Strategies for improving thermal performance and visual comfort in office buildings of Central Chile

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ABSTRACT: Overheating, high cooling energy demand and glare are recurrent problems in office buildings in Santiago and Valparaíso, Chile. Santiago (33°S) presents a Mediterranean climate, with a high temperature oscillation between day and night during cooling period. Valparaiso (33°S), by the coast, shows lower temperature fluctuation compared with Santiago. In order to evaluate impact on thermal and lighting performance of office buildings of these cities, a sensitivity study has been made. Variations on window façade area, type of glazing, orientation, solar protection, nocturnal ventilation and respective impact on energy and lighting performance has been considered. The methodology includes an evaluation of heating and cooling demand and variation of indoor temperature when no conditioning system is applied. For this purpose a simulation software under dynamic conditions was used (TAS). The effect on natural lighting was also analysed using Radiance software. This analysis was made using Daylight Factor, Daylight Autonomy (DA) and Useful Daylight Iluminance (UDI), considering different sky conditions. Completely glazed facades, even with selective glazing are not recommended for these cities. Glare problems are possible to be avoided with appropriated solar protection, orientation of windows and selective glazing.

Keywords: cooling demand, nocturnal ventilation, daylight, office buildings, visual and thermal comfort

1. INTRODUCTION

In Chile, around 4.73 million of square meters of buildings of the Industry, Commerce and Financial Institutions sector were constructed during 2008 [1]. 53,2% was built in Santiago and 6,6% in Valparaíso. In Chile there is no mandatory thermal behaviour requirements for office buildings and most of their design patterns are brought from developed countries, even if some architectural strategies, such as double skin, are not suitable –for example- in Central European countries due to the generation of overheating problems, especially when they are designed with fully glazed façades [2,3].

The effect of using different strategies of architectural design and its impact on energy demand of office buildings has been extensively studied in various countries. A study in the city of London concluded that a building with effective sun protection, optimised size of windows and reduced internal gains are important to achieve energy efficiency. This cooling demand was reduced to 23% for a week with moderate temperatures and 40% for a week of extreme temperatures, compared with the same demands of the building without using the mentioned strategies. Adding night ventilation, an additional reduction of 13% was possible [4].

Given that the mentioned problems in office buildings in countries with even less severe climate than ours during summer periods and due to scarce of information available in Chile about the effect of using certain design patterns, particularly fully glazed facades in office buildings, it is important to develop quantitative studies in order to evaluate and define design strategies for comfort and energy efficiency in this type of buildings of the country.

This paper shows results of a sensitivity analysis in order to know impact on cooling and heating demand on office buildings of Valparaíso and Santiago considering different variables. These variables are: window area, solar protection, type of glazing (single, double, clear and selective) and orientation of offices. On the other hand, in order to verify lighting comfort, also day light factor and iluminance for different combinations of mentioned variables have been studied.

Climate of Santiago is Mediterranean, showing high temperatures and solar radiation during spring and summer. The city is located between the coastal and the Andes Cordillera. Mean value of maximum temperature is 29,7°C and mean minimum is 13°C for the warmest month of the year (January). Mean temperature of coldest month (July) are: 3,9 °C (mean minimum) and 14,9 °C (mean maximum). A high temperature fluctuation is observed, especially in summer and intermediate seasons Climate of Valparaiso is influenced by the Pacific Ocean, showing lower temperature oscillation than Santiago Mean value of maximum temperature is 20,8°C and mean minimum is 13,5°C for the warmest month of the year (Jan.). For the coldest month (July), mean minimum is 9,2°C and mean maximum is 14,3°C.

2. METHODOLOGY

The methodology aims to study and analyze the thermal and lighting behavior of office buildings. The main objective of this work is to be able to conclude with recommendations for achieving simultaneously thermal and lighting comfort with energy efficiency. In other words, if certain strategies are recommended for achieving comfort with minimum heating and/or cooling energy demand, these strategies should also allow lighting comfort throughout the year, with different sky conditions. A design strategy for thermal comfort should not avoid achieving lighting comfort at the same time.

