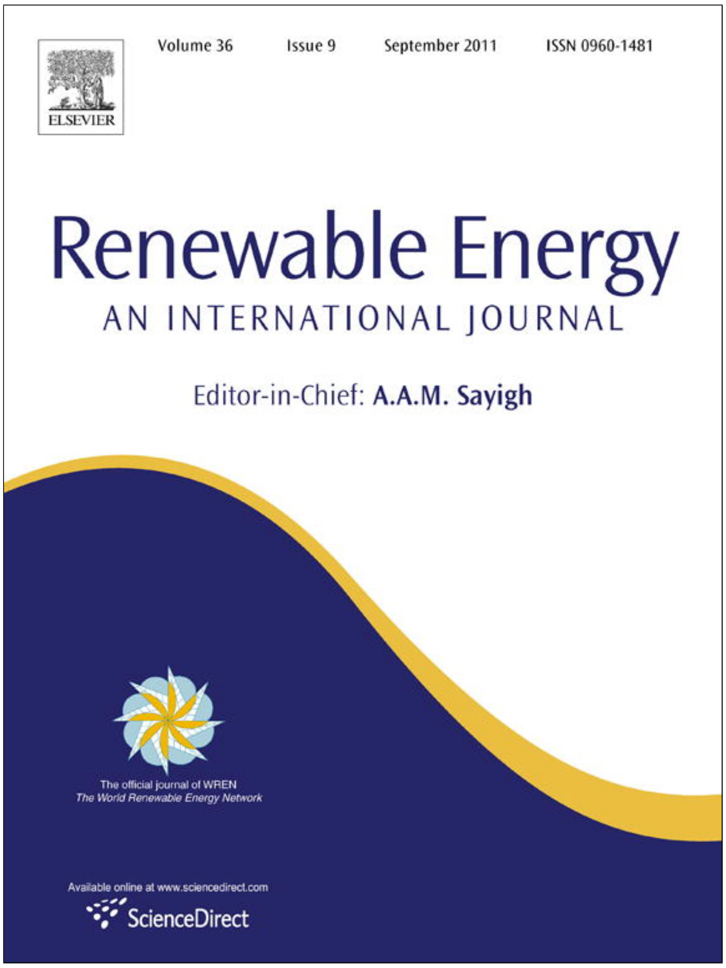
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Evaluation of the potential of natural light to illuminate buildings in dense urban environment. A study in Mendoza, Argentina

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ABSTRACT

Cities display an array of microclimates closely related to the composition of their surfaces and the relationships among their structures. The effect of the shadow cast by a high-rise building is a simple case of this situation. The incidence of the shadow on other buildings or urban spaces can be positive or negative, according to the bioclimatic requirements of the place and season. The understanding of the cause of these effects is key information that helps when planning new urban complexes or refurbishing existing ones.

Aiming at sustainable urban design, the building sector's energy efficiency, associated with bioclimatic design guidelines, is the most adequate way to achieve the desired goal and its consideration must be a priority in every situation where a high substitution potential of fossil by renewable energies exists, and it is available through control of the urban environment's morphology.

To make the solar energy use feasible in urban environments it is necessary to incorporate design guidelines into building and urban normative as parts of integral planning by compatibilizing desirable levels of solar access with urban density and considering shape and orientation of parcels, buildings and streets.

The paper presents the results of a study in Mendoza City, Argentina, on the daylighting potential in residential buildings, obtained through simulation and measurements "in situ". The electric energy consumed for lighting was analyzed, comparing different unit values for the apartments in the buildings of the city, considering their morphology and orientation.

1. Introduction

The quantity and distribution of natural light inside buildings is directly related to their design (distribution, orientation and dimension of openings), and conditioned by the site characteristics, the construction density aspects, height of buildings, dimensions and proportions of exterior spaces, direct sunning and sun reflection on exterior surfaces, as well as by the presence of trees, billboards and other components of urban scenery.

The current obligatory norms in Argentina which have a bearing on interior luminic availability in built-up spaces are those dependent on the Codes of Urban Construction (Códigos Urbanos de Edificación, CUE) in each municipality. In this particular case analyzed, the CUE regulates all the variables referring to the building morphological characteristics without contemplating the interior living conditions produced by the same.

Considering the important advantage of solar illumination potential (non-polluting, zero cost and inexhaustible), the task of evaluating the natural light resource availability was undertaken on urban structures applying the CUE's influence.

The national norms existing from the Instituto Argentino de Racionalización de Materiales (IRAM) and from the Asociación Argentina de Luminotecnia (AADL), establish minimum levels referring to illumination values for different living spaces in buildings. The drawback to these norms is that not being obligatory, they are only recommended parameters [17,18].

The importance of using natural light inside living spaces does not lie only in energy saving but also in the fact that most people show a preference for sufficient natural light both in their homes and in non-residential buildings [2]. Natural light provides a more attractive environmental quality and creates a suitable working place in which to carry out visual tasks comfortably during the daytime [8].

The results so obtained from the analysis of the morphology of Hong Kong, Ng finds that the variation in the urban design can lead

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to different conditions of daylight availability. For the same building density, there are different yields of lighting when the morphology was changed [14–16].

Several studies have evaluated the incidence of urban geometry on the energy efficiency of buildings. The obstructions reduce the availability of solar energy and daylight availability on the building façade [1,19,21–23].

2. Description of case analysis

The Metropolitan Area of Mendoza (MAM) is situated in the Andean foothills, at 750 m.a.s.l. (meters above sea level), in the North Oasis of the Province of Mendoza, Argentina. Its geographical coordinates are: 32.40° South Latitude and 68.51° West Longitude (Fig. 1).

The Andes Mountain Range to the west has a direct influence on the climate of the area. The wind, rainfall registers, the low humidity atmospheric percentage and high helium frame the area which forms part of the "South American arid diagonal" [7].

3. Methodology

The method is based on determining the level, and interior and exterior distribution of the available natural light within a Minimum Unit of Analysis, inserted in distinct space configurations corresponding to the urban area. In order to do this, an Analysis Theoretic Case, an Analysis Minimum Unit and a Control Case were carried out.

