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Exploring the impact of balconies on cooling energy demand in an arid climate zone

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Abstract

This paper explores the impact of balconies on the energy demand required for cooling in the arid climate zone of the city of Adrar, in Algeria. For the purpose to assess several situations of the balconies, we have chosen a parametric method based on a campaign of thermal simulations. The open and eliminated balcony type were selected and characterized by four parameters: the balcony to room ratio, the orientation, the window type, and the balcony position. A set of 100 simulations was selected randomly based on the Monte-Carlo probability technique. The final sample was corrected based on Cook's distance which gave 85 simulations as a final sample size. A generalized regression model was performed to identify the impact of each parameter. The accuracy of the model is above 97% and the sensitivity analysis shows that the most important factor is the balcony to room ratio which could reduce the energy demand up to 26% followed by the window type (24%), the orientation (8%) and the balcony position (5%). This conclusion stresses the idea of considering the balcony as a passive solution to reduce the cooling energy demand.

Key words: Adrar, arid climate zone, balcony, parametric analysis, cooling energy demand.

1 Introduction

The residential sector consumes more than 40% of the final energy consumption [1, 2], and several orientations are prepared across the world to reduce the use of fossil energy. To do so, several papers discuss the passive and the active ways to reduce the energy demand in the residential sector. Within the higher densities proposed and stressed by the sustainable development goals, the balconies constitute a real substitute for the courtyard [3]. The balcony also represents an important parameter in explaining the satisfaction of inhabitants regarding the cities' liveability [4, 5].

Ribeiro et al. in their review show that most of the studies considering the impact of balconies on the energy demand come from western and Asian cities [3]. For this purpose, the present

paper explores the idea stressing the **passive role** of balconies in reducing the energy demand in an arid climate zone [3]. We have selected the city of Adrar because its climate is typical and represents a large zone of Algeria's south Saharan.

In the second section of this paper, a literature review is presented aiming to highlight the balconies' type, and the methods used to carry out their effect on the cooling energy demand. The third section presents our method to identify the correlation between energy demand and the characteristics of balconies. The fourth section presents and discusses our results with a comparison with the results obtained from the literature review. Finally, in the fifth section, the conclusion highlights the results and limits of our approach and proposes some tracks for further research.

2 Literature review

The papers reviewed consider the balcony as an architectural solution to improve the Indoor Environment Quality (IEQ). Mainly, three objectives are targeted by researchers: (1) the impact of the balconies on the interior comfort, for heating and cooling demand [6], (2) airflow patterns and ventilation quality [7, 8] with and without balconies, and (3) the balcony as an acoustic shielding [9, 10]. Our paper fits in the first set of studies and aims to highlight the impact of balconies on the cooling energy demand.

The literature highlights several types of balconies. Three types are considered based on the opening criterion: (1) Open Balconies (OB), which are characterized by their direct opening to the outside. This type of balcony is stressed for the warm climate zones because of its shading potential [11, 12]. (2) Glazed Balconies (GB) reduce the contact between the balcony and the outdoor [13]. This type could be proposed by architects and is mainly recommended for the cold climates for their heat potential, or it could be also the case of a transformed balcony and this case is very widespread in the developing countries like Algeria, Tunisia, or Morocco [2]. (3) The third type of balcony is the Eliminated Balcony (EB) [14]. This case is also widespread in developing countries, and it aims to enlarge the indoor surface. In our case and as a response to the harsh side of our climate zone, we have selected the Open Balcony with some situations of Eliminated Balconies to be able to assess the importance of balconies in reducing the cooling energy demand.

To assess the importance of the impact of the balconies on the cooling energy demand, two main approaches exist: (1) A simulation [15, 16] and (2) in-situ-based approaches [17, 12]. Some papers consider the in-situ measurements as a technique of calibration to verify the quality of the simulations and to test new improvement techniques [22]. Because of its high flexibility in representing a high number of situations, the simulation-based approach is considered to predict the impact of the balcony on energy demand.