2.1. The building and thermal analysis

The sensitivity analysis is developed considering a square building containing office rooms on all four orientations. This 9 story building has been specially proposed and designed for this sensitivity analysis. Figure shows a plan (16X16m) of this building.

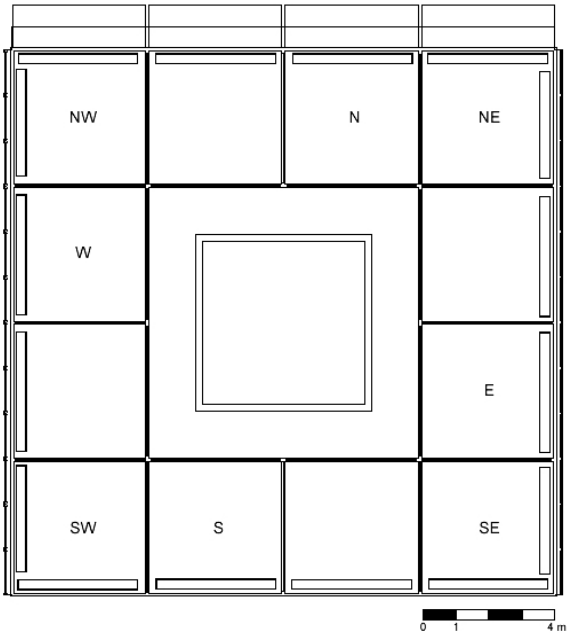


Figure 1: Plan of the building with the selected spaces and their orientations

Specifications of the original building are:

Reinforced concrete 150mm with external EPS 30mm. U=1,0 W/m2°C
Roof: Reinforced concrete 150mm with EPS 60mm. U=0,59W/m^2°C (in Valparaíso) and with 80 mm of EPS in Santiago. U= 0,40 W/m2°C.
Windows: single glazing, clear. U=5,8 W/m^2°C, Lighting transmittance: 0,90 Solar transmittance: 0,87.

In case of windows, this corresponds to the initial situation. Later, this type of glazing is changed during the sensibility process. It is necessary to mention that it is still common to find new office buildings with single glazing in the country.

Heating and cooling demand for different specifications of the building were estimated with TAS, software under dynamic conditions. Different ventilation rates may also be applied using this software, which permits to evaluate impact of nocturnal ventilation.

2.2. Internal gains and internal conditions

Internal gains of the buildings considered are the following:

People: 9,38 W/m^2 (sensible) 6,88 W/m2 (latent).
Lighting: 11 W/m2.
Equipment: 11,25 W/m2.

When cooling demand was estimated, the following temperatures in the inside of each office were considered:

Week days: Maximum of 26°C from 8:00 AM till 19:00 PM.
Weekend days: No temperature restrictions.
Infiltration rate: 0,3 ach.
Ventilation rate: 1,18 ac during week days from 8:00 AM till 19:00 PM.

2.3. Methodology for the thermal analysis

The methodology for thermal analysis (and for sensitivity analysis of the next point) considers the building of Figure 1, which changes on type of glazing, the presence and type of solar protection and in some cases, for cooling periods, nocturnal ventilation was assumed. Type of glazing used are: Clear single glazing clear (CS, 4mm) selective single glazing (SS, 6mm), clear double glazing (DGC) and selective double glazing (DGS). Properties of these types of glazing are shown in Table 1. LT: Light transmission, ST: Solar transmission

Table 1: Properties of different types of glazing.

	CS	SS	DGC	DGS
LT	0,90	0,60	0,82	0,54
ST	0,82	0,50	0,68	0,41
U (W/m2°C)	5,80	5,70	2,78	2,76

Type of solar protections that have been used are: Horizontal blinds (HB) and overhangs (OH). Nocturnal ventilation has been applied on cooling periods of the year with 8,0 ach from 23:00 till 7:00 AM of the next day, from Sunday night till Friday in the morning.

