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Design to Thrive

Solar Urbanism and Building Design in Buenos Aires – Design Guidelines

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Abstract: The Spanish grid inherited by Latin American cities divides the urban landscape into square blocks of equal size that are subdivided into identical plots of 8.66m width and varying depth. Building regulations standardise the options available within any given plot, as well as the resulting height-to-width ratios of streets. The orientations of the plots, and thus also of windows, are determined by the directions of the urban blocks. In combination with passive design strategies the paper shows that it is possible to achieve free-running conditions for residential units. The assessment was carried out in terms of number of hours the simulated indoor temperatures fell above or below the adaptive thermal comfort zone. The outcome is a set of design guidelines, tabulated for designers. Adoption of the guidelines is estimated to reduce average energy consumption by 2/3, resulting in large savings for occupants as well as for the State.

Keywords: Solar control, design guidelines, Buenos Aires

Introduction

Since 2016, after years of subsidies to domestic energy consumers in Buenos Aires, changes in State policy is seeing the subsidies being withdrawn and inhabitants having to bear the full cost of energy use. Whilst this has increased awareness of the need to reduce energy consumption, neither consumers nor the professionals dealing with the built environment have the know-how for undertaking such task. The aim of the research discussed in this paper was to provide guidelines for the application of passive techniques that would allow new and existing residential buildings in Buenos Aires to become free-running, that is to achieve thermal comfort conditions by passive means. To do so passive design strategies were assessed by simulation with Open Studio/Energy Plus for a range of representative configurations of the city's urban morphology and built form typologies. As with other Latin-American cities, the urban morphology of Buenos Aires is a legacy of the Spanish conquest and the city's planning norms and building regulations that have standardised the built form and its residential subdivisions (Fig. 1a-d). This modularity has guided the focus of the simulation studies and ensured generalisability of the results.

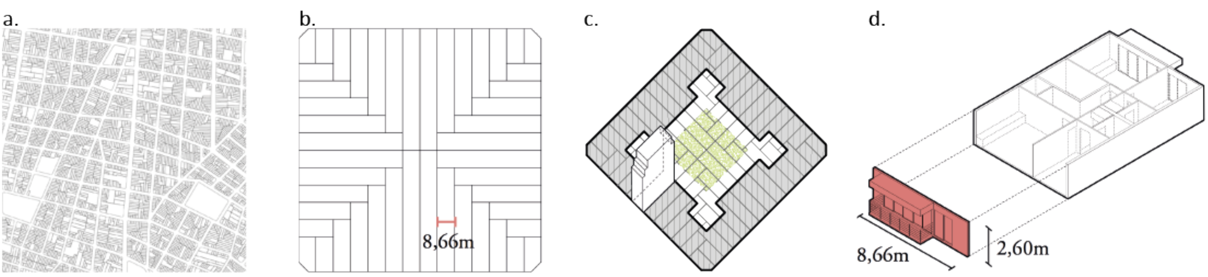


Figure 1. Modularity of the city of Buenos Aires

Methodology

Simulated free-running zone operative temperatures were evaluated against the adaptive comfort zone based on EN 15251 (category III). Conditions for simulations are shown in Figure 4. The EPW was taken from “Agronomía” weather station. Benchmarks were set as follows:

- Free-running, ideal practice: less than 200 hours below comfort and less than 100 hours above comfort by more than 1K. This averages to one hour per day on the three warmer months at times when occupants are mostly not at home; use of fan can help restore comfort in the warm period. In the cool period of the year, the temperatures below the comfort band of EN15251 occur mostly at times when occupants are asleep.

- Free-running, best practice: above 90% of time in comfort, less than 400 hours below comfort and less than 200 hours above comfort by more than 1^{o}K. It would represent, 4 hours a day during the 3 colder months, and 2 hours a day during the 3 warmer months.

- Good practice: above 85% of time in comfort.