The results regarding the impact of the balcony on the cooling energy demand show a positive impact and reduce the energy consumption by up to 12% in Hong Kong [18]. The authors explain this reduction by the shading potential of the overhang which decreases the amount of solar radiation. Authors also claim the positive technology effect of windows on the energy

cooling demand, i.e., the solar transmittance and the reflective or absorptive glazing.
In the same track, Raeissi and Taheri (1998) have also obtained almost the same results for the city of Shiraz in Iran [19]. The overhang shading potential could reduce up to 12.7% of the energy demand of cooling in the summer. Authors have considered the horizontal depth of balconies and they claim that it would be more profitable to consider the balcony geometry (depth) to reach a trade-off between the optimization of the energy demand required for cooling and lighting according to the fourth geographical orientations. In China, and for the same purpose, Yu et al. (2008) found a reduction of almost 8% in electricity energy demand achieved through the balcony overhang shading effect. A combined strategy (thermal insulation of exterior walls, the solar radiation absorptance of the exterior wall, window to wall ratio, window categories and the length of the overhang) could result in electricity saving potential of up to 21.08 and 34.77 % for cooling and heating respectively [20]. In the present paper, we aim to explore the impact of different balcony situations on the energy demand by varying several parameters. The next section explains the method adopted.

3 Method

The method adopted follows the steps below:

A. Conceiving the design of experiments:

The first step consists in conceiving an archetype on which several parametric variations could be applied. For this purpose, we have sketched a single room space of 18 m² as a reference design, and we have added a 2.1 m² of French window (1x2.1 m) and its dimensions remain fixed for all the other situations. See Figure 1 below.

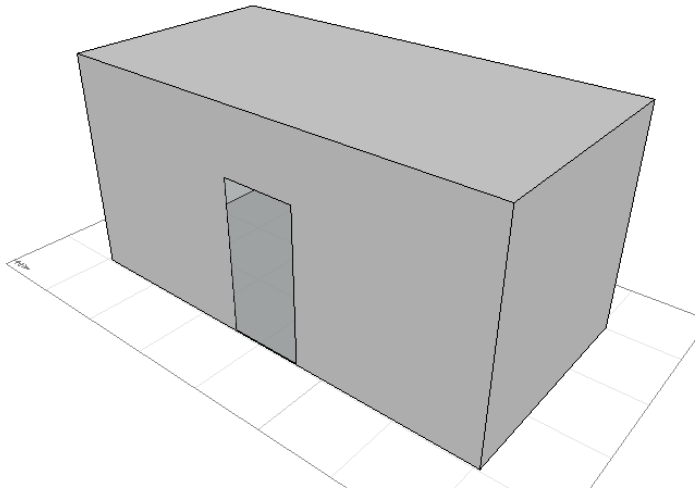


Figure 1: The base line design (no balcony situation)

B. Parametric variation:

To assess the impact of the balcony on the energy demand, we have selected four main parameters usually used by architects when designing balconies. (1) The balcony/room ratio. This parameter highlights the area of the balcony regarding the room area. And it could be obtained with overhang situation and by hollowed-out balconies (See Figure 2 below). We

have considered a range of ratios with several values: 0 (no balcony), 0.16, 0.2, and 0.5. (2) The second parameter considered is the position of the balcony, whether in the centre, left, or on the right of the room. (3) The orientation is the third parameter considered for this study. We have directly selected the four geographic orientations, north, west, east, and south. (4) The last parameter considered is the glazing type of the French window. We have considered two parameters for this purpose, the thermal transmittance (U-value) and solar heat gain (SHG) coefficient. Four cases were selected: (a) a simple glazing window (U value = 5.1 W/m².K and SHG = 0.94); (b) a double glazing window (U-value = 2.26 W/m².K and SHG = 0.75); (c) a double glazing window (U-value = 1.8 W/m².K and SHG = 0.60); and (d) the high performance high glazing window (U-value = 1.25 W/m².K and SHG = 0.45). All these window types exist already in the Algerian market. See Table 2.

