Parametric Analysis of School Classroom Typologies' Energy Performance

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ABSTRACT: This paper explores the potential of parametric analysis to deal with a large number of variables for the evaluation of energy performance of school classroom typologies. The analysis process involved the simulation of a base case in 10 different locations in Chile, representing different climatic conditions. Design variables included: 4 different orientations for the main façade; 5 different window sizes; 4 types of window glazing; 10 different thermal envelopes; and 3 different infiltration rates. The simulation was carried out with Energy Plus, using Gen Opt for the parametric analysis, which allowed simulating 48,000 combinations of variables in a relatively short period of time. The outputs included heating and cooling energy demand, as well as energy consumption of artificial lighting as a result of the contribution of daylight. Statistical analysis of the results allowed looking at how different combinations of design variables impact the overall energy performance, identifying the best case for each location. It also allowed looking at the most significant design variables for each climatic location, as well as to those variables that have little impact on the overall energy performance. The methodology proved to have great potential for identifying how the combination of simple design variables can affect energy performance.
Keywords: parametric analysis, school classrooms, simulation, energy performance, design strategies

INTRODUCTION

Energy efficiency and environmental comfort are becoming key issues in school buildings, as they accommodate children for long periods of time. Therefore, energy efficient school buildings not only save energy, but also provide a better and healthier learning environment for our children.

In Chile, most of the schools are free running buildings, with no heating or cooling system, and only those located to the south of latitude 36°S contemplate a heating system. There are no regulations in terms of energy efficiency in school buildings and very limited regulations in terms of environmental comfort. Therefore, previous field work in this subject has found poor environmental conditions in school classrooms, with low standards of thermal comfort and inadequate standards of indoor air quality [1] [2].

The State has been increasingly interested in developing knowledge, regulations and design guidelines for energy efficiency and environmental comfort in schools [3]. The task is complex, because the country has a very diverse climate and limited financial resources, which require looking at the problem from a holistic perspective.

The aim of this research work was to determine how different design parameters influence the total energy demand of a school classroom in different climatic zones of the country, using a novel methodology that combines parametric energy simulation and statistical analysis, which allows dealing with a large number of combinations of variables at the same time. In addition, the methodology allowed determining specific design features for the best performance classroom for each climate, based on combined outputs of heating, cooling and lighting demand.

Some authors have used similar methodologies [4], but the novelty of this work relies on the use of the software Gen Opt to organise the variables, allowing performing 48,000 simulations in a relatively short period of time.

CLASSROOM TYPOLOGY

The methodology consisted of the dynamic simulation of a basic classroom typology located in 10 Chilean cities, representing different climatic zones. The Chilean norm NCh1079 divides the country into 9 climatic zones; which vary from mild climatic conditions on the northern coast to very harsh conditions in the extreme south, passing through zones with hot summers and relatively cold winters in the central area (Fig 1). Not only has the length of the country generated this climatic diversity, but also the altitude that varies from the coast on the west to the high Andes on the east, resulted in clear variations across the width of Chile.

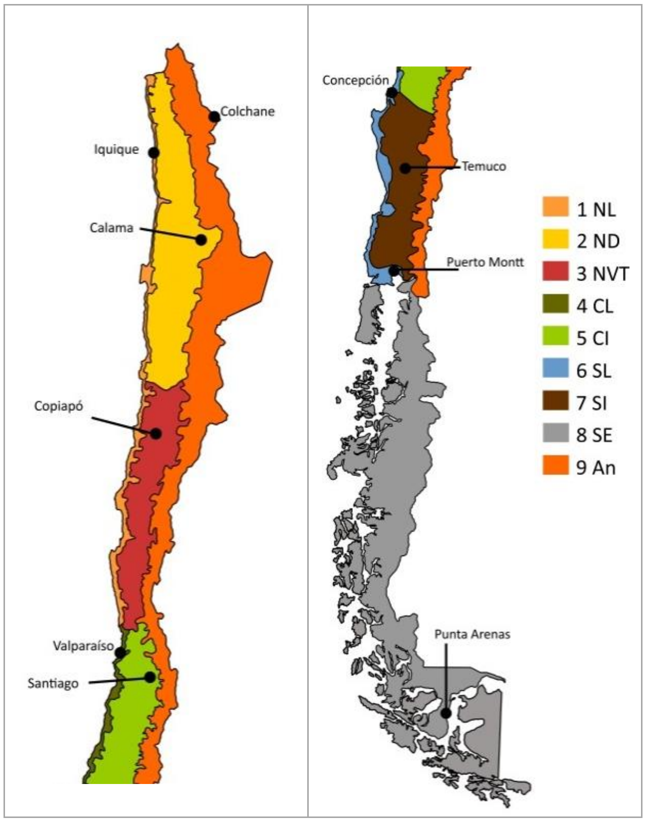


Figure 1: Climatic zones and selected cities.

