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The hourly profile of the anthropogenic component of the surface energy balance for the urban region of the Mexico City

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1. Introduction

In Mexico City the surface energy balance has been measured on several occasions, allowing only an indirect estimation of the anthropogenic component (**Q_F**). The latter study was conducted in 1998 (Oke, T. and Jauregui, E., 1999) in central Mexico City during dry season. From direct observation of the net radiation it was estimated a value for **Q_F** of about 20 Wm^{-2}. In this paper we show the hourly profile of this component, estimated from four main subcomponents, transport, industry, building and human metabolism. The average value for this subcomponents in a 24 hour period, is close to the showed in Oke and Jauregui (1999), 22.6 Wm^{-2}, with a maximum value of 37.7 Wm^{-2}. Each subcomponent was modeled using different methodological approaches and assigning an hourly profile through different time distributions obtained for different purposes, like distribution curves of emissions or daily electricity demand curves, depending on the heat source. For the transport subcomponent it was achieved a bottom-up approach, since more detailed activity data was obtained. But in general, this methodology only allows to disaggregate anthropogenic heat emissions temporarily, but not at lower geographical level. Results of anthropogenic component shows variations close to 300% throughout day. Considering the net surface energy balance, the **Q_F** represents up to 25% (Gartland, 2011), also, this component reaches three local maximum along 24 hours. These maximum values match each of the periods in which there has been observed the formation of urban heat island (UHI). From these results it is concluded that this component should be better studied to determine its relevance in the urban climate of the Mexico City and its influence at different scales.

2. Methodology

The problem of estimating the hourly profile for the anthropogenic component of the surface energy balance need estimate different anthropogenic heat sources using different methodological approaches. In this work four main subcomponents were considered, transport, industry, building, this can be divided into commercial and residential, and human metabolism. Among the assumptions for this subcomponents are that energy from fuel or electricity consumption is released totally as sensible heat, the hourly profile followed from one subcomponent that implies a combustion processes has the same distribution showed by its carbon monoxide emissions or any significant emissions generated during the processes or activity. In the case of electricity consumption, it was assigned the same distribution as the demand curve of electricity (CFE, 2011). Finally, for biological processes as human metabolism, it was assumed an hourly profile integrated by two different activity periods throughout the day.

The fuel used by the transport subcomponent was estimated from characteristics of the vehicle fleet like type, model, annual mileage (SMA, 2012), and energy efficiency (Chavez, B., and Sheinbaum, 2014), the hourly distribution it is the one followed by carbon monoxide (CO) emissions, since the transport sector contributes with 98% of the total CO emissions (SMA, 2012). Also the hourly distribution of CO emissions from stationary sources was used for fuel consumption in industry, for building the heat emissions from fuel consumption were modelled using the distribution obtained for volatile organic compounds (VOC) , it was estimated separately the fuel consumption by commercial and residential building, but in both cases it was used the hourly profile of volatile organic compounds (VOC) emissions since the most representative activities are cooking, heating or steam production through fuels. For commercial sources the VOC emissions are issued from solvents, and in residential from leakage and inefficient combustion of Liquefied Petroleum gas (SMA, 2012) (Figure 1). In the case of electricity consumption for all subcomponents it was followed the hourly profile of the demand curve for the Central Area of the national electricity system (Figure 2). The building and industry subcomponents were estimated considering fuels sold in the region of Mexico City and electricity consumption (Smith, C., Lindley, S., and Levermore, G., 2009).

For the human metabolism was modeled considering the national population recorded by the population census (INEGI, 2012) for each of the towns that make up the Mexico City (SEDESOL, 2012). (Figure 2). And, two different activity periods throughout day (Grimmond, S., 1992) and heat released during these activities considering the metabolism of a person of 70 kilograms.