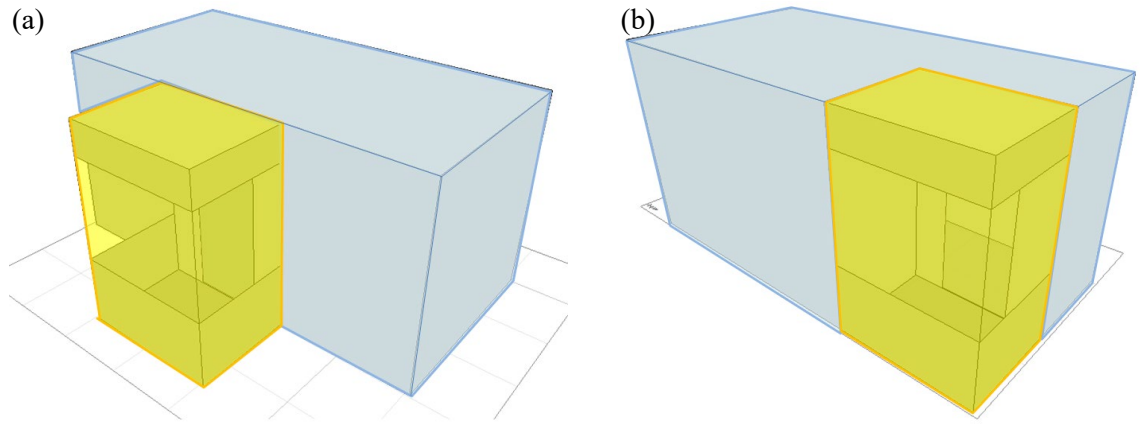


Figure 2: Balcony geometry and position. (a) Overhanging balcony, (b) Hollowed-out balcony

Other thermal characteristics of the room are fixed, and their values are considered as for the standards proposed by the regulatory document (DTR). See Table 1 below.

Table 1: Thermal characteristics of design elements

Building element	U-value
100 mm thick concrete slab on ground.	0.88 W/m².K
Ceiling (insulated pot floor, 200 mm)	0.36 W/m².K
Exterior walls (double brick cavity render, 150mm; 50 mm air gap; and 100 mm brick)	1.34 W/m².K

C. *Sampling*

A first random sample size of 100 simulations was considered based on the Monte-Carlo technique which is based on random sampling in the possible interval variation of each variable. The importance of this method is more felt when the interval is wide and when there is no linearity between the dependant and independent variables. Also, this method was used because it does limit the number of possible situations and cover a large range of parameter variation [21]. To perform an accurate model, we have corrected the sample by using Cook's distance. We have eliminated all the cases with a value higher than 0.2. A total of 85 simulations is the sample size considered to perform the model, see Appendices, Tables A-1

and A-2.

Table 2: Frequency of the parameters considered in the model

Parameters	Values	N (frequency)
Balcony/room ratio	no balcony	23
	0.16	27
	0.2	26
	0.5	9
Balcony position	Right	31
	Centre	24
	Left	30
Window type (U-value)	0.94	18
	0.75	26
	0.60	20
	0.45	21
Orientation	South	20
	East	18
	West	24
	North	23

A generalised regression model is performed based on the 85 simulations and the results are presented in the next section.

4 Results and discussion

The generalised regression model does allow considering all the parameters variation and permits to carry out the importance of each variation. The variance inflation factor (VIF) was checked to identify the multicollinearity of the variables introduced in the model. The VIF values of the entire variables are less than 3 and the tolerance values are larger than 0.2, which indicates that there is no multicollinearity, and all the variables are independent of each other [23], see Table 3 below. We have introduced the interaction between the window type and the façade orientation in the model. The accuracy of the model performed is above 97%, as indicated in Table 4 below.

