Atrium building design: key aspects to improve their thermal performance on the Mediterranean climate of Santiago de Chile

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Abstract

An atrium is a great glassed volume on a building that allows the light to enter within it. Its border location between indoor and outdoor implies that the environmental conditions like solar radiation, ventilation and heat energy appear intensified, turning them into spaces with a great environmental potential. However, in Santiago, these spaces have been designed imitating the aesthetic of buildings suited for colder climates. This has resulted in the fact that atrium buildings are often known by their low comfort standards and excessive cooling demands. The aim of this article is to answer in which way some design considerations on atrium buildings can maximize their energy saving potential in the Mediterranean climate of Santiago Chile. This is carried out with software Tas, which allows us to simulate the effect on thermal demand over a theoretical atrium building when changing three glazing types, three ventilation regimes and three solar protections forms; resulting in 27 iterations that reveal the more environmentally efficient combinations.

Keywords: atrium; environmental design; office building; Santiago Chile

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1 INTRODUCTION

The adoption of architectural elements or typologies developed from completely different technological and cultural backgrounds has been the predominant trend in Chile. Since the early 1990s, there has been a tendency in local architecture for the glassed curtain wall and the indiscriminate use of it in almost every mayor office building as well as a refusal to acknowledge any relationship with the environment (such as taking advantage of the natural conditions, radiation, wind etc.) [1]. This has caused excessive dependence on HVAC systems and huge thermal loads (because of the inexistence of thermal behaviour regulations for buildings others than residential). In this context, the atrium typology has been adopted imitating the aesthetic of buildings suited for colder climates and making use of inadequate materials and solutions, resulting in spaces often known by their low comfort standards [2]. It is estimated that the energy consumption of these kind of buildings with a good design is lower than 150 kWh/m^2/year for European countries [3] (whose climates are much more rigorous than Santiago).

2 WEATHER AND ATRIUM

The capital city of Santiago is located in the central valley of Chile (coordinates 33°27′ South 70°42′ West). One of the most important climate characteristics is the large variation between day and night temperatures; the difference between the maximum and minimum daily temperatures can normally reach 15°K (Figure 1). In fact, the monthly average minimum temperatures in Santiago are very similar to climates where atrium buildings have been successfully implemented, although the maximum temperatures and the high level of solar radiation are potentially a very serious problem. This situation leads to the hypothesis that the atrium could contribute to achieving the thermal comfort temperatures acting as a buffer space between the inside and outside of the building [4]; warming the building in winter and storing the cool air on summer nights, by means of night cooling, which has a great environmental potential in office buildings in Santiago [5].

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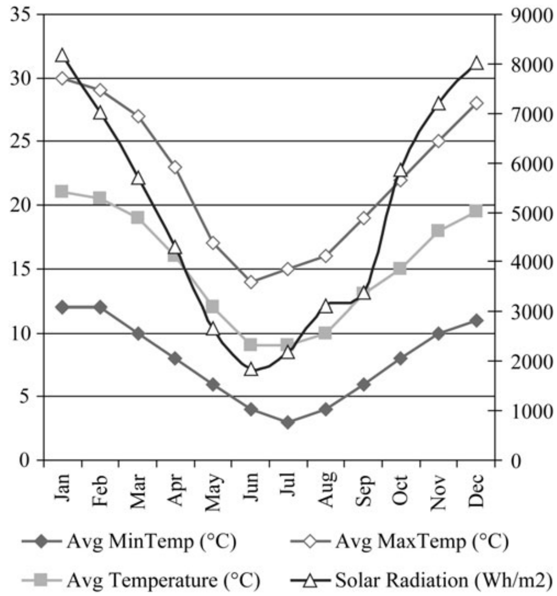


Figure 1. *Temperatures and solar radiation for Santiago, Chile.*

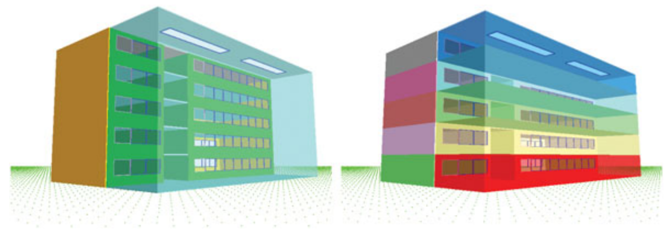


Figure 2. *Three-dimensional thermal model of atrium building and 3D thermal zone visualization on Tas.*

3 METHODOLOGY

This article studies the effect on thermal demand on an atrium space by testing all possible combinations of three categories that affect its performance (glazing material, ventilation strategies and solar protection). Each one of these three categories has three variations, giving a total of 27 results, which help to reveal the more environmentally efficient combinations and establish certain atrium design parameters on the Mediterranean climate of Santiago de Chile.

