Towards Passive Working Environments:
Free-running office in Guadalajara, Mexico

DANIEL ZEPEDA-RIVAS,[1] JORGE RODRÍGUEZ-ÁLVAREZ,[1,2]

[1] Universidade A Coruña, A Coruña, Spain
[2] Architectural Association School of Architecture, London, UK

ABSTRACT: Unlike vernacular architecture, most of the newly built office buildings in Mexico are poorly adapted to the climate. The main reason is a lack of normative to limit and regulate the environmental performance of office buildings, since the existing one, is focused on active methods, disregarding the possibility of free-running buildings. This research focuses on the interaction between architecture and the climate to design comfortable environments for office workers in the region of Guadalajara, Mexico. The investigation starts with a climate analysis to reveal the climate's challenges and opportunities as well as the potential for passive design strategies. Fieldwork was conducted in an office tower originally designed following the results of a predesign analysis. With the outcome from the case study, a building module was developed, and the initial parameters were set for further parametric analysis. The results were measured considering the percentage of time in comfort of each different case, as well as the percentage of time overheated. The study identified solar protection as the most effective passive strategy for the location, for the cases where is not possible, a high resistance building envelope is recommended with the inclusion of thermal mass, and insulation.
KEYWORDS: Office buildings, Free-running buildings, Natural Ventilation, Mexico, Design guidelines

1. INTRODUCTION

As part of the global efforts to reduce energy consumption, energy efficiency programmes have been implemented around the world. The possibility of success of these programmes is directly related to the normative on which they are based, whereas their outcomes can be measured according to the trends and consumption numbers during the periods after their implementation.

During the last decade, a peak of economic investment in happened in Mexico. This growth was directly reflected in the construction industry, therefore, the automatic appearance of numerous high-rise office buildings in all the major cities. One of the main concerns of this growth has been the extra loads to the state's infrastructure, together with the unplanned energy expend these buildings have brought [1], this is mainly the outcome of the absence a normative specifically focused in regulating the energy performance of office buildings, the closest to it, is the Mexican official standard for energy efficiency in non-residential buildings [2], which is a set of regulations oriented to a broad spectrum of non-residential buildings. As an attempt to fill this gap, the Leadership in Energy and Environmental Design (LEED) building standard was introduced into the context, disregarding the fact that it is a building energy standard developed for different climates, user's expectation and building regulations [3], hence, the proliferation of fully-glazed air-conditioned buildings, relying on the most inefficient methods for thermal comfort. In accordance with this, the failure of the application of the LEED standard and the national normative is reflected in the constantly growing energy demand for the purpose of space cooling [1], as if was forgotten that historically speaking, in a pre-carbon era, all of the buildings in Mexico were free-running and passive strategies were an essential part of the implicit architectural criteria.

The climates across the Mexican territory are within the classification of tropical and subtropical. These climates provide by definition the necessary conditions for the application of passive strategies [4], hence naturally ventilated free-running buildings seem to be a more logical response, rather than the typical non-climate responsive architecture that seeks to isolate the interior from the exterior. Free-running buildings are not only better in terms of energy saving, they are healthier buildings since they maintain a closer relationship between the occupants and the exterior, their whole operation is based in utilizing the climate features as means to create and maintain comfortable interior conditions [3].

This research is focused on exploring the climate potential for the application of passive strategies in free-running office buildings in a humid tropical climate. The objective is to analyse the climate and investigate the effectiveness of different passive strategies as means to create comfortable workspaces, the research is developed in the city of Guadalajara, Mexico.

