# MARKET OPPORTUNITIES FOR ADVANCED VENTILATION TECHNOLOGY

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**Title:** Night ventilation in urban environment

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## 1. Synopsis

This study investigates the application of night ventilation techniques in ten urban canyons, situated in the extended region of Athens, Greece. In order to determine the impact of the urban environment on the night ventilation performance, the outdoor air temperature and wind profile have been measured inside and outside the experimental canyons. The application of the night ventilation techniques has been studied in a typical single zone room and various simulations have been performed under controlled and free-floating operation, when single-sided and cross ventilation are considered, during the night period. The influence of the urban microclimate on the efficiency of the technique has been studied by considering the examined zone inside and outside the experimental urban canyons. The comparison of the results permits to evaluate the impact of the urban canyons on the effectiveness of the night ventilation techniques. The performed analysis shows that due to the increase of the air temperature and the decrease of the wind velocity inside the canyons, the potential of the studied techniques can be reduced significantly.

## 2. Introduction

The urban microclimate has an important influence on the application of passive cooling techniques in buildings. The heat island effect and the modification of the terrain in the urban environment can affect seriously the local climatic conditions. Therefore, the climatic characteristics in the centre of a city differ considerably with the rural ones. The use of the appropriate climatic data is essential, in order to study the thermal behavior of buildings in the urban environment, as well as, the efficiency of passive cooling techniques.

The efficiency of the night ventilation techniques is strongly related with the outdoor air temperature. Additionally, in the case of the natural ventilation it is necessary the knowledge of the wind field (velocity and direction). These parameters are important in order to evaluate the performance of these techniques. Frequently, the designers investigate the application of the night ventilation by using climatic date measured in a meteorological station located near to the studied building, because it is not always feasible to realize measurements in-situ. When the building is located in the urban environment these data are not accurate and they do not represent the climatic conditions of the building's location. The modified terrain influences strongly the wind field even for adjusted regions. Additionally, the heat island effect increases the outdoor temperature in the urban environment in regard with the rural surroundings of the city.

Since the urban canyon are more or less the units that compose the urban environment, their geometry and orientation, the construction materials, the anthropogenic heat sources, characterize and determine the thermal and air flow conditions in the urban domain. The study of these conditions is important in order to evaluate the application of the night ventilation techniques in the urban environment.

## 3. Experimental procedure and experiments

The experiments have been taken place in Athens (Greece), in the frame of the Joule programme POLIS (Polis, 1995). Ten urban canyons have been studied, representing different geometries and orientations, anthropogenic heat sources and vegetation. The thermal and airflow conditions have been examined by measuring the following parameters between June and September of 1997:

- **Measurement of the air temperature.** In order to measure this parameter, sensors measuring the air temperature were installed inside and outside the canyons. A white painted wooden box, mainly to protect them from the solar radiation, was used to cover these sensors. The upper and lower sides of these boxes were opened to facilitate the circulation of the ambient air through the boxes. The sensors used for the "inside the canyon" measurements were installed on the buildings facades, while the ones used for the "outside the canyon" measurements were installed on the roof of the buildings. The measuring time step was 15 min.
- **Measurement of the wind velocity and direction.** A three-axis anemometer was installed inside the urban canyons, to measure the three component of the wind. This anemometer was installed at a distance 1 to 2 meters away from the building's façade (Figure 2). To measure the wind field outside the canyon a second anemometer was installed at the roof of the same building, at a 6 meters height. The time step of the measurements was 12 seconds.

