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Features of a pedestrian thermal environment at a University Campus

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1. Introduction

Due to the many ways of urban occupation and to urban composition, pedestrians are subject to many different microclimates during a walk, and are often exposed to conditions of thermal stress (COHEN, POTCHTER and MATZARAKIS, 2013).

Features of occupation and urban geometry are factors influencing the urban climate. The variety of occupation and complexity of interactions among urban landscapes result in the development of microclimates in cities. The importance of these elements for sustainable development and achieving energy efficiency in cities has motivated researchers to study urban climates (SHASHUA-BAR et al., 2012; WANG e AKBARI, 2014).

The air temperature suffers direct influence from ground surfaces. While the built environment tends to store heat, the natural and vegetated surfaces have a lower potential of heat storage. These surfaces are usually colder than the impervious and artificial surfaces (YAN et al., 2014).

In addition, canyon geometry is one of the most important causes of microclimate changes. Urban canyon geometry may be expressed by the ratio between the height of the buildings and the width of the street canyon (H/W) or by the sky view factor (SVF). This latter is the portion of the sky viewed from an observer point on Earth and available for the heat exchange between surfaces and the atmosphere (BOURBIA AND BOUCHERIBA, 2010).

Thus, urban thermal comfort is the result of ground occupation and the obstructed sky caused by the proportions generated by H/W ratio. The sky is an important element for the thermal equilibrium of open urban spaces. It is essential for heat exchanges and for dispersing long waves emitted by surfaces and façades during the night. (OKE, 1973, SOUZA ET. AL. 2011).

During the day, sites with low SVF can lead to low temperatures of surfaces and, consequently, of the air, because of their obstruction to direct solar radiation. Nevertheless, during the night, places with low SVF may experience difficulties in the dispersion of long waves during heat exchange to the sky. Therefore, this process affects the thermal equilibrium and is favorable to the development of urban heat islands (YAN ET. AL., 2014).

Furthermore in this context, urban vegetation has a potential for regulating the air temperature of the urban environment. Green areas provide shade avoiding the heat gain of surfaces, and cooling the air, by evapotranspiration. Evapotranspiration occurswhen sensible heat is transformed into latent heat by the transpiration of the leaves. Nonetheless, depending on the season and weather conditions, this cooling effect of evapotranspiration that occurs during the day may contribute to high temperatures maintained during the night (ZHANG ET. AL., 2014).

This paper proposes a study of the pedestrian thermal environment, considering the influence of urban features on the air temperature at a University Campus.

2. Objective

The aim of the paper is to verify the thermal behavior of a University Campus, considering some indexes related to the built-up environment and consequently linked to pedestrian thermal comfort.

3. Methodology

Two data collection campaigns were carried out so that micrometeorological data of the air temperature and relative humidity could be registered. These microclimatic data were then analyzed in relation to four indexes of the built-up environment – the sky view factor (SVF), the occupation coefficient (O.C.), the urban vegetation coefficient (U.V.C.) and the Height/Width ratio (H/W). While the sky view factor represents the area of the sky available for heat exchange from an observation point, the occupation index is the percentage of an area occupied by buildings, the urban vegetation index is the percentage of an urban area occupied by vegetation, and the H/W ratio is the relationship between the height of an urban canyon and its width.

After statistical treatment, the data were incorporated into the software Quantum GIS (version 2.6), which is a free GIS platform. This environment was able to develop thematic maps, by applying an interpolation method to create a continuous surface of air temperature and relative humidity data.

3.1 Study area

The Campus at the Federal University of São Carlos (UFSCar) is situated on the outskirts of the city of São Carlos, Brazil. The city of São Carlos is an urban area located in the central region of São Paulo State, at an average altitude of 856 meters above sea level, and corresponding to the coordinates of 22º 01" South and 47° 54" West. According to Koeppen's classification, the area is under conditions of a tropical altitude climate, with rainy summers and dry winters. The map in Figure 1 shows the location of the UFSCar campus and the data collection points.