To calculate the interior luminic intensity field measurements, scale models and mock simulation programs were done through software like Lumen MicroR and Desktop Radiance 1.02 (Department of Energy, Berkeley Lab, U.S). The diagrams of interior distribution of light values obtained through simulations were carried out through Surfer Version 5.01 program.

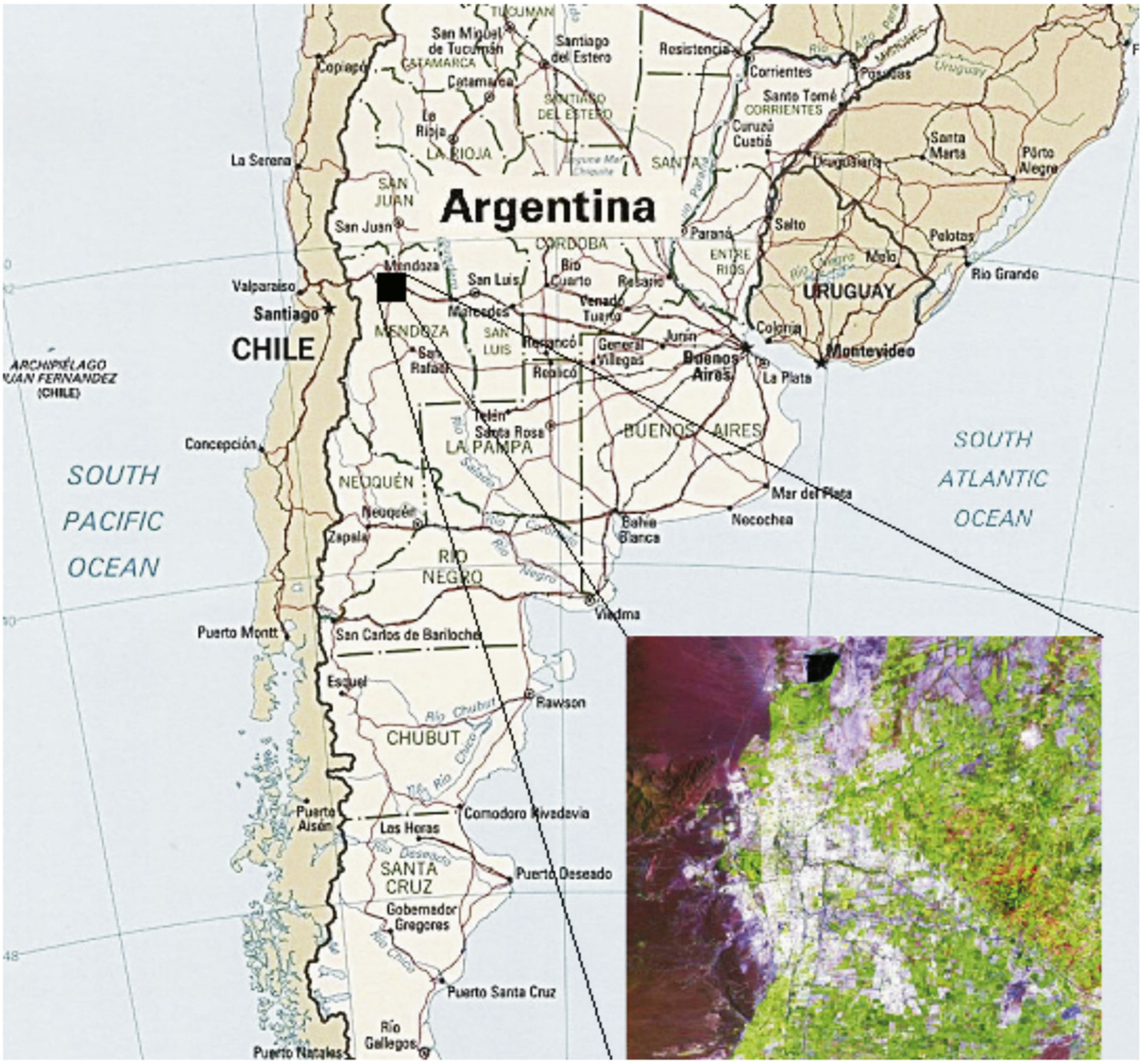

Fig. 1. Geographic position of the MMA in Mendoza.

Fig. 2. Real and simulated images.

The values obtained through measurements and simulations were compared to a Control Case and with the recommended values of acceptable minimum levels according to IRAM AADL J20-09 norms in Levels of Illumination (existing non compulsory norms) [6].

In the case of Desktop Radiance Program, apart from using it to obtain interior and external illumination levels, it was the calculus tool of the component incidence reflected on the interior light resource availability and on the façade surfaces in evaluated surroundings. For this type of case analysis no antecedents were had of previous use in similar environments to the ones simulated in clear sky situations, like those predominant in the area [9,24].

For this reason, in order to know the simulator's adjustment degree, field measurements were carried out to obtain luminance values (cd/m^2) of the building surfaces from one of the areas analyzed, besides measuring the enclosure's illuminance values which were compared to those obtained through the simulator in order to verify its accuracy. An adjustment of $+/-1.2\%$ was obtained, between the measured luminance values and those calculated by the software (Fig. 2).

3.1. Recommended levels of interior illumination

The tables of recommended illuminance levels, referred to in the norms of different countries are the result of a 20 year research concerning user preferences in different places performing different tasks. These studies are focused mainly on evaluating office jobs, because these are the most demanding, with longer working hours. The first results date from the '70s (IRAM, 1972). Translated into norms in Argentina, they establish recommended levels of interior space illumination [19].

Recent studies from the AADL indicate that at equal illumination values, the expected levels of comfort are different according to natural or artificial illumination. Interior illumination conditions must insure an adequate degree of visual comfort. The recommended levels of illumination will directly depend on the activity to perform, with a minimum, medium and high requirement that can be specifically distinguished. The first group includes transit

Fig. 3. Outline corresponding to the TCA analyzed.