Table 3: Multicollinearity test

	Tolerance	VIF
Balcony/room ratio	0.998	1.002
Balcony position	0.998	1.002
Window type	0.992	1.008
orientation	0.990	1.010

Table 4 : The generalised regression model

Source	The sum of squared type III	df*	Squared mean	f**	Significance
Corrected model	15759.900a	20	787.995	102.011	0.000
Constant	351794.959	1	351794.95	45542.008	0.000
Window type * Façade orientation	195.211	9	21.690	2.808	0.008
Bal/room ratio	3821.629	3	1273.876	164.911	0.000
Balcony position	102.819	2	51.409	6.655	0.002
Window type	5677.584	3	1892.528	244.999	0.000
Façade_orientation	582.050	3	194.017	25.117	0.000
Error	494.376	64	7.725		
Total	557306.759	85			
Corrected total	16254.276	84			

R^2 = .970 (R^2 adjusted = .960)

*df : degree of freedom
**f : f-statistics. All f-statistics values of the variables are greater than zero which means that the null hypothesis is rejected, and the model is good for predicting.

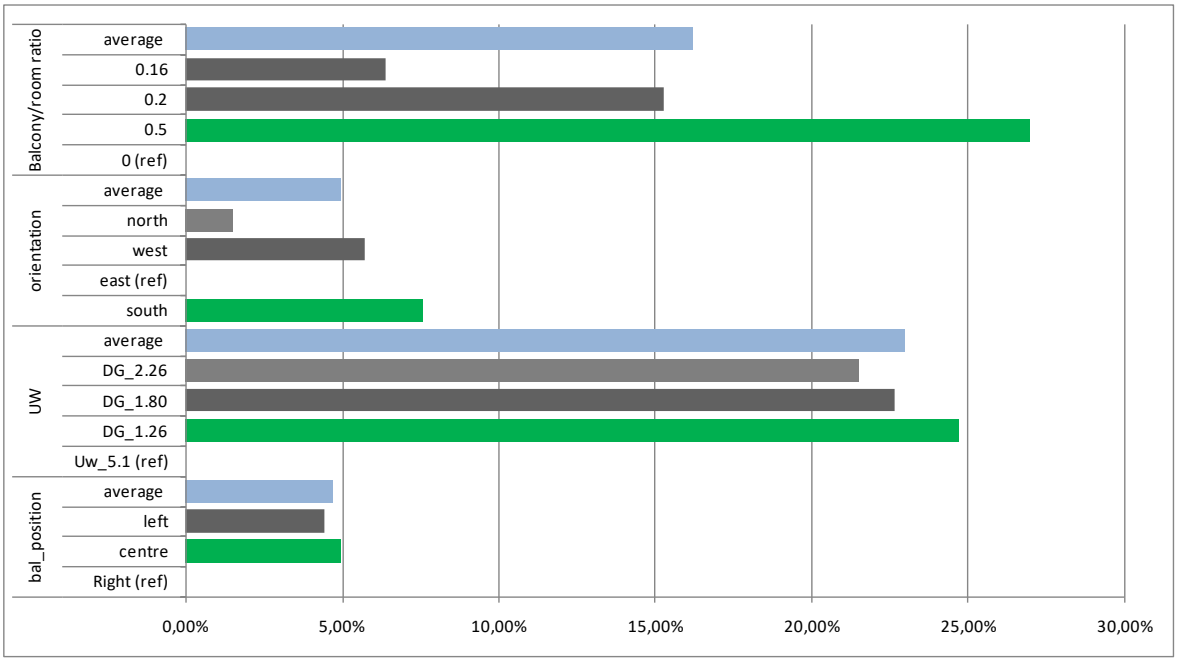


Figure 3: Energy saving for all the parameters

Figure 3 shows clearly that the balcony to room ratio plays an important role in reducing the cooling energy demand of up to 27 % for the ratio of 0.5. In the second position comes the window quality characterized in this paper by the solar heat gain (SHG) and the U-value of the window. The high-performance double-glazed window with an SHG of 0.45 and a U-value of 1.26 could reduce the cooling energy demand up to 24.70%. Also, it is worth to highlighting that the variation of the energy saving is almost the same for all the double