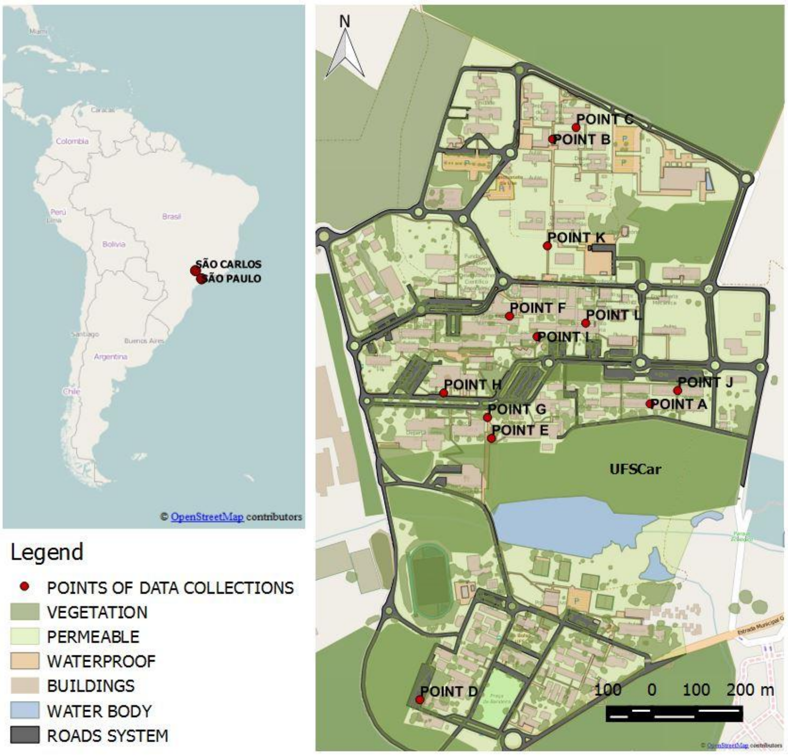


Fig 1: Location of the Federal University of São Carlos

3.2 Thermal data collection

To measure the air temperature and relative humidity, twelve data-loggers were placed at several points of the campus facilities. The selected sites were chosen for their conditions of urban occupation and built-up environment, so that samples of different pedestrian exposures could be registered.

The applied data-loggers for these campaigns were the HOBO Pro V2 U23-001 digital sensors, with an operation range from - 40º to 70º C, a precision index of 0.2^{o} C above 0^{o} C to 50º C, a resolution of 0.02 ºC to 25 ºC and a response time of 40 minutes under air movement of 1 m/s. The data-loggers were placed on light poles at a height of 2.5 meters, properly protected with direct solar radiation shields and an extra cover of reflexive foil to avoid the heat gains from light sources.

The data collection was carried out in September, 2014 and January, 2015. Satellite images could observe the atmospheric mass in this area and then only data corresponding to days with clear skies and calm winds were selected for analysis. This operation resulted in samples corresponding to the days of the 19th, 22nd and 23rd of October. Furthermore, the data was statistically treated in a digital spreadsheet so as to find the average, the maximum and the minimum values of a period of 12 hours of the day (from 7 a.m. to 6 p.m.) and 12 hours of the night (from 7 p.m. to 6 a.m.).

Simultaneously, we registered the data made available by the meteorological station of the National Institute of Meteorology (INMET), which are the data of the air temperature, relative humidity and air velocity and direction. This station is located in an open-sky site, with no obstruction to its surroundings.

In addition, the Lakes WRPLOT software was applied to make a compass rose with the speed and direction of the dominant winds during the study periods.

3.3 Urban Index Estimation

The SVF values were estimated using images taken from a digital camera equipped with a fish eye lens, which were also referenced in relation to the true north. These images were then processed in black and white and submitted to the computational program RAYMAN 1.2 (MATZARAKIS, 2010) to find the SVF values.

In order to quantify the other urban indexes of the built-up environment (which were the occupation coefficient (O.C.), the urban vegetation coefficient (U.V.C.) and the H/W ratio) - satellite images were incorporated into the Quantum GIS software, which served as the basis for redrawing the area in a vector file. In a radius of 50 meters from each collection point, the urban indexes were computed. The results of the urban indexes corresponding to each collection point can be observed in Table 1.