The Urban Block

The city’s urban blocks have the same dimensions and are subdivided into plots with a fixed frontage of 8.66m and varying depth regulated by planning and building regulations. Solar simulation studies were undertaken to assess solar exposure of building surfaces as a function of urban block geometry and street widths. The city’s urban blocks were grouped as follows:

1. Typical heights: Three major groups were identified:
    a. Low density (4- storey high): 38% of the building stock is in this group spread around the city
    b. Medium density (10-storey high): 30% of the building stock in commercial streets, and near the city centre
    c. High density (15-storey high): 14% of the building stock in the city centre and main avenues

As most of the city’s building stock was built before the height limits set by regulations, most urban blocks incorporate buildings of variable height.

2. Typical orientations of blocks:
    a. Due North +/- 10^{o}: 18% of the building stock - remaining from the first layout of the city
    b. 45^{o} from due North (+/- 10^{o}): 32% of building stock – blocks near the limits of the city, in the original suburbs.
    c. The rest of the regular blocks are oriented at adjustment angles, representing 21% of the building stock.

3. Typical street width is of 17m.

Whereas the most repeated block in the city is the 45^{o} of low density, the larger number of units is located in blocks of high density at 0^{o} and medium density at 45^{o}. It is then relevant to study the 8 orientations, with a focus on high density. The above-mentioned parameters affect the amount of incident solar radiation on the facades. This is shown in Fig. 2 for each orientation and for a sample of regular and irregular blocks. The warm period is considered from December to February, and the cold one from June to August.

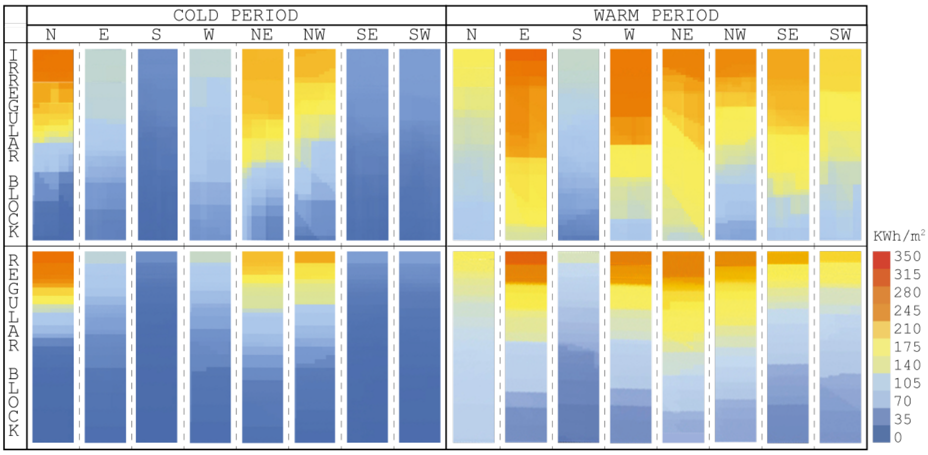


Figure 2. Solar radiation falling on facades of different orientation at different floor heights for regular and irregular blocks in Buenos Aires (latitude 34 South)

Irregular blocks present a similar profile to regular ones, but allow further penetration of solar radiation. Two of these configurations are illustrated in more detail in Fig. 3. These represent the most exposed and least exposed cases. In the warm period of the year the urban blocks oriented at 45° show a more even distribution of solar radiation than those at 0°, suggesting they have better potential for being free-running. East and West orientations present the highest range of solar radiation, and due South has the least exposure. In the cold period the Northern orientations seem to have a clear advantage over the rest. Blocks at 45° have two sides that receive a fair amount of solar radiation, whilst blocks at 0° only have one.