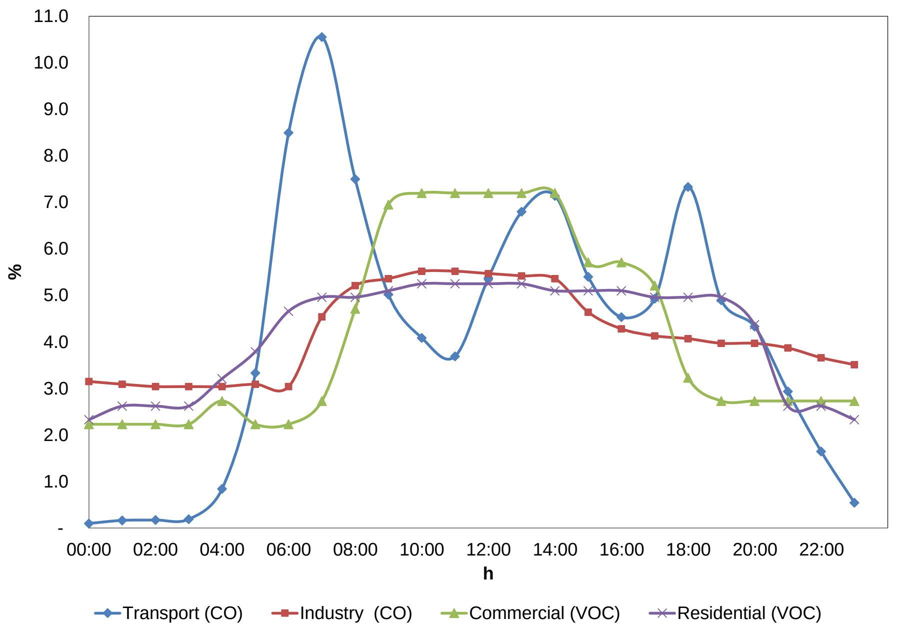

Fig. 1 Hourly distribution for gas emissions from anthropogenic sources, 2010

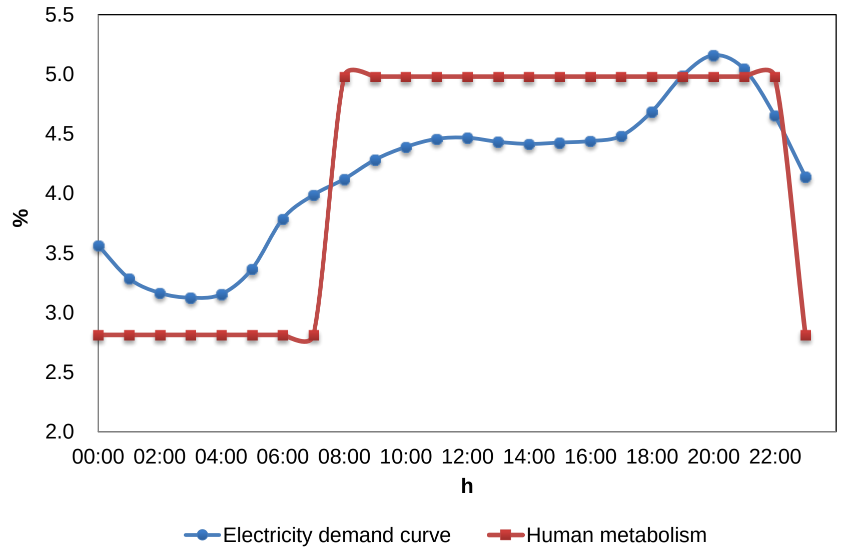

Fig. 2 Hourly distribution for electricity consumption and human metabolism

2.1 Model

The anthropogenic heat component $\mathbf{Q_F}$ given by its three subcomponents:

$$\mathbf{Q_F = Q_{FV} + Q_{FS} + Q_{FM}} \qquad \textbf{Eq. 1}$$

Where combustion processes and electric power consumption by transport are represented as $\mathbf{Q_{FV}}$, energy consumption by stationary sources as $\mathbf{Q_{FS}}$ that represent the industry, commercial and residential sources, and the heat produced by the human metabolism as $\mathbf{Q_{FM}}$**.** The hourly profile for all subcomponent is defined by the equation 2.

$$Q_F = \frac{\sum n_{ij} \times L_i(t) \times Ef_{ij} + \sum C_e(t) + \sum C_{lm}(t) + \sum n_i \times M(t)}{\sum A_i \times 3600} \qquad \textbf{Eq. 2}$$

Where:

n_{ij}: The number of cars by type (i) and model year (j).
L_i : The distance traveled per year, by vehicle type and the hourly profile given by the hourly distribution of CO emissions from transport.
Ef_{ij}: Energy efficiency by vehicle type and model year and the hourly profile given by electricity demand curve.
C_e: The consumption of electricity for transportation.
C_{lm}: Energy consumption by stationary sources (l) and energy consumption, fuel or electricity (m) with the hourly profile given by hourly distribution of CO emission from point sources for industry and VOC emissions from area sources for commercial and residential.
n_i: The population of Mexico City by town (i).
M: Human metabolic rate with the hourly profile defined by two activity periods for a 70 kg person.
A_i: The area of Mexico City with urban land use by town (i).

3. Results

The average value of **Q_F** for 2010 was 22.63 Wm^{-2}, with daytime values within the range [9.56 Wm^{-2}, 37.68 Wm^{-2}]. The average value estimated for the Mexico City by Oke and Jauregui (1999) of 20 Wm^{-2} is in this range.
The values accumulated throughout the day of fuel combustion are 65.1% of **Q_F**, from electricity consumption 27.3% and human metabolism 7.6%. The value obtained for **Q_{FM}** is higher than the value generally assigned to this subcomponent of about 2% of **Q_F**.

