The city as a good example through which we can try to understand the various forms of Man's control over the atmosphere – a case study of Oporto (Portugal) heat island

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I- Introduction

It not being our intention that this article be an expression of *nostalgi*a for the *Paradise Lost*, it is only our wish to emphasise some of the severe consequences which have resulted from the progressive and effective distancing of Man from his environmental support.

The economic system in which we live, based on profit[1] has transformed the cities into indispensable components, as artificial support for the "exchange" of goods, services and information. Exchanges these which are not done according to what is necessary but depend only on what already exists.

The maintenance of this type of relationship is only possible due to a diverse set of solid units of management of international economic systems, like the EC, the OECD or the World Bank. These large international organisations constantly on the alert so that the system in force functions, i.e., that the exchanges continue to take place in accordance with the rules imposed by those who have the largest quantity of resources. If we could detach ourselves from the whole socio-economic and political conjuncture in which we live and were reduced to our humble position as one more element in the Ecosystem[2], we would see that these institutions and, above all, the aims which justify their existence are incomprehensible, unnecessary and generators of the "noise" in the Ecosystem. It is precisely this knowledge of our fragile position in the Environment which assails our conscience, individually and socially, and which makes us feel guilty for the uncountable situations of Starvation in the world. It is only the respect for the acquired right some have to the property of resources which impedes that the

[1] To have profit as a goal means gaining, in each exchange, a little more than that which is given, which implies an unbalanced relationship, totally opposite to the one which presides the exchanges in the Ecosystem.

[2] A clarification of the use we make of the word Ecosystem and Ecosystems is absolutely essential at this point.

Apart from integrating, since the final years of the 80s, the vocabulary of a vast set of social, economic and political agents, or perhaps due to this very fact, this word has become empty of content, given the diversity of meanings to which it has become associated.

This ambiguity of meaning brings to mind one of the many definitions of the term, from among the uncountable authors who discuss this notion from a scientific point of view, that of P. DUVIGNEAUD in his book The Ecological Synthesis. According to this author, the ecosystem is "a whole made up of all the organisms which constitute a biocenosis, the diverse trophic or chorological relationships which unify them and all the interactions with the environment..". It is, therefore, a functional unit which can be applied to a large diversity of scales of analysis. As the author states "... at its limit, the biosphere composed of all the ecosystems in the world, is not more than a gigantic *terrestrial globe* ecosystem, in which all the parts are in perfect harmony..." (DUVIGNEAUD, P. The Ecological Synthesis, _____).

In accordance with this definition, we decided to use Ecosystem in the singular when we are thinking of the hierarchically superior functional level, which integrates the biocenoses and the factors of *global* environment as a whole. Whenever we refer biocenoses and biotopes of lesser dimension, we will use the term in the plural.

The urban ecosystem, for example, arises, in accordance with this logical structure, as an intermediate level of organization, which includes within itself other subsystems, but which is itself integrated in the gigantic Global Ecosystem. The perspective of analysis which we intend to adopt, as we will see later, of the climatope of Oporto is based, in a very special way, on the fact that it is not possible to ignore the reciprocal contributes of all the organisational levels to the final result.

others satisfy a basic necessity - nourishment. A problem which other elements of the Ecosystem resolve in much more simple and harmonious ways.

The cities, entirely artificial projections in an area where the exchange of surpluses demands new necessities, gave Man a greater possibility of controlling his habitat. This control unleashed and stimulated attitudes of progressive irreverence in relation to the Environment. The environmental support came to be seen as a "separate" entity. The idea of "cohesion" was completely lost in favour of a pretentious concept of Man's immunity when confronted with the consequences of his actions[3].

When we appeal exclusively to our intuitive/primary sensibility, we easily understand that the exaggerated anthropocentric view of the Ecosystem led us to concepts of self-sufficiency, of an excessive optimism and confidence in our capacity to control physical and biological processes. The notion of limit and balance underlying any open system, as is the Ecosystem, was lost. Intuitively, by up-bringing and because we have always been one more "operator" of an urban ecosystem, we perceive the various "nuances" that it has suffered during the last decades.

We believe that it is possible to conciliate individual freedom with the common good and that, less and less, national sovereignty can be seen as opposite to the global preoccupation with the Environment or that the quality of life and the well-being of the present generation does not necessarily imply that future generations be put at risk. With this book, we hope to contribute, at least, towards a diagnosis of the state of some of the environmental components in a determined, real area.

