Consiglio Nazionale delle Ricerche
Istituto di Scienze dell'Atmosfera e del Clima
Unità Organizzativa di Supporto di Padova

STM 2015

Monitoring of the microclimate and air quality inside the showcases of a museum in subtropical climate

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CONTENT

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1. INTRODUCTION

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1.1 *The Short-Term Mobility Program 2015*

An important portion of world's cultural heritage resides in subtropical regions where both human and financial resources for preserving museum collections are limited. Moreover, the showcase microenvironment is often the primary mean to safeguard tangible cultural heritage collections and their intangible expression.
As the studies concerning museums in developing countries with non-temperate climate and different economic realities are lacking, the microclimate and air quality inside selected showcases of the Paranaense Museum in Curitiba (Brazil) were assessed for the evaluation of damage risk for the heritage materials preserved.
The thermo-hygrometric conditions inside few selected showcases were monitored and the main pollutants were sampled. Based on the result of the research, sustainable, non-expensive solutions to improve the existing showcases for a better conservation and fruition of movable heritage objects in showcases were identified.
The results obtained characterize the situation of a subtropical museum for comparison with other museums in Europe.

1.2 *The Paranaense Museum*

The Paranaense Museum was founded in 1876 and has an important collection of history of Paraná, anthropology and archeology. Through his history it has had several headquarters. From 2002 onwards it is installed in Palácio São Francisco, located in the historical area of Curitiba (Fig.1).

Fig. 1 - The Paranaense Museum: external view

The Palácio, current headquarters of the Museum, has been built in a neoclasical style between 1928 and 1929 as the residence of the Garmatter family. In 1938, the Paraná government acquired the property to install its headquarters. The Palace started to be known as Palácio São Francisco due to its location in the São Francisco neighborhood. The government remained in this building until 1953, when it moved to Palácio Iguaçu, in Centro Civico. From 1961 to 2002 the Palácio São Francisco was used as headquarters to several institutions and was through some renovations,

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with the construction of annexes and restorations. In 1987 the original building was listed as National Historical Heritage and in 2002 it became the Paranaense Museum headquarters.

The Paranaense Museum was idealized by Agostinho de Leão and José Candido Murici as a private institution and it was opened on September 25, 1876, in Largo da Fonte, actual Zacarias Square. At that time, it was the first museum of Paraná and the third of Brazil. It started with a collection of 600 articles, including objects, indigenous artifacts, coins, stones, insects, birds and butterflies. In 1882, from a private museum it became a public one, becoming a teaching and research center, and providing "scientific missions" to take place in Paraná.
Nowadays the Paranaense Museum contains a collection of approximately 450 000 items, among them documents, maps, photos, videos and historical, archeological and anthropological objects.

The Museum is a complex of three buildings, from the 1930s, the 1960s and the 2000s (Fig. 2). The two older buildings have a different structure compared to the new one and their rooms hold temporary exhibits. Moreover, they don't have any system for environmental control (microclimate and pollutants), and the doors and windows are opened/closed without following a specific protocol. The newer building, a pyramidal structure of glass and steel, was built precisely to accommodate the permanent exhibitions, with air-conditioning system (but no dehumidification system and filter for particulate matter) and less frequent change of displays and their contents.

Fig. 2 - External view of the old (left) and new (right) buildings of the Paranaense Museum

Besides the display rooms, there are 4 technical reserves where spare piece of art are stored.
In all the three buildings there are a number of showcases of different typology and size, none of them equipped with autonomous system for the control of the microclimate and pollutants (Fig. 3 and 4).

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Fig. 3 - Showcases in the old buildings

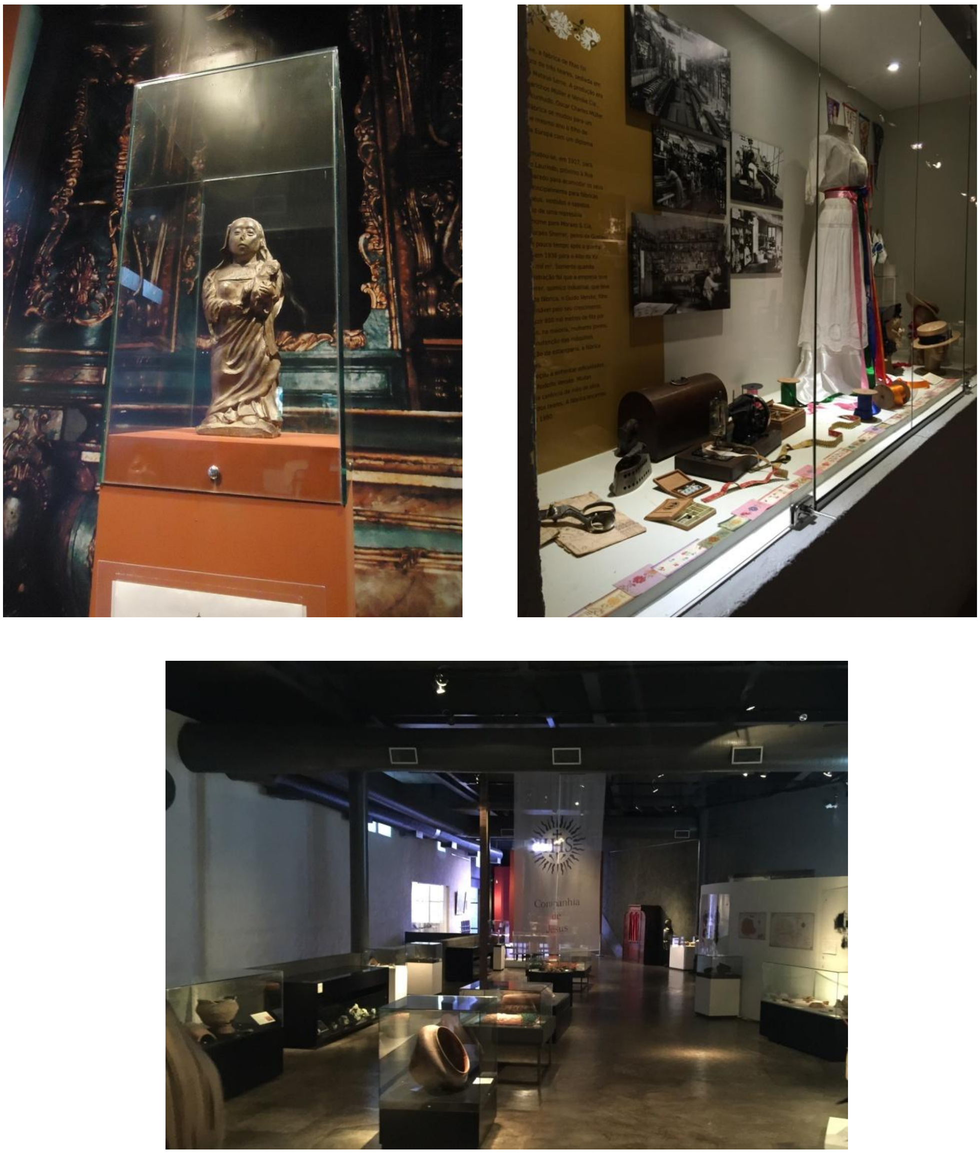

Fig. 4 - Showcases in the new building

The Museum is open to the public on Tuesday, Wednesday, Thursday and Friday from 9 to 18, on Saturday, Sunday and holidays from 10 to 16. On Monday the Museum is accessible only from the personnel. In particular, Monday 12th October was a national holiday, *Lady of Aparecida*, in honour Brazil's patron saint, hence the Museum was closed also to the staff.

During the working days there are several schools visiting the Museum.

On Sundays local craftsmen and collectors converge in the Curitiba's historic center to sell their goods at the city's famous *Feirinha do Largo da Ordem*, a street market which is held every Sunday from 9 to 14. On Sunday morning the street in front of the Museum (rua Kellers) is full of stands and people (Fig. 5).

Fig. 5 - Stalls in front of the Museum entrance during the Sunday Street Market

The air conditioning system is active only in the new part of the museum: only temperature is controlled and set at 20°C. The system is supposed to work 24 hours, with some exceptions due to extraordinary events or maintenance works. Also the storage rooms of the new and old buildings have an air conditioning system as well as dehumidifiers, working 24 hours as well.

The lighting system is composed by halogen lamps inside (50/20 watt) and outside (90/38 watt) the showcases, that are switched on/of manually, according to the opening hours of the museum and to the needs of the staff.

2. MICROCLIMATIC MONITORING

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2.1 Experimental methodology and instruments

The microclimatic monitoring of the Museum was performed with 9 automatic data loggers (8 Hobo[1] and 1 Tinytag[2]) equipped with sensors for the measurement of air temperature T (°C), relative humidity RH (%) and light intensity I (lux), except for one (Tinytag) that measured only T and RH.
With 12-bit resolution measurements, Hobo data logger U12-012 stores 43 000 data. A specific software (HOBOware) is available for logger setup, graphing and analysis. The logger start is programmable (also in delay mode), but the data logger has also a push button start. The direct USB interface allows a fast data offload. All the main specifications concerning the sensors included in the data logger HOBO U12-012 are visualized in Fig. 6.

Measurement range:
Temperature: -20° to 70°C (-4° to 158°F)
RH: 5% to 95% RH
Light intensity: 1 to 3000 footcandles (lumens/ft2) typical; maximum value varies from 1500 to 4500 footcandles (lumens/ft2)
Analog channels:
0 to 2.5 Vdc (w/CABLE-2.5-STEREO); 0 to 5 Vdc (w/CABLE-ADAP5); 0 to 10 Vdc (w/ CABLE-ADAP10); 4-20 mA (w/CABLE-4-20MA)

Accuracy:
Temperature: ± 0.35°C from 0° to 50°C (± 0.63°F from 32° to 122°F), see Plot A
RH: ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%, see Plot B
Light intensity: Designed for indoor measurement of relative light levels, see Plot D for light wavelength response
External input channel (see sensor manual): ± 2 mV ± 2.5% of absolute reading

Resolution:
Temperature: 0.03°C at 25°C (0.05°F at 77°F), see Plot A
RH: 0.03% RH

Sample Rate:
1 second to 18 hours, user selectable

Drift:
Temperature: 0.1°C/year (0.2°F/year)
RH: <1% per year typical; RH hysteresis 1%

Response time in airflow of 1 m/s (2.2 mph):
Temperature: 6 minutes, typical to 90%
RH: 1 minute, typical to 90%

Time accuracy: ± 1 minute per month at 25°C (77°F), see Plot C

Operating temperature:
Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing)
Launch/readout: 0° to 50°C (32° to 122°F), per USB specification

Battery life: 1 year typical use

Memory: 64K bytes (43,000 12-bit measurements)

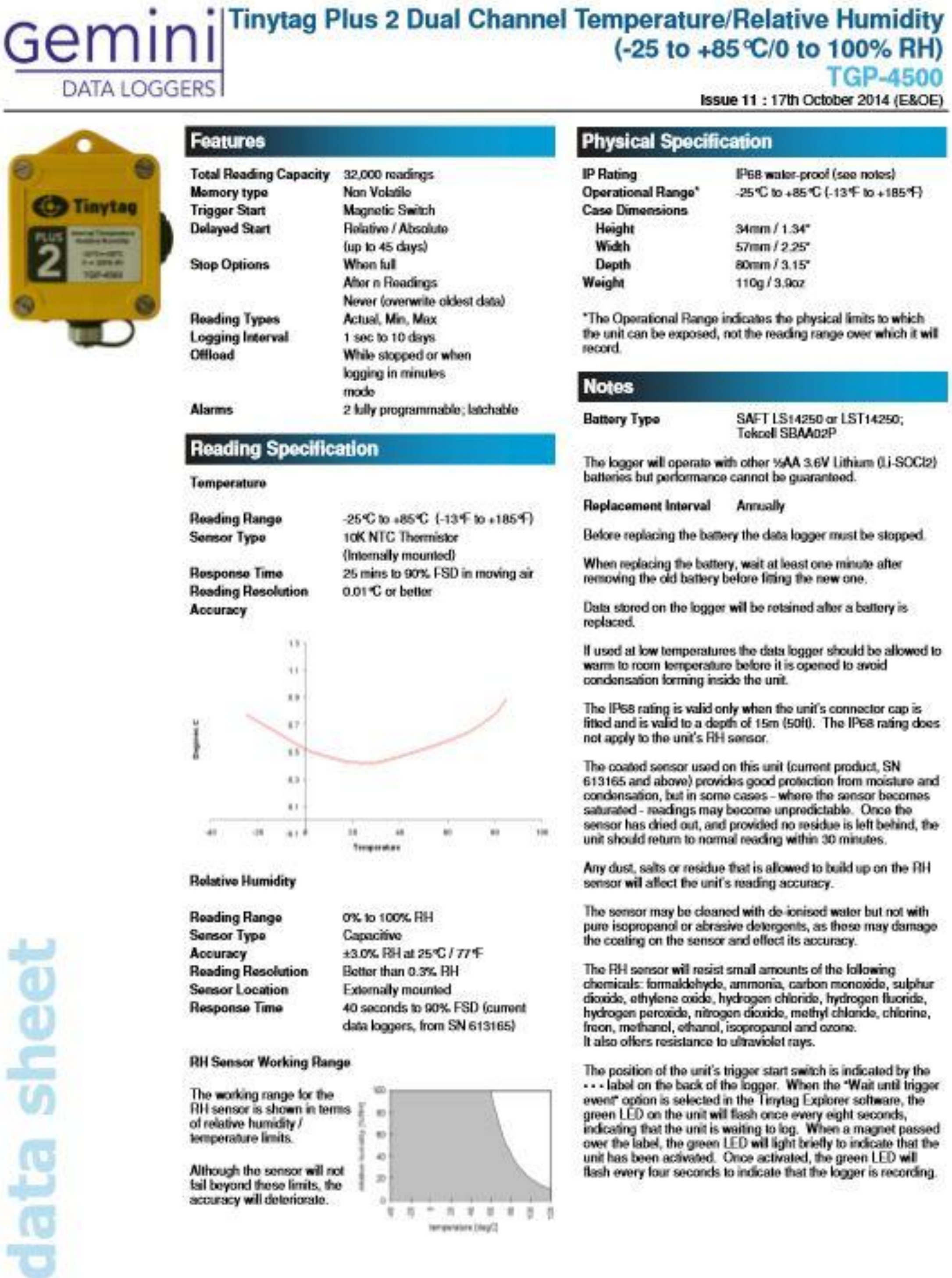
Weight: 46 g (1.6 oz)

Dimensions: 58 x 74 x 22 mm (2.3 x 2.9 x 0.9 inches)

Fig. 6 - Specifications and image of Hobo data logger

[1] http://www.onsetcomp.com/
[2] http://www.geminidataloggers.com/

The Tinytag Plus 2 data logger is housed in robust, waterproof (IP68 rated) case that is designed for use in a wide range of outdoor and industrial applications. All the main specifications concerning the sensors included in the data logger Tinytag Plus 2 are visualized in Fig. 7.



Gemini DATA LOGGERS

Tinytag Plus 2 Dual Channel Temperature/Relative Humidity (-25 to +85 °C/0 to 100% RH)

TGP-4500

Issue 11 : 17th October 2014 (E&OE)

Features

Total Reading Capacity	32,000 readings
Memory type	Non Volatile
Trigger Start	Magnetic Switch
Delayed Start	Relative / Absolute (up to 45 days)
Stop Options	When full After n Readings Never (overwrite oldest data)
Reading Types	Actual, Min, Max
Logging Interval	1 sec to 10 days
Offload	While stopped or when logging in minutes mode
Alarms	2 fully programmable; latchable

Reading Specification

Temperature

Reading Range	-25 °C to +85 °C (-13 °F to +185 °F)
Sensor Type	10K NTC Thermistor (Internally mounted)
Response Time	25 mins to 90% FSD in moving air
Reading Resolution	0.01 °C or better
Accuracy	

Relative Humidity

Reading Range	0% to 100% RH
Sensor Type	Capacitive
Accuracy	±3.0% RH at 25 °C / 77 °F
Reading Resolution	Better than 0.3% RH
Sensor Location	Externally mounted
Response Time	40 seconds to 90% FSD (current data loggers, from SN 613165)

RH Sensor Working Range

The working range for the RH sensor is shown in terms of relative humidity / temperature limits.

Although the sensor will not fail beyond these limits, the accuracy will deteriorate.

Physical Specification

IP Rating	IP68 water-proof (see notes)
Operational Range*	-25 °C to +85 °C (-13 °F to +185 °F)
Case Dimensions	
Height	34mm / 1.34"
Width	57mm / 2.25"
Depth	80mm / 3.15"
Weight	110g / 3.9oz

*The Operational Range indicates the physical limits to which the unit can be exposed, not the reading range over which it will record.

Notes

Battery Type	SAFT LS14250 or LST14250; Tekcell SBAA02P

The logger will operate with other ½AA 3.6V Lithium (Li-SOCl2) batteries but performance cannot be guaranteed.

Replacement Interval	Annually

Before replacing the battery the data logger must be stopped.

When replacing the battery, wait at least one minute after removing the old battery before fitting the new one.

Data stored on the logger will be retained after a battery is replaced.

If used at low temperatures the data logger should be allowed to warm to room temperature before it is opened to avoid condensation forming inside the unit.

The IP68 rating is valid only when the unit's connector cap is fitted and is valid to a depth of 15m (50ft). The IP68 rating does not apply to the unit's RH sensor.

The coated sensor used on this unit (current product, SN 613165 and above) provides good protection from moisture and condensation, but in some cases - where the sensor becomes saturated - readings may become unpredictable. Once the sensor has dried out, and provided no residue is left behind, the unit should return to normal reading within 30 minutes.

Any dust, salts or residue that is allowed to build up on the RH sensor will affect the unit's reading accuracy.

The sensor may be cleaned with de-ionised water but not with pure isopropanol or abrasive detergents, as these may damage the coating on the sensor and effect its accuracy.

The RH sensor will resist small amounts of the following chemicals: formaldehyde, ammonia, carbon monoxide, sulphur dioxide, ethylene oxide, hydrogen chloride, hydrogen fluoride, hydrogen peroxide, nitrogen dioxide, methyl chloride, chlorine, freon, methanol, ethanol, isopropanol and ozone.
It also offers resistance to ultraviolet rays.

The position of the unit's trigger start switch is indicated by the • • • label on the back of the logger. When the "Wait until trigger event" option is selected in the Tinytag Explorer software, the green LED on the unit will flash once every eight seconds, indicating that the unit is waiting to log. When a magnet passed over the label, the green LED will light briefly to indicate that the unit has been activated. Once activated, the green LED will flash every four seconds to indicate that the logger is recording.

data sheet

Fig. 7 - Specifications and image of Tinytag data logger

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The three parameters (T, RH and I) were measured continuously inside and outside the Museum from 7th to 21st October 2015, with a sampling time of 5 minutes.

2.2 Thermo-hygrometric sensors calibration

All the sensors were previously calibrated in climatic chamber for T and RH measurements. The instrumental set-up used for calibration is showed in Fig. 8 and included:

- Climatic chamber VC3 4034, Vötsch Industritechnik;
- Selelogic sPRT – 450 Smart Thermometer, Selelogic Instruments, range T (- 196 °C; 420 °C), accuracy 0.01 °C (-196 °C; 250 °C) and 0.02 °C (250 °C; 420 °C);
- Optidew High Performance Optical Dew Point transmitter, MICHELL Instruments, range RH (< 0.5 %; 100 %), accuracy ± 0,2 °C dp.