Tab. 1: Characterization of the urban design

	SFV	OC	UVC	H/W		SFV	OC	UVC	H/W
POINT A	0.32	0.41	0.25	1.0	POINT G	0.53	0.17	0.36	0.10
POINT B	0.58	0.38	0.00	0.47	POINT H	0.53	0.29	0.15	0.23
POINT C	0.47	0.44	0.01	0.36	POINT I	0.32	0.70	0.21	1.33
POINT D	0.18	0.18	0.64	0.18	POINT J	0.28	0.41	0.09	1.0
POINT E	0.22	0.19	0.53	0.10	POINT K	0.81	0.14	0.00	0.00
POINT F	0.65	0.47	0.08	0.50	POINT L	0.62	0.45	0.15	0.50

3.4 Development of thermal maps and analysis of the built-up environment relationships

Data of the air temperature and relative humidity were applied to develop the thermal maps, which were created using the interpolation method of inverse distance weighting. These maps were then combined with satellite images, resulting in thematic maps that evaluated and identified microclimatic zones within the university campus.

In addition, the thermal tendencies observed on the map were numerically considered by analysing the correlation index generated among the air temperatures and urban SVF indexes , C.O, U.V.C. and H/W. This analysis showed the interaction between the thermal environment and the microclimatic factors that contribute to determining the thermal comfort of the pedestrians.

4. Results

The maps of air temperature and relative humidity are presented in Tables 2 and 3. The sequential observation of the thematic maps shows a central area of the campus, where the occupation coefficient is the highest and the one-pavement typology of buildings is predominant. This was the area for which the highest air temperatures were registered during the day. However, this behavior was not the same during the night.

For the outer sites of the campus, the lowest temperatures registered could be associated to the fact of being in close proximity to a dense green area and a lake. These are sites presenting scattered built-up occupation, with building façades oriented to the North or South direction, which therefore, usually leads to favorable wind circulation and reduces the temperatures during the day.

Table 2: Thematic maps of air temperature

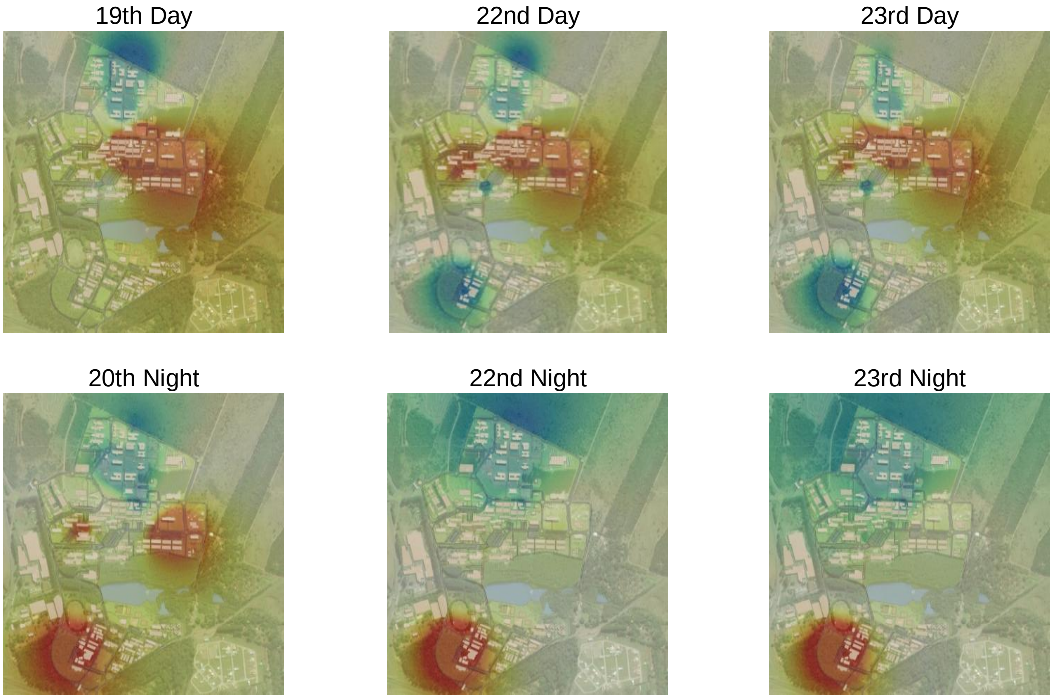
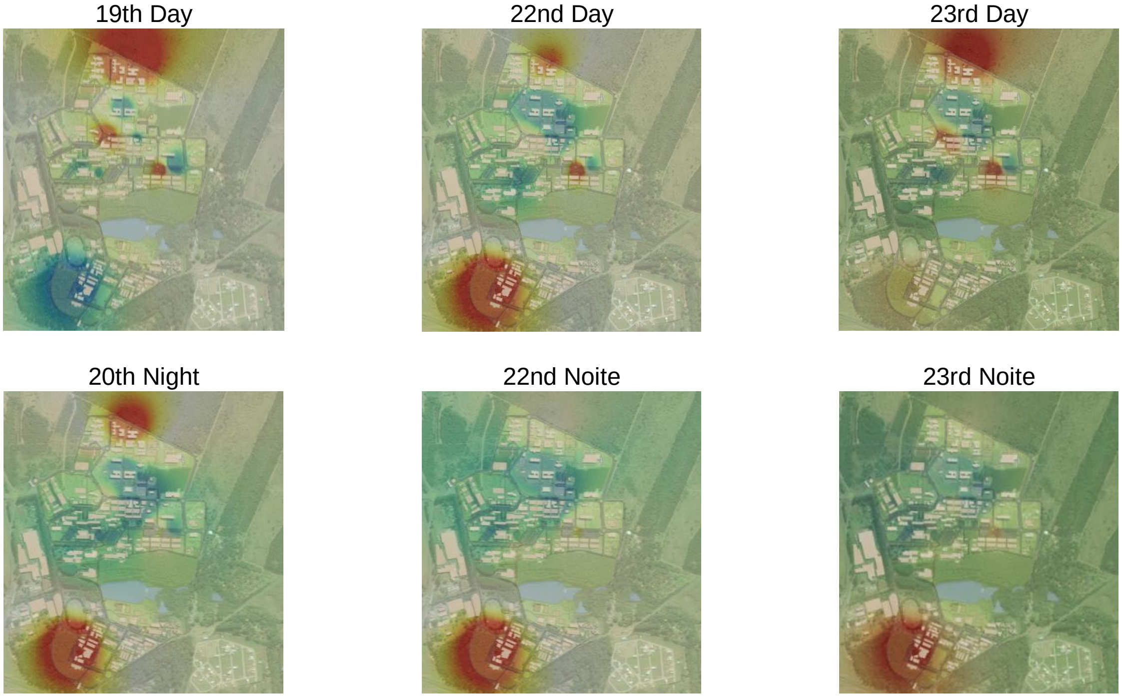


