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Measurements and Modelization of the Rosario City Heat Island, Argentina - Preliminary Results

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Abstract. In relation to climate, cities introduce a perturbation with respect to the adjacent (non-urban) lands, since houses, buildings, industries, streets, among others, are made of materials that usually have different optical and thermal properties. In particular, they storage heat in a larger fraction than bare land. Consequently, it is of interest to analyse the main variable that can characterize this difference, the *ambient temperature.* We present results of the measurements done with a thermometer (with an estimated maximum uncertainty of 0.2ºC) during the period June 2013 – June 2014, in different months of the year with clear sky and non-intense windy climatic conditions. The data were obtained at noon (around 13:00 local hour = Universal Time – 3 hours), traversing the city in the East-West and North-South directions. Particularly, in this work, we analyse the ambient temperature variation between the central dry Montenegro plaza and the Green Urquiza park. The first one is located among medium-height buildings (3 stories as a mean), while the second one is placed about 1770 meters away, in the border of the city, very near the coast of the large Paraná river (having it 60 km wide, including the delta islands). The mean temperature difference in the yearly investigated period was +0.7ºC, being higher in the central dry plaza than in the green park. Results for different climatic periods are: for autumn-winter, +0.3ºC and for spring-summer, +1.1ºC. A possible explanation of this behaviour is the different angular incidence of solar radiation at the altitudinal level that air temperature is measured, being lower in autumn-winter (with the Sun at approximately 40º mean elevation angle) than in spring-summer (∼70º mean elevation angle). We have also made model calculations, employing the Urban Weather Generator (UWG) model, developed by Bueno et al. at Massachusetts Institute of Technology, USA. As for the introduction of the climatological and building parameters, we have used climatological data from a rural meteorological station in the Energy Plus weather file format (.epw) and a parametric description of urban area in .xml format. We have also obtained a representation of the temperature behaviour in the central plaza, considering three scenarios. Scenario A represents the rural climate; scenario B portrays the current situation and scenario C verifies the *Energy efficiency and solar protection in building N° 8757* Ordinance introduced for the first time in Argentina, by the Municipality of Rosario city. The highest temperature was found in scenario B, being 2.5 ºC higher than in scenario A. Scenario C presents a temperature 1.5 ºC higher than scenario A. In conclusion, the urban heat island data obtained is of interest in the design of acclimatisation systems (since normally the non-urban airport temperature data is employed). Also, they can be used as a simulation at present of what will happen in the future, due to the temperature increase produced by the emission of greenhouse gases, responsible of the global warming.

1. Introduction

The Urban heat island (UHI) phenomenon is the increase in air temperature produced by urbanization. Buildings, roads, and other infrastructures replace the suburban areas and vegetation. These changes, particularly by soil sealing, building density and anthropogenic heat sources, form an “island” of higher temperatures than open land (EPA, 2018), [1]. It causes a significant increase of energy consumption, apart from exacerbating the effects of climate change and heat events. The annual temperature of a large city (as Rosario city, with about 1 million inhabitants or greater) may be 1°-2°C warmer than before urbanization (American Meteorological Society, 2018), [2].

Currently, the analysis of the urban-specific climate data takes a central role in urban planning and energy efficiency analysis in buildings. However, the weather data used today to run energy simulations generally refer to rural or suburban weather stations, causing significant errors in energy assessment as it does not take into account the urban heat island effect (Salvati et al, 2016), [3]