Finally, 3 different window sizes (window to façade ratio) were also applied. Cooling and heating energy demand was estimated (with TAS). Also, for each zone of a certain floor of the building, these energy demands were also estimated for offices with different orientations (N, NW, NE, W, E, SW, S, SE. See Figure 1).

2.4. Methodology for the sensitivity analysis

The seminal study of Hamby (1991) indicates that sensibility analysis may be conducted for a number of reasons including the need to determine: (1) which parameters require additional research in order to reduce the uncertainty of the input model, that is, the building performance; (2) which parameters are insignificant and can be eliminated from the final model; (3) which inputs contribute most to output variability; and (4) which parameters are most highly correlated with the output [5].

Besides sensitivities – that can be defined as the level of influence on the output model – the importance of the variables can be assessed. The term ‘importance’ is used here in the sense described by De Wit (2002), which expresses the relative contribution of a certain variable to the uncertainty, in the model output [6].

Between all the initially described aspects, (3) and (4) appears closely related since according to the same author, an important parameter is always sensitive because parameter variability will not appear in the output unless the model is sensitive to the input [5].

In this context, a factorial design involves a given number of samples per each input parameter and consequently running the model for all combination of samples [5]. This method is based on the sampling-based approach, where the model is repeatedly executed from the combination of input parameters sampled with some probability distribution. Since the design of this sensibility analysis consists in 4 input parameters with 3, 3, 4 and 8 parameters per each one, the total combination of samples gives a complete sample of 288 cases. Each case has an equal probability of occurrence corresponding to 1/N (0,35%, where N=288) due to a uniform probability density function was applied to each input parameter. Table 1 presents the different input parameters considered for this study and their associated variables.

Table 2: Input parameters for sensibility analysis

Input parameters	Number of variables	Description of variables
Glazing ratio*	3	20% 50% 100%
Types of solar protection devices	3	Without solar protection Overhang in N orientation and blinds for E and W orientations Blinds in N, E and W orientations
Types of glazing	4	Single glazing, clear Single glazing, selective Double glazing, clear Double glazing, selective
Orientations	8	All orientations (N, NE, E, SE, S, SW, W, NW)

(*) Ratio of the glazed area with respect to the total area of the exposed envelope

3. RESULTS

3.1. Thermal analysis

Respecting to temperature variation, as expected, overheating is observed in offices of northern, west and east orientation. When having 100% glazed buildings, even in Santiago and Valparaíso, overheating (or a high cooling energy demand) does surely exist in a summer day.

Under clear sky conditions, even in winter days, overheating is also possible to be reached. Figure 2 shows temperature variation in zones N of the building (according to Figure 1), when the building is completely glazed, with and without solar protection (which is supposed to be designed for cooling periods). Temperature is little higher when considering selective double glazing (DGS), respective to clear double glazing (DGC) with solar protection in this northern office room.

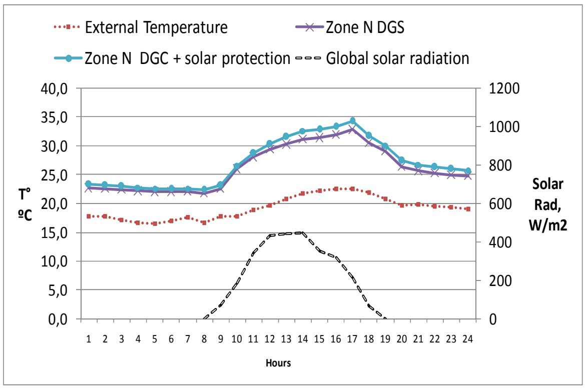


Figure 2: Temperature variation in Zones N of the building for a winter day in Valparaíso. 100% glazed façade. Winter day

Figure 3 shows that identical problems are also observed in the case of Santiago, applying a completely glazed façade during a winter day under clear sky condition.