Table 3: Thematic maps of relative humidity



The compass rose in Figure 2 shows that the wind speed registered in the analysis period reached the range from 3.6 to 5.7 meters per second, predominantly coming from a Southeast direction.

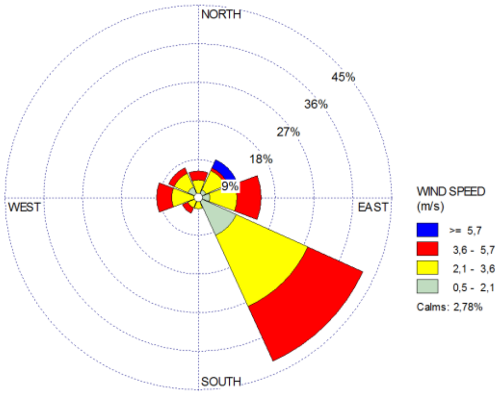


Fig. 2: Compass rose for the measurement period

4.2 Analyzing the thematic maps

During both day and night periods of analysis, the lowest average air temperatures were registered at Point K. This point is situated in an open site, far from the buildings and without any adult vegetation or high trees. The lowest H/W ratio (0.0) presented by this observation point and the lowest occupation coefficient (0.14) results in a configuration also favorable to wind circulation and reduction of temperatures.

During the day, the highest average air temperatures were registered at Point I, which is the one with the highest occupation coefficient (0.70) and the largest H/W ratio (1.33). During the night, the highest temperatures correspond to Point D. The lowest SVF value (0.18) at this point hampers the dispersion of long waves and the vegetation (U.V.C 0.64) increases the air humidity. Both are elements that act together resulting in stable patterns of temperatures at this point, where the temperatures reach higher levels than the other measurement points.

When comparing the average temperatures registered at UFSCar Campus with those registered at a point with total openness to the sky and situated on the outskirts of the urban area, the highest nocturnal temperature corresponded to Point D.

