FAUUSP, São Paulo, Brazil: an icon of Brazilian modern architecture with lessons and questions on environmental design and thermal comfort

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ABSTRACT: This paper addresses the thermal performance of the building housing the Faculty of Architecture and Urbanism of the University of São Paulo, FAU-USP. The interest generated in assessing the environmental performance of such a building is based on its iconic value and the unique architectural composition in which internal spaces were conceived to have physical and environmental features in response to the external environment as well as addressing the occupants' generally negative response to its internal environmental conditions. The studies presented in this paper are based on a 1-year research project that included interviews with the occupants, measurements and computer simulations. The measurements were taken based on the application of the Fanger's comfort assessment methodology (PMV and PPD), from which the results were compared to the users' responses. One of the results from the research demonstrated that the unusual architectural features proved to be more conceptual than environmentally effective.

Keywords: modern architecture, thermal comfort, environmental measurements, user's perception

1. INTRODUCTION

The interest in assessing the environmental performance of the FAU-USP building, focusing on thermal comfort, emerged from a combination of factors. One being the unique architectural design in which internal spaces were conceived to have both physical and environmental features in response to the external environment and the other being the iconic value of the building which since its completion in 1969, has been inspirational in architectural design to many architects both of its time and even today. However, whilst having received architectural acclaim, the environmental performance did not achieve similar success but has instead resulted in repeated complaints, by both students and staff alike, of poor thermal conditions.

The environmental assessments presented in this paper were based on a 1-year research period which comprised on site measurements and interviews with various occupants (staff and students). For this research, two types of spaces were selected: studios and lecture halls. In methodological terms, Fanger's thermal comfort indexes: PMV (predicted mean vote), and the resulting PPD (percentage of people dissatisfied) were applied using on site measurements, from which results were compared with feedback from the occupants' about the building's thermal performance. These, in turn, were based on a sequence of questions that were then used to recalculate PMV and PPD indexes [2].

Within the context of this research, the environmental assessment of the building of FAU-USP has two major precedents. The first one is the dissertation developed by FROTA (1982), *Clima local e micro-clima na Cidade Universitária* [3], and most recently the MPhil dissertation of RUSSO (2004), *Climatic Responsive Design in Brazilian Modern Architecture*, from the Martin Centre, Cambridge University [6]. Following the studies on thermal performance, another two 1-year research studies are in progress addressing the acoustics and daylighting performance of the main spaces within the building. Finally, the synthesis of these three studies - thermal, daylighting and acoustics - will lead to a comprehensive understanding.

Figure 1: FAU-USP: external view from the north-west and south-west elevations.

2. LOCAL ENVIRONMENTAL CONDITIONS

The city of São Paulo developed in an area originally characterized as a tropical-altitude climate, located at latitude 23º24 ´S, with altitudes between 720 m and 850 m and 60 Km from the sea. Previous geographic studies, which supported this investigation, showed a wide range and complex urban microclimates throughout the city, with five general local climatic zones and more than 30 localized microclimates spread across the urban fabric.

Following the definition of bioclimatic zones, according to Givoni adapted for Brazilian cities, the city has a mild climate, with average mean temperatures varying from 18^{o}C to 22^{o}C and humidity levels typically between 75% and 80% throughout the year [5]. Prevailing winds come from south-east with average speeds of 3.7 m/s. The comfort zone spans from April to November, accounting for 70% of the typical occupancy period for working/teaching spaces. The external climate exceeds the comfort zone during certain periods of the hottest months, typically 20% of the time (due to high humidity levels) and 10% in winter (during the early hours in the coldest months), based on pure natural ventilation principles.

The FAU-USP building is located within the university campus, which is a large green park surrounded by a former industrial neighbourhood and a busy highway. The area is characterized by pockets of intensive vegetation and trees with permeable surfaces cut by wide roads, large parking lots and low rise buildings scattered across the campus. The local microclimate is therefore considered to be similar to those defined as the reference weather file used for the application of Givoni´s Bioclimatic Zones, which were adapted to the Brazilian climates [5].