Authors ORCID:
1st : 0000-0001-9441-1203
2nd: 0000-0003-3141-3046

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2. CLIMATIC CONTEXT

The city of Guadalajara, Mexico is located in the Mexican tropic at the coordinates 20°40'36''N 103°20'51''W. In a climate classified as temperate Cwa climate, which is defined as dry winter humid subtropical climate according to Köppen's climate classification, theoretically speaking, the main characteristics of this climate are the diurnal and seasonal temperature fluctuations, wet summers with copious precipitation, and cold seasons with an average temperature above 0°C. These features are well reflected at the location, the average yearly temperature is 18°C, with a maximum monthly average temperature of 30.7°C and an absolute peak of 34.5°C, together with a minimum monthly average temperature of 6.5°C, with an absolute peak of -1.04°C. The highest monthly average temperature fluctuation is during the month of April with 17.5°K, while the lowest is during August with 8.5°K. Due to the high altitude of over 1,500 meters above sea level, solar radiation is also intense all year long and the presence of wind is also continuous with an average yearly speed of 1.8 m/s. Figures 1.

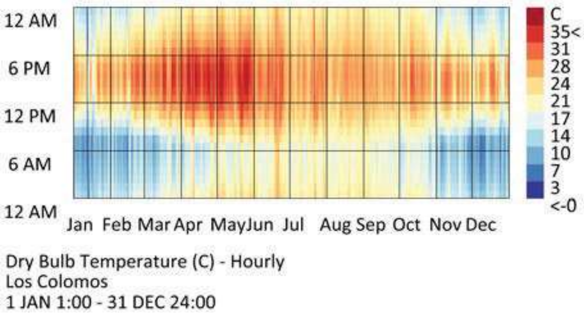

Figure 1: Yearly hourly temperature of the location

The main challenge for a building in a climate like this is to prevent overheating. During the cold season, overcooling should not be a problem since solar radiation is constant, and temperatures rise often above 20°C. According to a theoretical analysis based on the temperature, radiation and the airspeed of the location [5], the most efficient passive strategies are passive solar heating, thermal mass, natural ventilation and night cooling, Figure 2.

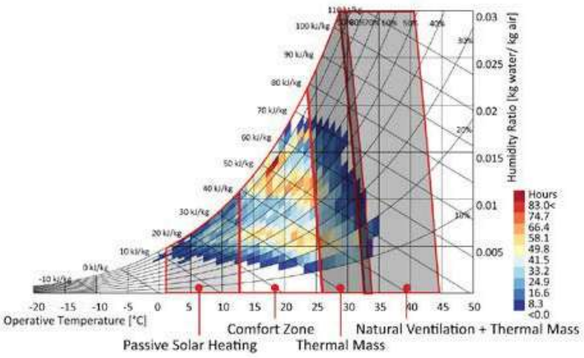

Figure 2: Psychrometric chart with passive strategies.

3. THERMAL COMFORT AND OVERHEATING

There is not an official comfort criterion established for the location. Although, the Mexican normative does not suggest or imposes any specific method to estimate comfort, the use of the LEED standard has implied the utilization of the ASHRAE's Standard 55 [6]. Nevertheless, use of this standard or the European CEN Standard EN 15251 (recently renamed to EN 16798) could be arguable since they were conceived considering meteorological and user's data from different geographic and cultural contexts, located at higher latitudes, therefore, differences in the user's satisfaction and comfort boundaries could be expected [3].

The utilized comfort algorithm in this research was the CEN Standard EN 15251 for naturally ventilated buildings . The European CEN standard was chosen given that it considers the exponentially weighted running mean of the daily mean outdoor air temperature (T_{rm}) rather than the mean monthly temperature or (T_{om}) considered by the ASHRAE standard 55, the use of the T_{rm} implies the inclusion of the thermal history of the subject giving more influence to the recent experiences (i.e. the constant high temperatures during a heatwave), for this reason, it is possible to say that the EN-15251 is better suited to predict the thermal stress induced by overheating since it considers the subject's ability to adapt and acclimatize. [3] Following this, it was also considered, a comfort bandwidth of ±4K, implying an 80% of acceptability limits as it specified in the application of adaptive theory for naturally ventilated buildings.

Since there is not a broadly accepted method to measure overheating in naturally ventilated buildings located in tropical tempered locations. An overheating assessment was elaborated considering the strength and frequency of operative temperatures above the upper comfort limit, with the interest of acquiring quantitative and qualitative data regarding the overheating hours. The method [7], [8] classifies and enumerates the number of hours in five different categories, number of hours above 0.1°K, 1°K, 2°K, 3°K and 4°K.

