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# The utilization of first derivatives and violinplots of meteorological parameters for the evaluation of thermal behavior of small urban sites.

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dated : 15 June 2015

## 1. Introduction

The most common way to present the thermal behavior of urban sites is the illustration via daily courses of significant parameters such as air temperature, mean radiant temperature and indices such as physiologically equivalent temperature etc. In addition the frequency classes' diagrams or the boxplots presenting the aforementioned parameters are widely used. In order to analyze thoroughly the bioclimatic behavior of the urban sites the utilization of the first derivative of fundamental meteorological – thermal parameters were presented. Moreover the graphic representation of the violinplot is able to make more comprehensive the frequency distribution of the selected parameters.

During this study were used the fundamental parameters for the assessment of thermal comfort such as the air temperature $T_a$, the mean radiant temperature ($T_{mrt}$) and the (PET) physiologically equivalent temperature (Matzarakis et al. 1999; Mayer and Höppe 1987) especially their first derivatives, $\Delta T_a/\Delta t$, $\Delta T_{mrt}/\Delta t$ and $\Delta PET/\Delta t$ along with the respective violinplots. The above "tools" were implemented in the case study of five small urban sites which differ on geometric configuration and the materials (vegetation, concrete etc). The cooling/heating process was investigated during summer and winter period.

## 2. Case study and the methods

For the implementation and the assessment of the violinplots and the first derivatives of the parameters such as air temperature ($\Delta T_a/\Delta t$), mean radiant temperature ($\Delta T_{mrt}/\Delta t$) and physiologically equivalent temperature ($\Delta PET/\Delta t$) five sites with various environmental configuration were selected. The major characteristics of the sites are described in the following table (Tabl.1). A more detailed description of the site is in the Charalampopoulos et al. (2014)

Table 1. Major characteristics of the selected sites

| Site name | Descriptions | Summer period S.V.F | Winter period S.V.F. | Albedo |
|---|---|---|---|---|
| S1 | Meteorological station | 0.93 | 0.93 | 0.35 |
| S2 | Building atrium | 0.35 | 0.37 | 0.20 |
| S3 | Green atrium | 0.20 | 0.51 | 0.20 |
| S4 | Arboricultural field | 0.68 | 0.74 | 0.15 |
| S5 | Small park | 0.07 | 0.49 | 0.20 |

The measurements period lasted 3 years starting on July 1st, 2003 and for the purposes of the present study, only days under sunny and calm wind conditions were included in the analysis.

In order to quantify more clearly the effect of vegetation and site configuration on thermal regime, violin plots were used as a first tool. The second tool that used in the present study is the air temperature, mean radiant temperature and PET rate, e.g. $\Delta T_a/\Delta t$ and $\Delta T_{mrt}/\Delta t$, $\Delta PET/\Delta t$ respectively. These rates are the results of the first derivative of the parameters on hourly basis. The estimation of the $T_{mrt}$ and the PET index was made via the RayMan model (Matzarakis et al. 2007; Matzarakis et al. 2010).

The violin plot synergistically combines the boxplot and the density trace (or smoothed histogram) into a single display that reveals structure found within the data (Hintze and Nelson 1998; Potter et al. 2010). The estimated density trace allows a clearer yet brief identification of special properties of the data that is particularly important when the distribution exhibits interesting characteristics. In addition, the violin plots indicate a clear view of the quantity of the parameter as a suitable combination with parameter's distributional characteristics. The violin plots of the data of the present study were developed via scripts of the R-Language.

## 3. Results and analysis

The following results and the sort analysis aim to present the new descriptive abilities of the first derivatives and the violinplots. The major advantage of using such depictions and parameters is to make more conceivable the bioclimatic functions of the materials (vegetation, concrete etc) and the geometric configuration (SVF).

### 3.1 Summer period

During the summer period the violin plots of $\Delta T_a/\Delta t$ rate present a high rate range (from 6 to 7 °C/h) at the sparsely or non-planted sites like S1, S2 and S4. All density traces have high positive skewness (Fig.1). The skewness coefficient has moderate values (0.5-1.0) at the densely vegetated sites (S3 and S5) and high at the other sites (S1, S2, S4).