The calibration of the T sensors was performed in the range (0 °C ; 60 °C) with a step of 10°C. The calibration of the RH sensors was performed in the range (25 % ; 90%) with a step of 10%, keeping temperature at 25°C.

Fig. 8 - Calibration set-up

The thermo-hygrometric values measured by HOBO and Tinytag data loggers were compared with the values measured by the sensors used as reference for accurate measurements, respectively Selelogic for T and Optidew for RH, and the best fitting line was found for temperature and relative humidity, after having previously checked the linearity of the sensors. In Fig. 9 the linear interpolation for T and RH of one data logger is showed as example. The absolute error in T and RH that characterized each data logger was calculated as the difference between the T and RH values measured with the high accuracy sensors (real value) and the ones calculated with the linear fit. The relative error was calculated by dividing the absolute error with the real value; for RH it was expressed as percentage. The highest relative errors in the ranges 10 - 40 °C for temperature and 30 - 100 % for relative humidity for all the data loggers used in the monitoring program are reported in Table 1. These range were selected according to the expected climate in Curitiba at end October and they were verified a posteriori.

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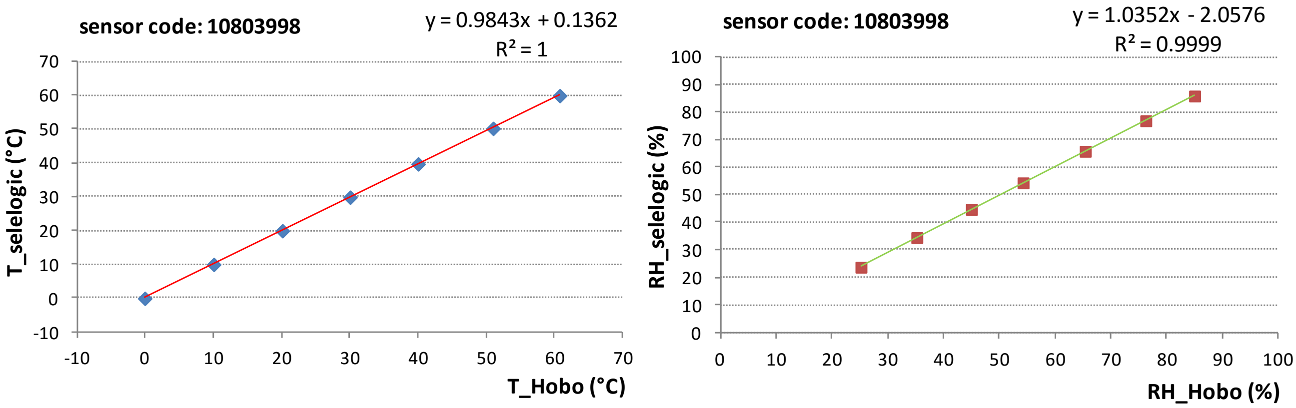

Fig. 9 - Calibration set-up data and linear regression for sensor Hobo 10803998

Sensor type	Sensor code	T max error (T 10÷40°C)	RH max error (%) (RH 30÷100 %)
HOBO	10803996	0.0022	0.0088
	10803997	0.0030	0.0093
	10803998	0.0048	0.0039
	10803947	0.0017	0.0083
	10803948	0.0028	0.0083
	10803950	0.0016	0.0095
	10803951	0.0014	0.0083
	10803952	0.0027	0.0052
Tinytag	704471	0.0204	0.0101

Tab. 1 - Maximum relative error in T and RH associated to each data logger

2.3 Measuring locations

The first task of the monitoring program was the selection of the more suitable places for the installation of the data loggers. The measuring points are listed in Table 2, their positions are indicated in the Museum maps in Fig. 10 (ground floor) and 11 (first floor), and they are showed one by one in Fig. 12-16.

Building	Floor	Location	Data logger code	Identification name
old	ground	inside showcase	10804547	OLD_indigenas_in
old	ground	inside room	10804548	OLD_indigenas
new	ground	inside showcase	10804551	NEW_animais_in
new	ground	inside room	10803998	NEW_animais
new	ground	inside showcase	10804552	NEW_fan_in
new	ground	inside room	10804450	NEW_fan
old	first	outside	704471	OUT
old	first	inside showcase	10803996	OLD_Ney Braga_in
old	first	inside room	10803997	OLD_Ney Braga

Tab. 2 - Monitoring points

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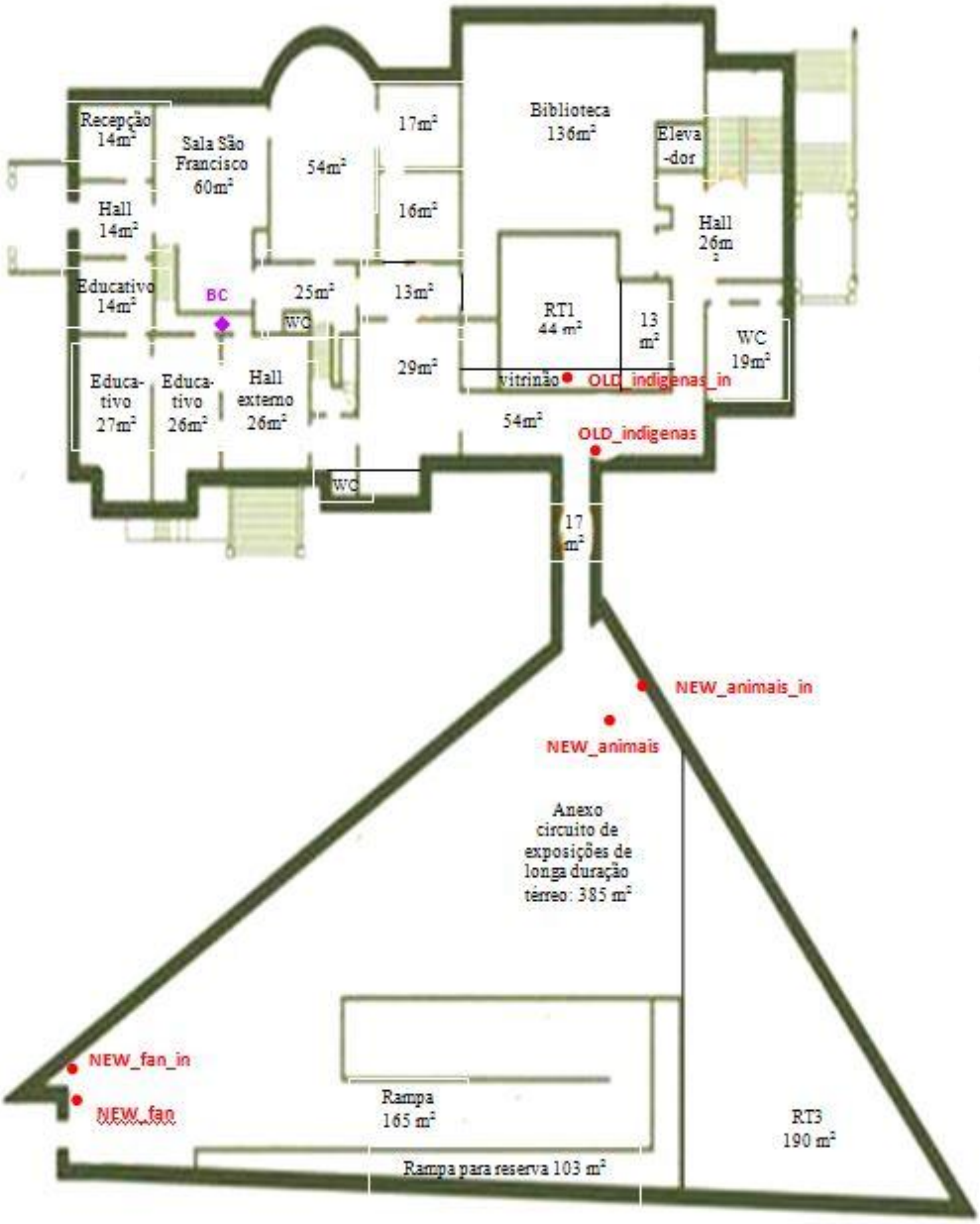

Fig. 10 - Map of Museum ground floor indicating the positions of the sensors

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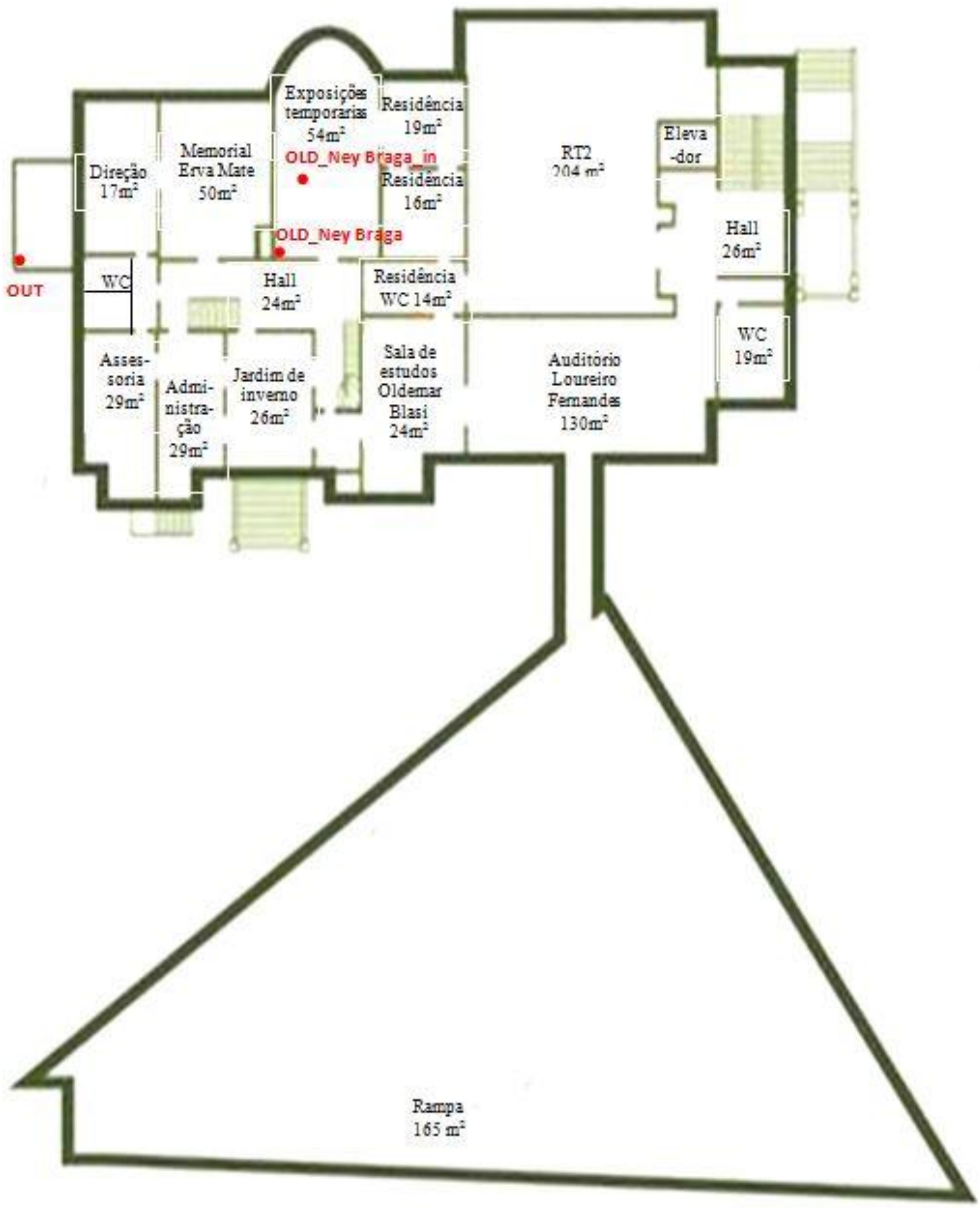

Fig. 11 - Map of Museum first floor indicating the positions of the sensors

When monitoring a museum environment is always necessary to study also the climate outside, in order to assess the influence of the external environment on the internal conditions. As the data taken from the meteorological station closest to the site under study might be not enough representative of the climatic conditions nearby the site, a data logger was placed outside, but as close as possible to the Museum. Even though the Tinytag data logger was designed for outdoor environment, it needed to be protected from direct rain and solar radiation. Hence, it was placed inside a protective box under the porch at the main entrance (Fig. 12).

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Fig. 12 - Outside monitoring location (named OUT)

Concerning the inside locations, the data loggers were placed both in the old and new buildings, in order to compare the microclimatic conditions in the different parts of the museum (Tab. 2, Fig. 10 and 11). Moreover, as the research program was focused on the showcases, the data loggers were installed inside selected showcases, and also outside the showcases, but still inside the room in which the showcases were located, in order to study the exchanges between the atmosphere in and out the showcases. Hence, 4 showcases were selected with the agreement of the Director of the Museum, two in the old buildings, two in the new one, taking into account the following requirements:

- different size (see Tab. 3) and type (Fig. 13-16);
- easily accessible;
- equipped with illumination system or exposed to natural/artificial radiation;
- preferably containing material sensible to microclimatic variations.

The sensors were installed in such a way to minimize the aesthetic impact and to disturb as least as possible the fruition of the exhibits from the visitors.

Building	Floor	Showcase dentification name	Dimensions (width/height/depth)
old	ground	OLD_indigenas	12 x 3.5 x 1 m
new	ground	NEW_animais	5.7 x 1.3 x 0.44 m
new	ground	NEW_fan	0.5 x 0.25 x 0.5 m
old	first	OLD_Ney Braga	0.75 x 0.3 x 0.74 m

Tab. 3 - Dimensions of the selected showcases

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Fig. 13 - Old part of the Museum, monitoring locations in the room of *Rituais Indigenas* temporary exhibition, inside room (OLD_indigenas) and inside a showcase (OLD_indigenas_in)

Fig. 14 - Monitoring locations in the new part of the Museum devoted to the permanent exhibition of the *Cenario representando acampamento de populacoes sambaqueiras e entorno*, inside room (NEW_animais) and inside a showcase (NEW_animais_in)

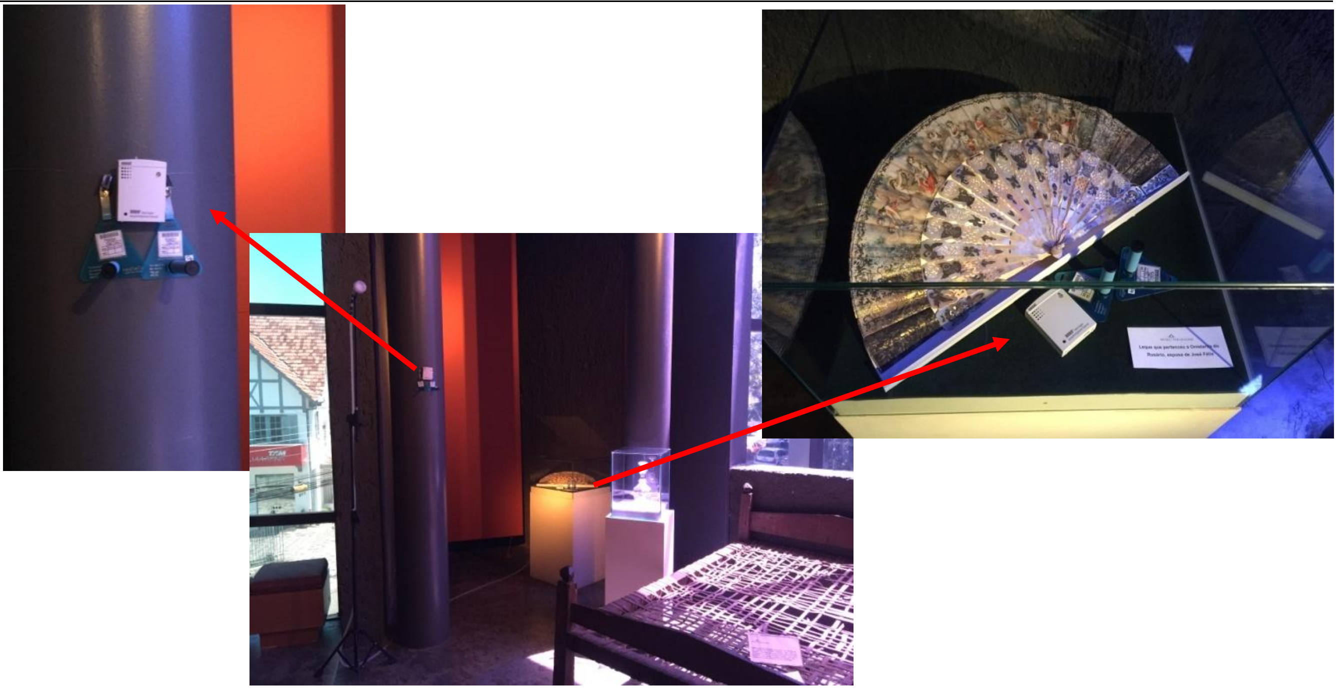

Fig. 15 - Monitoring locations in the new part of the Museum devoted to the permanent exhibitions, inside room (NEW_fan) and inside a showcase (NEW_fan_in)

Fig. 16 - Monitoring locations in the new part of the Museum devoted to the temporary exhibition devoted to *Ney Braga - Acervo Pessoal e Politico*, inside room (NEW_Ney Braga) and inside a showcase (NEW_Ney Braga_in)

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2.4 Data collection and analysis

The monitoring at the Museum Paranaense was carried out from 7th to 21st October 2015, according to the dates of the Short Mobility Program, that allowed a stay of 20 days maximum in a foreign country. Being a couple of week too short for a microclimatic monitoring, that needs at least 6 months or better 1 year to draw reasonable conclusions, some sensors have been left at the Museum in order to go on with the monitoring even after the end of the Short Mobility Program.

In the present report only the results related to the first 15 days of monitoring are analyzed and discussed.

Air temperature T, relative humidity RH and light intensity I have been collected continuously with a sampling rate of 5 minutes in the whole period 7-21 October 2015. Air specific humidity SH (g/kg) was calculated from the measured values of T and RH in order to evaluate the hygrometric exchanges between the different environments (outside/inside, among different rooms, room/showcase) and their evolution in time.

The average, highest, lowest values of all the mentioned parameters have been calculated for the whole period of monitoring, in order to have a general overview of the thermo-hygrometric conditions of each measuring point. Moreover, the daily variations of T and RH were calculated in order to analyze the stability of the thermo-hygrometric parameters in relation to the daily cycles.

Data elaboration and their graphical visualization allowed to:

- analyze the relation between the microclimate indoor and outdoor, studying the influence of the external climatic forcings to the Museum confined environment;
- study the temporal and spatial trends of the main physical parameters and their variations;
- identify the presence and entity of variations in the thermo-hygrometric conditions due to the management of the Museum spaces;
- study the difference between the microclimatic conditions during the opening and closing hours/day of the Museum;
- identity critical phenomena.

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3. AIR POLLUTANTS MONITORING

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3.1 Sampling procedures

For bulk elemental concentration analyses Particulate Matter (PM) was collected on polycarbonate membranes (nucleopore) by means of impaction. The sequential sampler was exposed indoors and outdoors for periods of 24 hours at a flow rate of 35 L min^{-1}. Sampling took place consecutively over the whole monitoring period in three locations, one outdoors and two indoors. The outdoor sampling point was located on the terrace at the first floor, just above the point where the outside T-RH data logger was placed (Fig. 17).