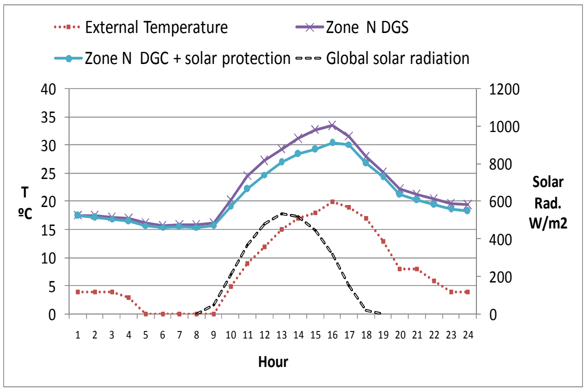


Figure 3: Temperature variation in Zones N of the building for a winter day in Santiago. 100% glazed façade. Winter day.

As observed, 100% façade ratio is not recommended for both cities considered in this study due to overheating generated even in some clear sky winter days. If the phenomenon occurs during winter time, it is expected to have it during summer.

In the city of Santiago, overheating is also observed with 20% of glazing ratio (clear or selective double glazing), especially when no solar protection is used. In this case, temperatures higher than 32°C are reached in western offices of the building. The problem is less intensive in Valparaíso.

Respecting to office energy demand, as expected, cooling is significantly higher than heating in both cities.

Table 2 shows cooling energy demand for the 6th floor of the building when using different glazing ratio on façade (considering double glazing selective). In all cases solar protection is applied, (blinds for east and west facades and overhangs for northern façades). On the right column, the cooling demand corresponds to situation when nocturnal ventilation is used. Comparing these values with those of the left column, it is observed that this strategy is highly effective in the city of Santiago (especially when combined with high thermal inertia due to use of external insulation). On the other hand, the lower cooling demand is reached when minimizing the glazing ratio.

Table 2.: Building cooling demand in Santiago

Glazing ratio	kWh/m2 y	kWh/m2 y
20%	20.2	9.9
50%	37.2	30.6
100%	62.9	47.2

In all cases showed in Table 2, heating demand is low, reaching 4,6 kWh/m2 y in the case of 20% of glazing and only 1,6 kWh/m2 y, in the case of a completely glazed façade.

In the case of Valparaíso, the lower cooling demand on floor 6 of the building was reached when considering 20% of selective double glazing, with a cooling demand of 14.6 kWh/m2 y and a heating demand of 3.7 kWh/m2 y.

3.2. Sensibility analysis

One of the most applied methods for parameter sensitivity analysis that use sampling techniques is the Pearson's product moment correlation coefficient [7]. This method appears as appropriate since parameter sensitivity depends not only on the range and distribution of an individual parameter, but also on those of other parameters to which the model is sensitive [5].

Pearson's correlation coefficient represents the quantitative estimation of the linear correlation for parameters values of input and output. This indicator is denoted by *r* and is defined as:

$$r = \frac{\sum_{j=1}^{n}(X_{ij} - \bar{X}_i)(Y_j - \bar{Y})}{\left[\sum_{j=1}^{n}(X_{ij} - \bar{X}_i)^2 \sum_{j=1}^{n}(Y_j - \bar{Y})^2\right]^{1/2}}$$

for the correlation between Xi and Y. The larger the absolute value of r, the stronger the degree of linear relationship between the input and output values. At the same time, a negative value of r indicates that the output is inversely (or negatively) related to the input.

Table 3 presents the correlation coefficients for the different input parameters with respect to the cooling demand in the case of Valparaiso. According to this, glazing ration appears clearly as the most sensitive parameter, secondly ranked by the types of solar protection devices (which is negatively correlated) and finally by the types of glazing. On the contrary, orientation does not appear with a statistically significant correlation (at the 0.01 or 0.05 level).

This result is highly consistent with the one-at-a-time sensitive analysis of the Figures 4 and 5, where the uncertainty of the glazing ratio and orientation, respectively, is propagated on the assessment results. Figure 4 shows as the high level of importance of glazing ratio, since the variability in output – as consequence of the input variability – is noticeable. On the contrary, Figure 5 shows as the variability of the output results per orientation is reduced, which is even more critical with regard to the range of low cooling demands. At the light of these results, it is clear that any design strategy proposed for new office developments in Valparaiso, should prioritize the ration of the glazed area with respect to the exposed façade. Very similar results were observer also in the case of Santiago.