For the summer period, as it was expected, the mean and the median values of $\Delta T_a/\Delta t$, $\Delta T_{mrt}/\Delta t$ and PET/$\Delta$t at the selected sites are close to 0 (Fig.1 and 2). More specifically, the rate range of $\Delta T_{mrt}/\Delta t$ is high during summer, reaching 36 °C/h in S2 (building atrium) whereas at the same time was only 6.9 °C/h at the S5 site (small park). During the same time period the rate range $\Delta$Ta/$\Delta$t reached 7 °C/h at S4 (arboricultural field) whereas at S5 site a value of only 3.6 °C/h was recorded (Fig 7). The cooling rate values (negative $\Delta T_a/\Delta t$ values) at S3 and S5 are higher, 1.5 and 1.4 °C/h, respectively. In addition, at these sites the density trace reveals a bimodal distribution when the sparsely or non-vegetated is with one mode peak.

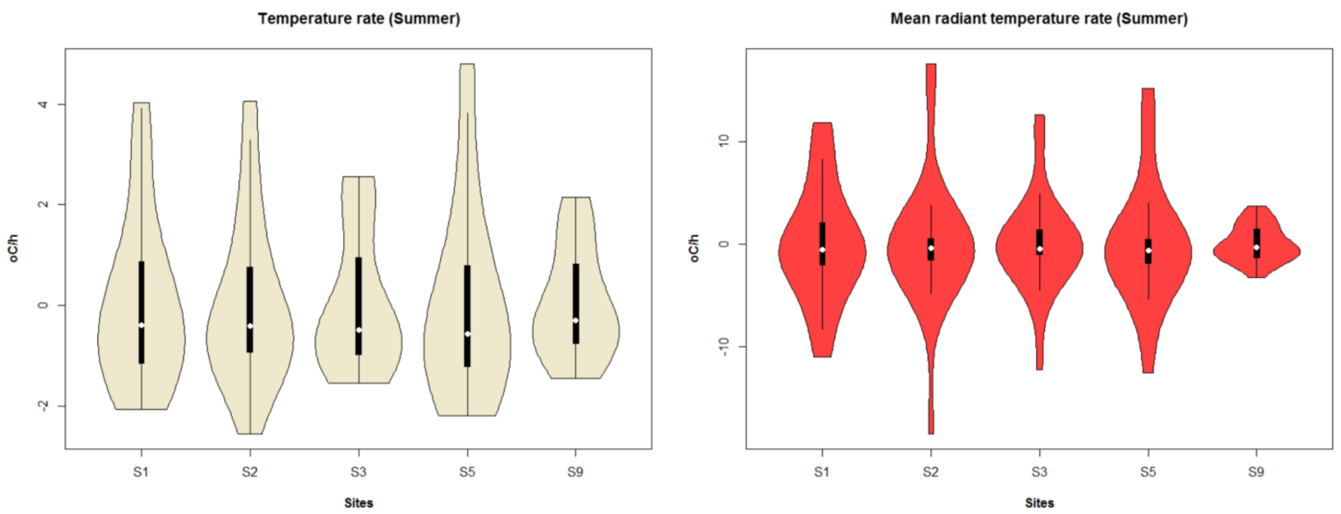


*Figure 1. Violin plots of $\Delta T_a/\Delta t$ (left) and of $\Delta T_{mrt}/\Delta t$ for the selected site during summer period.*

The violin plots of the $\Delta T_{mrt}/\Delta t$ during the summer period present a very high rate range at the building atrium (S2) taking a value of 36.0 °C/h (Fig.1). The distribution for this site has very long tails with both negative and negative values; the skewness coefficient is 0.42 indicating a fairly symmetrical distribution. This implies that the building atrium has the same potential to increase and to decrease the $T_{mrt}$ values. In addition, the distribution at the building atrium (S2) is trimodal - the secondary modes are the end of the two tails. This is in contrast to the smaller range for the small park (site S5) taking a value of 6.9 °C/h. This value indicates that the vegetation acts as a thermal buffer thus the Tmrt increasing rate is small. At the same time the negative values of the rate implies park's inability to cool down rapidly. Figure 2 illustrates the $\Delta$PET/$\Delta$t rate during the summer period. As it was anticipated the form of the distributions is similar to the $\Delta T_{mrt}/\Delta t$ distribution. The highest rate range ($\Delta$PET/$\Delta$t) was found for the building atrium (22.8 °C/h) indicating that this environmental configuration leads to rapid increase or decrease of PET values. Furthermore, at S2 site the skewness coefficient is low (0.65) indicating a moderate skewness with both negative and positive distribution tails. On the contrary the PET rate range distribution for the park (S5) is the lowest (3.6 °C/h) during the summer period. This is a consequence of the buffering ability of the vegetation combined with the low SVF value of the site. Comparing the distributions at the selected sites, it becomes obvious that the positive tail is longer than the negative. This is a further indication that the studied environmental configurations are able to increase PET more rapid than to decrease it.