Fig. 17 - Outside PM monitoring location

Two sampling points were selected indoors, one in one old building, one in the new building. The sampling point in the old building was placed in the corridor in front of the showcase devoted to the *Rituais Indigenas* temporary exhibition, very close to the monitoring point OLD_indigenas (Fig. 10, 13 and 18). The sampling point in the new building was placed nearby the *Fan* showcase, very close to the monitoring point NEW_fan (Fig. 10, 15 and 19).

Fig. 18 - Inside PM monitoring location in the old building

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Fig. 19 - Inside PM monitoring location in the new building

Gaseous air pollutants were sampled by means of radial diffusion passive samplers (Radiello®[3], Fondazione Salvatore Maugeri, Padova, Italy). This sampler comprised a compound-specific adsorbing cartridge, surrounded by a cylindrical microporous diffusive body, mounted on a supporting plate. The adsorbent for SO_2, NO_2, HAc and HFor was triethanolamine and for O_3 it was 4,4-dipyridylethylene. Cartridges were exposed in parallel for 1 week after which they were replaced for the second week of sampling. The sampling points were the same of the microclimatic monitoring, hence the diffusive samplers were placed close to the data loggers at each location listed in Tab. 2 (Fig. 13-16).
Black carbon (BC) was monitored continuously by an aethalometer (Magee Scientific, model Ae-10) (Fig.10) , that was placed at the ground floor of the old building (Fig. 20).

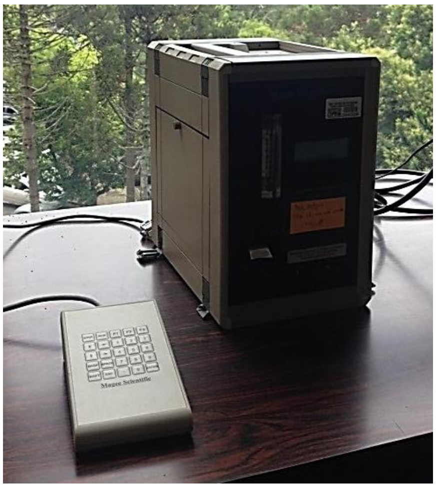

Fig. 20 - Aethalometer for black carbon monitoring

[3] www.radiello.it

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3.2 Measurement techniques

Bulk elemental concentrations of the PM were determined by using XRFS (Epsilon-5 high-energy polarized beam (HE-P) EDXRF). A Ge (PAN 32) detector with a resolution of 165 eV was used and allowed analysis from Z = 13. Due to an ultra-thin window detector, elemental analysis of low Z (i.e. C, N and O) could be facilitated. Quantitative calculations of particle composition were performed by a newly developed method based on iterative Monte Carlo simulations.

SO_2, NO_2, HAc, and HFor were analyzed by means of ion chromatography (dual column Dionex DX-120), after water elution. The ionic species SO_4^{2-} and NO_2^- were assessed on an AG14 guard column, preceded by an AS14 analytical column (Dionex, Sunnyvale, CA, USA). For the separation, the eluent was composed of 3.5 mM Na_2CO_3/1.0 mM $NaHCO_3$ and the flow rate was set at 1.2 mL min^{-1}. The separation of acetate (Ac^-) and formate (For^-) was performed with a GA-1 guard column and a custom-made 150 mm Allsep A-2 column (Alltech). The use of an isocratic 1.2 mM Na_2CO_3/0.9 mM NaHC O_3 buffer solution as eluent at a flow rate of 1 mL min^{-1} allowed a baseline separation between Ac^- and For^-. The extracted liquid was analyzed by UV–vis spectrophotometry for the O_3 concentrations.

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4. PRELIMINARY RESULTS OF MICROCLIMATIC MONITORING

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Located in Southern Brazil, Curitiba has a subtropical highland climate according to the Köppen[4] classification, i.e. a mild humid temperate climate with warm summers and no dry season. Over the course of the year, the temperature typically varies from 8 °C to 27 °C and is rarely below 3 °C or above 31 °C. Generally in October it is in the range 12-23 °C, with an average value of 16 °C. The relative humidity typically ranges from 50 % to 100 % over the course of the year, rarely dropping below 25 % and reaching as high as 100 %. In October the average value is typically 82 %, with average daily highest and lowest values between 60-100 %.
The probability that precipitation will be observed varies throughout the year. In October precipitation occurs around 60 %, with 10 days of precipitation on average.

During the monitoring period (7-21 October 2015), the measured values of air temperature and relative humidity (Tab. 4) were in accordance with the typical climate of Curitiba, only T was slightly higher than expected, being 19 °C on average and 31.4 °C at maximum. Precipitation occurred frequently, with several intense phenomena. The specific humidity varied between 7 and 15 g/kg, with an average value of 11 g/kg. Concerning the daily variations of the main physical parameters, temperature varied between day and night of 8 °C on average, with a maximum of 15 °C, whilst relative humidity changed up to 64 %, with an average value of 33 %.

OUTDOOR														
T (°C)					RH (%)					SH (g/kg)				
aver	min	max	ΔT daily aver	ΔT daily max	aver	min	max	ΔRH daily aver	ΔRH daily max	aver	min	max	ΔSH daily aver	ΔSH daily max
19.2	11.2	31.4	7.9	15.4	83	35	100	33	64	11.1	6.7	14.5	2.8	4.5

Tab. 4 - Average, minimum and maximum values and daily variations of air T, RH and SH outside the museum in the monitoring period

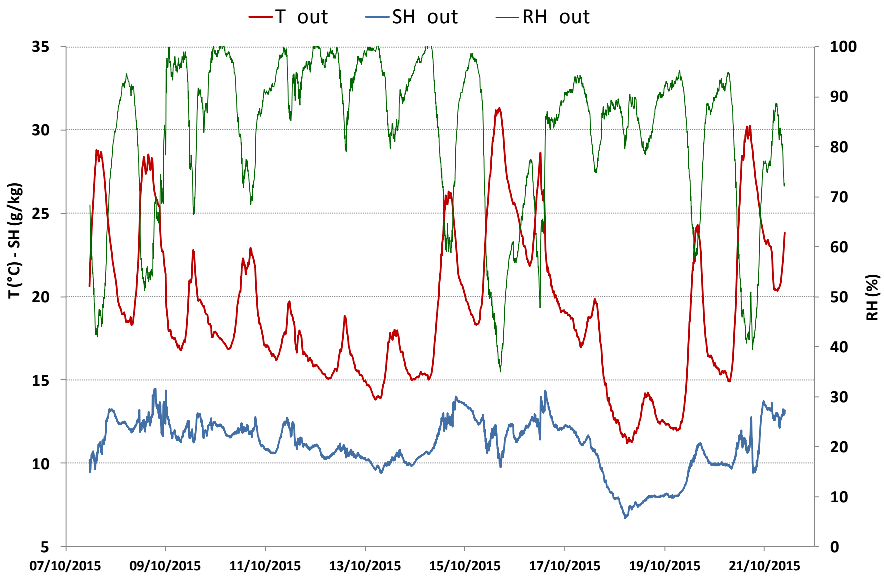

Fig. 21 - Time trends of air temperature, relative and specific humidity outdoors

[4] http://koeppen-geiger.vu-wien.ac.at/

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Fig. 21 shows the time trends of air temperature, relative and specific humidity in the monitoring period: relative humidity is much more influenced by temperature (inversely proportional), than by specific humidity (directly proportional).

3.1 *Old buildings*

ROOM OF *RITUAIS INDIGENAS* TEMPORARY EXHIBITION (named room I for simplicity)

T (°C)					RH (%)					SH (g/kg)				
aver	min	max	ΔT daily aver	ΔT daily max	aver	min	max	ΔRH daily aver	ΔRH daily max	aver	min	max	ΔSH daily aver	ΔSH daily max
OLD_indigenas														
20.9	16.2	25.3	2.9	5.3	74	55	90	14	28	11.3	7.2	14.9	2.7	5.4
OLD_indigenas_in														
21.3	18.5	24.3	2.1	3.5	70	61	75	5	10	10.9	8.7	13.1	1.2	2.0

Tab. 5 - Average, minimum and maximum values and daily variations of air T, RH and SH inside (OLD_indigenas_in) and outside (OLD_indigenas) the showcase

ROOM OF *NEY BRAGA - ACERVO PESSOAL E POLITICO* TEMPORARY EXHIBITION (named room N)

T (°C)					RH (%)					SH (g/kg)				
aver	min	max	ΔT daily aver	ΔT daily max	aver	min	max	ΔRH daily aver	ΔRH daily max	aver	min	max	ΔSH daily aver	ΔSH daily max
OLD_Ney Braga														
24.2	20.5	28.9	3.0	6.5	61	44	73	10	27	11.3	7.8	14.6	2.2	3.8
OLD_Ney Braga_in														
23.9	20.2	28.0	2.8	5.6	62	53	69	3	8	11.3	7.7	15.7	2.3	4.2

Tab. 6 - Average, minimum and maximum values and daily variations of air T, RH and SH inside (OLD_Ney Braga_in) and outside (OLD_ Ney Braga) the showcase

	Light Intensity (lux)				
	aver	min	max	ΔI daily aver	ΔI daily max
OLD_indigenas_in	40.9	11.8	122.2	97.3	110.4
OLD_Ney Braga_in	7.0	3.9	35.5	13.7	31.6

Tab. 7 - Average, minimum and maximum values and daily variations of light intensity inside the showcases in the old buildings

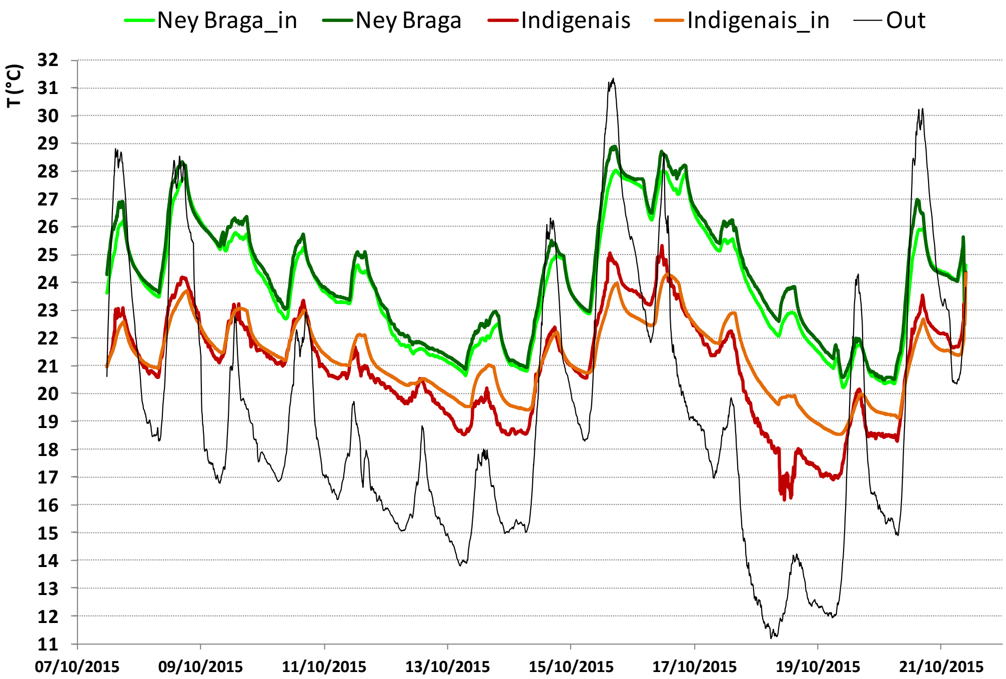

Fig. 22 - Time trends of air temperature inside the old buildings and outdoors

As expected the air temperature in the old buildings followed the time trend of the external temperature, but with differences in the average values and in the amplitude of the variations (Fig. 22, Tab. 4, 5 and 6).
The average temperature in room N was higher than in room I (of 3 °C) and also than outdoors (of 5 °C). Nevertheless, the highest T in the monitoring period was reached outdoors (31.4 °C), followed by room N (28.9 °C) and I (25.3 °C) (Tab. 4, 5 and 6).The location of the rooms contributed to this difference; in fact, room N was located on the first floor and it had three big door windows leading to a open terrace. During the day the shutters were close but the windows were open, hence the air heated by the hot surface of the terrace entered in the room. Room I was on the ground floor, just in front of the corridor leading to the new air conditioned building: the door dividing the old and new buildings was often left open, letting the conditioned air coming from the new part to the room I through the corridor.
The temperature inside the showcases followed the trend of the temperature outside the showcases, but with a reduction of the short-term variations, showing a more regular pattern. In room N temperature inside the showcase was slightly higher than outside, whilst the opposite in room I, with differences of about 0.4°C in the average values and of 1°C in the maxima in both cases (Fig. 22, Tab. 4, 5 and 6). Concerning the minima, in room N they were not significantly lower inside the showcase than outside, whilst in room I they were 2°C lower outside than inside the showcase. In room I the daily thermal variations were lower inside the showcases than outside (of 1.2 °C for the average, of 1.8 °C for the maximum), whilst in room N the difference was significant only for the maximum (0.9 °C) (Tab. 4, 5 and 6).
The daily thermal cycle inside the old buildings and inside the showcases, besides the influence of the external temperature, followed clearly the opening time of the Museum, with a little advance or delay in the starting of increasing/decreasing of temperature respect to the opening/closing

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hours, because of the thermal inertia and actions of the staff (Fig. 23). The holiday of 12th October was clearly recognizable from the analysis of the daily thermal cycles (Fig. 23): the Museum was closed also for the staff, not only for the visitors, hence the daily gradual increasing of air temperature from 9-10 till 16-18 wasn't observed.

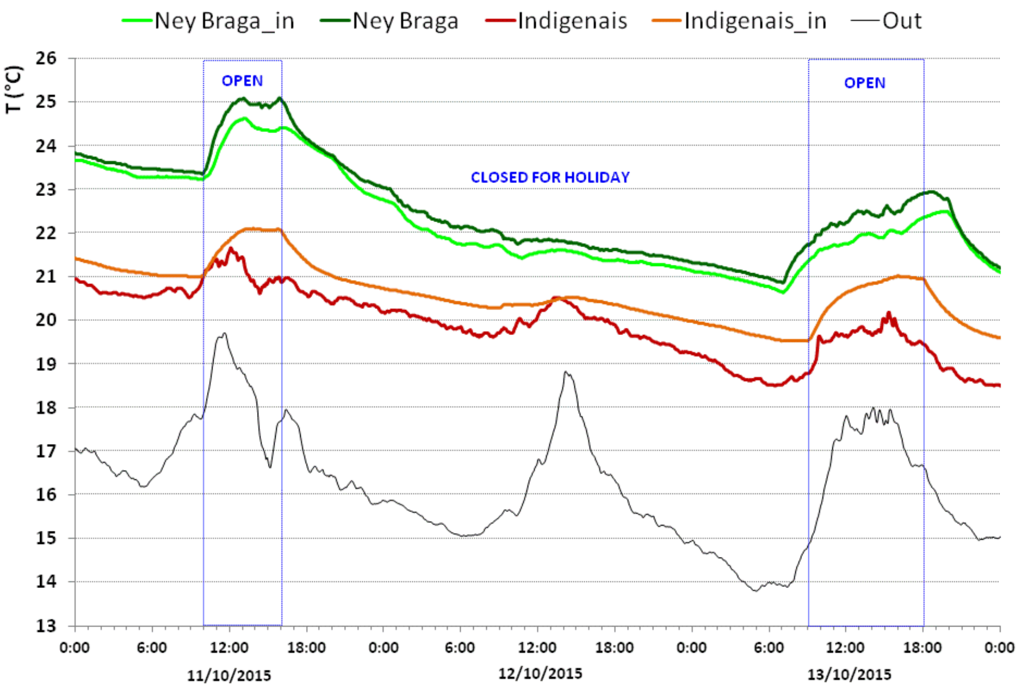

Fig. 23 - Daily thermal cycles of air temperature inside the old buildings and outdoors

Relative humidity inside the old buildings followed the general time trend of the external one, but less regularly than temperature, because RH depends both on temperature and specific humidity (Fig. 23). As expected, RH average values and also the amplitude of the variations indoors were much lower than outdoors (Tab. 4, 5 and 6). Relative humidity values followed the scale outdoor > room I > room N both in the average (83 % > 74 % > 61 %) and in the maximum values (100 % > 90 % > 73 %), whilst the minima were lower in room N (44 %) than in room I (55 %), both higher than outdoors were the lowest value was reached (35 %) (Tab. 4, 5 and 6).
Inside the showcases RH average values were lower (room I) or equal (room N) than outside, and the daily variations were reduced in amplitude respect to outside in both the rooms (Tab. 5 and 6); this phenomenon was particularly evident in room N, were the environment inside the showcase *Ney Braga* was the most stable one from the hygrometric point of view.

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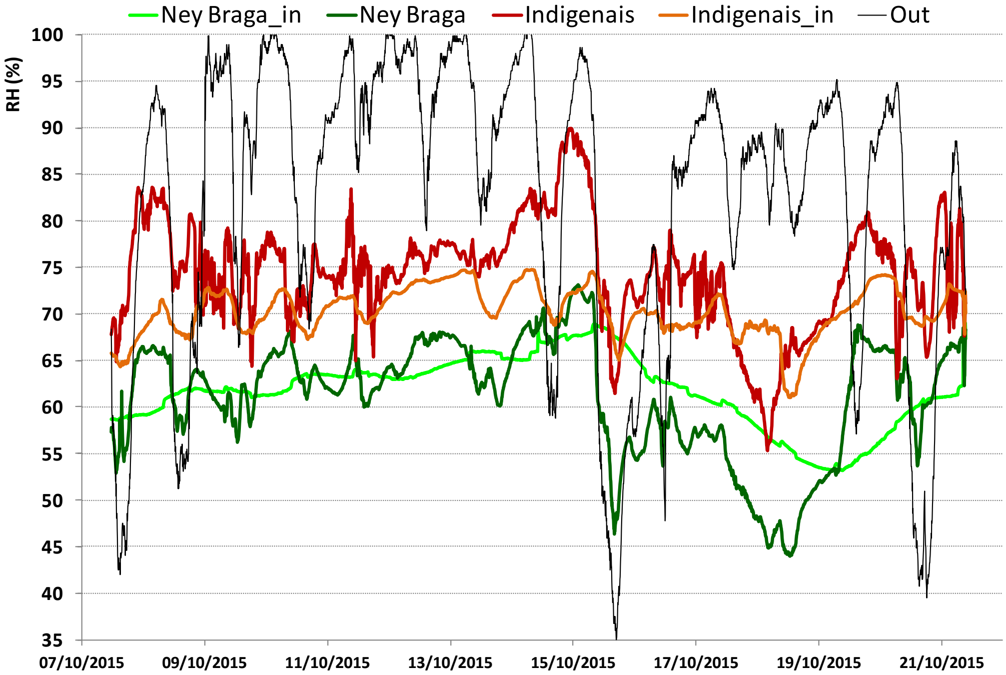

Fig. 24 - Time trends of air relative humidity inside the old buildings and outdoors

The daily trend of relative humidity inside the old buildings was influenced both by the external climate and the management of the Museum. Nevertheless, the atmosphere inside the showcases was not significantly perturbed and relative humidity remained quite stable (Fig. 25).

