Natural ventilation performance of heritage buildings in the Mediterranean climate. The case of a two-storey urban traditional dwelling in Nicosia, Cyprus.

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Abstract

The Mediterranean climate offers ideal conditions for the exploitation of natural ventilation as a cooling strategy. However, its effectiveness is highly dependent upon various parameters concerning architectural layout and occupant behaviour. This study provides insight on the way occupants interact with the buildings’ elements in order to achieve comfort, focusing on the occupants’ behaviour towards vernacular heritage buildings in Nicosia, Cyprus. A questionnaire based survey confirms that ventilation is a major cooling strategy. Further investigation is conducted on window operation patterns through simulation tools. After a thorough analysis of a large number of urban vernacular dwellings, a representative vernacular dwelling located in the urban core of Nicosia was selected as a case study. Its architectural layout reflects the typical arrangement of a two-storey dwelling with a three-bay interior arrangement and thus ensures a number of passive design strategies related to natural ventilation. The study explores two types of natural airflow; namely, wind effect, in single-sided and cross ventilation mode, and stack effect. The impact of daytime, night-time and all day ventilation is also assessed comparatively. The results indicate that occupant behaviour concerning window operation has significant impact on the overall thermal performance of the building. Finally, the comparative analysis confirms and quantifies the effectiveness of night ventilation as a cooling strategy.

Keywords: natural ventilation, vernacular dwellings, occupant behaviour

1 Introduction

The rising global environmental concern has increased the importance of thermal comfort studies and has highlighted the need for energy retrofit projects. The built vernacular heritage constitutes a large part of the existing building stock and incorporates typical examples of integration of environmental design principles, such as the consideration of climatic conditions, topography, rational use of local resources and construction techniques (Coch, 1998). Vernacular buildings have had a continuous life through time as occupied spaces, acquiring their specific form and layout as a result of an ongoing process of adaptation in response to both environmental and social challenges. While vernacular building envelopes incorporate a series of passive cooling and heating strategies, the effectiveness of several strategies relies on the interaction of the occupants with the integrated environmental design elements.

Natural ventilation requires the active participation of occupants and is acknowledged as a principal passive cooling strategy linked to the Mediterranean way of living. The design of vernacular dwellings offers the possibility of wind-driven ventilation, i.e. single-sided or cross ventilation, which arises from the different pressures created by wind around a building, as well as buoyancy-driven ventilation, i.e. stack ventilation which is driven by
density differences between cool and warm air, through a vertical flow path, such as an atrium, stairwell or chimney. The effectiveness of night ventilation is associated with climatic conditions and diurnal temperature fluctuation, as well as with the thermal inertia of buildings (Santamouris 2006, Givoni 1994, Blondeau 2001, Ogoli 2013, Shaviv et al. 2001, Martin et. al., 2010). Santamouris (2006) showed that night-time ventilation is suitable for climates with high daily air temperature fluctuations and relatively low night temperatures. Shaviv et al. (2001) examined the influence of thermal mass and night ventilation on the maximum indoor air temperature in a hot humid climate during the cooling period and suggested that daily air temperature fluctuation should be greater than 6°C in order to achieve an effective reduction in daytime peak air temperature of 3°C. Givoni (1994) stated that a daily air temperature fluctuation of about 10°C is required to achieve the cooling effect of night ventilation. Finally, according to Blondeau et al. (2001) night ventilation can decrease diurnal indoor air temperatures from 1.5 to 2°C, even when the average daily air temperature fluctuation is 8.4°C.

The use of massive structural elements and local materials with high thermal mass is quite common (Philokyprou et al., 2014) in the vernacular architecture of Cyprus. Kalogirou et al. (2002) argued on the potential of cooling load reduction when thermal mass is applied, as the temperature variations in Cyprus are ideal for the implementation of such a strategy. In situ measurements on ventilation strategies, conducted in traditional adobe buildings in Cyprus, confirm the effectiveness of night ventilation when the diurnal temperature fluctuation is 8-9°C (Demosthenous et. al., 2015).