3. ARCHITECTURE: THE ICONIC BUILDING

3.1 Architectural concept

The FAU-USP building – a characteristic example of Brazilian modernist architecture of the sixties - located in the São Paulo University Campus, was designed by the architect João Vilanova Artigas and was opened in 1969 [1]. The architecture of such a distinctive educational building was strongly influenced by the national political situation. In opposition to a recently empowered dictatorship, the spatial concept sought to foster social interaction promoting the discussion of democratic ideals.

Currently, the building houses students, professors and staff members totalling almost 1340 people. The building was conceived as an elevated rectangular box, 110 metres long by 66 metres wide and 15 metres high. Whilst the upper part of the building is a concrete box, the lower part is perceived as a glass box. Defining the spatial configuration, continuous intermediate floor levels connected by major ramps on one end and stairs on the other are positioned around a central open space, called *Salão Caramelo* (fig. 2), spanning the full height of the building. This central space was designed to function as a public square surrounded by different activities, enhancing the spatial integrity and providing a direct spatial, visual and environmental link between the inside and the outside [1].

Following the principals of modern architecture, the design concept symbolizes the synthesis of the building's physical stability, spatial organization and environmental strategies, resulting in an innovative design solution for its time, in which column free spaces benefit from the concrete structural design. In that respect, exposed and not insulated concrete walls, are lifted by concrete columns connected to a coffered concrete roof of square 2,5 x 2,5 metres module with highly translucent domes made of fibre glass, spanning the entire building plan.

Regarding the spatial and functional organisation of the internal spaces, the main entrance/hall is a large open space that acts as an internal "square" with ramps to the outside on the south-west orientation. Activities such as auditorium, administration, bar, exhibition hall and library, which include public facilities, are placed on the lower ground, ground floor and on the first two intermediate levels. These first levels are open to the outside with windows and glass walls (fig. 3). The upper two intermediate floors are more private with functions for exclusive use by professors and students: professors' rooms, lecture halls and double height studios. The design studios alone can accommodate up to 800 students.

The architect's intention was for the lecture hall and studios to have no windows and be perceived as a "creative temple" and communication with the outdoors is only possible through the domes of the coffered roof. The absence of windows and degradation of the skylights has a significant impact on both daylight and thermal performance of the building. However, irrespective of the negative environmental impacts of the architectural design, the building has been considered by many architectural critics as a masterpiece of Brazilian architecture.

Figure 2: FAUUSP internal square, with the entrance and the access to the ramps on the left.

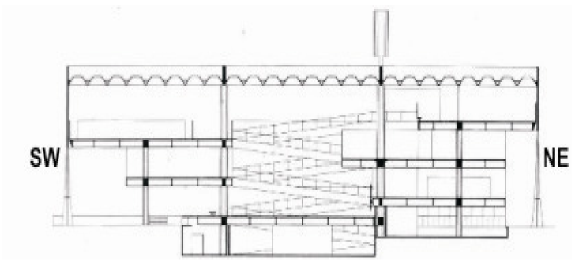


Figure 3: Building section from the south west (studios) to the north east (lecture halls) orientations.

On top of the pure architectural concepts, to fully explain the design fundaments of such a distinctive educational building, it must be mentioned the national political moment in which this building was idealized and built. At the time of the design, the country was experiencing its great political crises which culminated in the revolution that gave power to a dictator federal government one year before the opening of the building. In this context, the building concept sought to foster social interaction, being a metaphor of an inviting urban space.

3.2 Environmental strategies

The elongated façades of the building have a south-west and north-east orientation, which correspond to the locations of the design studios and the lecture halls, respectively, located on the upper levels. Therefore, a significantly area of the studios are (fig, 3) exposed to solar radiation during both summer and late winter afternoons. The lecture halls get direct sun during mornings in summer and a more significantly in winter. The first floors are shaded by the elevated concrete box which cantilevers over the edges of ground floor by 5 metres. The entrance level was originally conceived to be totally open, as if on *pilotis*. However, due to the need for administrative accommodation, the majority of the perimeter was sealed off, with rooms and glass windows separating the big "square" from the outside [7].

