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EXPERIMENTAL EVALUATION OF THERMAL BEHAVIOR OF THE RIO DE JANEIRO`S PLANETARIUM

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Abstract. *This paper aims at carrying out temperature, humidity and global solar radiation measurements inside and outside of the building referred as "Museu do Universo" in the Planetarium of Rio de Janeiro city, in order to evaluate its thermal behavior. The data acquisition system is a programmable logical controller from National Instruments Inc. (NI) named Compact Field Point model cFP-2020, supported by three dedicated signal conditioner boards with 16-bit resolution A/D conversion, which are two NI-RTD-124 boards for 4-wire RTDs connections and a NI-AI-110 analogical input board for receiving the signals from humidity sensors and pyranometers. The supervisory has been developed in NI Labview program, version 8, specifically for this application. It has continuously run, except in some maintenance periods. The supervisory has run in a notebook connected to cFP via a crossover RJ45 cable. The sampling rate was chosen as an instantaneous measurement at each 1 minute. It was 18 simultaneous and continuous measurements at all. Additionally, glazing façade temperatures has been scanned with a Testo 845 infrared thermometer from both its inside and outside surfaces. Temperature measurements of almost all air conditioning supply openings were carried out for verifying homogeneity. The measurements were taken on May, June and July of 2014. The temperature difference among the higher measured point at the top of the domus and conditioned lower floor temperatures has reached around 30°C in some instances. Internal and external glass surfaces have reached, respectively, 60°C and 50°C in a sunny day, and 50°C and 40°C in a completely cloudy day with only incidence of diffuse solar radiation. It was confirmed two different climatic zones: the ground and the second air conditioned floors maintained at around 20°C and the third non conditioned floor including the top of the domus, with a solar heated stagnated air. The heating effect observed from the current glazing façade indicates a great opportunity to energy efficiency actions, such as the adding of building integrated photovoltaic.*

Keywords: *thermal behavior, measured weather data, hygrothermal, energy efficiency, planetarium.*

1. INTRODUCTION

Energy use in buildings is a significant factor in world's overall energy consumption and a major contributor to greenhouse gases. Nowadays, approximately 25–30% of the total energy consumed in world is used in buildings. About 80% of the energy consumed in the commercial and residential buildings is used for space heating and cooling. Enhanced thermal protection is a therefore pre-requisite to construct or rehabilitate buildings to reach a reasonable energy consumption, satisfactory thermal comfort conditions and low operational costs. Energy saving can be obtained by insulation since significant part of heat losses or heat gains occurs through walls and ceilings (Papadopoulos and Giama, 2007).

In Brazil, electricity consumption in the residential, commercial, service and public buildings, is quite significant. It is estimated that nearly 50% of the electricity produced in the country are consumed not only in the operation and maintenance of buildings, as well as in artificial systems that provide environmental comfort for its users, such as lighting, air conditioning and water heating (Procel Info, 2015).

A building is more energy efficient than others when it provides the same environmental conditions with lower power consumption. The electricity consumption in office buildings is mainly due to the lighting systems, office equipment and air conditioning systems. They are responsible, respectively, by 24%, 15% and 48% consumption of the building (Lamberts, *et al.*, 1997).

Energy efficiency in buildings is then inherent to a development based on sustainability, inducing engineers and architects rethought their design techniques and technologies used until today, increasingly seeking the interaction between passive and active methods aimed at reducing the energy consumption and meet the needs of users (Aragão, 2014). The implementation of these passive and active strategies must never compromise comfort and healthy requirements (Givoni, 1992).

The availability of measured data on climatic variables and building parameters forms the basis for predicting, analyzing, and simulating the heating or cooling energy demand of buildings. Computational simulation programs often need input data on building materials, HVAC components, and hourly weather data (Lindberg, *et al.*, 2004).

Measurements over a long period of time have been made by scientists interested in studying the thermal performance of buildings. This data can be used by a lot of professionals in analytical and computational solutions, creating modeling techniques in buildings for better energy use and knowledge of the thermal performance of the building (Lindberg, *et al.*, 2004) and (Soutullo, *et al.*, 2014).

