ASSESSING THE INFLUENCE OF THE URBAN CONTEXT ON BUILDING ENERGY DEMAND

Francisco Sánchez and Servando Alvarez

E S. Ingenieros. Grupo de Termotecnia. Avda. de los descubrimientos s/n
41092 Sevilla, Spain

ABSTRACT

An energy balance over an urban area and over a rural one, reveals that the first case is always more complex than the last one. The urban context is able to change all the energy transferences mainly due to its own layout. Thus, analysing all the energy transferences one by one, we can find how they affect in a different way depending on the surroundings, among other influences. The combination of all the differences between an urban and a rural area, from an energy point of view, are responsible of the urban overheating mainly observed in the evening, what is the well-known "urban heat island" effect. It is, therefore, necessary to find the interrelations among all the mechanisms of heat transfer in an urban area, and in this way to be able to assess the influence of the urban context on building energy demand.

KEYWORDS

Urban heat island, climatic changes, urban heat balance, cooling requirements.

INTRODUCTION

The building energy demands due to cooling and heating have an increased importance in recent years, since they are responsible in a high degree of the global pollution, and in consequence of the global overheating. The complexity of the energy balance over an urban area and the difference in comparison with a rural one, justify the search of a complete model.

The present paper presents a model for treatment of climatic changes due to urbanization, as well as, the order of magnitude of each heat transfer mechanisms. By knowing the whole process, we are able to analyse how the cooling requirements are increased by the urban area. Finally, a complete example is studied to explain how energy savings can be expected at an improved urban area. This is expressed in terms of diminishment of cooling requirements, and it is mainly related to urban changes like street orientation, street aspect ratio, and presence of vegetation and mass of water.

MODIFICATIONS INTRODUCED BY THE URBAN CONTEXT

All the heat fluxes in a building outdoor thermal balance, are modified by the surroundings of the building, this is by the urban context. In this paper we present the reasons of these modifications, and an example to express the consequence in terms of building energy savings.

The presence of buildings modifies in a different degree all the energy balance terms in an urban context. Thus, the most important radiative effects are a decrease in the solar radiation receipt by areas in shadow, a local increase in solar receipt by reflection from sunlit walls, and the reduction of net long-wave cooling from surfaces near the building due both to a reduction in losses by long-wave exchange with sky, caused by the reduced sky view factor, and to an increase in gains by long-wave exchange with the usually warm buildings. Also in the immediate vicinity of a building, soil and air temperatures are often warmer than in open due to heat losses from the building, and as a result of the wind shelter provided, (Oke T. R., 1987).

Air Temperature

Air temperatures in densely built urban are higher than the temperatures of the surrounding rural country. This is a known consequence of increasing urbanisation, urban traffic, and the decreasing of vegetation and trees. The phenomenon is known as 'heat island' and its main effect on urban environment is to increase temperatures especially during summer period.

On the other hand, in many cases, this effect can be mitigated by using the ability of green areas and mass of water (urban heat sinks) to modify the air temperature of an urban environment. This cooling effect takes place when hot air is put into contact with a surface at a lower temperature. The vegetation and the water are able to maintain a lower temperature due to the evaporation that acts as a regulatory mechanism. In order to analyse the effect of a cool surface on the air temperature is necessary the use of a complex program like a commercial CFD code, or for very simple urban configurations, the use of simplified programs based on correlations or on experimental results (GREENCODE Project), (URBACOOL Project).

Wind Pattern

The presence of buildings acts over the wind as a shelter decreasing in general the wind speed, and always modifying the pattern of airflow.

If a building is part of an urban area the flow pattern depends on the geometry of the array, especially the height to width ratio (aspect ratio). When the buildings are relatively widely spaced ($H/W<0.3$) their flow pattern appears almost the same as if they were isolated. At spacings closer than these the main flow starts to skim over the buildings tops and drives a lee vortex in the street or courtyard. This vortex is reinforced by the downward deflection produced by the windward face of the succeeding building (Sánchez F., 1998).

Although in general we can expect that wind speeds within the urban canopy are reduced in comparison with rural winds at the same height, there are some situations in which the opposite can be found. One of these situations occurs when the faster moving upper air layers are either deflected downwards by relatively tall buildings or are channelled into 'jets' along streets oriented in the same direction as the flow. Another one occurs when regional winds are very light or calm. In this situation, the horizontal temperature gradient can be sufficient to induce a low-level breeze from the country into the city in the same manner as a sea breeze.

In this case, like in the study of air temperature modification, a CFD code is normally necessary. Another possibility is to apply a zonal model to a the volume between buildings.