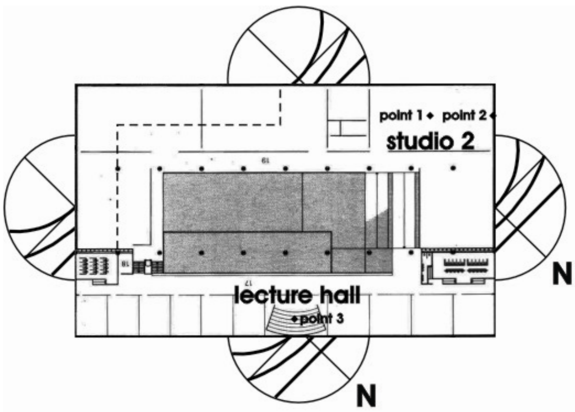


Figure 4: studios and lecture halls at plan level 8,5 m and 9,5 m respectively (the lecture hall and the studio highlighted were the areas selected as case studies). Dashed line – later enclosure of the ground floor.

The primary source of daylight penetration is through the fibre-glass skylights. With respect to the elevated part of the building, the spaces are all top lit. Daylighting and ventilation on the first floor, on the other hand, are provided by glass panels and windows, which have been successfully conceived. All windows are openable and structurally self supporting. The design of these openings allows effective stack ventilation in the spaces adjacent to them, whereas cross ventilation is not possible mainly due to the depths of the plans.

The entire building is naturally ventilated during the whole year. In the studios and in the lecture halls the air flow enters through linear apertures along the edge of the floors, located behind an internal concrete wall 2 metres high, and leaves via small openings (4 cm) integrated into the skylights. The central hall, *Salão Caramelo*, was also meant to enhance the overall stack effect in the building. However, previous studies (RUSSO, 2004) have shown that despite the height difference of 15m between the ground floor entrance and the top of the building the contribution of this atrium space is not effective unless wind assisted [6]. This fact could be attributed to the restrictive high level openings and also because of the substantial enclosure of the ground floor plan, with only the entrance left open (fig. 4).

With the choice of concrete as a material and the design of the building's components, the design definitely represents one of the major architectural expressions of the *Paulista School* of Brazilian modernism. However, the absence of any kind of insulation incurs problems resulting in undesirable heat losses in winter and increased heat gains in summer yielding high radiant temperatures.

In conceptual terms some of the environmental strategies incorporated into the design could meet comfort requirements, such as the stack effect through the openings in walls and skylights. Nevertheless, the detailing and specification of such strategies were not adequately developed. Others, such as the predominance of transparency in the roof and total lack of insulation are not appropriate to the local climatic conditions all impacting on the overall environmental performance.

Spaces, such as the lecture halls ands studios, are hot in summer and cold in winter. As part of a preliminary qualitative evaluation of the building's environmental features, it is possible to say that the significant amount transparency on the roof has been one of the main causes of discomfort in the studios and in lecture halls for two reasons: thermal discomfort (as a consequence of increased air and radiant temperatures) augmented by visual discomfort (excessive lighting levels resulting in disability glare on the working plane). Some of the original domes have been replaced on the last couple of by the same highly translucent ones. The contrast on solar radiation transmittance is sensitive - to give an idea of the extreme internal brightness, when all the domes were new, 30 years ago, records show that students used to wear sun-glasses in the studios. The dimensions of the dome apertures have also proved inappropriate for effective stack ventilation and therefore compromising even more thermal comfort. The lack air flow control and the lack of thermal insulation are major causes of thermal discomfort in winter and summer.

4. ENVIRONMENTAL ASSESSMENT

Two spaces were selected for this environmental assessment: a studio with south-west and north-west orientations, located at one of the corners of the concrete box, and a lecture hall located in the middle of a row of rooms (ref. Fig. 4). The choice was based on the spaces' particular design and environmental characteristics, solar exposure and occupation patterns. All studios are occupied all day, from Monday to Friday. The selected lecture hall is the only lecture hall/class room also occupied all day, from Monday to Friday.