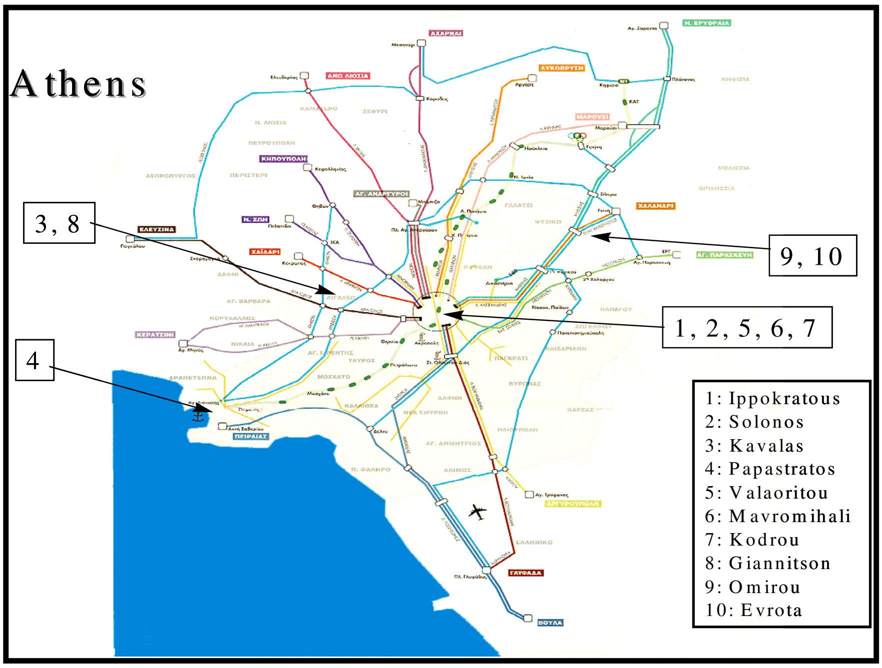


*Figure 1. The location of the ten urban canyons*

*Figure 2. The 3-axis anemometer used for the experiments*

In the following analysis the measurements of the outdoor air temperature, as well as, the corresponding data of the wind velocity and direction, measured inside and outside the experimental canyons, were used to investigate the application of the night ventilation in the urban environment.
The location of the experimental urban canyons is illustrated in Figure 1, while some important characteristics of these canyons are presented in Table 1.

| Canyon Name | Orientation | Height [H] and Width [W] | Canyon Characteristics | Measurement position | Measurement period |
|---|---|---|---|---|---|
| Ippokratous | 30° | H=21m W=12m H/W=1.75 | Center of Athens. Heavy traffic. | Façade North-West Height=10m | 13-24 June |
| Solonos | 120° | H=21m W=10m H/W=2.1 | Center of Athens. Heavy traffic. | Façade North-East Height=10.5m | 17-25 June |
| Kavalas | 140° | H=11m W=11m H/W=1 | Residential region. | Façade South-West Height =5.5m | 16-20 August |
| Papastratos | 60° | H=26m W=10.5m H/W=2.5 | Seaport of Athens. Industrial region. | Façade South-East Height =7m | 3-5 June |
| Valaoritou | 120° | H=21m W=8.5m H/W=2.5 | Center of Athens. Pedestrian street. | Façade South-West Height =9m | 10-13 July |
| Mavromihali | 30° | H=21m W=8.5m H/W=2.5 | Center of Athens. Medium traffic. | Façade South-East Height =9m | 28-31 July |
| Kodrou | 135° | H=14m W=5.5m H/W=2.5 | Center of Athens. Pedestrian street. | Façade South-East Height=6m | 29-31 July |
| Giannitson | 50° | H=11m W=11m H/W=1 | Residential region. | Façade North-West Height =5.5m | 12-24 August |
| Omirou | 145° | H=21&8m W=11m H/W=1.9&0.7 | Residential region. Low traffic. | Façade South-West Height=4m | 15-19 September |
| Evrota | 55° | H=21&14m W=10m H/W=2.1&1.4 | Residential region. Low traffic. | Façade South-East Height=4m | 15-19 September |

*Table 1. The main characteristics of the experimental urban canyons*

## 4. Measurements of the experimental urban canyons

The application of the night ventilation has been studied by using the outdoor air temperature measurements performed at the same location where the wind field was measured. In this paragraph the measurements of one canyon is presented (Ippokratous). The following analysis is mainly focused on the night-time period, because this is the period of interest for the night ventilation.

### *4.1 "Ippokratous" urban canyon*

This canyon is situated in the center of Athens. Its orientation is 30°, clockwise from the North-South axis. The height of the canyon is 21m, while its width is 12m (H/W=1.75). The vehicle traffic in "Ippokratous" is high and therefore the anthropogenic heat production is important. The measurements have been performed between 13 to 24 June. The outdoor air temperature and the wind field have been measured on the North-West façade of the canyon at a height of 10m. Figure 3 illustrates the air temperature measured inside and outside the canyon during the experimental period.