The basic classroom typology was defined according to the predominant characteristics of a school classroom in the country, which consisted of a 6m wide, 9m long and 3m high room. The materiality consisted of structurally reinforced concrete for walls (200mm), roof (120mm) and floors (170mm). The only singular design feature considered at this stage was an opaque wall next to the board, which limited the total width of the window area (Fig 2).

Occupation parameters were defined according to predominant conditions in schools, as each classroom would be occupied by 45 students and 1 teacher in a period from Monday to Friday, 8:00 to 12:00 and 13:00 to 16:00hrs, including 2 weeks of winter holidays in July and 12 weeks of summer holidays in December-February.

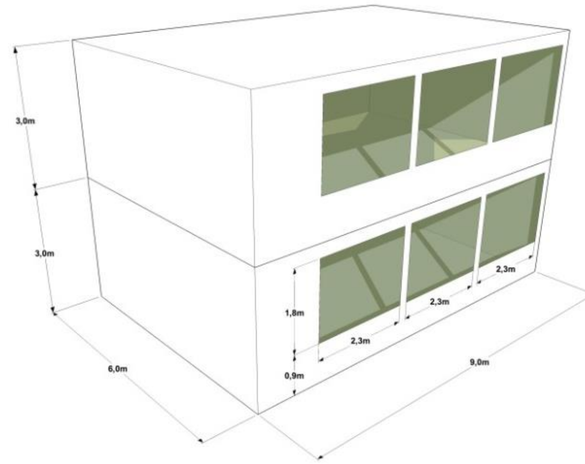


Figure 2: Basic classroom typology

Thermal losses due to ventilation were defined at a rate of 2ach, as required by the national regulation. It is important to note that the authors are aware that the ventilation rate of 2ach is not enough to provide an adequate indoor air quality, but it represents current practice, in line with regulations.

PARAMETRIC ANALYSIS

The classroom typology was analysed under different climatic conditions and with different design variables, which resulted in 48,000 combinations (4,800 per city). The simulation was carried out with Energy Plus, using Gen Opt for the parametric analysis, which allowed simulating 48,000 combinations of variables in a relatively short period of time.

The design variables included 4 different orientations for the main façade; 5 different window sizes; 4 types of window glazing; 10 different thermal envelopes; and 3 different infiltration rates (Table 1). The analysis also considered the position of the classroom at an upper or lower level of the building.

Table 1: Design variables

Design parameter	**Variables**
Orientation main façade	north, south, east, west
Glazing area/ floor area (%)	11 -14-17-20-23
Type of glazing	Single, double, double low-e, double solar control
Infiltration rate (ach)	0,5 – 1,5 – 2,5
Thermal envelope	A-B-C-D-E-F-G-H-I-K

Table 2: U value of Thermal envelopes

	U value (W/m²°C)		
	Walls	Roof	Floor
A	4.00	0.84	3.80
B	2.00	0.60	3.80
C	1.50	0.47	3.80
D	1.00	0.38	3.80
E	0.80	0.33	2.00
F	0.70	0.28	1.50
G	0.60	0.24	1.00
H	0.40	0.22	0.80
I	0.30	0.18	0.70
K	0.19	0.15	0.45

It is important to note that there are no regulation requirements for the U value of the envelope of non-domestic buildings in the country, so most school buildings would have a poorly insulated thermal envelope, in line with what we defined here as class A or B. Only a few schools that have been built during the last decade under energy efficient criteria would have a better insulated thermal envelope.

The outputs of the simulation included heating and cooling energy demand, as well as energy consumption of artificial lighting as a result of the contribution of daylight. The temperature set-point was defined as 20°C for heating and 26°C for cooling; and the lighting requirement was defined as 300 lux at the work-plane. Despite the fact that, as mentioned earlier, most schools are free running buildings in the country, it was considered that using the heating and cooling demand output was easier for making comparisons between the performance of classrooms in different cities, and between different combinations of variables in order to find the best design parameters.