glazed windows which means that there is no need to enhance the insulation or the solar heat gain up to 1.26 W/m².K and 0.45 respectively. A double glazed with a U-value of 2.26 and SHG of 0.75 W/m².K could reduce the cooling energy demand up to 21.51%. The impact of the orientation in reducing the cooling energy demand is observed for the south orientation of the facade because the south orientation has the maximum sun hours and the highest solar altitude which means that a deep balcony will reduce the solar incidence and create higher shading areas. Also, our results show a weak impact of the balcony position, with a small impact of 5% for a central position. The overhang effect could explain this impact.

A negative linearity behaviour is observed using a bivariate correlation between the cooling energy demand, the window type (-0.674), and the balcony to room ratio (-0.37). The cooling demand decreases with the increasing quality of the window and the depth of the balcony especially with hollowed-out balcony because it allows more shading potential.

Considering the construction cost, all the balcony strategies remain interesting and reduce the cooling energy demand, but the utility area is more important with overhanging balcony type. The highest energy saving potential is observed for hollowed-out balconies. Regarding the average value for each parameter, the window type gets the first position with an average value of 23%, followed by the balcony to room ratio with a 16.22% average value. The orientation and balcony position have approximately the same average impact of almost 5%.

5 Conclusion

In this paper, we have performed a sensitivity analysis based on a generalized regression model to assess the impact of the balcony characteristics on reducing the cooling energy demand for a room in Adrar, situated in an arid climate zone. Our results highlight the importance of the balconies as a passive solution to reduce the cooling energy demand. The balcony to room ratio which also could be interpreted as a balcony depth has an important shading potential, and its impact could reduce the cooling energy demand by more than 25% and more efficiently than a high-performance double-glazed window. The idea of stressing the balcony as a passive solution is verified in this climate zone. In this paper, we have considered only the impact of the balcony on the cooling energy demand based on the Open Balcony type. For further purpose and research, the glazed balcony or glazed and open balcony could be considered and analysed for both cooling and heating energy demand.

References

[1] Boukarta, S., & Berezowska, E. (2017). Exploring the Energy Implication of Urban Density in Residential Buildings. *Journal of Applied Engineering Sciences*, *7*(1).

[2] Boukarta, S., & Berezowska-Azzag, E. (2018). Energy demand of occupant's spatial modification in residential buildings. Case study of Médéa, Algeria. *Selected Scientific Papers-Journal of Civil Engineering*, 13(s1),15-28.

[3] Ribeiro, C., Ramos, N. M., & Flores-Colen, I. (2020). A review of balcony impacts on the indoor environmental quality of dwellings. *Sustainability*, *12*(16), 6453.

[4] Kotulla, T., Denstadli, J. M., Oust, A., & Beusker, E. (2019). What Does It Take to Make the Compact City Liveable for Wider Groups? Identifying Key Neighbourhood and Dwelling Features. *Sustainability*, *11*(12), 3480.