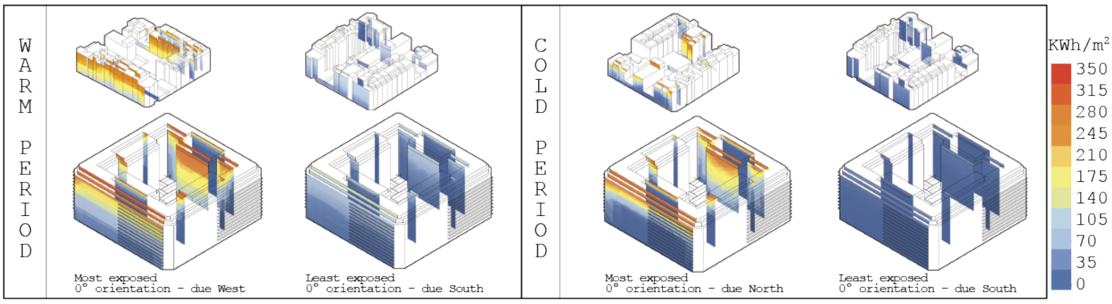
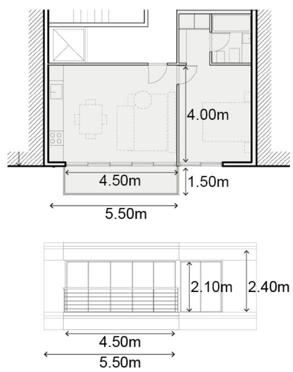


Figure 3. Solar radiation falling on typical blocks – Least and most exposed for warm and cold periods

Housing Units

Thermal and daylight simulations were performed on a model of a typical dwelling unit (Figure 4). The simulation model was calibrated on temperature measurements taken in an existing apartment (Collo, 2016). Note that provision of a balcony is compulsory in Buenos Aires being required by the building regulations.



CONDITIONS FOR SIMULATIONS

Room conditions
total area= 40m²
room considered: living room
thermal zone area= 22m²
floor to ceiling height =2.40m
balcony depth=1.50m

Envelope characteristics
W/W ratio= 64%
W/F ratio= 45%
U value wall= 0.65
U value window= 5.9
infiltration rate= 1.0 ach/h

Indoor conditions
occupants= 2
occupation period= 24 hours
lights= 4W/m2
electricity= 7W/m²
minimum fresh air requirement= 0.5 ach

- free running mode
cross ventilation: considered between the living room and the bedroom, through the open door
window opening: if temperature inside is above 24°C
- when loads are considered
cooling setpoint= 27°C
heating setpoint= 20°C

Figure 4. Basecase definition

Design Strategies

- Balcony : Variations included the balcony dimensions, retracted or protruding, opacity of balustrade, and role of vegetation.
- Solar protection: Variations included the addition of an awning, internal blinds, hanging vegetation and horizontal and vertical louvers.
- Winter strategies: Variations included reduction of the window-to-floor ratio to 30%, the addition of night shutters, curtains, different glazing properties (U=3.1, U=2.7, U=2.0), and a reduction in the infiltration rate from 1.0 to 0.5 ach. A lower reduction in the infiltration was not considered since it is the minimum fresh air requirement for the units.

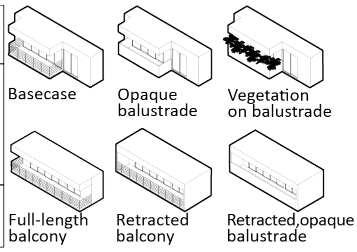
Results

Balcony morphology

Table 1 provides a comparative summary of results obtained from the simulations performed on the balcony variants. The comparison is drawn in terms of percent of time over the year with indoor operative temperature above, below or within comfort range. This is listed for West and North facing balcony variants. The Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) ratios are also listed and compared in the Table.

Table 1. Balcony morphology results

	Basecase		Opaque balustrade	Vegetation on balustrade	Full-length balcony		Retracted balcony		Retracted and opaque balustrade
% of time	W	N	W	W	W	N	W	N	W
In comfort	39.6	52.8	42.1	42.1	39.8	55.5	41.9	54.1	44.9
Above	45.5	43.6	39.8	39.7	42.7	39.5	40.1	38.7	34.2
Below	14.9	3.6	18.1	18.2	17.5	5.5	18	7.2	20.9
UDI	54%		73%	81%	70%		71%		79%
DA	91%		88%	85%	90%		89%		88%



The form of the balcony has a clear effect on indoor conditions, but is not in itself sufficient to block direct solar radiation on all the orientations. Varying the length of the balcony can be a useful tool to further regulate solar gains. Adding an opaque balustrade and retracting the balcony are as helpful for summer as they are detrimental for winter, which leaves the decision to the designer or subjected to other conditions. Adding vegetation on top of the balustrade does not modify conditions inside.