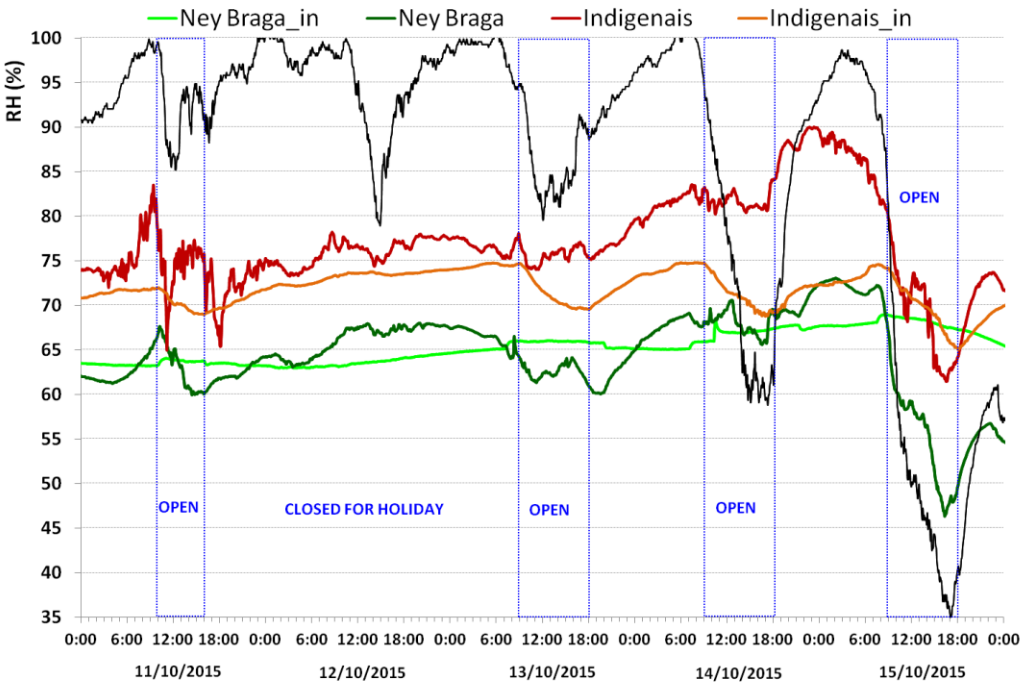

Fig. 25 - Daily thermal cycles of relative humidity inside the old buildings and outdoors

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The specific humidity calculated for the different locations showed no remarkable difference in the main values (Tab. 4, 5 and 6), nor in the time trends (Fig. 25), except for the point inside the *Ney Braga* showcase, that was characterized by the highest maximum. Moreover, in room I SH daily variations inside the showcase were lower on average than outside, whilst in room N they were similar. The maxim SH daily variation in room N was even higher inside the showcase than outside, the opposite than in room I. This was probably due to the wood structure of the *Ney Braga* showcase, that responded to the thermo-hygrometric variations of the room absorbing and releasing moisture. The SH peak inside that showcase was registered in the mid afternoon of the 15th October. Looking at the thermal trend (Fig. 22), air temperature on 14th October was increasing respect to the previous days, reaching on early 15th October afternoon the highest value outdoors. The wood structure reacted to this thermal increase releasing water vapour, that was accumulated inside the small environment of the *Ney Braga* showcase (Fig. 16). This phenomenon was not observed in *Indigenais* showcase, because of the different material structure and the bigger size. In addition, *Indigenais* showcase had more exchanges with the outside atmosphere due to the circular holes in the upper part of the glass panel (Fig. 13), and in fact the SH levels inside and outside the showcase were similar.

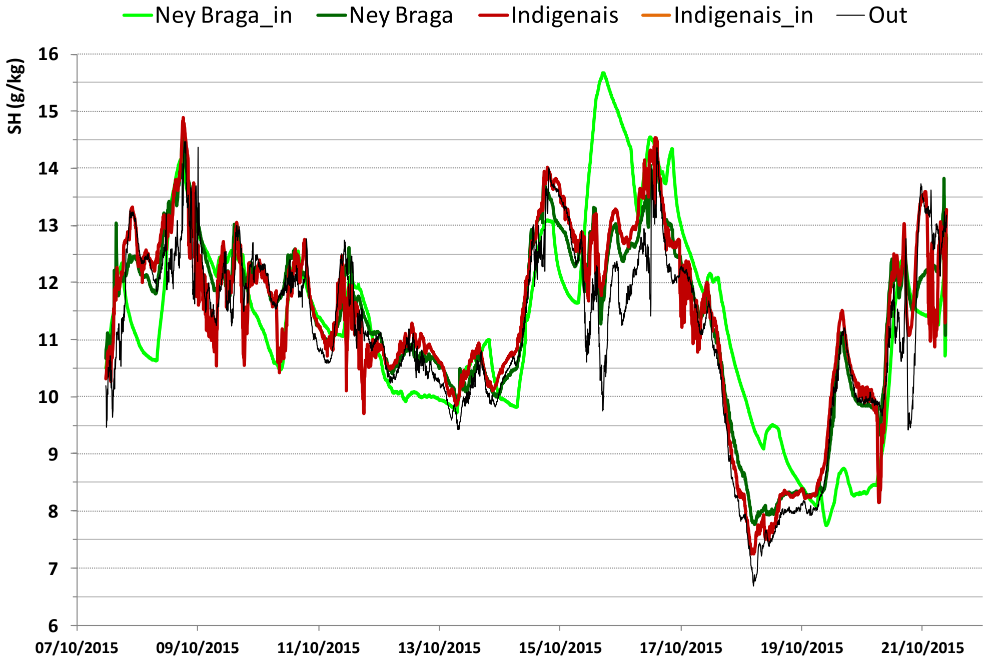

Fig. 26 - Time trends of air specific humidity inside the old building and outdoors

Concerning light intensity, a comparison between the different rooms and the situation inside/outside the showcases is not much significant, as it depends strongly on the location of the points of measurement in relation to the light sources.

Fig. 27 shows the light intensity trend inside the two showcases under study in the old buildings. The higher (of one order of magnitude) levels measured in the *Indigenais* showcase respect to the *Ney Braga* one (Tab. 7, Fig. 27) are due to the position of the light sources: in the former they are inside the showcase, in the latter outside (Fig. 13 and 16).

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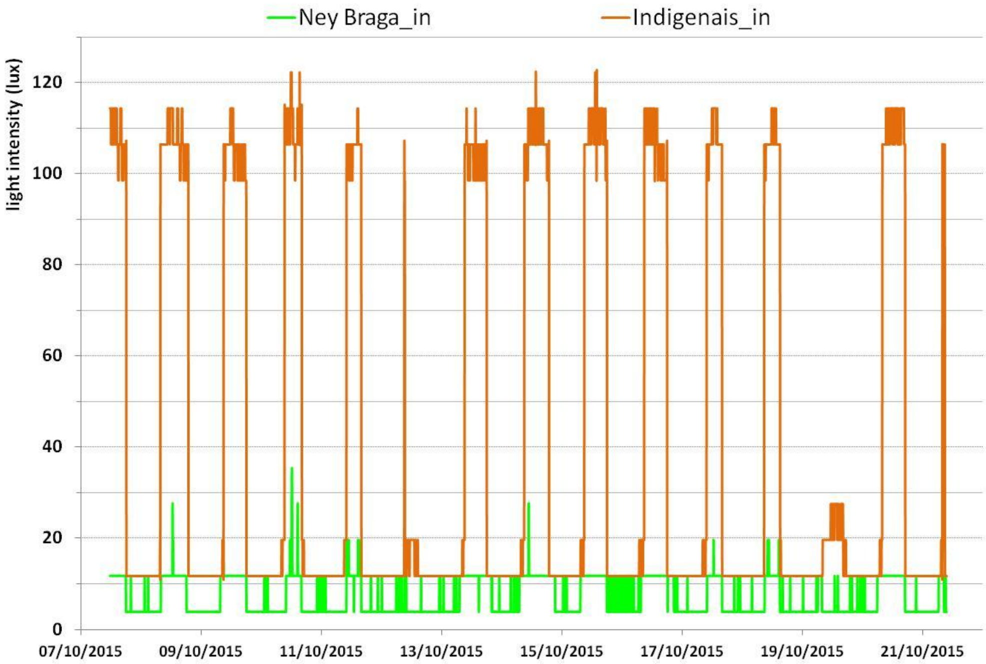

Fig. 27 - Time trends of light intensity inside the two showcases in the old building

In the *Indigenais* showcase the daily time trend of light intensity was a square wave following the opening hours of the Museum (Fig. 28). The peak observed on the holiday of 12th October was due to the temporary switch on of the lights at 9, in order to let me change the filters for the PM monitoring.

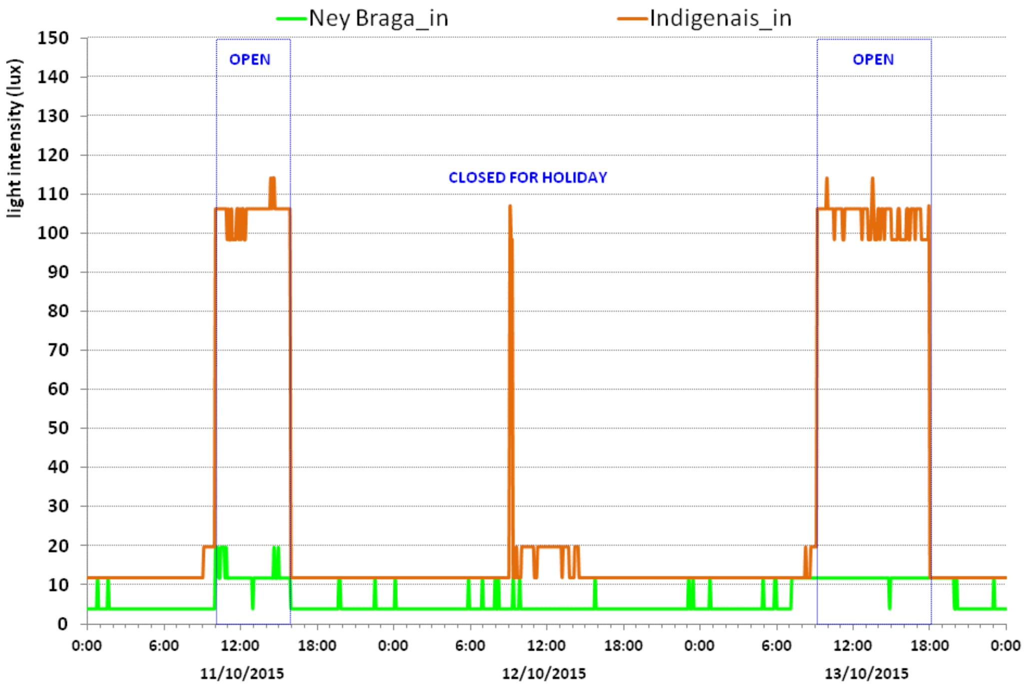

Fig. 28 - Time trends of light intensity inside the two showcases in the old building during few days

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3.2 *New building*

ROOM OF PERMANENT EXHIBITION OF *CENARIO REPRESENTANDO ACAMPAMENTO DE POPULACOES SAMBAQUEIRAS E ENTORNO* (named room S for simplicity)

T (°C)					RH (%)					SH (g/kg)				
aver	min	max	ΔT daily aver	ΔT daily max	aver	min	max	ΔRH daily aver	ΔRH daily max	aver	min	max	ΔSH daily aver	ΔSH daily max
NEW_animais														
20.0	16.9	24.9	3.1	5.3	63	54	79	9	16	9.1	6.4	12.8	2.5	3.9
NEW_ animais_in														
20.9	17.4	26.2	4.3	6.4	59	49	70	8	11	9.0	6.8	12.6	1.8	3.5

Tab. 8 - Average, minimum and maximum values and daily variations of air T, RH and SH inside (NEW_animais_in) and outside (NEW_animais) the showcase

ROOM OF PERMANENT EXHIBITION OF *FAN* (named room F)

T (°C)					RH (%)					SH (g/kg)				
aver	min	max	ΔT daily aver	ΔT daily max	aver	min	max	ΔRH daily aver	ΔRH daily max	aver	min	max	ΔSH daily aver	ΔSH daily max
NEW_fan														
20.5	17.1	25.5	3.4	5.7	62	51	80	10	18	9.2	6.5	13.5	2.4	4.5
NEW_fan_in														
21.3	18.1	25.9	3.0	5.1	63	57	69	3	9	9.9	8.0	13.2	1.9	3.2

Tab. 9 - Average, minimum and maximum values and daily variations of air T, RH and SH inside (NEW_fan_in) and outside (NEW_fan) the showcase

	Light Intensity (lux)				
	aver	min	max	ΔI daily aver	ΔI daily max
NEW_animais_in	11.5	3.9	82.8	340.6	425.8
NEW_fan_in	21.7	3.9	2179.9	520.4	2716.0

Tab. 10 - Average, minimum and maximum values and daily variations of light intensity inside the showcases in the new building

Despite the presence of the air conditioning system, also the air temperature in the new building followed the time trend of the external temperature, and this result gives an indication of the performance of the system. The temperature indoors was characterized by similar average values than outdoors, but with variations reduced in amplitude (Fig. 29, Tab. 8, 9 and 10).

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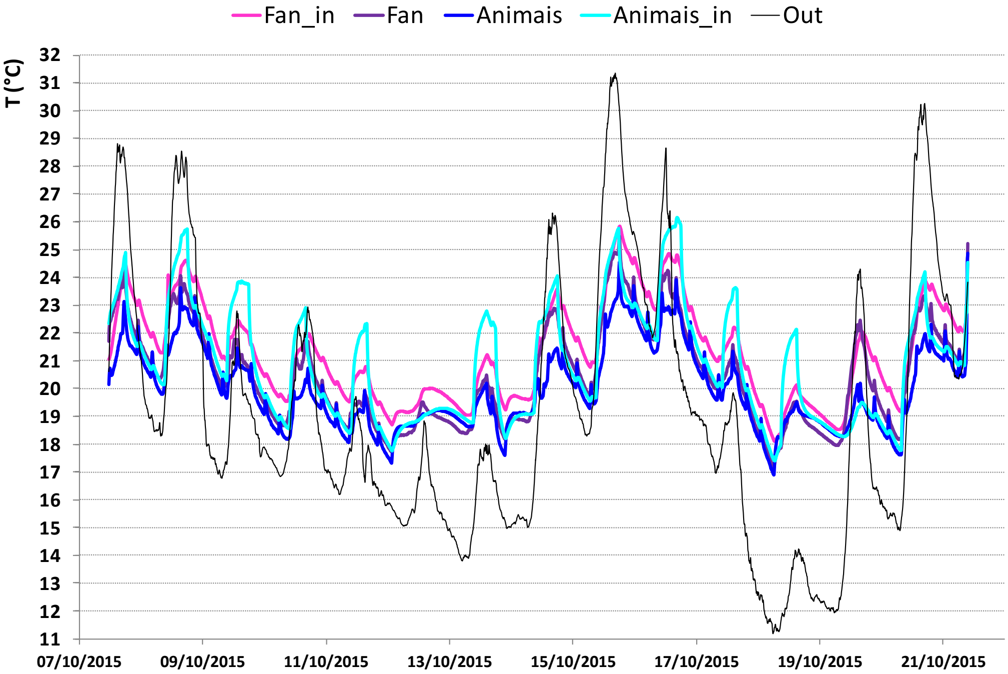

Fig. 29 - Time trends of air temperature inside the new building and outdoors

The average temperatures measured in the new building were about 1 °C higher than outdoors. Nevertheless, the maxima and the minima reached indoors were about 6 °C respectively lower and higher than outdoors (Tab. 8, 9 and 10). The average and highest daily variation values were reduced 2 or 3 times passing from outdoors to indoors (Tab. 8, 9 and 10).
Concerning the atmosphere inside the showcases, the temperature was slightly higher (up to 1 °C) than outside in the average, maxima and minima values. The *Fan* showcase registered the highest average temperature, whilst the highest absolute value was reached in the *Animais* showcase, because of the illumination system.
The relation between the daily thermal variations measured inside and outside the showcases were different in the two rooms: in room S the variations inside the showcase were higher than outside, whilst the opposite in room F. This was probably due to the presence of the light sources inside the showcase in room S.

As already discussed for the old buildings, besides the influence of the external climate, the daily thermal cycles inside the rooms S and F, and inside the showcases, followed the management of the museum, i.e. the opening days and hours, despite the air conditioning system was supposed to work 24 hours (Fig. 30).

Several thermal peaks were observed during the day but also during the night (Fig. 31), probably related to the working of the air conditioning system, as they were not observed in the old building. These maxima were clearly visible in the air temperatures of both the monitoring points

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(rooms S and F, but actually it was a single big room, being the different collections divided by panels), but they were negligible inside the showcases.

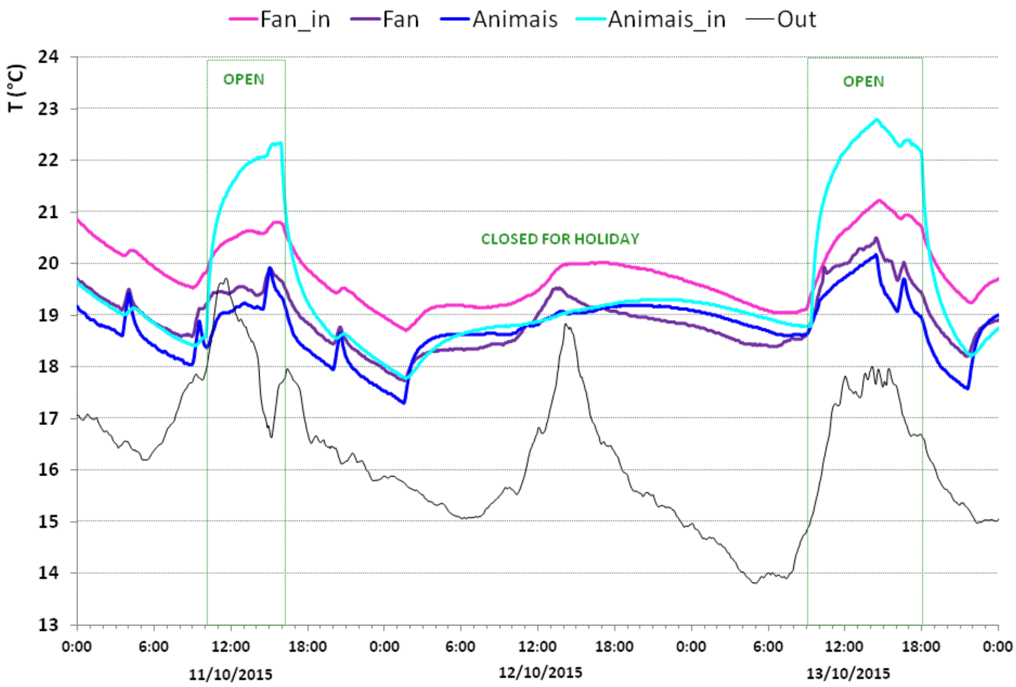

Fig. 30 - Daily thermal cycles of air temperature inside the new building and outdoors

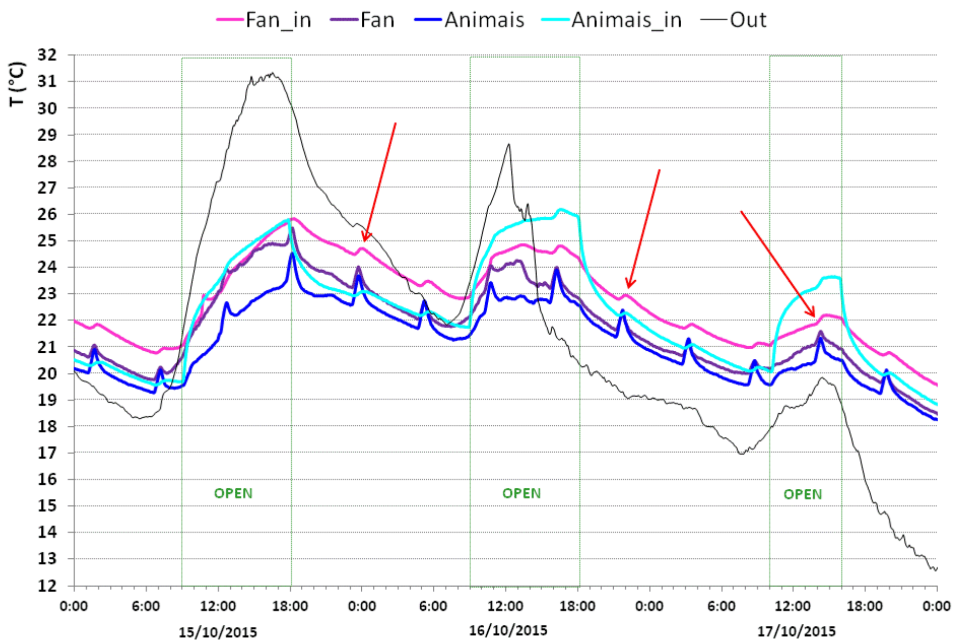

Fig. 31 - Daily thermal cycles of air temperature inside the new building and outdoors

The influence of external relative humidity on the RH inside the new building was not as significant as in the old building: in fact, RH in rooms S and F was quite stable during the whole monitoring period, being in the range 59-63 % on average, whilst outdoors was 83 % on average (Fig. 32, Tab. 4, 8 and 9). The highest values (around 80 %) were reached on the holiday of 12th October, when probably the air conditioning system was turned off, even if it was supposed to work 24 hours.

