Investigating the effect of summer night ventilation on the urban buildings’ thermal and energy performance using numerical approaches

S Tsoka¹,²
¹School of Science and Technology, Hellenic Open University, 26335, Patras, Greece
²Faculty of Civil Engineering, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece
stsoka@civil.auth.gr, stsoka@eap.gr

Abstract. The present study aims to evaluate by simulation means, the effect of different night ventilations rates on the thermal and energy performance of typical building units, located in dense urban areas in Thessaloniki, Greece, both under thermostatic control and free-floating conditions. The numerical assessment is conducted with the dynamic building energy performance simulation model EnergyPlus. A parametric analysis, involving 4 different air flow rates (i.e., 3 ACH, 5ACH, 10ACH, 15ACH) has been carried out for 8 typical building units, located in 4 different urban areas in the city of Thessaloniki, presenting different morphological characteristics. In all cases, single side ventilation has been considered rather than cross ventilation, to evaluate the less optimal, building configuration scenario. The obtained simulation results revealed the significant effect of night ventilation on improving the thermal and energy performance of all the examined building units. Still, the morphological characteristics of the case study areas in which the examined building units are located, also affected the obtained simulation results and the achieved cooling energy savings.

1. Introduction
Night ventilation by natural means (i.e., opening of windows) consists a widely applied and investigated passive technique towards the control of both the cooling energy demand and the indoor thermal conditions during the summer period [1]; its effect on the buildings’ thermal performance has been quantified either by observational [2] or by simulation means [3] and the reported findings suggest that the application of night natural ventilation may considerably reduce the next day peak indoor temperature even up to 3°C, while in thermostatically controlled buildings, a noticeable reduction of the peak cooling loads can be achieved [4].

The method relies on the introduction and circulation of the outdoor cooler air into the thermal zones of the buildings (during the summer nights and only provided that the ambient temperature is lower than indoor temperature) to cool down both the indoor Tair values but also the building elements. In fact, the circulation of the air inside the building results in an increase of the convective heat dissipation from the structural elements (i.e., building envelope and internal walls), while the warmer air is exhausted into the outside environment, representing a heat sink, the capacity of which is primarily determined by the difference between the indoor and outdoor air temperature [5]. The efficiency of the night ventilation is thus primarily related to the meteorological conditions of the investigated study area, involving (a) the outdoor temperature and its relative difference with the...
indoor air temperature of the examined building and (b) the local wind flow characteristics such as wind speed and direction. Yet, when it comes to the potential of the night ventilation technique in urban buildings, the wind sheltering and the induced decrease of the wind speed value inside the urban canyons along with the higher ambient air temperatures may considerably affect the efficiency of the method [5].

Evidence from existing studies reveals the important effect of the high building thermal mass on the efficiency of the night natural ventilation [6]; in summer, the thermal mass elements of the building, such as the envelope components and the indoor walls, store and absorb heat during the day, reducing thus the building’s peak cooling loads; the stored heat is then progressively released after the late evening while the application of night ventilation techniques contributes to the dissipation of a part of it through convective phenomena, induced by the circulation of the cool outside air. As a result, combining high thermal mass with night ventilation can contribute to a lower and delayed peak indoor Tair value the next day, improving the indoor thermal conditions but also reducing the cooling energy needs [7]. Considering the significant role of the night ventilation on the improvement of the buildings’ thermal performance, a parametric analysis with the Energy Plus simulation tool, involving different air flow rates is here conducted for generic building units that are located in different urban areas of Thessaloniki, presenting different morphological characteristics. It should be noticed that other methods to decrease the buildings energy performance during summer period as, for example, by a better use of energy from the inhabitants [8], are not studied here. Section 2 describes the methodology that was implemented in the study, while the results and the conclusions are given in Section 3 and 4 respectively.