Rethinking the relationships Man/Environment from a geographical point of view, we intend to make clear that it is imperative we assume a less irreverent and more humble attitude, in relation to the environmental support on which we depend. Seeing as the relationships of dependency between the various components of the Ecosystem are multiple and complex, we have opted for an attempt at understanding a little more the whole through the study of a tiny fraction: the urban climatic subsystem.

Therefore, Oporto's *climatope* interests us only as an integral part of a biotope where a community of living beings inter-relate.

We share with S. BOYDEN[4] the idea that "... the city is a gigantic immobile animal, consumer of vast quantities of oxygen, water and organic matter e excretor of carbon dioxide, sulphur dioxide, fumes, water vapour and organic waste..." and we will use the atmospheric pollution - strong acidity (SO_2) and black fumes - as an indicator of the rate at which the urban functional activities inter in the climate of the area and the effect of this rate on the concentration or dispersion of elements injected into the atmosphere.

II – The Climate as an applied concept to planning policies

The notion of "climate", as an expression of atmospheric conditions, varies, therefore, in accordance with the necessities of the investigator. Currently, the need to understand the climate is absolutely imperative, seeing as we can no longer tidy it away in big homogenised groups according to highly generic characteristics, because it has been understood that the slightest climatic variations can provoke economic and social readjustments, and that the consequent scenarios are unimaginable.

The applicability of Climatology in the implementation of policies of sustained development, implies the adoption of a concept of climate as an open, active and complex system, whose vitality is in direct dependency on the capacity to exchange energy and matter with the exterior, retarding for as long as possible total entropy. Seen as an open system, it comports a multiplicity of states of equilibrium, some of which would put in risk the presence of life on the surface of the Earth.

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[3] An idea which is supported by several authors, amongst whom we find S. McBURNEY and M. HOUGH, when they declare:

"...When mechanised and computerised energy has effectively separated most people from putting their own effort into the procurement of essential resources [...] The resultant consumers are so distanced from what goes into the manufacture of consumer items that there is little reverence for them. In turn, this provides the appropriate psychological seabed in which to nurture the concept of the "throw-away" society..." (McBURNEY, STUART, Ecology into economics won't go - or life is not a concept, Green Books, Devon, 1990, p.155).

"...A house is an imposition on the land when the resources necessary to sustain it are funnelled through a one-way system: water supply - bathroom tap- drain- public sewer. or, food- kitchen- dump. The by-products of use serve no useful function..." (HOUGH, MICHAEL, City form and natural process, Routledge, London, 1989, p.24).

[4] BOYDEN, S.V.et al., The ecology of a city and its people, Australian National University Press, Camberra, 1981, p.18.

News of a recent past underlines the unstable balance of the "climatic system" and alert us to the necessity of understanding the complexity of this organised structure capable of memorising events and of conferring consequences in time.

If the climate is considered a level of general resolution in the Climatic System and if this global system is believed to be constituted by a series of integrated subsystems, it is possible to foresee the co-participation of Man and Nature in the elaboration of the final result. (C. MONTEIRO, 1976) [5]. The climatic system is, therefore, a global structure, organised and ranked horizontally (in structure) and vertically (in function). ARTHUR KOESTLER, cited by C. MONTEIRO (1976), symbolises this idea by means of the analogy of a tree and a Chinese box.

During the development of the initial trunk, it is possible to perceive various levels of organisation linked by polarised nuclei at diverse strata, which filter the entrances of energy from the superior levels and control the passage of the fluxes produced in the inferior levels. According to Koestler, each of these organised structures possess fixed rules of operation. However, the elements which are to be conducted are varied, leading to an infinity of possible final results.

In the case of the climatic system, we believe in the existence of a series of rules of operation, but the global climate will reflect the various solutions adopted by the inferior structural levels (regional and local climatic subsystems) to filter, select and conduct energy and matter.

In our opinion, it is essential that an evaluation of the extent of Man's co-participation at the climatic system's level of general resolution be carried out. There can be no doubt that the use of fossil fuels, the current agricultural practices and the increasing exploitation of watercourses, result in a substantial increment of chemical elements in the bio-geo-chemical cycles. The modification in the chemical composition of the gaseous layer, which separates the Earth's surface from the Ecosystem's main energetic source, will undoubtedly affect the globe's climate, by altering in a systematic way the final results at inferior resolution levels.

III - The Urban Environment

Our choice of the urban environment is due to the fact that the cities are undoubtedly the most refined example of Man's superior attitude in relation to the rest of the Ecosystem, which McHARG [6] designated as the vertex of the pyramid of Man's illusions of superiority in relation to his environmental support.