This paper provides insight on the cooling strategies applied by the occupants of vernacular dwellings in the urban core of Nicosia. The occupant thermal comfort assessment, and the occupant behaviour concerning window operation modes, is explored on an annual basis, based on a questionnaire survey of an extended sample of urban vernacular dwellings. In situ measurements and simulation tools are used in order to quantify the contribution of ventilation driven by wind or buoyancy forces according to multiple operational modes, potentially applied by the occupants, i.e. all day, daytime and night-time ventilation, during the hot summer period. For this purpose, after a comprehensive study of a large number of dwellings in the urban area of Nicosia, a representative case study building was selected; whose building envelope design offers multiple ventilation options.

2 Occupants’ behaviour and thermal comfort assessment

An overview of the vernacular architecture of Cyprus, and more specifically of the urban historic centre of Nicosia, reveals several architectural features and passive design techniques which cool or warm indoor spaces through the exploitation of local climate conditions. Such strategies involve the materials and construction techniques, orientation of the building, the existence of semi-open spaces, the proper location and size of openings, the existence of shading devices such as window shutters etc. (Philokyprou et al., 2013). However, some of the possibilities offered by the design of traditional dwellings require the active participation of the occupants. The question addressed here is: which of these strategies are used by contemporary occupants and to what extent?

In order to answer the above research question, a questionnaire-based survey was carried out, involving a large number of occupants of traditional dwellings in the urban core of Nicosia (n=60). For the purposes of this paper, the results presented are related to the overall comfort assessment of the occupants and their behaviour, focusing on the cooling strategies and window operation patterns applied.
2.1 Occupants’ assessment on the overall thermal comfort
The overall thermal sensation (TS) of occupants was evaluated for the four seasons, based on the responses to the question: “How do you find the thermal environment inside your traditional house during winter / summer / spring / autumn?”. The ASHRAE thermal sensation scale was used ranging between hot / warm, slightly warm / neutral / slightly cool / cool / cold. The results reported correspond to a percentage of the total sample (n= 60).

The majority of respondents claimed to have a neutral feeling during the intermediate seasons and discarded the need of auxiliary heating or cooling systems. Specifically, 96.7% of the respondents expressed a neutral thermal sensation for spring, and 98.3% for autumn. As far as the thermal sensation during winter is concerned, opinions varied; 40% of the respondents evaluated the building as warm / hot, 35% as neutral, while, the remaining 25% appraised it as cool/cold (Figure 1).

Concerning the description of the dwelling during the summer, 45% of the respondents opted for cool, while 35% of them for slightly cool, neutral and slightly warm (Figure 1). It is worth noting that, the respondents’ choice to characterise the dwelling as cool intended to emphasize the relative temperature difference between the external and internal environment, pointing out the comfort conditions provided within traditional dwellings. Although it seems difficult for field study respondents to balance and express their thermal preferences with accuracy (Cena and de Dear, 1999), it can be safely said that the thermal comfort of vernacular buildings is deemed by the occupants to be within the range of 80% acceptability during the summer period.

2.2 Occupant behaviour
The answers of respondents to the question “What do you do in order to cool down or prevent overheating within the indoor spaces during the summer?” confirm the fundamental assumption of ACS that people take actions in order to restore their thermal comfort (Nicol and Humphreys, 1973). Specifically, 83.1% of respondents apply shading by closing the external venetian blinds, 61% by wetting or watering the yard and, thus, providing evaporative cooling and 95% operate the windows in such a way that increases airflow through cross ventilation. Despite the passive means available for cooling, the vast majority of the sample (97% of respondents) resorts to occasional use of technical means, i.e. fans and air conditioning, in order to achieve thermal comfort.

Focusing further on the ventilation strategy applied by the occupants -as this constitutes the more widely used cooling strategy-, Philokyprou et al. (2013) pointed out the importance of the size and location of the windows in the vernacular architecture of Cyprus. The presence of small-sized openings, called arseres, at a considerable height, mainly on the street façades, contributes to stack-driven ventilation and enhances the extraction of hot air from...
the building, due to the difference in temperature and density of the incoming air. However, according to the findings of the survey, only 41.9% of the users, with arseres in their buildings, take advantage of their existence. This can be attributed to either lack of awareness regarding the role of these openings, or to difficulty in accessing the particular openings due to their high level location, or due to interventions that render these windows inaccessible.

