URBAN ENERGY SIMULATION OF A SOCIAL HOUSING NEIGHBOURHOOD IN BOGOTA, COLOMBIA

A.V. Cifuentes Cuéllar[1], J. Kämpf[1]

1: Solar Energy and Building Physics Laboratory (LESO-PB), Swiss Federal Institute of Technology (EPFL), Station 18, 1015 Lausanne, Switzerland

ABSTRACT

High demographic dynamics and greater poverty in developing countries carry the urgent need to provide low cost housing to the poorest in urban regions. In Colombia the development of social housing settlements is characterized by two deficits, a quantitative one (related to urban density) and a qualitative one (related to indoor building conditions). It is therefore imperative to identify solutions that may lead to the adequate development of social housing in Colombia. This paper studies the relation between urban density and indoor thermal conditions of buildings of a social housing neighbourhood located in Bogotá, with the help of an urban energy simulator.

The particular location of the case study, close to the Equator, brought up many challenges. At first, remarkable differences were found when comparing the simulation results with the international norm CEN (EN 13790). The thermal model had to be slightly adapted for a good dynamic behaviour of the room temperatures. Moreover, as the constructional model of social housing is realised without any insulation, the thermal behaviour is very sensitive to the infrared exchanges with the environment, and as such the estimation of the ground temperature had to be refined. This latter point reinforces the idea of the importance of the infrared exchanges between adjacent buildings. Finally, satisfactory results were obtained from the models' improvements leading to an increase of confidence on the simulation results. With the optimised performance of the simulation tool, numerical simulations of radiatively interacting shelters were carried out heading to an analysis of the relation between different urban variables (such as site coverage, plot ratio, building and urban forms) and the thermal comfort of buildings' occupants. The study comprises the verification of the thermal model for simulations, the definition of a thermal discomfort indicator, and finally simulations of a social housing neighbourhood in Bogotá, the capital of Colombia. Results show that it is possible to maintain the same high human density and to improve thermal behaviour of the settlement by combining lower site coverage with higher buildings, which can provide architects and urban developers with helpful insights to improve social housing planning in Colombia.

Keywords: urban energy simulation, social housing, urban density, thermal comfort, Bogotá.

INTRODUCTION

By the horizon of 2050 urban areas are forecasted to hold almost 70% of the world's population. In developing countries the situation is even worse due to higher demographic dynamics and greater poverty rates that force governments to provide low cost housing to the poorest in urban regions. In Colombia's specific case, the social housing phenomenon has been characterized by two major deficits [1]. In one hand a quantitative deficit that carry the development of high density social housing settlements (macro-projects) [2], and on the other hand a high qualitative deficit that affects the well-being of inhabitants in comfort terms [3]. It seems therefore imperative to identify solutions that may lead to the adequate development of social housing in Colombia. Thus, computer modelling happens to be an invaluable decision support tool as it potentially allows for a quick and somewhat precise evaluation of thermal performance associated to different urban scenarios.

For the first time, the urban energy simulator CitySim developed at EPFL [4] is used to simulate the thermal behaviour of a social housing neighbourhood located in Bogotá, the capital of Colombia.

METHODOLOGY

The aim of the study is to analyse the relation between urban density and thermal behaviour of buildings in a social housing neighbourhood in Bogotá. For this, the free floating dynamic thermal behaviour of the buildings has to be evaluated since Bogotá has a tropical highland climate with a yearly average temperature of 14.4°C, and no cooling nor heating are used to reach adequate internal thermal conditions. To gain confidence in simulation results, a verification of the urban energy simulator CitySim with the CEN (EN 13790) standard was carried out. It helped us to improve the solver and consequently a thermal discomfort indicator was defined in order to analyse three variations of the selected case study. As boundary conditions for the simulations, climatic data were obtained from MeteoNorm [5] and 2D and 3D information of the case study were obtained directly from the designers of the project [6].

Verification of the thermal model

As we rely on a software that has never been used exclusively for buildings without heating and cooling systems, results were verified through an inter-model comparison between CitySim and LESOSAI, the latter used for the certification and thermal balance calculation in buildings [7]. To acquire hourly thermal data for a complete year, calculation in LESOSAI was based on the CEN (EN 13790) standard. A simplified model of a typical building from the case of study was analysed using both simulation engines. Table 1 shows the input values associated to the virtual models.