To survive and win in diminutive spaces, urban Man has completely lost the notion of his multiple relationships of dependency with the surrounding space. The manner in which the water we use in our homes is put at our disposal, does not make us think about the river, fountain or spring where it comes from. The drain canalisation to the sewage system is sufficiently efficient so as not to give us the time to appreciate the profound differences in the chemical composition of the water which runs from the tap and that which goes down the drain. And where does this intricate sewage network discharge? It is certainly in a place far, far away, which we avoid at all costs when we wish to "enjoy nature". The trophic chain of the urban citizen, as affirmed by some authors, can be resumed as the short distance between the supermarket and the garbage bin.

The larger the cities, the more deprived the urban citizen is of contact with the environment, the more disdainful is he or, simply, the more he ignores the other elements of the Ecosystem. The latter becomes increasingly hostile and Man takes refuge, for longer periods of time, in artificial environments. The building, a protective shelter during some hours at night or during the season of the year which is, in climatic terms, more rigorous, becomes the only possible place to be during the 24 hours of the day.

But, in spite of all this, more and more people continue to flow into the cities and the trend points to this continuing to be the preferred environment by the majority of the world's population in the 21st century. The motive which leads people to overcoming the inertia of life in the country, much calmer and healthier, has to be, obviously, the search for a "better quality of life". This fact, when considering what was said before and all that we know in relation to the city, seems profoundly contradictory. What type of offer of quality of life and well-being can be associated with them, which justifies the preference of over 40%[7] of the globe's population and which propitiates an alarming tendency to increase until the end of the century. Only a severe loss of the notion of

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[5] MONTEIRO, C.A.F., Teoria e clima urbano, IGEOG, Univ. de São Paulo, São Paulo, 1976.

[6] "...The cosmos is thought to be a pyramid erected to support man upon its pinnacle, reality exists only because man can perceive it, indeed, God is made in the image of man..." (McHARG, IAN L., "The place of nature in the city of man", Challenge for survival, land, air and water, PIERRE DANSEREAU, (ed.), Columbia University Press, New York, 1970, p.41).

[7] "...In 1800 only some 50 million people lived in urban areas: by 1985 the number of urban dwellers had risen to 2 billion. In 1800 only 5% of the world's population were urban dwellers, now the proportion has risen to more than 40%, and by the year 2010 more people will live in towns and cities than in countryside..." (LEAN,G., HINRICHSEN, D., MARKHAM,A., Atlas of the Environment, WWF, Arrow Books, London, 1990, p.21).

Man's real dimension in the world can justify these types of unnatural options which, apart from being aggressive on the other elements, are above all fatal for Man himself.

Perhaps if we analyse the concept of well-being and quality of life, will we be able to understand this apparently conscious march to a collective suicide of the species. According to S. BOYDEN [8], quality of life and well-being vary from group to group and from era to era. For the common citizen living these final years of the 20th century, "well-being" means having the capacity to survive and to reproduce, to be able to practice diversified physical exercise without exhausting himself, to be able to rise and then maintain his position in society and, obviously, to feel well emotionally. The fulfilment of all or a majority of these requisites constitutes the aspirations of most people at the end of this millennium.

It is, perhaps, in the over valorisation of the 3rd condition in relation to the others, that resides the explication for the remarkable increase in the capacity for suffering of modern societies, which leads people to exchange more balanced relationships with the Ecosystem, like the ones which exist in the rural environment, with the increasingly inhospitableness of the large metropolitan areas.

Urbanism is only one more of the phases, according to S. BOYDEN (1981), in the unbalanced process of domination of the environment, which probably started after the discovery of fire, followed by the development of agriculture and which culminated with industrialisation. And, from the discovery of fire to the industrial revolution, greater and more important environmental impacts succeeded each other.

Up until approximately half a million years, Man was integrated in the environment in a more or less balanced manner (feeding himself on natural products and plants). The energy transferred to predators and decompositors was identical to the sum of the energetic value of the products consumed.

The elevated concentration of populations in urban centres, attracted initially by a potential improvement in their quality of life, led forcibly to a progressive maximisation of the usage made of the urban area, in relation to the functions which are attributed to them: transformation of raw materials, technological innovation, transport, education and socio-cultural dynamisation. Man (from a physical and psycho-social point of view) and space were the greatest losers in this process of unbridled growth of the urban nuclei. The search for constant positive feedback generated disturbances in the Ecosystem's equilibrium and altered the value of each of the system's elements, favouring some in detriment of others.

The innumerous activities associated with the phenomenon of urbanisation, in which Man is a privileged agent, are responsible for substantial changes in the first few hundred metres of the atmosphere, due to physiological changes in the fauna and flora, due to alterations in the topography, to the creation of new forms of accumulation (waste and garbage dumps) and removal (extraction of sand, gravel and rock) and to modifications in the water circulation.