Regarding the window operation pattern, as shown in figure 2, three main operation modes are applied concerning the time and duration of ventilation within the day: all day ventilation (24-hours), daytime ventilation and night-time ventilation. Two additional modes of effective window opening are applied: wide and partial opening of windows, corresponding to a different airflow rate. During the periods of winter, autumn and spring, the findings show that the wide opening of windows is preferred in the morning. During the summer period, windows are preferred wide open during the morning, afternoon and night and less frequently at noon. As made evident, night ventilation is used mainly during the summer rather than in the other seasons, revealing that occupants acknowledge its effectiveness as a cooling strategy. Yet, another interesting observation is the apparent preference towards all day ventilation. Given that the temperatures of the external environment during noon and the afternoon are higher than the ones of the indoor environment in the summer, it can be deduced that the above behaviour might not be beneficial in terms of heat exchange and might be associated with the preference of increased air movement. Nonetheless, as highlighted by other researchers, thermal comfort alone may not suffice to predict adequately human behaviour in the interior of buildings (Borgerson and Brager, 2002). Indeed, Fabi et al. (2012) provided an extended literature review on the drivers of window opening behaviour; mentioning a series of driving forces for energy related behaviour in residential buildings, i.e. physiological, psychological, social, environmental and contextual.

![Figure 2: Window operation pattern of vernacular dwellings in the urban core of Nicosia.](image)
3 The cooling effectiveness of ventilation
3.1 The case study building

Following an extended survey on the vernacular heritage of the historic core of Nicosia, more than 100 buildings were examined in terms of typology and environmental design principles. Several vernacular buildings, located within the area that is enclosed by the Venetian walls, were selected for detailed investigation and monitoring of the interior thermal conditions. The study made evident that, even though various typological and morphological elements of the original building types changed over time so as to adapt to the urban context, a number of environmental design features, especially those concerning ventilation, remained prevalent in the urban vernacular architecture of Nicosia. The study showed that the most common building typology was the tripartite arrangement of the main part of the building. This arrangement offers ventilation possibilities of wind driven ventilation, (through the windows), as well as buoyancy-driven ventilation (through the stairwell). The position of the case study building within the urban tissue, and the location of the courtyard, favourite cooling ventilation driven by wind, as wind direction during the summer period is north and/or northwest. It is a typical two-storey urban dwelling with a rectangle-shaped typology and a triple-bay arrangement. The entrance of the house is achieved through the central bay, called portico (Figure 3, 4). The portico mainly refers to an intermediate semi-open space through which the access from the street to the courtyard was achieved and sometimes it refers to a through space with large openings towards the yard (Demi, 1997). A typical morphological element of this building type is the projection of part of the central room, with extended window surfaces on the upper floor, called sachnisi (Figure 3, 4). The specific morphological element became widespread, in various forms, in the 19th and in the beginning of the 20th century in the wider Balkan Peninsula and shares common characteristics with traditional buildings encountered in the Eastern Mediterranean (Oiikonomou and Bougiatioti, 2011, Umar et al., 2013).

![Figure 3: The case study building](image)

The structural system of the building comprises of load-bearing mud brick walls of 50 cm width, resting on a stone foundation and a timber double-inclined roof. The projecting volume of the main façade (sachnisi), is a lightweight construction formed by timber frames 20 cm wide, originally filled with adobe or stones. This building has been renovated and the traditional filling material was replaced by autoclaved aerated concrete blocks for insulation purposes. The original roof structure has also been modified and insulation foam-boards were added to improve thermal performance.
### 3.2 The simulation tool

This study employs the building energy analysis simulation tool EnergyPlus v8.3. The graphic interface of Design Builder v4.6 software is used for modelling the building’s geometry and for inputting other data. In order to accurately predict the thermal performance of selected zones of the building (portico, central room of upper floor), data regarding the geometry, activity, internal gains, as well as infiltration and ventilation, were integrated into the model. Natural ventilation and infiltration measurements are calculated based on window openings, cracks, buoyancy and wind-driven pressure differences. The ventilation control mode is set to constant, enabling windows to open for fresh air-supply, regardless of inside and outside temperature and enthalpy. The airtightness of the building is deemed poor. Simulations employ full interior and exterior solar distribution, calculating the amount of solar radiation falling on each surface of the building zone including the floor, walls and windows, taking into account factors such as direct solar and light transmission through internal windows. The thermal properties of the construction materials were identified by the use of non-destructive experimental methods.