Therefore, studies are currently being made to reduce the demand for energy for heating and cooling of buildings. Ways to monitor the energy consumption of commercial, services, public and residential buildings, as well as energy saving prospects in heating and cooling these buildings have been widely discussed (Aragão, 2014), (Lindberg, *et al.*, 2004), (Westergren, *et al.*, 1999), (Mihalakokou, *et al.*, 2002), (Jaber, 2002) and (Nagai, 2002).

In the lacking of climatic data from the building case study, a way to evaluate its thermal performance is through in-site data acquisition using a set of sensors strategically located at points where are needed knowledge about the hygrothermal data variation in a certain space time.

This paper aims at carrying out temperature, humidity and global solar radiation measurements inside and outside of the building referred as Museum of Universe in the Planetarium of Rio de Janeiro city, in order to evaluate its thermal behavior. The measurements were requested by the German company Ecofys, contracted by the German International Cooperation Agency (Deutsche Gesellschaft für Internationale Zusammenarbeit - GIZ) for performing computational simulations of the current air flow and thermal performance of the exposition area of the Museum of Universe.

2. GÁVEA PLANETARIUM / MUSEUM OF UNIVERSE: A BRIEF BACKGROUND

The headquarters of Rio de Janeiro City Planetarium Foundation has two buildings designed by the architects Ricardo and Renato Menescal: Gávea Planetarium (1970) and Museum of Universe (1998).

The former building, an example of brutalist architectural style, presents the following characteristics: façades entirely in raw concrete, with a few openings at east and west sides; a southbound entrance porch in columns composed by triangular pleated faces; roofed by an open air amphitheater for shows and sky observation. The building is completed by a copper dome. A few changes were implemented through the years: the former conference room was changed to a small arena theater, and the dome auditorium, which formerly housed a Zeiss Spacemaster projector to an audience of 130 seats, was adapted to digital shows to 90 spectators.

The original building reached the peak of its service capacity in the 1990s, by receiving about 100,000 visitors/year. Additional area and modernization of facilities were needed, focusing on the installation of a science center with interactive exhibits and experiments. The new Planetarium design, anchored to a more advanced projector (Zeiss Universarium VIII-TD), resulted in a 4 pavement building (including basement), with total area of 12.160 m², and equipped with a 23 m diameter dome for 260 spectators. The works began in 1995 and were completed in 1998. Figures 1 and 2 show, respectively, an external sight of this building and an internal sight of its glazing façade.

Inside the new building, its several sectors are organized around the great dome of reinforced concrete and the entrance plaza oriented to the north, that houses a large ramp that accesses the 3 exhibition pavements, and is covered by a large glassed domus. The outer walls are entirely coated in granite and have few windows, all protected by brise-soleils in translucent alveolar polycarbonate. The roof comprises a large terrace around the glassed domus, equipped with 4 telescopes for sky observation and accessed from the ramp; and a lower terrace connected to the roof of the former building. These two terraces are connected by stairs framed by flower pots in raw concrete.

Figure 1. External sight of the Museum of Universe building.

Figure 2. Internal sight of the glazing façade.

3. PLANETARIUM FOUNDATION COMMITMENT TO SUSTAINABILITY AND ENERGY EFFICIENCY ACTIONS

The current management of Planetarium Foundation, begun in 2009, added a new unit at West Zone of Rio de Janeiro (Santa Cruz Planetarium), raised the service level to the public, reaching 477,000 of attendances in 2013, and consolidated in its 2013-2022 Strategic Plan environmental sustainability strategies. The main strategies are: GHG emissions tracking, and energy efficiency actions, in order to reduce electricity consumption. These actions have the support of the local electric power company (Light Serviços de Eletricidade S.A.), including:

- the recently completed refurbishing of the air conditioning system, including replacement of chillers and pumps the hydraulic system, and installation of a supervisory system that allows on-line equipment tracking and control;
- a future photovoltaic system integrated to the glassed domus façade for educational purpose, by associating it to an especially designed exhibition that will show the whole path of the energy generated by the sun to its final use in the building. Photovoltaic glass panels will replace the current domus glass with new low-e glass panels, combining lighting needs in exhibition areas and the intent to mitigate the entry of solar radiation inside the building, by increasing roof shading areas. Technical consulting services required for the development of these projects were supported by GIZ (Gesellschaft für Internationale Zusammenarbeit).