At the level of the atmosphere, urbanisation has had significant negative impacts, altering the meteorological phenomena which result from the physical-chemical exchanges operated in the Earth-Atmosphere interface. If we remember that 100% of the humidity, 75% of the heat input, as well as 40% of the kinetic energy are due to the Earth's surface[9], the magnitude of the climatic alterations generated by any urban nucleus becomes evident.

The physiological alterations in the fauna and flora induced by a selection of species in function of the urban habitat, is frequently in disequilibrium with the surrounding environment. Immunisation, natural or artificial, against certain diseases (e.g. tuberculosis, plague, etc.), favoured enormous increments in the population. The vast quantities of accumulated waste in the cities generated profound disequilibrium in the trophic chain, through the creation of special conditions for the proliferation of species which feed off them, like rats, worms and other creatures. The vegetable species developed adaptations to the high quantities of lead, sulphur dioxide, carbon monoxide and dioxide, as well as the decrease in the number of hours of sunlight[10] and the increase in light (artificial illumination) during the night. It is, therefore, legitimate to speak of urban fauna and flora with original trophic and chorological relationships.

In any process of urbanisation, the alterations in the topography provoked by new forms of accumulation (waste materials and garbage dumps) and removal (extraction of sands, gravel and rock) are incalculable. The substract, over valorised due to its scarcity, is subject to multiple uses for sanitary purposes (caption wells, sceptic tanks), for the development of the community and/or for diversion. People's preference for higher regions, far from fumes, dust clouds and noise, usually aggravates the pressures to which the physical substract is subject,

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[8] BOYDEN, S.V. et al., The ecology of a city and its people, Australian National University Press, Camberra, 1981, p.103.

[9] CHANDLER, T.J., "Urban climates and the natural environment", Int.J.Biometeor., vol.20, nº2, 1976, p.129.

[10] "...a turvação da atmosfera londrina fá-la perder cerca de 270h/ano de sol no centro da cidade e 100-150h/ano de sol nos subúrbios..." (***in English***: "... London's overcast and smoggy atmosphere makes it loose about 270hrs/annum of sunlight in the centre of the city and 100-150hrs/annum of sunlight in the suburbs..."), (CHANDLER, T.J., "Urban climates and the natural environment", Int.J.Biometeor., vol.20, nº2, 1976, p.130.)

seeing as the stability of the slopes and their movements are not, from a technical point of view, easy to prevent. The extraction of water and minerals, associated with alterations in the chemical composition of the water and gases, increases the risks of subsidence.

In the urban environment, the water circulation systems are profoundly altered by the changes made in the drainage volume and by the infiltration regulation, as well as by the development of an entirely artificial system used to supply water and remove sewage. In urban centres, there exists a total reorientation of the ground water and breakdowns in this domain represent paralysation in uncountable urban functions.

In view of all this, the city seems to us a good example through which we can try to understand the various forms of Man's ascendancy over the atmosphere, biosphere, hydrosphere and the lithosphere, especially seeing as it will be the environment chosen by the near totality of the globe's population at this century's end.

IV - Oporto's urban climate

The city of Oporto, in spite of being a singular area when considering the combination of geographic factors which characterise it, provokes significant alterations in the regional climate, due to its functional vitality.

Neither the E-W topographic differentiation, nor the proximity of two important mosaics of water (the ocean and the Douro River), nor, much less, the repercussions in terms of the diversity of area occupation, inherent to its more than eight centuries of history [11], are sufficient to dissimulate the impacts of the urban metabolism, at least, at the level of its energetic balance.

The model which served as our initial motivation, and which made us foresee a maximum difference between the temperature of the city and its periphery[12] of 6.9ºC, did not prove itself so distant from reality as one could expect it to be, when considering the geographic and functional specificity of Oporto.

The altimetric differences, the effect of the sea breeze, the climatological effects of the proximity of the Douro River, the unequal distribution throughout the city of green areas with diverse characteristics and the different typologies of occupation of the urban area, contribute towards a distortion of the "heat-island" but, rarely can they annul it. In accordance with the relative weight which, momentarily, the physical-chemical characteristics of the air mass permit they have, so some factors become evident and others are annulled.

The fact that the temperature records observed within the administrative limits of the city of Oporto were systematically higher to those recorded, at the same time, at the Oporto-Serra do Pilar station, reinforces the relationship of causality which exists between the magnitude of the urban phenomenon and the energetic excess generated. All the more so when we verify positive thermal anomalies for register points within the city, which are near and/or have characteristics very similar to those of Oporto-Serra do Pilar.

This relationship of cause-effect between the rate at which the modus vivendi of urban Oporto takes place and the increase in temperature, became specially obvious in the analysis we carried out on the semi-hourly temperature records in the Av. da Liberdade between the 22nd and the 24th of December in 1990.

We recall, to this end, that the between 7 a.m. on the 22nd of December (Saturday) and 12 p.m. on the 24th of December (Monday), the temperature increased uninterruptedly. Abnormal behaviour in terms of temperature, only understandable if we consider that during those three days in December (Christmas shopping), the city centre prolonged its period of greatest vitality well into the night.

Having demonstrated the existence of impacts on the energetic balance, provoked by the presence of other sources of heat and/or by a greater storage capacity and energy conduction, due to spatial rearranging, artificially produced by Man, we intend to identify the areas where these impacts manifest themselves more clearly.

During approximately 9 years of experimentation, under the most diverse weather conditions, in different seasons and at varying hours of the day, we verified that the posts included in the Av. Aliados-Pç. Republic-R. Boavista area and the Marquês-Constituição-S. Roque area frequently registered temperatures superior to those registered at the other posts disseminated throughout the city.

These two "urban heat islands" coincide with the city centre, from an administrative and functional point of view. The first delimits the coalescence of the main CBD, located at Av. Dos Aliados, with the secondary CBD, around the Boavista ring-road. The second includes the points most used by the transport network, of best accessibility to the city centre, which serves the E area of the city, apart from being an area where the residential function coexists with a large number of small and medium industries.

Unfortunately, it was not possible to obtain, due to the methodology used and to the reduced technical and human resources available, an image as simplified as we would desire of the functioning to Oporto's climatic subsystem in the face of very similar exterior stimuli.

The processes of resolution in Oporto's climatic subsystem under generically similar synoptic situations were quite diverse. The Oporto's thermal nocturnal pattern denoted great vulnerability, in relation to the different types of synoptic situation, as well as in relation to small nuances within the same type of synoptic situation.

However, from the analysis of the various examples selected, it seems possible to state that it is not true that the "heat-island" is more diluted under situations of depression or turbulence than it is under the effect of anticyclonic situations.

In fact, the "heat-island" was specially evident on days of great stability, weak barometric gradient, weak wind and frequent periods of calm. Conditions normally associated with the presence of anticyclonic situations,

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[11] "...O burgo episcopal, por doação de D.Teresa em 1120 ao bispo D.Hugo, que depois concedeu aos portuenses o primeiro foral, em 1123, crescerá impulsionado pelo relançamento do comércio que nesta altura se verifica na Europa...", (***in English***: "...The Episcopal borough by donation of D. Teresa in 1120 to the Bishop D. Hugo, who later conceded the population of Oporto its first charter, in 1123, would grow impelled by the resurgence of the trade which was at that time flourishing in Europe...") MARQUES, H., FERNANDES,J., MARTINS, L., 1990, p.7.

[12] With knowledge of the enormous controversy, latent in the bibliography consulted, in relation to the location and the real significance which should be attributed to these two points of comparison and having no intention of rekindling it at this moment, we wish only to point out that we consider *periphery* the area administratively exterior to the city, in which the Oporto-Serra do Pilar is included.

but which, as we saw, can arise under the influence of situations of depression, when the ascendant movement of the air is conditioned by the presence, in altitude, of a "cold drop", or when caused by a strong base heating.

On a majority of the days with turbulence, areas of depression and anticyclonic margins, what we frequently verified was a disturbance in the explicatory capacity of the two geographic factors considered - distance from the sea and altitude - in any case, testified by the loss of meaning in the coefficients of correlation.

Nevertheless, these two geographic factors proved decisive in explaining Oporto's thermal nocturnal pattern, on days under the effect of dry, either very hot or very cold, air masses.

It is also significant that there was no particular intensification in the "heat-island" during the coldest time of the year. In our opinion, this did not occur because, on the one hand, the annual thermal amplitudes were quite weak and, on the other, because the state of Portugal's economic development is not compatible with the generalised use of the incredibly varied range of equipment which can be used to create a more comfortable ambience in the interior of buildings.

From what we have observed during this phase of the book, the energetic excesses which sustain Oporto's climatic subsystem and justify the positive thermal anomalies, particularly significant in some points of the city, are above all due to the association of intense traffic, great compactness of the constructed area and irregular topography in these areas.

When trying to establish a spatial scale of the relationships of cause directly implicated in this manifestation of a climatic change, it is possible to find, for instance, that the slight warmth of the coastal sea water during the past twenty years, specially during the Winter months, is not extensive to deeper sea waters.

Although it is not possible to rule out the assumption that this is an effect of the Global Warming (mentioned by some authors in relation to our geographic region), the fact that no relationship was established between the temperature registers made along the coastal waters and the deep waters does not support this theory.

It seems more plausible to believe that the causes that confirm the successive increase of the temperature at Oporto-Serra do Pilar are mainly the consequence of a local greenhouse effect, caused by a hasty urbanisation process which has occurred in the area around the station, specially during the last two decades.

It is important to remember that it was precisely during the 80's that the city of Oporto experienced an unparalleled economic growth. This economic growth was responsible, in terms of space, for an intense pressure on the environment, namely in terms of land usage and alterations in the chemical composition of the atmosphere.

The dependency relationships between the growth of the different urban activities and alterations in the regional thermal pattern were clearly identifiable from the results obtained during surveys carried out in different locations, which revealed and identified heat-island(s) within Oporto.

Neither the topographic differences between the Eastern and Western parts of the region, nor the two water surfaces close to the city (the sea and Douro River), nor even the consequences resulting from the spatial occupation throughout more than eight centuries of History (which brought unique and original features to Oporto), have diminish Oporto's urban metabolic impacts, specially its energetic balance.

Although Oporto is quite far from the model used in this research at its first stage (in terms of the combination of different geographic factors), which made us expect to find a major difference of 6.9ºC between the temperature in the city and in the surrounding area, prove to be quite close to the real situation one would have expected to find, due to its functional and geographical specificity.

The altimetrical differences, the effect of the sea breezes, the climatic effects resulting from the proximity of the Douro River, the differentiated distribution of green areas in Oporto and the different types of urban space occupation, altered the form of the "heat-island", but very seldom are its effects annulled. The alteration or reversal of some of these factors fluctuate according to the physical and chemical characteristics that, at a given moment, the air masses over the area can cause.

The fact that the observed temperature registers within the administrative boundaries of Oporto were always higher than those observed, at the same time, at the station of Oporto-Serra do Pilar, reinforces the relationship of cause between the dimension of the urban phenomenon and the energetic excesses generated. The more so, we have found positive thermal anomalies in register points in the city very similar to those of Oporto-Serra do Pilar.

This relationship of cause-effect, between the rate which the modus vivendi of urban Oporto takes place and the temperature's raise, can be specifically identified by the correlation established between the semi-hourly temperature records in the Av. dos Aliados (Oporto) between the 22nd and the 24th of December 1990.

We recall, to this end, that between 7 a.m. on the 22nd of December (Saturday) and 12 p.m. on the 24th of December (Monday), the temperature increased uninterruptedly. An abnormal behaviour in terms of temperature is only understandable because during those three days the downtown experienced its greatest vitality period, prolonging it well into the night.

Having demonstrated the existence of impacts on the energetic balance, provoked by the presence of other sources of heat and/or by a greater storage capacity and energy conduction, due to spatial rearranging, artificially produced by Man, we intend to identify the areas where these impacts manifestations are more clear.

After approximately 4 years of experimentation, under the most diverse weather conditions, in different seasons and at varying hours of the day, we verified that the posts included in the areas of Av. Aliados - Pç. República - R. Boavista and Marquês - Constituição - S. Roque registered

temperatures superior to those registered at the other points disseminated throughout the city. This fact led us to determine two potential "heat-islands".

These **two "heat-islands"** coincide with the administrative and functional city centre. The first "heat-island" delimits the coalescence of the main CBD located at Av. da Liberdade, with the secondary CBD around the Rotunda da Boavista. The second includes the points most used by the transport network of best accessibility to the city centre, which serves the East area of the city, apart from being an area where the residential function coexists with a large number of small and medium industries.

In fact, the "heat-island" was specially evident on days of great stability, weak barometric gradient, weak wind and frequent periods of calm. Conditions normally associated with the presence of anticyclonic situations, but which, as we saw, can arise under the influence of depressionary conditions, when the ascendant movement of the air is conditioned by the presence, in altitude, of a "cold drop", or when caused by a strong base heating.

On a majority of the days with turbulence, depressionary areas and anticyclonic margins, what we frequently verified was a disturbance in the explicatory capacity of the two geographic factors considered - distance from the sea and altitude.

Nevertheless, these two geographic factors proved decisive to explain Oporto's thermal nocturnal pattern, on days under the effect of dry, either very hot or very cold, air masses.

It is also significant that there was no particular intensification in the "heat-island" during the coldest time of the year. In our opinion, this did not occur because, on the one hand, the annual thermal amplitudes were quite weak and, on the other, because the state of Portugal's economic development is not compatible with the generalised use of the incredibly varied range of equipment which can be used to create a more comfortable ambience in the interior of buildings.