Measurements of indoor temperature and relative humidity levels (USB-2-LCD data loggers), as well as external weather data (Davis Vantage Pro-2), were monitored on site in order to confirm the digital model. For the verification of the model, the inequality coefficient (IC) was calculated according to equation 1 (Williamson, 1995):

$$IC = \frac{\frac{1}{n} \sum_{i=0}^{n} (D_{\text{sim},t} - D_{\text{exp},t})^2}{\sqrt{\frac{1}{n} \sum_{i=0}^{n} (D_{\text{sim},t})^2} + \sqrt{\frac{1}{n} \sum_{i=0}^{n} (D_{\text{exp},t})^2}}$$

where $D_{\text{sim},t} = (T_{\text{int},t} - T_{\text{ext},t})_{\text{sim}}$ is the simulated and $D_{\text{exp},t} = (T_{\text{int},t} - T_{\text{ext},t})_{\text{exp}}$ the recorded temperature differences. IC presents the degree of agreement between measured and simulated data, ranging in value between 0 and 1, with 0 indicating a strong correlation. The IC was calculated to be 0.16 for ground floor and 0.29 for the first floor. This indicates a fair level of accuracy of the simulation tool and credibility in terms of the research findings on the thermal performance of the building under study.
3.3 Thermal comfort assessment background

The case study building is supported by technical means for heating and cooling. However, since vernacular heritage buildings are mainly naturally ventilated, for the purposes of this paper, the case study is considered as a free-running building. Therefore, the adaptive approach introduced by de Dear and Brager (1998) is adopted, integrated within ASHRAE Standard 55 (ASHRAE, 2004). According to the Adaptive Comfort Standard (ACS), the acceptable indoor operative temperature, $T_{\text{comf}}$, is expressed as a function of the mean monthly outdoor air temperature, $T_{a \text{ (mean)}}$. A mean comfort zone band of 5°C is estimated for 90% acceptability and 7°C for 80% acceptability, around the optimum indoor comfort temperature, calculated as in equation 2 below:

$$T_{\text{comf}} = 0.31 * T_{a \text{ (mean)}} + 17.8$$  \hspace{1cm} (2)

Given that the focus is on the summer conditions, the present paper examines only the months with the highest temperature levels, i.e. July and August. The correspondent thermal comfort zone for 80% acceptability ranges for July from 23.7°C to 28.7°C, and for August from 23.9°C to 28.9°C.

3.4 Case study scenarios

In order to estimate the impact of ventilation on the thermal comfort of the vernacular building under study, multiple scenarios of window operation patterns are comparatively examined. Specifically, two parameters are considered: a) the type of ventilation offered by the building’s elements, i.e. single-sided and cross ventilation and b) the period of time within the day when ventilation is applied according to the findings of the occupant behaviour survey, i.e. daytime, night-time and all-day ventilation. The space under study on the ground floor is the central part of the building that corresponds to the entrance of the building, i.e. portico. Respectively, on the first floor, the space under study is the central part that includes the sachnisi and is connected to the portico through the interior staircase.

On the ground floor, only single-sided ventilation was examined (opening of windows towards the courtyard) as security and privacy reasons do not allow the prolonged opening of doors or windows toward the street. The single-sided ventilation mode on the first floor refers to the operation of the windows toward the courtyard, while cross ventilation refers to the opening of the street front façade windows and particularly, opening of the windows of sachnisi. The effective opening surface of windows is considered to be 30% in all cases, which corresponds to partially open windows. Table 1 presents the case study scenarios. The reference scenario is considered to be the operation mode that the occupants usually apply during the summer (derived from their questionnaire answers).

