Architectural Design Strategies Based on Experimental Analysis in Office Buildings in Santiago, Chile

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ABSTRACT: Overheating, glare and high energy demand are recurrent problems in office buildings in Santiago, Chile (33°27'S 70°42'W) during cooling periods. Santiago climate is Mediterranean, with intensive solar radiation and high temperatures during spring and summer. More than 50% of office buildings of the country are built in this city. Currently, policies regulating the energy use in this type of building do not exist in Chile and their design patterns are imported from other countries without considering local climate requirements. This paper show results of a research where thermal and lighting performance of different type of office buildings in Santiago have been studied. Buildings were selected through a cluster analysis applied to a sample of 101 buildings, representing those constructed during the last years in the city. This analysis considered the following façade variables: % of transparency, presence of solar protection (SP), type of SP, number of floors. Clusters obtained are the following: Combined façades without external solar protection, fully glazed façades with external solar protection and fully glazed facades without solar protection. Continuous lighting and temperature measurements have been made in different buildings representing the 3 mentioned clusters. Measurements of lighting and solar gains through different facades were also made. A survey applied to users has shown the perception that they have regarding to thermal and lighting comfort. Results showed critical thermal and lighting problems in fully glazed façade buildings. Better performance was showed in buildings with a certain percentage of opaque façade area. External SP and glazed area control are highly recommended for energy efficiency in office buildings of Santiago, Chile.

Keywords: office buildings, comfort, overheating, glare.

INTRODUCTION
Windows are the most significant component of the building envelope because of their impact on comfort and energy use per unit building area. Solar radiation is transmitted through windows providing natural light and heat gain to the space [1]. Therefore, windows are used to provide outdoor view and natural light, which impact satisfaction, health, productivity of building occupants [2, 3]. Daylight also contributes to reduce electricity consumption for lighting [1, 4] and its associated cooling energy use. This is crucial to design high performance buildings because energy consumption for lighting and its associated cooling energy use is between 30 and 40% of the total building energy consumption. On the contrary, solar gains has negative impact on energy consumption because cooling energy use are proportional to the solar gains, and large solar gains turn in higher cooling energy demand and energy peak loads. As consequence, glazing façades are key components of the building performance that needs to be designed carefully by architects in the early stages of the project.

High cooling energy demand and thermal comfort problems have become more frequent and serious in the past 10 years due to larger glazed areas in building façades [5]. For instance, Khun [6] indicates that 70% of the peak cooling load in Galileo building (a fully glazed tall building in Frankfurt) was caused by solar gains. In Central Chile, due to climate conditions, offices buildings show higher cooling than heating demand. This is even more critical given that office buildings built in recent years have mainly fully glazed facades with large amounts of heat gains caused by solar radiation.

Overheating and glare are common problems on this type of buildings in Central Chile [7, 8].

METHODOLOGY
This paper shows preliminary results of a research to determine the solar and light transmission of different
types of facades which used in office buildings in Santiago. With this purpose, a complete database of office buildings that have been built in the last 7 years in Santiago was generated. With this database a cluster analysis was made, determining the types of buildings that represent different typologies recently constructed in the urban area of Santiago.

For each of the clusters, we chose a building, which have been monitored since January 2012. We started with temperature and relative humidity in rooms with different orientations. The purpose of these measurements is to know the environmental conditions of them during labour days (when normally air conditioning is used). Measurements during weekends (when the building is normally unoccupied) allows to know the temperature conditions achieved without the effect of internal gains. A survey related to comfort conditions has also been applied.

CLIMATE OF SANTIAGO DE CHILE
Climate of Santiago is Mediterranean, showing high temperatures and high solar radiation in spring and summer periods. During January, the warmest month of the year, mean value of maximum temperature is 29.7°C, with a mean minimum of 13.0°C for identical month. For July (coldest month of the year), mean maximum is 14.9°C and mean minimum is 3.9°C.

OFFICE BUILDINGS IN SANTIAGO DE CHILE: CLUSTERING ANALYSIS
In order to establish the main characteristics of office buildings in Santiago de Chile a cluster analysis was made. The purpose of this analysis is also to study the solar and lighting transmission properties in office buildings facades that are representative of this city. For this analysis was developed a database of 101 buildings, representing 100% of the buildings that were built in 6 municipalities of the Metropolitan Region of Santiago de Chile. These municipalities are: Santiago, Vitacura, Las Condes, Huechuraba, Providencia and Lo Barnechea. The main characteristics of these buildings are the followings: 96% of them are less than 6 floors, with 37% between 6 and 10 floors. 46% use curtain walls and 33% have combined walls (opaque and glazed). 52% of the buildings have a transparency between 75 and 100% and 72% of buildings do not show any type of solar protection on their facades. For cluster analysis following variables were considered: Percentage façade transparency, use or not of solar protection, type of solar protection and use of operable windows or not.

Clusters obtained are the following: 1.- Combined façade (glazed and opaque, between 50 and 74% of transparency) without external solar protection. 2.- Fully glazed facades (75-100% of transparency) with external solar protection. 3.- Fully glazed facades (75-100% of transparency) without solar protection. 51% of buildings belongs to cluster 1, 29% to cluster 2 and 20 to cluster 3.

According to methodology, buildings representing each of the mentioned clusters were selected. In 4 buildings, representing each one of the three clusters, continuous measurements of indoor temperature and relative humidity have been doing since January 2012. In cluster 3, measurements have been conducted in 2 buildings with different types of glazing. One with single glazing clear and the other one with double glazing clear. For registering climate information, two different meteorological stations, close to buildings were installed. Global radiation, temperature, relative humidity, precipitations, winds velocity and wind direction is being registered.

