Microclimatic units in the UFMG ecological station in Belo Horizonte, Brazil: methodological aspects and the role of vegetation in thermal impacts

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Resumo

Este artigo analisa a influência da vegetação nas variações de temperatura e umidade relativa do ar em área urbana. Os dados foram produzidos em diferentes episódios entre os anos de 2010 e 2013 no interior e proximidades à Estação Ecológica da UFMG em Belo Horizonte-MG. A análise considerou a relação dos dados mensurados com as características físicas do ambiente (relevo e uso da terra) sob condições atmosféricas diferenciadas. As unidades microclimáticas delimitadas no espaço da Estação Ecológica mostraram grau diferenciado de comprometimento com fatores naturais e da área urbana limítrofe.

Palavras-chave: vegetação, áreas urbanas, unidades climáticas.

Abstract:

This article analyzes the influence of vegetation on variations in temperature and relative humidity in an urban area. The data were produced in different episodes between 2010 and 2013 in and near the UFMG Ecological Station in Belo Horizonte, Brazil. The analysis compared the relationship of measured data with the physical characteristics of the environment (topography and land use) under different atmospheric conditions. The micro-units defined in the Ecological Station showed a differential degree of commitment to natural factors and the surrounding urban area.

Key-Words: : *vegetation, urban areas, climate units.*

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Introduction

the association between “climate” and “atmosphere” is quite common, normally referring to the latter as the gaseous layer that surrounds the planet Earth. However, there are two common misunderstandings: (1) it is clear that there is a direct relation between climate and atmosphere, although climatology’s main object of study is not exactly the atmosphere itself, but rather the relationship between the atmosphere and the Earth’s surface (continents, oceans, vegetation, etc.); (2) it is not about the gaseous layer that “surrounds” the planet, but rather the gaseous layer that is “an integral part” of the planet, resulting from the joint and reciprocal action of the geological, biological, and even human processes, though, in this case, restricted to highly limited spaces (as occurs in cities).

Submitted to the influence of climatic factors that organize themselves in macro and mesoscales, what appears is a “layer of air near the soil” (microclimate), which participates constantly and actively in the biological life of Earth. Within this, in the majority of cases, a wide range of essential conditions can be found. The wind, for example, is strongly influenced by the effect of friction and reduces in speed when measured near the surface. The soil itself, when it receives radiation, transforms into a (passive) source of radiation. In other situations, it drains the heat from the air, working like a heat drainer, a situation that can lead to thermal inversions on the soil surface. Vegetation can be found under diverse weather conditions and in interaction with the atmosphere, which is considered by numerous authors as the synthesis of environmental conditions. Köppen used the distribution of this component as one of the criteria used in the classification of Earth’s climates. According to Geiger (1961), the behavior of climatic elements is peculiar when near the soil. These differences arise even in small areas, caused by soil characteristics and land use, by the slope and topography of the terrain, as well as by biotic relationships. The specificities of the Earth’s surface (form, function, material, processes, etc.) play a key role in its interaction with solar radiation.

There are numerous situations in which vegetation contributes to diminish thermal impacts. In the tropics, for example, where there is a thermal surplus practically year round, the presence of vegetation and aquatic surfaces can aid in dissipating the heat, especially in cities where, together with the natural surplus, there is the additional anthropogenic origin. Magalhães and Crispim (2003, p.65), in an article published in the journal “Science Today”, synthesizes the importance of vegetation in urban areas:

> [...] these elements can help to improve the climate, diminish air pollution, save energy, and alleviate the household budget [...] forests can play a significant role in one’s physical and mental health and have a positive influence, for example, on the recovery of post-op patients. [...] Separate or together, they perform functions linked to sensorial and aesthetic satisfaction [...] Some studies have been able to estimate the potential effect of forest coverage on the use of energy for air conditioners in American homes. The presence of three trees reduced annual expenses with cooling systems from 10% to 50% (which represents 200 to 600 KWh or $30 to $110) [...] Both forest ecosystems and isolated trees serve as refuge and food for other levels of the ecological network, ensuring the permanence of a larger number of organisms.

The partitioning of space has the aim of the diagnosing and ordering of the environment in question in an attempt to conserve it (sustainable use of natural resources). In a prior study, Jardim et al. (2011) considered the importance of knowledge regarding the dynamics of the environment and the climate as a natural resource capable of retroacting upon the space which has produced it (through feedback mechanisms), both stimulating its development and complexity (dissipation of pollutants, thermal comfort, use of rainwater, natural ventilation, etc.) and drawing it nearer to situations of natural disasters (critical situations of atmospheric pollution, temperature extremes, floods, etc.). Moreover, the problems associated with the physical-environmental scenario in the city of Belo Horizonte reveal the inappropriate use of the city's natural resources (including the climate), which served as the underlying inspiration for this work.

The studied area is located in the urban space of Belo Horizonte (south-central portion of the state of Minas Gerais) on the campus of the Federal University of Minas Gerais (UFMG), at The UFMG Ecological Station, limited, approximately, to the coordinates of 19°52'31"S and 43°58'23"W. This area is located within the university campus and covers an area of 114 ha, with altitudes ranging from 815 to 870 m. According to Neves (2002), the vegetation includes semideciduous forests and savanna. The topography includes the presence of flat-topped to arched hills and polyconvex slopes with varied inclines sculpted upon migmatitic gneiss metamorphic rocks belonging to the Belo Horizonte Complex. From the climatic point of view, one of the main characteristics of climate is the existence of a dry season in the winter. The genesis of the rainfall, concentrated in the three months of summer (December, January, and February), depend on the interactions among the tropical, equatorial, and extratropical systems. The total annual rainfall in Belo Horizonte, under normal climatic conditions (1961-1990), is an average of 1491.3 mm, concentrated in the three months of summer, with an average annual temperature of 21.8°C.