4.3 Analyzing tendencies

Complementing the analysis of thematic maps, the data of air temperatures cross-examined with four urban indexes: sky view factor, urban vegetation coefficient, occupation coefficient and H/W ratio. The results point out a significant relationship among them.

The correlation coefficient (R) generated by the relationship between the air temperature and SVF confirms that there is a tendency of thermal accumulation in areas with low access to the sky. During the night, the SVF presented a negative relationship with the air temperature at all the data collection points. The larger the area of sky available for thermal exchanges between the point and the sky, the lower the nocturnal temperature registered (Figure 3).

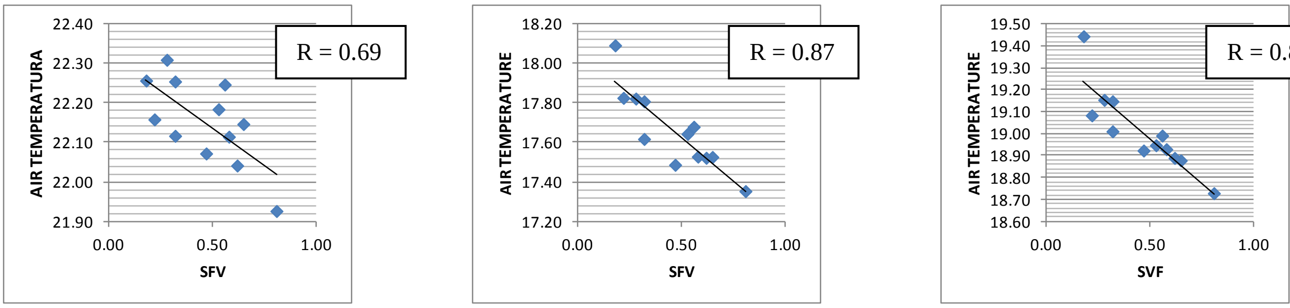


Fig.3: Air temperature and SVF

According to Figure 4, the urban vegetation coefficient has presented a positive relationship with the nocturnal air temperatures. During the night, the vegetated areas are associated to a thermal accumulation. The high humidity generated by evapotranspiration of the vegetation allows the formation of thermal spots, in such a way that during the night the points under the trees tend to keep stable temperatures.

Associated to this effect, the U.V.C and the SVF are also correlated. Large vegetated areas, with adult trees, dense canopy and large size tend to restrict the visibility of the sky and thus, minimize the heat exchange of surfaces and façades with the sky. Therefore, points with low SVF values with high U.V.C. are warmer and more stable than the others.

During the day, the SVF and the U.C.V. had no direct relationship with the air temperatures. In this period, the cooler effect of the evapotranspiration was not enough to be registered by the air temperature patterns of the studied points.

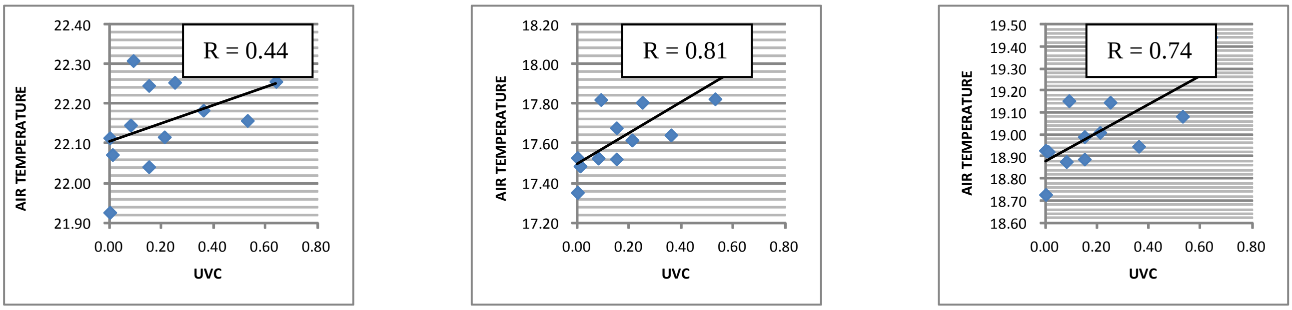


Fig.4: Air temperature and U.V.C.