[5] Omrani, S., Garcia-Hansen, V., Capra, B. R., & Drogemuller, R. (2017). On the effect of provision of balconies on natural ventilation and thermal comfort in high-rise residential buildings. *Building and Environment*, *123*, 504-516.
[6] Hastings, S. R. (2004). Breaking the "heating barrier": Learning from the first houses without conventional heating. *Energy and Buildings*, *36*(4), 373-380.
[7] Chand, I., Bhargava, P. K., & Krishak, N. L. V. (1998). Effect of balconies on ventilation inducing aeromotive force on low-rise buildings. *Building and environment*, *33*(6), 385-396.
[8] Kahsay, M.T.; Bitsuamlak, G.T.; Tariku, F. CFD simulation of external CHTC on a high-rise building with and without façade appurtenances. *Build. Environ*. 2019, 165.
[9] Kropp, W., & Bérillon, J. (1998). A theoretical model to investigate the acoustic performance of building facades in the low and middle frequency range. *Acta Acustica united with Acustica*, *84*(4), 681-688.
[10] Wang, X.; Mao, D.; Yu, W.; Jiang, Z. Acoustic performance of balconies having inhomogeneous ceiling surfaces on a roadside building facade. Build. Environ. 2015, 93, 1–8.
[11] Giovannini, L., Verso, V. R. L., Karamata, B., & Andersen, M. (2015). Lighting and energy performance of an adaptive shading and daylighting system for arid climates. *Energy Procedia*, *78*, 370-375.
[12] Saleh, P. H. (2015). Thermal performance of glazed balconies within heavy weight/thermal mass buildings in Beirut, Lebanon's hot climate. *Energy and Buildings*, *108*, 291-303.
[13] Mihalakakou, G. (2002). On the use of sunspace for space heating/cooling in Europe. *Renewable Energy*, *26*(3), 415-429.
[14] Kim, G., & Kim, J. T. (2010). Healthy-daylighting design for the living environment in apartments in Korea. *Building and Environment*, *45*(2), 287-294.
[15] Foged, I. W. (2019). Thermal responsive performances of a Spanish balcony-based vernacular envelope. *Buildings*, *9*(4), 80.
[16] Nowak-Dzieszko, K., & Rojewska-Warchał, M. (2015). Influence of the balcony glazing construction on thermal comfort of apartments in retrofitted large panel buildings. *Procedia Engineering*, *108*, 481-487.
[17] Dahlan, N.D.; Jones, P.J.; Alexander, D.K.; Salleh, E.; Alias, J. Evidence base prioritisation of indoor comfort perceptions in Malaysian typical multi-storey hostels. Build. Environ. 2009, 44, 2158–2165.
[18] Chan, A. L. S., & Chow, T. T. (2010). Investigation on energy performance and energy payback period of application of balcony for residential apartment in Hong Kong. *Energy and Buildings*, *42*(12), 2400-2405.
[19] Raeissi, S., & Taheri, M. (1998). Optimum overhang dimensions for energy saving. *Building and Environment*, *33*(5), 293-302.
[20] Yu, J., Yang, C., & Tian, L. (2008). Low-energy envelope design of residential building in hot summer and cold winter zone in China. *Energy and Buildings*, *40*(8), 1536-1546.
[21] Kaoula, D., & Bouchair, A. (2019). The pinpointing of the most prominent parameters on the energy performance for optimal passive strategies in ecological buildings based on bioclimatic, sensitivity and uncertainty analyses. International Journal of Ambient Energy, 1-28.
[22] Babaee, F.; Fayaz, R.; Sarshar, M. The optimum design of sunspaces in apartment blocks in cold climate. Archit. Sci. Rev. 2016, 59, 239–253.
[23] Li, C., Li, J., & Wu, J. (2018). What drives urban growth in China? A multi-scale comparative analysis. *Applied Geography*, *98*, 43-51.