Solar protection

Table 2 provides a comparative summary of results obtained from the simulations performed on summer strategies. Figure 5 illustrates them. The comparison is drawn in terms of percent of time over the year with indoor operative temperature above, below or within comfort range. This is listed for West facing facades. The Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) ratios are also listed and compared in the Table.

Table 2. Summer strategies results

West orientation	Basecase	Awning on Basecase		Internal blinds	Hanging Ivy	Awning on Retracted balcony		Horizontal Louvers	Vertical Louvers
% of time		non-eng.	engaged	engaged		non-eng.	engaged		
In comfort	39.6	42.2	48.8	47.4	40.2	45.2	54.2	48	42.7
Above	45.5	42.6	34.9	37.5	44.6	36.1	24.7	29.7	32.1
Below	14.9	15.2	16.7	15.1	15.2	18.7	21.1	22.4	25.2
UDI	54%	86%		83%	74%	71%		87%	84%
DA	91%	76%		87%	88%	89%		87%	78%

Shading activation

Engaged User:
indoor temperature >27°C
incident solar rad. >150W/m²

Non-Engaged User:
indoor temperature >29°C
incident solar rad. >350W/m²

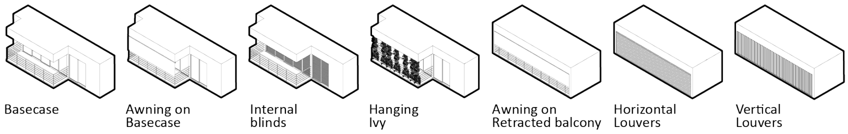


Figure 5. Illustration of summer strategies

Application of shading on western and eastern orientations is mandatory for summer. Amongst the strategies presented, the most efficient one is the use of an awning, attaining maximum levels of comfort (+9.8%) without loss of daylight inside. This can form part of the initial design or added later by occupants. Use of fixed louvers reduces solar gains in winter (period below comfort can increase by 4.4% or 7.2% depending on the type), as well as affecting views. Blinds or vegetation are other means for additional solar protection though with lesser good overall results.

Winter strategies

Table 3 provides a comparative summary of results obtained from the simulations performed on winter strategies. The comparison is drawn in terms of percent of time over the year with indoor operative temperature above, below or within comfort range. This is listed for North and South facing facades. The Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) ratios are also listed and compared in the Table.

Table 3. Winter strategies results

	Basecase U=5.9		+ Nightshutters U=1.92		+ Curtains U=2.7		Infiltration 0.5 ach		Glazing A U=3.1 t=0.8		Glazing B U=2.7 t=0.7		Glazing C U=2.0 t=0.5		+ Wall insulation U=0.45		W/F ratio A 30%		W/F ratio B 15%	
% of time	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S
In comfort	52.8	49.5	46.4	54.5	48.5	53.8	35.9	46.8	40.1	47.1	38.5	47.1	49.7	51.4	52.4	49.3	50.3	51.2	48.4	53.5
Above	43.6	24.2	52.5	25.6	50.2	25.3	63.4	34.4	59.0	32.8	60.8	33.9	49.4	29.5	43.8	24.6	47.7	25.2	50.6	25.3
Below	3.6	26.2	1.0	19.9	1.3	20.9	0.7	18.7	0.9	20.1	0.7	19.0	0.9	19.1	3.8	26.1	2.0	23.6	1.0	21.2
UDI	84%		84%		84%		84%		87%		89%		91%		84%		88%		88%	
DA	90%		90%		90%		90%		89%		88%		80%		90%		86%		50%	

When facing North, the base case is already close to free-running with only 3.6% of time below comfort. Adding night-shutters can reduce this to 1% and covers the coldest hours. South-facing variants are 26.2% of time below comfort. Adding thermal insulation to walls does not help. The most effective strategy is to improve airtightness of the building reducing infiltration to 0.5 ach, followed by better glazing and the addition of night shutters.