This paper presents an application of the Urban Weather Generator (UWG) software [4, 5] as a design tool to provide climate-specific information at a neighbourhood scale in Rosario city, Argentina. These authors inform that the software permits “to calculate air temperatures inside urban canyons from measurements at an operational weather station located in an open area outside a city. The error of UWG predictions stays within the range of air temperature variability observed in different locations of the same urban area”. In the present work, the prediction data are compared to the urban air temperature measured with a thermometer, in a central dry square of this city. The model calculations permit to determine the temperature behaviour in the central Montenegro plaza and surroundings, considering three scenarios. Scenario A represents the rural (non-urban) climate; scenario B portrays the current situation and scenario C verifies the Energy efficiency and solar protection in building N° 8757/2011 Ordinance introduced for the first time in Argentina, by the Municipality of Rosario city. This Ordinance establishes the obligation to analyse and optimize the building envelopes in order to reduce the energy consumption for thermal conditioning both in heating and cooling. The behaviour of exterior walls, ceilings, transparent surfaces and solar protections of each room needs to comply with the maximum values of established thermal transmittance and the solar exposure factor according to the orientation. The highest value allowed of thermal transmittance in walls is 0.74 W/m2K and in roofs is 0.38 W/m2K (Municipalidad de Rosario, 2011), [6] figure 1.

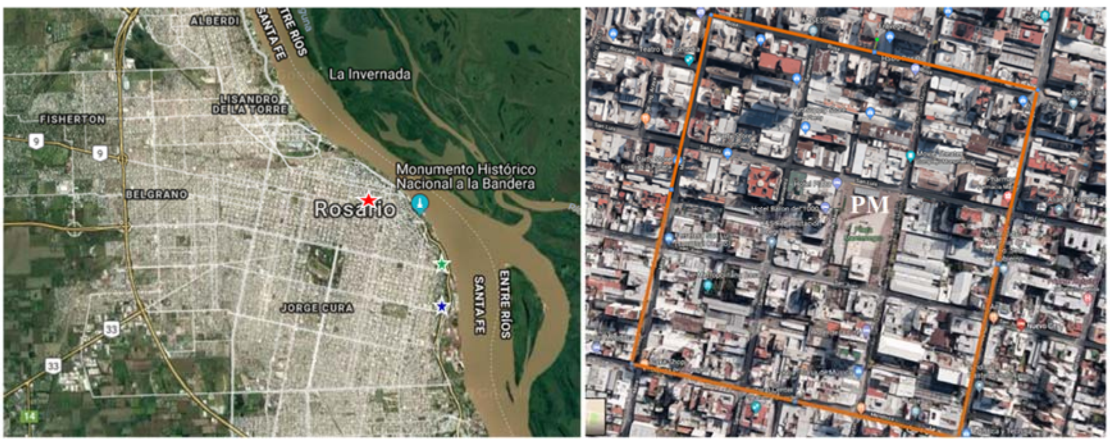

Figure 1. left- Geographical location of the Rosario city (Argentina) and the measured and modelled sites: Montenegro plaza and surrounding squares (red star), Green Urquiza park (green star) and Instituto de Física Rosario building (blue star), right - Selected blocks of the central region of the Rosario city: PM indicates the (dry) Montenegro plaza. Source: Google Earth maps

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2. Methodology

2.1. Software UWG

We will apply the scenarios comparison to the particular case of Rosario city, located in the Argentine Humid Pampa and at the geographical site: 32° 57’ S, 60° 44’ W, 25 m asl. Its population was 989.000 inhabitants in 2016, taking into account the small variation in the number of citizens in the last decades and considering as a reference the 2010 census. This census determined that Rosario city had 948.000 inhabitants in this year, as indicated in the official web page of the Municipality of Rosario, Argentina, [7].

The studied area includes 9 blocks located in the centre of Rosario City, Argentina. This checkerboard is limited by Rioja and Mendoza streets, and Mitre and Maipú streets. The choice was based on previous field measures taken at this area that showed some of the highest temperatures in this city.

Firstly, a field work was conducted in the area, placing particular emphasis on the analysis of building typologies, constructive systems and traffic. Preliminary results show:

1) Heavy traffic, particularly of cars and public transport;
2) Old buildings made mainly of cement plaster and bricks, with no insulation layers and high infiltration and ventilation rates.
3) Intense commercial activity.
4) Small number of trees or other vegetation per surface area.