We have detected that, according to the functional vitality of each of the different Oporto's subareas, there were changes in the intensity of the positive thermal anomalies registered. These frequent positive thermal anomalies were definitely associated with a greater density in the use of space, heavier traffic areas, areas with a higher anthropic heat sources, etc.

Therefore, it seems reasonable to say that the energetic excess that provisions Oporto's climatic subsystem and sustains the positive thermal anomalies, particularly significant in some areas of the city, are due, mainly, to the association (in those areas) of heavy traffic, high density of urbanisation and irregular topography.

Although all arguments favour the local greenhouse effect (induced by the growing urbanisation process in Oporto) as the most plausible hypothesis for these climatic changes, the good conditions of dispersion or cleaning of the atmosphere in the region of Oporto restrains us to deepen this possible explanation, unless we first determine the chemical composition of the low atmosphere.

In fact, we have detected several potential dangerous sequences, even for short periods of exposition in June, August, September and October 1988 and July 1989. In some of these examples, the high levels of SO_2 lasted 8 days.

The selection of the days in which there were higher concentrations of SO_2 resulted in the definition of two different groups, according to the most polluted days. The posts outside the city have more frequently registered the highest concentrations between June and October. The posts in the city reached, or even surpassed, the maximum accepted limit, more frequently in the period between December and March.

This complementarity in terms of the highest concentrations of SO_2, during the same period of the year and in two geographical areas so close to each other, can only be understandable if we accept, at the same time, a diversity of sources and local atmospheric dispersion conditions.

Any intention to demonstrate conclusively the relationships of causality implied by the maintenance of extremely high concentrations of SO_2 in some areas would be pretentious, but it seems to us that the set of facts and/or coincidences collected during our attempt at understanding the mechanisms involved in this phenomenon can help to clarify it.

In the first place, through a comparative analysis of the daily records taken at each post of some climatological elements on days of greater concentrations of SO_2, it is possible to define what we designate as the climatological profile of the most polluted days.

Included in this climatological profile are the days of moderate temperature, without precipitation, with relative insulation above 50%, high solar radiation, medium average cloud cover below 5/10, weak wind and from the predominant ESE quadrant, for the centre of the city, and from ESE or NNW for the posts exterior to the city.

Secondly, we demonstrated statistically that, while at the posts on the city's periphery the most polluted days occurred preferentially in the presence of the Atlantic Subtropical Anticyclone, at the posts located in the interior of the city, despite having predominated under the effect of anticyclonic situations, they did not occur in the presence of any subtype in particular.

We also verified that the sources which are potential suppliers of SO_2 on the outskirts of the city and within its interior, are very different, be it in relation to the quantities emitted, be in relation to their distribution in area.

From the conjugation of this set of facts it was possible, even if controversial, to suggest some explanatory hypotheses for the diversity of causes which condition the accumulation of SO_2 at the posts located within the city of Oporto's interior and on its outskirts.

The predomination of greater concentrations of SO_2 during the period from June to October at the posts on the city's periphery can be justified by the frequent presence, at this time of the year, of the Atlantic Subtropical

Anticyclone, with which a low thermal inversion is normally associated. The excellent conditions of atmospheric stability, reinforced by the inversion, contribute decisively towards the difficulty in dispersion of the SO_2 released in this area, primarily by the Petrogal Refinery. Although the predominant direction in this area occurs from NW, the wind's low speed does not permit that the pollutants released in this area move away from the emissary sources. It is perhaps due to this that they do not affect the city of Oporto, at least in its Southern half, which would fall within their trajectory.

In Winter, even though the contribution of the main emissary source is not different, the fact that the air circulation occurs in the whole area from the E quadrant, helps us to partially understand the lesser occurrence of high concentrations of SO_2. The effluents emitted tend to be conducted W of the coastal line, maintaining or precipitating over the ocean.

In the city, the number and type of emissary sources of SO_2 are very different. Although they emit individually much less quantities of SO_2, the potential sources of SO_2 in the urban area, due to their great dispersion, particularly in the oriental half of the city, substantially hinders the detection of cause-effect relationships which we seek. So much so that this large dispersion of sources, in spatial terms, is associated with restrictions imposed by the topographical differentiation and by the large and complex multiplicity of microclimates generated within the city's interior.

The importance of local factors is, moreover, quite patent in the great variability of the synoptic situations present on days of high concentrations of SO_2 at the posts in the city centre.