RESULTS: TEMPERATURE VARIATION
In offices, in general, temperature was measured at a point close to the facade (by the window) and at a point farthest from the window (away from the window). First of all, the temperature variation inside an east office of a building of cluster 3 (Fully glazed without solar protection, single glazing clear) was measured. (See figures 1), observing overheating. In a weekend day (when no air conditioning is used), a significant temperature difference between the measured close to the window and those measured at approximately 3 m from the window is observed. (See figure 2).

Figure 1: Building cluster 3, single glazing clear without solar protection. East oriented office.
Comparing measurements of fully glazed office building with a combined façade building (cluster 1, with opaque and glazed area without solar protection, double glazing. See figure 3), it is observed that in the latter the risk of overheating is lower. In this case, type of glazing is selective. In fact, the type of glazing and the lower size of windows may explain the less overheating observed in this building, compared with the fully glazed window of cluster 1 (figure 2). Figure 4 shows indoor temperatures of a building of cluster 1. Anyway, it should be mentioned that the comparison is difficult to be made (and therefore not absolute) due to -for example- to the effect of office size and different orientations of offices. Future measurements consider solar transmittance measurements through the windows using a pyranometer (internal and external).

A building with a fully glazed façade (curtain wall. 100% glazed area. With solar protection), was also measured. In fact, continuous indoor temperature of different office rooms was registered. This building has a solar protection which is automatically activated when the respective façade receives direct solar radiation (Figure 5).

Together with the presence of solar protection, windows of the façade are double glazing selective. The effect of sun protection in a west oriented office (plus the probable the effect of selective glazing) is shown in Figure 6. During weekend days, when the air conditioning system is not being used, indoor temperatures are significantly below than the outdoor temperatures.
Figure 6: Building cluster 2 with solar protection. North oriented office. Summer days.

Figure 7: Natural lighting in a north oriented office, fully glazed, without solar protection. Building of cluster 3

In both cases, measurements were made at 50 cm of the façade and bay the opposite wall, around 3 m from the façade.

LIGHTING AND SOLAR TRANSMISSION

On the other hand, two cases of continuous daylight measurements during clear sky days, in offices with no artificial lighting will be shown. These measurements were made in north oriented offices of two different buildings. Figure 8 shows the case of an office with double-glazing clear, without external solar protection and no internal curtains. Figure 9 shows measurements of natural lighting in a north-facing office, with double glazing and selective windows, where an external solar protection is automatically applied when direct solar radiation impacts on the facade.

Figure 8: Natural lighting in north oriented office, fully glazed, with solar protection.

In the first case (figure 7), glare is evident, showing the need for sun protection (external) for avoiding this phenomenon.

In this building, the survey that was applied clearly showed the need for some type of protection to prevent glare. A survey applied to occupants showed that 59% of respondents indicated that the used internal curtains of their office to avoid problems of excess natural lighting. 52% indicated that excessive lighting is a significant problem for lighting comfort. Measurements of illuminance on a 70 cm height plane in a south west office during a winter day (Figure 9) showed enough lighting, even if the building presents a low size of windows (Figure 10).
Colour of curves show different distances (cm) from window as it can be seen in Figure 9.

In the same building of Figure 10, but in a north east office, lighting measurements during clear sky (July 3rd) showed glare if no internal curtain is applied (Figure 11).

Finally, a measurement of solar gain through a facade with double glazing and selective external sun protection is shown. (Identical office of lighting measurements of figure 5). External radiation (horizontal) (RAD EXT in the graph) is highly lowered by the use of solar protection and the type of glazing. DRAD07 and DRAD08 shows internal radiation (measured with a pyranometer installed 50 cm from the facade).
Solar transmission in a north oriented office, with double glazing selective and with solar protection

Figure 13: Solar transmission in a north oriented office, with double glazing selective and with solar protection

Figure 14: Solar transmission in a north east oriented office, with single glazing without solar protection

Figure 14 shows identical type of measurements in a northeast oriented office with single glazing and without solar protection. (Identical office of lighting measurements of figure 12). An important difference in solar transmission is observed, significantly decreasing in the latter case, regarding the former. Solar transmission is higher than 600 W/m², which may cause overheating, even in winter time. In fact, during clear sky days, in this office, heating (during winter days) was not necessary. Figure 15 shows installation of internal and external pyranometers.

CONCLUSION
Preliminary measurements have been shown in different types of office buildings in Santiago, Chile. These buildings were chosen in order to represent those that have been built in recent years. A significant number of office buildings in Santiago de Chile are built without solar protection systems (72%). 51% are fully glazed buildings with facades without this type of protection. This causes overheating and glare problems in these buildings in the city. Indoor measurements of temperature in offices of different orientations show problems of thermal and lighting comfort in these buildings, showing deficiencies in architectural design.

Measurement results show that it is highly recommended to use solar on facades with different orientations. Probably the reduction in size of the glazing is also an important strategy to be considered.

Simultaneous measurements of solar and light transmission in different types of facades, along with temperature and humidity and complemented by feedback from users, shows an interesting methodology to define strategies of architectural design with thermal and lighting comfort criteria in this types of buildings.
As noted above, this paper shows preliminary results which will continue for at least a full year. The methodology applied in this study considers continuous internal temperature measurements. Internal surface temperature measurements in glass facades will be added in the next future. There will also be measurements of solar transmission through glazed system (including solar protection when this exists), installing an external pyranometer with identical orientation of the window (vertical). At the same time, a laboratory for simultaneous measuring of solar and lighting transmission of a façade system (glazing + solar protection and/or internal blinds), in different orientations is under construction. With this laboratory, façade systems used in office buildings in Santiago, Chile will be studied, along with measuring the most appropriated systems to be recommended for the climatic conditions of the city.

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REFERENCES