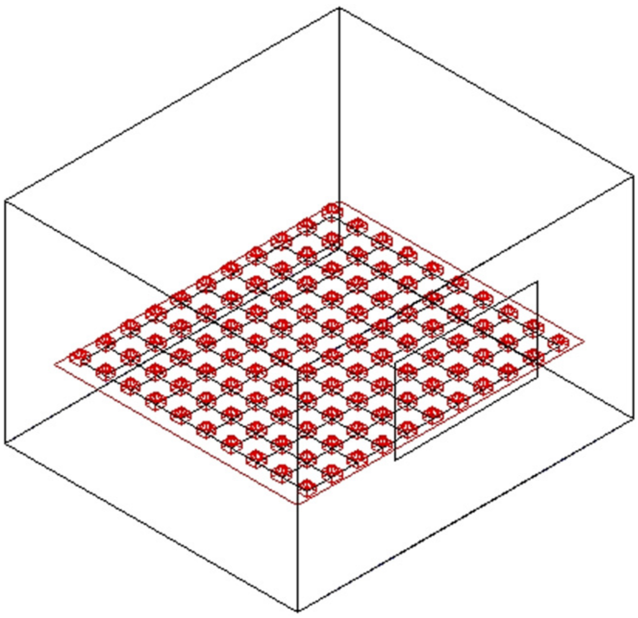

Fig. 4. Outline of AMU used and location of spots placed for acquisition of data.

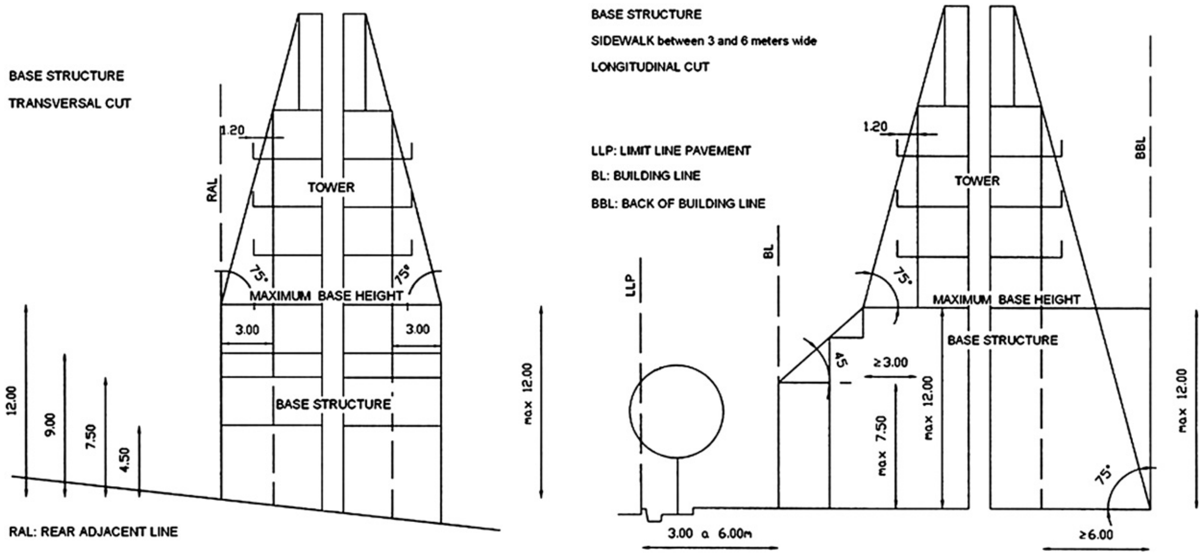

Fig. 5. Outline of obligatory limits for a high density zone from Mendoza's CUE.

zones, or places with little or transitory use, such as storerooms or bathrooms. In the second group, with illuminance values ranging between 200 and 1000 lux, are found places of frequent use, work zones, school rooms and study rooms. And finally, with values of over 1000 lux, certain environments are found where highly detailed work is carried out, like surgery zones or in cases of special industrial activities.

On analyzing illuminance recommended values for living quarters in a dwelling, it can be noticed that these are included in the first two groups, presenting greater illumination demands in the living places with values of 300 lux, or the work or study places with 500 lux. Considering the global exterior luminic availability of MMA (in winter time reaching 60,000 lux), the ability to reach these values in interior spaces will depend essentially on a design specially focused to this end [5,17].

3.2. Definition of the Analysis Theoretic Case (ATC)

In MMA's high density area, there is no case in which the incidence of a norm can be totally evaluated because there are no blocks of buildings wholly densified or built under a code from the same epoch. There are also urban empty spaces and ancient low buildings that attenuate the total density effect.

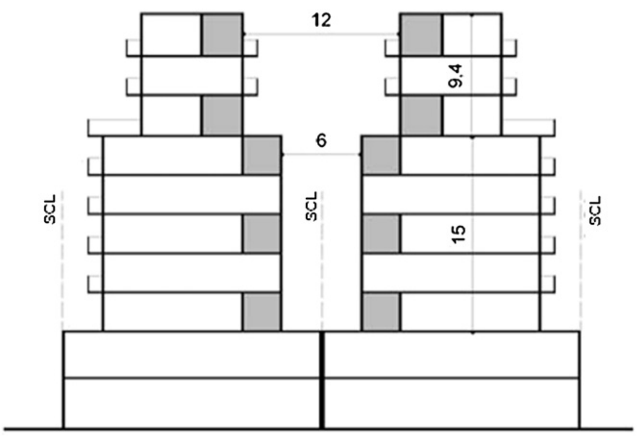

Fig. 6. Outline cut with location of analysis minimum units. Analysis outline with side limits (SCL: Side closing line).

The evaluation was carried out over a TC Analysis, made by an existing dense block of buildings, with the maximum density allowed by current norms. The result in volume affords an analysis case in which to evaluate the use of the CUE on interior luminic living conditions of building environments inserted in highly densified surroundings (Fig. 3). Within the analyzed morphology we localized as register points the Minimum Units of Analysis.

3.3. Definition of the Analysis Minimum Unit (AMU)

Once the evaluation cases selected, we proceeded to determine the AMU that reflect in their interior and exterior variables incidence, about the availability of interior natural light. The dimensions of the analysis minimum unit were established in a structure of 14 m^2 of surface and 2.5 m high, with a window corresponding to 12% of the floor area. All of these values are the minimum established by the CUE for a 1st category space. In the simulation of the same we placed, at a height of 0.80 m (stipulated as a work level), 100 spots for acquisition of data (Fig. 4).