4.1 Design characteristics of the spaces

Studio: 32m long by 17m wide and 5,5m high, at 8.5m above ground level with 72 domes (original domes) (fig. 5). Lecture hall: 17m long by 11m wide and 3,65m high, at 9.5m above ground level with 24 domes. In order to create the dark environment necessary for projection and also to improve their thermal performance, all of the domes were painted white on the outside and black on the inside, in all lecture halls (fig. 6).

Figures 5 and 6: at the top – studio, at the bottom - lecture hall during the environmental assessments: measurements and questioners.

Building materials: external walls un-insulated concrete; rubber coated floors; coffered roof with concrete beams and fibre-glass domes; internal partitions (full height between lecture halls but only 3m high between studio spaces).

4.1 General methodology

- On-site measurements of climatic variables during both hot and cold days.
- Application of questionnaires to obtain occupants' responses on thermal comfort (in parallel with site measurements).
- Calculation of PMV (predicted mean vote), according to Fanger's comfort criteria methodology, for hot and cold days, using the results from the measurements [2].
- Comparative analyses between the results obtained from the PMV index (based on measured data and responses to questionnaires).

In consideration of previous studies, this work added another layer of information, based on occupants' feedback about the building's thermal performance, to test the appropriateness of Fanger's methodology in this specific environmental context, knowing that cultural and built aspects do have an influence on the results [7]..

4.2 Measurements

Measurements were taken over two periods of the year: 31st of March end 1st of june(still within the hot reason) and from the 22th to the 24nd of June (cold season). Prior to these measurements being taken, preliminary measurements were made to test the equipment and the procedures. The climatic variables measured were air and radiant temperatures (TRM), humidity and air velocity, between 8.00 am to 5.00 pm, in both spaces.

The first three variables were registered in intervals of 30 minutes, whilst air velocity was measured every four hours, for 10 minutes, in 10 seconds intervals. All measurements were taken at 1.1m height (according to ISO 7726/98) [4], in the centre of the spaces. In the studio another point adjacent to the external south-west wall was established to take measurements of radiant temperatures, in order to find the influence of the roof and walls on the total mean radiant temperature.

Onset HOBO H8 data logger were used to measure air temperature and humidity. Air velocity and globe temperature were measured with the H&K Thermal Comfort Data Logger - Type 1221. Mean radiant temperatures were calculated based on globe temperatures.

4.3 Questioners

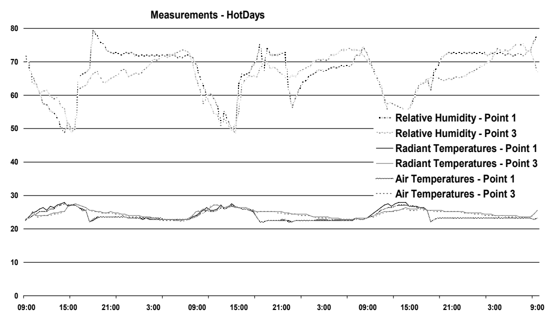
The questionnaires were issued once in the mornings and once in the afternoons, both in the studio and in the lecture hall, whilst taking physical measurements. The occupants were asked three questions. The first one addressed thermal sensations, from which the PMV and the PPD results were established through comparison between Fanger's model and filed measurements. The second one related to the occupants' expectations. In this question they were asked whether they would like to feel warmer or colder, following the 7 points of the PMV scale. Combined with the first question, the answers from these two questions can show a different value of PPD, since some degree of subjectivity is included. This would be the case if somebody answers "slightly hot" in the first question and "no change" in the second one. Finally, the third question focused on the degree of occupants' tolerance to the thermal conditions, in order to classify the importance of comfort (or discomfort) to the occupants' acceptability of the space and ultimately their will to stay [7].