We have also considered the performance of exterior walls, roofs, transparent surfaces and solar protections related to the different typologies. On the one hand, as volumetric heat capacities of the materials prove to be rather high, buildings store considerable amounts of internal energy when undergoing a temperature change. On the other hand, high values of thermal transmittance and total solar heat gain coefficient of single glazing windows also contribute to the urban heat island intensity in the area.

The data obtained was later used to calculate the parameters required in the Urban Weather Generator, an urban heat island effect modelling software developed by Bueno et. Al (2012), from the Massachusetts Institute of Technology. This software calculates air temperatures inside urban canyons from measurements obtained in nearby rural (or suburban) weather stations.

The variables related to the three considered scenarios were introduced as three different input files in the software. Scenario A (rural conditions) was described by the .epw input file obtained in Energy Plus software (see https://energyplus.net/) ; scenario B was based on the parameters that describe the current situation of the area, and scenario C considers the variables obtained in the Energy Efficiency and Solar Protection in Buildings Ordinance nº 8757/2011 of the Municipality of Rosario. This Ordinance represents a pioneering effort in building regulations.

Particularly, it sets maximum allowable values for thermal transmittances in order to optimize building envelopes and, thus, reducing energy consumption related to thermal conditioning (heating and cooling). This process implies the need to incorporate thermal insulation in roofs and exterior walls, and to add solar protection in transparent enclosures according to the orientations. It is expected that the compliance of this regulation will reduce the emission of greenhouse gases produced by the non-renewable energy sources. We present in Figure 2 the boundary conditions of the urban boundary layers and rural boundary layer.

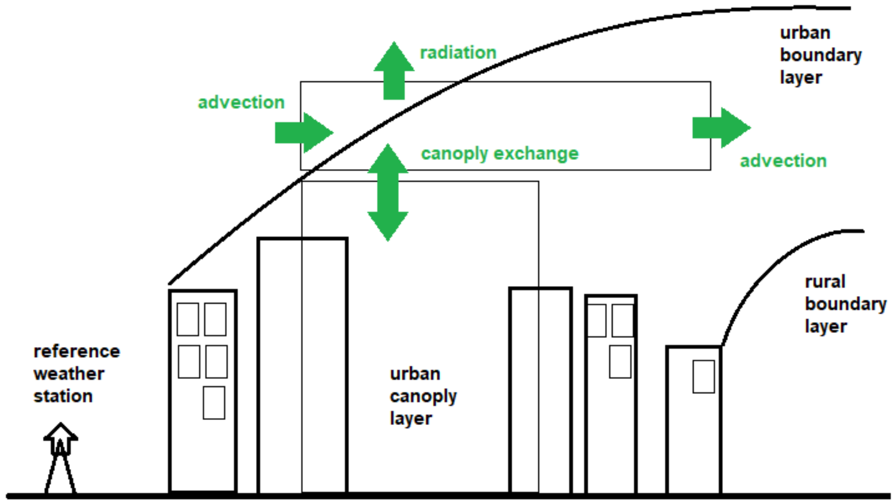


Figure 2. The boundary conditions of the urban canopy and urban boundary layers are shown below, [8]

2.2. Temperature measurements

2.2.1. Thermometer measurements
In order to study the UHI of the Rosario city, we made a series of ambient (air) temperature measurements, employing an analogue thermometer (with an estimated uncertainty of 0.2 °C) and traversing the city in the East-West and North-South directions. These measurements were done around noon, with clear sky and non-windy conditions, in the July 2013-June 2014 period. In this work we present the particular data corresponding to the following sites (as indicated in figure 1. Left): dry Montenegro plaza and Green Urquiza park, at the border of the city, 1770 m from the other site and near the coast of the Paraná river, having this river a wide extension of about 60 Km, including a large Delta of islands. Due to the distance between both measurement points a mean time delay of around 20 minutes exists between them, that was taking into account in the data analysis. We added the temperature data registered in our automatic weather station (Davis, model Vantage Pro 2), installed in the building of the Instituto de Física Rosario (CONICET – National University of Rosario), placed in the Centro Científico Tecnológico Rosario (CONICET), at the intersections of Ocampo and Esmeralda streets (about 3 km away from the central point).