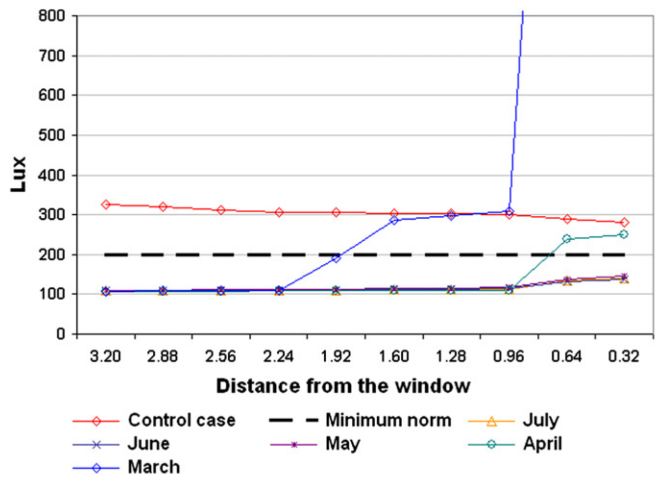

Fig. 7. Illuminance values for level +0.80 m, over the basement, south exposure for critical months.

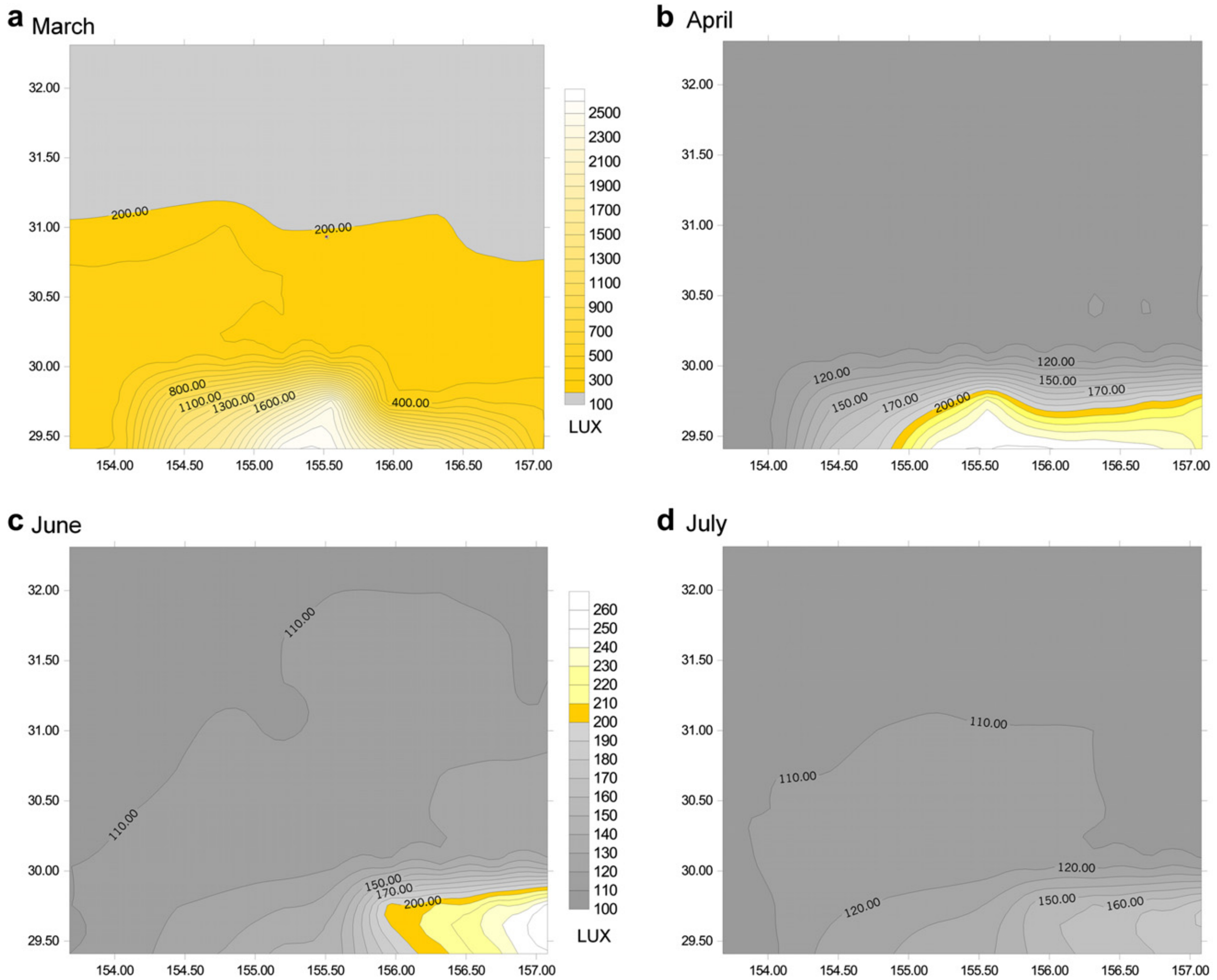

Fig. 8. Interior distribution for natural light for a level +0.80 m above the floor for different months of the year facing south.

3.4. *Definition of the Case Control (CC)*

A Control Case is an AMU that receives no incidence from its immediate surroundings which modify the availability and interior distribution of natural light. The CC was used as a reference frame to evaluate the incidence of obstructions and close reflecting parameters on the AMU.

4. Evaluation of the availability of the natural luminic resource in the building interior

In arid climates generally, as is the case particularly in the MMA (Mendoza Metropolitan Area), 76% of the year corresponds to clear skies with the presence of the sun in the daytime [3].

Studies carried out in the Province of Mendoza have revealed that electricity consumption of buildings related to illumination has a high incidence over the total energy expense. The residential sector consumes 26.48% of the total electric power, with 11% net consumption corresponding to illumination in the urban household sector [10,20].

To these values must be added the losses due to the low efficiency in generating and transferring of electric energy, with especially high losses in thermoelectric plants where efficiency seldom exceeds 35%. From these values, the amount of energy lost in generating and transferring electricity can be deduced, and from this the real percentage used in illumination.

