processes. Phys. Fluids26, 086603 (2014).
36. Thravalou, S., Mouzourides, P., Michael, A., Philokyprou, M. & Neophytou, M. K.-A. A field study on the environmental conditions of street canyons in dense, historic, urban centres in the Mediterranean. The case of Nicosia, Cyprus. in Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions / 3rd Euro-Mediterranean Conference for Environmental Integration (EMCEI 2021) (SPRINGER, In print).
37. Thravalou, S., Michael, A., Neophytou, M. K.-A. & Philokyprou, M. The ventilation capacity of earthen vernacular buildings with timber projections (sachnisi) in dense urban canyons – Findings from a field study in the Mediterranean. in SBE23 (2023).