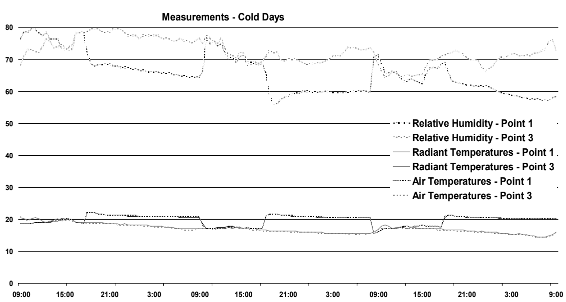
5. LESSONS AND QUESTIONS FROM THE ENVIRONMENTAL STUDIES

5.1 Thermal data analysis

Hot days: comparing the results from the two spaces, the measurements during the hot week showed a temperature variation of 5°C, whilst the relative humidity varied from 78% to 49%. Of the three points, point 1 had the highest air and radiant temperatures: 28°C and 30°C, respectively, at 14.00hs (fig. 7). From these measurements, the combined effect of high humidity and high air temperatures generates thermal discomfort and requires increased ventilation rates. However, in all points the difference between air and globe temperatures was not higher than 2°C, which shows that in the zone of occupancy, the radiant heat from the roof was not affecting comfort directly [7].

When analyzing such results, it is important to underline that during the measurements of the summer days the sky was partially clouded (which is a typical condition in São Paulo) but at the same time this does not represent extreme summer conditions which the building can be subjected to in clear-sky conditions, when the transmittance of solar radiation is substantially higher. This is especially true for the studios, as opposed to the lecture halls, where the domes were painted outside and inside. When considering the relative humidity, the results show the opposite – the values are higher in point 3 (lecture hall) than in the other two points (studio). This is a consequence of keeping the doors closed in the lecture hall when the room is occupied, which demonstrates that the strategy of creating natural ventilation between the floor opening and the domes does not work effectively during hot days. Meanwhile, in the studios, the continuous volume between adjacent studios allows a more constant air flow.





Figures 7 and 8: air and radiant temperatures, RH in the studio and lecture hall (points 1, 3).

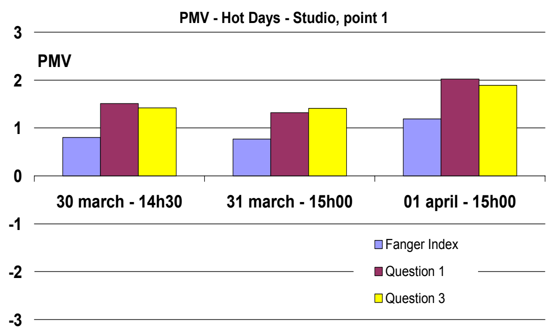
Cold days: During this period, the measurements showed small temperature variations. As per the hot days, the difference between air temperature and globe temperature was negligible, which was expected due to the reduction in solar radiation during this time of the year. In the studio (point 1), the lowest air and globe temperatures registered simultaneously was 15,6°C (fig. 8), whilst the relative humidity varied from 80% to 58%. In the lecture hall (point 3), temperatures were lower: the minimum air temperature and globe temperatures were 14,8°C and 15,2°C, respectively, with high relative humidity, reaching 79% [7].

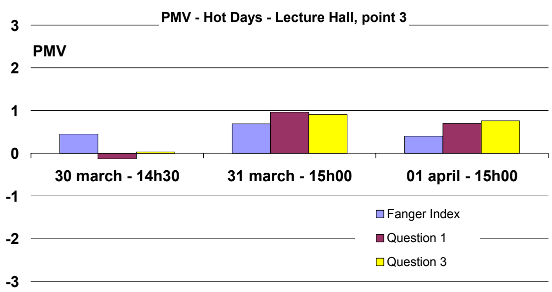
5.2 Comparative analysis

Hot days: The PMV based on the occupants' responses shows that the environmental conditions of the two areas are close to "comfortable" only in the morning of first day. The dissatisfaction towards "hotter" increased over the days, following the rise of internal conditions in both spaces (fig. 9 and 10).