Free-running buildings

The results quoted above were for the unobstructed upper floors. Simulations were also carried out for different floors to determine how different strategies may apply to each floor of the buildings on the urban block. The results are shown on Table 4 and Fig. 6. Table 4 provides a comparative summary of results obtained from the simulations performed on optimised free-running buildings. The comparison is drawn in terms of percent of time over the year with indoor operative temperature above, below or within comfort range. This is listed for the 8 orientations on the 14 floors.

Table 4. Free-running buildings

level	N: % of time in comfort inside	N: above	N: below	N: hrs out of comfort >1ºC	N: <1ºC	N: category	S: % of time in comfort inside	S: above	S: below	S: hrs out of comfort >1ºC	S: <1ºC	S: category
14	95.5	1.7	2.8	62	104	ideal	90.4	2.7	6.9	114	345	best
13	96.7	1.3	2.0	42	71	ideal	91.1	2.1	6.7	87	329	best
12	96.7	1.2	2.1	41	69	ideal	91.5	1.9	6.6	72	311	best
11	97.0	1.1	2.0	30	67	ideal	92.4	1.4	6.2	48	284	best
10	96.1	1.1	2.9	29	97	ideal	92.5	1.2	6.2	44	282	best
9	95.0	0.9	4.1	24	181	ideal	92.5	1.2	6.3	40	285	best
8	92.2	0.9	6.9	24	319	best	92.4	1.1	6.5	35	290	best
7	90.2	0.9	8.9	24	414	good	92.3	1.1	6.6	32	294	best
6	89.4	0.8	9.7	23	474	good	92.3	1.0	6.7	30	297	best
5	88.9	0.8	10.3	23	491	good	92.3	1.0	6.8	27	298	best
4	88.7	0.8	10.5	22	500	good	92.3	1.0	6.8	26	299	best
3	88.6	0.8	10.6	22	501	good	92.3	0.9	6.8	23	298	best
2	88.6	0.8	10.7	22	502	good	92.4	0.9	6.7	20	297	best
1	88.7	0.7	10.6	17	498	good	92.5	0.9	6.6	19	287	best

level	W: % of time in comfort inside	W: above	W: below	W: hrs out of comfort >1ºC	W: <1ºC	W: category	E: % of time in comfort inside	E: above	E: below	E: hrs out of comfort >1ºC	E: <1ºC	E: category
14	84.3	3.2	12.5	158	706	-	86.6	3.3	10.1	143	551	good
13	85.1	2.8	12.1	127	671	good	86.9	2.9	10.2	111	540	good
12	84.4	2.6	13.0	117	723	-	86.7	2.5	10.8	107	588	good
11	85.4	2.2	12.4	96	683	good	87.5	2.2	10.3	97	541	good
10	88.7	2.0	9.3	95	461	good	90.5	2.2	7.3	92	345	best
9	88.5	1.9	9.6	76	470	good	90.7	1.9	7.4	77	350	best
8	88.1	1.6	10.3	67	511	good	90.4	1.7	7.8	68	379	best
7	87.5	1.4	11.0	54	560	good	90.1	1.6	8.3	57	409	good
6	86.9	1.3	11.8	48	592	good	89.6	1.4	9.0	51	432	good
5	86.6	1.2	12.3	38	625	good	89.5	1.2	9.3	46	468	good
4	86.3	1.0	12.7	28	651	good	89.2	1.2	9.6	39	485	good
3	86.1	0.9	13.0	22	670	good	89.1	1.0	9.9	32	503	good
2	86.0	0.8	13.2	19	686	good	89.0	1.0	10.1	25	506	good
1	86.0	0.8	13.2	16	683	good	88.9	0.9	10.2	20	502	good