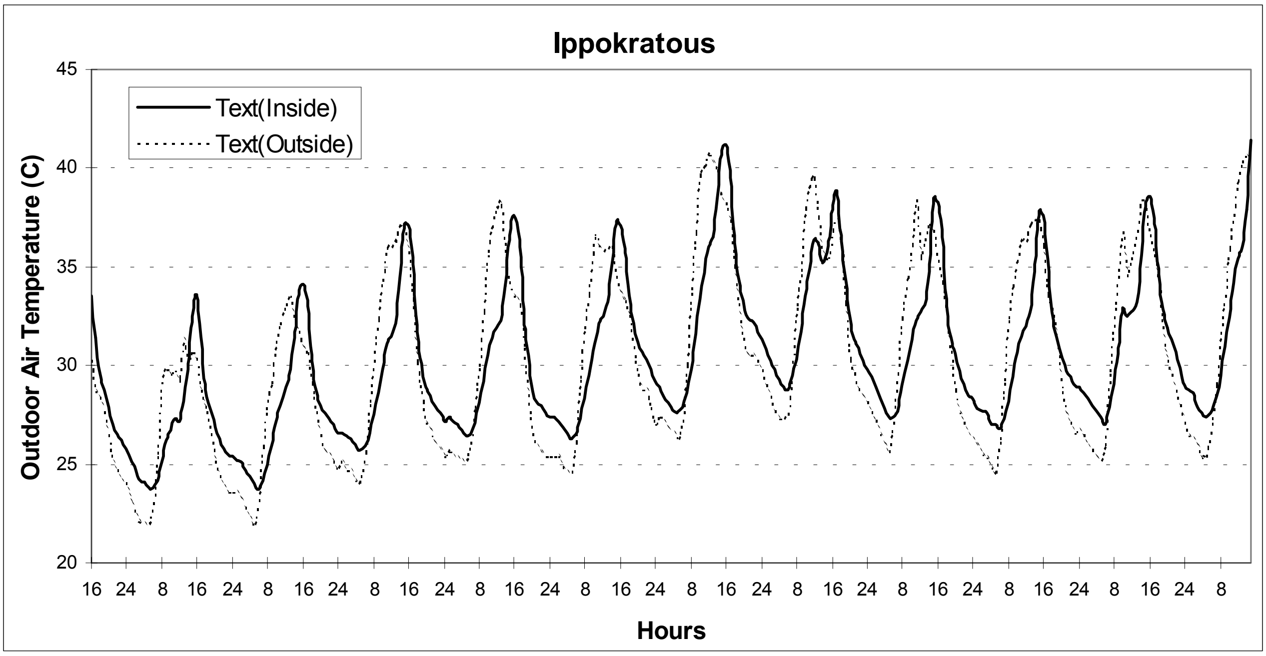


*Figure 3. The outdoor air temperature measured inside and outside the "Ippokratous" urban canyon*

The comparison between the two datasets of the outdoor temperature indicates that the daily amplitude of the air temperature outside the canyon is greater than the one measured within the canyon. Additionally, the maximum of the temperature measured inside the canyon is time delayed in regard with the temperature measured outside the canyon. The sensor of the temperature is installed on the west façade of the canyon and therefore the temperature in this façade has a daily maximum during the afternoon. During the night period the air temperature outside the canyon is lower than the one measured inside. The long wave radiation exchanges, during the night, between the surfaces of the canyon does not permit the "evacuation" of the heat, which is stored in the construction materials during the day time period. Therefore, the reduction rate of the temperature is lower than the one outside the canyon. For this reason the nighttime surface temperature and consequently the air temperature inside the canyon are

higher than the temperature at the top of the canyon where the sky view factor is more important than the one inside the canyon. The measurements indicate that during the night period the average difference between the temperature inside and outside the canyon is close to 1.8 $^{o}$C.
The following figure (Figure 4) illustrates the wind velocity and direction measurements for the "Ippokrtous" canyon. The data sets in these graphs represent the horizontal component of the wind velocity. According to this figure during the day time period the difference between the wind velocity measured inside and outside the canyon is very important. The existence of the canyon reduces strongly the wind velocity and modifies the wind direction.

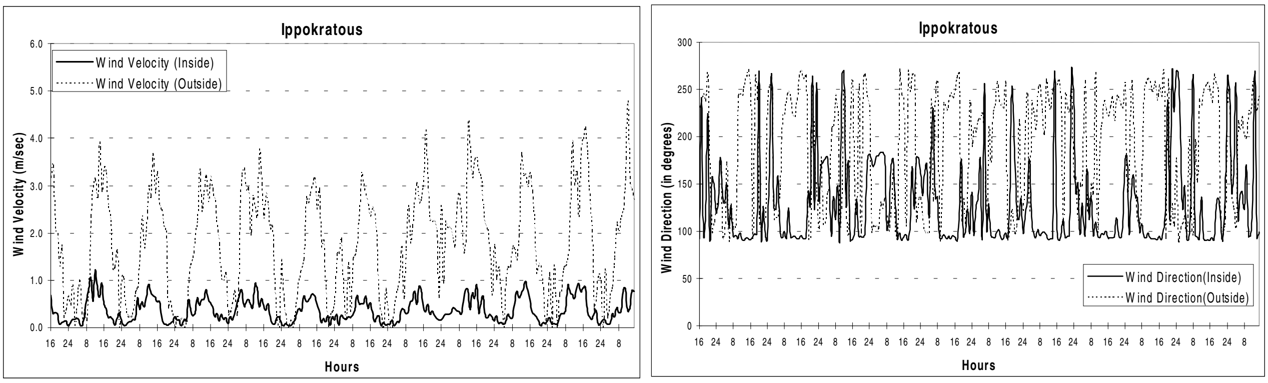


*Figure 4. The wind velocity and direction measured inside and outside the "Ippokratous" urban canyon*

On the other hand, during the night, the height of the boundary layer is decreased and the differences of the temperature and the pressure are reduced, in regard with the daytime, mainly due to the absence of the solar radiation. Therefore the wind velocity is reduced outside the canyon and the difference between the wind velocity measured inside and outside the canyon is lower than the one measured during the day. Regarding to the experiments performed in "Ippokratous" canyon and during the night period, the difference of the wind velocity between the two measurement positions is close to 0.61 m/sec.