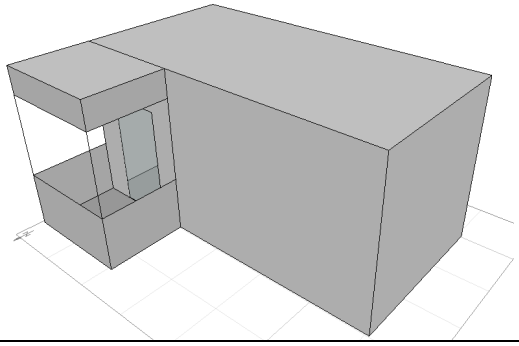
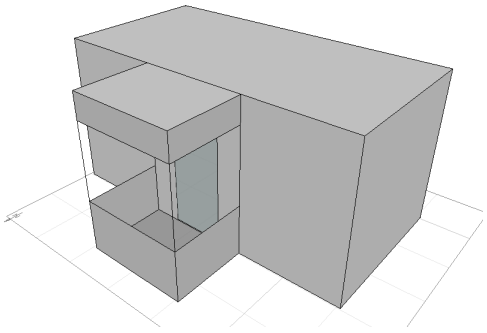
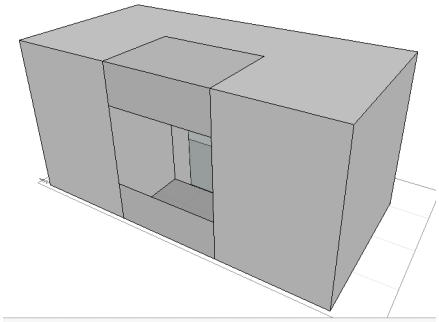
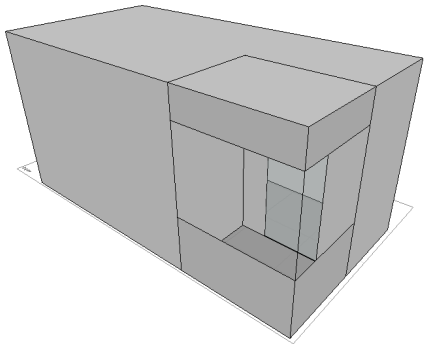
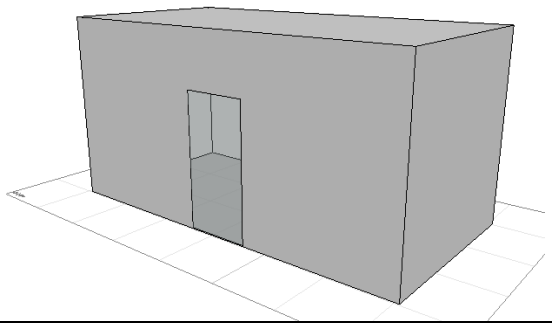
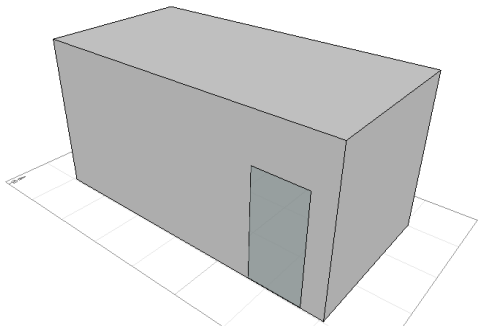
Appendices:

Table A- 1: The parametric variation

Cases	Bal_ratio	Bal_pos	Solar_heat_gain	Faç_orien	Cooling_demand
1.	0.16	Left	DG_0.75	east	73,92
2.	0.16	Centre	SG_0.94	north	83,24
3.	0.2	Left	DG_0.75	east	85,09
4.	0.16	Centre	DG_HE_0.45	west	69,26
5.	0.2	Right	SG_0.94	west	102,48
6.	No balcony	Centre	DG_0.65	north	80,11
7.	No balcony	Right	DG_HE_0.45	south	79,72
8.	No balcony	Right	SG_0.94	south	104,03
9.	0.2	Left	SG_0.94	west	108,24
10.	0.16	Right	DG_0.75	east	74,87
11.	0.2	Right	DG_HE_0.45	west	76,68
12.	0.16	Centre	DG_HE_0.45	north	66,52
13.	No balcony	Right	DG_HE_0.45	east	83,25
14.	No balcony	Left	DG_0.65	east	83,64
15.	No balcony	Centre	DG_HE_0.45	east	83,25
16.	No balcony	Centre	SG_0.94	north	100,10
17.	No balcony	Centre	DG_0.65	east	83,64
18.	0.5	Right	DG_0.65	north	55,77
19.	0.16	Right	DG_0.65	south	68,80
20.	0.16	Left	DG_HE_0.45	east	70,56
21.	0.2	Right	DG_0.75	south	78,73
22.	0.16	Centre	SG_0.94	west	92,00
23.	0.16	Right	DG_0.75	south	72,03
24.	0.2	Left	DG_0.75	north	83,05
25.	0.5	Left	DG_HE_0.45	south	66,60
26.	0.5	Left	DG_0.75	east	68,25
27.	0.2	Right	DG_HE_0.45	south	74,63
28.	0.16	Left	DG_0.75	west	72,69
29.	0.5	Left	DG_HE_0.45	west	62,37
30.	0.16	Centre	DG_0.65	north	70,15
31.	0.2	Left	DG_0.75	south	81,88
32.	No balcony	Centre	DG_HE_0.45	north	78,57
33.	0.16	Left	DG_HE_0.45	north	66,52
34.	0.2	Centre	DG_0.65	north	67,99
35.	0.2	Centre	DG_0.75	south	71,48
36.	0.16	Left	DG_HE_0.45	west	69,26
37.	0.2	Centre	DG_0.75	west	73,53
38.	0.16	Left	SG_0.94	east	95,68
39.	0.2	Right	DG_HE_0.45	north	73,50
40.	0.16	Centre	SG_0.94	east	95,67
41.	0.2	Left	SG_0.94	west	108,24
42.	0.16	Left	DG_HE_0.45	south	67,52
43.	No balcony	Left	DG_0.65	north	80,11
44.	0.16	Right	DG_0.65	north	67,81