GENERAL RESULTS

The first stage of the analysis involved looking at the results along the country, so Figure 3 shows the average energy demand of the classroom, considering the 4,800 combinations of design variables for each city.

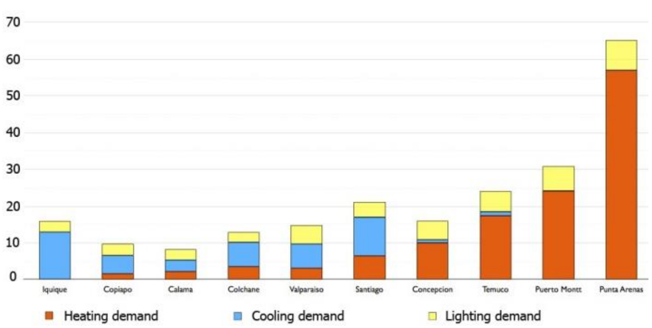


Figure 3: average energy demand (kWh/m² y)

In general, the results show that those cities located in the south of the country (right of the Graph) would have the largest energy demands, mainly for heating. In addition, the lighting demand increases to the southern latitudes, due to the limited contribution of daylight.

In the northern city of Iquique (left of the Graph), the classrooms would have the largest cooling demand and no heating, so design strategies in this climatic zone should focus on controlling risks of overheating. In cities located in the northern and central zones, heating and cooling demand tend to balance out, so the design strategies should be dynamic through the seasons.

A statistical analysis allowed determining how different design variables impact the total energy demand of the classroom, allowing identifying those design parameters that present higher differences between their best and worst cases.

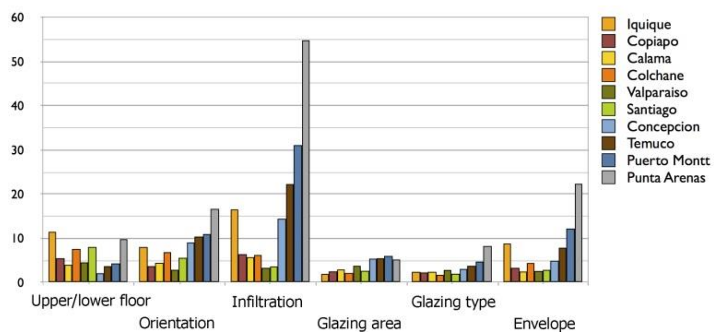


Figure 4: influence of design parameters - difference in energy demand (kWh/m² y)

The results show that the most important design parameter is the infiltration rate, particularly in the southern (and coldest) zones, where a low infiltration rate would diminish the heating demand. Nevertheless, it is important to observe that it also has an important effect in Iquique, but in this case a high infiltration rate is preferable, as it allows cooling by night-time ventilation.

Another influential design parameter is orientation, which has a higher impact on the southern zones. In all climatic zones, except for Iquique, the preferable orientation would be north due to lower heating demands. In Iquique, the preferable orientation would be south, as it involves lower cooling demands.

The thermal envelope is also an important design parameter, mainly in the southern zones, where a highly insulated envelope would result in lower heating demands.

The location of the classroom on an upper or lower floor has a higher effect in some cities than others, but in all cases, classrooms located on the upper floor would have higher energy demands than those located on the lower floor, due to heat gains and losses through the roof.

On the other hand, the size and type of glazing is not a relevant design parameter for the energy performance of the school classroom, as the difference between the best and worst cases is very insignificant in all cities.

RESULTS BY CLIMATIC ZONE

The second stage of analysis involved looking at the results for each of the 10 cities separately, in order to define the most significant parameters; the performance of the best, worst and average cases; and to define the design features of the best classroom for each city, according to the design parameters that were analysed.

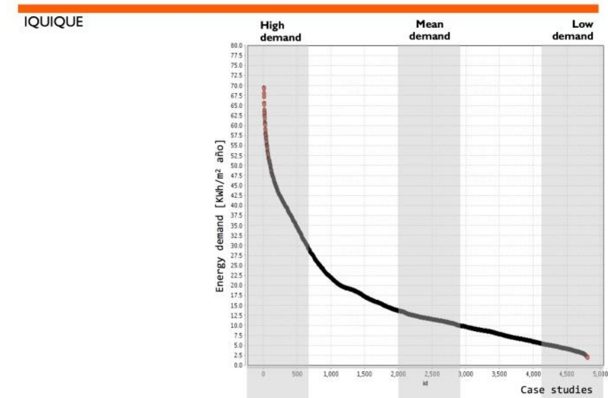
This paper reviews only the results for the northern coastal zone (Iquique), central interior zone (Santiago) and extreme southern zone (Punta Arenas).