4. CASE STUDY

The building taken as case study was the Cube Tower I (Figure 3). It was designed by the Spanish firm Estudio Carmen Pinos, It was finished during the year 2009, and it has been fully occupied ever since, the building is located in one of the financial districts of the city. Although it does not possess a building energy standard, it was designed considering the application of passive strategies following the self-imposed objective of becoming a naturally ventilated free-running comfortable office building, [9]

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Figure 3: Tower Cube I by Estudio Carmen Pinos

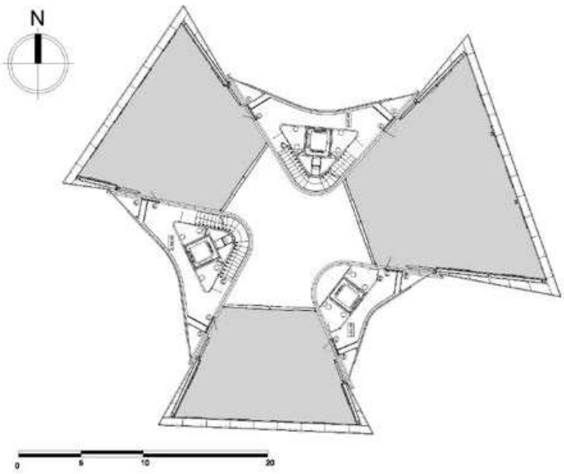

Figure 4: Typical floor plan of the building.

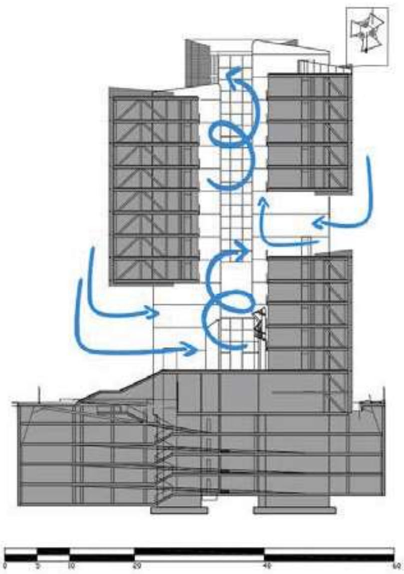

Figure 5: Cross-section of the building.

The application of environmental criteria through passive strategies can be noticed at plain sight. The building is mainly composed of concrete, it possesses a double façade with a first layer of solar protection and a second layer of glazing, and is divided into three volumes attached to a vertical hollow structure, implying with these features, plenty of thermal mass, the reduction of solar gains, and the enhancement of surface exposure area, the vertical hollow nucleus maximizes the airflow through buoyance and stack effect. Figure 4 shows what could be called the typical floor plan of the building, considering that it is not followed completely because of the removed spaces for the airflow optimization, this is possible to appreciate in figure 5, where a cross-section of the building is shown. The identified passive strategies were thermal mass, solar protection, orientation massing, passive solar heating and the possibility of crossed ventilation and night cooling.

A digital model of the building was prepared, and the first set of thermal simulations were elaborated. The architectural plans and the constructive specification (Table 1) were provided by the administration and the designing studio, a fieldwork campaign was carried out with the purpose of a better understanding of the energy balance of the composing elements in the building, it included the placement of dataloggers, thermal imaging and general occupation statistics. With the gathered information, the interior conditions were modelled Figure 6, successively, the first set of simulations was performed, during this sets, it was found that the measured performance could be improved, but the occupant decided to remain like that, theoretically speaking during the warmest hours of the day, temperatures were above

the upper comfort limit, for less than 2°K during periods of approximately 2 hours, but the analysis showed that it was the occupant's choice, since they had access to the window operation and air-flow could be improved together with the thermal sensation and operative temperature. With this in consideration, a window operation algorithm was programmed, the algorithm considered the upper and lower comfort band temperatures as limits for the maximum and minimum outdoor temperature for natural ventilation, as well as slight openings of 1% overnight for night cooling.