Then, the whole volume is divided into a little number of cells, and equations for mass balance and heat balance have to be written for each cell. Additional equations describe conduction through the walls, convection between outside wall surfaces and cells, and long-wave and short-wave radiant interchange among the outside wall surfaces.

Short-Wave and Long-Wave Radiation

It has long been known that urban areas have less sunshine than their surroundings. This is an urban effect that can not be doubted because sunshine duration is governed by the general weather situation so that differences in small areas are induced by local effects. Only in mountainous regions are similar mesoclimatic effects noted. In industrial cities the loss in sunshine duration can be between 10 and 20 percent. Similar losses are observed in terms of the energy received at the surface below the urban dust shield.

The urban reduction in energy received at the ground is greatest at low solar elevations, i.e., in the early morning and late afternoon hours. In winter and autumn the frequent low-level inversions contribute to the accumulation of pollutants and hence to the radiation loss. In spring the generally higher wind velocities and, in summer, the greater convection contribute to the dispersal of pollutants and thus the relatively smaller radiation loss (Landsberg, 1981).

The presence of obstacles like trees complicates extremely the calculation of the multiple reflections in the surrounding of a building. Furthermore, the long-wave exchange is controlled by a huge number of different surfaces and, in consequence, of view factors. All these reasons lead to the development of a calculation method able to take into account the direct, diffuse and reflected radiation, and to treat with many surfaces.

Water in Street Landscaping

Ponds and fountains can be effective air conditioning systems in open spaces because of their ability to keep water temperatures lower than air temperature, and their low reflectivity. Ponds have a reflectivity of approximately 3% at times of maximum solar radiation, and therefore reflect little solar radiation towards occupied zones. They absorb a lot of solar radiation, up to 80% depending on the depth of pond. All this solar radiation does not however produce a significant increase of water temperature because of the pond’s thermal inertia and evaporation at its surface. The water pond inertia is directly proportional to water mass and therefore proportional to its depth. With increasing water pond inertia, the water temperature decreases. The daily range of water temperature (maximum to minimum difference) is reduced and there is a phase shift between air and water temperatures.

When the pond is in shadow, the incoming solar radiation is reduced, with a reduction in water temperature. This temperature reduction increases with increased shading of the pond.

A single water drop moving through the air experiences the following processes:

- Heat flows from the air to the drop (if the air is hotter than the drop).
- Water evaporates from the drop to the surrounding air. The hotter the drop is, the more water will be evaporated
- The drop slows down as it moves through the air

The first two processes affect the temperature of the drop in different ways. Heat transfer will warm it up but evaporation will cool it down. As a result of these two opposite tendencies, an equilibrium drop temperature is reached (the wet bulb temperature of the air). Once the drop has reached the wet bulb temperature, the extra energy needed to evaporate more water has to come from the surrounding air. This means the surrounding air is cooled.

Trees in Street Landscaping

The complexity of a vegetated surface as a system of sinks and sources of heat, mass and momentum is such that an exact description of its physical behaviour is almost impossible. Two problems are faced to describe a correct behaviour of a vegetated system. The first one is linked to the complexity and the heterogeneity of the foliage and the second one, to the turbulent nature of the air flow within and above the canopy. These reasons force us to use a simplified model based on reasonable assumptions (Kondo J. and Watanabe T., 1992), (Bruse and al., 1998).

The main effects of trees on urban climate are shading, wind shielding and cooling effect by absorbing solar radiation which is then dissipated by evapotranspiration and sensible exchange with the environment.

Using the global energy balance of a leaf, its surface temperature can be calculated. The difference between the leaf temperature and the air temperature depends on the value of the diffusive resistance and the gap between the net long-wave and solar radiation flux, and the latent heat flux. In this, if the net radiation flux is almost dissipated by the evaporation process, the leaf temperature will be very close to the ambient temperature. Furthermore, evapotranspiration estimation in urban environment is very complex for trees because lots of parameters have to be taken into account (available water, stomata closure, shade and sunlight, wind movement,…) and it should be easy in a first level to let the temperature of trees at a value close to air temperature. In that way, the cooling effect is included via the absorption of the solar radiation by the foliage of the trees without an increase of the foliage temperature i.e. no sensible heat transfer with the outside air.

EXAMPLE OF AN INTEGRATED CASE

In the framework of Greencode project, a program focused on the calculations of the urban context impact in the building energy performance, it was developed (GREENCODE Project). In a first level, this program evaluate the modifications of the building surrounding conditions, like air temperature, air velocity, impinging solar radiation, etc. All these calculations are carried out taking into account the presence of trees and water films in the street canyon, and the aspect ratio and orientation of it.