## 5. Study of the night ventilation in the experimental urban canyons

In order to evaluate in which degree the urban environment influences the energetic/thermal performance of the night ventilation, the application of this technique was studied by using the climatic conditions measured inside and outside the experimental urban canyons. The analysis of the measurements indicates that the dominated climatic conditions inside and outside the urban canyons frequently are different. The local microclimate is strongly related with the form and the geometry of the canyon, its orientation, the heat sources and the construction materials. Usually, the building related researchers are using climatic data measured in meteorological stations near to the examined building location. Regarding the application of the night ventilation in the urban environment this approach overestimates, in most cases, the efficiency of the technique. Generally, the daily amplitude of the air temperature is higher outside an urban canyon than inside. Additionally, the geometrical form of the canyon reduces the penetration of the solar radiation during the daytime period, but on the other hand decreases the cooling rate of the structural elements during the night because the canyon's surfaces obstruct the direct emission of the long wave radiation to the sky. This phenomenon affects the air temperature inside the canyon and reduces the efficiency of the night ventilation. Moreover, the geometry of the canyon decreases the wind velocity and modifies the wind direction. The comparison between the climatic conditions inside and outside the canyon, during the night time period, shows that the air temperature is higher and the wind velocity is lower inside the canyon. Also, the wind direction in most cases is totally different between these two situations. The canyon's geometry and the angle of incidence of the wind determine the airflow in the urban canyon and consequently the wind field. Thus, the efficiency of the night ventilation depends on the location where the climatic data are measured.

To study the application of the night ventilation in the urban environment, two typical zones were defined (Figure 5). These zones represent the part of a building situated in an urban canyon. The first zone has only one window (window (1) in Figure 5), while the second one has two windows (windows (1) and (2) in Figure 5). Both zones are identical, except the number of the windows. These two zones were studied as natural ventilated during the night period (single sided ventilation for the first zone and cross ventilation for the second one), by using the climatic data measured inside and outside the ten experimental urban canyons. To simulate the thermal behavior of the previous mentioned zones when they are considered inside and outside the experimental urban canyons, the TRNSYS (Klein, 1990) software tool has been used. This approach permits to evaluate the influence of the urban environment in the efficiency of the night ventilation. Additionally, two operation strategies were studied, free floating and air-conditioned operation, in order to investigate the application of the technique under different operation conditions.

The simulated typical zones were considered as semi-exposed at the external environment. The floor area of each zone was $36m^2$, while its volume was $144m^3$. The operation schedule of the zones was 9:00 to 18:00. The set point temperature for the operation of the A/C system was equal to $27^oC$, during the operation schedule of the zones. The application period of the night ventilation was 22:00 to 6:00.

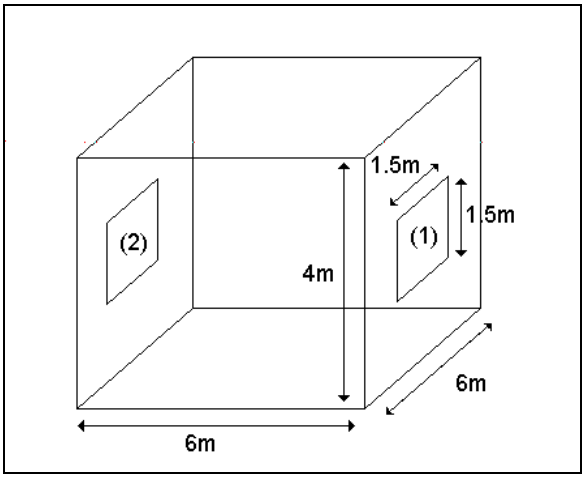


*Figure 5. The typical zone*

To calculate the airflow rate due to the natural ventilation (single sided or cross ventilation), the AIOLOS software (Allard, 1998) has been used. The results of this airflow study were utilized as inputs in the TRNSYS software, to calculate the energy gain due to the night ventilation. In the following paragraph the obtained results for the "Ippokratous" urban canyon are presented.

***5.1 "Ippokratous" urban canyon***

In order to study the application of the night ventilation in the case of the thermostatically controlled zone, the cooling load and the internal air temperature has been calculated when single-sided and cross ventilation strategies are considered during the night period. Figure 6 illustrates the results when the zone is situated inside and outside the urban canyon, for the single-sided ventilation case. According to this figure, during the application of the night ventilation, the average difference of the internal temperature between the two locations of the building is close to 0.6°C. This difference is quite low because the airflow rate between the two locations of the zone differs averagely only 0.2 air changes per hour (Figure 8). Also, the cooling load for the 12 days period is 4240 $Wh/m^2$, when the climatic data measured inside the urban canyon are used. For the case where the zone is located outside the canyon the cooling load is reduced to 3850 $Wh/m^2$. Therefore, the existence of the urban canyon decreases the energetic potential of the night ventilation and increases the cooling load of the studied zone by 9.2%, for the "Ippokratous" canyon.