level	NW: % of time in comfort inside	NW: above	NW: below	NW: hrs out of comfort >1ºC	NW: <1ºC	NW: category	NE: % of time in comfort inside	NE: above	NE: below	NE: hrs out of comfort >1ºC	NE: <1ºC	NE: category
14	92.6	3.0	4.4	141	154	ideal	93.4	2.7	3.9	109	156	ideal
13	93.8	2.6	3.7	106	120	ideal	94.2	2.5	3.4	96	121	ideal
12	93.5	2.5	4.0	100	143	ideal	94.2	2.3	3.6	93	137	ideal
11	93.9	2.2	4.0	86	141	ideal	94.5	2.0	3.5	80	132	ideal
10	93.1	2.1	4.9	81	184	ideal	94.2	1.9	3.9	75	143	ideal
9	93.9	2.0	4.2	74	145	ideal	95.5	1.8	2.7	72	76	ideal
8	93.3	1.9	4.9	71	186	ideal	95.0	1.7	3.2	68	111	ideal
7	92.5	1.7	5.8	68	250	best	94.2	1.6	4.2	65	154	ideal
6	91.6	1.6	6.8	59	295	best	93.3	1.5	5.2	61	213	best
5	91.2	1.4	7.4	51	330	best	92.6	1.4	6.0	56	254	best
4	90.7	1.2	8.1	49	389	best	92.1	1.3	6.6	50	288	best
3	90.2	1.2	8.6	58	410	good	91.8	1.2	7.0	42	311	best
2	90.1	1.0	8.9	62	424	good	91.6	1.1	7.3	34	334	best
1	90.2	0.9	8.9	60	422	good	91.8	1.0	7.3	23	329	best

level	SW: % of time in comfort inside	SW: above	SW: below	SW: hrs out of comfort >1ºC	SW: <1ºC	SW: category	SE: % of time in comfort inside	SE: above	SE: below	SE: hrs out of comfort >1ºC	SE: <1ºC	SE: category
14	88.8	2.3	8.8	93	430	good	88.8	2.3	8.9	92	435	good
13	90.4	2.1	7.5	83	353	best	90.4	2.0	7.6	79	357	best
12	91.5	2.0	6.5	84	293	best	91.4	2.0	6.6	78	296	best
11	92.7	1.8	5.5	75	241	best	92.5	1.9	5.6	77	243	best
10	93.0	1.8	5.1	73	221	best	93.0	1.8	5.2	75	214	best
9	93.2	1.8	5.0	73	210	best	93.1	1.8	5.1	75	211	best
8	93.3	1.7	4.9	73	208	best	93.2	1.8	5.0	74	209	best
7	93.4	1.7	4.9	71	207	best	93.3	1.7	5.0	71	208	best
6	93.4	1.7	4.9	70	206	best	93.3	1.7	5.0	71	207	best
5	93.5	1.7	4.9	69	204	best	93.3	1.7	5.0	70	207	best
4	93.5	1.7	4.8	68	204	best	93.5	1.7	4.9	68	206	best
3	93.6	1.7	4.8	66	198	best	93.5	1.7	4.8	67	205	best
2	93.7	1.6	4.7	61	189	ideal	93.6	1.6	4.8	66	200	ideal
1	93.9	1.6	4.5			ideal	93.8	1.6	4.6	66	190	ideal

The lower five floors of high density blocks present similar results irrespective of orientation. The top four floors are the most exposed and require maximum solar control. These also correspond to all the floors of low density blocks as well as the top four floors of medium density blocks. The five intermediate floors (and the five lower floors of medium density blocks) present an in-between behaviour. It is recommended to apply solar protection with the possibility of extra insulation or reduction to the window-to-floor ratio in the future.