2. Methodology

2.1. Case study areas and investigated building units

The effect of summer night ventilation on the thermal and energy performance is evaluated for 8 generic building units of 1st and 3rd floor level, considered to be located in 4 urban sites of the city of Thessaloniki (40.64° N, 22.94° E), having diverse morphological characteristics. The google earth images of the 4 case study areas and the street canyons in which the examined building units are located, along with their principal geometrical characteristics are shown in Figure 1. All four case study areas mainly contain buildings of residential use; the first two areas (i.e., Pittakou and Mitoudi areas) are the denser ones and the vegetation presence inside the street canyons is rather low. On the other hand, the street canyons of the third study area (i.e., Vafopoulou area) are characterized by considerably higher vegetation presence, consisting of tall, mature deciduous trees of acer type. Finally, Gavriilidou area, the fourth case study area, has the lowest surface density among all the examined cases with high vegetation ration inside the street canyons, involving however trees and bushes of lower height. The different morphological characteristics of the 4 sites are expected to significantly influence the site-specific microclimatic characteristics such as air temperature, insolation levels etc. which will in turn affect the building units’ energy performance.

Figure 1. Google earth image of the 4 case study areas, position of the building containing the examined building units and street view of the respective street canyons.
2.2. Investigated building units and simulation set up

The plan of the generic building unit and the respective 3D model, introduced in the EnergyPlus tool, is presented in Figure 2. The apartment is considered to be an intermediate one, having other neighboring apartments on the same floor, while the staircase area is assumed to be an unconditioned thermal zone (no thermostatic control). Only the main façade of the building unit is thus exposed to the exterior conditions, while the vertical façade, separating the apartment from the staircase, is exposed to an unconditioned thermal zone. The floor, and the ceiling and the rest of the vertical facades of the apartment are considered as adiabatic due to the same operational schedules between the apartments. The generic building unit is located once at the 1st and then at the 3rd floor level, to assess the energy performance of typical apartments at the lower and intermediate levels of urban street canyons. Figure 3 presents the surrounding obstacles that were considered as shading objects in the Energy Plus simulations. Special attention was given in the case of Vafopoulou area so as to accurately represent the presence of the tall trees and the respective porosity of the trees foliage.

All simulations are conducted for the existing building envelope, in which there is no thermal insulation as the building containing the investigated building units have been constructed prior of 1979, in a period when there were no specific requirements for the thermal protection of the building. The opaque external building wall, giving towards the external air consists of brick masonry with \( U = 1.64 \text{ W/m}^2\text{K} \) and the bearing vertical components, consisting of reinforced concrete, present \( U \) values be-tween 2.53 \( \text{W/m}^2\text{K} \) and 3.17\( \text{W/m}^2\text{K} \), depending on their width. Similarly, the brick wall and the reinforced concrete components, giving towards the non-conditioned staircase area present \( U \) values of 1.43 \( \text{W/m}^2\text{K} \) and 2.06 \( \text{W/m}^2\text{K} \) respectively. Regarding the openings, the conductance of the synthetic frame is \( U_f = 2.8 \text{ W/m}^2\text{K} \), the double-glazed glass conductance is equal to \( U_g = 2.8 \text{W/m}^2\text{K} \). In parallel, the operational schedules of the generic building units, involving occupancy, lighting, equipment, ventilation, heating and cooling setpoints have been set according to the values of the Technical Guides of the recast of the Hellenic Thermal Regulation of the Energy Assessment of Buildings [9]. The heating season covers the period October 15\textsuperscript{th} till April 30\textsuperscript{th} whereas the cooling season starts the 1\textsuperscript{st} of June and ends the 31\textsuperscript{st} of August. The heating and cooling setpoints were set to 20 \( ^\circ \text{C} \) and 26 \( ^\circ \text{C} \) respectively and the infiltration rate was set to 1.0 ACH. Finally, in summer period, a night ventilation rate of 3ACH has is considered (i.e., base case scenario of night ventilation) provided that the indoor air temperature is higher than the outdoor temperature by 1.0 \( ^\circ \text{C} \).

Moreover, the hourly weather file that was used for the dynamic energy performance simulations has been created so as to capture the site-specific microclimatic conditions of each case study area. The detailed procedure for the creation of the hourly weather datasets is given in [10] and [11].