The second set of simulations were performed using the programmed natural ventilation algorithm, followed by the overheating assessment. The comfort hours and percentage of time in comfort were calculated considering an occupancy time from 9:00 to 19:00 hrs, the optimized model was capable to reach a total of 95.17% of the time in comfort equivalent to 3821 hours out of 4015, the 4.83% or 194 hours of occupancy time above the upper

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Table 1: Constructive materials, densities, and U-values

Elements	Materials	U-Value	Width
Exterior Walls	Concrete	2.8 W/m²K	300 mm
Interior Walls	Gypsum	2.5 W/m²K	150 mm
Exterior Windows	Single Glazing	5.2 W/m²K	12 mm
Shading	Wood	5.9 W/m²K	25 mm
Slab	Concrete & Flooring	0.33 W/m²K	4500 mm

Table 2: Physical dimensions and proportions of the office module.

Interior Surface	105.7 m²
Interior Volume	370 m³
WFR	0.69
WWR	0.77
Infiltration	1 ACH
Interior Height	3.00 m

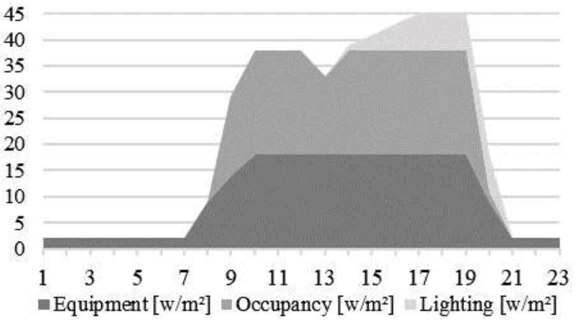

Figure 6: Interior conditions of the building.

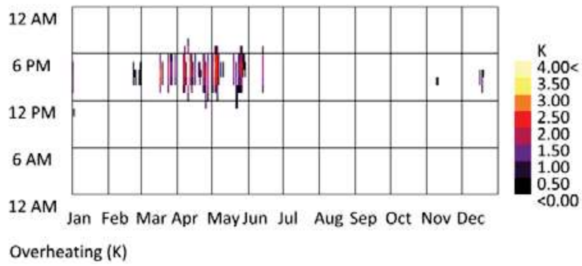

Figure 7: Overheating assessment of the building module.

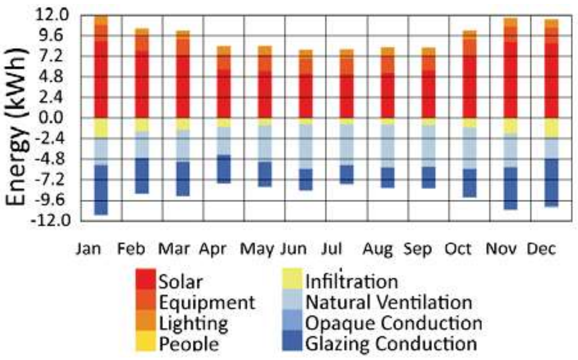

Figure 8: Energy balance of the building module.

comfort limit, was composed by 118 hours or 2.94% of occupancy time above 0.1°K but below 1°K, 63 hours or 1.57% above 1°K but below 2°K, 11 hours or 2.94% above 2°K but below 3°K, 2 hours or .05% above 3°K but below 4°K, and no hours above 4°K. In figure 7 is possible to appreciate a chronological distribution of these hours. Following this results, the energy balance of the office suite was calculated (Figure 8) where is possible to appreciate the heat balance of the office suite, the major source of heat gains correspond to the solar gains, followed by the equipment gains in second place, and the lighting gains in third, the heat gains from the occupants are considered but it is not possible to appreciate them due to the scale of the graphic, in the side of the heat losses, the elements with the mayor discharge of energy are the natural ventilation and the glazing depending on the season, followed by the infiltration, the heat losses through the opaque conductions are also considered but not visible at the scale of the graph.