Northern coastal zone – Iquique

This climatic zone is arid and highly influenced by the sea, which generates low temperature variations, high relative humidity and cloud cover in the mornings. The temperatures are usually relatively high, where Iquique has an average temperature of 21°C in summer and 15°C in winter.

The total energy demand of the 4,800 combinations of school classrooms in Iquique was organised in Fig 5 showing a descending curve. A statistical analysis allowed determining the common design features of the 10% of cases with the highest energy demand; the common design features of the 10% of cases with average energy demand; and the common design features of the 10% of cases with the lowest energy demand.

The results for Iquique show an important variation in energy demand between the best and worst cases, which rely mostly on the cooling demand, as there is virtually no heating demand. The common features of the worst cases are: west orientation; highly insulated and airtight envelope; large glazing area and low-e glazing. These design features in a classroom located at the upper level generates a cooling demand of 69.2 kWh/m^2, which is very high compared to the best cases.



	High demand	Mean demand	Low demand
Orientation	EAST	EAST	SOUTH
Floor	2°	2°	1°
Envelope	K	H	A
Infiltration	0,5	2,5	2,5
Glazing area	23%	11%	23%
Glazing type	Low E	Solar	Single
Q heating	0,0	0,1	0,5
Q cooling	69,2	6,0	1,9
Q lighting	0,4	7,7	0,5
Q total	69,6	13,8	2,9

Figure 5: energy demand of classrooms in Iquique (kWh/m^{2}y) and design features of best, worst and average cases

The common features of the 10% best cases in Iquique are illustrated in Fig 6. A south oriented classroom, with a poorly insulated envelope, high infiltration rates, and single glazing would have a cooling demand of only 1.9 kWh/m^2. A large window area of 23% would also diminish the lighting demand in this orientation. The high infiltration rate has a positive effect in this climate because it allows night-time ventilation.

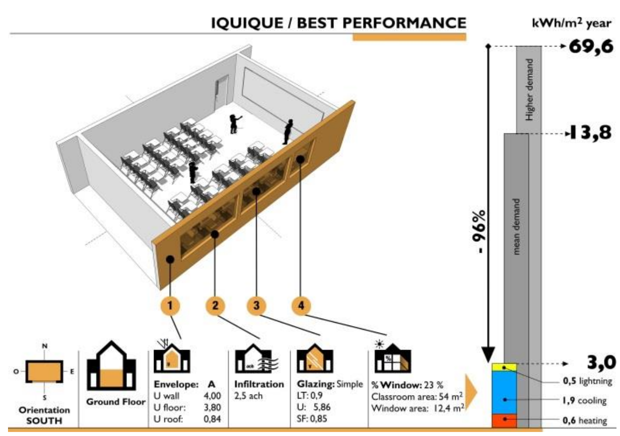


Figure 6: best performance classroom for Iquique

In addition, the statistical analysis allowed identifying the common features of the best cases by orientation and by level. This is due to the fact that designers might not able to choose the orientation of the classrooms, and they would definitively have classrooms located on lower and upper levels, so this information would affect other design decisions.