If we compare the efficiency of natural illumination to artificial we can conclude that the first can be 10 times more efficient than the common lamp. From the energy consumed by an incandescent bulb, less than 10% is transformed into visible light while the rest is thermic energy. In the case of a fluorescent bulb the percentage improves, 20% is visible light and the rest is heat [4,5].

At present, although with sufficient luminous intensity in the daytime, one ends up using artificial light. It is easier and more convenient to rely on electric installations rather than with more detailed study on the maximum advantage of natural light. Even if in many cases the use of electricity for illumination is necessary, in other cases the loss of space quality, expense and impact produced do not justify it.

4.1. *Incidence of urban morphology on the potential use of natural illumination*

The regional approach of natural illumination involves the ways in which urban space takes form, responds, takes advantage, and benefits from the regional resources such as the presence of the sun, its duration and trajectory, the conditions of the sky, and other climactic elements.

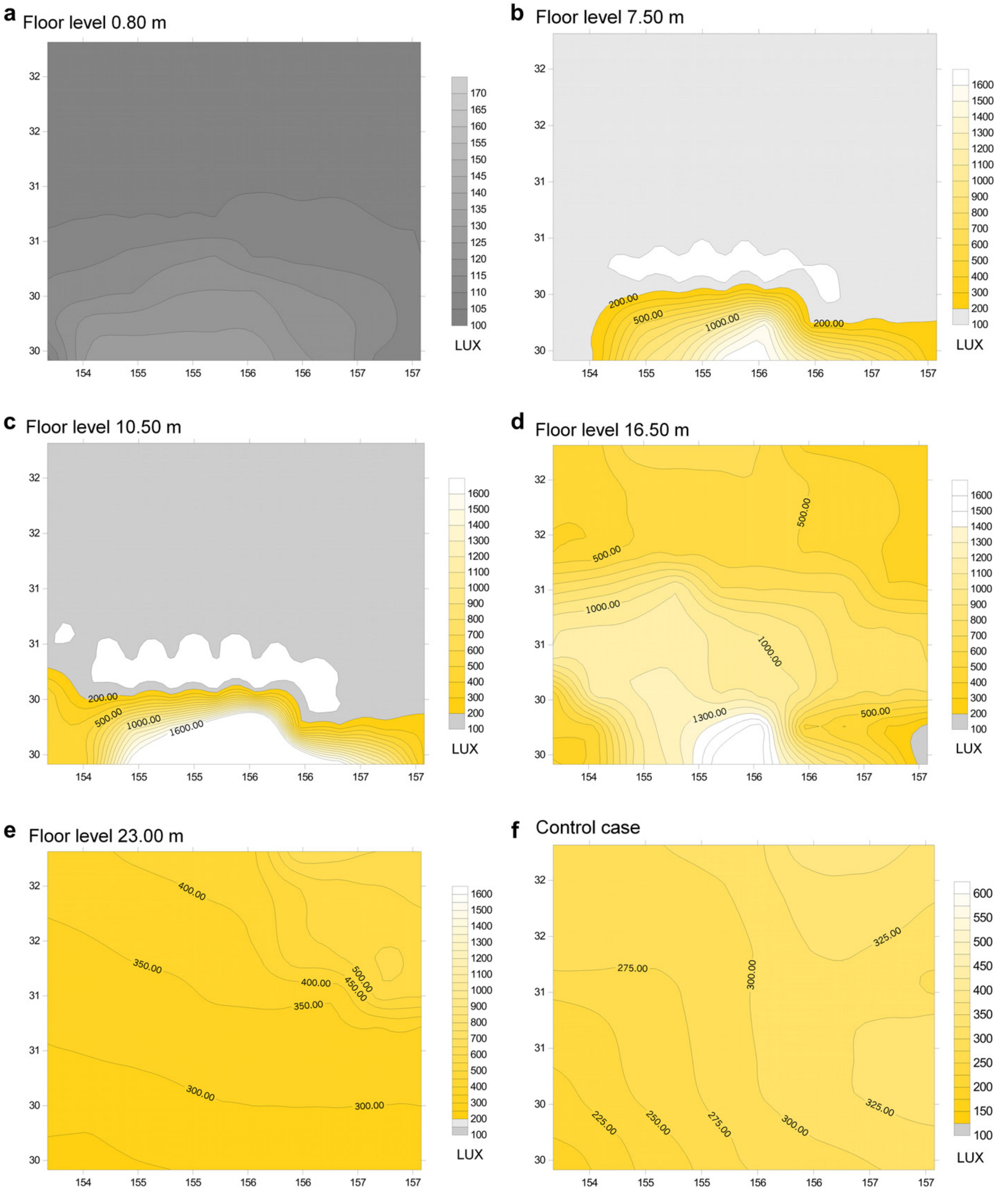

Fig. 9. Plano metric graphs of interior illuminance distribution for the different building levels for the months of June, facing south.

To evaluate the incidence of the urban morphology on the amount and quality available of natural light in interior spaces during the hours of the day, at different time of the year, is an important step towards being able to obtain design lineaments that will enable a maximum advantage of the available resource and ensure the interior quality of living space in buildings. The built-up space influences in a positive way (reflected component) and in a negative way (obstructing the sky vault) the availability of the luminic resource.

4.2. Nearby obstructions

Incidence on the luminic resource availability is minimum when produced by obstructions, in the case of low density buildings; this is where the construction design is important. In high density constructions the availability of the resource cannot be guaranteed only with a good design. One depends on the measures established by the CUE which determine the measurements of withdrawals and angles limiting a plot of land within the urban grid network and the volume of construction possible.

4.3. Side and rear limits

The established dimensions in codes referring to the separation of constructed volumes determine the conditions of interior spaces, generally not evaluated [11,12]. These include measurements of maximum withdrawals and height of buildings that delimitate the building's morphology without evaluating the block of buildings design generated by these norms, and habitability of space interior.

The CUE of Mendoza [13] establishes the measurements and angles that delimitate high-rise buildings in the zone. These measurements also establish the separation between buildings and according to this the minimum measurements of the plots that accept this type of building. Due to the required limits, high-rise buildings are usually placed on plots made of two smaller ones to be able to reach a volume economically viable with the real estate investment (Fig. 5).