4. MATERIALS AND METHODS

All sensors have been installed at locations indicated by Ecophys, although 2 were risen for attaining safety requirements for the Planetarium's visitors.

Table 1 presents the location and the type of all sensors. Table 2 presents their metrological characteristics and specifications. Figure 3 illustrates sensor locations.

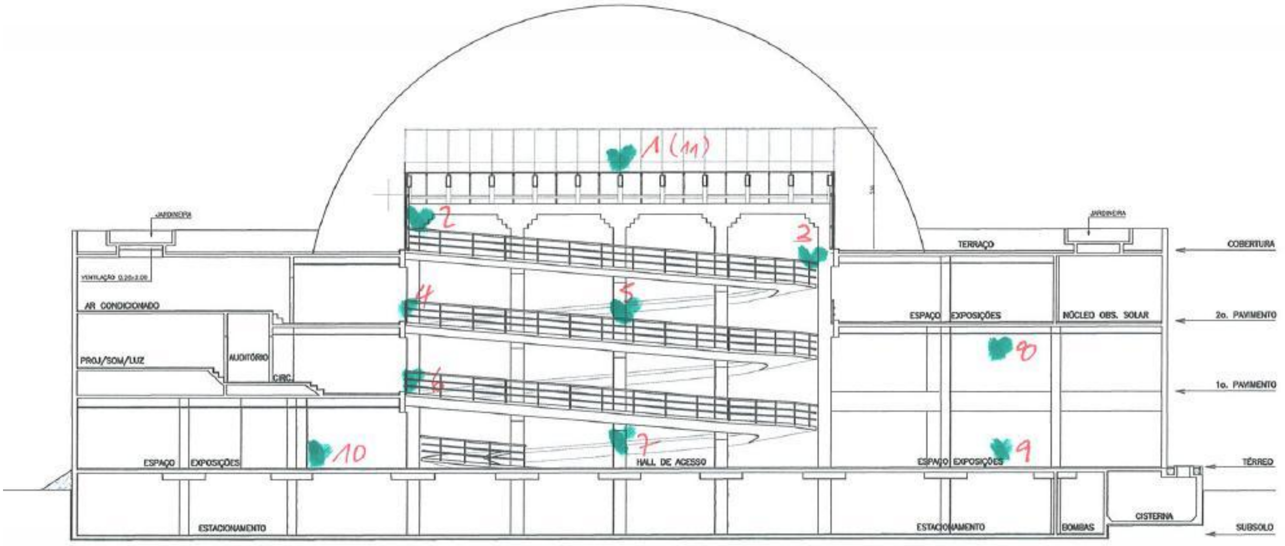

Figure 3. Location of the measuring points.

All temperature sensors are 4-wire platinum resistance thermometers type Pt -100, referred as RTD. The chosen for 4-wire RTD is due this configuration is more accurate because it eliminates ohmic losses from the measurements, taken into account that distances from the cFP and far sensors exceeded 30 meters.

The global solar irradiation measurements were taken with pyranometers located at the same azimuth and tilt angles of the glazing façade.

Humidity sensors, based in HIH-4000 Series (Honeywell), were mounted in a small box with holes, as shown in Figure 4. Each one was located as close as possible to a temperature sensor, since the humidity sensors require temperature compensation. This was done by the equation provided by the manufacturer manual, as below.

$$V_{Sensor\ RH} = \frac{V_{out} - (0.9237 - 0.0041T + 0.000040T^2)}{(0.0305 + 0.000044T - 0.0000011T^2)} \quad (1)$$

With V in volts and T in ºC.

Still based on the manufacture manual, the value of the RH is a linear function of the $V_{Sensor\ RH}$, as below.

$$RH = \frac{V_{Sensor\ RH} - 0.958}{0.03068} \quad (2)$$

Thus, a sub-VI, based in two *Maths Scripts*, was developed in order to receive V_{out} and T as input and returns the *RH Value* as output. So, the first *Math Script* was used to calculate the corrected $V_{Sensor\ RH}$ and the second to calculate the *RH Value*.