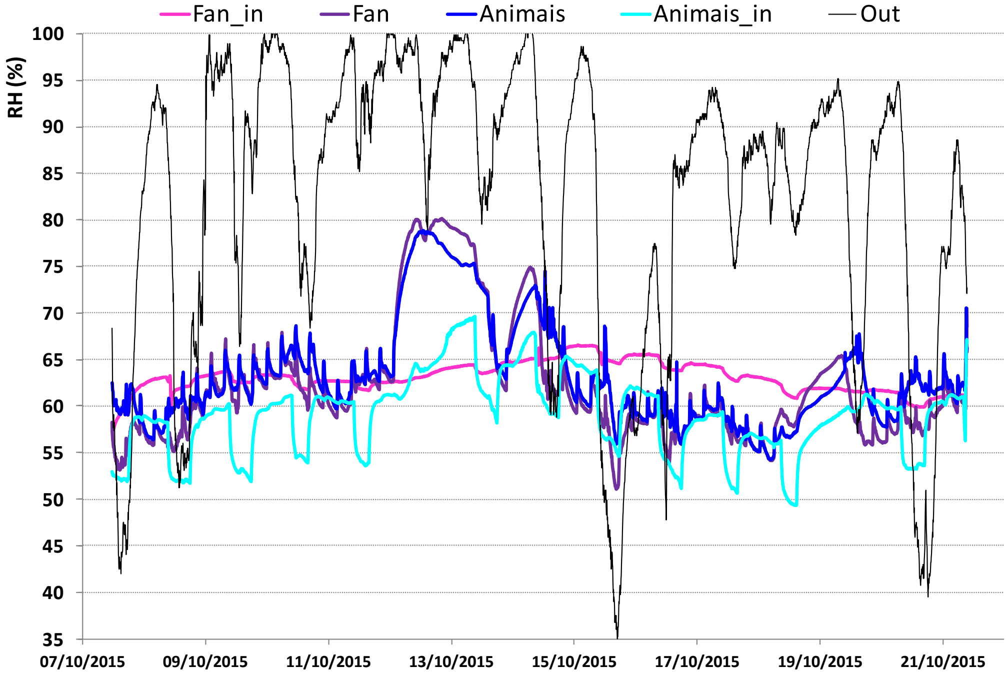

Fig. 32 - Time trends of air relative humidity inside the new building and outdoors

The amplitude of the RH variations indoors was one third than outdoors on average and in the maxima (Tab. 4, 8 and 9).
As expected there was not so much difference in the microclimatic conditions of the two points inside the new building as they belong to the same big environment, where the air circulated freely, despite for simplicity they were named as belonging to two different rooms.
Nevertheless, the hygrometric behaviour of the two showcases showed a completely different trend (Fig. 33), as in *Animais* showcase it was strongly determined by the impact of the lights: the moments of increase in temperature and thus decrease in relative humidity corresponded to the switching on the lights at the Museum opening, the opposite at the closing (Fig. 30 and 34).
Inside the showcases RH variations were reduced in amplitude respect to outside, both in the average and in the maxima values; the small showcase *Fan* showed the most stable hygrometric conditions (Tab. 8 and 9).
As already pointed out, the daily trend of relative humidity inside the new building was much more influenced by the management of the Museum than by the external climate. In fact, during the holiday on 12th October there was an increase in the RH level indoors, as the air conditioning system was not working (Fig. 33). The showcase environment showed a behaviour quite independent by the correspondent room in fact, the RH inside *Fan* showcase remained

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unperturbed, and the hygrometric conditions inside *Animais* one were strongly influenced by the impact of the lights installed inside the showcase (Fig. 34).

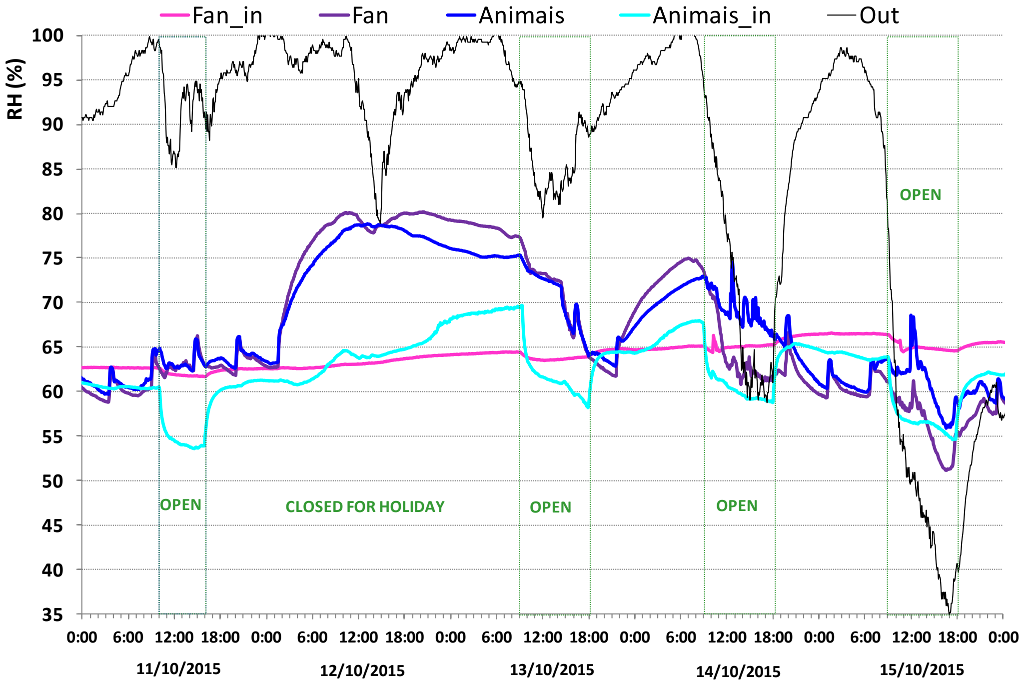

Fig. 33 - Daily thermal cycles of relative humidity inside the new building and outdoors

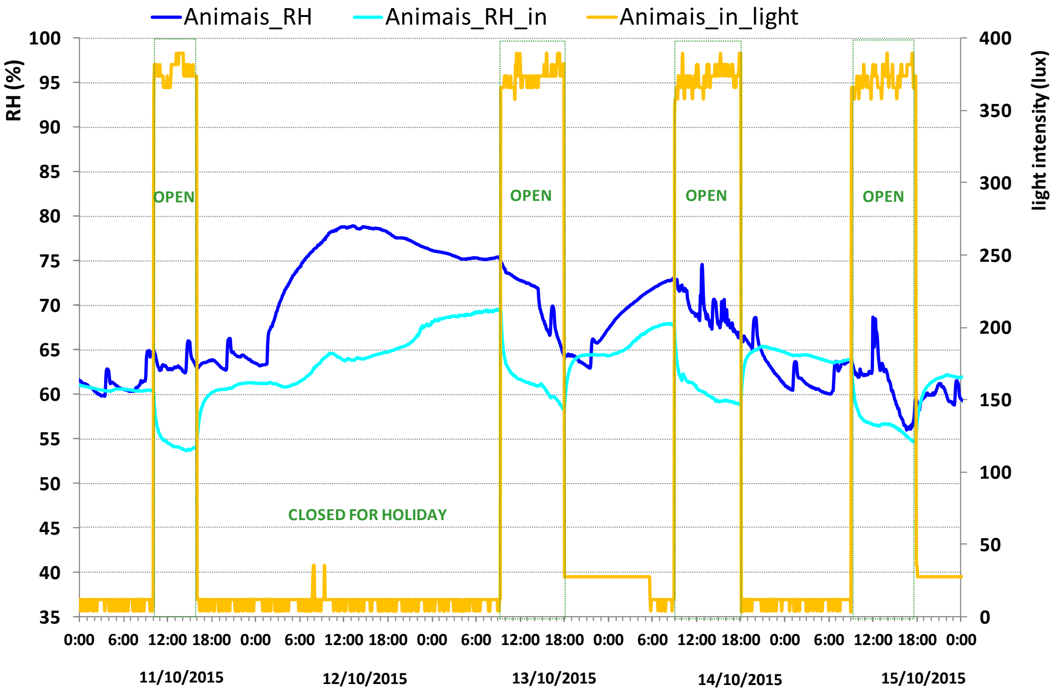

Fig. 34 - Time trends of light intensity inside the *Animais* showcase during few days

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The specific humidity inside the new building was lower than the external one, but the two points of measurements indoors had similar SH main values (Tab. 4, 8 and 9). The SH time trend inside both the showcases was different than outside, in particular for the *Fan* showcase, in which SH was higher on average than outside, but not in the maxima, nor in the daily variations (Fig. 35).

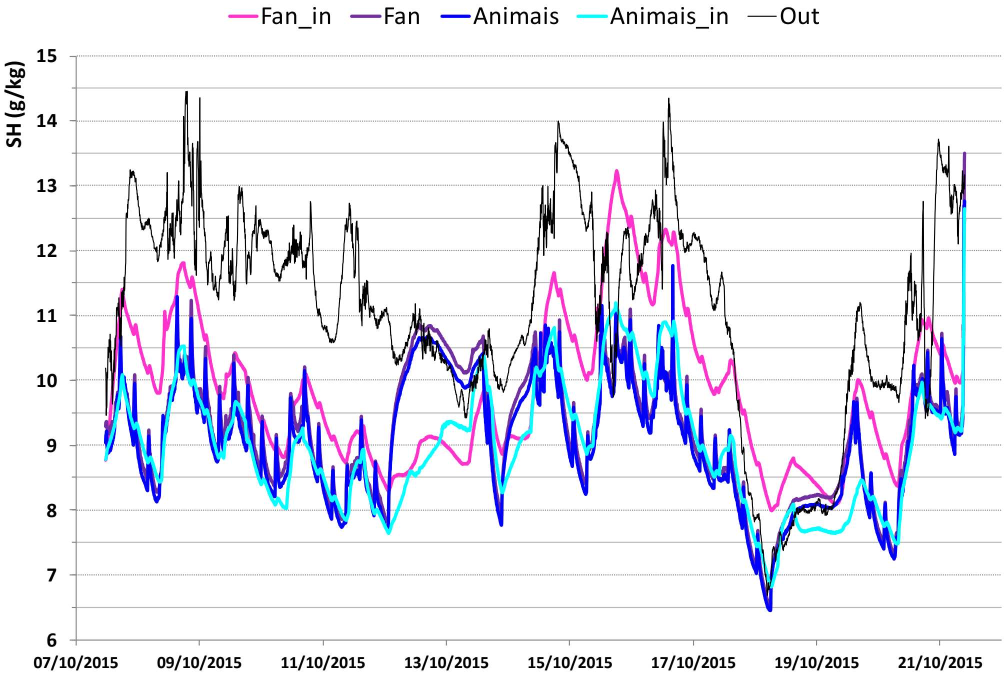

Fig. 35 - Time trends of air specific humidity inside the new building and outdoors

The SH peaks registered in the *Fan* showcase were similar to the ones registered inside the *Ney Braga* showcase, in particular the highest one on the 15th October, as the structure of the two showcases is wooden made, with the difference that the former has a box shape, the latter a table shape with legs. Moreover, the small *Fan* showcase seemed quite an independent environment, with reduced vapour exchange with the outside atmosphere, as also happened for the *Ney Braga* showcase (Fig. 26), whose dimensions were the same order of magnitude (Tab. 3).

Analyzing the temporal trend of T, RH and SH inside the showcases, it is evident that RH is the result of the synergistic actions of T and SH, with which is respectively in inverse and direct proportion. In *Fan* showcase, the positive peaks of temperature corresponds to the positive peaks of specific humidity, and this made the relative humidity constant (Fig. 36). The same would have occurred in *Animais* showcase without the contribution of light, that caused an increases in T that was not balanced by an increase of SH of an amount sufficient to stabilize RH (Fig. 37).

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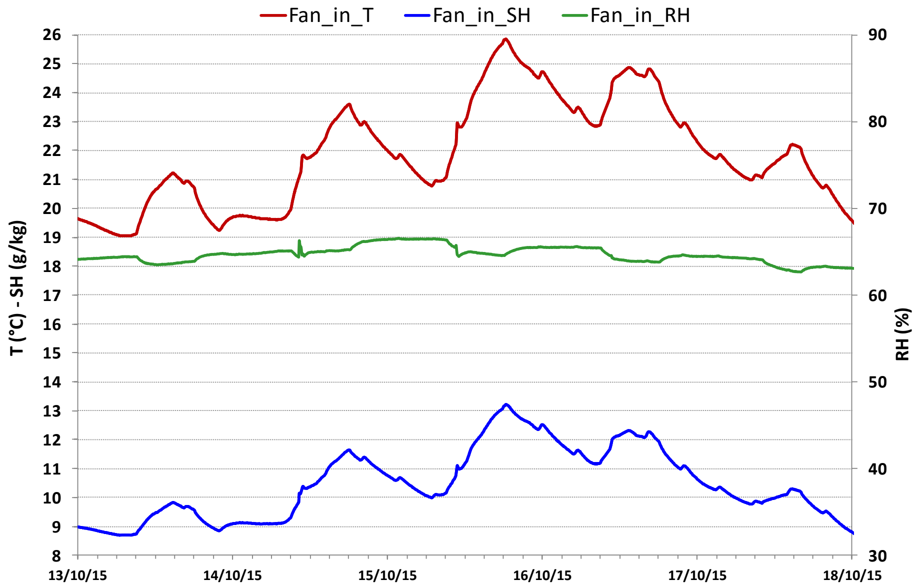

Fig. 36 - Time trends of air temperature, relative and specific humidity inside *Fan* showcase

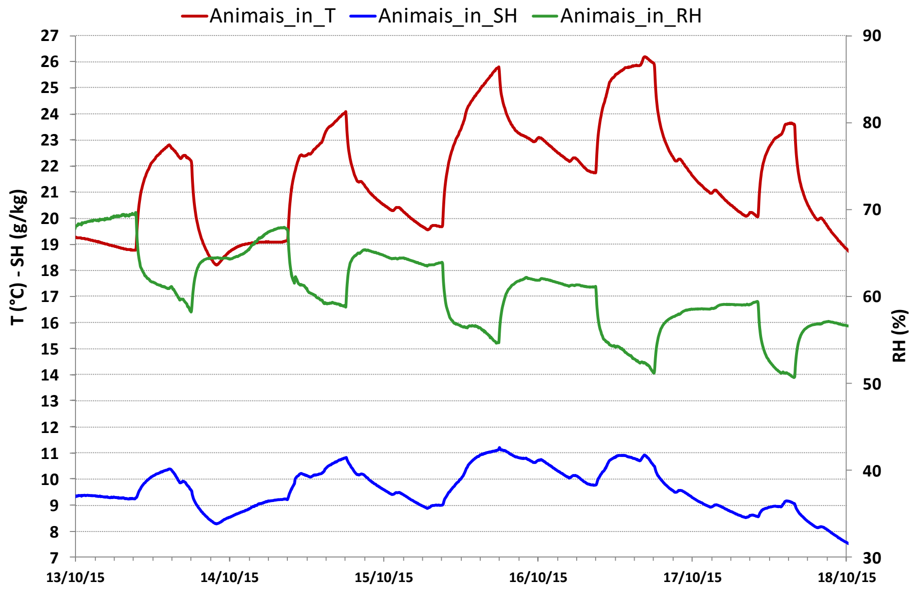

Fig. 37 - Time trends of air temperature, relative and specific humidity inside *Animais* showcase

Besides few very high peaks in light intensity recorded in the *Fan* showcase, in general light impact was more remarkable in *Animais* showcase, as the lamps were placed inside the showcase, directly pointing the collection (Fig. 38). In fact, the periodic peaks of light intensity in *Animais* showcase followed clearly the opening hours of the Museum (Fig. 39).

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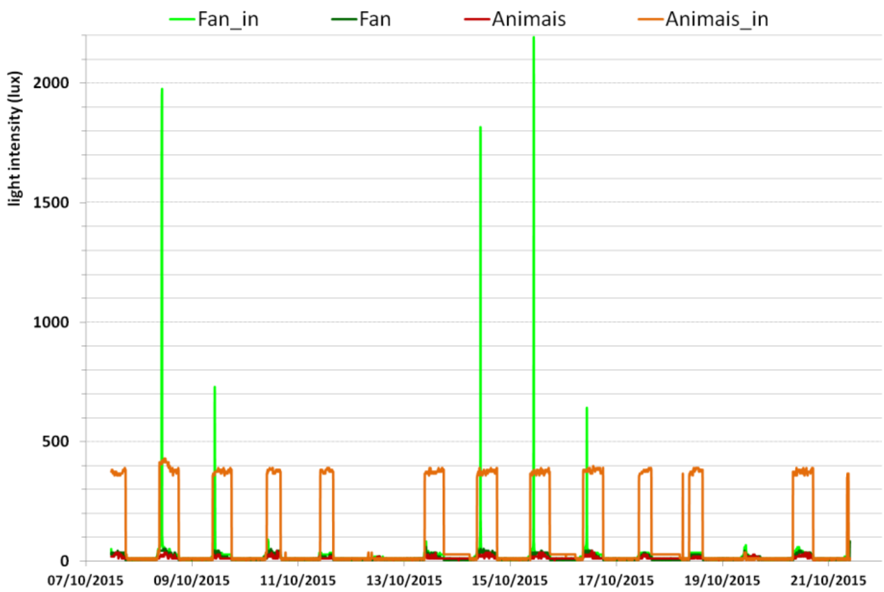

Fig. 38 - Light intensity trend inside the showcases in the new building

The peaks up to 2200 lux registered in *Fan* showcase are due to the impact of solar radiation passing through the big windows of the new building, in specific hours (middle morning) of the sunny days (Fig. 39 and 40).