As an example, two cases have been solved to be compared: first a street without any vegetation, and second with mature vegetation. A comparison on air (inside and outside the canyon) and surface temperatures (ground and facades) for the two cases demonstrates the action of trees on their environment. During all the simulated period, temperature differences appear with the increase of the vegetation cover. The effects are important with maximum surface temperature of the ground decreasing from 50°C to 30 °C and a heat island (difference between inside and outside canyon) decreasing from 8°C to 0 °C (figures 1 to 4).

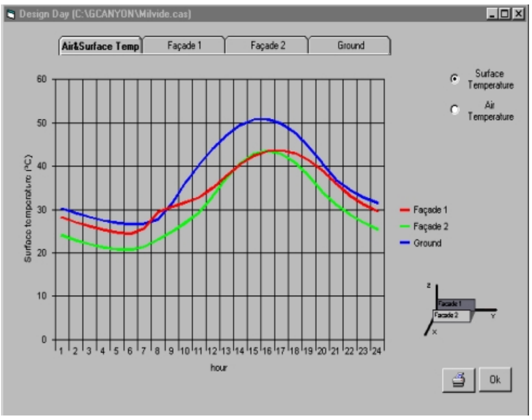


Figure 1: Surface temperature (no vegetation)

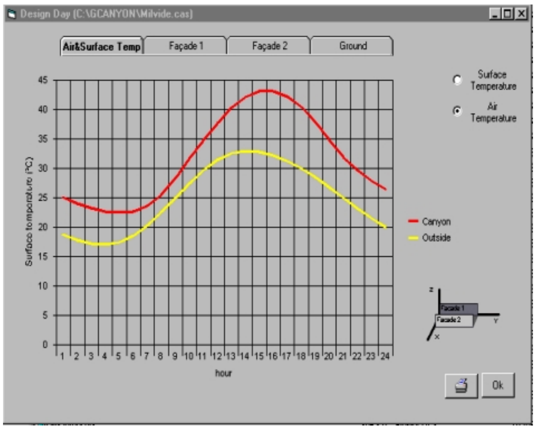


Figure 2: Air temperature (no vegetation)

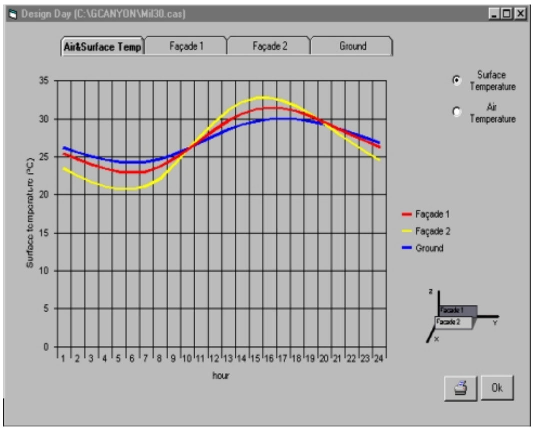


Figure 3: Surface temperature (mature vegetation)

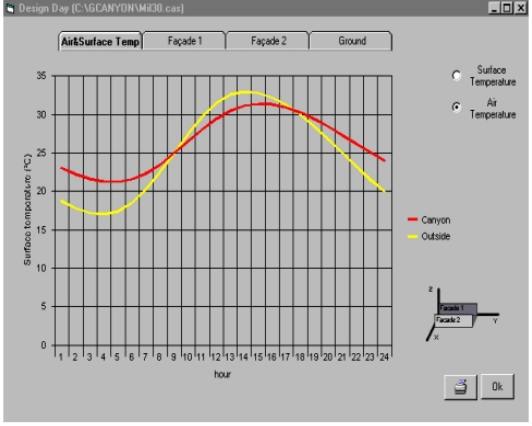
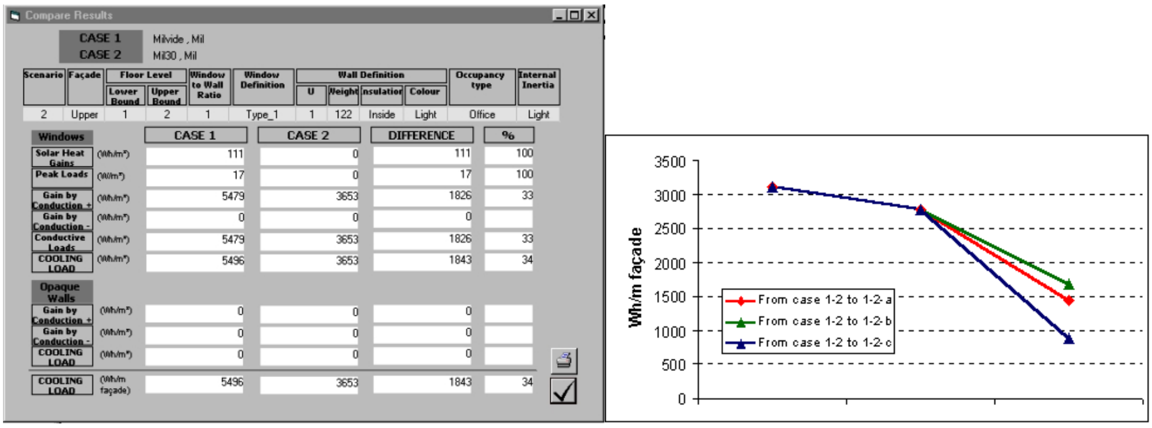


