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Impact of the Transport on the Urban Heat Island

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***Abstract*—**The development of transport systems has negative impacts on the environment although it has beneficial effects on society. The car policy caused many problems such as: - the spectacular growth of fuel consumption hence the very vast increase in urban pollution, traffic congestion in certain places and at certain times, the increase in the number of accidents. The exhaust emissions from cars and weather conditions are the main factors that determine the level of pollution in urban atmosphere. These conditions lead to the phenomenon of heat transfer and radiation occurring between the air and the soil surface of any town. These exchanges give rise, in urban areas, to the effects of heat islands that correspond to the appearance of excess air temperature between the city and its surrounding space. In this object, we perform a numerical simulation of the plume generated by the cars exhaust gases and show that these gases form a screening effect above the urban city which cause the heat island in the presence of wind flow. This study allows us: 1. To understand the different mechanisms of interactions between these phenomena.2. To consider appropriate technical solutions to mitigate the effects of the heat island.

***Keywords*—**Atmospheric pollution, impact on the health, urban transport, heat island.

Nomenclature

F*	net energy received, J
FD	directly radiated solar energy, J
Fd	diffusive radiated solar energy, J
U0	wind velocity, m/s
T0	Initial temperature, K
Y0	fraction of Co2
k	turbulent kinetic energy, J
R	constant of perfect gas
Dm	diffusivity coefficient
Sc	Schmidt number

Greek Letters

Φ	*a* production of human energy, J
Φ_H	means sensible energy heating the lower layers of air, J
Φ_E	latent energy carried by evapotranspiration, J
Φ_S	stored energy in buildings, J
ρ	Density, kg/m3
ε	dissipation of the turbulent kinetic energy
mt	turbulent viscosity
$\Phi_L^{\uparrow}$, $\Phi_L^{\downarrow}$	Latent and sensible heat, respectively, J

I. Introduction

URBANIZATION is one of the major events of the modern world due to its progress at a pace that tends to accelerate. Today there are more than 3 billion urban dwellers and, by 2025, there could be three quarters of the population or even 80 % of the world population living in urban cities [1].

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This urbanization causes an increased need for mobility in conjunction with the expansion of trade and the improvement of accessibility to different parts of the globe which then leads to congestion in traffic. Urban centers are often developed according to specific natural settings and thus in singular conditions. Thus, the transport will concentrate mainly in the urban areas and its impact will therefore appear dramatically on the environment and the atmosphere that lead to climate change. Cars and vehicles contribute to heat emission in urban areas. The total heat emitted by vehicles may remain trapped in poorly ventilated urban canyons, thereby reducing the thermal comfort of city dwellers. Vehicle emissions also contribute to the formation of urban smog and global warming [2]-[4], Climatic conditions and urbanization have harmful effects on society directly through the most intense heat waves that can give rise to what was called the effect of urban heat island and the latter occurs because of urban microclimates and higher summer temperatures. According to observations, this temperature difference, mainly due to the urban built environment, varies between 2 and 12°C and is particularly threatening for the urban population [5]. The changing demands of summer comfort in buildings and air conditioning have vastly grown recently. Thermal loads could be doubled by the heat island effect, while the coefficient of performance (COP) of air conditioning systems could be reduced by 25% [6]. The densification of cities and the overall increase in energy consumption cause the increase of the energy dissipated, and air conditioning systems represent a significant contribution as their load increases with warming. This allows us to schematize this issue by Fig. 1. There is also the phenomenon of convection: when the air is heated by the city it rises as it expands and becomes lighter than cold air. In short, it cools and falls. Thus creates a "dome" above the city where air masses move in an upward motion.