AIMS

The present article seeks to understand the influence of vegetation on climate variables (temperature and relative humidity) and its role in diminishing thermal and hygrometric impacts of the air on urban areas through measurements taken inside the station and in the surrounding areas of the UFMG Ecological Station.

Parallel to this, beginning with the subsidies generated and considering the interaction with topography components, land use, and atmospheric conditions (succession of weather types), this work also seeks to identify and map out the microclimatic units found within the UFMG Ecological Station.

METHODOLOGY

The data used in the analysis (air and surface temperatures – exposed soil, plant litter, grass, pavement, etc. – relative humidity, winds, and cloudiness) were obtained in successive field works between 2010 and 2013. A portion of the data comes from hourly measurements taken only in the morning and afternoon, normally between 9:00 am and 4:00 pm, inside and in the surrounding areas of the UFMG Ecological Station. The main sequence of data involved a continuous hourly follow-up, with the use of data loggers, at 60-minute intervals between measurements over a 24-day period (between April 21 and May 14, 2013).

Digital thermo-hygrometers installed inside of weather shelters, sling psychrometers, digital thermometers for surface readings, and data loggers were used in this study (Fig. 01). The calibration of the equipment using the INMET-Pampulha automatic weather station made it possible to compare the data. This same station was used as a local control of climatic conditions.

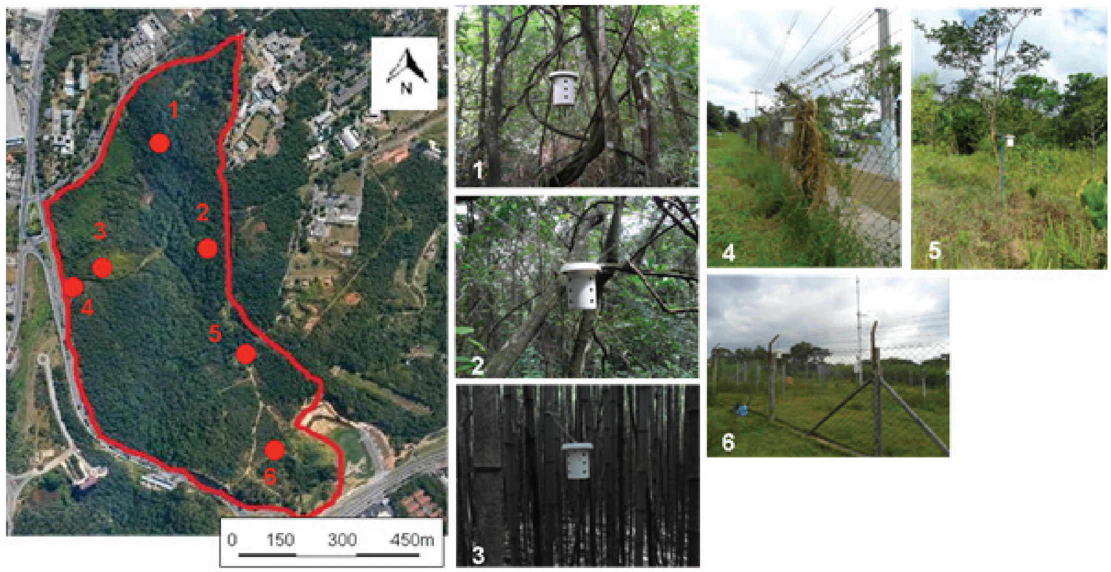
Fig. 01 **Instruments used to measure climatic variables: 1. Weather shelter of passive wind (general and base view); 2. Data loggers, model HT-440, from Icel Manaus; 3. Sling psychometer; 4. Digital thermometer for surface readings; 5. Digital thermo-hygrometer for fixed readings; 6. Anemometer; 7. Two-channel digital thermometer; 8. Digital thermo- hygrometer for mobile readings. Photos: Carlos Henrique Jardim.**

The synoptic situation, regarding the action of atmospheric systems during the measurement period, was verified by analyzing weather satellite images (www.cptec.inpe.br) and synoptic cards (www.mar.mil.br), beginning with the identification of the main centers of high and low pressure, as well as through peculiarities regarding the characteristics of the cloud cover (response spectrum, texture, luster, form, etc.).

The criteria that guide the installation of the Ecological Station posts included aspects concerning topographical characteristics (altitude and topography) and land use (vegetation – density, size – and proximity to urban areas), as well as the availability of staff and instruments to take the measurements.

The general characteristics of the posts included those that represent dense forest formations and/or with a predominance of tree layers (Fig. 01, photos 01, 02, and 03) and those that represent open areas, with a sparse presence of vegetation and urban components (Fig. 01, photos 04, 05, and 06).

Fig. 02. Location of the weather shelter in the UFMG Ecological Station: 1. Atlantic Rainforest; 2. Cerrado (savanna) 3. Bambuzal (bamboo Forest); 4. Border of the Ecological station at Carlos Luz Avenue; 5. Deforested savanna; 6. Top of the hill station at INMET. Photos: Carlos Henrique Jardim and Heli Cássio Monteiro.