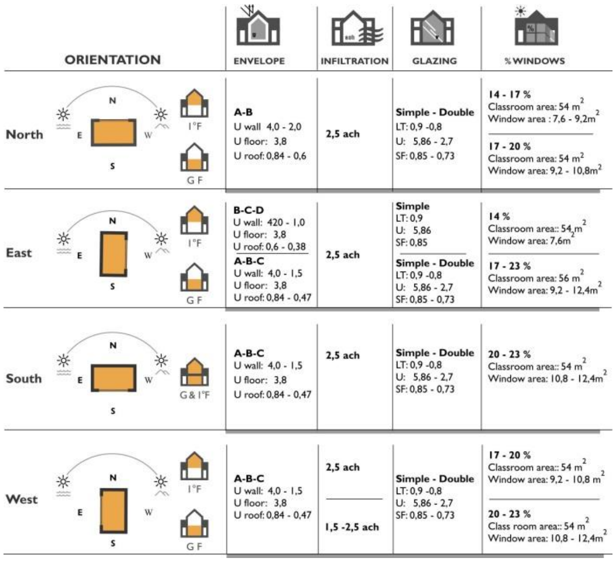


Figure 7: best design features by orientation - Iquique

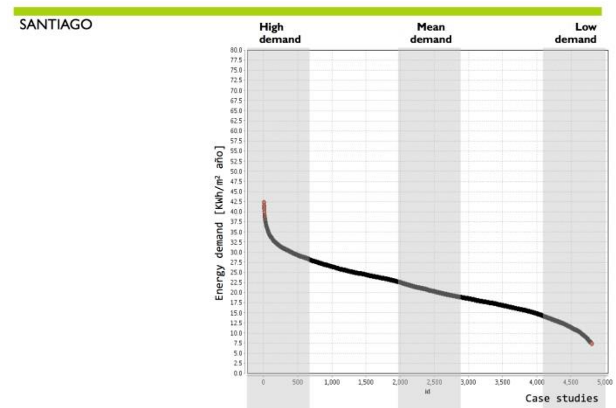
The results show some minor variations by orientation, such as smaller glazing areas for the north and west orientations, which respond to the need to minimize solar gains.

Central interior zone – Santiago

This climatic zone represents the area at the centre of the country, characterised by a mediterranean climate with well-defined seasons. Santiago is located at latitude 33°26'S, with an average temperature of 20.1°C in summer and 8.2°C in winter, and important daily temperature variations. The annual rainfall of 310mm is concentrated in winter.

The total energy demand of the 4,800 combinations of school classrooms in Santiago was organised in Fig 8 showing a descending curve. The results show a smaller variation between the performance of the best and worst cases than in Iquique and Punta Arenas, due to the fact that this climate varies significantly between summer and winter, which means that some features and appropriate for winter conditions and others are appropriate for summer conditions. Therefore, it was more difficult to arrive to clear design recommendations for this climate, which also occurred with the cases located in Valparaiso (central coastal zone), which has a mild climate.

This is evident when looking at the results of the statistical analysis, which shows that the common features of the worst cases are: east orientation; poorly insulated and airtight envelope; small glazing area and low-e solar control glazing. These design features in a classroom located at the upper level generates a cooling demand of 17.4 kWh/m^2, a heating demand of 4.7 kWh/m^2 and a lighting demand of 8.9 kWh/m^2. Therefore, we can understand that some features will negatively affect the cooling demand, while others will affect the heating or lighting demand, but there is a complex relationship between the variables and the performance.



Orientation	EAST	SOUTH	NORTH
Floor	2°	1°	1°
Envelope	A	H	C
Infiltration	0,5	2,5	0,5
Glazing area	11%	17%	23%
Glazing type	Solar	Solar	Low E
Q heating	4,7	13,1	1,2
Q cooling	17,4	3,9	6,0
Q lighting	8,9	10,0	0,8
Q total	30,0	27,0	8,0

Figure 8: energy demand of classrooms in Santiago (kWh/m^{2}y) and design features of best, worst and average cases

The common features of the 10% best cases in Santiago are illustrated in Fig 9. A north oriented classroom, with a medium insulated envelope, low infiltration rates, and large glazing area with double glazing, would have a total energy demand of 8.2 kWh/m^2, where the most important component will be the cooling demand.

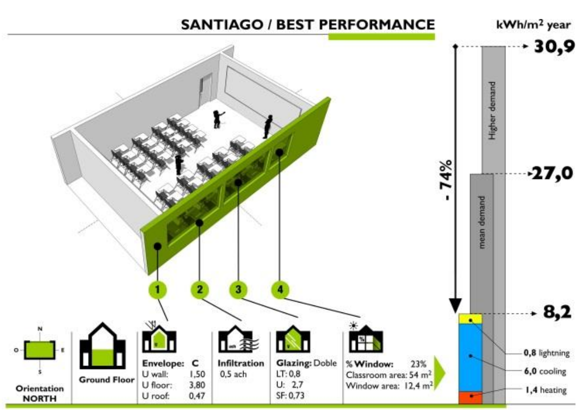


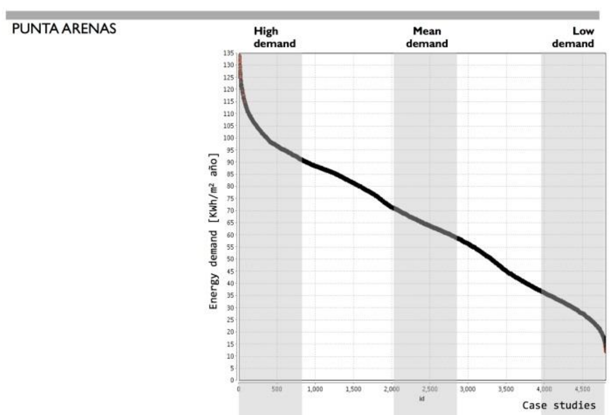
Figure 9: best performance classroom for Santiago