Table 3: Pearson's correlation coefficient for the different input parameters with respect to the cooling demand in the case of Valparaiso

	Pearson's r
Glazing ratio	0.73
Types of solar protection devices	-0.25
Types of glazing	0.12
Orientation	0.10

Correlation is significant at the 0.01 level (2 tailed)
Correlation is significant at the 0.05 level (2 tailed)

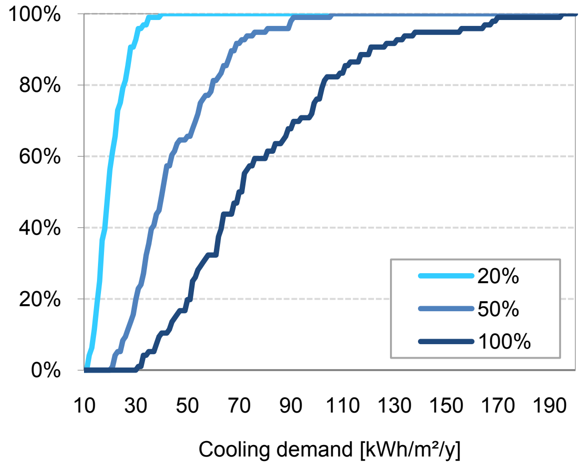


Figure 4: Cumulative frequency for cooling demand with respect to glazing ratio in the case of Valparaiso.

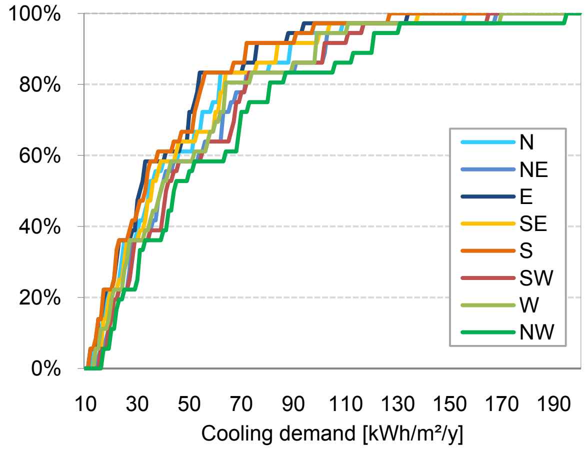


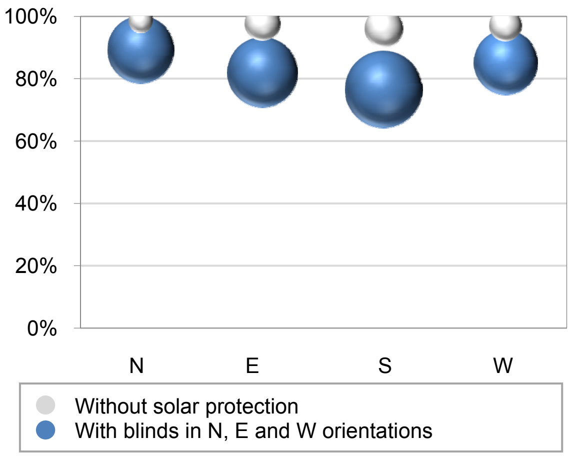
Figure 5: Cumulative frequency for cooling demand with respect to orientations in the case of Valparaiso

3.3. Daylight analysis

Figures 6 and 7 present the results of the daylight analysis in terms of daylight autonomy (DA) and useful daylight illuminance (UDI) for the range over 2000 lux for the case of Santiago.

DA uses work plane illuminance as an indicator of whether there is sufficient daylight in a space so that an occupant can work by daylight alone [8]. In this case, the required minimum illuminance level was defined for a basis of 500 lux according to the recommendations of IESNA [9].