2.2.2. Electronic sensors and data acquisition system for temperature and humidity measurements.
It can be measured temperature and relative humidity with electronic sensors and data acquisition system, interconnected through an Arduino microcontroller (which is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software) (Arduino, 2018), [9]. Arduino is a platform that allows the programming of a micro-controller, which is the integrated circuit responsible for the implementation of a programmed logic. The choice of using Arduino was based on its open code, open hardware and simplified C++ language. This makes the platform suitable for automation projects and control systems. ATmega chips do not present considerable hardware advantages over others microcontrollers but, being integrated with Arduino boards, it allows to obtain all kinds of projects presented in the public online community. Besides, Arduino modules and shields are offered, which facilitate the peripherals wiring.

Figure 3 Left, describes the main components: temperature (T) and relative humidity (RH) sensors, batteries, resistances, capacitors, transistor and electrical interconnections. In Figure 3 Centre, we present detail of both T and HR sensors. We see in Figure 3 Right the position of the system in the *Centro Cultural Fontanarosa* building placed at the heart of the Montenegro plaza.

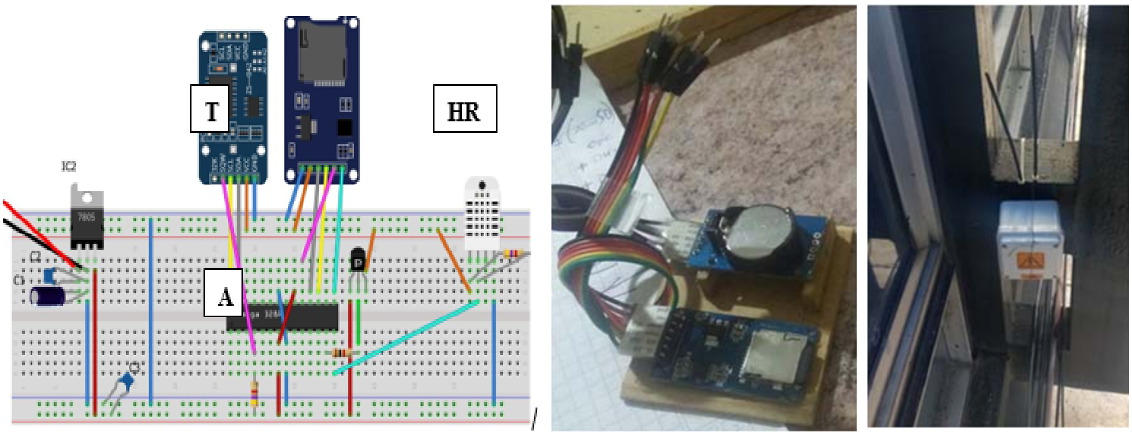


Figure 3. left - Schematic representation of the circuitry of the electronic sensors of temperature (T) and relative humidity (RH) and Arduino (A) data acquisition system; Centre: Temperature and humidity sensors;
right - The position of the Arduino measurement system in a building at the middle of the (dry) Montenegro plaza, Rosario city, Argentina.