Regarding the night, natural ventilation scenarios, given that a measurement campaign was not possible in the current research due to limitation of resources, the examined air flow supplies were issued from previous experimental studies, performed in dense urban areas of Greece. More precisely, Geros et al. [5] have conducted on site microclimatic measurements (i.e. air temperature, wind speed and direction) in 10 dense urban canyons in Athens, Greece during June and September 1997. The examined canyons were all located in central, residential areas of the city Athens and their aspect ratio varied from 1 to 2.5, including both shallow and narrow canyons. The measured air temperature, wind speed and direction have been then introduced to AIOLOS software to estimate the potential airflow rate for single sided ventilation of a typical thermal zone. Given the higher urban \( \text{Tair} \) values during the summer nights and the significant decrease of wind speed inside the urban canyons, moderate values ranging between 1.6 ACH and 3.0 ACH have been found for 7 out of the 10 examined canyons, while a higher air flow supply of 10 ACH has been reported for 1 canyon. Furthermore, findings from another experimental study, carried out in 214 residential building in suburban areas in Athens, Greece [12], indicated that the encountered air changes ranged between 2 ACH and 30 ACH with the highest frequency being noticed for 5 ACH.

Based on the above-mentioned remarks, 3 different air flow rates of night ventilation have been considered for the examined building units: a moderate value of 5 ACH and 2 higher air flow supplies of 10 ACH and 15 ACH. In other words, given that the base case simulations for all the examined building units involved an air flow supply of 3 ACH, the parametric analysis will examine the effect of the increase on the night air flow supply by 2 ACH, 7 ACH and 12 ACH. In all cases, single side
ventilation rather than cross ventilation is considered, since all openings are located to the South façade of the examined building units. It is also important to mention that in all the investigated scenarios (i.e., base case and 3 scenarios), the night cooling by natural ventilation means (a) does not simultaneously occur with the air-conditioning system, (b) occurs only when a minimum difference of 1.0 °C is noticed between the indoor and the outdoor air temperature, during the period 00:00 – 08:00 a.m.

Figure 2. Plan and 3D view of the generic building unit.

A total number of 32 simulations (i.e., 8 examined building units x 4 scenarios of natural ventilation) have been conducted. For every examined building unit, the boundary conditions and the cooling setpoint temperature (i.e., 26 °C) remain the same during all simulations and only the night summer ventilation rate is modified. The simulation results that will be further analyzed include: (a) the annual cooling energy needs for all 4 scenarios of nigh ventilation intensity and (b) the time delay of the maximum next day indoor Tair value due to the night ventilation.
3. Results and Discussion

3.1. Effect of night ventilation on the annual cooling energy needs

The annual cooling energy needs for the various air flow rates, for the examined building units are presented in Figure 4. It can be generally said that, for all 1st and 3rd floor building units, the higher the night ventilation air flow supply, the higher savings of the cooling energy demand. More precisely, for the 1st floor building unit in Pittakou canyon, the reduction on the cooling energy needs due to night ventilation varies from 5.3% to 23.5% when the night air flow supply is increased from 3 ACH to 5 ACH and 15 ACH respectively, while the corresponding energy conservation for the 1st floor Vafopoulou apartment is 12.0% and 40.8% . Moreover, increasing the night air flow supply by 2ACH (from 3 to 5 ACH) and 7 ACH (from 3 to 10 ACH) contributed to a decrease of the annual cooling energy needs of the 1st floor building unit in Mitoudi street by 8.8% and 22.5% respectively, while the corresponding decrease for the 1st floor building unit in Gavriilidou reached 6.2% and 17.2%.

A similar trend has been also noticed for all the examined 3rd floor building units in which the application of higher night ventilation rates, considerably affected their cooling energy demand, with the potential of the method being increased as a function of the air flow supply. In fact, the obtained results suggested that even for a relatively moderate increase of the air flow rate (i.e. from 3ACH to 5 ACH), the annual cooling energy needs were reduced by 8.0%, 7.7% and 5.9% for the apartments in Pittakou, Mitoudi and Gavriilidou street canyons whereas for an air flow rate of 10ACH, the corresponding achieved energy conservation is 19.5%, 20.2% and 18.4% respectively. Again, as with

---

**Figure 3.** Plan and 3D view of the generic building unit.
the 1st floor building units, the highest differences on the cooling energy needs are achieved when an air flow supply of 15 ACH is considered. Yet, as already mentioned, in dense urban areas where the geometry of the street canyons considerably attenuates the air flow and the ambient Tair values are generally higher, moderate air flow rates, close to 5ACH are more frequent, while higher values, close to 15 ACH are mainly encountered in areas of lower building densities, in which the UHI phenomenon and the wind speed reduction are of lower importance [12]. Still, in the current study, different magnitudes of air flow rates have been examined, covering both moderate and increased values, so as to acquire a more detailed perspective on the efficiency of the technique, towards the improvement of the building units’ thermal performance.