4 EXPERIMENTAL CONDITIONS

4.1 The initial atrium building

In order for this study to be representative, the dimensions, volume and configuration for this building are defined according to the regulations of the business park '*Ciudad Empresarial*', located at the north part of Santiago. Saying that, the proposed theoretical building is an office building of 10 m by 30 and 17 m of height (five levels) that has a north-oriented adjacent atrium of 7 m by 30 and 17 m of height, which has roof outlets on its top for ventilation purposes.

4.2 Thermal modelling assumptions

On the three-dimensional (3D) thermal model, the building is divided on five thermal zones (each level one zone). The atrium is also segmented on five thermal zones to measure the stratification and its incidence on thermal demands [6] (Figure 2).

The internal gains for the building are the following: lighting 12.7 W/m^2; occupancy 14.6 W/m^2; equipment 17.5 W/m^2. The internal gains for the atrium space are: lighting 5 W/m^2; occupancy 6 W/m^2.

Comfort ranges vary on the building and the atrium; for the building are between 20°C and 25°C, and the atrium has a range between 18°C and 26°C. The wider comfort range admitted on the atrium is necessary to achieve the environmental potential because of the 'buffer effect'.

The schedule for the building occupation and internal gains is all working days from 8:00 to 19:00 h.

The ventilation and infiltration are set to 1 air change per hour (ach) on the atrium and the building continuously.

The *U*-values of the constructions are: external walls $U = 0.5$ W/m$^{2\circ}$C; internal walls $U = 0.9$ W/m$^{2\circ}$C; floors $U = 0.3$ W/m$^{2\circ}$C; roof $U = 0.2$ W/m$^{2\circ}$C; ceilings $U = 1.1$ W/m$^{2\circ}$C; windows $U =$ variable.

5 ATRIUM ITERATIONS

There are nine types of variations for the atriums, which correspond to: three glazing options, three ventilation regimes and three types of solar protection. All the possible combinations of these variables are simulated according to the following chart:

G1	G1	G1	G1	G1	G1	G1	G1	G1
V1	V1	V1	V2	V2	V2	V3	V3	V3
S1	S2	S3	S1	S2	S3	S1	S2	S3
G2	G2	G2	G2	G2	G2	G2	G2	G2
V1	V1	V1	V2	V2	V2	V3	V3	V3
S1	S2	S3	S1	S2	S3	S1	S2	S3
G3	G3	G3	G3	G3	G3	G3	G3	G3
V1	V1	V1	V2	V2	V2	V3	V3	V3
S1	S2	S3	S1	S2	S3	S1	S2	S3

where G1 is the single glazing $U = 5.7$ W/m$^{2\circ}$C, *g*-value = 0.76; G2 the double glazing $U = 2.8$ W/m$^{2\circ}$C, *g*-value = 0.72; G3 the LowE double glazing $U = 1.8$ W/m$^{2\circ}$C, *g*-value = 0.57; V1 the windows always closed; V2 the windows open on summer nights; V3 the windows open on summer nights and when $18^\circ C \leq T \leq 26^\circ C$;

S1 no solar protection (0% shade on atrium);

S2 the solar protection on summer (50% shade on atrium);

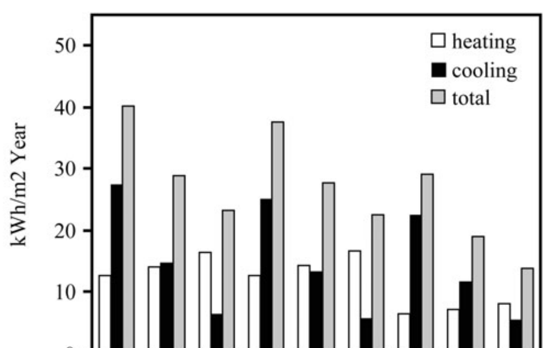
S3 the solar protection all year (100% shade on atrium).

6 RESULTS

These results correspond to the thermal demand of the space of the atrium, estimated by means of thermal modelling software Tas building designer.

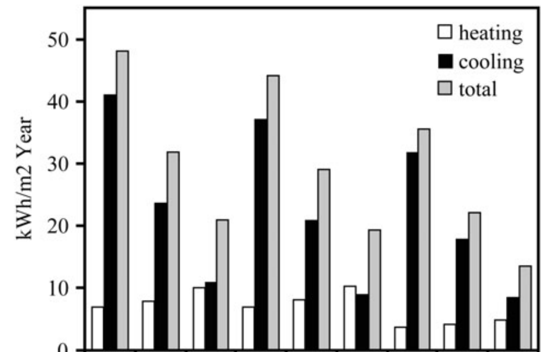
The nine first iterations show all the options with single-glazing atrium (Figure 3). The maximum heating demand is produced on the variation with 100% of solar protection and night cooling (G1 V2 S3). On the other side, the highest cooling demand is when the windows are always closed and there is no solar protection for the atrium (G1 V1 S1). When analysing the ventilation, we can see that all the results with only night cooling have an average reduction of ~10% on cooling demand compared with the option where the windows are closed; however, the most efficient ventilation regime is when the windows are open on the periods where external air temperature lies between 18°C and 26°C (V3). In all the options, the largest impact on the cooling demand is when the atrium is fully protected from direct solar radiation reaching a top reduction of 75% when comparing (G1 V1 S1) and (G1 V1 S3). The lowest total demand (13.8 kWh/m^2 year) occurs in the iteration where exists solar protection all the year and the ventilation is used at the time that outside temperatures are between 18°C and 26°C (G1 V3 S3).