3. Results and discussions

3.1. Software UWG model calculations

It was done a model calculations employing the UWG software that solves the urban energy canyon balance (which is sensible to the heat fluxes from walls, windows and the roofs) of the selected urban site, in the three scenarios described in item 2.1. Figure 5 displays the monthly mean ambient temperature behaviour (in °C) as function of the hours of the (clear sky non-windy) day, for the months of January, March, July and October for these three scenarios. From the annual mean ambient temperature, we determined the difference value around noon (the measurement period), between the different scenarios. We found that temperature in scenario B (urban area), is 2.5ºC higher than in scenario A (non-urban area). Scenario C (assuming energy efficiency and solar protection measures is applied in all buildings) presents, in the same time interval, a temperature 1.5 ºC higher than scenario A. In Figure 5 we can see monthly mean ambient temperature behaviour (in °C) modelled employing the UWG algorithm as function of the hours of the (clear sky) day, for the months of January, March, July and October for three scenarios. In all the diagrams the model solves the energy balance in similar form. The urban canyon energy balance is sensible for the heat fluxes from walls, windows and the roofs.

3.2. Measurements with (analogue and digital) thermometers

In the Southern hemisphere Winter time (July-September), the temperatures oscillates between around 24 °C and 10 °C, depending on the meteorological conditions of the region: the arrival of hot air from the North (Brazil) or cold air from the South (Patagonia) (Figure 6 left). A large increase is observed in Spring (October-December), a maximum in the range of 32-36 °C in Summer (January-March) and a decrease in Autumn (April-June). As can be seen almost always the temperature measured at the central Montenegro plaza (PM) is higher than at the Green Urquiza park (PU), and even more at the Instituto de Física Rosario (IFIR) building. Actually the most important results for the present study are the differences between the central part of the city with respect to the other two (near the border of the city) sites. This can be seen in Figure 6. Right, where the difference values: PM minus PU and PM minus IFIR is represented. The first difference has a value of 1.0 °C and the second one of 1.5 °C. Due to the time delay indicated in item 2.2.1 between the measurements done at PM and PU and the fact that temperature increases in this 20-minute time interval in a value of 0.3 °C. So the final differences are 0.7 °C for PM – PU and 1.2 °C for PM – IFIR.