**Figure 4.** Annual cooling energy needs for the examined 1st (a) and 3rd (b) floor building units.

### 3.2. Effect of night ventilation on the time delay of the maximum indoor temperature

Apart from the reduction of the cooling energy needs and the number of the overheating hours, another positive effect of the nocturnal natural ventilation involves the delayed occurrence of the next day peak indoor temperatures for several hours, especially in buildings having high thermal mass and high thermal inertia [7]. During summer period, the outdoor and indoor walls and partitions, consisting the building units’ external and internal thermal mass, would store an important part of the high solar gains during the day, contributing thus at the reduction of the peak indoor Tair values; since the stored heat will be progressively released into the indoor environment at a later time (i.e. mainly during the late hours when the outside air temperature is low), the application of nocturnal natural ventilation will contribute on the dissipation of the released heat and the cooling of the indoor and outdoor structural elements, leading thus to a time lag on the occurrence of the next day peak indoor temperature. Again, it has to be emphasized that in the urban areas, experiencing higher outdoor Tair values due to the urban heat island phenomenon, the efficiency of the night ventilation regarding the time lag of the occurrence of peak indoor Tair values may be compromised, especially under extreme heat wave conditions etc. [13]. Here, the 17th of June has been selected as a day in order to assess the effect of night ventilation on the time delay of the next day maximum indoor Tair. For this day, the average daily outdoor Tair value, calculated from the input weather data (for all study areas and for all building units) had the lowest deviation from the long-term average outdoor Tair value, for the whole cooling period. Besides, a reason that an extreme summer day has not been selected for the analysis relies on the high night outdoor air temperatures, exceeding the threshold values for the operation of the night natural ventilation (i.e., natural ventilation cannot occur if the outdoor Tair value exceeds 28 °C).

The hourly Tair profile and the respective time delay for the maximum indoor temperature due to the different air flow supplies of natural night ventilation for all the examined 1st and 3rd floor, non-insulated building units is given in Figure 5. The obtained results generally reveal the significant effect of the passive cooling technique on the reduction of the indoor Tair value, with the efficiency of the method ranging as a function of the air flow rate. More precisely, in the 1st floor building unit in
Pittakou canyon, the maximum reduction of the indoor air temperature due to night ventilation varies between 0.40 °C, 1.0 °C and 1.5 °C for a higher air flow rate by 2 ACH, 7 ACH and 12 ACH respectively and it occurs in the very early morning, around 5:00 a.m. In parallel, a delay in the maximum daily peak temperature (i.e., 26 °C) of around 3 hrs has been observed for an air flow rate of 5 ACH, while for 10 ACH and 15 ACH the peak indoor temperature is never reached. A similar trend is also noticed for the 3rd floor building unit in Pittakou, in which the maximum indoor Tair drop due to night ventilation varies between 0.35 °C and 1.5 °C for a higher air flow rate by 2 ACH and 12 ACH correspondingly, while its occurrence has been again observed in the very early morning. Besides, increasing the night air flow rate to 5ACH, contributed to a decrease on the average daytime indoor temperature (i.e., from 08:00 a.m. to 17:00 p.m.) by 0.23 °C, while a 3 hrs delay of the maximum daily peak temperature has been also observed.

Regarding both the 1st and 3rd floor apartments in Gavriilidou street, the maximum indoor Tair in the base case scenario (i.e., 26 °C) is reached almost 3 hours earlier compared to the building units in Pittakou, due to the higher solar gains received by the building envelope and transmitted into the thermal zone. Moreover, applying a higher night ventilation rate of 5 ACH in the 1st floor Gavriilidou apartment only resulted in a small indoor Tair decrease during daytime that did not exceed 0.1 °C, whereas the respective delay in the maximum daily peak temperature was 2 hrs. Yet, more important modifications on the daytime indoor air temperature have been noticed after increasing the night ventilation rate by 7 ACH and 12 ACH, reaching 0.40 °C and 0.70 °C respectively, whereas the maximum daily peak temperature is only marginally reached in the late evening for the 10 ACH.