The major cumulative contribution throughout the day was the transport subcomponent, with a participation of 42.2%, followed by industry with 28.4%, residential with 14.7%, human metabolism with 7.6% and, finally, commercial with 7.1%.

The anthropogenic component of heat reaches the minimum value at 0 hours and the maximum at 7 hours (Figure 3). The predominant contribution of fuel combustion activities was the transport subcomponent. This contribution defines three: from 4 to 10 hours, from 11 am to 16 pm; and 17 to 21 hours. Then contributions of industry, residential, human metabolism and commerce show a steady behavior.

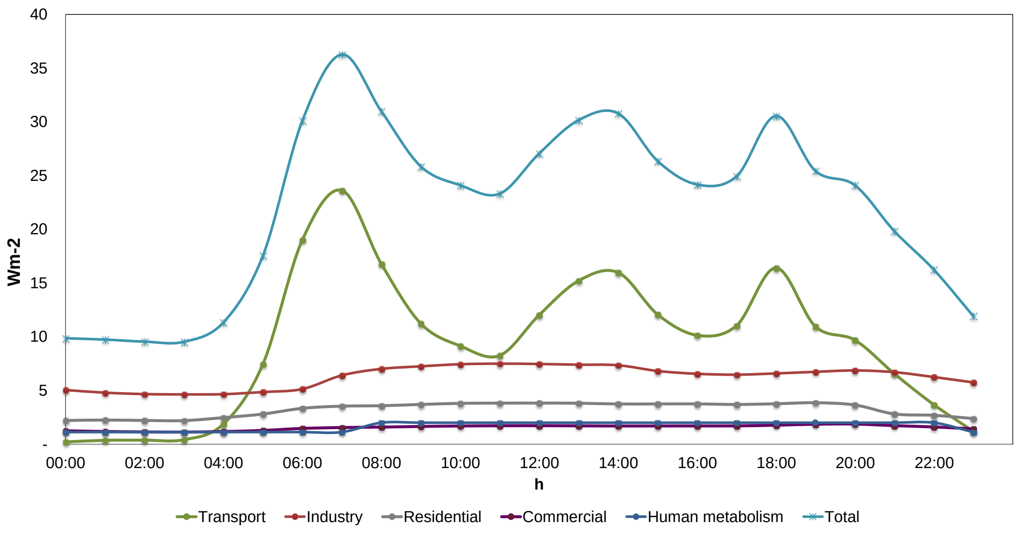

Fig. 3 Anthropogenic contribution to surface energy balance of Mexico City by source (Wm^{-2}), 2010

4. Conclusions

1) The estimation of $\mathbf{Q_F}$ of the surface energy balance for Mexico City in 2010, through methodologies bottom-up and top-down provided a value close to experimentally estimated in 1998 by Oke and Jauregui of 20 Wm^{-2}, it is within the range of uncertainty for this study, 22.08 ± 4.94 Wm^{-2}.
2) The hourly profile of $\mathbf{Q_F}$ splitted into transport, industry, residential, commercial and human metabolism subcomponents, allows to understand the contribution of each subcomponent ant its relevance throughout the day, being more significant the participation of transport sector.
3) According to the $\mathbf{Q_F}$ hourly profile obtained, there is a considerable increase in the early hours of the day (4 to 10 hours), which coincides with the period of highest incidence of solar radiation in Mexico City.
4) It also notes that the dominant subcomponent in most of the day is transportation, specifically for fuel consumption, reaching at certain times of day the average value calculated for $\mathbf{Q_F}$.
5) There are three local maxima of $\mathbf{Q_F}$ determined at 7, 14 and 18 hours and are within each of the three periods set by Jauregui (1997) for the urban heat island (UHI) formation. The local maximum of 7 hours, which is also the global maximum, is within the period in which the urban heat island is more frequent and intense in Mexico City, 21-10 hours in these period the UHI is observed in the dry season, also in this period 50% of the anthropogenic heat is released. The following maximum, set at 14 hours, is within the period where daytime UHI is observed from 11 to15 hours, but having a lower intensity of 3 to 5 °C and with relatively shorter duration. Likewise, in this period it is released on average 26% of the anthropogenic heat.
6) The last local maximum recorded at 18 hours, is in the evening period ranging from 16 to 20 hours where the UHI has an intensity of between 4 and 5 °C, and is observed both in the dry season as rain. Also, within this period it is issued on average 24% of the anthropogenic heat.
7) The value obtained for $\mathbf{Q_F}$ is according to Taha (1997), between 15 and 150 Wm^{-2} during the year.

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