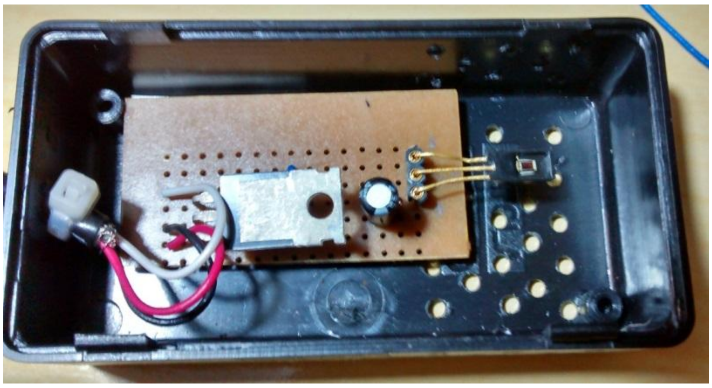

Figure 4 – Humidity sensor set.

The sensors were wired through 4-way AWG 22 or AWG 26 cables with electromagnetic shield. All connections were welded for avoiding poor contact noises. No operational amplifier was needed because the NI cFP inputs has filters (which "cleans" the signal) and amplifiers (that matches the signal level). No energy supply for sensors was needed, except for humidity sensors which required an additional power source due to their feeding voltage.

Where necessary, sensors were shaded by aluminum paper plate, as shown in Figure 5. External humidity and temperature sensors were shielded from direct solar radiation and rain with a semi-cylindrical cover shaded by aluminum paper plate, as illustrated in Figure 6, specially constructed for this application.

The data acquisition system is a programmable logical controller from National Instruments Inc. (NI) named Compact Field Point model cFP-2020, supported by three dedicated signal conditioner boards with 16-bit resolution A/D conversion, which are two NI-RTD-124 boards for 4-wire RTDs connections and a NI-AI-110 analogical input board for receiving the signals from humidity sensors and pyranometers. All signal conditioner boards are mounted with NI-CB-01 connection blocks.

Figure 5. Shaded temperature sensor.

Figure 6. Shield for external sensors.

Table 1. Sensor types and locations.

References of north-south (X), east-west (Y) and elevation (Z) axes: X = northern face of the central column; Y = eastern face of the central column; Z = ground floor				
Number	Type	X (m)	Y (m)	Z (m)
1	RTD	-8.92	0.00	12.00

2	RTD	-2.05	1.50	12.84
3	RTD	-0.80	1.80	12.30
4	RTD	8.88	0.00	10.67
5	RTD	-9.64	0.00	8.63
6	RTD	0.00	-8.47	9.51
7	RTD	0.00	0.00	7.86
8	RTD	15.63	0.00	2.38
9	RTD	14.62	0.00	5.70
10	RTD	-9.64	0.00	5.36
11	RTD	-14.14	0.00	2.30
12	RTD	0.00	0.00	1.00
13	RTD	0.00	-4.66	11.63
14	RTD	0.00	-7.53	6.89
Internal solar radiation	Pyranometer	0.00	0.00	11.70
External solar radiation	Pyranometer	9.60	4.50	12.36
Internal relative humidity	Integrated circuit humidity sensor	0.10	0.00	7.86
External relative humidity	Integrated circuit humidity sensor	0.00	-4.66	11.63

Table 2. Sensor metrological characteristics and specifications

Type	Manufacturer	Model	Range	Precision / sensibility
4-wire RTD	Exacta	EX-33-PA-S4-304-03-30-C-TPR-45-14-N-F-I-CCA	- 50°C to 200°C	± 0.1 °C
Air humidity	Honeywell	HIH-4000	0 to 100 %	± 3.5 %
Solar irradiation	Kipp & Zonen	CMP 3	0 to 2000 W/m²	5 to 20 µV/W/m²

The cFP sampling rate was a value per second. The recording rate was chosen as an instantaneous measurement at each 5 minutes, but it has been increased to 1 per minute since May, 16th, in order to enable to use mean values as smoothing strategy after observation of output fluctuations on external sensor measurements due to variable wind effect.

The supervisory has been developed in NI Labview program, version 8, specifically for this application. The supervisory has run in a notebook Dell Latitude 120L, Pentium M 1.73GHz, 2GB RAM, 40GB HDD, connected to cFP via a crossover RJ45 cable, with Windows XP SP3 as operational system that was compatible with Labview 8. First attempting for using newer computer with the current Windows 8 with Labview 8 has no success and consumed time. The older Labview 8 was the only licensed version available.