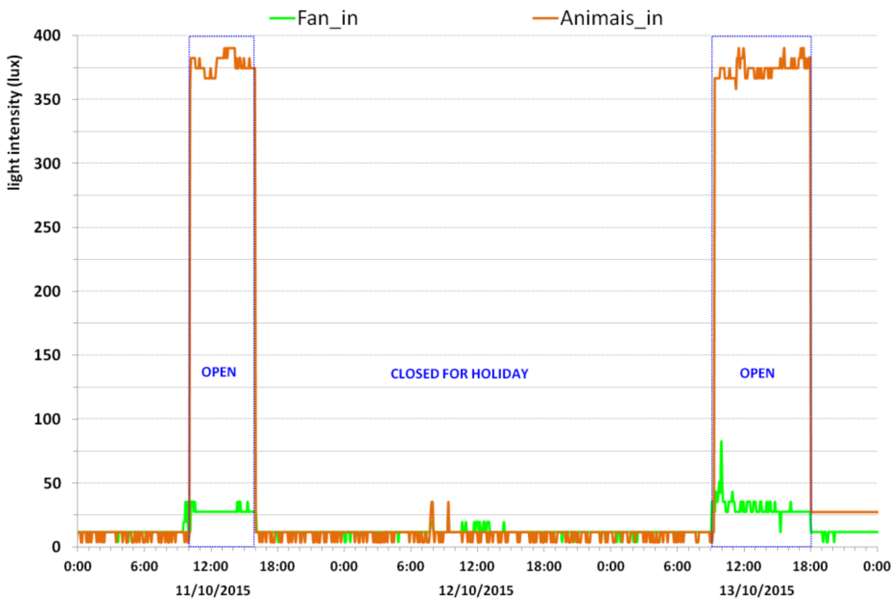

Fig. 39 - Light intensity trend inside the showcases in the new building

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Fig. 40 - Impact of solar radiation on *Fan* showcase

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5. PRELIMINARY RESULTS OF AIR POLLUTION MONITORING

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The Paranaense Museum since 2002 has been installed in Palácio São Francisco, located in the historical area of Curitiba, just at the edge of the urban area, at the corner of two streets characterized by not very high volumes of traffic, Rua Kellers and Rua Pereira (Fig. 41). The air quality in Curitiba is considered good by the Government[5].

Fig. 41 - Map of Curtiba with the location of the Museums Paranaense[6]

In the following sections only the very preliminary results of the pollutants monitoring will be presented, as the analysis of the majority of the samples has just be completed, and some of them are still in progress, being this kind of analyses time consuming and the instrumentation shared with several research projects at the Federal University of Paraná. Hence, being the deadline of the present report two months after the conclusion of the STM program (October 2015), one can give only preliminary comment to the data at today, that in turn will be confirmed, integrated and/or corrected.

5.1 ***NO_2, SO_2 and O_3***

Table 11 displays the concentrations obtained for NO_2 and O_3 gases in the monitoring period. The NO_2 results are not complete as the samples collected in the first week are still under analysis. The concentration of SO_2 was below the instrumental detection limit (DL) in all the sampling points, even in the outside air, so it was not included in the Table.
The concentration values of O_3 outside of the building are considerably higher than the ones obtained in the indoor environment. Moreover, the concentrations measured in the old buildings are higher than the ones obtained in the new building (Tab. 11, Fig. 42 and 43). Usually, for naturally ventilated buildings the indoor concentration values of O_3 are approximately half of the

[5] http://www.iap.pr.gov.br/
[6] © Satellite image by Google Maps

outdoor values[7]. At Museum Paranaense, this tendency is confirmed in the old buildings, whilst in the new building the indoor concentration is much lower than that, which can be due to high rate of deposition of O_3, or to reactions with other pollutants in the indoor atmosphere of the Museum. In interpreting the results one may consider the presence of the air conditioning system in the new building.
The showcases resulted characterized by even lower levels of O_3, with comparable concentrations regardless of the buildings (Tab. 11, Fig. 42 and 43), probably because of the high reactivity of O_3.

Sampling period	07-14/10/2015		14-21/10/2015	
Sample location	NO_2 (μg m^{-3})	O_3 (μg m^{-3})	NO_2 (μg m^{-3})	O_3 (μg m^{-3})
OLD_Ney Braga	analyses in progress	18.7	17.1	22.2
OLD_Ney Braga_in		0.8	4.8	<DL
OLD_indigenas		16.3	15.9	18.4
OLD_indigenas_in		1.2	6.5	0.1
NEW_animais		3.4	8.6	4.1
NEW_animais_in		0.8	9.2	0.1
NEW_fan		4.0	8.9	3.7
NEW_fan_in		1.0	3.0	<DL
OUT		28.0	16.8	38.8

Tab. 11 - Results obtained for gases in the monitoring period (DL: detection limit)

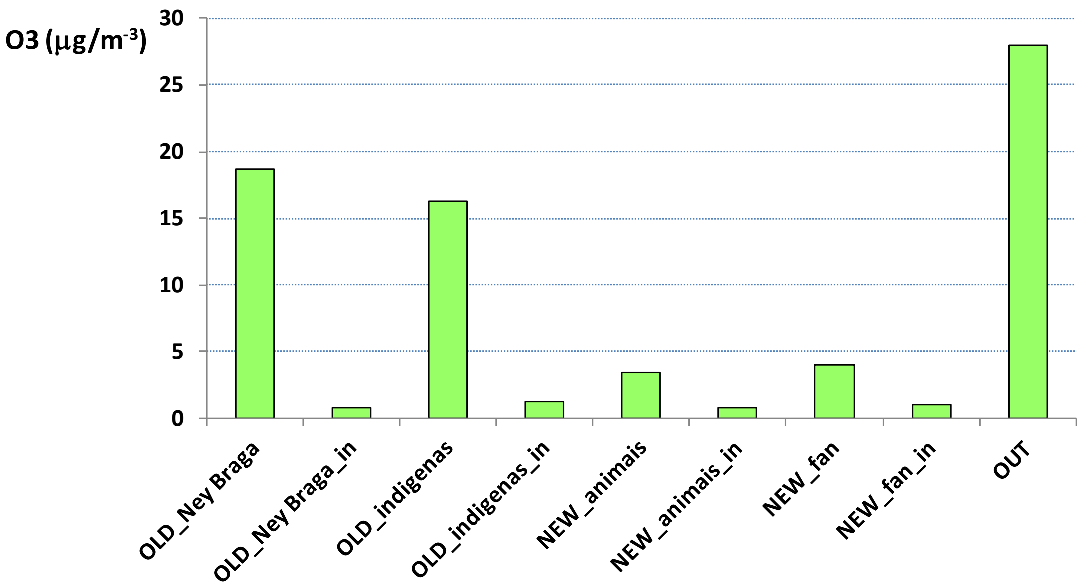

Fig. 42 - Concentrations of O_3 obtained in the different sample locations in the first week

[7] Shaver C., Cass G. Ozone and the deterioration of works of art. Environ Sci Technol 1983, 17, 748-52

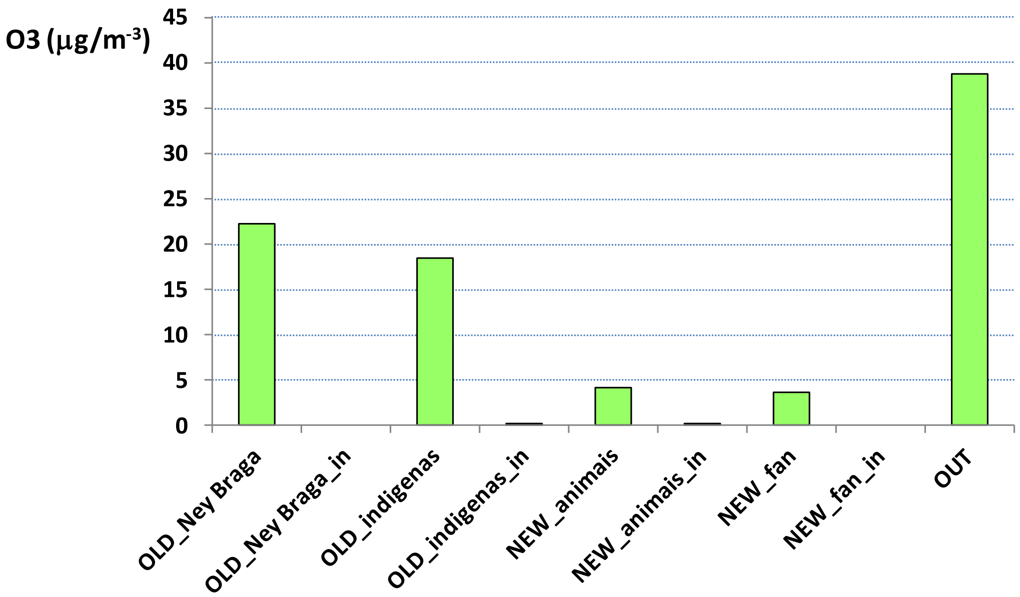

Fig. 43 - Concentrations of O_3 obtained in the different sample locations in the second week

Concerning NO_2, only the data related to the second week can be described. One may wait the end of the analyses to drawn final conclusions.
The measured concentration of NO_2 outside was high probably because the Paranaense Museum is located in the corner of two streets of vehicular traffic (Fig. 41). The concentration values of NO_2 inside of the old buildings were comparable to the ones obtained outside, whilst in the new building they were reduced of 1.5 factor respect to outside.
In the old building the concentration of NO_2 inside the showcases was much lower than outside them, whilst in the new building there was less difference between the environments inside and outside the showcases. Anyhow the concentrations values of NO_2 inside the showcases were all of the same order of magnitude, being the *Fan* and *Animais* showcases characterized respectively by the lowest and highest concentrations (Tab.11, Fig. 44).
These preliminary results show that NO_2 entered the Museum with the outside air and that there were not strong sources inside the Museum. The showcases had a different air exchange with the air, hence the concentration decreased differently due to the possible deposition of NO_2.
The preliminary results on the I/O ratio of both the pollutants indicates that there were no significant sources indoor, nor inside the showcases.

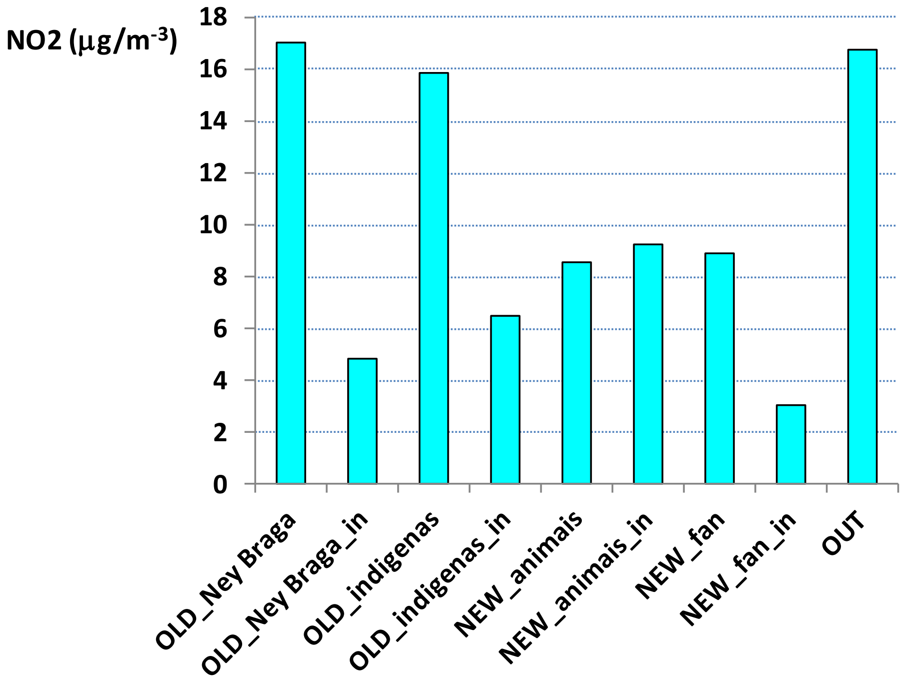

Fig. 44 - Concentrations of NO_2 obtained in the different sample locations in the second week

5.2 *Acetic and formic acids*

Table 12 displays the concentrations obtained for HAc and HFor in the second week. As for NO_2, only the data related to the second week can be described, hence only preliminary conclusions can be drawn at present.

Sample location	HAc (µg m^{-3})	HFor (µg m^{-3})
OLD_Ney Braga	19.5	11.1
OLD_Ney Braga_in	155.7	<DL
OLD_indigenas	14.7	9.2
OLD_indigenas_in	105.9	8.9
NEW_animais	17.3	8.7
NEW_animais_in	45.5	37.0
NEW_fan	10.6	5.7
NEW_fan_in	351.8	173.6
OUT	10.3	4.5

Tab. 12 - Results obtained acetic acid (HAc) and formic acid (HFor) in the second week (DL: detection limit)

The concentration values for HAc inside the Museum were comparable to outdoor values, being in the range 10-20 μg m^{-3}, regardless of the building (Tab. 12, Fig. 45). The concentrations measured inside the showcases were higher than the ones in the correspondent rooms, with the I/O ratio of 7-8 for the old buildings, of 3 for the *Animais* showcase and up to 33 for the *Fan* showcase (Tab. 12, Fig. 45). This result indicates the presence of sources of HAc inside the showcases.

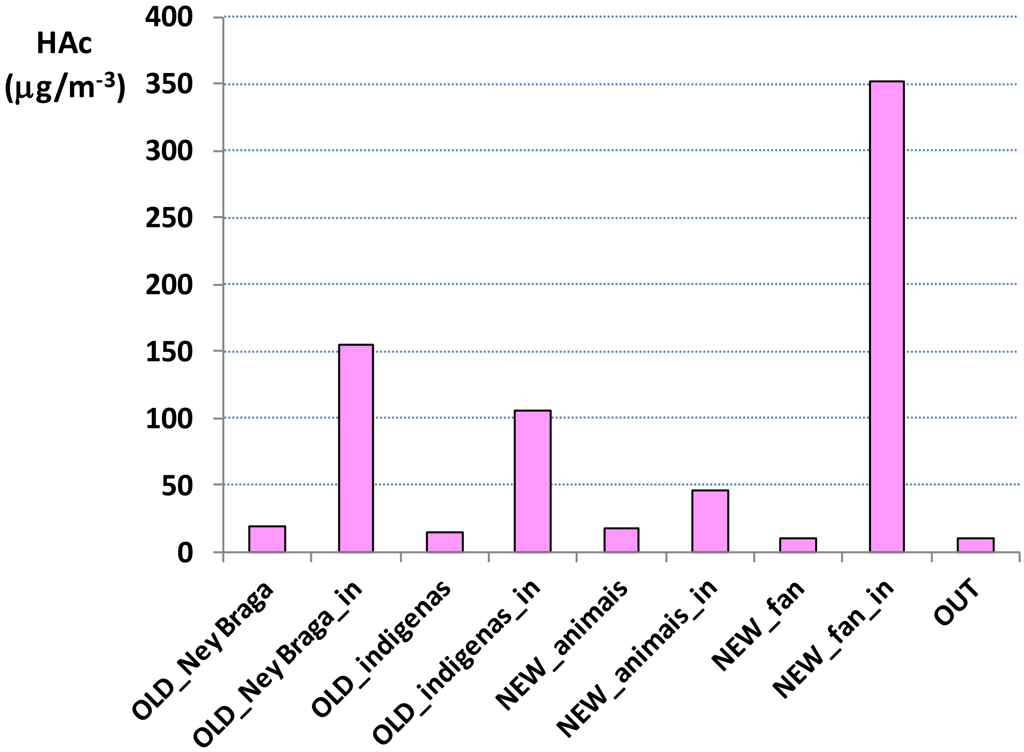

Fig. 45 - Concentrations of HAc obtained in the different sample locations in the second week

Also the indoor concentration values for HFor were comparable to outdoor values, regardless of the building (Tab. 12, Fig. 46). The concentrations measured inside the showcases were similar to the other sample locations in the old buildings, whilst the values measured in the two showcases of the new building were higher than the other points of monitoring (Tab. 12, Fig. 46), with an I/O ratio of 5 and 30 respectively for the *Animais* and *Fan* showcases.

This result confirms the presence of sources of both HFor and HAc inside the *Fan* showcase. The possible sources of these gases inside the showcases are under investigation.

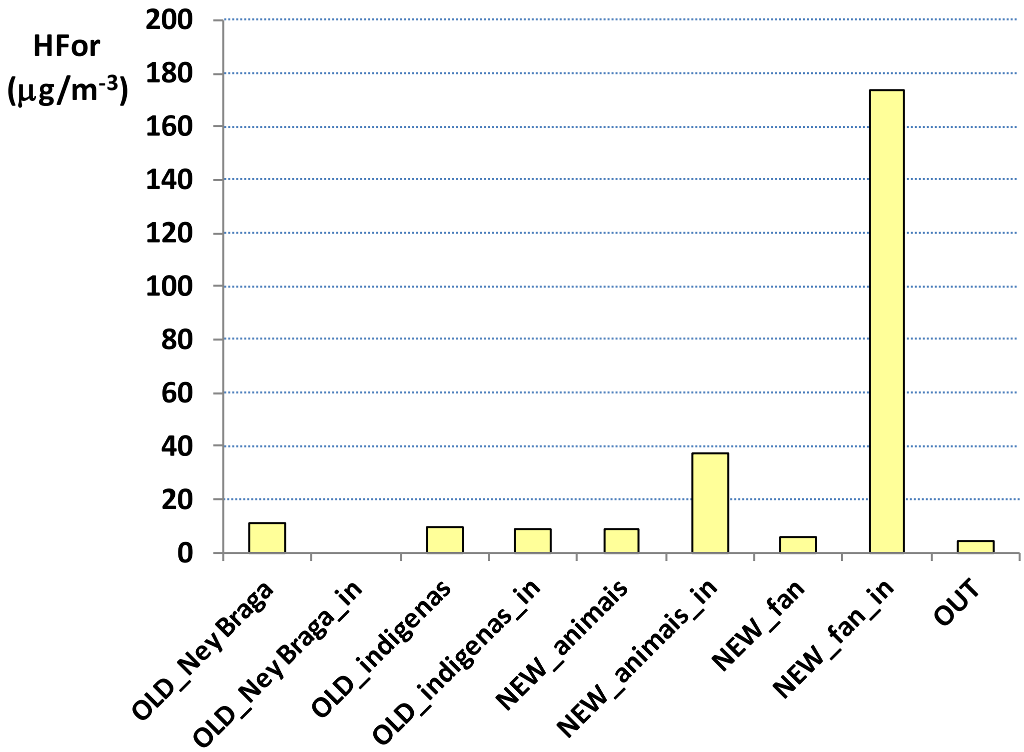

Fig. 46 - Concentrations of HFor obtained in the different sample locations in the second week

5.3 *Black carbon*

The average, maximum and minimum concentrations of black carbon (BC) measured the Museum in the monitoring period inside are reported day by day in Table 13. The same data are showed in Figure 47, where the day of the week (from Monday to Friday) is indicated in abscissa for a better interpretation of the preliminary results.

In general, one may note an increase in the BC concentration Monday to Friday. Anyhow, the indoor concentration values obtained by the present monitoring are similar or lower than those of studies carried out in American museums and also in another museum located in Curitiba, the Oscar Niemeyer Museum[8].

A positive results is the low amount of black carbon (soot) particles inside the Paranaense Museum. The deposit of these types of particles on works of art is recognized as being the main reason for the soiling and chemical degradation of collections.