45.	0.2	Right	SG_0.94	west	102,48
46.	0.16	Centre	DG_HE_0.45	east	70,55
47.	No balcony	Left	DG_HE_0.45	south	79,73
48.	No balcony	Left	DG_0.75	south	83,77
49.	0.2	Left	DG_0.65	south	79,79
50.	0	Centre	DG_0.65	west	82,52
51.	0.5	Right	DG_0.75	north	55,79
52.	0.2	Left	DG_0.75	west	85,86
53.	0.16	Centre	DG_0.75	north	70,02
54.	0.2	Right	DG_0.75	south	78,73
55.	No balcony	Centre	DG_0.75	west	85,72
56.	No balcony	Right	DG_0.75	west	85,72
57.	0.2	Left	DG_0.65	east	82,24
58.	No balcony	Centre	DG_0.65	south	80,98
59.	0.2	Right	DG_0.75	east	82,05
60.	0.16	Centre	DG_0.65	south	68,82
61.	No balcony	Right	SG_0.94	west	110,31
62.	0.2	Right	DG_0.75	north	77,63
63.	No balcony	Right	DG_0.65	north	80,11
64.	0.2	Right	SG_0.94	west	102,48
65.	0.16	Right	SG_0.94	north	83,23
66.	0.16	Right	DG_0.75	east	74,87
67.	No balcony	Left	SG_0.94	north	100,10
68.	0.2	Right	DG_0.75	east	82,08
69.	0.5	Left	DG_0.65	west	64,38
70.	0.5	Right	DG_0.65	west	55,84
71.	0.5	Right	DG_HE_0.45	south	55,71
72.	No balcony	Centre	DG_HE_0.45	south	79,73
73.	No balcony	Left	DG_0.75	north	82,64
74.	0.16	Centre	DG_0.75	west	72,69
75.	No balcony	Right	SG_0.94	east	114,59
76.	No balcony	Centre	SG_0.94	east	114,59
77.	0.2	Left	SG_0.94	south	95,44
78.	0.2	Right	DG_0.65	west	77,80
79.	0.16	Right	DG_HE_0.45	west	69,91
80.	0.16	Left	DG_0.65	north	68,08
81.	0.2	Left	SG_0.94	west	108,24
82.	0.5	Right	DG_0.65	south	55,68
83.	0.16	Left	DG_0.75	west	72,69
84.	0.2	Left	DG_0.75	north	70,02
85.	0.16	Centre	DG_HE_0.45	north	66,52

Table A- 2: Geometry of some modelled cases (the thickness of the overhang was not considered)

Overhanging balconies with 0.16 balcony to room ratio	
	
Left position and north orientation	Central position and north orientation
Hollowed-out balconies with 0.2 balcony to room ratio	
	
Central position and west orientation	Right position and west orientation
No balcony	
	
Central position and East orientation	Central position and south orientation