The supervisory has continuously run since May, 2nd up to June 16th without failures, except for some maintenance periods. Data were recorded as text type file (*.txt), organized in columns by sensor. All computer resources that could interrupt the data acquisition were disabled, as automatic Windows update, hibernating and other energy saving functions, wireless device and so on.

Additionally, scanning of glazing façade temperature was carried out with a Testo 845 infrared thermometer, in order to complement information for better understanding the thermal performance of the building. Both internal and external faces were evaluated.

After finishing the recording period, all temperature sensors were simultaneously immersed in a mixing of water and melting ice for checking their readings and all have passed, the maximum error found was lesser than 0,5°C.

5. RESULTS AND DISCUSSION

5.1. Measurement Results

Due to space limit, only three consecutive days are illustrated for temperature in Figure 7 and humidity and radiation in Figure 8. The temperatures from higher locations (sensors 1 to 4) were always above the external air temperature (sensor 13) during the sunlight period, clearly denoting the heating effect promoted by the glazing façade. The temperature difference among the higher measured point (sensor 2) and conditioned lower floor temperatures (sensors 8 to 12) has reached around 30°C in some instances.

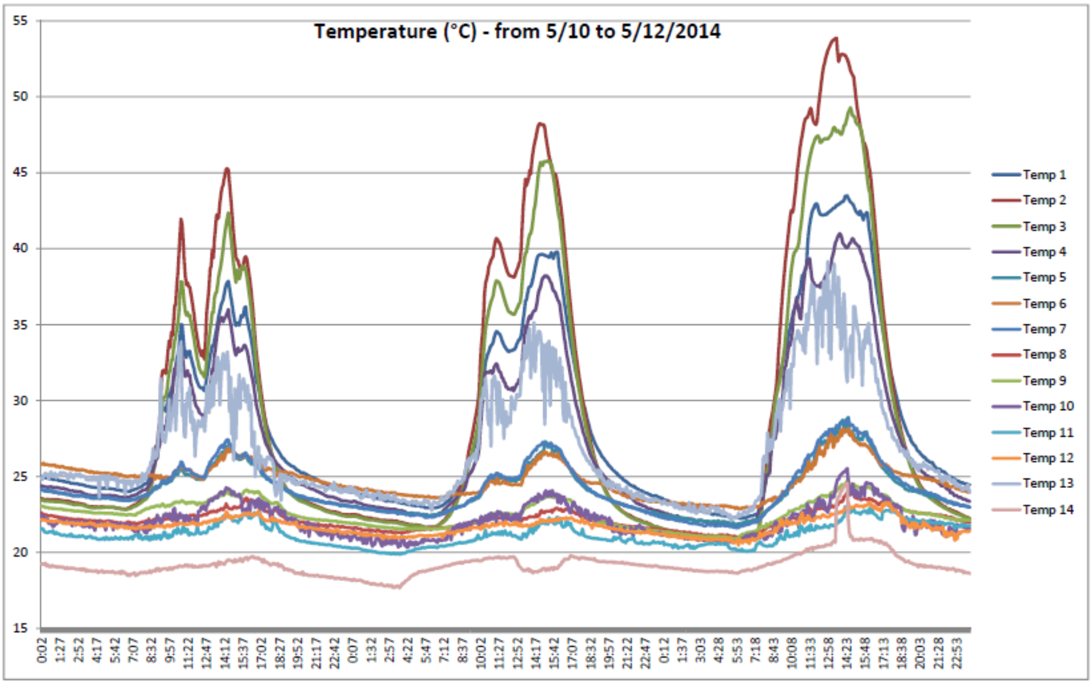

Figure 7. Temperatures from 5/10/2014 to 5/12/2014.