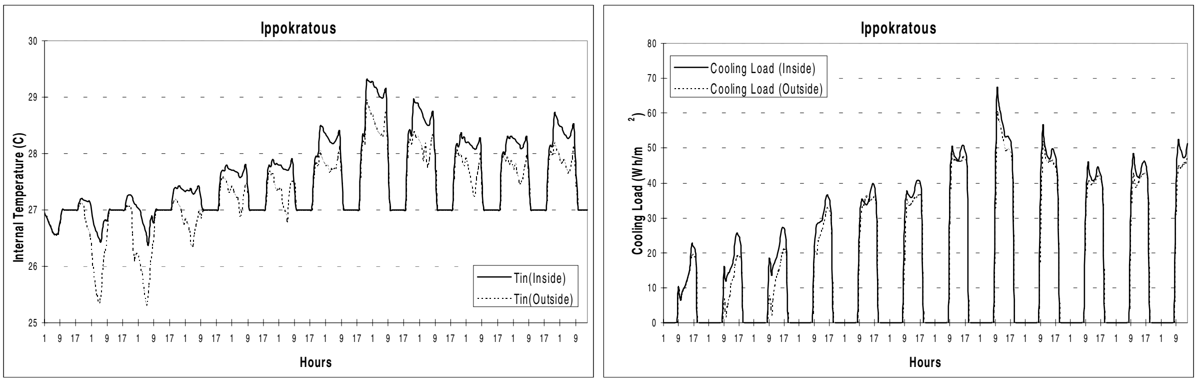


*Figure 6. The indoor temperature and the cooling load, for the A/C operation of the zone and for single-sided ventilation ("Ippokratous")*

When the typical zone was under free-floating operation, the internal temperature, as well as, the difference of the indoor temperature when the zone is considered inside and outside the "Ippokratous" urban canyon has been calculated (Figure 7).

For all the experimental period, the two indoor temperature profiles differ averagely about 0.7°C, while the maximum difference is 2.2°C. During the operation of the building (9:00-18:00), when the zone is situated inside the canyon, the indoor temperature is 0.6°C higher than the case where the zone is considered outside the canyon.

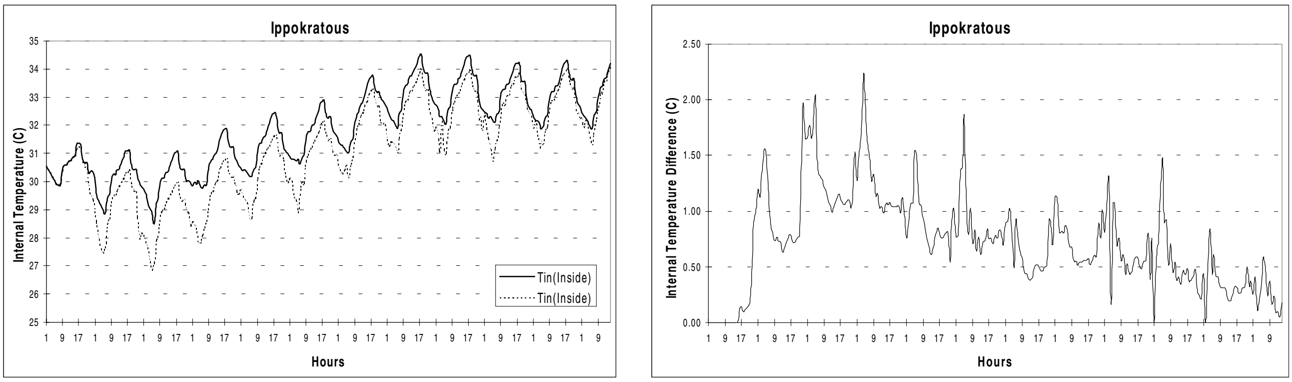


*Figure 7. The indoor air temperature and the difference of the indoor air temperature between the two locations of the zone, under free-floating operation, for the single sided ventilation*

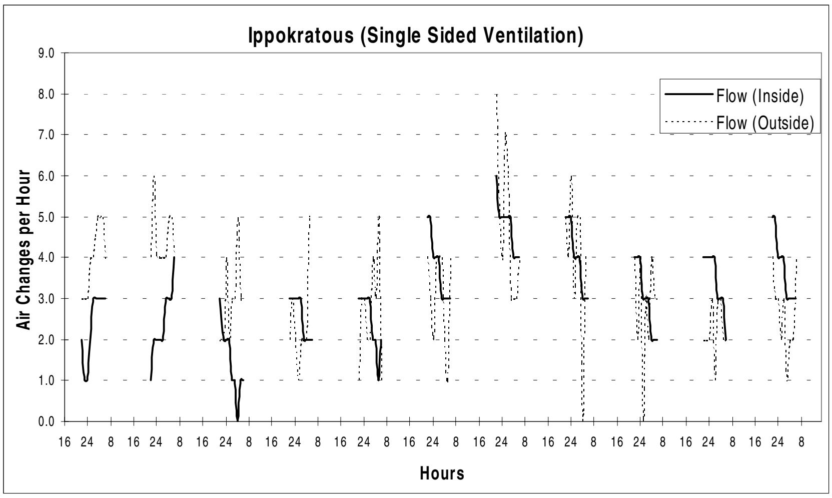


*Figure 8. The airflow rate for the single sided ventilation, inside and outside the "Ippokratous" urban canyon*

The use of cross ventilation during the night time period increases the influence of the urban canyon on the night ventilation's efficiency. The airflow rate during the application of the technique is in average 12.6 ACH higher when the zone is considered outside the canyon (Figure 11). This difference indicates that the use of climatic data measured outside the urban canyon for the energy study of the night ventilation overestimates the energetic influence of this technique.