4.4. Incidence of nearby obstructions evaluation

To analyze the incidence of the dimensions of nearby obstructions on the luminic resource availability, we simulated the interior conditions of an AMU included within selected urban spaces.

The AMU was placed inside the buildings configuration, at different levels and exposures, facing the wall of another building at a distance determined by the CUE according to each case analysis.

In this case, with a configuration of side limits between dividing lines, five positions at different levels of height were evaluated. Each height had a separation from the neighboring building, stipulated by the CUE, of 6 and 12 m (Fig. 6).

From values obtained through simulations carried out for the "Control Case" (identical configuration to the analyzed without the influence of nearby obstructions), it was detected that the south exposure is the least favorable as to the intensity of the luminic resource that it receives during the whole year. This is why this case was used as a comparison of minimum parameter for the different selected configurations.

Registers show that the influence of nearby obstructions on the availability of natural light in interior spaces of analyzed surroundings is critical at lower levels, whatever the window exposure. The results (1st floor over the basement) for the winter months do not reach the minimum established by norms (200 lux) for main dwelling spaces; keeping to a mean of 100 lux between the months of April and August, increasing values from the months of March and September which coincides with an increase in solar height (Fig. 7).

With respect to the interior distribution of the values, in the winter months none of the inner points of the total (100 measuring points) reach the minimum established by the IRAM AADL norm. In the months of March and April these percentages increase 56% and correspond to zones close to windows (Fig. 8).

When analyzing the illumination linear values of the perpendicular transversal cut to the window, varying the height of the study case position, on the higher levels of the building (16.5 m above base), the incidence of the obstructions is noticed, and the influence of the component reflected on the close vertical walls appears.

The values obtained show variations of up to 800% in the resource availability between inferior (0.80 m above base) and superior levels (16.50 m above base). The last level (23 m above base) presents a special case in that its values vary with respect to the lower level and resemble those of the Control Case. This is due to its position which does not receive the influence of the reflected component of the nearby building, showing lower values with a more homogenous distribution.

The graphs on Fig. 9 show the location of window spaces that correspond to the lower part of the figure. The grey tones represent values inferior to 200 lux (minimum level established by the IRAM AADL norm) and the colors between yellow and white show superior values. These correspond to zones in which the established work surface (0.80 m above floor level) is well illuminated.

In the cases of intermediate levels (7.50 m and 10.50 m height), although they present areas close to well lighted openings, the distribution is deficient, with great existing contrasts (variations between 100 and 1500 lux) making it difficult for the eye to adapt and rendering those rooms highly uncomfortable.

In all of the analyzed cases, the luminic resource availability in the inferior levels is deficient and does not meet the minimum requirements of quality illumination established by the norm for main dwelling spaces in the central months of the year. These values are reflected in the real consumption of the apartment units analyzed. The lower levels of the towers have a mean yearly consumption greater than the higher levels, without considering their exposure (Fig. 10).

The effect of sky vault obstruction on the lower levels, with a mean yearly consumption greater than the higher levels, causes increased values of up to 100%, without influence of the exposure.

Both in the study case of the incidence of lateral limits as in the analysis, only in the period between the end of spring and the summer months, do the lower levels of the building receive sufficient illumination. Considering that the lineaments of design stipulated in the building code, regulating the dimension of distances between buildings in both cases, do not comply with the objectives ("They must receive direct light and air through windows."), we proceeded to analyze which were the minimum admissible limits for the interior luminic quality of interior spaces not to be affected.

Based on the related values between the building line and the height of the obstacle different alternatives were evaluated for the least favorable case (level +0.80 m above base, with exposure south in the month of June) to be able to establish the point from which all the main spaces of the building, no matter their location (exposure and height) could count with the necessary quantity and quality of interior illumination.

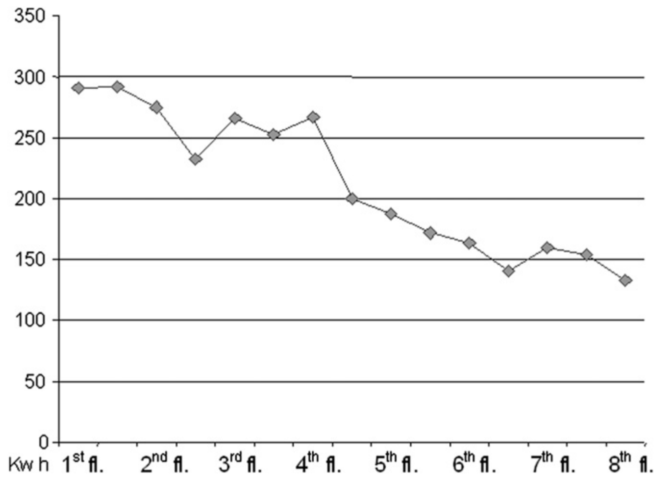

Fig. 10. Comparison of electricity consumption per floor level.