However, the fact that we verified that the predominant quadrant of the wind, at any of the climatological stations, in the period from December to March, is from E, excludes the possibility of the SO2 accumulated in Oporto's atmosphere proceeds from the industrial pole in the NW of the city and leads to deduce that the high concentrations of SO2 registered, at this time of the year, in the city's interior, proceeds from within the city itself.

The winds proceeding from the E quadrant can accumulate great quantities of pollutants, seeing as they cross over the whole of the oriental area of the city, where the largest number of potentially pollutant industries are located. This, in association with the mechanic subsidence provoked by the fact that they pass from the highest area of the city to less elevated surfaces, can justify, in part, the high concentrations of SO_2 recorded at the posts in the city centre.

In Summer, the predominant winds from the W and NW quadrants can function as effective agents of Oporto's atmosphere clean up, as they transport the SO_2 emitted in the city out of its limits. The most elevated surfaces, in the city's oriental area, now contribute towards promoting the mechanical ascension of the air proceeding from W and its eventual dispersion.

However, knowing that at any time of the year, in the urban centres and, in particular, in Oporto's, owing to the great compactness of constructed area, there are rarely good conditions of air ventilation and dense layers of mixture, essential to an effective atmosphere clean up, it is not possible to understand why there exists the predominance for episodes of greater pollution at specific times of the year.

However, it is precisely between December and March that low thermal inversions occur with more frequency in the area, and these promote an additional decrease in the density of the mixture layer.

We could, therefore, think that the peaks of pollution in the city, apart from representing the pollution generated in the city itself, only manifest themselves when, together with the local climatic factors, occur other restrictions related with the vertical structure of the atmosphere, namely the presence of low thermal inversions.

This proven state of progressive degradation and the already worrying quality of the air over the region of Oporto has, in our opinion, definitely reinforced the argument in favour of the regional scale of these modifications in the energetic balance, by demonstrating that, although good conditions of atmospheric dispersion characterise this region, the local greenhouse effect has been increasing primarily at the on account of the excretions emitted into the atmosphere by the urban metabolism.

After having emphasised the magnitude and intensity of the impacts provoked by Man on one of the urban Ecosystem's components, we now wish to demonstrate how the latter is become more and more hostile to Man.

This was exactly what we tried to do when we sought to relate the results of the modifications detected in some of the climatological parameters and the degradation of the quality of the air in the region of Oporto with the aggravation of certain pathologies.

Asthma attacks, as well as bronchitis attacks have developed and worsened in children with less than 10 years, on days when the minimum, medium and maximum temperatures and when the relative insulation were higher than the total average for the period considered (1/4/87 to 31/3/91). A majority of the 494 cases of asthma and of the 96 cases of bronchitis detected occurred during the Winter months, precisely on days when the temperatures was slightly higher than the monthly average.

As we verified that, during the analysis carried out, there exists a coincidence between the period in which the largest number of asthmatic attacks were identified with the time of the year in which an increase in the pollution peaks at the posts located within the city, as well as with the time of year in which the "Heat-island" intensified, we only wish to suggest one of the many possible examples of our frail capacity of physiological adaptability to slight nuances in the Ecosystem in which we are integrated.

In our opinion, this example is highly relevant and, taking into consideration the decisive role attributed to cities in the future, again as a motor of regional development, though now with basis on its image, and on the quality of life and well-being that it is able to offer, we cannot avoid criticising, as an example, some of the

planning actions foreseen in the Plano Geral de Urbanização - PGU (General Plan of Urbanisation), whose intended effects may prove difficult to achieve in their totality, due exclusively to the absence in its conceptual phase of these and other environmental components.

The knowledge of several urban thermal patterns during the diagnostic phase of the P.G.U would have alerted the decision-makers to, for example, the importance of restricting, apart from the volumeteries, the construction materials, the colours of the façade, in certain areas of the city.

The valorisation of the importance of the NNE-SSW topographical differentiation associated with great frequency, in this area, with winds from the E quadrant, in promoting the degradation of the quality of the air in the central areas of the city, in detriment of the inputs generated in the oriental area of the city, could, for example, lead the decision-makers to imagine the order of the grandeur of the impacts, provoked by the increase in the number of emissions throughout the new internal ring-road (Via de Cintura Interna), on the quality of the air in the central nucleus of the city, which this infra-structure was intended to protect.

If it is certain that we now understand, even if only a little better, the mode of functioning of Oporto's urban ecosystem and, above all, are surprised with the magnitude of the impacts detected in the energetic balance and verified through the intensity of the "heat-island(s)", in a geographic conjecture where all the factors contribute towards its dilution, there remain many doubts and uncertainties.