Figure 9 presents the calculated cooling load for the experimental period and the indoor air temperature, for the case of cross ventilation. When the zone is located inside the "Ippokratous" canyon the cooling load was estimated equal to 5330 Wh/m$^2$, higher than in the case of single sided ventilation due to the existence of two windows (higher solar gains). When the zone is located outside the canyon, the cooling load is 4320 Wh/m$^2$, and therefore is reduced by 19%.

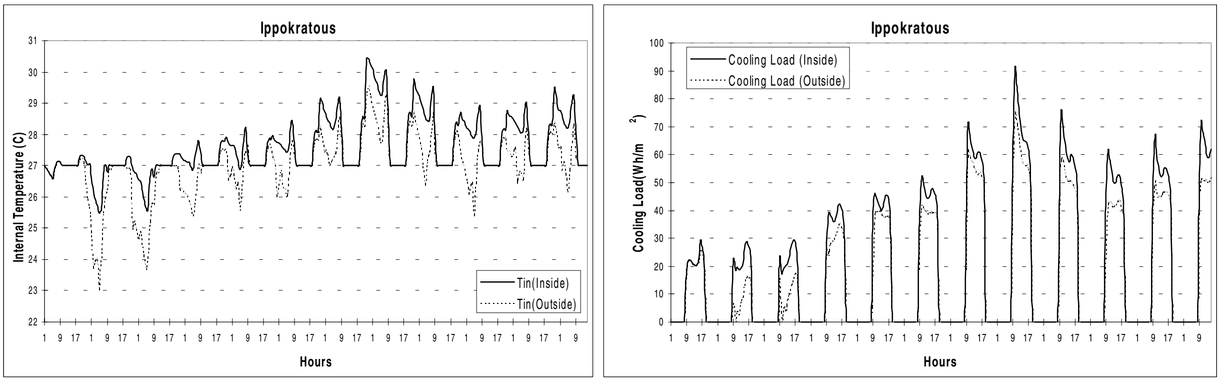


*Figure 9. The indoor temperature and the cooling load, for the A/C operation of the zone and for cross ventilation ("Ippokratous")*

According to Figure 9, during the application of the night ventilation, the average indoor temperature difference between the two situations of the zone is close to 1.4 $^{o}$C.

When the zone is under free-floating operation, the influence of the night ventilation on the indoor temperature is very clear (Figure 10). During the studied period the average difference of the indoor temperature between the inside and outside the canyon position of the zone is close to 1.6 $^{o}$C, while the maximum value of this difference is 4.1 $^{o}$C. Also, during the operation period of the zone this difference has an average value equal to 1.3 $^{o}$C (max=2.2 $^{o}$C).

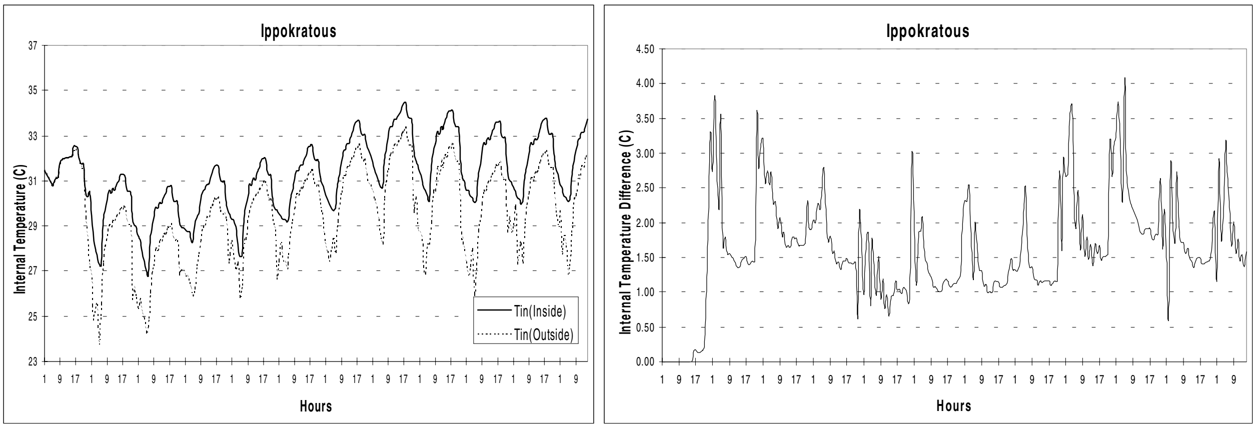


*Figure 10. The indoor air temperature and the difference of the indoor air temperature between the two locations of the zone, under free-floating operation, for the cross ventilation*