As classrooms in Chile would normally have no heating or cooling system, these results show that the risk of overheating would be the main task to design classrooms in Santiago, which houses 60% of the country's population.

Extreme southern zone – Punta Arenas

This climatic zone is characterised by low to very low temperatures and the presence of snow in some areas. Punta Arenas is located at latitude 53°8´S, with temperatures varying from 6.5°C to 14.7°C in summer and from -1.1°C to 3.7°C in winter.

The total energy demand of the 4,800 combinations of school classrooms in Punta Arenas was organised in Figure 10 showing a descending curve. The results for Punta Arenas show an important variation in energy demand between the best and worst cases, which rely mostly on the heating demand, as there is no cooling demand. The common design features of the worst cases are: south orientation; poorly insulated envelope; high infiltration rates; small glazing area and single glazing. These design features in a classroom located at the upper level generates a total energy demand of 134 kWh/m^2, which is very high compared to the best cases.



Orientation	SOUTH	WEST	NORTH
Floor	2°	1°	1°
Envelope	A	B	K
Infiltration	2,5	1,5	0,5
Glazing area	11%	11%	23%
Glazing type	Single	Solar	Low E
Q heating	121,2	56,8	8,0
Q cooling	0,0	0,0	0,0
Q lighting	12,8	12,7	4,3
Q total	134,0	69,5	12,3

Figure 10: energy demand of classrooms in Punta Arenas (kWh/m^{2}y) and design features of best, worst and average cases

The common features of the 10% best cases in Punta Arenas are illustrated in Figure 11. A north oriented classroom, with a highly insulated and airtight envelope, and low-e glazing, would have a heating demand of only 8 kWh/m^2. A large window area of 23% would also diminish the lighting demand in this orientation to 4.3 kWh/m^2.

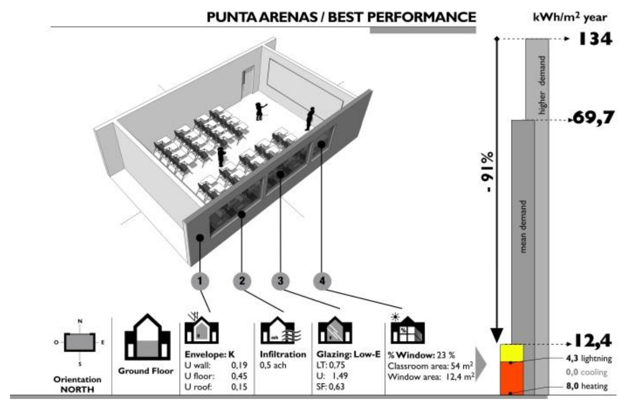


Figure 11: best performance classroom for Punta Arenas

The results are predictable for a cold climate, which ends up in design recommendations focused on insulation and airtightness. This research project involved a second stage that looked into some options for improving ventilation in winter, such as heat recovery systems.

CONCLUSION

The benefits of the methodology based on parametric analysis for determining energy demand is that it allows looking at the impact of different design parameters with a large number of variables, at the same time, giving a more holistic view of the problem. This benefit is emphasised by the use of three different energy outputs: heating, cooling and lighting demand, which allowed looking at how some design strategies tend to balance energy performance.

With this methodology, the results were somehow predictable in those cities with a well-defined climate, i.e. warm climate with only cooling demand (Iquique) or cold climate with only heating demand (Punta Arenas), as the recommended design features focused on solar control and heat dissipation for the warm climate, and insulation and airtightness for the cold climate.

Interestingly, the results were not predictable in those climates with well-defined seasons - cold winters and hot summers (Santiago) - as some design strategies improve the cooling demand but affect the heating and lighting demand or vice versa. Therefore, it is possible to identify how cost-effective some design strategies might be when they are analysed in relation to other variables and to different energy outcomes.

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