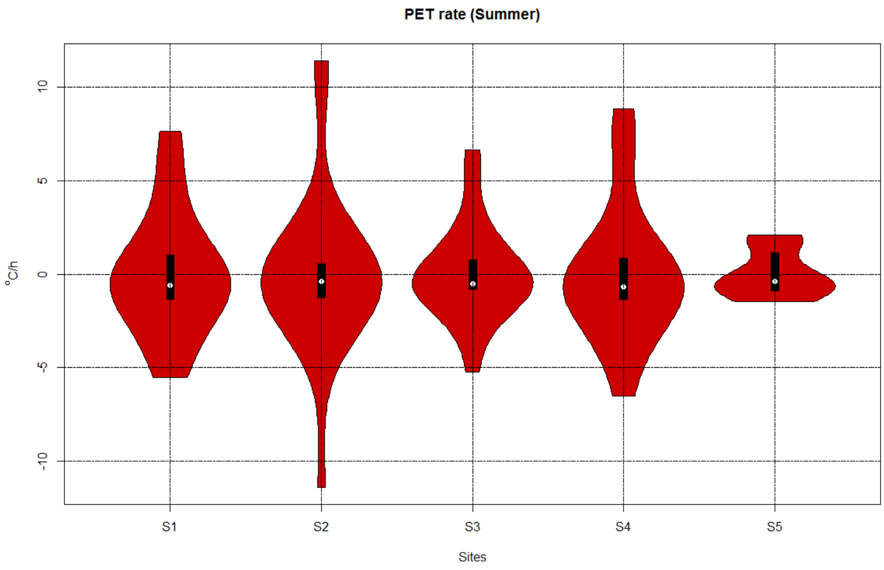


*Figure 2. Violin plots of ΔPET/Δt for the selected site during summer period*

The rates of ΔPET/Δt were higher at summer than during the winter period, reaching 12 °C/h for the S2 site in the morning whereas was only 2 °C/h during the winter. The biometeorological behavior is similar for the S1 and S5 sites reaching 8 °C/h early in the morning (07:00-08:00 LST). On the other hand, the densely vegetated S5 acts as a sink of thermal discomfort 'absorbing' a significant part of the 'environmental pressure'. The highest rate of ΔPET/Δt at site S5 is less than 3 °C/h.