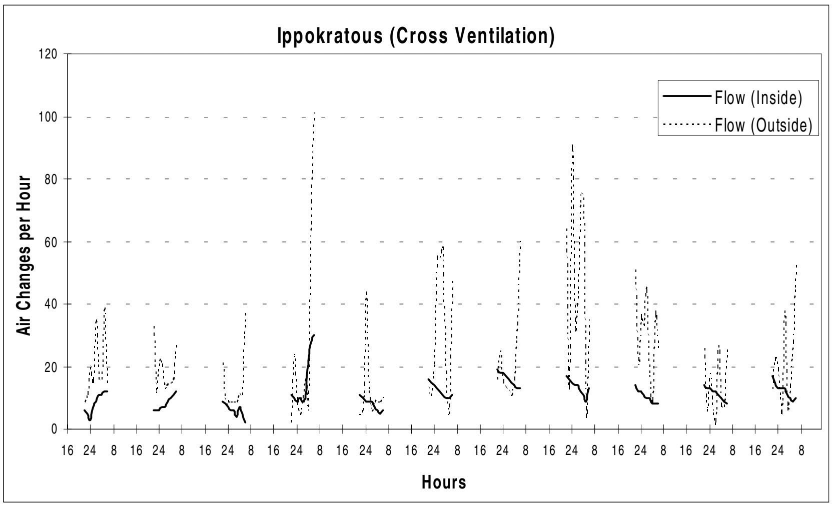


*Figure 11. The airflow rate for the cross ventilation, inside and outside the "Ippokratous" urban canyon*

## 6. Conclusions

This study investigates the application of the night ventilation in the urban environment. To perform this analysis two typical zones have been defined, in order to study the application of two ventilation strategies, single sided and cross ventilation, as well as, two operational modes, air conditioned and free floating.

The efficiency of the technique is strongly related with the outdoor temperature and the wind field, when the ventilation is natural. To evaluate the influence of the urban environment on the efficiency of the technique, measurements of the outdoor air temperature and the wind field have been realized, inside and outside ten urban canyons located in the extended urban area of Athens. These measurements indicate that the climatic conditions between these two positions can be very different. This comparison shows that during the night, the air temperature is higher inside the urban canyons in regard with the outside conditions. On the contrary, the wind velocity is lower inside the canyon and the wind direction is determined mainly by the geometrical characteristics of the canyon and the angle of incidence of the wind.

By using the measurements performed inside and outside the ten urban canyons, the air flow rate has been calculated during the application of the night ventilation, when the ventilation is single sided and cross. To evaluate the difference of the airflow rate, between the two locations of the typical zone, the average difference between the two data sets has been calculated (Figure 12). The results of this analysis indicate that the airflow rate is reduced, when the climatic data measured inside the canyons are used. According to the following figure, for the single sided ventilation, the difference of the airflow rate between the two situations is not important. This difference varies between 0.2 to 10 air changes per hour. On the other hand, for the cross ventilation case the airflow rate difference is more important, (variation between 4 to 69 ACH). In this case, the role of the wind is determinative for the achieved ventilation rates. Therefore, the existence of the canyon reduces the airflow rate during the application of the night ventilation.

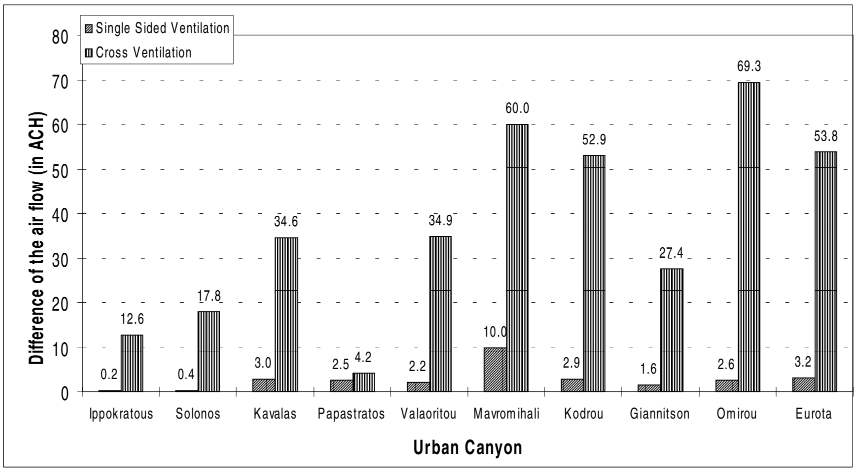


*Figure 12. The average difference of the airflow rate calculated inside and outside the ten urban canyons, for the single sided and cross ventilation*