The Atlantic Rainforest or Semidiciduous Seasonal Forest post (43°52'31,1"S; 43°58'20,5"W; alt. 851m), one of the phytophysiognomies of the Atlantic Rainforest, adapted to the rainy seasons that last no less than five months a year, are characterized by dense, secondary forest formations, with a shrub and tree layer, and soil covered in tree litter. What can be found are the presence of epiphytes, lianas, and tree elements that are larger than 10-15 m in height (or taller in preserved formations).

The post installed in the “Cerrado” or Savanna (19°52'41,4"S; 43°58'16,1"W; alt. 858 m;) is characterized by typical vegetation species of this domain, with a predominance of tree elements (it is possible to walk fairly easily through the vegetation, which is different from the post described above), thin trunks, and smaller in size than those of the Atlantic Rainforest post.

In the area called “Bambuzal” or Bamboo Forest (19°52'43,1"S; 43°58'26,5"W; alt. 836 m), the vegetation layer was homogeneous with a variable height of 03 to 07 m (or more), with a highly shady environment, in addition to the presence of a thin layer of dry leaves covering the soil.

The posts that represented open areas with a sparse vegetation layer (predominance of herbaceous strata) included the posts of the deforested areas within the savanna (19°52'53,6"S; 43°58'10,8"W; alt. 863 m), the INMET weather post (19°53'2,40"S; 43°58'9,60"W; alt. 869 m), and the post at the border of the Ecological Station with Carlos Luz Avenue (19°52'47"S; 43°58'31,4"W; alt. 830 m). This latter location includes urban components (proximity in relation to the pavement of the avenue and constant passage of cars, buses, and trucks).

The results were obtained bearing in mind the relationship between the measured climatic elements and the physical characteristics of the environment in which the samples were collected and the type of weather on the day, beginning with simultaneous and continuous hourly/daily comparisons of the data collected in the different posts, using quantitative indicators of the variation in temperature and relative humidity (absolute, average, and hourly/daily amplitude values) as references.

The methodology employed in this study is based on that reported by Monteiro (1971; 1975; 2003) as regards the "Rhythmic Analysis", through the continuous and concomitant representation of the climatic elements measured on the surface and their respective relation to the local/regional context, as well as the " Urban Climate System", using a model describing the conveyance of energy within the system (identification of energy input, distribution of energy by components of the system, types of impact, and the mitigation of the process).

In an attempt to formulate the second part of this study's aims, regarding the definition of climatic units, what was taken into consideration was the low density of the posts and, therefore, its insufficiency to cover the entire space of the Ecological Station. In this sense, it was considered that the temperature and relative humidity data were representative of spaces whose environmental characteristics were similar. In each of the units, particular features were traced that were capable of characterizing the microclimate of a given space, the product of the interaction of the surface controls (topography and land use) with the evaluated climatic elements (air temperature and relative humidity) under the influence of specific synoptic conditions. A similar criteria was reported by Monteiro (1990) and adopted by Tarifa (2002) for the mapping of the climatic units in the Maciço da Juréia region on the southern coast of the state of São Paulo, performed by Tarifa and Armani (2001a; 2001b) in the definition of the natural and urban climatic units of the city of São Paulo and by Jardim (2007) in the hydrographic region of the Aricanduva River.

Brief theoretical review

The concept of "system" applied to the comprehension of natural and anthropic systems (ecosystems and geosystems) in studies on "landscape", is able, according to Christofoletti (1999), to identify the energy "input" of the "geosystems" within a given climate. It should be emphasized, however, that the influence of the climate is not present only in this final phase, but rather, according to Monteiro (1975; 2003), participates in the entire process, from the energy input, passing through the interactions among the components of the system, to the final product, perceived as an environmental impact, and its forms of mitigation.

These relations, according to Bertrand (1972), establish themselves in a hierarchy, that is, from the reduced spaces to the level of the forest biotypes, to the spaces of biome dimensions (zonal spaces). This passage from one scale to another is accompanied by qualitative and quantitative changes, that is, in addition to the dimension of the object, the factors responsible for the organization of the event/phenomenon and the methodological approach itself are modified to comprehend the problem.

Upon modifying the diverse entrance and exit components of solar and thermal radiation, the Earth's surface (comprised of different landscape units) transfers a part of its characteristics to the volume of overlying air, which can be translated, according to Monteiro (1971), by the "rhythm" of the variations of the climatic elements. The variations of these elements integrated to the diversity of the spaces on Earth assume their own characteristics at different moments, which runs in line with the succession of the types of weather. The interrelation and chain of these climatic elements reveal the genesis and the specificities that assume the values of the climatic attributes over a given period of time and space, hence the unique character conferred upon the local climate by Sorre (1934).

Specifically regarding the relation between climate and vegetation, an infinity of work has yet to be produced. Among the foreign authors who have been fairly widely studied by Brazilian researchers, the works of Geiger (1961) stand out, especially concerning the variety of experiments carried out in diversified situations as regards the landscape (topography and land use, mainly). The work of Olgyay (1998) is equally important in the realm of architecture and treats the relationship between buildings and elements of nature.

As regards Brazilian researchers, this issue is frequently dealt with in theses and dissertations that treat urban climatology, bioclimatology and climate, and architecture. In this context, some key works stand out. Tavares (1997) compared two different locations within the city of Sorocaba, one in the urban area and another in the rural area (the latter located 20 km from the urban area on the Ipanema Farm). Through a seasonal series of 3 ½ years, Tavares claims, on various occasions, that the temperature of the air on the farm is higher than that measured in the urban area, especially in the afternoon. This fact was attributed by the author to the local dynamics of air circulation.