Figure 4: Air temperature (mature vegetation)

Using these results as input data for a thermal building simulation program, it is possible to compare the thermal behaviour of the different floors for the different situations (with or without vegetation). In the following figures, the energy savings due to vegetation for an office at the ground floor, are shown:



CASE 1 Milvide , Mil
CASE 2 Mil30 , Mil

Scenario	Façade	Floor Level		Window to Wall Ratio	Window Definition	Wall Definition				Occupancy type	Internal Inertia
		Lower Bound	Upper Bound			U	Weight	Insulation	Colour		
2	Upper	1	2	1	Type_1	1	122	Inside	Light	Office	Light

Windows		CASE 1	CASE 2	DIFFERENCE	%
Solar Heat Gains	(Wh/m²)	111	0	111	100
Peak Loads	(W/m²)	17	0	17	100
Gain by Conduction +	(Wh/m²)	5479	3653	1826	33
Gain by Conduction -	(Wh/m²)	0	0	0	
Conductive Loads	(Wh/m²)	5479	3653	1826	33
COOLING LOAD	(Wh/m²)	5496	3653	1843	34
Opaque Walls					
Gain by Conduction +	(Wh/m²)	0	0	0	
Gain by Conduction -	(Wh/m²)	0	0	0	
COOLING LOAD	(Wh/m²)	0	0	0	
COOLING LOAD	(Wh/m façade)	5496	3653	1843	34

Figure 5: Cooling energy savings due to outdoor modifications.

With this schedule it can be seen that cooling loads are 34 % lower in the case with mature vegetation compared with the no vegetation case. As it can be seen, the results obtained with planting trees on the sidewalk area (red line) are similar to those obtained when the plantations are made on both locations (blue line), while the effect when planting on the central green area is much lower (green line). On the other hand, the impact on the ground level is logically higher when both zones are planted. Anyway, which is much more interesting is that it can be found the strategy of planting trees on both areas does not provide an improvement on cooling loads requirements as high as the direct addition of the other two strategies.

CONCLUSION

The complexity of the urban context, and the particularities of each case compare to a rural case, are the reasons that explain the difficulty of obtain general results, and conclusions. Each case has to be analyse separately, and for it, all the design alternatives have to be compare in terms of energy requirements.

In a general way, we can say that benefits of vegetation in urban environment are qualitatively well-known but there is a lack for quantitative results in complex situations. By comparing different urban cases with numerical simulations, pertinent information can be addressed to urban designers and architects. Impact of trees on temperatures and on outdoor comfort have been pointed out. Energy consumption of buildings are related to solar loads, wind flow patterns and external air temperature. So, improvements on urban microclimate should have direct and indirect consequences on energy savings. Therefore, programs and studies like the one presented above, are completely necessary to assess the influence of the urban context on building energy demand.

References

Bruse, M. and Fleer, H. (1998). *Simulating surface-plant-air interactions inside urban environments with a three dimensional numerical model*. Environmental Modelling & Software, Elsevier, Vol 13, Issue 3-4, pp. 373-384.

GREENCODE Project: *Reglementary Frame For Renewable Energy Use In Urban Site Through Vegetation Plantings And Strategic Surfacing*.

Kondo J. and Watanabe T. (1992). *Studies of the bulk transfer coefficients over a vegetated surface with a multilayer energy budget model*. Journal of Atmospheric Sciences, 39, 23, 2183-2199.

Landsberg H. (1981), *The Urban Climate*. International Geophysics Series. Vol. 28 Academic Press.

Oke T. R. (1987), *Boundary Layer Climates*. Routledge, London, UK, ISBN 0-415-04319-0.

Sánchez F. (1998), *Estudios Numéricos de la Capa Límite Urbana Orientados a Mejorar el Microclima Alrededor de Edificios.* Proyecto fin de carrera. Universidad de Sevilla, ETSII.

URBACOOL Project: *Energy Efficient Cooling Systems & Techniques For Urban Buildings.*