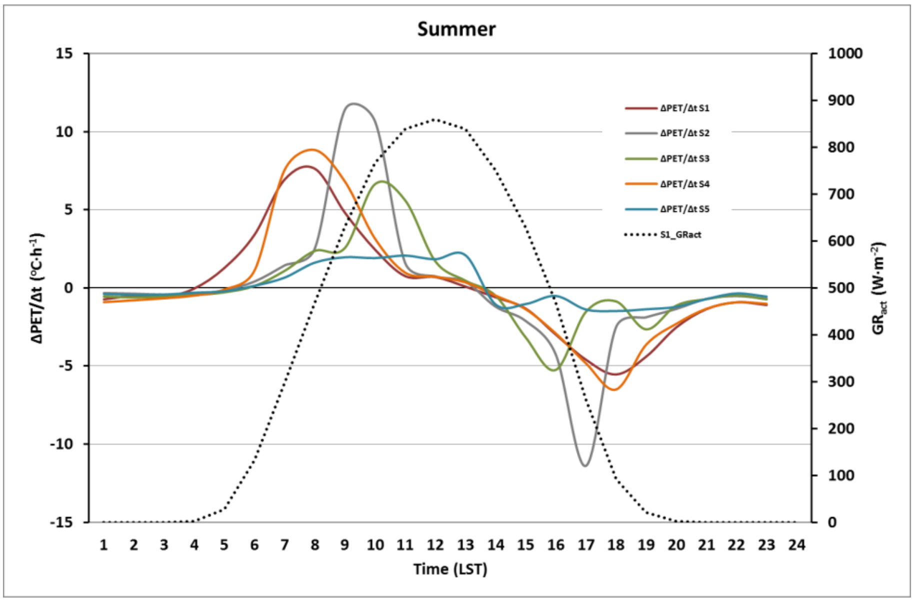


*Figure 3. The course of mean radiant temperature rate (ΔPET/Δt) of the selected sites and the course of global radiation ($GR_{act}$) during summer period.*

### 3.2 Winter period

The violin plots, shown in Figures 4 and 5, illustrate the distribution of $\Delta T_a/\Delta t$, $\Delta T_{mrt}/\Delta t$ and ΔPET/Δt values during winter period. As shown in Figure 4, the minimum rate range recorded at S2 (Building atrium) was 3.8 °C/h whereas the maximum was at S1 (reference site) with a measured value of 7.2 °C/h. The building atrium (as a consequence of the concrete existence) tends to act thermally as a "storage" absorbing the morning heat and releasing slowly the collected heat during the nocturnal cooling process. Due to the aforementioned thermal behavior the air temperature rate range is the lowest during the winter period. Also, as it was anticipated the average rate was close to 0 °C/h and the median is slight negative (from -0.3 to -0.2). The distribution is highly right-skewed (the coefficient is always higher than 1.0) for all sites. The positive skewed distribution indicates that the rate of the heating process could be higher and with higher frequency than the cooling rate. As figure 4 illustrates, the positive tail of the distribution is fading out gradually when the negative tail is steeper. In addition, the distribution of $\Delta T_a/\Delta t$ at S2 is slightly bimodal (the second mode is close to 2.3 °C/h).

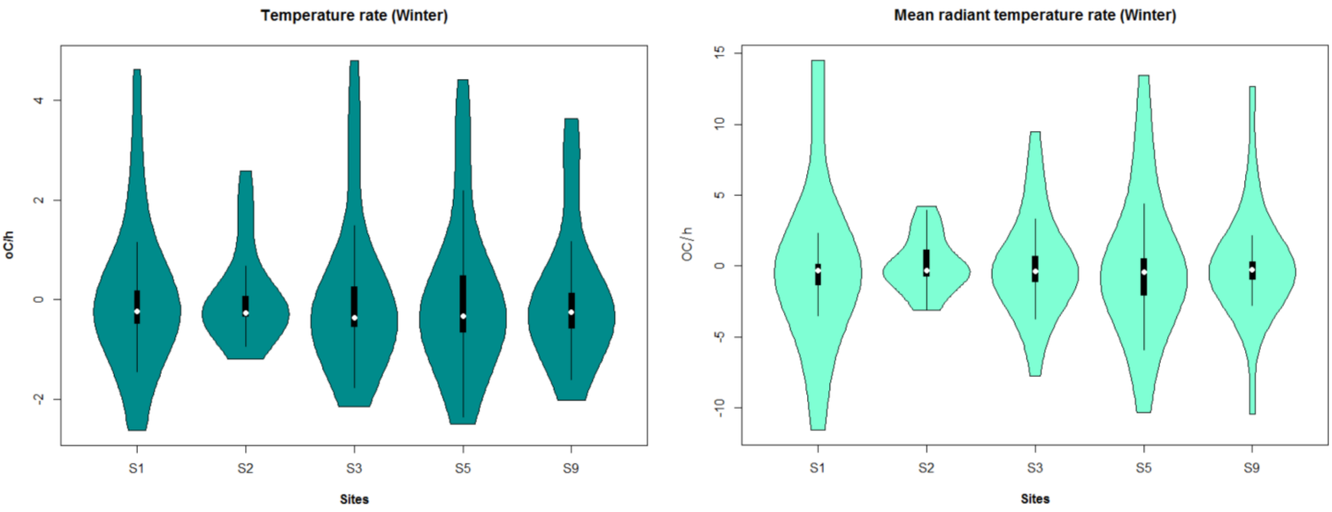


*Figure 4. Violin plots of ΔTa/Δt (left) and of ΔTmrt/Δt for the selected site during winter period.*

During the same time period the lowest rate range of $\Delta T_{mrt}/\Delta t$ was 7.3 °C/h (Site S2, building atrium) whereas the highest was at S1 site (reference site) with a value of 26.0 °C/h (Fig 4). According to the skewness coefficient, the distributions at S1, S3, S4, S5 are moderate-skewed (between 1.0 and 0.5). At site S2, however, the distribution is approximately symmetric having a value lower than 0.5 (Bulmer 1979). All distributions indicate a positive skewness with long tails. The $\Delta T_{mrt}/\Delta t$ is bimodal with the second mode close to 3 °C/h.