UDI constitutes other important dynamic daylight metric. This indicator is dynamic daylight performance measure illuminances, which uses hourly climate-data (mainly direct and diffuse radiation and cloudiness) for a specific location and based also on a work plane. The advantage of this condition – in comparison to static metrics – is that the UDI considers the quantity and character of daily and seasonal variations of daylight for a given building site [8].



Note: The centre point of each bubble is the extent of overeating measured in percent (mean value for the different points across the space). The area of the bubble represents the standard deviation for the distribution of values including the same points.

Figure 6: Bubble plots for daylight autonomy (DA) based on a required illuminance level of 500 lux in different orientations in Santiago

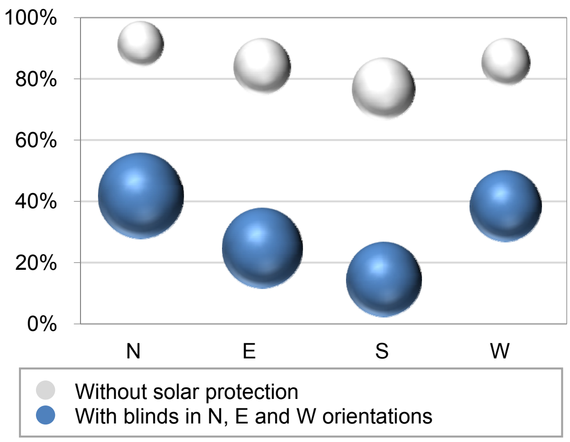


Figure 7: Bubble plots for UDI in the range over 2000 lux for different orientations in Santiago

As it name suggest, the aim of UDI is to determine when daylight levels are useful for the user, in this cases neither too dark (less than 100 lux) nor too bright (over 2000 lux). This range is proposed by Nabil & Mardaljevic (2006) based on occupant preferences in naturally illuminated offices [8].

Based on the upper thresholds of 2000 lux, the resultant UDI metric was applied to this research, which may suggest the presence of glare. At the same time, daylight autonomy was applied for a level of 500 lux. Both of them were assessed over a grid of 36 points (6 rows x 6 columns) at 1.0 m height in the study case office already represented in Figure 1.

Figures 6 and 7 show the impact of incorporating horizontal blinds in north, east and west orientations in terms of the useful illuminance. The percentage of UDI over 2000 lux is clearly lower when these devices are considered. However, as the area of each bubble represents the standard deviation, the dispersion of values may be higher. At the same time, DA shows that it is possible to guarantee an adequate minimum level of illuminance even with the use of blinds.

These results suggest, for example, that the incorporation of lightshelves (in combination with blinds) may contribute to reach a most homogenous illuminances inside the room, without jeopardize the favorable mean values. However, this hypothesis constitutes a new aspect of the research that it should be tested by means of a series of new simulations. Consequently, the use of lightshelves in the context of office buildings in Santiago is proposed as further research.

4. CONCLUSIONS

First of all, completely glazed façade office buildings are not recommended for cities of Santiago and Valparaiso, Chile. In both cities, with different climates, the best thermal performance (regarding cooling energy demand) is reached with the lower the window ratio (20%), especially when considering solar protection on glazed areas, which is highly recommended – in order to avoid overheating - for north, east and west orientations. At the same time, with respect to the visual comfort, the incorporation of blinds permit to suggest that glare problems at least may be reduced or even avoided.

It was also observed that in the case of Valparaiso, higher attention to window area than to orientation of the building should be taken into account.

In the case of Santiago due to high temperature fluctuation during cooling period of the year and use of thermal inertia, nocturnal ventilation has been shown to be highly effective for reducing cooling demand. When considering this strategy, combined with a low window ratio (20%, double glazing selective) and effective solar protection, cooling demand decreases in an 84% respective to a completely glazed office building, with identical type of glazing and solar protection.

This research permitted to conclude that it may be possible to reach thermal and visual comfort with energy efficiency in office buildings of Santiago and Valparaiso.

5. ACKNOWLEDGEMENTS

This research has been carried out as part of the project FONDECYT N° 1090602 funded by CONICYT, Chile.

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