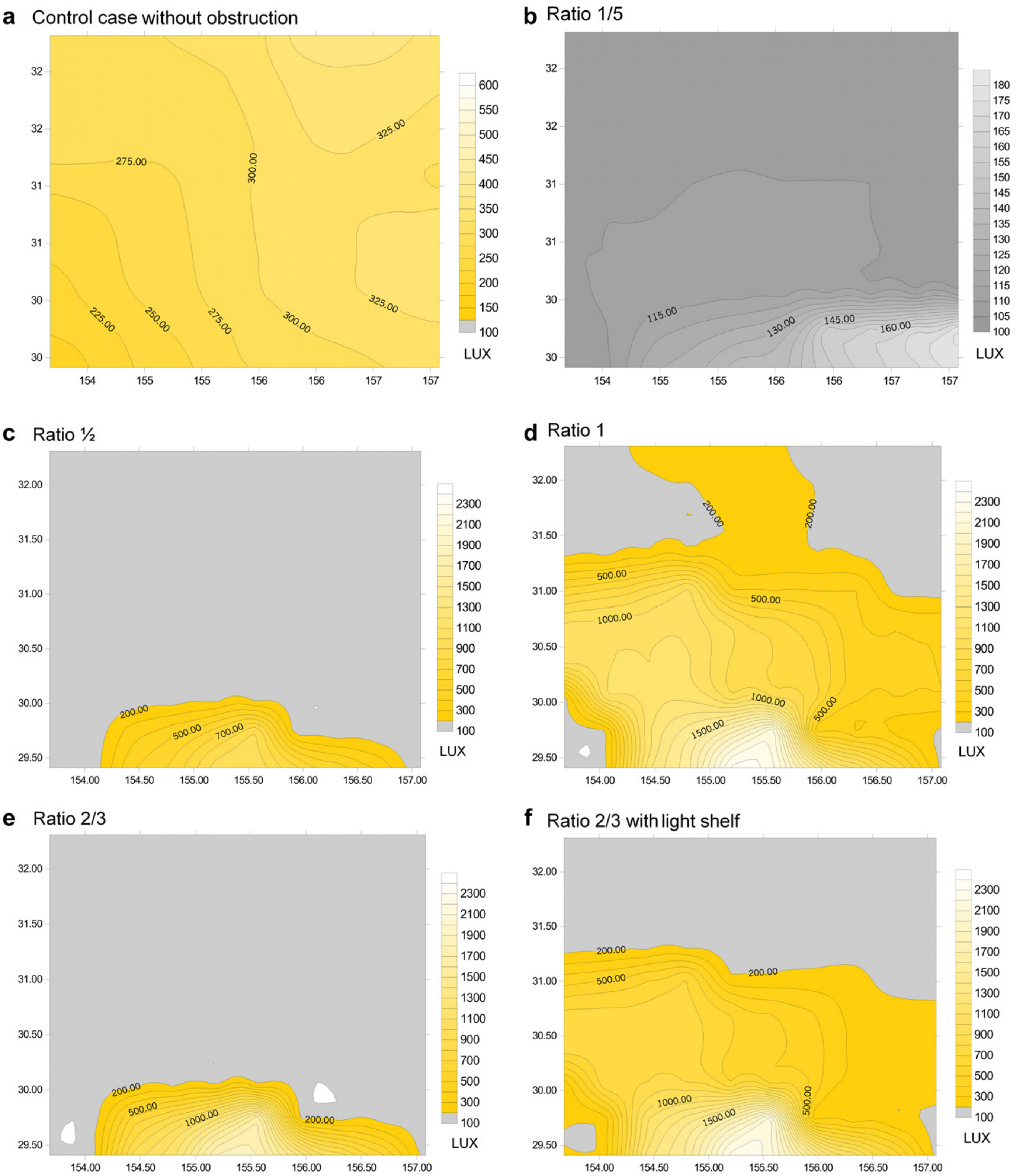

Fig. 11. Graphs of interior luminance distribution for the different ratios between the distance and the height of the obstacle, facing south, June, and 12 hours by the sun.

Four proportions were evaluated and the analysis results show that for the evaluated situations only when reaching a relation equal to 1, that is to say the separation difference equivalent to the next building's height, 87% of the inner points of the analyzed space, counted with acceptable values of natural illumination.

In the case of a 2/3 ratio, with normal measuring, only 11% of interior evaluated points counted with an illumination level over 200 lux, which in useful surface is similar to the case of the 1/2 ratio. In the case of the 2/3 ratio the illumination intensity that reaches the work level is equivalent to double the 1/2 ratio (900 lux

Fig. 12. Outline of analyzed block of buildings, maximum density possible according to the CUE of the Capital City.

against 1800 lux respectively) Counting with a higher luminic intensity allows the application of natural illumination strategies, in the case of the 2/3 ratio. By adding a light shelf of 0.50 m to the minimum analysis unit at the base of the window, the change was significant, going from the initial values of 11% of the good illumination point to 56% of the total work surface (Fig. 11).

Therefore, the optimum ratio of separation between buildings and their heights is between the 2/3 and 1 in relation to the height of the same. The resulting urban high density morphology would be very different from the one presented as a study case and would enable obtaining all interior spaces to reach minimum levels of natural illumination intensity and quality (Figs. 12–14).

The analysis presented evaluates all the aspects that have incidence on the luminic resource. It offers basic lineaments to be followed when integrating the interior habitability luminic variable in urban planning.

5. Conclusions

The developed evaluation methodology was confirmed and applied to other climactic zones. Thus establishing the elements of urban morphology that have most influence on the luminic habitability for interior building spaces in these regions.

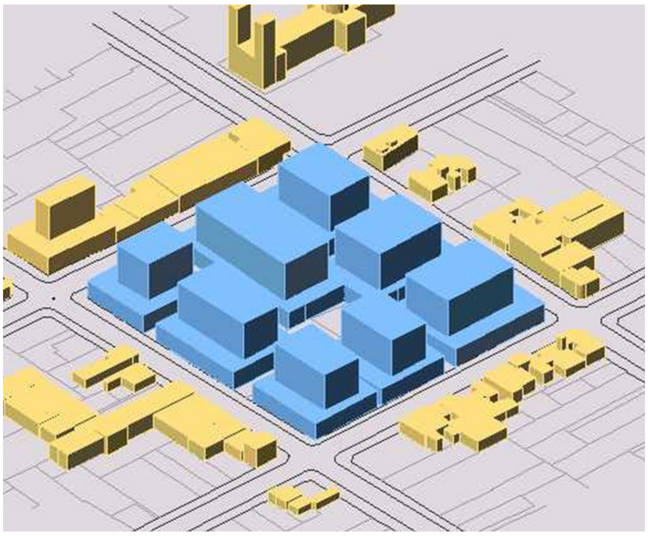

Fig. 13. Alternative outline 1, building height 15 m, and maximum density possible according to natural illumination availability.