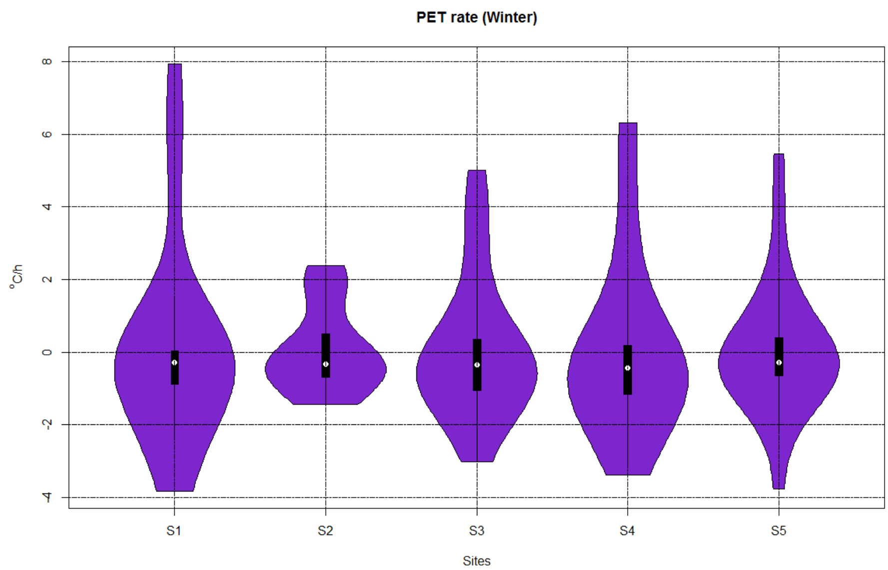


*Figure 5. Violin plots of ΔPET/Δt for the selected site during winter period.*

The violin plots of ΔPET/Δt (Fig. 5) indicate similar patterns to the $\Delta T_{mrt}/\Delta t$. There is a strong relationship between $T_{mrt}$ and PET (Krüger et al. 2013; VDI 1998). The distribution of the rate is positively skewed at all sites. The skewness coefficient is higher than 1.0 for the distributions for the sites S1, S3, S4 and S5. The only site that develops a moderate-skewed distribution is the building atrium (S2) having the shortest tail due to the long daily shaded period. This site presented the lower ΔPET/Δt rate (3.8 °C/h) whereas S1 the highest one (11.7 °C/h). The S2 distribution is bimodal having the second mode close to 2.0 °C/h. All violin plot diagrams present the distributions to have a long and gradual positive tail along with a steep and negative tail. This indicates a limited cooling ability of the sites compared to the ability for heating (increasing $T_a$, $T_{mrt}$ and PET).

