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ON CITIES AND ENTROPY: A THERMODYNAMICAL VIEW OF THE LARGE TOWNS

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ABSTRACT

Present article proposes the application of the concept of entropy in the study of the environmental impacts created by a large city. It was taken a strictly thermodynamic approach of cities as heat sinks that generate entropy. The formalism of caloric field theory was adopted to establish the relationship between entropy caused by thermal exchanges and the physical environmental parameters considered. The notion of evolutional global time was introduced in order to treat entropy more objectively in the context of thermodynamics. A table with the rates of change of entropy in some cities was set.

Keywords: entropy; thermodynamics; irreversible processes; caloric field theory

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1. INTRODUCTION

The concept of entropy is one of the least understood and at the same time one of the most evoked in sciences, pseudo-sciences and semi-sciences. Bunge (2002), in his Dictionary of Philosophy, observes that

> "Há dois conceitos técnicos de entropia diferentes e não relacionados, a saber: o físico e o informacional. Nenhum deles é relevante para a filosofia, embora a palavra 'entropia' seja uma favorita entre os filósofos pops".[1] (BUNGE, 2002).

Also, Bunge (1973) highlights a common wrong idea:

> "[…] the interpretation of entropy as a measure of our ignorance is invalid, for it involves the erroneous identification of statistical mechanics with epistemology." (BUNGE, 1973),

and he continues saying that it is abusive to

> "[…] reduce entropy increase to loss of human information about the system, for this deprives statistical mechanics and thermodynamics of objectivity" (BUNGE, 1973).

Most of these claims are correct except for one. We would agree with Bunge on the lack of value of the concept of entropy for philosophy if he had not repeated the misconception of negentropy (BUNGE, 1973).

Undoubtedly, imaginationist and voluntarist idealism brought ills to the study of entropy, beginning with the association of a figurative time counted by clock-hands. From a macroscopic point of view, everything indicates that entropy progresses gradually and slowly from the past to the future, so that time must be treated more adequately as an evolutional variable on a scale independent of the conventional time of daily life.

The permanent advance of entropy makes the spurious idealism in the notion of "negative entropy" — the misconception of negentropy — give rise to the rational and objective concept of "entropy deceleration". So, what makes sense to state is that, locally, we can have decelerated entropy and some correlated effects. There is no "negative entropy", but rather "entropy deceleration" (just as it does not make sense to speak of negative movement, but acceleration and deceleration). Entropy is a quantity that can only grow. Its deceleration gives the impression that it has been reversed, as each accelerating state is able, under certain circumstances, to trigger surprisingly organized processes (for instance, frequent aerobic

[1] There are two different and unrelated technical concepts of entropy, namely: the physical and the informational. None of them is relevant to philosophy, although the word 'entropy' is a favorite among pop philosophers. (author's free translation).

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exercise increases secondary vascularization, producing microvessels that reduce the risk of fatal vascular accidents, although the aging of the organism continues to progress, at best, to natural organ failure).

From there one can already see how much nonsense is expected when searching the subject. Of course, this almost universal appeal to entropy, from thermodynamics to economics, through biology and information theory, reflects at least a feeling that it is fundamental, yet little understood (postmodern sociologists and systemic-minded management theorists use entropy in a way that promotes obscurantism rather than enlightenment).

There are two main facts that compose the misunderstandings surrounding entropy: firstly, the more technical, concerns the distancing from its thermodynamical origins; secondly, the more subjective, concerns the excesses of voluntarist and imaginationist idealism. In the first case, issues are discussed by an unqualified quorum. In the second case, speculation comes not from scientific plausibility, but from gratuitous fiction.

Howsoever, I think the problem in dealing with the notion of entropy comes mainly from the supremacy of the mechanistic educational model; it is more difficult to deal with intrinsic thermal exchanges in complex systems. For example, it is unlikely that, by looking at a steel structure in full oxidation, one would think of the loss of energy associated with the degeneration of steel by the action of oxygen (there was an earlier consumption of thermal energy to produce the steel pieces, so that oxidation equals wasted energy). Hence it seems that thermodynamics shows itself the most complete physical science to understand that every process of transformation entails irreversible wear and loss. So, what we are looking for with technology is not only to perform things efficiently, but to do it effectively, that is, with a minimum of losses, slowing the advance of the entropy.

That supremacy of the mechanistic educational model is not entirely fortuitous. Ironically, thermodynamics had its origins in observations of mechanical phenomena. According to Hiebert (1981), we can say that thermodynamics born from the discovery of an invariant correspondence between the macroscopic movement of a body and the heat dissipated by this movement; in other words, a correspondence between the amount of mechanical work that disappears and the amount of heat that appears. We have here a statement which, by the very nature of the world of external things, would lead to an analysis of the amount of energy that cannot be used in a complete cycle of mechanical work. It was precisely this analysis that led to the notion of entropy.

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Serious and competent authors have defined entropy in slightly different but equivalent ways. Ultimately, we can understand it as 1) the magnitude that quantifies the thermodynamical degradation of a system, and 2) the quantity that describes the incapacity of a system to process (convert) energy. Hence it is seen that remote associations of entropy with degenerating systems must go through thermodynamics, albeit indirectly, but not by mere formal analogies.

It is true that all human activity on the planet consumes energy. The problem is how to formalize this consumption in terms of the second law of thermodynamics, when the theoretical physical aspects of the system in question are not so evident. Depending on the scale of the system, however, it is possible to create a thermal emissivity representation; an urban system would be a good example.

A great city, being the center of complex and diversified human relations, bears a thermodynamical image if we think of the heat dissipated in traffic, civil construction works, industrial machines, mobile telephony, human bodies, residential lamps, public lighting, and so on. However, the main objective of this work is to construct not a complete thermodynamical image but a starting point for more precise researches on the control variables necessary for an effective urban management of energy and wastes from its dissipation[2].

2. METHODS AND APPLICATIONS

Climatology is a very complex science, so if we were to analyze urban climatic phenomena in their particularities, we would most likely find ourselves in trouble in a tangle of possibilities, some of which considered controversial. Fortunately, present macroscopic approach allows us to observe an object with middling homogeneous areas under the prism of its global thermal emissions, something that considerably simplifies the analysis in progress.

There is no scarcity of imagery devices to aid modern urban climate studies. With the increasing development of satellite imagery systems, the images produced have come to constitute an important tool for observing and analyzing climatic phenomena, particularly with respect to urban environments. Images from the NOAA / AVHRR satellite (spatial resolution of 1.1 km at Nadir) are applicable to climatic studies of large urban centers, while images from the Landsat 5 and 7 satellites, with spatial resolutions of 120 and 60 meters, respectively, have provided support to the study of configuration and thermal variation in the intra-small size.

[2] Modern thermodynamics emphasizes the continuous evolution of "out-of-equilibrium" systems under a continuous energy supply.

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Faced with so many resources, several authors have been working on the theme of urban heat (GÁL; UNGER, 2014; LI et al., 2016; MIDDEL et al., 2018; ZENG et al., 2018).

The concept of caloric field is in fact a deepening of the idea of thermal field (SERPA et al., 2016; SERPA, 2017a; SERPA, 2017b; SERPA, 2018) with the main difference that the field, at first non-massive[3], is described in its evolution as being a complex scalar associated with its own entropy by a field equation,

$$\partial_q \partial^q \xi + \; 1 - \gamma^2 \; \xi - 2\gamma^2 \xi \ln|\xi| = 0, \qquad (1)$$

where ξ is the field and γ is the opacity of the medium. In fact, this construct may be generalized to varied contexts of thermal irradiation, although the gauging only manifests beneath an intense field, where thermochemical transformations occur from a certain amount of matter in interaction with the field[4].

That equation of field evolution is deduced from a Lagrangian density whose role is precisely to establish a coded symmetry for derivation of the equations of "motion" of the system in question. The complex scalar representation was chosen to ensure an always positive entropy according to the field equation; also, it generalizes the formalism so that, when gauging is applicable, it becomes technically useful. So, for instance, let us take the caloric field

$$\xi = e^{i2n\gamma q - \vartheta}$$

with its conjugate

[3] The choice of a non-massive scalar field is based on a very simple argument on the diffusion of energy: if the diffusion of heat must remain linked to a kind of matter, so heat can never diffuse under the vacuum, which is wrong, since heat can propagate in the form of radiation. So, there is no reason to suppose a massive solar energy field in the fundamental assumptions of the theory. Nevertheless, heat and mass are transmutable into one another, so that I am led to believe that mass is simply a kind of condensation of what I mean by massive caloric field. Thus, one can say that, from the mechanical point of view, mass interacts with gravitational field; from the thermodynamic point of view, via caloric field. Non-massive caloric fields bring very practical consequences for the control of the entropy production (SERPA, 2018).

[4] In the theory of caloric fields, the gauge field is closely linked to the appearance of the so-called "minimal thermal mass factor of dynamic interaction", which responds by a massive feedback to the original field due to the thermochemical interaction between field and matter under high temperatures.

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$$\xi^{\dagger} = e^{-i2n\gamma q-\vartheta},$$

where q is the generalized coordinate, n is the polytropic index, γ is the opacity of the medium and ϑ is the refractive index of the medium. The polytropic regime assumption is in fact a simplifier hypothesis[5] (SERPA, 2018). Lagrangian density is given by

$$\mathcal{L} = \partial_q\xi^{\dagger}\ \partial^q\xi - |\xi|^2 + \gamma^2 |\xi|^2 \ln|\xi|^2 . \quad (1.a)$$

Application of Noether's theorem shows that there is a conserved caloric strength Q,

$$\frac{\partial\mathcal{L}}{\partial(\partial_q\xi)^{\dagger}}(\partial_q\xi)^{\dagger} + \frac{\partial\mathcal{L}}{\partial(\partial^q\xi)}(\partial^q\xi) - \mathcal{L} = Q \quad (1.b)$$

$$\frac{\partial\mathcal{L}}{\partial\ \partial_q\xi^{\dagger}}\ \partial_q\xi^{\dagger} + \frac{\partial\mathcal{L}}{\partial\ \partial^q\xi}\ \partial^q\xi\ -\ \partial_q\xi^{\dagger}\ \partial^q\xi\ + |\xi|^2 - \gamma^2 |\xi|^2 \ln|\xi|^2 = Q$$

$$\partial_q\xi^{\dagger}\ \partial^q\xi\ +\ \partial^q\xi\ \ \partial_q\xi^{\dagger} -\ \partial_q\xi^{\dagger}\ \partial^q\xi\ + |\xi|^2 - \gamma^2 |\xi|^2 \ln|\xi|^2 = Q \quad (1.c)$$

Derivatives of both fields are

$$\partial^q\xi = i2n\gamma e^{i2n\gamma q-\vartheta}$$

and

$$\partial_q\xi^{\dagger} = -i2n\gamma e^{-i2n\gamma q-\vartheta}.$$

Second derivative of the first field is

$$\partial_q\partial^q\xi = -4n^2\gamma^2 e^{i2n\gamma q-\vartheta}. \quad (2)$$

Substituting in field equation, it follows

$$-4n^2\gamma^2 e^{in\gamma q-\vartheta} +\ 1-\gamma^2\ \ e^{i2n\gamma q-\vartheta} + 2\gamma^2\vartheta e^{i2n\gamma q-\vartheta} = 0;$$

$$-4n^2\gamma^2 + 2\gamma^2\vartheta - \gamma^2 + 1 = 0;$$

$$\gamma^2\ \ 2\vartheta - 4n^2 - 1\ \ = -1;$$

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[5] To the real conditions of the troposphere of Earth corresponds the state with the polytropic thermal stratification. I assume that the whole atmosphere has a polytropic stratification (vertically finite).

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$$\gamma = \frac{1}{\sqrt{4n^2 + 1 - 2\vartheta}}. \quad (3)$$

This is the expression of the opacity as a function of polytropic index and refractive index, remembering that the range of interest of the polytropic index is limited to $0 \leq n \leq 5$. For the air, with a significant degree of humidity, we may consider $n = 1.2$, which is approximately the value observed in Earth's atmosphere. Assuming the refractive index of the air equal to 1.0003 and substituting both values in expression (3), we obtain

$$\gamma = \frac{1}{\sqrt{4 \times (1.2)^2 + 1 - 2 \times 1.0003}} = 0.458378.$$

This is the mean Earth's atmosphere opacity in normal conditions. It is noteworthy that field entropy, given by

$$S = \int -2\gamma^2 |\xi|^2 \ln|\xi| \, dq, \quad (4)$$

is positive for any value of the field. To check this, take the expressions

$$|\xi|^2 = \xi\xi^\dagger = e^{i2n\gamma q - \vartheta} e^{-i2n\gamma q - \vartheta} = e^{-2\vartheta},$$

$$\ln|\xi| = \ln\sqrt{\xi\xi^\dagger} = \ln\sqrt{e^{-2\vartheta}} = \ln\left(e^{-2\vartheta}\right)^{1/2} = -\vartheta,$$

and replace in equation (4),

$$S = \int 2\gamma^2 e^{-2\vartheta} \vartheta dq = 0.05685q.$$

The generalized coordinate is a time function, not the time "t" of clocks but the global evolutional time "τ" valued in the interval $[0,1]$. Within this very small range, the growth of entropy can be excellently described by

$$S = 0.05685 e^{\kappa\tau},$$

with

$$q = e^{\kappa\tau}.$$

By definition, the rate of entropy variation is given by

$$\frac{d^2 S}{d\tau^2} = 0.05685 \kappa^2 e^{\kappa\tau}, \quad (5)$$

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with κ being the average Sky View Factor (SVF) of the city. Since the entire lifetime of a city is undefined, and since the global evolutional time range is very small, we can assume that the variable τ has "now" a very small value[6] in generic time Units (**tU**), which would allow us to approximate the exponential function to 1. According to the table furnished by Middel *et al* (2018), I adapted another table with the rate of entropy for some cities in the world (Table 1).

Table 1: Average entropy rate for some cities.

CITY	SVF (average)	AVERAGE ENTROPY RATE (J/ºK.tU²)
Manhattan	0.545	0.016886
Paris	0.586	0.019522
Singapore	0.595	0.020126
Seoul	0.680	0.026287
Tokyo	0.693	0.027302
Vancouver	0.713	0.028901
Philadelphia	0.720	0.029471
Bonn	0.746	0.031638
San Francisco	0.811	0.037391

Source: adapted by the author from Middel *et al*, 2018.

Thus, the theoretical entropy accelerates as SVF increases.

3. DISCUSSION

Measuring the field we can evaluate the entropic trail that it leaves, and so, comparing different trails among distinct climatologically similar cities, we can establish a parameter of weighting indicative of the volume of irreversible processes that affect the environment in the immediate vicinity of each city. Note that the advancement of entropy was analyzed here only in terms of assumed natural environmental conditions.

Both the refractive index and the opacity of the medium may vary significantly for anthropogenic reasons, thus affecting the rate of change of entropy. In this way, caloric field is only understood in its interaction with matter insofar as the only thing observed is the degradation of the system, not the entropy, not even the degradation of the field itself.

In present study, the concept of heat island was implicit in the entire large city. Important contributions in modeling local heat islands were brought by Oke (1978, 1981, 1982, 1988), among which the relation between height-distance of buildings that led to the use of the above referred technique known as the SVF, expressed through the equality

$$dT_{max} = 15.27 - 13.88 \times SVF,$$

[6] In fact, it is possible to relate clock time t to τ via Green's functions, but this is not the case to do this in present paper.

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where dT_{max} = intensity of the heat island (ºC) (OKE, 1982). According to this formula, the author argues that the island of heat is increased or reduced because of the loss or heat gain of the radiation by the "obstruction index" of the sky. The SVF is still widely used today as one of the most efficient urban spatial indicators for radiation and thermal environmental assessment (ZENG et al, 2018).

The obstruction index is similar to the blurring γ-factor (opacity) of the medium in the former caloric field theory. In the original equation of the caloric field, the quantity $(1 - \gamma^2)$, named "luminothermic capacity", acts on the field to express the influence of the environment. The opacity may be considered both from the point of view of the radiation that arrives from an external source, and from the radiation returned to the medium from a diffusing source heated on the terrestrial surface.

Lastly, it's interesting to note that conserved caloric strength implies

$$\frac{d}{d\tau}\left[\, \partial_q \xi^{\dagger} \;\; \partial^q \xi \;\; + |\xi|^2 - \gamma^2 \, |\xi|^2 \ln |\xi|^2 \right] = 0.$$

Substituting the derivatives,

$$\frac{d}{d\tau} \;\; 4n^2\gamma^2 e^{-2\vartheta} + e^{-2\vartheta} + \gamma^2 2\vartheta e^{-2\vartheta} \;\; = 0,$$

which is obviously true for any global time.

4. CONCLUSION

Present article showed a new approach of urban entropy based on the concept of caloric field developed previously in detail by the author (SERPA, 2017a, 2017b, 2018). In fact, it is a continuation of author's former research (SERPA et al., 2016) on the issue of sustainable environmental management with regard to human urban waste interactions withal, since these interactions are frequently source of economic, health and aesthetic problems.

From the field equation, considering only thermal effects of solar radiation on the urban environment, it was possible to give a satisfactory relation between the refractive index and the opacity of the medium, from which entropy and its rate of growth were obtained.

Both opacity and refractive index largely mirror the level of local pollution. Also, the work discussed a global time variable as the most adequate to treat entropy, since the conventional lifetime of a city is undefined. It is hoped that this approach shall win adepts to improve the model with inclusion of anthropogenic parameters in order to build a more

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complete representation that helps studies in environmental economics and urban ecology. It is also expected that the model shall be applied to Brazilian cities.

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