Figure 13 illustrates the relative difference between the cooling load calculated inside and outside the ten urban canyons. The obtained results indicate that the cooling load calculated by using the climatic data measured inside the canyons, is higher than the one calculated when the "outside the canyon" climatic conditions are considered. This conclusion is justified because the temperature is higher inside the canyon, while the airflow rate is lower. However, the calculations concerning the "Papastratos" and the "Evrota" canyons show an inverse behavior. In these cases, the biggest part of the cooling load is observed the first day of the calculations, before the application of the night ventilation. The calculation of the cooling load is performed during the operation schedule of the zone, during the daytime period, when the outside the canyon air temperature is higher and therefore the thermal gain due to infiltration is also higher, than the one inside the canyon. For the two previous mentioned canyons, after the first day application of the night ventilation, the indoor temperature is almost continuously less than the set point temperature and therefore for the remaining days the cooling load is almost zero. The following figure illustrates that the relative difference of the cooling load, between the two locations of the zones varies between –6 to 89%, for the single sided ventilation. For the cross ventilation case, this difference is between –18 to 72%. Consequently, the utilization of the climatic conditions dominated outside the canyon, overestimates the efficiency of the night ventilation.

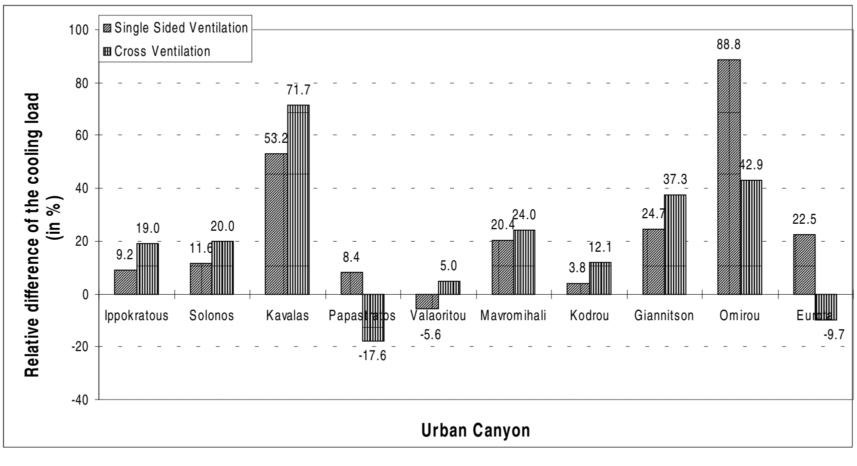


*Figure 13. The relative difference of the cooling load calculated inside and outside the ten urban canyons, for the single sided and cross ventilation*

Finally, the Figure 14 illustrates the difference of the indoor air temperature of the zone, under free-floating operation, between the two climatic situations. This difference refers during the operation of the typical zone. According to this figure, the application of the cross ventilation increases the difference of the temperature between the two locations of the zone. For the single sided ventilation, this difference varies in a range of 0.02 to 2.6 $^{o}$C. Respectively, for the cross ventilation this difference is increased and varies between 0.2 to 3.5 $^{o}$C.

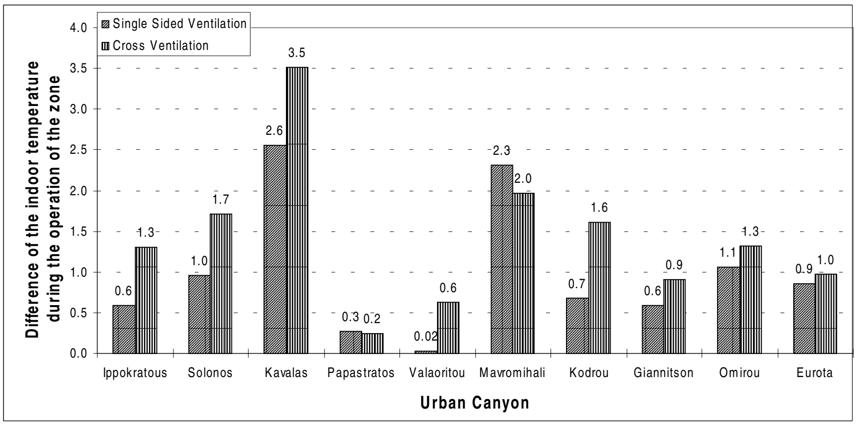


*Figure 14. The difference of the indoor air temperature calculated inside and outside the ten urban canyons, for the single sided and cross ventilation*

The previous analysis indicates that the use of the climatic conditions dominated outside the urban canyons is not appropriated for the study of the night ventilation (and generally for the study of passive cooling techniques) when applied in buildings located within the urban canyons. The utilization of these climatic data overestimates the efficiency of the technique and does not permit to simulate the thermal behavior of the buildings correctly. In order to simulate the outdoor thermal and airflow conditions in the urban canyons, it is possible to use numerical models (CFD), but there are problems concerning the correct definition of the boundary conditions. The measurements' grid should be quite dense in order to determine the boundary conditions with an acceptable resolution. On the other hand, it is necessary to develop simplified models, which will be able to simulate the climatic conditions dominated inside the urban canyons, with a limited number of inputs.

## 7. References

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