BUILDING			
LOCATION	Country		Colombia
	Weather Station		Santa fe de Bogota
	Altitude of building site	m	2560
GEOMETRY	Volume	m^3	3217.4
	Large width	m	21.34
	Small width	m	10.47
	Height	m	14.4
	Net surface	m^2	223.42
OCCUPATION PROFILE	Living room, bedroom		
People	Quantity	P	142.5
	Metabolic activity	met	1.2
	Sensible heat	W/P	68.2
Electrical appliances	Specific power	W/m^2	12
Lighting	Specific power	W/m^2	56.46
HEATING AND COOLING	Summer	°C	60
	Winter	°C	-30
VENTILATION	Infiltration	m^3/hm^2	5.62
		v/h	0.4
	Window natural ventilation		no
PHYSICS	Thermal conductivity of soil	W/m·K	2
	Thermal capacity	$kJ/m^2 \cdot K$	511

ENVELOPE			
ROOF	Surface Area	m^2	223.42
	Calculated U-Value	$W/m^2 \cdot K$	5.1136
	Emissivity	%	90
	Absorption coefficient	%	90
	Shortwave Reflectance	%	42
	Glazing Ratio	%	0
FLOOR	Surface Area	m^2	223.42
	Calculated U-Value	$W/m^2 \cdot K$	3.9474
	Emissivity	%	90
	Absorption coefficient	%	90
	Shortwave Reflectance	%	42
	Glazing Ratio	%	0
East and West Facade	Surface Area	m^2	143.424
	Calculated U-Value	$W/m^2 \cdot K$	2.161
	Emissivity	%	90
	Absorption coefficient	%	90
	Shortwave Reflectance	%	50
	Glazing Ratio	%	0
North and South Facade	Surface Area	m^2	264.816
	Calculated U-Value	$W/m^2 \cdot K$	2.161
	Emissivity	%	90
	Absorption coefficient	%	90
	Shortwave Reflectance	%	30
	Glazing Ratio	%	40
	Surface Area	m^2	105.926
	Width	cm	1248
	Height	cm	849
	Simple Glass	mm	4
	Frame Fraction	%	30
	G-Value	%	92
	U-Global	$W/m^2 \cdot K$	5.87
	Blinds		no
	BlindsIrradianceCutOff	$W/m^2 \cdot K$	1385
	Shading Coefficient	%	0

Table 1: Main characteristics of the simplified model - Input values in LESOSAI and CitySim.

To illustrate the results obtained from the inter-model comparison a zoom was made on a period of the year in which we noticed significant differences in the internal building's temperature. The period starts from the 4105 hour of the year and ends in the 4205 hour which is essentially in the intermediate part of the year, from 21 to 24 June. In Figure 1, we present the results obtained with LESOSAI (labelled Lesosai) and CitySim (labelled CitySim_1), in which we notice important differences in the thermal behaviour. The major cause of the discrepancy was identified: the constructional model of social housing contains no insulation (as one can see from the U-Values in Table 1); therefore the buildings' thermal behaviour is very sensitive to the infrared exchanges with the environment. Consequently the radiant environment is of great importance in the thermal simulation, and as such a correct estimation of the surrounding buildings' and ground's temperature is necessary. After a modification on the ground temperature model that was implemented in CitySim for taking measured data instead of calculated ones, a more similar behaviour was found compared to LESOSAI (see the label CitySim_Tg in Figure 1). However, a presence of a phase shift between the results remained. To solve this issue, a last adjustment of the solver was carried out in order to distribute the thermal inertia to the air and wall temperature nodes according to the penetration depth δ_e of a 24 hours harmonic temperature variation in the material of the walls as calculated by Equation 1 in which λ, ρ, Cp and T are respectively the conductivity (W/m·K), density (kg/m^3), specific heat (J/kg.K) of the concrete, and T corresponds to the time period of 24 hours (given in seconds).

$$\delta_e = \sqrt{\frac{\lambda * T}{p * Cp * \pi}} \quad (1)$$

Figure 2 shows the variations in thermal results with the last adjustment (labelled CitySim_PD) compared with LESOSAI (labelled Lesosai). An acceptable thermal behaviour was achieved with CitySim, which allowed proceeding with the definition of the thermal discomfort indicator.

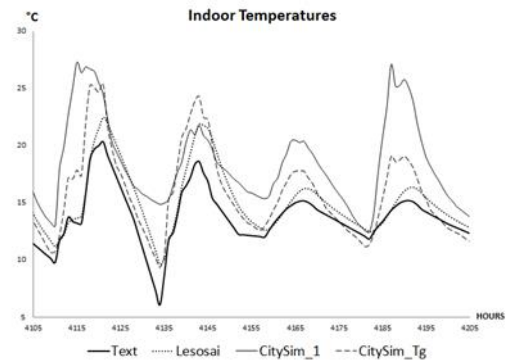

Figure 1: Inter-model comparison – Effect of ground temperature.

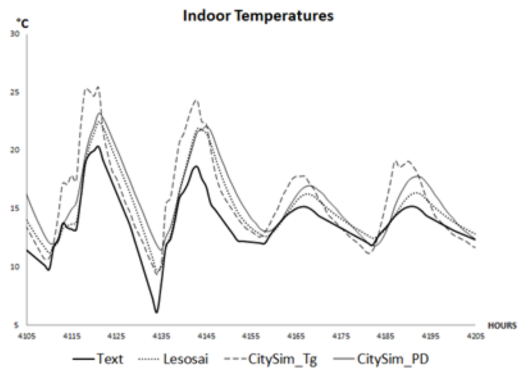

Figure 2: Inter-model comparison – Effect of penetration Depth.

Definition of thermal discomfort indicator

Based on Givoni's bioclimatic chart for Bogotá that aims at predicting the indoor conditions of the building according to the outdoor prevailing conditions [8] a comfort zone of internal temperatures between 18°C and 25°C was delimited. Consequently discomfort is understood as any indoor temperature (T_i in Equation 2) lower than 18°C or higher than 25°C. Hence to define a discomfort indicator that takes into account dynamic variation of internal building temperatures for each hour of a complete year, we calculated from Equation 2 the amount of degrees-hour for hypothetical heating (to achieve 18°) and for hypothetical cooling (to achieve 25°C). The final result is the total yearly average of degrees-hour spent outside of the defined comfort zone during 8760 hours.

$$DH=\frac{1}{8760}\sum_{i=1}^{8760}[max(18-Ti,0)+max(Ti-25,0)] \quad (2)$$

A scale from DH=0 to DH=3 was defined for the yearly average, where DH=0 means internal temperatures during the whole year in the comfort zone, DH=1 means internal temperatures on average 1° outside of the comfort zone, and DH=3 means internal temperatures on average 3° outside of the comfort zone. In this scale a DH until 2 is considered an acceptable difference, and a DH between 2 and 3 an unacceptable difference.

Case study

The project "Las Huertas" a social housing neighbourhood, located at the south of Bogotá (4°63', -74°08') was selected mainly for two reasons: First, because it is a macro-project that follows the actual Colombian social housing regulations that encourage building "the greater number of houses in the available area" [9]. And second, because of its very high human density. These specific conditions allowed us to better understand the problem of urban density in social housing in Colombia and to design a case study according to a real situation. For study purposes we selected 3 plots of land from the total macro-project. Figure 3 gives a 2D representation of the chosen area, and the density parameters are described in Table 2.

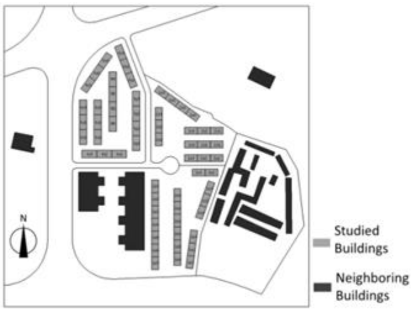

Figure 3: Selected plots of land.

CASE	Building Footprints	Site Area	Total Floor Area	Habitants
	m^2	ha	m^2	
1	11914.33	3.88	71485.98	4320

CASE	Number of Buildings	Buildings Height	Site Coverage	Plot Ratio	Human Density
		m	Building footprints / site area	Total floor area / site area	hab/ha
1	60.00	14.40	0.30	1.84	1113
2	30.00	28.80	0.15		
3	90.00	9.60	0.46		

Table 2: Density parameters for Las Huertas' selected plots and description of 3 case studies

We considered the quantitative deficit problem by studying three different urban scenarios with the same plot ratio but different site coverage (Figure 4) i.e., human density is the same in all cases. To conserve the same plot ratio build heights were modified as shown in Table 2.

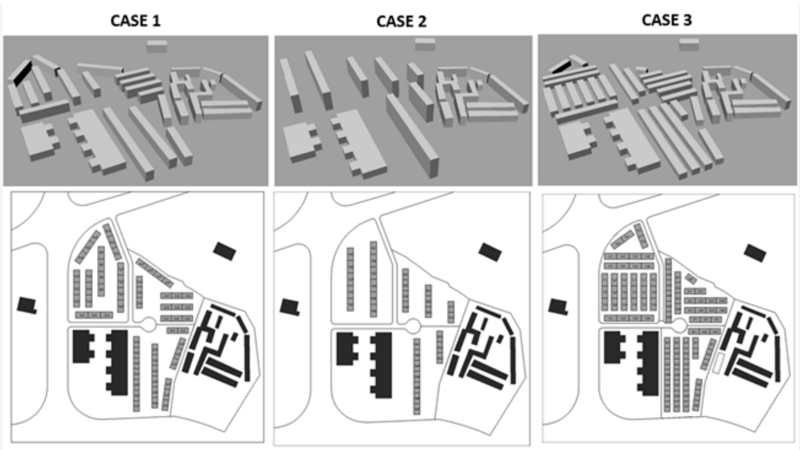

Figure 4: 3D and 2D representations of 3 urban scenarios

To evaluate the free floating dynamic thermal behaviour of the buildings it is compulsory to know the hourly occupancy profile related to the high human density. Since we only have the total number of potential occupants but not the variations of their presence, it was necessary to use for simulations standard profiles of occupancy, lighting and equipment. For this, and due to the lack of available data, the Swiss norm SIA 2024 was taken into account.