The simulation results together with the overheating analysis show the possibility of creating and maintaining comfortable conditions. Even when most of the overheating is concentrated during the 3 hottest months of the year, the actual recurrent overheating is in between 0.1°K and 2°K completely manageable with the proper application of adaptive strategies, the percentage of time above 3°K indicate that strong overheating is rare and high levels of thermal stress are also uncommon, but still within the effective spectrum of adaptive opportunities. The main feature of the building and therefore, the office module, is the combinations of strategies rather than the single application of them, the first layer of the façade, the solar protection, blocks around half of the incoming solar radiation, the other half, is absorbed by the building elements, and stored inside the thermal mass, thereafter, slowly release as longwave radiation from where it is flushed by the infiltration, natural ventilation and night cooling, the lack of insulation and high resistance materials, also help with the discharge of the heat gains during the non-occupancy time, the proportion of the office modules of the building provide enough thermal storage as well as exposure area for the storage and release of heat, with additional effect to the mean radiant temperature perceived by the occupants.

4. ANALYTIC WORK

The physical proportions and constructive specifications found in the building and the office suite were interpolated to a building module (table 2), subsequently, two sets of additional simulation runs were performed. The simulations were performed with a modelled rectangular office module

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of 105m² with windows oriented towards the north and south, the roof and floor slabs were adiabatically considered since it was assumed that the module was part of a vertical development.

The first set of additional simulations was performed only changing the solar protection, maintaining all the other features as they were found in the case study. The unmodified features were internal conditions, infiltration rate, building materials, internal height, and glazing ratio (tables 1 and 2). A parametric shading device was modelled as an overhang and it varied in each simulation run, a total of five runs were executed, the placement of the overhang started perpendicular to the walls, in the first cases it only covered the incoming radiation from the highest point of the sun's altitude, the protection only covered the north and south facades, the model was programmed to increase progressively from 0 to 2.70 meters, until the overhand was capable of blocking all the incident direct solar radiation.

The results of these simulations are shown in Figure 9, where the percentage of overheating hours are shown in the Y-axis, while the different overhang lengths are shown in the X-axis. In the figure it is possible to appreciate a decrease from 20.2 to 3.1 of percentage overheating hours, the first 1.2 meters of the shading device are the most effective since they decrease the percentage of time overheated in less than half, subtracting the 12% of overheating hours, from 20.2% to 8.0%, the following additional 0.90 meters from 1.2 to 2.1m of overhang length, only decrease the 4.2 % of time overheated, the following 0.60 meters only 0.7% of overheating hours.

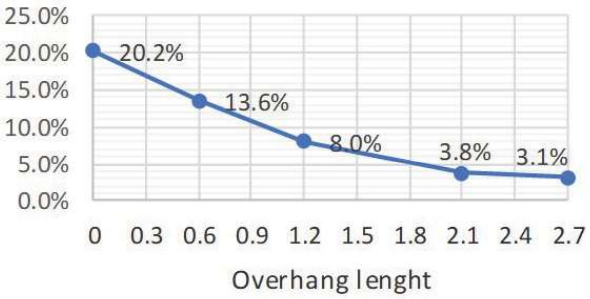

Figure 9: Relationship between the overhang length and overheating hours.

The second set of additional simulation runs was performed completely suppressing the so–lar protection, varying the wall types, window types, internal height, and glazing ratio. On a first subset, different resistance values for the building envelope elements were tested, maintaining the internal height and glazing ratio as they were found in the base case. The tested combination included the original single glazing windows with a U-value of 5.2 W/m²K, as well as double glazing windows of 2.7 W/m²K mixed with the original concrete wall of 300mm with a U-values of 2.8 W/m²K, a thinner concrete wall of 150mm depth and 4.7 W/m²K, and a wider double layer wall of 300mm of concrete plus 160mm of insulation with a U-value of 0.33W/m²K. On a second subset, different internal heights of 2.7m, the original 3.0m and 3.3m were tested, versus to different glazing ratios of 0.2, 0.4, 0.6 and the original 0.8, maintaining the original resistance values of the envelope.