[8] R. H.M. Godoi, B. H. B. Caneiro, S. L. Paralovo, V. P. Campos, T. M. Tavares, H. Evangelista, R. Van Grieken, A. F. L. Godoi. Indoor air quality of a museum in a subtropical climate: the Oscar Niemeyer Museum in Curitiba, Brasil. Science of Total Environment, 452-453 (2013) 314-320

Day	Mean (ng m^{-3})	Maximum (ng m^{-3})	Minimum (ng m^{-3})
07/10/2015	1584	10199	91
08/10/2015	2392	5980	811
09/10/2015	1073	2571	107
10/10/2015	747	2360	356
11/10/2015	850	3509	112
12/10/2015	431	1235	38
13/10/2015	929	2625	213
14/10/2015	1670	3410	151
15/10/2015	2384	5312	1403
16/10/2015	2921	14329	1165
17/10/2015	815	1467	347
18/10/2015	436	1687	77
19/10/2015	848	2024	40
20/10/2015	2837	10198	177

Tab. 13 - Results obtained for black carbon in the monitoring period inside the Museum

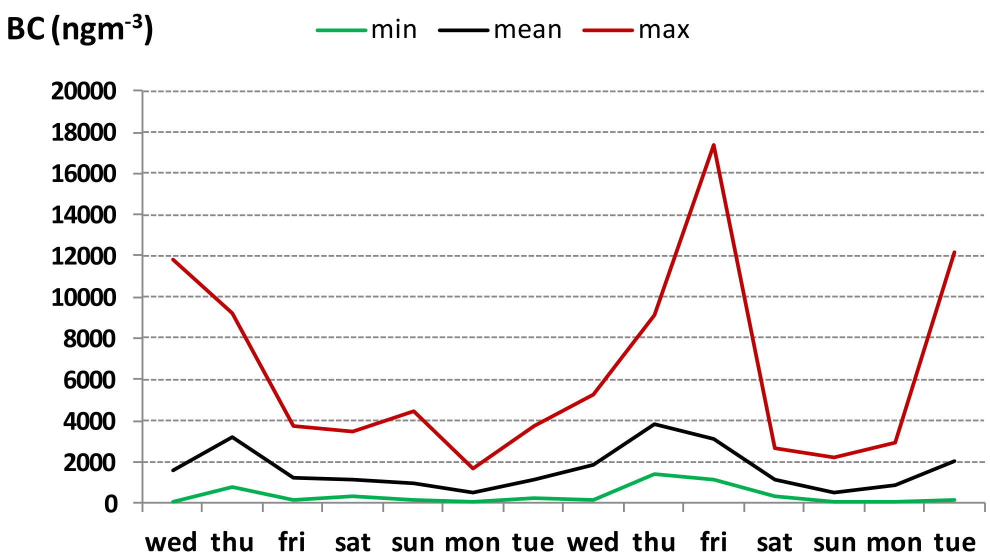

Fig. 47 - Concentrations of black carbon inside the Museum in the monitoring period

5.4 *Particulate Matter*

The EDXRF preliminary results obtained inside and outside of the Paranaense Museum are presented in Tables 14. Once the final data are available, the sources of the indoor concentrations of PM will be identified and discussed. The indoor concentrations of PM are expected to depend on aerosol transport from outdoors and also on the transit of people in and into the indoor environment.

Sampling date	Sampling place	Elements (ng m^{-3}) Al	Si	Cr	Cu	Pb	Fe	Co	Ti	Ni	Mn	Se	Pt
07/10	inside new	0.1	0.2	0.0	0.0	<DL	0.1	0.0	0.0	0.0	0.0	0.0	<DL
	inside old	0.4	791	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.1	0.0	<DL
	outside	-	-	-	-	-	-	-	-	-	-	-	-
08/10	inside new	0.0	0.2	0.0	0.0	<DL	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	0.5	871	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.1	0.0	<DL
	outside	0.3	546	0.0	0.0	0.0	358	0.0	0.0	0.0	0.0	0.0	<DL
09/10	inside new	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	<DL	0.1	0.0	0.0	0.0	0.0	0.0	<DL	0.0	0.0	<DL	0.0
	outside	0.1	454	0.0	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	<DL
10/10	inside new	0.0	0.1	0.0	0.0	<DL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	0.1	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	<DL
	outside	0.1	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	<DL
11/10	inside new	0.0	0.1	0.0	0.0	<DL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	0.3	1.3	0.0	0.1	<DL	0.5	0.0	0.0	0.1	0.2	0.0	<DL
	outside	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	<DL
12/10	inside new	0.0	0.1	0.0	0.0	<DL	0.0	0.0	<DL	0.0	0.0	0.0	0.0
	inside old	0.2	0.8	0.0	0.0	<DL	0.4	0.0	0.0	0.1	0.1	0.0	<DL
	outside	0.1	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	<DL
13/10	inside new	0.0	0.2	0.0	0.0	<DL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	0.2	0.7	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	<DL
	outside	0.2	577	0.0	0.0	0.0	388	0.0	0.0	0.0	0.0	0.0	<DL
14/10	inside new	0.0	0.2	0.0	0.0	<DL	0.1	0.0	0.0	0.0	0.0	0.0	<DL
	inside old	0.5	997	0.0	0.0	0.0	703	0.0	0.1	0.0	0.1	0.0	<DL
	outside	930	1636	0.0	0.0	0.0	1205	0.0	0.1	0.0	0.1	0.0	0.0
15/10	inside new	0.1	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	<DL
	inside old	0.0	<DL	<DL	0.1	<DL	0.0	<DL	0.0	0.2	<DL	<DL	<DL
	outside	1556	2285	0.0	0.0	0.2	1885	0.0	0.2	0.0	0.1	0.0	<DL
16/10	inside new	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	<DL	<DL
	inside old	0.4	840	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	<DL
	outside	457	926	0.0	0.0	0.0	661	0.0	0.1	0.0	0.0	0.0	<DL
17/10	inside new	0.0	0.1	0.0	0.0	<DL	0.0	0.0	0.0	0.0	0.0	<DL	0.0
	inside old	0.1	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0

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	outside	0.4	810	0.0	0.0	0.0	424	0.0	0.0	0.0	0.0	0.0	<DL
18/10	inside new	0.0	0.1	0.0	0.0	<DL	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	inside old	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	outside	0.2	579	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	<DL
19/10	inside new	0.1	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	<DL
	inside old	0.2	0.6	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	<DL
	outside	680	1463	0.0	0.0	0.0	775	0.0	0.1	0.0	0.0	0.0	<DL
20/10	inside new	0.1	0.3	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	<DL
	inside old	1265	2014	0.0	0.0	0.2	1449	0.0	0.1	0.0	0.1	0.0	<DL
	outside	1444	2252	0.0	0.0	0.2	2521	0.0	0.3	0.0	0.1	0.0	0.0
Sampling date	**Sampling place**	**Al**	**Si**	**Cr**	**Cu**	**Pb**	**Fe**	**Co**	**Ti**	**Ni**	**Mn**	**Se**	**Pt**

Tab. 14 (part 1)- Results of the EDXRF bulk analysis of total PM inside and outside the Museum Paranaense during the monitoring period (DL: Detection Limit)

		Elements (ng m^{-1})										
Sampling date	**Sampling place**	**Sn**	**S**	**Sr**	**Br**	**P**	**Na**	**Cl**	**K**	**Mg**	**Ca**	**Zn**
07/10	inside new	<DL	0.3	<DL	0.0	0.2	<DL	<DL	0.2	<DL	0.1	0.0
	inside old	<DL	0.6	0.0	0.0	0.2	<DL	<DL	0.4	<DL	0.5	0.0
	outside	-	-	-	-	-	-	-	-	-	-	-
08/10	inside new	<DL	0.2	0.0	0.0	0.1	<DL	0.0	0.1	<DL	0.1	0.0
	inside old	<DL	0.6	0.0	0.0	0.3	<DL	0.0	0.4	<DL	0.6	0.0
	outside	<DL	0.2	0.0	0.0	0.2	<DL	0.0	0.2	<DL	470	0.0
09/10	inside new	<DL	0.2	0.0	DL	0.1	<DL	<DL	0.2	<DL	0.1	0.0
	inside old	<DL	0.1	0.0	0.0	0.1	<DL	<DL	0.1	<DL	0.0	<DL
	outside	<DL	487	0.0	0.0	0.2	<DL	0.0	0.4	<DL	620	0.0
10/10	inside new	<DL	0.1	0.0	<DL	0.1	<DL	<DL	0.1	<DL	0.0	0.0
	inside old	<DL	0.4	0.0	<DL	0.2	<DL	<DL	0.3	<DL	0.2	0.0
	outside	<DL	0.3	0.0	<DL	0.2	<DL	<DL	0.2	<DL	0.3	0.0
11/10	inside new	<DL	0.1	0.0	<DL	0.1	<DL	<DL	0.1	<DL	0.0	0.0
	inside old	<DL	1.3	0.0	<DL	0.7	<DL	<DL	1.3	<DL	0.5	0.0
	outside	<DL	0.3	0.0	<DL	0.2	<DL	<DL	424	<DL	0.2	0.0
12/10	inside new	<DL	0.1	0.0	0.0	0.1	<DL	<DL	0.1	<DL	0.0	0.0
	inside old	<DL	0.9	0.0	<DL	0.5	<DL	<DL	0.7	<DL	0.3	0.0
	outside	<DL	0.4	0.0	<DL	0.2	<DL	<DL	0.3	<DL	0.1	0.0
13/10	inside new	<DL	0.1	0.0	<DL	0.1	<DL	<DL	0.1	<DL	0.1	0.0
	inside old	<DL	0.3	0.0	<DL	0.2	<DL	0.0	0.2	<DL	705	0.0
	outside	<DL	0.3	<DL	<DL	0.2	<DL	<DL	0.2	<DL	0.3	0.0

Sampling date	Sampling place	Sn	S	Sr	Br	P	Na	Cl	K	Mg	Ca	Zn
14/10	inside new	<DL	0.3	0.0	DL	0.1	<DL	<DL	0.2	<DL	0.1	0.0
	inside old	<DL	990	0.0	0.0	0.4	<DL	<DL	0.6	<DL	756	0.0
	outside	0.0	780	0.0	0.0	0.3	<DL	<DL	590	<DL	1289	0.0
15/10	inside new	<DL	0.5	<DL	0.0	0.1	<DL	<DL	0.3	<DL	0.0	0.0
	inside old	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.1	<DL	0.0	<DL
	outside	<DL	845	0.0	0.0	0.4	<DL	<DL	750	<DL	822	0.0
16/10	inside new	<DL	0.4	0.0	0.0	0.1	<DL	<DL	0.2	<DL	0.1	0.0
	inside old	<DL	858	0.0	<DL	0.2	<DL	<DL	0.4	<DL	0.3	0.0
	outside	<DL	532	0.0	0.0	0.1	<DL	<DL	0.3	<DL	0.3	0.0
17/10	inside new	<DL	0.3	0.0	0.0	0.1	<DL	<DL	0.1	<DL	0.0	0.0
	inside old	<DL	0.6	0.0	0.0	0.2	<DL	0.2	0.4	<DL	0.1	0.0
	outside	<DL	658	0.0	0.0	0.2	<DL	448	429	<DL	0.3	0.0
18/10	inside new	<DL	0.2	0.0	<DL	0.1	<DL	<DL	0.1	<DL	0.0	0.0
	inside old	<DL	0.3	0.0	0.0	0.1	<DL	0.1	0.2	<DL	0.1	0.0
	outside	<DL	0.4	0.0	0.0	0.1	<DL	0.1	0.2	<DL	0.3	0.0
19/10	inside new	<DL	0.2	0.0	<DL	0.1	<DL	<DL	0.2	<DL	0.2	0.0
	inside old	<DL	0.3	0.0	0.0	0.2	<DL	<DL	0.2	<DL	0.3	0.0
	outside	0.0	0.3	0.0	0.0	0.2	<DL	0.0	408	<DL	1298	0.0
20/10	inside new	<DL	543	<DL	0.0	0.2	<DL	<DL	0.4	<DL	0.1	0.0
	inside old	<DL	1249	0.0	0.0	0.4	<DL	<DL	1007	<DL	1026	0.0
	outside	0.0	688	0.0	0.0	0.2	<DL	<DL	794	<DL	1335	0.0

Tab. 14 (part 2) - Results of the EDXRF bulk analysis of total PM inside and outside the Museum Paranaense during the monitoring period (DL: Detection Limit)

The major elements detected in the samples collected were Al, Si, Fe, S, P, K and Ca. The outside samples in general showed elemental concentration higher than the inside ones, with the exception of S that in two days (14 and 16 October) was detected in higher concentrations inside the Museum than outside.

The new building was characterized by lower concentrations than the old buildings for all the elements.

In addition, the masses results indicated that the major accumulation of PM was outside the museum, as expected.

A soon as all the analyses are completed, the average values and standard deviations for each element will be calculated.

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6. DISCUSSION AND CONCLUSIONS

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6.1 *Risks of hot and humid climates for collections*

Hot and humid climates present particularly high thermal and moisture loads that create challenges for effectively managing the interior environment for the preservation of the collections and the historic building fabric, as well as for the occupant comfort.
In 1994 the Canadian Conservation Institute[9] (CCI) introduced the ten agents of deterioration that pose a risk of damage to collections. The last 4 of this list, namely pests, pollutants, light (UV and IR), incorrect temperature and humidity fall into three mechanisms of deterioration and damage: biological, mechanical and chemical.

Biological risk to cultural heritage collections is largely due to the activity of organisms that directly cause damage to objects and materials: microorganisms (fungi and bacteria), insects and vermin, in descending order of the risk they pose. In hot and humid climates, the abundance of water and the elevated temperatures for substantial periods of the year make microorganisms activity the dominant biological risk to collections. In particular, fungal activity poses a greater risk than bacterial activity because it can occur at lower level of humidity (around 75 % versus 90 % RH). The nutrients needed to support fungi are plentiful in organic collections. Optimal T and RH conditions for fungal spore germination in the presence of the nutrients are specific to species. In hot and humid climates, management of humidity conditions rather than temperature may be a more effective means limiting mold activity in the collection space. While the threshold levels are species specific, maintaining humidity levels below 75 % RH can prevent germination and growth for a wide range of fungal species. Even if the 75 % RH limit is exceeded, the duration of the event remains an important parameter. When humidity in a space is near the threshold value for germination, temperature gradients become an important consideration.

Environmentally induced **mechanical damage** can include:

- dimensional change due to shifts and/or fluctuations in T and RH;
- embrittlement or deformation of materials due to extreme temperature or humidity conditions;
- material fatigue or embrittlement due to repeated cycling of T and RH;
- material rupture when moisture content cycling results in crystal formation of soluble salts.

The risk of mechanical damage is affected by many factors, i.e. ranges of T and RH, the coefficients of thermal and moisture expansion of the material, and so forth. Anyhow, in hot and humid climates, the annual ranges of ambient temperature and humidity are small compared to the wider ranges of these variables in temperature climates. Hence, the risk of mechanical damage may be lower in hot and humid climates than in other climatic zones. However, there remains a risk for mechanical damage to collections when relocated from unconditioned ambient environments to interior environments that are substantially different with respect to average T and RH. Moreover, in an artificially controlled environment the risk due to a change in T and RH is not eliminated, because a failure of the mechanical equipment may occur.

[9] CCI 2013 Framework for preservation of museum collections http://www.cci-icc.gc.ca/discovercci-decouvriricc/preventive/15-eng.aspx

Most museums in hot and humid climate contain objects that were created and used locally and were historically exposed to environmental conditions that differ significantly from the conventionally accepted museum environmental specifications of 21 °C and 50 % RH - recommendations[10] that were primarily developed for major European, British and North American museum in colder and less humid climates. Moreover, is well known that present-day state of conservation of objects and collections vulnerable to mechanical damage depends on the T and RH conditions experienced in the past that are synthetically summarized in terms of "historic climate", i.e. the climate in which an object has always been kept, or has been kept for a long period of time and to which it has acclimatized. Hence, an object should be preserved without departing from the historic climate. The only acceptable changes are improvements that reduce fluctuations in the climatic conditions.
Consequently, the ranges of T and RH that pose low mechanical risk are object specific and dependent on its past use, environmental exposure and conservation treatment histories.

The various materials of an object continuously interact chemically with the surrounding environment. These reactions, which can result in **chemical damage**, are strongly influenced by:

- temperature;
- humidity;
- reactive pollutants;
- light.

In hot and humid climates, the abundance of thermal energy and moisture increases the risk of chemical deterioration and damage for organic and inorganic materials.
Many chemical reactions are dependent on temperature and increasing temperature results in faster reaction rates. Humidity also plays an important role in the promotion of chemical deterioration processes, such as the electrochemical reaction of corrosion. The environmental factors T and RH are key parameters in determining the theoretical lifetime of an object due to chemical deterioration.
Short- and log-term exposure to elevated pollutant concentrations can damage a variety of collections materials by acidification (paper), corrosion (metals), discoloration (pigments and dyestuffs), or loss of strength (textiles). A summary of the major gaseous pollutants that are risks to cultural heritage and their sources can be found in ASHRAE 2011[11].
Exposure of an object to natural or artificial light can induce photochemical reactions that may result in damage. In order to evaluate the light exposure risk to museum collections in hot and humid climate the European standards[12] can be used as reference. In fact, even if in hot and humid climates, the high levels of solar radiation and the use of open windows for natural ventilation can expose objects to damaging light levels, this doesn't affect the light threshold values that cause damage, that have been established experimentally. Moreover, in indoor environments, the main threat for material conservation is artificial light, whose management in Museum environments is often independent at all by the natural one.

[10] http://www.conservation-wiki.com/wiki/Environmental_Guidelines
[11] AHRAE "Museums, Galleries, Archives and Libraries" 2011
[12] CIE 157:2004 and CEN/TS 16163:2013

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In order to minimize the environmental risks to collections, a risk management approach is needed to balance risks and establish conservation priorities for the environmental management specific in hot and humid climate. The starting point of this approach is the prioritization of the risks, according to which biological damage is the greatest risk to collection in hot and humid climate due to the prolonged periods of high humidity that are conducive to the growth of microorganisms as fungi and bacteria.
Mechanical deterioration constitutes a serious risk to collections in regions where dry seasons and humid or wet seasons result in wide variations of humidity and possibly temperatures.
Chemical damage represents a lesser risk to collections relative to biological and mechanical damage. The majority of surviving collections in hot and humid climates have already undergone initially rapid rates of chemical deterioration by processes such as hydrolysis or corrosion, and subsequent reaction rates have slowed with the depletion of reaction sites on objects.

6.2 *Comparison with the recommended values of temperature, relative humidity and light*

Conventional standards and guides for environmental collections management in temperate climates are problematic when applied in hot and humid climates. Hence, a classification protocol for target environmental conditions specific for risks to mixed cultural heritage collections in hot and humid climates, named Conservation Environment Classification-Hot and Humid (HH) protocol, was developed by the Getty Conservation Institute[13], based on the principles of risk-based guidance for managing the collections environment of ASHRAE "Museum, Galleries, Archives and Libraries". This protocol is based on the three prioritized risk factors - microbial, mechanical and chemical - and presents a series of humidity and temperature environmental targets and classification criteria for conservation environments (Tab. 15).

Concerning the risk to light exposure, CIE 157:2004 and CEN/TS 16163:2013 normative can be taken as reference documents also in hot and humid climates. According to these standards, materials of cultural property are grouped into four classes of sensitivity to luminous exposure. For each class, a limit in the cumulative annual luminous exposure (ALE, measured in lux-hours per year, i.e. $lx\ h\ y^{-1}$) has been established (Tab. 16). This is calculated as a product of the allowed instantaneous illuminance level (measured in lux, i.e. lx) and the total annual exposure time (AET, measured in hours per year, i.e. $h\ y^{-1}$). As the cumulative effect is the main factor, ALE should be respected, whilst it is possible to increase the illuminance level if the AET is adequately reduced, leaving unchanged their product.