RESULTS

Simulation results take into account urban form, urban density, materials and thermal heat gains by occupants, lighting and equipment, according to the previously defined occupancy profiles. Figure 5 shows the influence of site coverage on thermal discomfort, the latter is illustrated with a colour scale from white to black where 1.7 was the lowest DH value obtained from simulations and 2.6 was the highest.

Case 3 with a site coverage of 0.46 (see Table 2), presents the highest discomfort rate with a DH=2.32, that is considered as an unacceptable difference. Case 2 with the lowest site coverage has the lowest DH. This can be explained by the effect of the larger vertical obstruction angle in case 2, which increases the distance between rows, and as a result more solar irradiation arrives to the buildings. In all three cases there is a better performance of buildings with a North-South orientation. Case 2 takes advantage of this privileged orientation allowing the settlement to achieve a lesser discomfort rate.

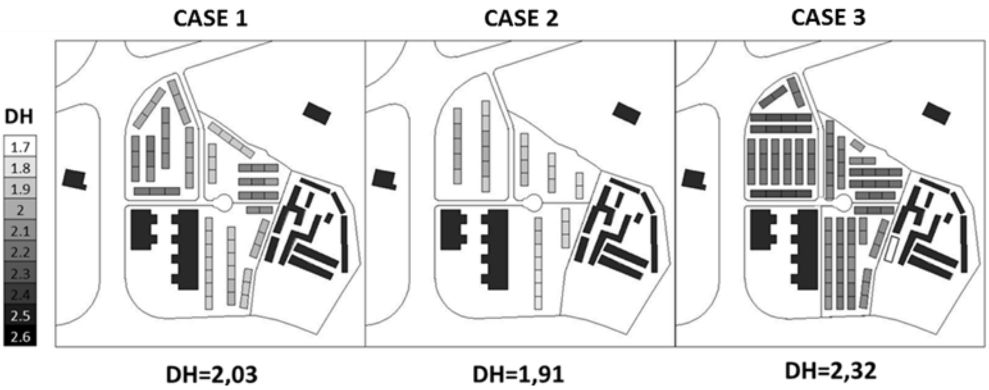

Figure 5: Yearly average discomfort indicators of three cases

Some interesting results were remarked in Cases 1 and 2; in the first case a zoom was made in order to see more clearly the influence of building's orientation (Figure 6). North-South oriented buildings show a considerably better thermal behaviour than those with an East-West orientation. In the second case the zoom aims to emphasize the effect of horizontal obstructions (Figure 7). A degradation of the scale of colours is evidently noticed i.e. DH values are affected by a reduction of the irradiation coming from the sides.

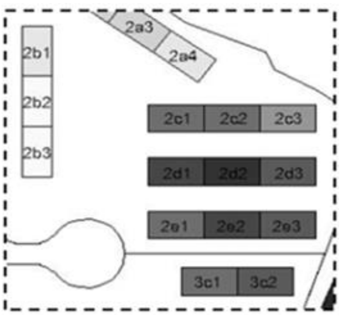

Figure 6: Zoom of case 1 *Figure 7: Zoom of case 2*

CONCLUSIONS

Three parameters associated with urban density have an influence on the average discomfort rate of urban settlements: vertical obstructions, horizontal obstructions and orientation of the buildings. Horizontal obstructions are related to site coverage (plan view), while vertical obstructions are related to plot ratio (elevation view). It was noticed that it is possible to reduce the discomfort rate of the neighbourhood and maintain the same high human density by combining lower site coverage with high rise buildings. In this way reducing vertical and horizontal obstructions of buildings can lead to more solar irradiation. Orientation is another important parameter that affects the thermal behaviour of buildings and therefore of urban settlement. North-South is the privileged orientation in Bogotá and architects and urban planners should take advantage of it in order to reduce the average discomfort rate of social housing neighbourhoods.

In a future perspective, further studies may analyse discomfort rates by floor levels defining one thermal zone per floor. It would be interesting to evaluate the effect of thermal inertia and glazing ratio on discomfort rates by changing some of the buildings' model parameters. Finally, architects and urban planners of Colombia have the challenge of creating sustainable urban habitats with a better environmental quality. To reach that objective, urban energy simulation is an invaluable support tool to manage the high urban and human densities that characterize cities in developing countries.

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