Figure 10: Relationship between the envelope types and overheating hours.

The results of the first subset of simulations are shown in Figure 10, where is possible to appreciate an increase in the percentage of time in comfort as the U-values of building elements decrease. The first 3 columns (from left to right) are the cases with the lowest percentage of time in comfort corresponding to the cases with single glazing, where it was revealed a slight increase of performance of 0.9% as the resistance of the opaque elements increases, the following 3 columns are the cases were double glazing was tested also showing a minimum slight increase of performance of 0.5% as the resistance of the opaque elements increased. With this result, it is possible to state the relevance of the effect of the glazing, especially in cases where there is a suppression of solar protection and a high glazing ratio, a glazing material with a high resistance is desirable since it is the only protection against the exterior and solar gains, however, regardless of the resistance of the walls and glazing, the highest percentage of time in comfort achieve in this set of simulations was 84%, when the base case was 95.17%. In the original case study, the solar protection not only protects the interior from the

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radiation, but it also permits a heat exchange during the night-time allowing the captured heat gains to escape.

Table 3: Relationship between internal height and glazing ratio versus overheating hours.

Internal Height	Glazing ratio	Glazing type	% of time in Comfort
2.7	0.8	Single	79.5
3	0.8	Single	79.8
3.3	0.8	Single	82.0
2.7	0.6	Single	83.1
3	0.6	Single	83.2
3.3	0.6	Single	85.5
2.7	0.4	Single	87.8
3	0.4	Single	88.0
3.3	0.4	Single	90.8
2.7	0.2	Single	93.7
3	0.2	Single	93.9
3.3	0.2	Single	95.7

The results of the second subset of simulations are presented in Table 3, where is possible to perceive the minimal effect of the interior height among the cases with the same glazing ratio, as well as the significative effect of the glazing ratio in all of the cases. The internal height showed a general average increase of performance of 1.2% across the 4 different tested glazing ratios, as it escalates from 2.7m to 3.3m, while the reduction of glazing ratio showed an average increase of performance of 4.6% when comparing only the cases with heights of 3.3 meters, the highest percentage of time in comfort was obtained by the case with an interior height of 3.3m with a 95.7%, corresponding to the 0.2 glazing ratio, while the percentage of time in comfort for the same height but with a glazing ratio of 0.8, as it is in the case study, is 82%, with a difference of 13.8% among them. The obtained results, highlight the importance of the glazing ratio when there is no solar protection considered, a decrease in the glazing area, implies a decrease of solar gains as well, an increase of the thermal mass, thus less solar gains for the interior and a lower operative temperature, even though all of the tested models in this second subset, had a lower resistance value than the better performing models in the first subset, it was possible to increase the percentage of time in comfort by reducing the glazing ratio.

5. CONCLUSION

This paper focuses on exploring the extent and application of passive strategies for free running office buildings in temperate tropical climates. As a starting point, the research starts with a climate analysis and a building precedent was analysed as well as the effectiveness of the passive strategies detected, moreover, further analysis is elaborated in a module where the previous findings were applied. The results were measured considering the percentage of time in comfort of each different case.

This study identified solar protection as the most efficient and effective passive strategy for naturally ventilated office buildings at the location. The application of a shading device allows the possibility of increasing the glazing ratio until desired daylight levels are reached, but it is important to keep in mind the risk of glare due to the brightness of the tropical sky. Another advantage of the consideration of solar protection is the possibility of more window opening areas for natural ventilation. When the solar protection is omitted, the best performance is achieved with a high resistance envelope with a combination of thermal mass and insulation, combined with a low glazing ratio, the main issue with this configuration is the reduction of daylight and natural ventilation area. Similar results can be expected as long as the not tested features such as proportion and orientation are kept similar to values kept during the work.

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