<table>
<thead>
<tr>
<th>Table 1. Case study scenarios</th>
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<tr>
<td><strong>First floor</strong></td>
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<tr>
<td>Ventilation Type</td>
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<tr>
<td>Day (07:00-19:00)</td>
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<tr>
<td>Night (19:00-07:00)</td>
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<tr>
<td><strong>Ground floor</strong></td>
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<tr>
<td><strong>portico</strong></td>
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<tr>
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<tr>
<td>Day (07:00-19:00)</td>
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<td>Night (19:00-07:00)</td>
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SV stands for single sided ventilation, CV stands for cross ventilation.
3.5 Results and discussion

This section addresses the thermal performance of the aforementioned window operation patterns under the influence of the examined ventilation modes, i.e. single-sided ventilation, cross ventilation and displacement ventilation due to buoyancy forces, i.e. stack effect. Moreover, additional factors such as time and duration of ventilation within the day, i.e. all day ventilation (24-hours), daytime ventilation and night-time ventilation were also considered. The results of the hourly simulation on the first and ground floor are presented in tables 2 and 3 respectively.

According to the findings, when applying the actual window operation mode used by the occupants, i.e. reference scenario, the ground floor meets the comfort conditions of 80% acceptability almost throughout the examined period (96.8% of the time), while the first floor only for 38.8% of the time. The mean operative temperature on the first floor, which is exposed to solar heat gains from the roof, is 1.5 °C higher than the respective temperature in portico, reaching 29.8 °C. The thermal stability recorded in the interior environment (less than 2°C diurnal indoor temperature fluctuation compared to the outdoor fluctuation of 8.7 °C) (Figure 5) is attributed to the building’s high thermal mass and is in line with other studies concerning the thermal behaviour of heavyweight vernacular dwellings (Oikonomou and Bougiatioti, 2011, Martin et.al., 2010).

<table>
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<tr>
<th>Table 2: Operative temperature (°C) levels and fluctuation in the central part of the ground floor (portico)</th>
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<tr>
<td>REF.</td>
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<tr>
<td>July</td>
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<tr>
<td>Mean T (max)</td>
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<td>Mean T (min)</td>
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<td>Mean Daily Fluctuation</td>
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<td>August</td>
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<td>Mean T (max)</td>
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<td>Mean T (min)</td>
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<td>Mean Daily Fluctuation</td>
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<td>Percentage of time within the comfort zone for 80% acceptability</td>
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*refers to dry bulb temperature

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<th>Table 3: Operative temperature (°C) levels and fluctuation in the central part of first floor (sachnisi)</th>
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<tr>
<td>REF.</td>
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<tr>
<td>July</td>
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*refers to dry bulb temperature
In a temperate climate such as the one of Cyprus, daytime natural ventilation can be efficient provided that the solar and internal gains are low and/or the thermal inertia is high (Santamouris, 2006). Daytime ventilation can be used in the morning to cool down the indoor air and the thermal mass of the building so long as the outdoor temperature is below the indoor temperature. Indeed, according to the findings, the application of all-day ventilation, in portico, in comparison to reference scenario is found to have a beneficial effect. Specifically, the application of all-day ventilation in portico, i.e. S4, results in a slight improvement of the thermal comfort of portico (reaching 97.6 % of the time within the comfort zone) and in a notable improvement of the thermal comfort on the first floor, raising the percentage of time within the comfort zone from 38.8%, in reference scenario, to 59.3%. The respective mean daily fluctuation of the operative temperature in portico is recorded to rise from 1.7°C to 2.4°C, revealing greater heat exchange rate. However, all-day ventilation is less effective than night-time ventilation. Specifically, when applying night-time ventilation in portico, i.e. S3, the percentage of time within the comfort zone rises to 99.1% for portico and 64% for the first floor.

As mentioned above, the central part of the ground floor, portico, is connected to the central part of the first floor through the interior staircase. In this way, the temperature difference between the indoor space and the outdoor environment causes a density difference whereby the upper opening drives outflow and the lower opening at the ground floor drives inflow. However, this buoyancy-driven flow, i.e. stack effect, occurs simultaneously with the wind effect and the two phenomena counteract each other (Gładyszewska-Fiedoruk, & Gajewski, 2012). Therefore, the improvement on the thermal performance of S4 with respect to the reference scenario is attributed to the simultaneous effect of these phenomena.

Cross ventilation ensures higher air-change rate than single-sided ventilation; thus, if applied at night when the heat exchange with the external environment is beneficial, better results are expected. Indeed, the opening of windows in sachnisi on the first floor, i.e. S1, improves the thermal conditions with respect to single-sided ventilation applied to reference scenario, raising the percentage of time when the first floor lays within the comfort zone from 38.8% to 46.2%.