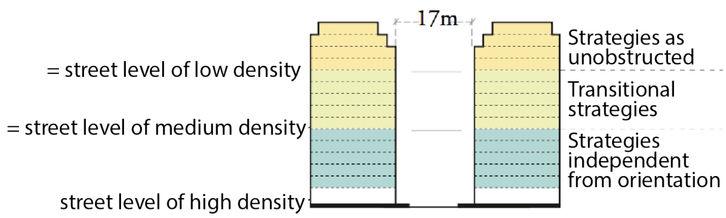


Figure 6. Design Strategies for different floors as a function of solar obstruction

By applying these strategies any residential unit can have between 84.4% and 97% of its time inside the comfort band. Most of the units (45%) fall into the category of best-practice. However, there is a clear advantage for the units on the blocks rotated 45° compared to the units on the blocks oriented to the main cardinal points. More than half of the apartments on 45° blocks present ideal practice conditions, with a minimum number (11%) of units on good free-running conditions, whereas this proportion is inverted on 0° oriented blocks.

Annual space heating and cooling loads were calculated for the three main orientations to assess likely energy consumption and compare potential energy savings, Fig. 7. For these simulations the zone temperature set-points were taken as 27°C and 20°C respectively as representing plausible values for air-conditioned dwellings, though some people would prefer lower settings in the summer period. Note that these settings differ substantially from the upper and lower limits (31.4°C and 19°C) of the adaptive thermal comfort band used on comfort assessment under free-running conditions. The benefit in terms of reduced space heating loads is clear on all the orientations, leading to reduction of some three quarters of the base case energy consumption

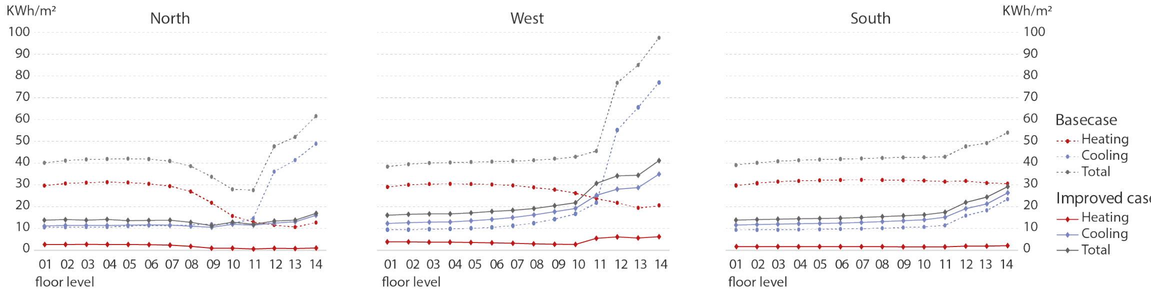
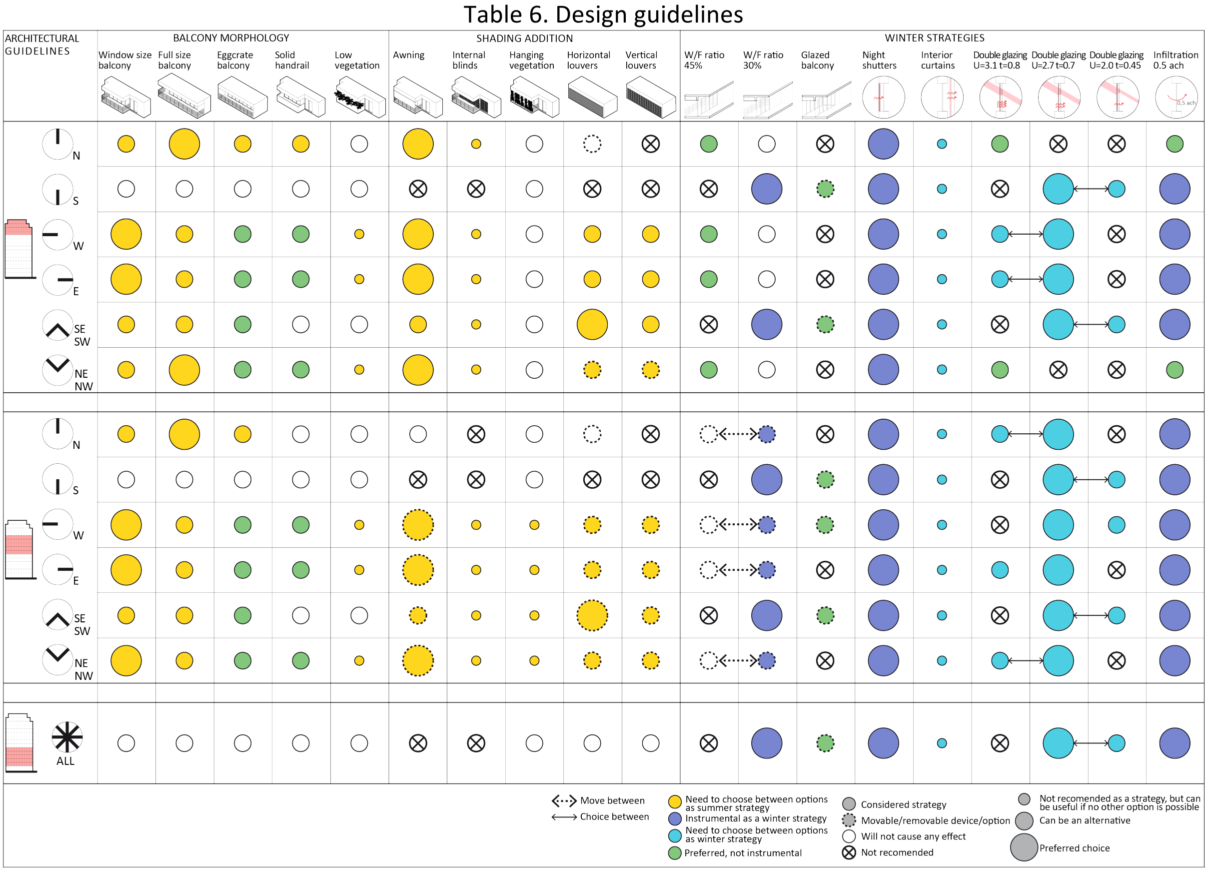