The second nine iterations show all the options with double-glazing atrium (Figure 4). Because of the better *U*-value, all heating demands are reduced compared with the first nine iterations; also, all the cooling demands are bigger. The variations where ventilation occurs when temperatures lies between 18°C and 26°C (V3) have the best results over the other ventilation regimes and when that type of ventilation is combined with 100% of solar protection, the result shows the lowest demand of all iterations on this article (G2 V3 S3)



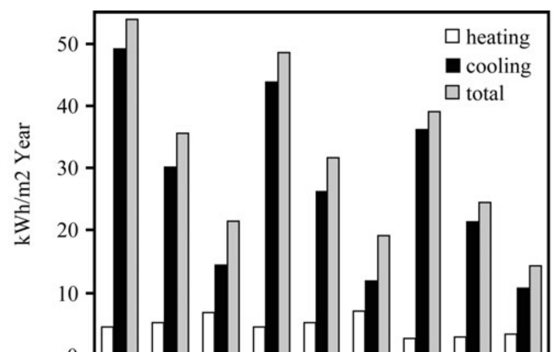
	G1 V1 S1	G1 V1 S2	G1 V1 S3	G1 V2 S1	G1 V2 S2	G1 V2 S3	G1 V3 S1	G1 V3 S2	G1 V3 S3
heating	12.7	14.1	16.5	12.6	14.2	16.8	6.7	7.3	8.3
cooling	27.4	14.8	6.6	25.1	13.4	5.8	22.5	11.8	5.6
total	40.2	28.8	23.2	37.6	27.6	22.6	29.2	19.1	13.8

Figure 3. *Heating, cooling and total demands for the nine iterations of the atriums with single glazing (G1).*



	G2 V1 S1	G2 V1 S2	G2 V1 S3	G2 V2 S1	G2 V2 S2	G2 V2 S3	G2 V3 S1	G2 V3 S2	G2 V3 S3
heating	7.0	8.0	10.1	7.1	8.1	10.2	3.8	4.1	4.9
cooling	41.0	23.8	10.8	37.1	20.9	9.1	31.8	17.8	8.5
total	48.0	31.8	20.9	44.1	29.0	19.3	35.6	22.0	13.4

Figure 4. *Heating, cooling and total demands for the nine iterations of the atriums with double glazing (G2).*



	G3 V1 S1	G3 V1 S2	G3 V1 S3	G3 V2 S1	G3 V2 S2	G3 V2 S3	G3 V3 S1	G3 V3 S2	G3 V3 S3
heating	4.6	5.4	7.0	4.6	5.4	7.1	2.7	3.0	3.5
cooling	49.3	30.2	14.5	43.9	26.3	12.0	36.4	21.5	10.9
total	53.9	35.6	21.5	48.5	31.7	19.1	39.0	24.4	14.4

Figure 5. *Heating, cooling and total demands for the nine iterations of the atriums with lowE double glazing (G3).*

13.4 kWh/m^2 year. The last set of nine iterations represents the results of simulating all the options with lowE double-glazing atrium (Figure 5). In all these cases, the heating demands are the lowest; nonetheless, the cooling demands are reaching their peaks compared with the single- and double-glazing atrium iterations. That situation causes the higher total demands, giving a maximum value of 53.9 kWh/m^2/year, when there is no solar protection and the windows are always closed (G3 V1 S1). On the other hand, the minimum total demand for the lowE glazing is 14.4 kWh/m^2/year, which is higher than the minimum total demand on single- and double-glazing atrium iterations.

7 CONCLUSIONS

The analysis performed over the 27 atrium iterations revealed the more efficient options and showed that it is possible to acquire a dramatic reduction of over 70% in the total demand for this atrium if we compare the worst-case scenario (G3 V1 S1) versus the more efficient one (G2 V3 S3). In order to achieve these reductions, the solar protections were crucial. Considering the high amount of direct solar radiation that these north-faced atriums receive through the year, the better results were reached when atriums were fully shaded. The iterations of glazing materials showed that if no solar protection exists, overheating tends to be a serious problem, especially on the lowE option. The ventilation regime also proved to be very important, giving the worst results when the windows are always closed and the best results when natural ventilation is combined with night cooling. Finally, the dramatic difference between the worst case and the more efficient option reveals the urgency of thermal behaviour regulations for office buildings in the Chilean context.

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