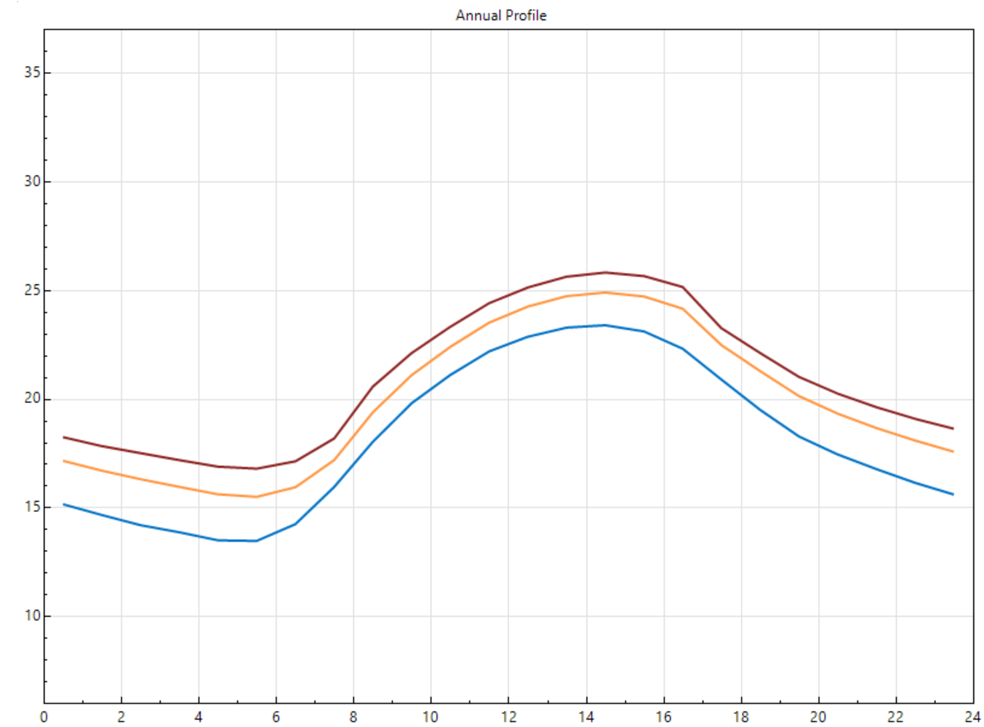
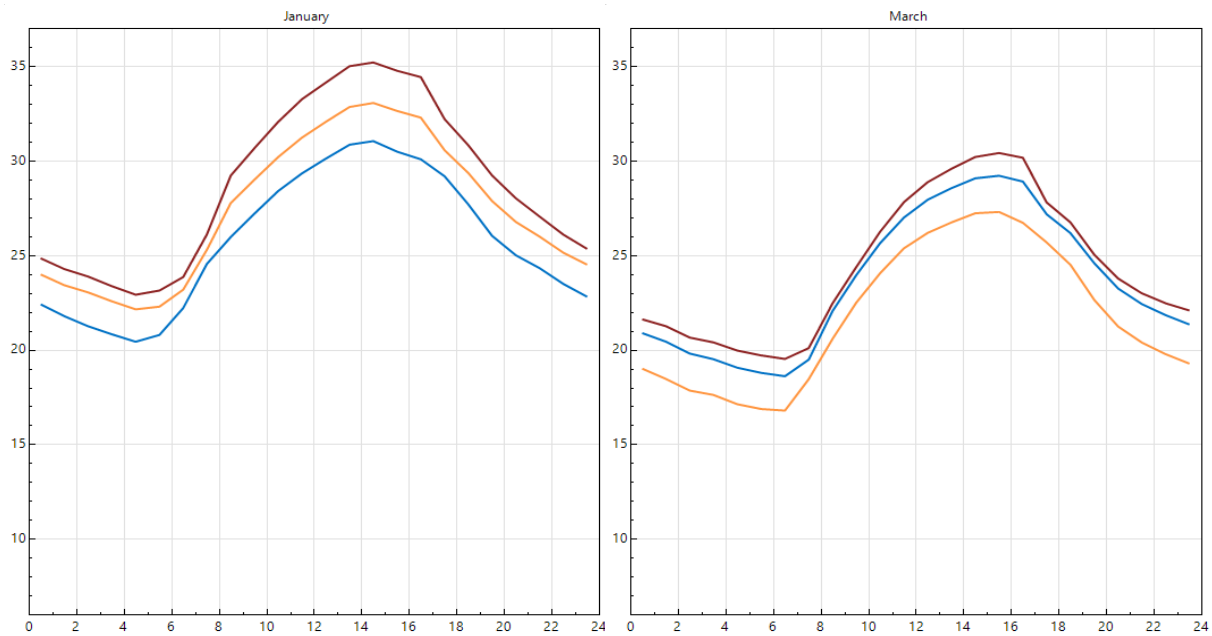


Figure 4. Representation in study zone of annual mean of the ambient temperature behaviour (in °C) modelled employing the UWG algorithm as function of the hours of the (clear sky) day, for the Plaza (seca) Montenegro and surrounding squares, for different scenarios: scenario A considering the actual situation (red) and scenario B assuming that all the buildings incorporates the Energy efficiency and solar protection Ordinance 8757/2011 of the Municipality of Rosario (orange). The air temperature at the rural (non-urban) site is also included as scenario C (blue).



a) b)