[13] S. Maekawa, V. L. Beltran, and M.C. Henry. Environmental Management for Collections. Alternative Preservation Strategies for Hot and Humid Climates, Getty Publications, Getty Conservation Institute, 2015, 344 pages

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Risk		Humidity (% RH)			Temperature (°C)		
Category	**Specific Risk (statistic)**	**Parameter**	**Criteria**	**Class**	**Parameter**	**Criteria**	**Class**
Microbial risk[1] (dominant risk in hot and humid climates)	Germination threshold	97.5 percentile (P97.5, x)	$x \leq 65$	A[6]	*Microbial activity will typically remain dormant at temperatures above 40°C.*		
			$65 < x \leq 70$	B			
			$70 < x \leq 75$	C			
			$x > 75$	F			
Mechanical risk[2,3] (overall class determined by lowest class of any specific mechanical risk)	Short-term variation	Rolling 24 hr variation, 95th percentile (P95, x)	$\Delta 0 \leq x \leq \Delta 10$	a	Rolling 24 hr variation 95th percentile (P95, x)	$\Delta 0 \leq x \leq \Delta 4$	a
			$\Delta 10 < x \leq \Delta 20$	b		$\Delta 4 \leq x \leq \Delta 10$	b
			$x > \Delta 20$	f		$x > \Delta 10$	f
	Seasonal variation	Absolute difference in seasonal means (means ≤ 70% RH, x)[5]	$\Delta 0 \leq x \leq \Delta 10$	a	Absolute difference in seasonal means (x)	$\Delta 0 \leq x \leq \Delta 10$	a
			$\Delta 10 < x \leq \Delta 20$	b		$\Delta 10 < x \leq \Delta 20$	b
			$x > \Delta 20$	f		$x > \Delta 20$	f
	Deviation from historical mean	Absolute difference between annual and historical mean (x)	$\Delta 0 \leq x \leq \Delta 10$	a	Absolute difference between annual and historical mean (x)	$\Delta 0 \leq x \leq \Delta 10$	a
			$\Delta 10 < x \leq \Delta 20$	b		$\Delta 10 < x \leq \Delta 20$	b
			$x > \Delta 20$	f		$x > \Delta 20$	f
Chemical risk[4]	Deviation from historical mean	*Consider condensation risk at high humidity and depressed surface temperatures.*			Difference between annual and historical mean (x)	$x > \Delta 5$	++
						$\Delta 3 < x \leq \Delta 5$	+
						$\Delta{-3} \leq x \leq \Delta 3$	0
						$\Delta{-5} \leq x \leq \Delta{-3}$	–
						$x < \Delta{-5}$	– –

1 While adherence to Class C criteria will limit most microbial activity, meeting criteria for Class A or Class B will further extend the time period until mold germination and will restrict growth.
2 Due to variations in material response times to humidity and temperature fluctuations and construction techniques, the risk of mechanical damage is object specific.
3 If deliquescent salts are present, one must maintain humidity below the deliquescence point to limit the risk of salt-related mechanical damage.
4 Chemically unstable collections should be stored in cold (−20°C) or cool (10°C) conditions, while only stable metal collections treated against corrosion or having natural patina may be stored at conditions above 60% RH.
5 If seasonal mean humidity exceeds 70% RH, mechanical risk due to seasonal humidity variation is assigned to Class f. Above 70% RH, small shifts in humidity can result in large changes in a material's equilibrium moisture content and may lead to irreversible dimensional change.
6 Though a lower humidity limit is not given for Class A microbial risk, the maintenance of an excessively low humidity condition may introduce mechanical risk by deviating far from the historical humidity mean.

Class Designations and Risk Levels

Microbial Class
A: no risk B: low risk C: moderate risk F: high risk

Mechanical Class
a: no risk b: moderate risk f: high risk

Chemical Class
++: significantly increased risk
+: moderately increased risk
0: similar risk
–: moderately reduced risk
– –: significantly reduced risk

Tab. 15 - Conservation Environment Classification-Hot and Humid (HH) protocol showing RH and T criteria for mixed collections in hot and humid climates

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Material classification	Examples of materials	ALE (lx h y^{-1})	Illuminance (lx)	AET (h y^{-1})
Insensitive	Metal, stone, glass, ceramic, enamel	No limit	No limit	No limit
Low sensitivity	Canvas, frescoes, wood, leather, bone, ivory	600 000	200	3 000
Moderate sensitivity	Textiles, watercolour, pastel, various paper (drawings, manuscripts, miniatures), historic objects (botanical specimens, fur, feathers)	150 000	50 (limit for visibility)	3 000
High sensitivity	Silk, sensitive pigments, photographic documents	15 000	50 (limit for visibility)	300

Tab. 16 - Limiting illuminance and annual exposures for material sensitivity classifications[14]

The microclimate inside the selected showcases of the Paranaense Museum was evaluated taking into account the above mentioned standards, respectively the Conservation Environment Classification-Hot and Humid (HH) protocol for temperature and relative humidity, and the CIE 157:2004 and CEN/TS 16163:2013 for light, even if they are not specifically addressed to showcases.
In fact, standards on showcases are rather lacking at International level. The European Standard UNI EN 15999-1:2014 "Conservation of cultural heritage - Guidelines for design of showcases for exhibition and preservation of objects - Part 1: General requirements" has been published in March 2014. This first part contains general indications for the construction of the showcases in order to assure the safe and secure display of cultural heritage objects, reducing environmental interaction and complying with the requirements for better preservation. This standard, even when completed with the Part 2, is not specifically addresses to hot and humid climates. Anyhow, the general requirements for showcases design can be applied in every climatic zone.
Hence, for the evaluation of the environmental conditions inside the showcases of the Paranaense Museum the only standards available for the museum collections in hot and humid climate have been considered, even if not specifically addressed to showcases.

Concerning **microbial risk**, as stated by the HH protocol, the 97.5 percentile of RH, i.e. the germination threshold, was calculated, instead of RH maximum values, in order to exclude short and uncommon excursions. The calculation was performed for all the locations (outside and inside the Museum but outside the showcases) for comparison.
According to the results (Tab. 17), the environment inside the showcases was characterized by lower risk for microbial growth than the correspondent environment outside the showcases, regardless of the location in the old or new buildings. In particular, all the showcases resulted in Class B, i.e. low risk, except for *Indigenas* showcase that showed moderate risk (Class C). Almost all the points of measurements indoors, but outside the showcases, belonged to the same Class F as

[14] The reference values of illuminance and AET are typical values whose product determines recommended ALE. One may depart from the reference values provided that their product remains unchanged.

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outdoors, again regardless of the building, hence of the presence of the air conditioning system. The only exception was the *Ney Braga* room that was characterized by high risk.

Point of measurement	P95.7 Humidity (%)	Class	Risk
OLD_Ney Braga	71	C	moderate
OLD_Ney Braga_in	68	B	low
OLD_indigenas	87	F	high
OLD_indigenas_in	75	C	moderate
NEW_animais	78	F	high
NEW_animais_in	68	B	low
NEW_fan	80	F	high
NEW_fan_in	66	B	low
OUT	100	F	high

Tab. 17 - Microbial risk evaluation

Concerning the **mechanical risk**, only the short-term variations of temperature and relative humidity were evaluated, no seasonal variations, nor deviation from historical mean, being available only the 15 days data collected during the STM program. In the future, it would be possible to evaluate also the seasonal variations and the deviation from the historical mean, as some sensors have been left in the Museum to continue the monitoring.

All the indoor environments that were controlled, being them simply inside the rooms or inside the showcases, met Class a and b (only for RH), hence they were characterized by no or moderate risk of mechanical damage (Tab. 18). In particular, no risk for mechanical stress resulted inside the showcases. All the rooms monitored inside the Museum, regardless of the presence of the air conditioning system, showed moderate risk for short-tem variations of relative humidity.

Point of measurement	Rolling 24 hr variation, P95 RH (%)	Class	Rolling 24 hr variation, P95 T (°C)	Class
OLD_Ney Braga	14.1	b (moderate risk)	3.8	a (no risk)
OLD_Ney Braga_in	5.2	a	3.9	a
OLD_indigenas	11.8	b	3.2	a
OLD_indigenas_in	5.8	a	2.2	a
NEW_animais	12.8	b	2.6	a
NEW_animais_in	7.7	a	3.1	a
NEW_fan	15.9	b	2.7	a
NEW_fan_in	1.7	a	2.6	a

Tab. 18 - Mechanical risk evaluation

As historical data were not available, only the contribution of light exposure to **chemical risk** was evaluated for the collections inside the showcases. The two weeks monitoring period was considered as representative of the annual behaviour, hence the calculations performed on the

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two weeks data were proportionally extended to the whole year and reported in Tab. 19. According to the results, the cumulative annual luminous exposure estimated for the *Indigenas* and *Animais* showcases were higher than the recommended values for the materials of which the objects displayed in the two showcases were made. ALE inside *Indigenas* showcase was twofolds the recommended one, and inside *Animais* showcase it was almost three times the threshold value. Nevertheless, being *Rituais Indigenas* a temporary collection, the measured light exposure levels could be suitable for future collections. On the contrary the *Animais* showcase displays permanently the *Cenario representando acampamento de populacoes sambaqueiras e entorno*, hence the illumination system is not respective of the conservation requirements.

Point of measurement	Material classification[15] for the showcase	Examples of materials exhibited in the showcase	ALE (lx h a^{-1}) measured	ALE (lx h a^{-1}) required
OLD_Ney Braga_in	Moderate sensitivity	Paper, metal	60 590	150 000
OLD_indigenas_in	Moderate sensitivity	Feather, stone, ceramics	356 590	
NEW_animais_in	Moderate sensitivity	Stone, bones, taxidermized animals	998 344	
NEW_fan_in	Low sensitivity	Paper, ivory	188 873	600 000

Tab. 19 - Light exposure risk evaluation

6.3 *Comparison with the recommended exposure values for various materials and museum*

Table 20 summarizes the main guidelines for atmospheric pollutants inside museums, in order to preserve the artworks exposed. For most of the gases, there is considerable variation in the exposure values recommended by different sources. This reflects the fact that detailed knowledge in this area is lacking and a consensus has yet to be reached.

The preliminary results indicated that the mean concentration values for SO_2 inside the Museum obtained in the present research are negligible, hence much lower than in European museums. This difference can be explained due to the fact that in Brazil there is much higher use of ethanol as automobile fuel, which emits no SO_2, than diesel, which is largely used in Europe and still constitutes a (minor) source of SO_2 to the urban atmosphere.
The concentration values for O_3 inside the Museum were below the limits defined by the US National Bureau of Standards[16], and inside the showcases they are reduced to trace level, as recommended by Thomson[17].

[15] The material classification for the whole showcase is given by the most sensible among the materials of which the objects displayed are made
[16]National Bureau of Standards (1983) Air quality criteria for storage of paper-based archival records, NBSIR 83-2795, National Bureau of Standards, Washington DC.
[17]Thomson, G. (1986) The Museum Environment, 2nd ed. Butterworths, London.

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On the contrary, the NO_2 concentration inside the Museum but outside the showcases was higher than both the standards, whilst inside the showcases it attended the limits defined by the Museum Environment, but not the ones established by the US National Bureau of Standards.

Species (sources)	Item	Recommended exposure values	Basis
Sulphur dioxide *(outdoor)*	Paper-based records	0 ppb < 0.4 ppb (1,0 $\mu g\ m^{-3}$)	British Museum Libraries[18] US National Bureau of Standards
	Leather book bindings	< 0.1 ppb	Larsen et al Epidemiological study[19]
	General museum interiors	< 4 ppb (10,5 $\mu g\ m^{-3}$)	Thomson
Nitrogen dioxide *(mainly outdoor)*	Paper-based records	0 ppb < 2.5 ppb (4,7 $\mu g\ m^{-3}$)	British Museum Libraries US National Bureau of Standards
	General museum interiors	< 5 ppb (9,4 $\mu g\ m^{-3}$)	Thomson
Ozone *(mainly outdoor)*	General museum interiors	0 ppb	Thomson
	Paper-based records	< 13 ppb (26 $\mu g\ m^{-3}$)	US National Bureau of Standards
Formic and acetic acids *(indoor)*		NOT CURRENTLY SPECIFIED Measurements of these pollutants have been rare until recent years. Only now is a database of measurements being built up, and research being done to ascertain their threshold values.	

Tab. 20 - Recommended exposure values for various materials and museum interiors[20]

6.4 *Quality assessment of the environmental conditions inside the showcases*

On the basis of the preliminary results of the monitoring program the quality of the environmental conditions inside the showcases of the Paranaense Museum has been assessed in terms of microclimate (temperature and relative humidity) and pollutants (gases).
It was not possible to sample PM inside the showcases because only three equipments were available and because they were not properly suitable for monitoring inside the showcase environment. Anyhow, the showcases didn't have notable problems concerning particulate

[18] BS5454:2000 Recommendations for the storage and exhibition of archival documents. British Standards Institution, London.
[19] Larsen, R (ed) (1996) Deterioration and Conservation of Vegetable Tanned Leather, Protection and conservation of European cultural heritage, Research Report No 6.
[20] Blades N., Bordass W., Oreszczyn T., Cassar M. Guidelines on pollution control in museum buildings, London: Museum Practice, 200.

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deposition. There was not a specific cleaning protocol in the Museum and dust was removed manually on demand (when there was visual evidence of accumulation).
In addition, the results on gases are partial, as the analyses are still in progress, hence only very preliminary conclusions can be drawn, and they need to be validated when the laboratory activity will be completed.

The general **microclimatic conditions** inside the showcases were better than the ones outside the showcases with respect to the conservation issues.
In the old buildings the thermo-hygrometric levels inside and outside the showcases were similar on average, but the amplitude of the variations were reduced, as the minima were increased and the maxima decreased. The *Ney Braga* showcase was characterized by an increase of the daily highest variation of specific humidity respect to the room in which the showcase was located and the temporal trend of SH inside the showcase showed several peaks, due to the wood structure of the showcase itself.
In the new building the comparison between the outside and inside showcase environments showed some differences respect to the behaviour in the old buildings, putting in evidence also some differences between the two showcases investigated. Average temperature was similar or slightly higher inside the showcases than outside, but the maxima were higher inside as well as the minima. The daily thermal variations were higher in *Animais* showcase, lower in *Fan* showcase respect to the correspondent room. The relative humidity values were similar inside and outside the showcases on average, with minima increased in *Fan* showcase respect to outside, the opposite in *Animais* showcase, whilst the maxima were reduced in both the showcases. The amplitude of the daily hygrometric variations were similar in all the point of measurements, except for the *Fan* showcase, where they were remarkably reduced. The maxima of the RH daily variations were reduced in both the showcases, respectively of a factor of 2 and 1.5 in *Fan* and *Animais* showcase. Specific humidity was higher on average inside *Fan* showcase, but the daily variations were lower inside both showcases than outside.

The comparison between the environments inside all the showcases, regardless of the building in which they are located, indicated that the *Ney Braga* one had the higher average T and SH, whilst the *Indigenas* showcase had the higher average RH. The *Animais* showcase was characterized by the highest daily thermal variations both on average and in the maxima, and also by the highest daily hygrometric variations on average. Specific humidity was higher in *Fan* showcase than in all the other showcases, whilst concerning the daily variations the lowest were recorded in *Indigenas* showcase and the highest in *Ney Braga* showcase.

Concerning light, the two big showcases, regardless of the building, showed the most important problems related to the switching on the lamps during the opening hours of the Museum.
It is worthwhile to notice that the 1 day stop of the air conditioning system due on the occasion of the holiday didn't affected the thermo-hygrometric level inside the showcases of the new building.

With respect to the specific risks to museum collections in hot and humid climate, biological risk resulted low (moderate in *Ney Braga* showcase), the mechanical risk not significant. The main

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problems were related to the illumination systems and to the materials of which the two smaller showcases were built (both issues will be discussed in the following section).

In order to evaluate the **air quality** of the Paranaense Museum and to compare it with other international museums the final results are required, hence only preliminary considerations can be drawn at present.
SO_2 and O_3 presented low concentrations inside the showcases, below the limits defined by both the standards, whilst NO_2 didn't attend the guidelines.
Acetic and formic acids were detected in quite high concentrations inside some showcases, indicating the presence of possible sources, that required further investigation.
The PM was not measured directly inside the showcases, but the preliminary results of the elemental analysis of total PM seemed to indicate no particular damage potential to the collections. As soon as the analyses are completed, the results obtained will be discussed more in depth and compared with the findings of other studies and of other locations.

6.5 *Conclusions*

On the basis of the results of the monitoring program at the Paranaense Museum, some mitigation actions can be suggested in order to improve the microclimatic conditions inside the showcases.

In museums **lighting** is a compromise between the needs of visual appreciation and those of a good conservation of the works of art. Exhibition lighting fundamentally implies three problems: correct vision and enjoyment of colours, direct and indirect effects of photons reaching exhibits and convective air movements and soiling generated by the light sources.
All light sources have a characteristic emission spectrum, including in different proportions the UV and IR bands that are noxious and not useful for colour vision. Decay will depend on the light spectrum and intensity, but also on the specific material illuminated.
The best solution in every museum or gallery would be to keep the environment in the dark and to light exhibits with the lowest intensity of visible light required for viewing and only when people really want to watch them. This goal cannot be easily attained, hence more practical solutions are needed to realize the best compromise between conservation and vision.
The lighting systems of the showcases at the Paranaense Museum should be improved. In particular, the lamps of *Indigenais* and *Animais* showcases should not point directly at the exhibits and they should be placed outside the showcases. In fact, showcases with exhibition lamps inside will likely become small greenhouses because glass panes allow the passage of light in the visible range but less in the IR. Given that the IR emission may be largely relevant, especially with incandescent lamps (halogen lamps in the Paranaense Museum), heat is trapped inside the exhibition case, overheating objects and lowering the RH level. A good solution would be to place lamps outside the case and transport light inside with optical fibres. Another good strategy could be to use cold light from LEDs, if excellent colour rendering is not priority. Fluorescent lamps are

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not a good option because they have larger heat dissipation and this might be a problem when placed inside a closed showcase.

Concerning the **supporting structure** of the showcases, wood should be replaced with another material, as it reacts to the thermo-hygrometric variations of the room and it exchanges moisture with the internal atmosphere of the showcase. A sudden increase of the specific humidity inside the showcase, as it was observed in *Ney Braga* and *Fan* showcases, should be avoided in particular in case of hygroscopic and organic materials displayed.

The *Indigenais* showcase was characterized by the higher **microbial risk**, even if it was categorized as "moderate" and the relative humidity never exceeded the threshold value of 75 % RH. Nevertheless, the environment inside the showcase could be improved reducing the exchanges with the atmosphere outside the showcase that was characterized by higher levels of specific and relative humidity, and lower temperatures. Probably it would be enough to close the holes in the front glass panel to slightly reduce the hygrometric level, without increasing so much the thermal level. Of course this operation should be done together with the changes of the lightning system.

A permanent microclimatic monitoring of the Museum is strongly recommended, including the storage rooms, that actually preserve the heritage objects that are displayed during the temporary exhibitions in the old part of the Museum. In fact, besides the continuous monitoring of the thermo-hygrometric conditions in which the objects are preserved and the control of the good working of the active systems (air conditioning, dehumidifier, etc.), the comparison between the microclimate inside the storage and the exhibition rooms allow to verify the respect of the historic climate, i.e. the past indoor climate, if this climate has been proved not be harmful by a qualified specialist.

Concerning **air pollutants**, the preliminary results indicated that the most important issue is related to the high HAc and HFor concentration values. Possible sources of these gases inside the showcases need to be identified, in order to suggest some interventions to improve their air quality.

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