Similar effect is recorded in the case S5 in comparison to case S3. Specifically, S5 combines the beneficial effect of cross ventilation and night-time ventilation and presents the most efficient performance; portico accounts for 99.9% of the time within the extended comfort zone and the first floor for 71.6% of the time. As observed in figure 5, night-time ventilation succeeds in reducing peak operative temperature in portico to the level of 90% acceptability. An overall reduction of 1.5°C in the mean operative temperature in portico is recorded (with respect to reference scenario) and of 1.2°C on the first floor. The results are in line with other studies concerning the effectiveness of cross ventilation in respect to single-sided ventilation (Stabat, 2012) and the effectiveness of night ventilation in the climatic conditions of Cyprus (Kalogirou et. al. 2010, Demosthenous et. al., 2015).

Finally, it is noted that in all the examined scenarios, where ventilation is applied at ground level (S3-S5) or not (reference scenario, S1 and S2), the portico offers very high levels of comfort, with 96.8% of time within the comfort zone for 80% acceptability for the reference scenario and 99.9% for scenario S5. The above demonstrates that the application of the examined ventilation strategies has less impact on the thermal performance on the ground floor compared to the first floor. This is attributed to the limited effectiveness of single-
sided ventilation, the introverted character of the ground floor that has less glazed surfaces and limited wall surfaces exposed to the external environment, as well as to the fact that the first floor has elevated solar heat gains deriving from the roof.

Figure 5: Operative temperature (°C) levels in portico on the ground floor (above) and sanchisi area of the first floor (below), on the 1st and 2nd of July.

4 Conclusions
Natural ventilation relies on natural driving forces i.e. wind and buoyancy, which are highly variable. However, the ability to predict thermal comfort conditions attributed to certain airflow characteristics is essential for designing and implementing passive environmental strategies. In this study, ventilation is approached as the main cooling strategy applied by occupants of heritage buildings in the urban core of Nicosia. The extended questionnaire-based survey confirms the interaction of the occupants with the building elements in order to apply ventilation strategies for the improvement of indoor thermal conditions during the hot summer period. The results on the operation of windows reveal that although thermal comfort is not the prime driving force for occupant behaviour, proper ventilation strategies are positively exploited for cooling purposes during the summer period. According to the respondents’ answers concerning thermal sensation, 80% of occupants declare that the indoor thermal conditions of traditional dwellings are in satisfactory levels during the summer period without the use of any technical cooling systems.

The ventilation performance was recorded and evaluated by in situ measurements and software simulation, in a representative case study building that bears the typical layout of a two-storey building with a three-bay arrangement and the morphological element of sanchisi on the first floor. The study explores two types of natural airflow; i.e. wind effect,
through the operation of windows in single-sided and cross ventilation mode, and stack effect through the stairwell. An additional parameter investigated was the period during which windows were operated within the day, focusing on daytime, night-time and all day ventilation.

The results reveal that cross ventilation presents higher cooling efficiency compared to single-sided ventilation due to a higher air change rate. Additionally, night ventilation is found to be more effective than daytime and all-day ventilation, as opening the windows during the night results to greater diurnal indoor temperature fluctuation and higher air change rate, which consequently enhances convective heat loss from mass elements and dissipates the heat outdoors. Specifically, the overall reduction of the mean operative temperature in the case of night-time ventilation (S5) compared to the reference scenario is 1.5°C on the first floor and 1.2°C on the ground floor. The aforementioned performance is attributed to the simultaneous effect of wind and stack effect. Further improvement of ventilation effectiveness can be achieved through the incorporation of ceiling or floor fans that can increase air speed within the indoor spaces and thus, significantly increase comfort levels.

The present study underlines that the Mediterranean climate offers ideal conditions for the exploitation of natural ventilation as a cooling strategy during hot summer period. The effectiveness of natural ventilation is highly dependent upon various parameters including the ventilation type, the period during the day applied, building architectural layout and the occupants’ behaviour. Further investigation on the aforementioned parameters will provide a thorough understanding of the role of natural ventilation in the thermal comfort of vernacular buildings.

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