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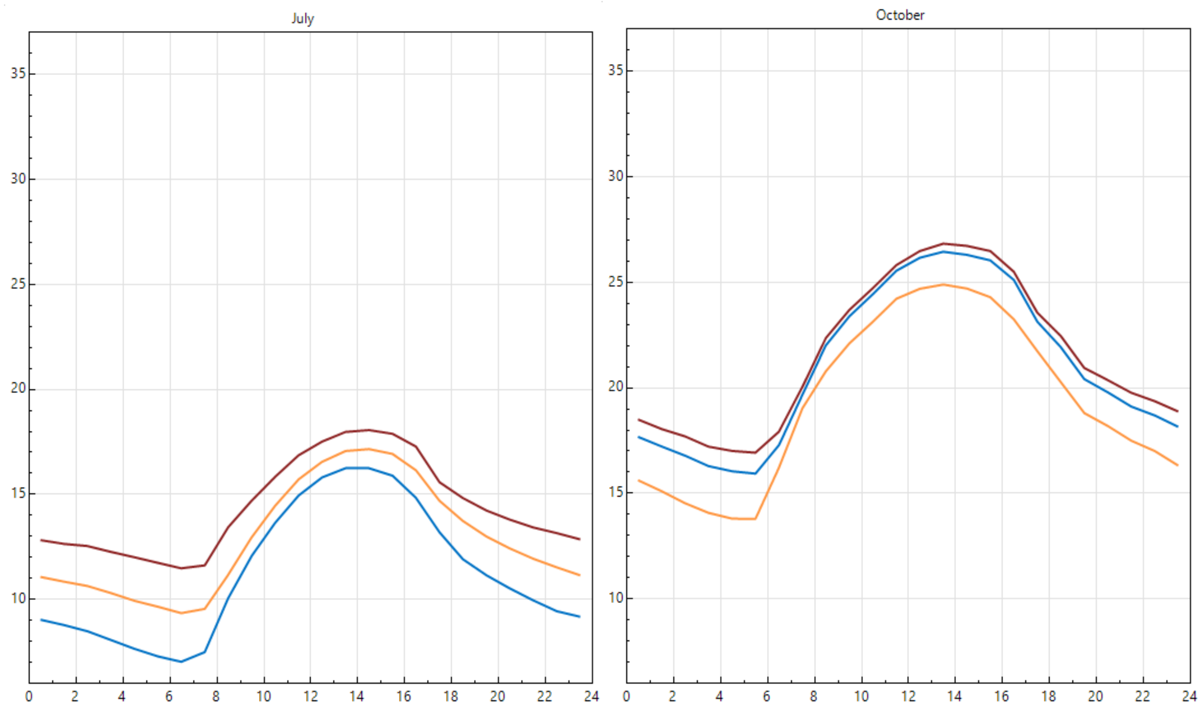

c) d)

Figure 5 a-d). Monthly mean ambient temperature behaviour (in °C) modelled employing the UWG algorithm as function of the hours of the (clear sky) day, for the months of January, March, July and October. Same notation as in Figure 4.

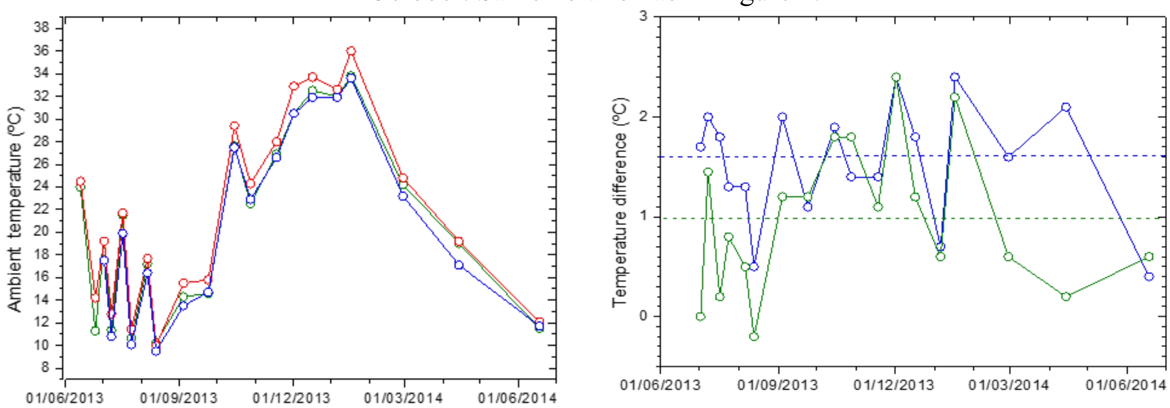

Figure 6. left) Ambient temperature measured with thermometer at Rosario city, Argentina, with clear and non-windy conditions, in the July 2013 – June 2014 period. The different data sets correspond to: Plaza Montenegro (red point and line), Green Urquiza park (green point and line) and Institute of Physics Rosario (blue point and line).