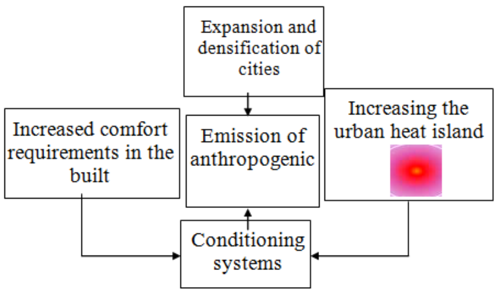


Fig. 1 The structure of the interaction of urban densification and comfort requirements of the building that cause the increase of the effect of the UHI

II. Urban Heat Island Phenomenon

A. What is an Urban Heat Island?

An urban heat island is defined as an urbanized area characterized by higher summer temperatures than the surrounding environment, [7]. The discovery of this physical phenomenon dates back to 1833, when [8], has undertaken a study of the temperature of the air in London and its surroundings Fig. 2. The wind in the city is the result of the upward movement of warm air masses to the cold regions. In the urban context, where the heat differences are much more numerous, and cause the emergence of breezes, Fig. 2, that is to say weak winds turn cold areas to warmer areas. This is particularly important in the context of the urban heat island: this causes breezes from the countryside to the city, but even within the city, between, for example a park, colder and hot streets, or even within the same street. These breeze campaigns create a dome effect over the city and are particularly harmful during peak pollution.

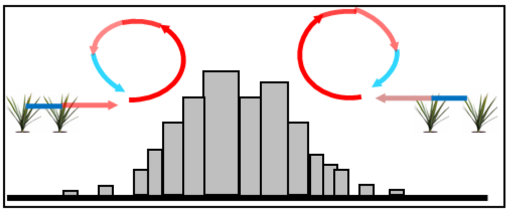


Fig. 2 Thermal breeze from rural to the city

Typically this temperature excess is of about DT = 2-4 °C which depends on the population and the wind speed in the following form [4];

$$\Delta T_{(u-r)MAX} = \frac{P^{0.25}}{(4U)^{0.5}} \qquad (1)$$

TABLE I
ICU Intensity ICU Versus Wind Speed in Paris City Center

Wind speed m/s	ICU Intensity
1	4.5
2	3.4
3	3.4
4	2.6
5	2.2

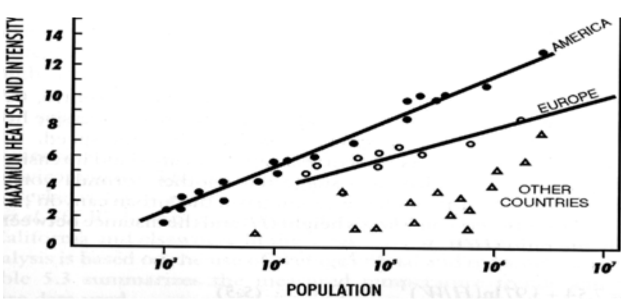


Fig. 3 Evolution of the maximum intensity of the ICU [8]

This excess varies depending on the size of the agglomeration Fig. 3, season, location, time, and the speed of the wind, see Table I. These phenomena are associated with frames and more dense urban areas. They are caused by the absorption of solar energy by urban areas, mainly dark surfaces such as roofs and pavements. Part of this energy is reflected (Albedo).

B. Factors Contributing to the Formation of Urban Heat Island

In urban areas, roofs, walls of buildings, are important factors in the formation of urban heat islands. Indeed, the fact of reduction of green space and changing it with materials that absorb heat promotes the formation of heat island since these materials once they have absorbed heat during the day to emit it overnight. Referring to Fig. 4, we find the Albedo values for different types of urban surfaces. Albedo measures the amount of solar energy reflected by a surface, [7]. Albedo is a measure of the ability of a surface to return the incident solar energy (which comes to the surface of the earth). It is a number between 0 and 1 (0 being a perfectly black surface which absorbs all the incident energy and 1 in perfect mirror that reflects all of the incident energy). A low Albedo means higher energy absorption and higher surface temperatures. Contrariwise, if the Albedo is high, it means cooler temperatures. In this case, we can see that the asphalt (Albedo 0.05-0.20) and tar and gravel (Albedo 0.3 to 0.18) are favorite places for urban heat islands. In addition, the black surfaces exposed to the sun can become hotter than the white surfaces, in order of 21°C. We can then say that a potential method of reduction of heat island is to use high Albedo roofs for very dense cities, consisting of older and low-rise buildings in hot and sunny climates. With the high use of air conditioning, the presence of a heat flux related to district heating, traffic and industrial activity are also significant factors that contribute to the formation of urban heat islands.