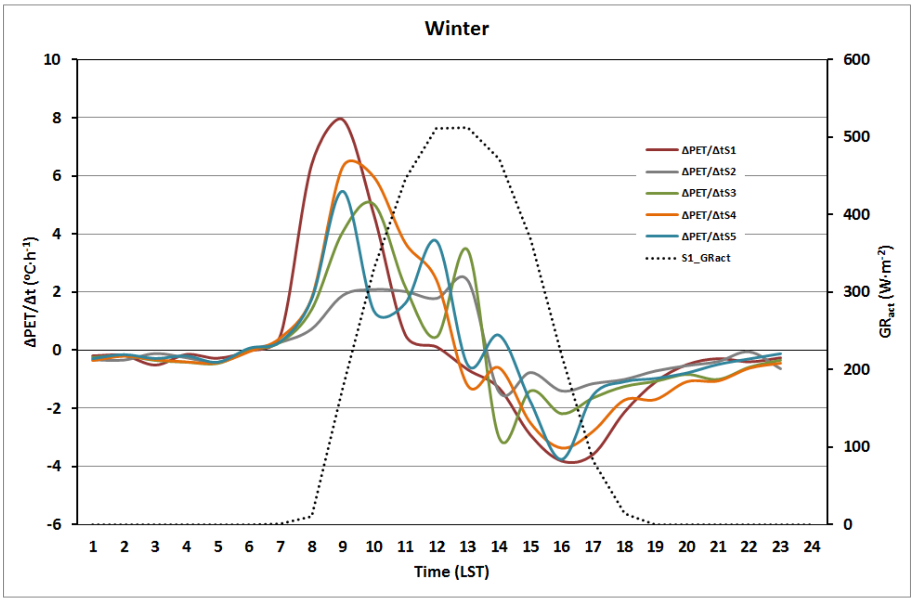


*Figure 6. The course of mean radiant temperature rate (ΔPET/Δt) of the selected sites and the course of global radiation ($GR_{act}$) during winter period.*

Figure 6 illustrates the ΔPET/Δt daily course. As it was anticipated, ΔPET/Δt develops a similar pattern to the $\Delta T_{mrt}/\Delta t$. The abundant vegetation in sites S3 and S5 acts as a buffer zone reducing the rate of PET rise/decline. Thus, during morning hours (08:00-10:00 LST) the values of the rate are reaching 5 °C/h and during early afternoon hours it is less than -4 °C/h. On the contrary, the inadequate or the total lack of vegetation in sites S4 and S1, leads to high ΔPET/Δt rates during morning hours (07:00-10:00 LST) and also during afternoon hours (15:00-18:00 LST). This implies the inability of S1 and S4 sites to moderate thermal conditions.

## 4. Conclusion

The present study reveals the bioclimatic impact of the vegetation and the geometric characteristics as they are quantified via the SVF factor. But, the focal point of this publication is the implementation of first derivatives and the violinplots for the evaluation of thermal behavior of small urban sites. Some conclusions about the thermal behavior of the sites and the capability of the first derivatives are the following:

1. The potential of the vegetation to act as a thermal buffer zone is more evident during the summer period and it is higher when vegetation is combined with low SVF values. Also, the vegetation is an effective medium in terms of reduction the heating rate during daytime in the summer and in the winter period.
2. In the case of sites having similar geometric configurations as the building and the green atrium (S2 and S3 respectively) the daily courses and the violin plots indicate similar qualitative but quite different quantitative characteristics. Building and green atrium sites form similar frequency distributions of $\Delta T_{mrt}/\Delta t$ and ΔPET/Δt rates (violin plots). The rate range for the S2 site is higher during the summer period (for both rate parameters) whereas at the S3 site the range rate is higher during winter period.
3. The existence of dense vegetation forms low SVF values, leading the sites to delay both the heating (low heating rates) and the night cooling process. So, when the SVF values are low (due to the existence of trees) the reduction of heating rate is linked with a reduction of night cooling
4. In the building atrium (S2) the maximum ΔPET/Δt during summer is almost 6 times higher than during the winter period. Also, during the summer period for the building atrium (S2) the $\Delta T_{mrt}/\Delta t$ and the ΔPET/Δt range was 7 times higher than in the small park (S5).
5. The range of parameters as $\Delta T_{mrt}/\Delta t$ and ΔPET/Δt is a sufficient indicator of the biometeorological behavior of an environmental configuration, especially when the focus is the buffer potential of the site. Additionally and in daily perspective for a specific environmental configuration would be a measurement of the potential human thermal stress.
6. In general, changes in parameters such $\Delta T_a/\Delta t$, $\Delta T_{mrt}/\Delta t$ and ΔPET/Δt provide important information for the comprehensive evaluation of the thermal behavior of materials (vegetation, concrete etc.), and their geometric configuration. Also the aforementioned parameters may be a proper basis to investigate the reaction of human body under changing atmospheric thermal conditions.
7. The violin plot is a reliable tool to visualize related information to the bioclimatic behavior of outdoor spaces and, in general, various environmental configurations. The combination of the density trace along with the range,

the median and other descriptive statistics measures of bioclimatic parameters may lead to useful information.

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