Thermal Analysis of the Urban Canyon Based on the Variables: Orientation, Wind and Vehicular Anthropogenic Heat

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Abstract. The city and its behavior in the transfer of heat, generates lines of research that study phenomena such as the Island of Urban Heat (ICU); Within its formation factors, the heat expelled by the vehicle is the least analyzed in the literature. Thanks to the Computational Fluid Dynamics (CFD) software and its validation with measurements in the field, data is acquired to examine the thermal behavior in an urban canyon based on the number of cars passing through it and the heat expelled by its engines, the speed of the wind and orientation. The results show that the temperature increases between 26% to 10% more, and the highest values are in the simulated cases with a north-south orientation, affecting the passer-by as to the energy efficiency of the buildings.

1. Introduction
The knowledge of urban climate today, is an issue that concerns all specialists involved in the planning of cities. Situation that, when not being considered, leads to the increase of the phenomenon of the Island of Urban Heat (rise of internal temperatures in comparison to its surroundings) [1]. And, therefore, to an excessive use of electrical energy to solve the thermal conditioning of the space.

All the factors involved such as: a) the decrease of the green area, b) the low wind speed due to the high density of the building, c) the lining materials of the construction surface and d) the anthropogenic heat (vehicular combustion, of energy and human metabolic heat), have generated this problem in the outer spaces, so they are issues that must be addressed in depth to be handled properly and thus achieve the balance that satisfies both the population and the integration of cities in sustainability so demanded today.
Considering that the research uses different urban scales to determine the weighting of each of these factors. In this work, the urban canyon is used, which according to Stromann-Andersen & Sattrup [2] is a simple basic urban structure that offers, in field measurements, data with repetitive patterns and his form is defined as a microclimate [3].

In the present work, the variable to investigate is the anthropogenic heat \( Q_{FV} \) that occurs in the urban environment due to vehicles \( Q_{FV} \). According to Sailor [4], the inclusion of \( Q_{FV} \) has significant implications for urban climate, air quality and energy demand. A proposed way has been the estimation associated with the densities of the urban population, coupled with a homogeneous spatial distribution in magnitude and location equal to natural insolation; now it is known that the magnitudes are locally different in Wm\(^{-2}\) and it depends on the location and time.

According to Lin et al. [5], within mesoscale urban modeling, software uses established parameters such as 90, 50, and 20 Wm\(^{-2}\), respectively, for high, medium, and low density urban categories [6]. Currently, research such as Dong et al. [7] seek the estimation of these values in more detail in several cities, giving results: Hong Kong (493), Singapore (353), New York (297), Portland (188), Macau (185), Seoul (175), Pusan (147), Montreal (147), Chicago (141), and Tokyo (141) (unit: Wm\(^{-2}\)).

The analysis of Sailor and Lu [8] suggests that, in cities such as Houston, the total anthropogenic warming of the vehicle sector is 300 Wm\(^{-2}\) during the afternoon peak hour. In Beijing a study, has identified a correlation with \( Q_{FV} \) (53.9 Wm\(^{-2}\)) and the amplifying of the temperature from 0.91°C at 8:00 am, as well as the conclusion that the average heat intensity of the vehicle during the day it is 2 to 10 times the intensity during the night [9].

To estimate \( Q_{FV} \) and its weighting in the temperature patterns of an urban canyon, this document uses a three-dimensional idealized configuration model, to be analyzed by the CFD software; the results are validated against measurements taken in the field.

### 2. Description of the Simulation Model

In this investigation, the heat transfer calculations are solved through the unstructured finite volume solver ANSYS FLUENT 14.5, in general, according to Mirzaei [10], the urban environment can be investigated using CFD software.

An air volume of 190x180x60 meters was idealized, from which two rectangular 100x50x10 meters are subtracted to define two block blocks with a separation of 10m, resulting in an aspect ratio H/W=1 (height of buildings between widths of the street). The separation of the two blocks simulates the urban canyon, from which the volumes of the cars are extracted. The maximum number of cars is 20 units, followed by simulations with 15, 10, 5 and 0 cars to determine the thermal behavior of the canyon.

Another variant in the simulation is the orientation of the canyon, obtaining two more variables, North-South and East-West. The materials used in the simulation are specified in table 1, as well as their thermal and radiation properties, all based on [11].

| Materials   | Thickness (m) | Density (Kg/m\(^3\)) | Specific Heat (j/kg-k) | Conductivity (W/m-k) | Emissivity \( \varepsilon \) |
|-------------|---------------|-----------------------|------------------------|----------------------|-----------------------------|
| Ground      | 0.20          | 2,300                 | 840                    | 1.00                 | 0.90                        |
| Wall Flattened | 0.15        | 1,570                 | 1,000                  | 0.53                 | 0.90                        |
| Bodywork    | 0.01          | 7,850                 | 456                    | 50                   | 0.50                        |

The model assumes that the flow of heat has as properties to be constant, isotropic and without viscous dissipation. The Reynolds Avaraged Navier-Stokes (RANS) equations are used, and for the turbulence model K-epsilon Realizable Model is applied, together with the option of Scalable Wall Functions for the treatment in the vicinity of the walls. The Radiation model, Surface to Surface, is also used, and using the Solar calculator, the radiation values in the model are estimated with the coordinates where the field data were taken for the validation.
The border conditions used were: the symmetry on the sides of the volume; on the back the condition of constant pressure was fixed; for the front face, a wind speed of 0.0, 1.2 and 2.2 m/s is set; the buildings, the pavement and the car were established as walls that intervene in the radiation. To simulate the heat that the cars issue, a constant temperature of 60°C was established in the hood.

3. Validation

The values obtained by the simulation are compared with measurements taken in the city and port of Veracruz, Mexico, with geographic location of 19°10'51" north latitude and 96°08'34" west longitude, and altitude above sea level of 15 m. The average temperature in the city is 32 °C with 70% relative humidity. For more information on the methodology refer to [12]. As shown in the graph, the behaviors are very similar, however, there are variations of 0.1 to 1°C (figure 1). The explanation to the variation can be given to the entry of the wind creating vortices in the ends of the canyon and therefore altering the values obtained in the field measurements.

4. Results and Simulation

The results show, in relation to the number of cars an expected rise in temperature, however, the increases, although they are progressive, were not proportional. According to table 2, if the initial value of the canyon is taken with zero cars as a base and a comparison is made with the 5, 10, 15 and 20 canyons, the following can be observed: a) the East-West oriented canyons with five automobiles, at any wind speed the average thermal gain is 0.70%, b) on streets with E-O orientation, with 10 units the increase is 1.7%, however, there is a clear difference of almost 2.5°C with the North-South orientation, c) the E-O orientation values, with 15 and 20 units become stable with 2.6% to 2.9% more gain and d) a progressive increase of 2% in the N-S orientation is observed for every 5 units that are added.

| Initial Value- | 0 cars | 5 cars | 10 cars | 15 cars | 20 cars |
|---------------|--------|--------|---------|---------|---------|
| 0.0m/s E-O    | 32.12  | 0.8%   | 2.4%    | 3.5%    | 3.3%    |
| 1.2m/s E-O    | 38.39  | 0.7%   | 1.5%    | 2.5%    | 3.0%    |
| 2.2m/s E-O    | 30.79  | 0.5%   | 1.2%    | 2.0%    | 2.5%    |
| 0.0m/s N-S    | 35.12  | 2.0%   | 3.7%    | 5.4%    | 9.1%    |
| 1.2m/s N-S    | 30.61  | 2.2%   | 4.5%    | 6.5%    | 8.6%    |
| 2.2m/s N-S    | 34.18  | 2.1%   | 4.5%    | 6.5%    | 9.1%    |

Regarding the wind speed, the E-O oriented canyons between a wind of 1.2 and 2.2 do not vary much with a general loss of 1.6°C, but the N-S, as shown in table 3, with a wind of 1.2 m/s, the loss is 3.3°C in general and when the value increases to 2.2 m/s the loss is a difference of 1°C more.
Table 3. Table of losses due to the effect of wind in °C.

| # Cars | 0.0m/s E-W | 1.2m/s E-O | 2.2m/s E-O | 0.0m/s N-S | 1.2m/s N-S | 2.2m/s N-S |
|--------|------------|------------|------------|------------|------------|------------|
| 0      | Base value in °C | -1.5       | -1.3       | -3.3       | -4.2       |            |
| 5      | 32.12      | 32.37      | 32.88      | 39.39      | 39.16      | 39.82      |
| 10     | 32.37      | 32.88      | 33.22      | 39.16      | 39.82      | 40.48      |
| 15     | 33.22      | 33.18      | 33.18      | 40.48      | 41.87      | 41.87      |
| 20     |            |            |            |            |            |            |

The smallest amount of increase of the thermal profile in the urban canyons, are those oriented East-West, that is, with façade facing north and south, taking them as a base, when there is no wind, from 0 to 15 cars the gain is on average, 20%, however, rises to 26% when 20 units or cars are reached (table 4).