Finally, the current climatic conditions experienced more frequent periods of extreme heat contributing to increases in minimum and maximum temperatures and. An increased number of days of extreme heat once again favor the formation of urban heat islands Fig. 5.

C. Consequence of Urban Heat

The urban heat islands increase electricity consumption for air conditioning. So it takes more energy to meet this need, which results in an increase in air pollution in the form of smog and sulfur dioxide and greenhouse gas emissions, [9]. The urban heat island can make life difficult for people with respiratory illnesses. The dispersion of pollutants will be even stronger when the wind speed is high. The turbulence can be described to be as similar to the molecular motion occurring on a large scale movement. This phenomenon governing the exhaust gas of cars in urban areas is one of the most difficult issues to treat mathematically. Our study is an attempt which will focus on the contribution and influence of transport on the phenomenon of the urban heat island.

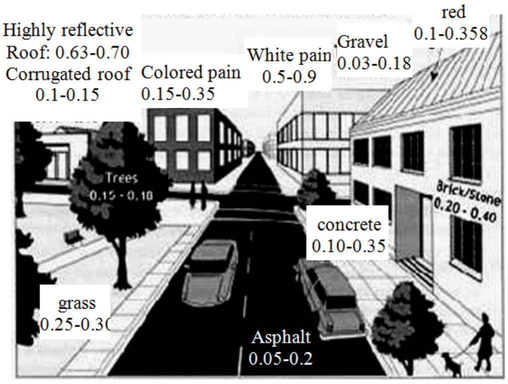


Fig. 4 Albedo values of an urban area

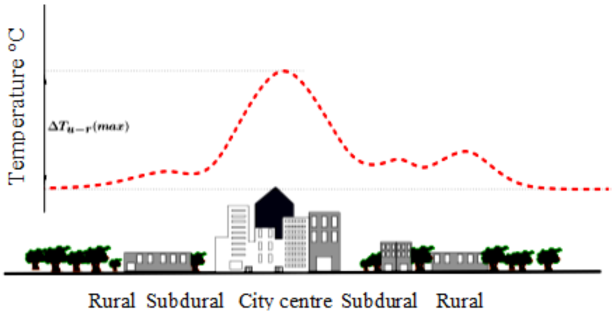


Fig. 5 Thermal profile of urban the heat island

III. Mathematical formulation

A. Physical Analysis of the Phenomenon

To answer the above questions, it is necessary to emphasize the differences between the city and the surroundings. Basically the city has a significant roughness forcing the air to rise and change the energy balance. A floor cover which inhibits the anthropogenic evaporation phenomenon leads to the production of energy emission of large amounts of pollutants. In the area of urbanization normal energy balance is written as:

$$\Phi^* = (\Phi_D + \Phi_d)(1-a) + \Phi_L^{\downarrow} + \Phi_L^{\uparrow} \quad (2)$$

where Φ^* is the net energy received, Φ_D is directly radiated solar energy, solar energy Φ_d is scattered by aerosols, $\Phi_L^{\downarrow}$ and $\Phi_L^{\uparrow}$ are latent and sensible heat respectively. The infrared balance $(\Phi_L^{\downarrow} + \Phi_L^{\uparrow})$ is averaged, in effect; the fraction $\Phi_L^{\downarrow}$ of the radiation of the atmosphere tends to increase due to large number of aerosols that trap solar energy and converts it into infrared which is especially sensitive at night. This explains in part the island heat at night, despite the fact that infrared balance may change. To explain the presence of the urban heat island, we must take into account the energy received by the community. This consumption is as follows:

$$\Phi^* + \Phi_a = \Phi_H + \Phi_E + \Phi_S \quad (3)$$

where Φ_a is the production of human energy which is mainly due to industry and transportation, Φ_H is the sensible energy heating the lower layers of air, Φ_E is the latent energy carried by evapotranspiration and Φ_S is the building storage energy. To highlight the impact of transport on the heat island effect, we focus on the part of the energy generated by urban transport.

B. Physical and Mathematical Model

In the context of interest here, the development of these means of transport could reduce emissions of anthropogenic heat involved in the heat island effect, especially in the summer regarding the automobile Fig. 6. We can approximate the gas transportation (including cars, for example) by panache of gas coming out of a chimney height Fig. 6. The presence of significant concentrations of soot in these plumes also causes their heating by absorption of radiation, which contributes to their ascent. Processes affecting pollutant concentrations during transport are complicated, often non-linear, and cannot be investigated solely from the observations. It is therefore necessary to use numerical models to represent and assess their impact on the plumes [9].

Fig. 6 Urban transport also contributes to the formation of heat islands

Auto emission is likened to a chimney that removes these air emissions (carbon dioxide and air in our case) with a speed U_0 and temperature T_0 and a fraction Y_0 of pollutant (CO_2) see Fig. 7 (a). A plume which is subjected to the wind velocity U_0 and temperature T is obtained. Automobile emissions are assumed to be a mixture of gases ejected in the road by a chimney as presented in Fig. 7.

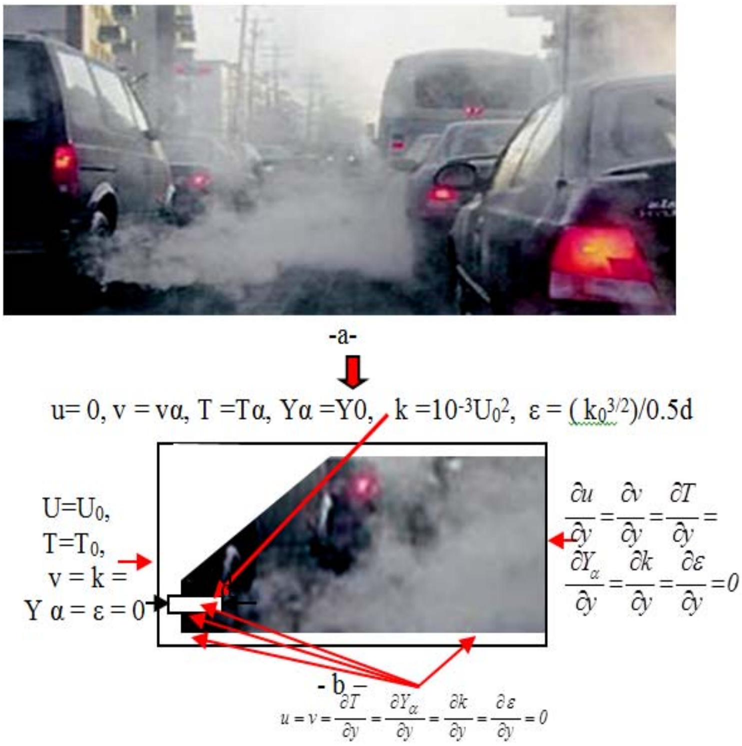


Fig. 7 (a) Gases cars, (b) Industrial chimneys

Under the conditions that the flow is considered 2D, incompressible, obeying the Boussinesq approximation, and turbulent and stationary, the wind speed is constant and the temperature gradient in the atmosphere is neglected. The study site and the reactive gas are a rectangular area, the equations governing the flow of these emissions can therefore be written:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho U_j)}{\partial x_j}=0 \tag{4}$$

$$\frac{\partial \rho U}{\partial t}+\frac{\partial(\rho U_i U_j)}{\partial x_j}=-\frac{\partial(P+\frac{2}{3}\rho k)}{\partial x_i}+\frac{\partial\left[(\mu+\mu_t)(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_J}{\partial x_i})\right]}{\partial x_j}+S_{vitesse} \tag{5}$$

$$\frac{\partial \rho C_P T}{\partial t}+\frac{\partial(\rho C_P T U_j)}{\partial x_j}=-\frac{\partial\left[(\lambda+\frac{\mu_t}{\Pr_t}\rho k)\frac{\partial T}{\partial x}\right]}{\partial x_i}-\frac{\partial[(U_i\tau_{ij}]}{\partial x_j}-\sum_1^n(h_\alpha^0+h)w_\alpha \tag{6}$$

where

$$\tau_{ij}=\mu(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}),\ h=\sum_1^n Y_\alpha h_\alpha, h_\alpha=\int_{Tref.}^{T} c_P dT, P=\rho T\sum_{\alpha=1}^n\frac{Y_\alpha R}{M_\alpha} \tag{7}$$

For the fluid mixture one must solve the equation of mass transfer of species:

$$\frac{\partial \rho Y_\alpha}{\partial t}+\frac{\partial(\rho U_i Y_\alpha)}{\partial x_j}=\frac{\partial}{\partial x}\left[(C_P D_m+\frac{\mu_t}{SC_\alpha})\frac{\partial \rho Y_\alpha}{\partial x_j}\right]+w_\alpha \tag{8}$$

with $w_\alpha = b_\alpha Y_\alpha + c_\alpha$ *and* D_m is the diffusion coefficient of the species with the boundary conditions and the use of the k-e model. The Numerical simulation gives the results presented in section of results and discussion.

V. Results and Discussion

Fig. 8 shows the streamlines obtained for a Reynolds number of 10^5. Analysis of these graphs shows that the state of the gas escaping from the chimney is characterized by a vortex that forms behind the chimney and presents an obstacle to the flow. The presence of the vortex traps many particles thus leading to an accumulation of the pollutant near the chimney. This result is in agreement with that reported by [9]. This accumulation is involved in the formation of heat islands.

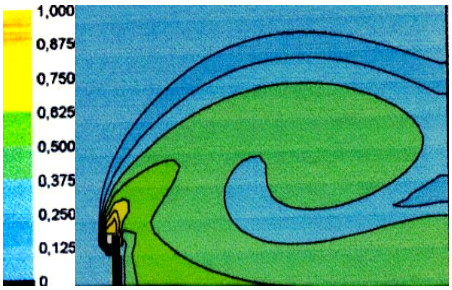


Fig. 8 Streamlines of the flow

Fig. 9 shows the contours of the turbulent viscosity. For a heterogeneous distribution of the latter we see that the area where this accumulation is important is in the recirculation zone corresponding to the maximum kinetic energy where it decreases moving upwards.

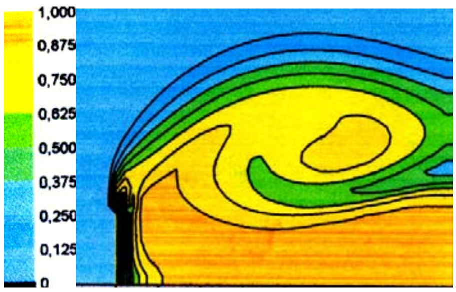
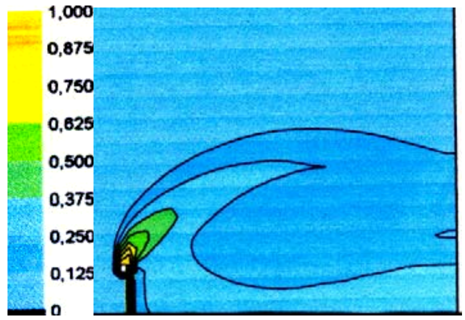