Tarifa (2002), through surveys conducted in the natural areas of the coastal uplands of Juréia-Itatins (Southern coast of the state of São Paulo), identified the connection between different rhythms in the variation in air temperature and the distribution of rainfall, that is, the relation with mesoscale factors (linked to atmospheric circulation) and microscale (topography and vegetation). The imposition of mesoscale systems (action of frontal systems, for example) neutralizes the organization of climatic systems in microscales. Minimal variations in soil temperatures (1.0°C to 2.0°C) and in the content of air vapor (evaporation of 1.2 mm in five days) inside the tall grass of the alluvial plane confirm the strong microclimatic control exerted by the vegetation and support from ocean moisture through air currents.

Gouvêa (2002), using the example of Brasilia and data concerning temperature and relative humidity, points out the inefficiency of wide open grassy spaces in relation to the thermal impact, mainly during the dry season, and suggests that the type of vegetation that would be appropriate for cities set up in inland areas of the tropical climate must include native species of small and mid-sized leaves and evergreens.

Mascaró and Mascaró (2005) reported on various aspects regarding the function of vegetation in urban areas, such as its placement on sidewalks for the passage of pedestrians, the reduction of noise, shading provided by building façades, etc.

Armani (2004) took measurements in a forested hydrographic basin in the center of the city of Cunha (SP) from the Serra do Mar State Park. In addition to the role of the topography in the definition of topoclimates, associated with differential heating of the parts, the author also points out the role of vegetation in climate control. He shows that the cleared areas located in the middle of the forest would be subject to extreme values, even if considering their proximity with rivers and forests, in turn reaching negative differences of 45% in relative humidity and positive differences in more than 7.0°C in the air temperature in relation to the neighboring areas.

Carmo et al. (2010), Jardim (2005; 2010), and Jardim and Monteiro (2013) discussed aspects concerning the interactions between the climatic variables (especially temperature, relative humidity) and other landscape elements, including urban and rural areas, and the UFMG Ecological Station's own space.

Results

The diversity of environments within the UFMG Ecological Station is an important aspect, even though it is located in a relatively restricted space. The joint control exerted by vegetation and topography in a microscale is varied and interferes in terms of the balance of radiation. Nevertheless, these variations must be seen as a complement to the local and regional atmospheric circulation, defining factors of the hourly/daily weather conditions. The Earth's climates, regardless of their scale of organization, are a result of the balance between the entrance and exit of vertical components and horizontal components, referent to the advection of air, modulated by the characteristics of the surface of the land.

In an attempt to clarify some aspects of the nomenclature used in the discussion section, this study turned to findings reported by Vide (1999), and supported in Oke (1978)[1], regarding the terms of radiation balance. According to this author, the radiation balance of short waves includes radiation that is direct and diffuse ($K\downarrow$) and reflected ($K\uparrow$) with its balance expressed by $K^* = K\downarrow - K\uparrow$. The balance of short-wave radiation, generically called "heat", is given by $L^* = L\downarrow - L\uparrow$, in which the first term is radiation or "heat" received by "counter-radiation" and the second is the "heat" emitted in both active and passive forms by objects and surfaces. The "greenhouse effect", produced mainly by the water vapor dispersed within the atmosphere, clearly influences the balance of long-wave radiation.

The balance of all of the radioactive waves (both long and short) is expressed by $\pm Q^* = \pm Q_H \pm Q_E \pm Q_G \pm \Delta Q_S \pm \Delta Q_A \pm \Delta Q_P + Q_M$, where Q^* is the sum of all of the radioactive energy waves. ΔQ_A corresponds to the variation in energy related to the advection of air. The Q_G flow represents the sensitive heat transferred through the surface in depth, which is incorporated into the term ΔQ_S (indicator of the variation of energy stored in the volume). The terms Q_H and Q_E indicate turbulent energy flow between the surface and the adjacent air, respectively, in the form of sensitive and latent heat. The term Q_M represents the metabolic heat with a constantly positive signal, while ΔQ_P represents the energy involved in the metabolic processes of the plants (non-parameterized).

Measurements of temperature and the relative humidity were taken in a wide range of situations, although good weather conditions predominated (anticyclone tropical domain linked to the action of the Subtropical Anticyclone from the South Atlantic), with few clouds or without clouds (or even with rising cloudiness during the day), which provided a high number of hours with sunshine and hot days. These circumstances favored the structuring of microclimatic spaces, which differed from the situations marked by a strong advection of air, cloud cover, and rainfall (cyclonal domain), when there is an imposition of the characteristics of the mesoscale systems, in turn attenuating the difference in temperature and humidity.

On September 18, 2010, the state of Minas Gerais saw weather conditions of relative atmospheric stability associated with the influence of a low pressure center with minimal expressiveness in the region, brought about by the action of the Continental Equatorial Mass and the widening low pressure

[1] OKE, T. R. Boundary Layer Climates. Londres: Methuen & Co. Ltd., 1978.

systems linked to the effects of the cold front that were already dissipating into the Atlantic ocean, as shown by the presence of high clouds (cirrostratus) covering the entire sky (8/8).

The accumulation of energy within the environment due to the incidence of solar radiation during the day, under the conditions described above, were significant, producing thermal amplitudes of higher than 8.0°C in dry air temperatures and near 18.0°C in the values taken on the surface (low grass and exposed soil). In the latter case, one aggravating factor is the property of the materials and implements in the urban realm, such as bricks, cement, gates, roof tiles, iron, etc. These absorb a large quantity of energy in the form of short waves, in addition to conducting and accumulating more heat than do organic materials, in turn producing high temperature values and amplitudes among the posts. During the period between 9:00 am and 4:00 pm, the headquarters of the Ecological Station, located in an open and grassy area, showed a minimum of 25.0°C and a maximum of 34.2°C; The Atlantic Rainforest, 22.0°C and 32.0°C; Bambuzal (Bamboo Forest) 21.0°C and 29.0°C; and at the border of the Ecological Station with Carlos Luz Avenue, 27.0°C and 35.0°C. On the surface, the temperature values varied between 24.5°C and 43.9°C on the concrete sidewalk in the Carlos Luz Avenue post. By contrast, in the stretch inside of the Bambuzal post, the temperature varied between 19.1°C and 22.9°C; on the tree litter from the Atlantic Rainforest, it varied between 19.3°C and 22.4°C; and on the low grass at the headquarters, it varied between 24.8° and 37.4°C. At 2:30 pm; the Bambuzal post registered 29.0°C as compared to 35.0°C on Carlos Luz Avenue. At this hour, the Atlantic Rainforest post registered 31.0°C. The relative humidity varied between 70% in the morning hours at the Atlantic Rainforest and Bambuzal posts and near 20% during the hottest hours at the Carlos Luz post.

The data measured on October 1, 2011, under atmospheric conditions that were similar to the prior episode, also showed variations in temperature and relative humidity, evidenced by high amplitudes. During the period between 9:30 am and 4:00 pm, the temperature values in the Atlantic Rainforest post varied between 25.0°C and 33.0°C. In the Cerrado, these values fluctuated between 27.0°C and 32.0°C, in Bambuzal between 25.0°C and 30.0°C, and at the border of the Ecological Station with Carlos Luz Avenue between 28.0°C and 34.0°C. The most significant hourly difference occurred at 3:00pm between the Bambuzal post (26.0°C) and the Carlos Luz Avenue post (31.0°C). The relative humidity presented values of above 70% in the morning (77% in Bambuzal at 9:30 am) and approximately 20% in the hotter hours of the day (26% on Carlos Luz Avenue). In the Bambuzal and Atlantic Rainforest posts, this value remained at above 30% during the measuring period.

The lower temperature values described for the Bambuzal and Atlantic Rainforest posts illustrates the obstruction imposed by the tree canopy as regards the entrance of solar radiation, both of direct and diffuse radiation ($K\downarrow$), resulting in very low balance, compensated (in part) by the advective transport of heat (the typical shade of these spaces demonstrates this characteristic). This fact, associated with the exceptionally low properties of conduction (QG) and heat storage (ΔQS) of the vegetation (the organic materials are, in general, poor conductors/storers of heat) and the high value of the specific heat of the water (1.0 cal/g°C), in addition to the high rate of evapotranspiration in this environment, when part of the sensitive heat (QH) is transformed into latent heat (QE), they act together to diminish the heat exchanges, thus attributing high thermal inertia to the environment.

The specific heat values of the concrete and asphalt (0.2 cal/g°C), which are four to five times lower when compared to those of vegetation and water (0.8 cal/g°C, close to that of water at 1.0

cal/g°C), coupled with the opaqueness of the soil and paved surfaces, accumulates the energy in the form of heat in its surface portion (few centimeters), which is different from the water, which distributes the heat through a much smaller volume, due to its relative transparence and currents.

Despite the measurements taken, however, one must bear in mind that the results obtained are strictly linked to the aforementioned weather conditions. Under stable weather conditions, with thick cloud cover (8/8) and light and continuous rainfall, which was the case on November 10, 2012, resulting from the formation of an unstable line over a large portion of the state of Minas Gerais, the differences in temperature among the different posts of the Ecological Station, even among those representing the forested area in comparison with the station's border area with Carlos Luz Avenue, were practically null and void during the monitored period (between 10:30 am and 2:30 pm). At the station's border with Carlos Luz Avenue, the temperature varied between 20.0°C and 22.0°C, while in the Bambuzal post no significant variations could be perceived, remaining at 20.0°C. In the Atlantic Rainforest post, the temperature remained between 21.0°C and 22.0°C, while in the grassy areas of the Station's headquarters, the temperature remained between 20.0°C and 21.0°C.

This can also be applied to larger dimension spaces, such as in the comparisons between cities and rural areas, under similar weather conditions, which was observed by Lopes and Jardim (2012) through their simultaneous measurements between the urban area of Contagem and the periurban/rural area of Betim (Brazil). The thick cloud cover obstructed part of the entrance of direct radiation, while the remaining balance reached the surface in the form of diffuse radiation, leading to a lesser absorption and a lower level of heat storage, in turn reducing the temperature differences.

According to that shown in Table 01, the continued measurements taken by data loggers over a 24-day period revealed the lowest average air temperature value in the Bambuzal post (17.3°C) and the highest value in the INMET post (20.1°C).

Table 01 **Average, maximum, minimum, and amplitude value of the variable of temperature and relative humidity during the entire measurement period (April 20 to May 14, 2013).**

		Bamboo	Carlos Luz Avenue	Savanna	Deforested Savanna	Atlantic Rainforest	INMET
Temp. (°C)	Average	17.3	18.9	18.1	17.7	18.1	20.1
	Absolute maximum	25.0	30.4	25.9	30.0	24.2	29.6
	Absolute minimum	10.8	10.1	12.1	9.3	12.9	12.0
	Amplitude	14.2	20.3	13.8	20.7	11.3	17.6
Humidity (%)	Average	71	66	69	68	70	59
	Absolute maximum	88	86	86	88	85	84
	Absolute minimum	40	26	39	30	41	27
	Amplitude	48	60	47	58	44	57

This result was due to the homogeneity and high density of the vegetation layer in the Bambuzal post, which ensures a low permeability of the wind, minimizing heat exchanges by air advection, at the same time in which it reduced the entrance of direct solar radiation (predominance of the diffuse radiation component illustrated by the shaded areas of the environment). This situation of the INMET post, in contrast to that of the Bambuzal post, favored the predominance of the direct solar radiation component, consequently increasing the production of sensitive heat. Also included in this analysis is the fact that, in the case of the Bambuzal post (as well as in the Savanna and Atlantic rainforest posts), one portion of the sensitive heat (which is naturally low due to the low availability of direct and diffuse solar radiation) is absorbed in the process of vegetation evapotranspiration (transformed into latent heat), while another portion is absorbed by the metabolic processes of the plants themselves (photosynthesis and respiration). These factors, when summed together, result in lower temperature (and higher relative humidity) values and a reduced thermal amplitude.

The greater average and amplitude values shown by the posts of the deforested savanna area, INMET, and Carlos Luz Avenue was due largely to the greater permeability of the air in these environments (horizontal transport of heat through air advection). In the case of the INMET post, its altitude (highest of the group, at 869m) and the topographical situation (hilltop) forced them to face the effects of both local and regional circulations, while the remaining posts, in addition to this factor, were also influenced by the circulation of air induced by the topography itself (formation of anabatic and katabatic winds) due to its situation in lower altimetric quota, especially that of Carlos Luz Avenue (830 m), and topography that is characteristic of the bottom of a valley.

The movement of the cool air from the top to the base of the hill at night (catabatic wind) brought about a reduction in temperature values at night, while during the day it provided the formation of anabatic winds (ascension of hot air to the hilltop), which is the result of the relative confinement of the air in depressions. Also important to this is the relative absence of vegetation in the sense of facilitating heat exchanges and the presence of active and passive sources of heat production from anthropogenic origins at the Carlos Luz post.

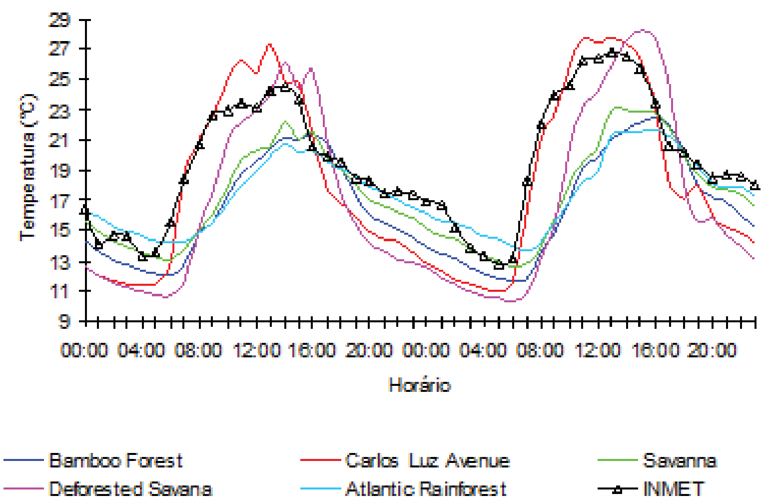
The post of the deforested savanna area, closely accompanied by the Carlos Luz post, concentrated nearly the total of the maximum and minimum daily values during the 24 consecutive days of measurement. According to that illustrated in Table 01, these posts, respectively, concentrated the highest thermal amplitude values (20.7°C and 20.3°C) in comparison to the amplitude values verified in the Atlantic Rainforest post (11.3°C). The average daily differences of the posts of the deforested savanna area and Carlos Luz posts, in relation to the cooler posts of the Atlantic Rainforest and the Bambuzal, were higher, at 6.9°C (normally between 12:00 pm and 3:00 pm), and lower at 3.9°C (6:00 am).

The hourly/daily sequence of the days of April 26 and 27, 2013 (Figure 03) illustrate these relations concerning the variation in temperature and relative humidity. In general, the posts that showed higher temperature values, which is the case of Carlos Luz Avenue and the deforested savanna area (deforested Savana or Deforested "Cerrado"), the greatest availability of sensitive air (QH) was due to the entrance of direct solar radiation, given that the surface in these locations was (almost) completely exposed and covered with herbaceous vegetation.

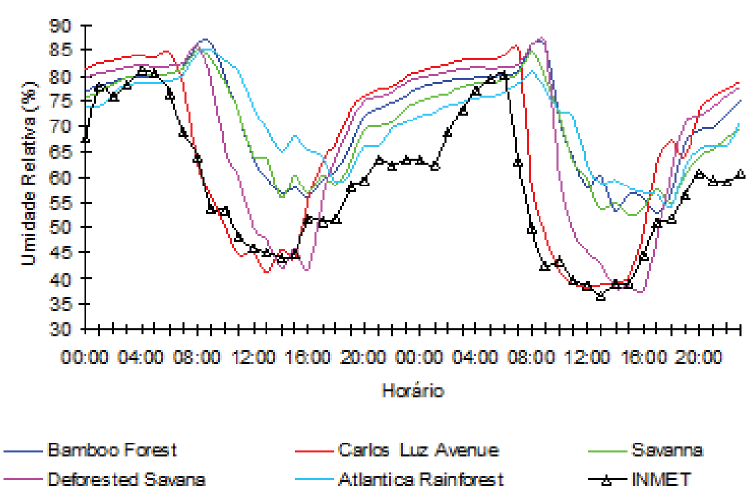
Once the radiation is absorbed, both in the soil and on the paved surfaces, the heat produced is temporarily stored only in the first few centimeters of these surfaces and is then transferred quickly to the overlying air layer. It is important to remember that the process of the transference of heat at depths within the soil is extremely inefficient (transference of heat by molecular contact or conduction). Hence, the heat is fully concentrated near the surface, and the low value of specific heat from these materials, approximately 0.2 cal/g°C (as compared to water at 1.0 cal/g.°C), accelerated both the gain and the loss of heat. This shows why in the referred posts, according to Table 01, the values relative to the thermal and hygrometric amplitudes of the air were greater than those in the posts located under dense coverage of tree vegetation.

Fig. 03 **Temperature variation (graph 01), relative humidity (graph 02), and temperature at the surface of the soil (graph 03), beginning with the posts installed in the UFMG Ecological Station in a typical sequence that is representative of the entire period of measurement (April 26-27, 2013, and September 24, 2011).**

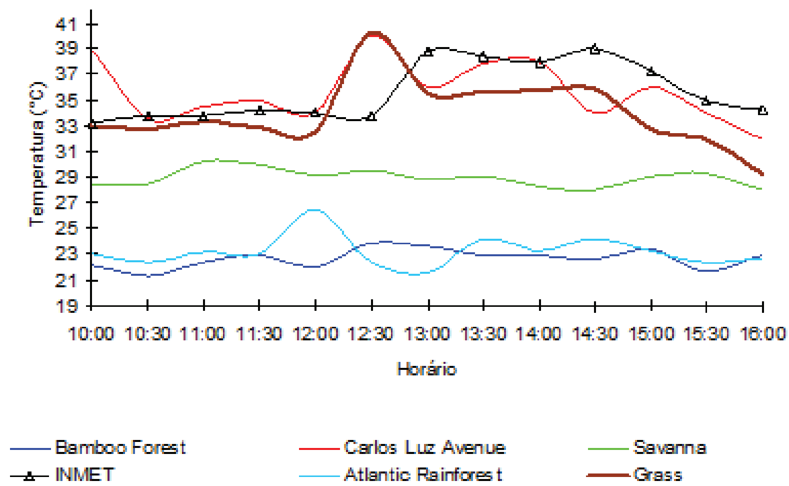
Graph 01 Air Temperature (26-27/04/2013)



Graph 02 Relative Humidity (26-27/04/2013)



Graph 03 **Soil Temperture (26-27/04/2013)**



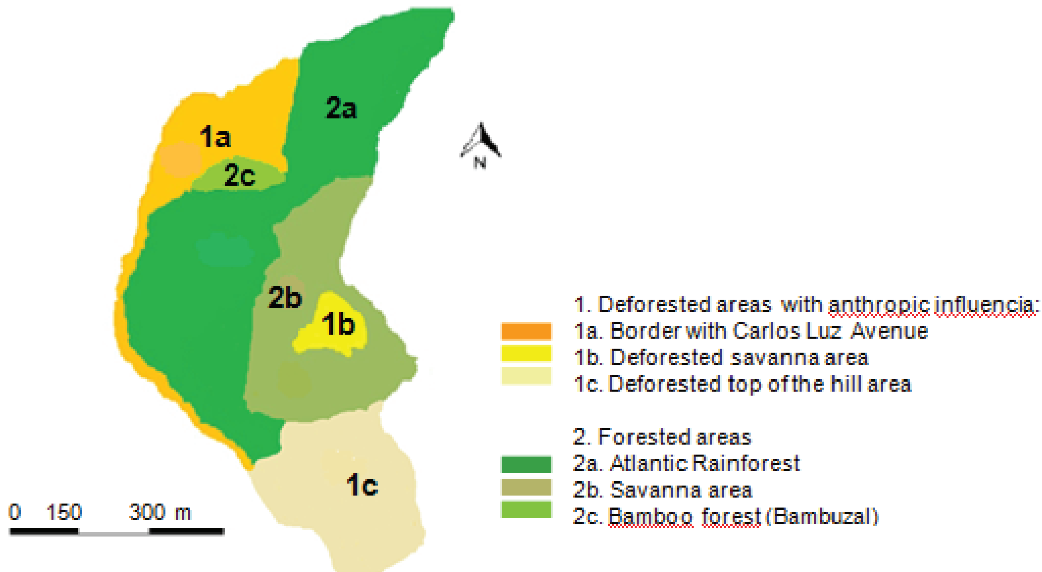
In the posts located under dense coverage of tree vegetation (Atlantic Rainforest, Bambuzal, and Savanna or Cerrado), the radioactive balance was small (as evidenced by the lower air temperature values) due to the obstruction caused by the treetops. Consequently, the thermal amplitude values were lower than the other posts located in open areas (11.3°C in the Atlantic Rainforest as compared to 20.7°C in the deforested Savanna or Cerrado), a result which showed the most efficient conditions of the conservation of the heat produced (ΔQS), stemming from the presence of water in the environment and the increase in the thermal inertia of the environment (Fig. 03 – Graph 02), associated with the reduction in the entrance of wind through the vegetation layer (ΔQA), minimizing the advective transport of heat.