Table 4. Percentage table according to the increase in °C due to orientation.

| # Cars | 0.0m/s E-W | 1.2m/s E-W | 2.2m/s E-W | 0.0m/s N-S | 1.2m/s N-S | 2.2m/s N-S |
|--------|------------|------------|------------|------------|------------|------------|
| 0      | Base value °C | -1.5       | -1.3       | -3.3       | -4.2       |            |
| 5      | 32.12      | 32.37      | 32.88      | 39.39      | 39.16      | 39.82      |
| 10     | 32.37      | 32.88      | 33.22      | 39.16      | 39.82      | 40.48      |
| 15     | 33.22      | 33.18      | 33.18      | 40.48      | 41.87      | 41.87      |
| 20     |            |            |            |            |            |            |

5. Conclusions

Figure 2 shows the average of the air temperatures in each simulation, considering that the incoming wind has a constant of 30°C. As you can see the average temperature of the air ($T_{aw}$) higher, is presented in the canyon with 20 cars with N-S orientation and no wind. The lowest $T_{aw}$ in the canyon with East-West orientation and wind of 2.2 m/s, however, there is not much difference between the temperature that is generated with wind speeds of 1.2 and 2.2 m/s for both orientations.

The North-South orientation of the canyon (facades towards East-West) are those that represent higher elevation in the thermal profile, because the solar path crosses perpendicularly; causing that both the horizontal area (street) and the façade facing east, add twice as much area heated by solar radiation.

We can conclude with base to the results that the investigation threw that a) the majors increases are located in the North-South orientation (facades East-West), b) the wind speed is a very important factor
because in conditions of zero speed the data is greater but the difference between 1.2 and 2.2m/s is not relevant and; c) that the number of cars is indistinct in relation to the wind speed and the temperature decrease, where the E-O orientation loses from 1.5 to 1.8 °C and N-S from 3.3 to 4.6 °C.

An objective to follow is to determine how the temperature is modified taking the width and height of the blocks as a variant. The present information seeks the awareness of having updated data of the $Q_{FV}$ for the simulation of buildings that seek their energy efficiency, in relation to their environment.

References
[1] Santamouris M, Haddad S, Saliari M, Vasilakopoulou K, Synnefa A, Paolini R, Ulpiani G, Garshasbi S, Fiorito F 2018 On the energy impact of urban heat island in Sydney: Climate and energy potential of mitigation technologies, *Energy Build.* **166** 154-64.

[2] Stromann-Andersen J, Sattrup P A 2011 The urban canyon and building energy use: Urban density versus daylight and passive solar gains, *Energy Build.* **43**(8) 2011-20.

[3] Santamouris M 2013 Energy and Climate in the Urban Built Environment, Routledge, 102-38.

[4] Sailor D J 2011 A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment, *Int. J. Climat.* **31**(2) 189-99.

[5] Lin C Y, Chen F, Huang J C, Chen W C, Liou Y A, Chen W N, Liu S C 2008 Urban heat island effect and its impact on boundary layer development and land-sea circulation over northern Taiwan, *Atmosp. Enviro.* **42**(22) 5635-49.

[6] Sailor D J, Georgescu M, Milne J M, Hart M A 2015 Development of a national anthropogenic heating database with an extrapolation for international cities, *Atmosp. Enviro.* **118** 7-18.

[7] Dong Y, Varquez A C G, Kanda M 2017 Global anthropogenic heat flux database with high spatial resolution, *Atmosp. Enviro.* **150** 276-94.

[8] Sailor D J, Lu L 2004 A top-down methodology for developing diurnal and seasonal anthropogenic heating profiles for urban areas, *Atmosp. Enviro.* **38**(17) 2737-48.

[9] Wang Y, Sun R, Chen L 2017 The impact of vehicle emissions on microclimate in Beijing, *metropolis. Acta. Ecolog. Sinica.* **37**(3) 953-9.

[10] Mirzaei P A 2015 Recent challenges in modeling of urban heat island, *Susta. Cities Soci.* **19** 200-6.

[11] Cengel Y, Ghajar A 2011 Heat and mass transfer. Fundamentals and applications (4th. ed.). Barcelona: McGrawHill.

[12] Grajeda R, Alonso E, Esparza C 2018 Vehicular Anthropogenic Heat in the Physical Parameters of an Urban Canyon for Warm Humid Climate, *34th Int. Conf. Passive Low Energ. Archite.* **1** 225-30.