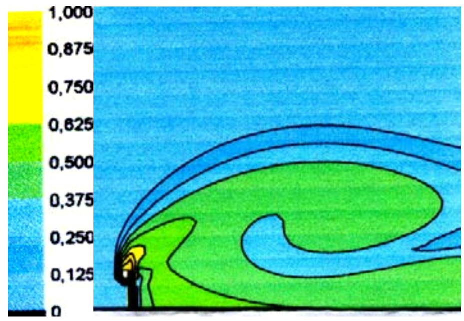
Fig. 9 Iso-contours of turbulent viscosity

Iso-contours of the turbulent energy and dissipation, shown in Fig. 10, show that the energy of turbulence, k, is conveyed downstream along the field so that its dissipation has a maximum value just at the outlet of the chimney. This explains the increase in temperature in this region than elsewhere.

Fig. 11 shows that the hottest areas are located in the recirculation zone which is usually just above the centers of cities. This further magnifies their risk of pollution (CO2) generated by the combustion of hydrocarbons, which participates in the formation of the greenhouse effect, especially when the wind speed is not zero. In the case of a heat island, at ground level, the isotherms close around the city. Over time the temperature increases, Figs. 11 (a)–(d), and when the wind is moderate a phenomenon known as urban panache develops and defines the urban boundary layer. However it forms a cell which promotes the dome of pollutants and the stagnation over a city and a slow convective flow [10].

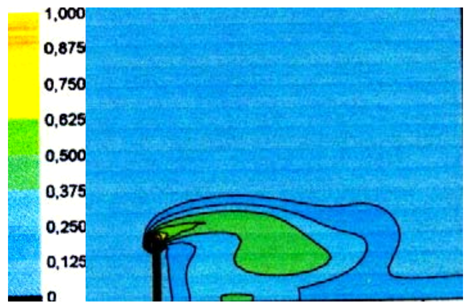


(a)

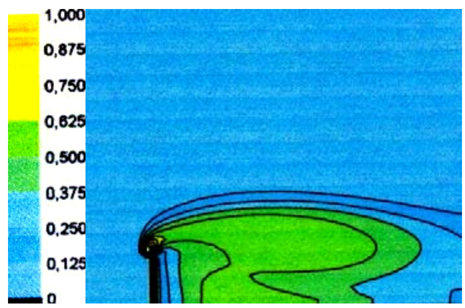


(b)

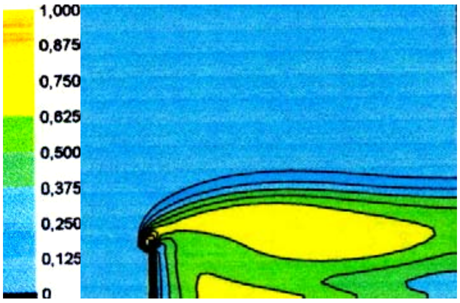
Fig. 10 Iso-contours: (a) Energy of turbulence, (b) Its dissipation



(a)



(b)



(c)

(d)

Fig. 11 Dimensionless temperature contour's for different dimensionless times

To significantly reduce the impact of traffic, the objective is to seek to reduce the use of cars. And this can only be achieved through an approach to promote the use of active and public transport, while reducing the number of parking spaces, creating a pedestrian environment, and making the vegetation of the city. Two factors contribute to the raising of a plume emitted from a point source (exhaust): i- The strength of convective flow; ii- Buoyancy due to heat plume relative to middle ambient.

VI. Conclusion

The ICU is an urban effect given consideration in the design and management of the city. As the phenomena of ICU, climate change and air pollution are interrelated ways to implement a fight against these problem. It is therefore essential to work towards reducing the emissions potentially toxic to humans and the environment, ejected by the major sources recognized as urban transport. In this context, we consider the industrial use of hydrogen as a fuel to replace fossil hydrocarbons. Indeed, the gases produced by combustion contain no CO2 or CO or soot and unburned hydrocarbons [11]. The fight against the ICU also requires a reassessment of planning policies and implies preference of white or colored surfaces, reforesting cities, developing transport, and real changes in the behavior of future users of transportation which will not be achieved through an approach to promote the use of active and collective transportation.

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