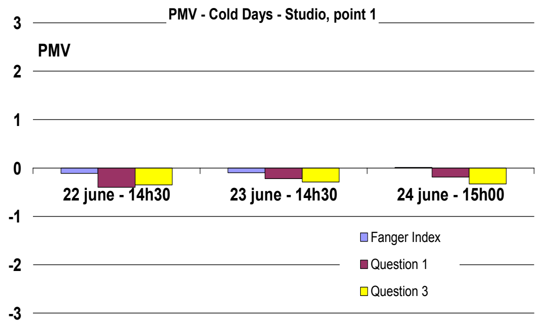
Cold days: the occupants' responses during the winter period followed a similar pattern as per the summer days. In the first morning the PMV was close to "comfortable" in both spaces, moving towards a "colder" period over time (fig. 11 and 12).

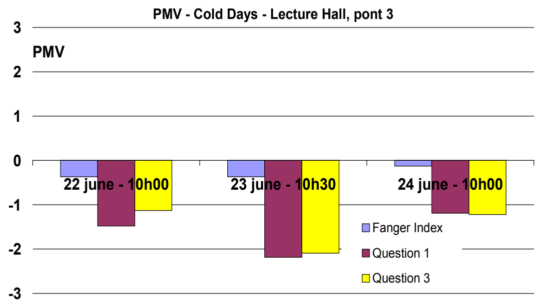
The comparative analyses between the results of Fanger's model based on the application of filed measurements and the occupants' responses showed that the occupants consider the building to be hotter in summer and colder in winter than Fanger's PMV/PPD based results/data (fig. 9 - 12)]. It is possible that these results are related to the frustration of the occupants with the design and environmental aspects of the building which have other effects on the occupants' sense of comfort, other than purely temperature, humidity and air velocity, such as absence of windows and visual communication, lack of acoustic privacy and other psychological parameters.





Figures 9 and 10: PMV taken from measurements and occupants' responses during hot days in the studio and in the lecture hall (points 1 and 3). The occupants' responses include questions 1 and 2.





Figures 11 and 12: PMV taken from measurements and occupants' responses during cold days for the studio and lecture hall (points 1 and 3). The occupants' responses include questions 1 and 2.

6. FINAL CONSIDERATIONS

The unusual architectural features of the building, which were partially justified in the design supported by their theoretical environmental performance, proved to be more conceptual than really effective. The undersized apertures at roof level and ineffective stack ventilation coupled with the transparent horizontal surface for daylight access results in both glare and over-heating during the hot days. In that respect, the results demonstrate a degree of dissatisfaction by the occupants during the warmer periods of the year, which would definitely be aggravated under clear sky conditions.

The difference between the results of Fanger's index, based on measurements against the occupants' responses highlights that the issue of environmental performance of such "unusual" buildings cannot be simply explained only by building physics. It requires a broader understanding of comfort that must include spatial perception, users´ behaviour and psychology. Hence, the building of FAUUSP - a unique architectural piece at the climax of Brazilian modernism - brings lessons and questions about the building's overall environmental performance.

The Fanger's methodology is often criticized for generalizing human responses on purely physiological terms, but is equally praised by its sophisticated modelling of human physiology. However, it does not addresses cultural differences and associated acceptance levels nor does it consider the concept of human adaptability to climatic variations.

The comparative analysis between the measurements and the questionnaires demonstrated sensitive differences. According to Fanger´s index, both spaces showed acceptable conditions for the occupants (PMV < 1), whereas in practice, the user's responses reflected a higher level of dissatisfaction. This was particularly the case during the colder period but the highest difference was found during the warmer period in the studios.

Overall, the comparative analysis showed a poor correlation between Fanger´s model and the results from the questionnaires. As identified previously, the users´ responses were actually more sensitive to heat and cold than the Fanger´s indices implied.

There was only a single day in which this trend was not registered. With regards to the application of such questionnaires, the unexpected results also highlight the importance of the need for a longer period of field work. Because of such relatively poor correlation, the need for defining a new model, in which the variables and the scale of the predicted mean vote should be revised to recognise both local specific conditions as well as psychological parameters, becomes evident.

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