Figure 7. Comparison of energy consumption for the three main orientations

Discussion

Table 6 summarises the recommendations for designers and occupants extracted from the results of simulation studies performed on full buildings under free-running conditions (Collo, 2016). These characterise the relevance or otherwise of each strategy for any dwelling on any location within the city of Buenos Aires. The recommendations are presented under three categories that represent the three groupings of floor levels introduced in Fig. 6 above, and encompass the eight main orientations of urban blocks and the design strategies considered in the previous sections of the paper. Strategies marked in yellow or blue mean they are somehow relevant for that unit. The bigger the circle, the larger the importance of that strategy to bring the unit into comfort under free running conditions. Green means the strategy is preferred, but not instrumental. Crosses represent the non-adequacy of the for that case. Dotted lines signify that the construction should be able to be moved.

Table 6. Design guidelines



Bringing typical housing units of Buenos Aires into acceptable comfort under free-running conditions seems to be straight forward considering schemes that are common practice. The highest deficiency today is in terms of winter strategies, given that most of what is built has single glazing, high infiltration rates and no night shutters. This problem has its grounds on the fact that developers commissioning the project are not the end users. Therefore, they spend less money on the construction at the expense of the occupant's energy consumption. Balconies imposed by regulations are highly beneficial for solar protection. However, shading devices, that are necessary in exposed eastern and western orientations, became less and less common to allow more views. The lowest floors of high density barely receive solar radiation, and their residential use is not recommended. If this is the case, maximum insulation should be provided in all the orientations, without neglecting the size of the window for daylight purposes. Reducing energy consumption significantly seems easy to adopt if the strategies are properly employed. If new blocks were to be built, rotating them at 45^{o} presents marked advantages for all the apartment units.

Conclusion

Improving the quality of construction and raising awareness amongst architects will be instrumental for domestic energy consumption to be lowered in the forthcoming years. The guidelines presented here do not impose restrictions on architects or occupants as they mostly involve common practices. The simulation studies reported in this paper showed that adopting these guidelines can help achieve occupant thermal comfort conditions for between 84% and 97% of time in any apartment in Buenos Aires. Also, electricity bills for heating and cooling can be cut down to 1/3 of the current values, with an enormous impact both in the user's economy and the current energetic crisis.

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