On the other hand, the occupation coefficient and the H/W ratio are related to the air temperature registered during the day. These indexes, however, are not related to the nocturnal temperatures registered at the Campus. We believe that this fact is associated to the orientation of the buildings, which is favorable to the natural ventilation and dispersion of the long waves produced by buildings and surfaces. The correlation found among the C.O., the H/W and the air temperature can be observed in Figures 5 and 6.

As the campus is primary constituted by buildings of medium height, during the day, when the short waves are the dominant radiation flux, the low values of C.O. and the H/W ratios allow significant access of direct solar radiation, contributing to the heating of these areas.

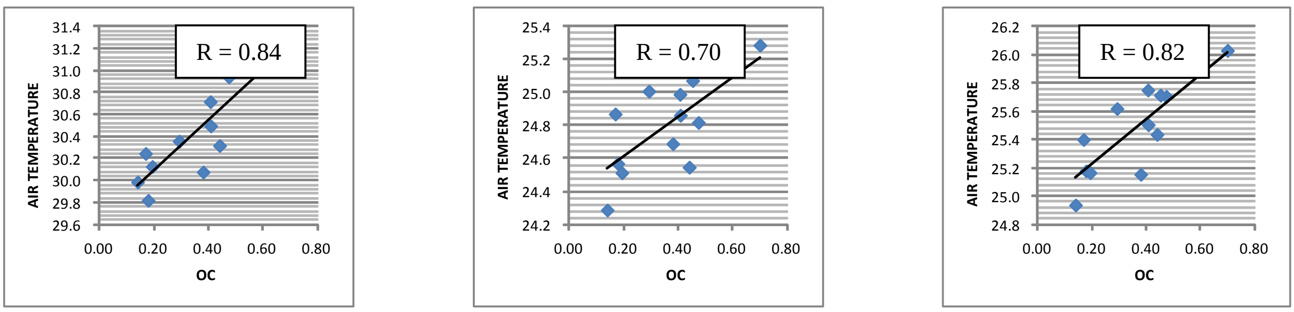


Fig.5: Air temperature and C.O.

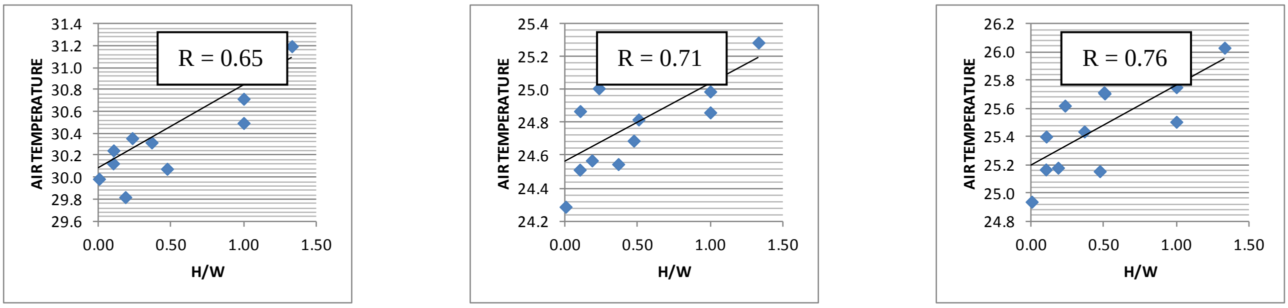


Fig.6: Air temperature and H/W ratio

5 Conclusions

This paper verified the thermal environment of the campus at the Federal University of São Carlos, by applying thematic maps, which were developed in a Geographical Information System (GIS). Four urban indexes were compared to the air temperature in order to evaluate the interaction between the constructed environment and the microclimate of the campus.

The aforementioned thematic maps could help to manage the area, guiding action plans to mitigate the heat island phenomena. This could be a step to achieve sustainable development by considering the thermal efficiency of the urban occupation.

The results suggest that there might be an ideal range of SVF to promote users' thermal comfort. For the configuration presented by this university campus, the development of nocturnal heat island is mostly associated to the presence of dense trees in the urban canyons rather than to the urban indexes. Due to the density of the campus trees, there is a tendency of heat accumulation under their canopy, generating obstacles to the sky and blocking the dispersion of long waves during the nocturnal period.

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