Even more favorable are the indoor thermal conditions in the building units of Vafopoulou canyon in which the maximum daytime indoor Tair value is close to 25 °C, both for the 1st and 3rd floor apartments. Again, the application of higher night ventilation rates further improved the indoor thermal conditions in both building units. Indicatively, increasing the night air flow rate by 2 ACH, 7 ACH and 12 ACH in the first-floor apartment has led to a reduction of the next day’s peak indoor daytime Tair value by 0.20 °C, 0.50 °C and 0.60 °C respectively whereas no delay in the maximum daily peak temperature has been observed for all the examined scenarios.

**Figure 5.** Hourly Tair profile and the respective time delay for the maximum indoor temperature due to the different air flow supplies of natural night ventilation for all the examined building units.

### 4. Conclusions

The present study aimed to evaluate via numerical approaches the role of night ventilation on the improvement of the energy and thermal performance of generic building units, located in dense urban areas of the city of Thessaloniki. The results of a parametric analysis, examining the effect of different
air flow rates of summer night ventilation on the building units’ indoor thermal conditions, have been discussed. 3 different air flow supplies of single-sided night ventilation have been considered, involving a moderate value of 5 ACH and 2 more important air flow supplies of 10 ACH and 15 ACH. It was found that even a moderate increase of the night air flow supply (i.e., from 3ACH to 5ACH) can lead to a substantial energy conservation for all building units whereas reduction on the cooling energy needs increased as a function of the air flow supply. Increasing the night ventilation rate by 2ACH may provide a delay on the maximum daily peak temperature of around 2-3 hours, while only a moderate reduction on the next day, average daytime indoor Tair value has been noticed in all the examined building units. Yet, the parametric analysis has shown that the decrease of the mean daytime indoor Tair is more important for an air flow supply of 15ACH, overpassing even 1.0 °C in some of the examined building units.

Acknowledgements
This study was conducted in the context of the PhD thesis of the corresponding author [11].

References
[1] Shaviv E, Yezioro A and Capeluto I G 2001 Thermal mass and night ventilation as passive cooling design strategy Renewable energy 24 (3-4) 445-52
[2] Geros V, Santamouris M, Tsangrasoulis A and Guarracino G 1999 Experimental evaluation of night ventilation phenomena Energy and Buildings 29 (2) 141-54
[3] Kolokotroni M, Giannitsaris I and Watkins R 2006 The effect of the London urban heat island on building summer cooling demand and night ventilation strategies Solar Energy 80 (4) 383-92
[4] Santamouris M, Mihalakakou G and Asimakopoulos D 1997 On the coupling of thermostatically controlled buildings with ground and night ventilation passive dissipation techniques Solar Energy 60 (3-4) 191-7
[5] Geros V, Santamouris M, Karatasou S, Tsangrassoulis A and PapanikolaouN 2005 On the cooling potential of night ventilation techniques in the urban environment Energy and Buildings 37 (3) 243-7
[6] Yang L and Li Y 2008 Cooling load reduction by using thermal mass and night ventilation Energy and Buildings 40 (11) 2052-8
[7] Balaras C 1996 The role of thermal mass on the cooling load of buildings. An overview of computational methods Energy and Buildings 24 (1) 1-10
[8] Vogiatzi C, Gemenetzi G, Massou L, Poulopoulos S, Papaefthimiou S and Zervas E 2018 Energy use and saving in residential sector and occupant behavior: A case study in Athens Energy and Buildings 181 1-9
[9] TOTEE20701-1/2017 Technical Guides of the recast of the Hellenic Thermal Regulation of the Energy Assessment of Buildings, in, 2017
[10] Tsoka S, Tolika K, Theodosiou T, Tsikaloudaki K and Bikas D 2018 A method to account for the urban microclimate on the creation of ‘typical weather year’datasets for building energy simulation, using stochastically generated data Energy and Buildings 165 270-83
[11] Tsoka S 2019 Urban microclimate analysis and its effect on the buildings energy performance, PhD thesis, Aristotle University of Thessaloniki, Faculty of Civil Engineering
[12] Santamouris M, Sfakianaki A and Pavlou K 2010 On the efficiency of night ventilation techniques applied to residential buildings Energy and Buildings 42 (8) 1309-13
[13] Santamouris M, Papanikolaou N, Livada I, Koronakis I, Georgakis C, Argiriou A and Assimakopoulos D 2001 On the impact of urban climate on the energy consumption of buildings Solar energy 70 (3) 201-16