In graph 03 (Fig. 03), regarding temperature on surfaces, although this was measured outside of the main measuring period, it is interesting to observe that the values obtained from the grassy vegetation (low grass) is similar to the variation obtained on an exposed soil surface (between 10°C and 20°C higher than that obtained in a forest environment), which is the case of the Carlos Luz Avenue and the INMET posts, attesting to the relative inefficiency of this element in the diminishing of air temperature, which is in accordance with findings from Gouvêa (2002). It is clear that ample grassy surfaces ensure good conditions for the infiltration of water into the soil, but this has little influence on thermal comfort, especially if the boundary areas have been paved, given that its friction coefficient, as compared to that of the tree vegetation, is quite low, allowing for the free circulation of air and, consequently, the transport of heat.

In a forest environment, the variation in temperature on the soil's surface rarely surpasses 1.0°C or 2.0°C throughout the day, due to the reduced radioactive balance within the environment (low value of ΔQS). In this context, the transference rates of heat in the soil (±QG), when compared to those of open areas, are severely diminished. The variations on the exposed soil (dry and compacted) register a high daily amplitude, which can surpass 30°C and register an absolute value of near or higher than 50°C depending on the weather conditions.

Considering the above discussion, this study proceeded to the characterization of the climatic units in the Ecological Station, as shown in the representative scheme in Figure 04 below and discussed thereafter.

Fig. 04 Partitioning in microclimatic units in the UFMG Ecological Station. Source: Google Earth; Image Design: Heli Cássio Monteiro.



The representative units of the deforested area with an anthropic influence included the border of the Ecological Station with Carlos Luz Avenue (unit 1a), the deforested savanna or the deforested Cerrado area (unit 1b), and the area where the INMET station is located (unit 1c). These units present microclimatic dynamics that are similar to the urban boundary areas. The urban implements present in these spaces and/or in the surrounding areas, such as the paved surface of Carlos Luz Avenue and the spots of exposed soil, possess the characteristic of an ample surface for the absorption of short wave radiation, in addition to the best properties of conduction and temporary storage of heat, which is gradually released throughout the day and night.

In these spaces, the measurements taken of the relative humidity (occasionally) reached lower levels than that recommended as the minimum levels for the good health and well-being of humans of 30%. The temperature of the air fluctuated, on average, from 6.0°C to 8.0°C during the day, while the surface temperature exhibited amplitude values of between 17.0°C and 20.0°C (in the Atlantic Rainforest and the Bambuzal posts, the amplitude remained at around 11.0°C to 14.0°C). It was not uncommon for these units, when compared to the other units, to show values of higher than 4.0°C or 5.0°C when considering prompt measurements. The (near) absence of tree vegetation in these spaces favors the advective transport of heat from the urban boundary areas.

Units that are representative of the forest environment include: Atlantic Rainforest (unit 2a), Savanna or Cerrado (unit 2b), and Bambuzal (unit 2c). In general, the radioactive balance and, therefore, the availability of sensitive heat within these units were always lower when compared to the previous units, which can be explained by the temporary differences in air temperature of less than 5°C/6.0°C during the day and significantly higher during the late night at 2.0°C/3.0°C, as shown in Fig. 03. Although the radioactive balance was small, the conditions for the conservation of heat proved to be better than those of the units containing deforested areas. The thermal amplitudes in the Savanna/Cerrado (13.8°C), Atlantic Rainforest (11.3°C), and Bambuzal (14.2°C) unit, as compared to that of the Carlos Luz Avenue (20.3°C) and of the deforested savanna area or deforested Savanna/Cerrado (20.7°C) also show a similar result.

It is worth noting that even in the posts that are characterized by dense tree formations, despite their lower amplitudes, the air temperature within the unit during the day was higher than that obtained on the surface, together with the forest substrate. This fact evinces the contributions of air advection in urban boundary areas (remembering that the air is heated from the bottom up, that is, from the surface in the direction of the higher layers of the atmosphere). The action of the winds promotes the heat (and humidity) exchange, characterizing the influence of the surrounding areas of the unit, since the urban context around the station is the very metropolis of Belo Horizonte.

Final Considerations

Although the vegetation is one of the main components of the landscape, considering its importance in the overall ecological picture and its effective role in diminishing the thermal and hygrometric impacts of the air, especially at the hottest times of the day, the manner in which this component occurs in urban spaces, distributed in limited and extremely fragmented areas, minimizes the possible effects regarding climate control. According to Euclydes and Fonseca (2013), 12.6% of the territory of Belo Horizonte is located in protected areas, which are heavily concentrated in the southern and southeastern borders of the city, following the Curral Ridge (Serra do Curral) (Rola Moça Ridge State Park, Ecological Station of Cercadinho, Mangabeiras Municipal Park, and Baleia State Park).

Though the distribution of green areas does not satisfy the true need of the city in the sense of producing an effect on its local climate, this does not minimize the role of this environmental component. On the contrary, it in fact reinforces the need to set up a program for the implementation and recovery of spaces set aside for environmental conservation, aimed at raising the quality of life and the environmental quality of the city.

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