right) Temperature difference between the ambient temperature measured in Rosario city, Argentina, at the Green Urquiza park (green point and line) and at the Instituto de Física Rosario (blue point and line), both with respect to the central Montenegro plaza. The temperatures were obtained from the figure 2 data. The horizontal (broken) lines are the mean values for each set of values of the same colour.

Another interesting result is the difference PM - PU, but for different climatic periods. They are: for Autumn-Winter, +0.3 ºC and for Spring-Summer, +1.1ºC. A possible explanation of this behaviour is the different angular incidence of solar radiation at the altitudinal level that air temperature is measured, being lower in Autumn-Winter (with the Sun at approximately 40º mean elevation angle) than in Spring-Summer (~70º mean elevation angle).

3.3. Measurements with the electronic system

Employing the temperature and relative humidity sensors placed in an Arduino microcontroller (described in item 3.3), we obtained the corresponding results for the day 17 March to 19 March (in the morning) 2018. Table 1 displays the registered minimum and maximum temperatures measured at a building placed in the Montenegro plaza and the comparison with the non-urban Rosario Airport data. Mainly due to the thermal inertia of the building, their differences was positive in the minimum as well in the maximum.

Table 1. Temperatures measured in an urban (Montenegro plaza) and non-urban (Rosario airport official weather station) site, [10]

Site (at Rosario, Argentina)	17 March 2018 Tmin (Tmax)	18 March 2018 Tmin (Tmax)	19 March 2018 Tmax (Tmin) in °C	Mean difference in temperature Rosario Airport – PM
Building placed in the Montenegro plaza	21.8 °C (30 °C)	18.3 °C (30.4 °C)	13.2 °C ----	+4.2 °C (+1.6 °C)
Rosario Airport	18 °C (29.1 °C)	17.0 °C (28.1 °C)	5.8 °C (27 °C)	----

4. Conclusions

From the preliminary results obtained in the present work, we can derive the following conclusions in relation to the Rosario city heat island:

- The annual mean measured temperatures at the centre and in the borders (Green Urquiza park and IFIR) of the Rosario city differ in 0.7 °C and 1.2 °C, respectively. The larger difference in mainly due to the fact that the IFIR building site is placed at a larger distance from the centre than the Green Urquiza park site. For the PM minus PU difference, when separated in Spring-Summer (rather hot) and Autumn-Winter (rather cold) periods, the first one is 0.3 °C and the second one 1.1 °C.
- The highest temperature was found in scenario B, being 2.5 ºC higher than in scenario A. Scenario C presents a temperature 1.5 ºC higher than scenario A. In conclusion, the urban heat island data obtained is of interest in the design of acclimatisation systems (since normally the non-urban airport temperature data is employed). Also, they can be used as a simulation at present of what will happen in the future, due to the temperature increase produced by the emission of greenhouse gases, responsible of the global warming.
- In conclusion, when comparing the three scenarios, Ordinance nº8757/2011 fosters more favourable thermal conditions that result in an upgrade in public health, comfort and heating and cooling loads for buildings. This scenario shows, once again, the urgent need to develop mitigation and adaptation measures in urban environments.
- The application of the mentioned Ordinance is one excellent strategy for reduce urban heat island.
- We like to point out that the urban heat island data obtained are of interest in the design of climatization systems (since normally the non-urban airport temperature data is employed). Also, they can be used as a simulation at present of what will happen in the future, due to the temperature increase produced by the emission of greenhouse gases, responsible of the global warming (IPCC 2013), [11].

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