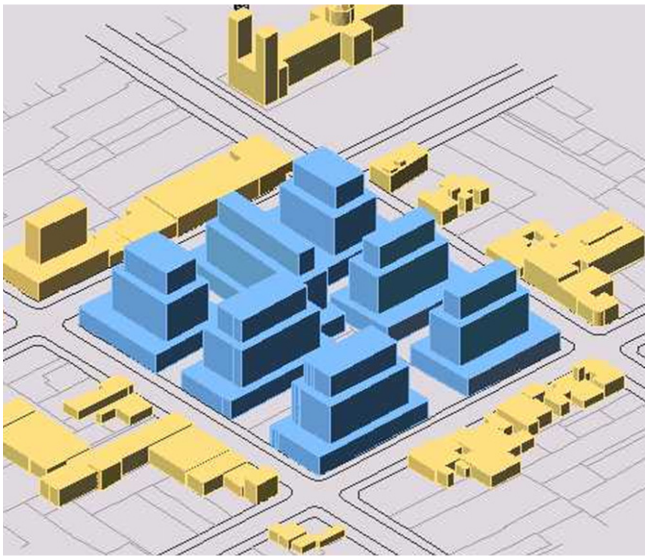

Fig. 14. Alternative outline 2, building height 25 m, and maximum density possible according to natural illumination availability.

Being able to identify urban indexes by intentional criteria is the purpose of this study. It is an advance to be able to establish standards that will allow future identification and evaluation of the analyzed variables concerning the luminic habitability of the different configurations that the city offers.

In the case analyzed, it is evident that the CUE's demands are limited to morphological aspects without considering the incidence of these decisions on interior habitability. At the present time, due to these same code requirements, main living spaces are condemned to having second rate characteristics according to their position in the building.

It is fundamental to consider the contribution of the component reflected by nearby sunny façades and the incidence of obstructions to the sky vault, in closed urban dwellings, since variations superior to 110% are to be found in the different configurations evaluated.

The existing ratio between the availability of natural illumination in building interiors, its potential use and the energy consumption destined to artificial illumination shows the importance of being able to establish interior obligatory minimum values of the natural resource. Thus contributing not only to space quality but also to the reduction of environmental effects derived from energy production.

The study developed sets the basis for a change in urban current growth towards greater habitability and energy efficiency on construction. This change must be effective at all intermediate stages, from territorial regulation to the use and maintenance of buildings, and would have a result of characteristics and regional scale, without imposition but with consensus.

References

[1] Baker N, Steemers K. Energy and environment in architecture. London: E&FN Spon; 2000.
[2] Boyce PR. Why daylight? Closing plenary session. Conference of daylighting technologies for energy efficiency in buildings; 1998. p. 359–66.
[3] Esteves A. Relevamiento y evaluación de los recursos climáticos en la provincia de Mendoza para su utilización en el diseño de construcciones bioclimáticas. Actas de la XII Reunión de ASADES, Buenos Aires; 1987. p. 391–8.

[4] Fontoynont Marc, editor. Daylight performance of buildings. France: James and James; 1999.
[5] Garcia Fernandez J. Luminotecnia. Iluminación de interiores y exteriores, http://edison.upc.es/curs/ilum; May 2002.
[6] Norma Nacional IRAM AADL J20-06 Niveles de iluminancia. Instituto de Racionalización Argentina de Materiales, Asociación Argentina de Luminotecnia; 1972.
[7] IPCC Working Group II. The regional impacts of climate change; 1998.
[8] Littlefair P. Daylight and sunlight in site layout planning. Urban Environment U.K. 2001;70(3):177–85.
[9] Ubbelohde MS, Christian Humann. A comparative evaluation of daylighting software: superlite, lumen micro, lightscape and radiance. In: Proceeding of conference of daylighting technologies for energy efficiency in buildings; 1998. p. 439–515.
[10] Estudio energético integral de la Provincia de Mendoza. Mendoza, Argentina: Ministerio De Ambiente Y Obras Publicas; 1998.
[11] Mesa NA, Cortegoso J, de Rosa C. Evaluación del potencial solar en entornos urbanos. Revista Avances en Energías Renovables y Medio Ambiente 2000;4(2):11.01–16. Millor, Salta, Argentina.
[12] Mesa NA, Cortegoso J, de Rosa C. Incidence of morphological and technological features of building envelopes on the energy savings potential of urban building stocks in mesothermal arid regions cities. PLEA 2001, Florianópolis, Brasil; 2001. p. 547–51.
[13] Código urbano y de edificación. Recopilación y actualización. Ciudad de Mendoza: Municipalidad de Mendoza; 2000.
[14] Ng E. A study on the accuracy of daylighting simulation of heavily obstructed buildings in Hong Kong. Brasil: IBPSAC; 2001. p. 1215–22.
[15] Ng E. Studies on daylight design and regulation of high density residential housing in Hong Kong. Lighting Research and Technology 2003;35(2):127–39.
[16] Ng E. A study of the relationship between daylight performance and height difference of buildings in high density cities using computational simulation. In: Proc. IBPSA – international building performance simulation association, Montreal, Canada; 2005. p. 847–52.
[17] Pattini Andrea. Recomendaciones de niveles de iluminación en edificios no residenciales. Una comparación internacional. Revista AVERMA 2000; 4:05.07–12. Salta, Rep. Argentina.
[18] Pattini Andrea. Eficiencia lumínica de dispositivos de control de luz solar aplicables a ventanas de aulas, en la Provincia de Mendoza. Tesis doctoral, Fac. de Ccias, Exactas y Tecnológía, U.N. de Tucumán; 2003.
[19] Ratti C, Baker N, Steemers K. Energy consumption and urban texture. Energy and Buildings 2005;37:762–76.
[20] Petróleo, Gas & Química. Argentina. Revista Petroquímica 1998;16(143):12–8.
[21] Steemers K. Energy and the city: density, buildings and transport. Energy and Buildings 2003;35:3–14.
[22] Tregenza P. Mean daylight illuminance in rooms facing sunlit streets. Building and Environment 1995;30(1):83–9.
[23] Tsangrassoulis A, Santamouris M, Geros V, Wilson M, Asimakopoulos D. A method to investigate the potential of south-oriented vertical surfaces for reflecting daylight onto oppositely facing vertical surfaces under sunny conditions. Solar Energy 1999;66(6):439–46.
[24] Dubois MC. Impact of shading devices on daylight quality in offices: simulations with radiance. Sweden: Department of Construction and Architecture, Division of Energy and Building; 2001.