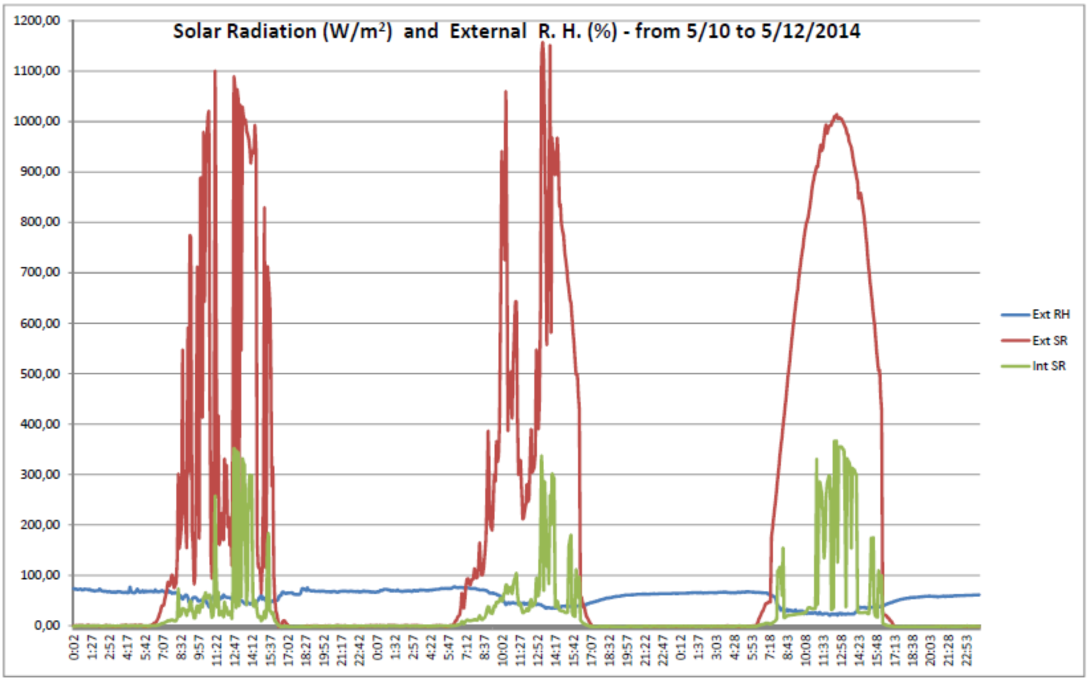

Figure 8. Solar radiation from 5/10/2014 to 5/12/2014.

Supply air temperatures (sensor 14) have clearly indicated when the air conditioner system was turned on or off. Higher duct supply air temperatures (sensor 3) indicate that it has been out of service during all measured period, confirming information obtained from the Planetarium staff that it is seldom turned on.

The internal global solar radiation suddenly increases and decreases due to alternating sensor exposure to sunlight and its shading by the steel frame of the glazing façade. During the day period, the internal relative humidity decreases because the air conditioner system is turned on, and the external relative humidity decreases due to the air heating without adding significant water vapor mass.

There are great fluctuations in the external temperatures recorded, due to they are instantaneous values rather than mean values, impacted by variations in wind speed and solar radiation. The sensor location is in a terrace, on the top of the building, and the local air is heated by the neighboring surfaces when stagnated and when the wind speed is high, a colder fresh air comes to the sensor. The air relative humidity fluctuations is expected because the relative humidity decreases as the temperature increases when remaining almost the same content of water vapor mass.

Internal and external glass surfaces have reached, respectively, 60°C and 50°C in a sunny day, and 50°C and 40°C in a completely cloudy day with only incidence of diffuse solar radiation.

6. CONCLUSIONS

It was confirmed two different climatic zones: the ground and the second air conditioned floors maintained at around 20°C and the third non conditioned floor including the top of the domus, with a solar heated stagnated air.

The heating effect observed from the current glazing façade indicates, as expected, a great opportunity to energy efficiency actions, such as the previously considered adding of building integrated photovoltaic. Since the photovoltaic surface is much less reflective than the glass surface, and commercially available system yields are around 15%, the selection of the photovoltaic system must take into account mechanisms that avoid (or reduce) heat penetration inside the domus.

It is recommended to add an air exhaust system at the top of the domus, to remove the heated air, instead of the current air duct system, that blows down this heated air, mixing it with the lower temperature air from lower floors, increasing the energy consumption from the air conditioning system. This air exhaust can be done by natural convection, through superior openings, or by forced convection, may be through inverting the current higher duct system.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE