3encult

EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

D 6.2 Documentation of each study case CS2 Palazzo d´Accursio/Municipal Palace, Bologna (Italy) Delivered at M42

EUROPEAN COMMISSION

DG Research and Innovation

Seventh Framework Programme

Theme [EeB.ENV.2010.3.2.4-1]

[Compatible solutions for improving the energy efficiency of historic buildings in urban areas]

Collaborative Project – GRANT AGREEMENT No. 260162

Technical References

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0 Template for Case study presentation

0.1 General Information

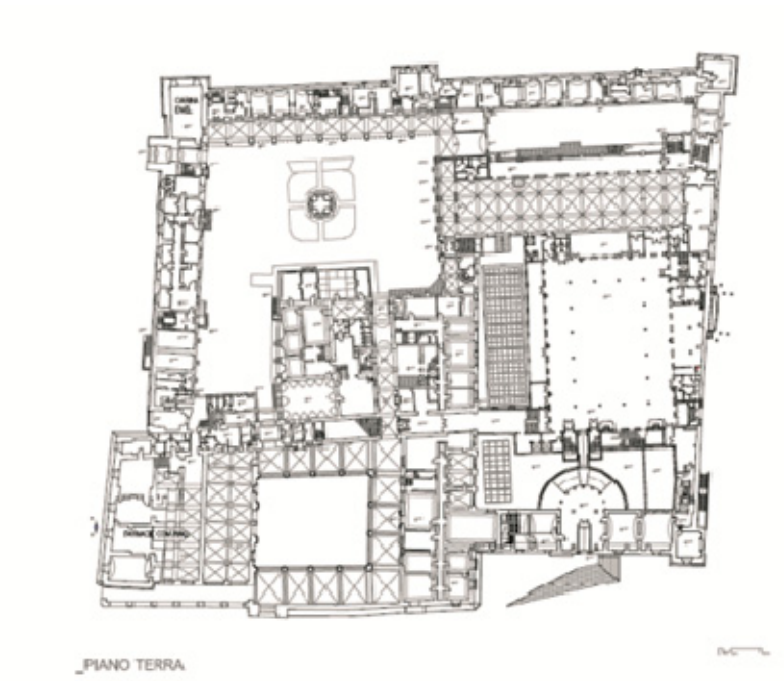
Location	
	
Name and location of building	Palazzo d'Accursio, Piazza Maggiore, 40100 Bologna Cadastral number: 6 Altitude: 54 Heating days: 15 October-15 April: 183 days Heating degree days: 2259 HDD
Previous locality names	Palazzo della Biada (1295)
Legal investigation	**Ownership**: Municipality of Bologna **Local legislation**: Urban Building Regulation **Protection status**: Listed building in accordance with law 42/2004 (Italian Code of Cultural Heritage and Landscape)
Heritage administration	The subject in charge of the object is the local Authority for Cultural Heritage, together with the Bologna Municipality which is the owner. The building is qualified as *building of historical and architectonic interest* in the Urban Building Regulation Code, and therefore admits only respectful interventions of renovation and maintenance.

Deliverable D6.2 Documentation of each study case

Responsible Planner/ Architect	Municipality of Bologna- Public works and infrastructures department – Cultural Heritage sector – Arch. Manuela Faustini Fustini
Local case study team	Manuela Faustini Fustini, Fabio Andreon, Francesco Tutino, Daniele Zappi, Chiara Margini, Pamela Lama, Federica Legnani, Davide Capuzzi, Camilla Colla, Elena Gabrielli, Marco Giuliani, Enrico Esposito, Antonio del Conte, Valerio Nannini, Sandra Dei Svaldi, Mena Viscardi, Nicola Silingardi
Name and company of surveyor	Arch. Manuela Faustini Fustini - Municipality of Bologna, Silvia Gialluca, Ing. Enrico Esposito - Artemis srl, Arch. Valerio Nannini, Arch. Nicola Silingardi – ICIE

Aerial view of Palazzo D'Accursio seen from South-West

Aerial view of Palazzo D'Accursio seen from the North

General description incl. building problems	
	
Date of construction	1295- First phase of construction- Original nucleolus of the building
Architect/Artist/other persons	1425 Fioravante Fioravanti designed main courtyard after a fire that destroied this part of the palace. 1478 Nicolò dell'Arca placed the statue of Madonna on the facade of the Palace 1513 Bramante built the staircase 1547 Vignola built the portal inside the courtyard 1550 Alessi built the portal of the principal facade of the Palace 1562 Prospero Fontana painted the Chapel of the Cardinal at the 2° floor (cappella Farnese) 1583 Francesaco Morandi (called Terribilia) completed the construction of the east part 1661 Paolo Canali redesigned the south front of the principal courtyards 1874 Antonio Zannoni restored the front of the palace 1879 Raffaele Faccioli restored the main front on Piazza Maggiore
Architectural style	Medieval with later Renaissance parts: not homogeneous architectural style, severe architectonic language for the XIV century part, decorated and embellished features for the XV century part;
Typology of building	Palace

Deliverable D6.2 Documentation of each study case

Original objective	Since the origin, in the medieval phase, the Building had a central role for the city being at first the Public Warehouse and collective goods repository for the citizenship. Soon it was turned into the official venue of the local Authority and Government.
present use	Municipality Head Offices – Town Hall
expected use in the future	Municipality Head Offices - Town Hall
Construction materials	Brick for the wall structure; Marble and sandstone for the decoration; Wood for roof structure, tiles and copper plates for its covering;
Construction method	Masonry construction
Short description of building	The original nucleus of the building was the so called Biada Palace, used for the storage of grain. This has been then expanded over the centuries to become the institutional headquarter of the city. It was protected by walls and towers, located at the four corners of the quadrilateral perimeter, with entries in the middle. The building has hosted different institutions and functions in several historical phases.Since 1336 The Palace hosted the city Government, then the papal legation, and later on it testifies the Cisalpine Republic period. Nowadays it is the seat of the city municipality and of prestigious Museums, such as the Morandi Museum and the Arts Municipal Collections, which houses paintings and furnishings from the Middle Ages to the 19th century.The Palace is located in the historical centre of Bologna, in the core of an ancient formation where the original Roman urbs used to be. The northern view is towards the ancient Via Emilia (now known in that stretch, as via U. Bassi). Maggiore Square, on which the main facade of the Palace overlooks, is the hub of the public life in the city, where the public and religious festivities are celebrated.
Number of Axes	Three axes
Shape of roof	Hipped roof
Internal access	Central access
Status quo	Complex building, consisting of parts with different architectural styles, seat of public institutions, two museums (the Morandi Museum and the Municipal Collections of Ancient Art), a citizens information office and a municipal pharmacy
Overall conservation status	No structural problems; antiquated plants network.
Actual European energy standard	There's actually no Energy standard norm for historic buildings.
building problems with regards humidity	In general the presence of humidity is very limited, although it must be remembered that IRT will show it only in the presence of superficial evaporation, otherwise it could pass unnoticed to this type of investigation. The IRT investigation of Palazzo D'Accursio has required several measurement

	sessions during the period February-July 2011, due to the complexity of the structure and also because only the passive approach has been chosen, due to very large surfaces to be explored; different environmental situations have allowed to put in evidence many hidden structural characteristics of the building, along with a series of problematic spots.
building problems with regards salts	No problems concerning salts were found.

Planned activities within the project	
Diagnosis	The proposed work is to consider some strategic points inside the Palace to analyse the state of the art from a thermo-hygrometer point of view. These areas should help detecting: building structure type and different destinations of use of the building: • characteristics and maintenance conditions of the building envelope; • heating and cooling; • types of the fixtures; • type of lighting adopted; • types and distribution terminals; • description of the systems installed in thermal power stations and distribution substations; • description of the air handling units and cooling equipment, if any; • technical operating features, type of control. This first analysis will be conducted with the aid of special tools and equipment such as infrared cameras, advanced data-logger, etc. Subsequent energy audits, purely intended as processing of information gathered, will be performed using validated software that, running an energy balance of the building with the allocation of energy consumption in end-use, allows to evaluate the energy benefits from different interventions aimed at reducing energy consumption. Interventions may include: building envelope; the plant systems; adaptation to the mode of use through an adjustment or partition of the system.
Planned solutions	1. new control systems and air handling system monitoring; 2. new energy-saving systems dictated by innovative lighting fixtures; 3. insulation systems for walls and coverage floors; 4. insulation system of the windows.
Monitoring system	Monitoring is done through several commercial and experimental technology systems under evaluation.
Simulation	Simple methodology using dedicated software like PHPP and Energy Plus

Transfer to urban scale concept	The aim is to study solutions compatible with the historical monument and the cultural functions that take place inside, increasing energy efficiency and implementing proper strategies for the energy sustainability and urban regeneration of the City of Bologna.
Others	Heating elements made of cast iron radiators and to a less extent of steel, powered by two power stations to produce a mixture of steam and hot water heating fluid with critical consequences in the proper management of the heat delivery;- Lack of control systems such as zone valves and thermostatic valves, with high levels of environmental pollution.

0.2 Building Assessment

Cultural Value (Specific valuable aspects)	
Architectural historical value	The building's architectural and historical distinctive features are really that of including in a "unique" a summation of architectural and decorative styles (from the Middle Ages to the Renaissance and after) that makes it particularly interesting and representative at the level of various study design characteristics.
Cultural historic value	The building has an historical and cultural value for the city, being the Palace that hosted and still hosts most important Institutions - civil, political, and religious - in different historical phases. Therefore the building has always symbolically represented the Authority governing the city.
Context value	The urban system of squares made by Maggiore, Nettuno and Re Enzo Squares is the place where the most prestigious monuments and buildings of the city and the representative offices of the most important city institutions concentrate. Maggiore Square represents the civic community of Bologna, is dominated by the impressive facade of San Petronio Basilica which stands in front of “Palazzo del Podestà” and is concluded by the 16th century colonnade of “portico dei Bianchi” which connects the Square to Galvani Square.
Social value	The building has a very strong symbolic value for the community of Bologna, having hosted the most important Municipality institutions.
Constraints conditions	Precise indications about the type of renovation admitted for buildings of historical and architectural interest are given the article n. 25 of the Urban Building Regulation Code. In particular the interventions can be: • the renovation of the architectural features and the restoring of altered parts: • renovation of outer facades or interiors, • philological re-construction of eventually missing

parts of the building,

- conservation or restoring of shared spaces like courtyards and gardens;
- the consolidation with substitution of un-repairable parts without modifying the position and height of major walls, lofts, ceilings, stairs and roofs (with re-making of the original roof covering;
- the removing of elements that have been recently added or are incoherent with the original scheme of the building;
- the insertion of essential technological and sanitary installations, respecting the previously given constraints.

The building is qualified as building of historical and architectonic interest in the Urban Building Regulation Code, and therefore admits only respectful interventions of renovation and maintenance. The typologies of intervention and modification admitted are described at the art. n. 57 of the Building Regulation Code, specifically with requisites nr. IS 1, 2, 3.

In particular, the Regulation Code prescripts to preserve the original integrity of every architectonic, artistic and decorative element of it.

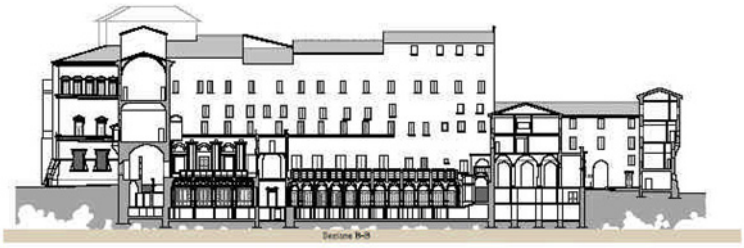
For the preservation of original characters of the building, the limitations, given by the requisite IS nr. 1 of the Code, are the following ones:

- to preserve and conserve the building roof in its original shape and consistence, and this concerns specifically interventions like the insertion or addition of chimneys, skylights, gutters or pluvial; in particular, in the conservation of the original shape of the roof, every new component put in substitution must have the shape and colour of the previous original one;
- roof insulation and ventilation must be extended to the whole roof surface, keeping the thickness inferior to 20 cm, eventually rising the roof's height;
- to insert small chimneys for airing in order to conserve the original shape of the roof, putting them close as possible to the roof top, avoiding products made of cement, fibre – cement, or plastic ;
- to keep the technological installations for the reception of signals (like parabolic antennas for TV/Earth satellite signals) within the number of one for building, placing them inside indoor locations or on secondary pitches;
- to satisfy the need for lighting of every indoor room, avoiding the opening of slots in the roof pitches, using only skylights, keeping these aligned to the existing ones, at a distance of at least 1,5 m from the gutter's line;
- to keep the gutters and the pluvials in good conditions: in case of substitution, products made of

	plastic or zinc laminate must be avoided; • To keep the original shape and design of every façade: this concerns specifically the opening of new windows or the changing of the dimensions of the existing ones, the making of terraces, balconies, bow-windows or façade chimneys which is avoided for all the facades facing external public spaces. Only the re-opening of previous existing windows is permitted. Modifying existing openings is allowed only if the façade overlooks minor patios or backing spaces and if it collaborates to the rational reordering of the façade image. • The impact on the façade of the positioning of electrical wirings must be reduced as far as possible; the wires and the installations components must be hidden in every possible way, as far as the norms on safety allow it, by locating them inside the building or under the paving of the street or the one of the porch, When on main facades, they should be aligned and positioned in order not to interfere with decoration or painted parts. It is avoided to install heat pumps, boilers, air conditioners, or motor condensing units on roof pitches, on main facades and under porches. • To extend the maintenance of original plasters and superficial coatings to every coated façade of the building, in order to preserve them as they were. • To keep the original window infixes and shading elements in every external perimeter wall. In case of substitution, which is admitted only if the original components cannot be repaired, the new inserted elements must have the same partition, material, colour and shape of the previous. • Then, for the preservation of the historical characters and of the original indoor distribution scheme of the building, the constraint, expressed by the requisite IS n.2 of the Code, prescript to maintain the original status:; In particular: adding new dividing surfaces is allowed only if they do not interfere with the façade's openings; • Original dividing walls, even the secondary ones with no structural function, with architectural value or original decorations, original garrets or suspended ceilings with historical value must be maintained and renewed; • New lofts located inside the rooms must be fixed to the opposite wall facing the external one with windows and openings, at a distance of at least 2,40; • The whole area of the new single rooms located inside the historic building can't exceed the 30% of the whole area of the building; • New rooms can be located in the under-roof space only in case the electrical installations and wiring needed do not interfere with existing elements of architectural and historical value; • The constraint for the preservation of external and

	open spaces of historical buildings, given by the requisite IS n.3, prescripts to keep the original organization and conditions of gardens and courtyards. Therefore: the installation of service lifts, anti-fire stairs or elevators, which cannot be done by means of enclosed volumes, is permitted only in minor courtyards and patios, on minor architectural value facades, positioning them outside of the optic cone of the inner major rooms or entry porches. • The ecological balance of gardens cannot be altered. Original garden pavements and furniture must be maintained in the original conditions.
Limits and prescriptions arising from Area Regulations	According to the Emilia-Romagna Regional Law, the Structural Plan of Bologna (PSC) has listed Palazzo d'Accursio as one of the "buildings of historical and architectural interest" (edificio d'interesse storico architettonico). Some of those buildings are also listed by the national law. The PSC has set the aim of the preservation (to maintain the value of the buildings of historical and architectural interest in the urban context or in the landscape) and some rules for any interventions and change in use. Any kind of intervention that involves those buildings which are also listed by the national law (like Palazzo d'Accursio) must be allowed by the authority for the preservation of the cultural heritage, namely the so-called Soprintendenza. Therefore every action or use modification involving the buildings only listed in the PSC must respect the restoration criteria set. For more detailed rules, the PSC refers to the Urban Building Regulation (Regolamento Urbanistico Edilizio). Precise indications about the type of renovation admitted for buildings of historical and architectural interest are given the article n. 25 of the Urban Building Regulation Code. I The typologies of intervention and modification admitted are described at the art. n. 57 of the Building Regulation Code, specifically with requisites nr. IS 1, 2, 3. In particular, the Regulation Code prescripts to preserve the original integrity of every architectonic, artistic and decorative element of it. Then, for the preservation of the historical characters and of the original indoor distribution scheme of the building, the constraint, expressed by the requisite IS n.2 of the Code, prescript to maintain the original status:; The constraint for the preservation of external and open spaces of historical buildings, given by the requisite IS n.3, prescripts to keep the original organization and conditions of gardens and courtyards.
Limits and prescription determined by the owner	In 2010, the Municipality adopted an internal regulation for the use of municipal halls, both by private bodies or associations, and by the same administration. Such regulation lists those Palace halls that can be used for hosting public events, whose compatibility must coherent with the structural and monumental characteristic of the place. Inside these halls, it is not possible to assemble structures

	which differ from those already present and it is not allowed to place food services of any kind. The use of the halls is affected by all the applicable safety standards and at night the constant control of the access should be guaranteed.
Preservation concept	The main concept is to preserve the original integrity of every architectonic, artistic and decorative element of it, in particular: • the consolidation with substitution of un-repairable parts without modifying the position and height of major walls, lofts, ceilings, stairs; • the insertion of essential technological installations, respecting the previously given constraints; • the reversibility of each intervention.

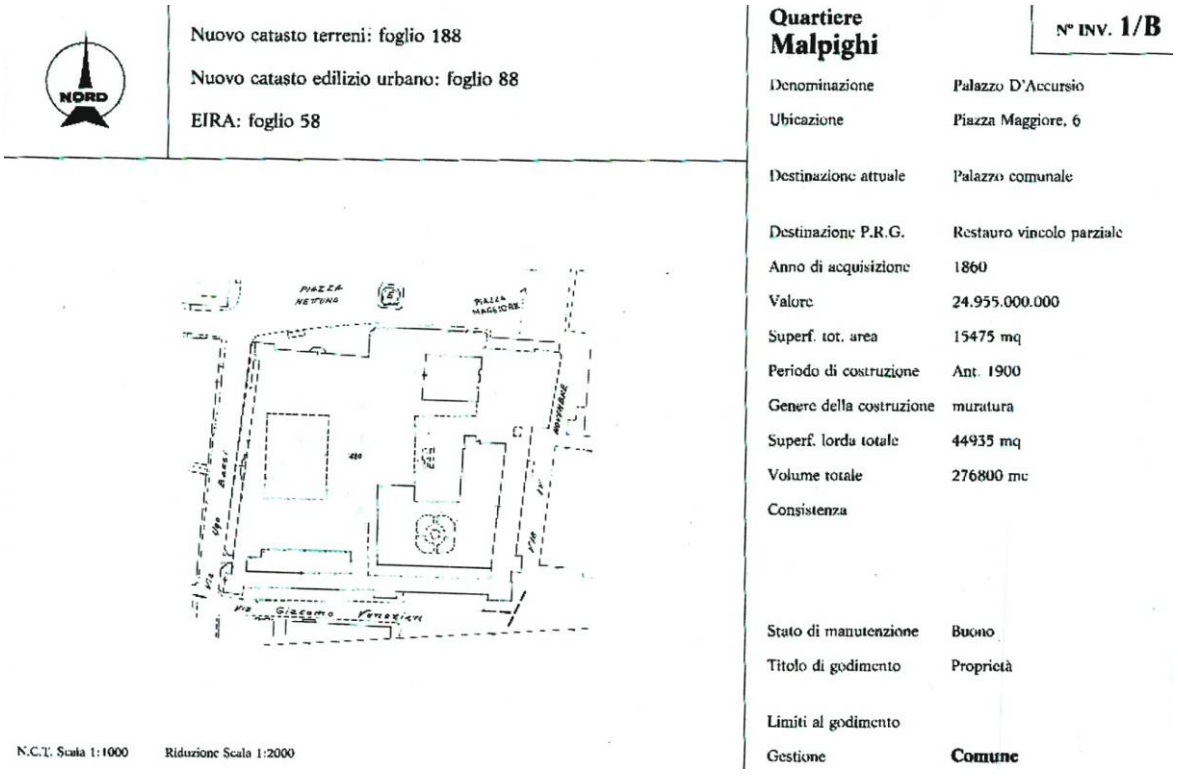
Documentation	
diagrams/drawings	1pAccursio.pdf, 1trapAccursio .pdf, ptAccursio .pdf, 2pianoAccurCollez.pdf 
expertises/reports	CS2-BlowerDoorTest.pdf, CS2-Hygrothermal and environmental monitoring.pdf, CS2-Tests in Room 14 (Sala Agostini).pdf, CS2-Tests on the external facades.pdf, CS2-The applied hygrothermal and environmental monitoring system.pdf, Doc 3EnCult_281112_analisi energetica stato di fatto.pdf, Doc 3EnCult_290113_monitoraggio.pdf
photographs/images	context photo.jpg, groundfloor plan.jpg

0.3 Detailed description

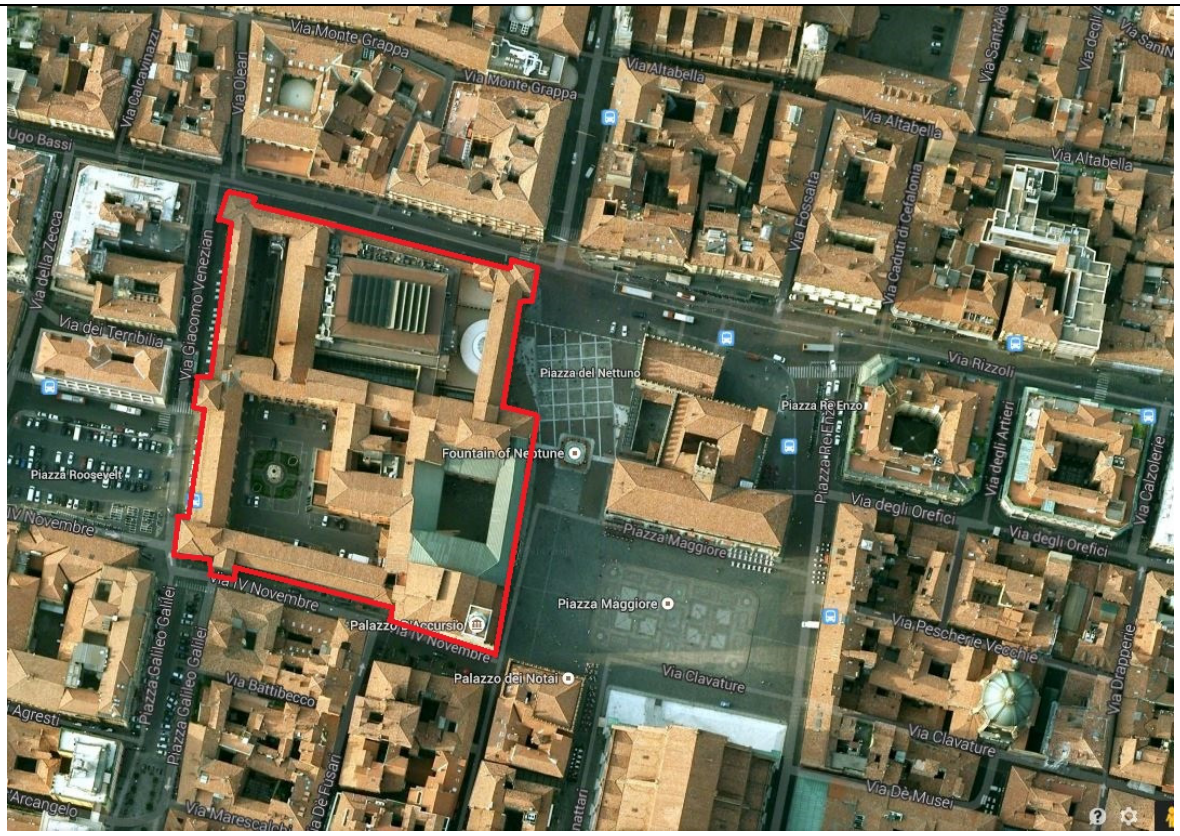
0.3.1 Urban Context and Local climate data

Urban Context

Cadastral map excerpt/site plan



Deliverable D6.2 Documentation of each study case



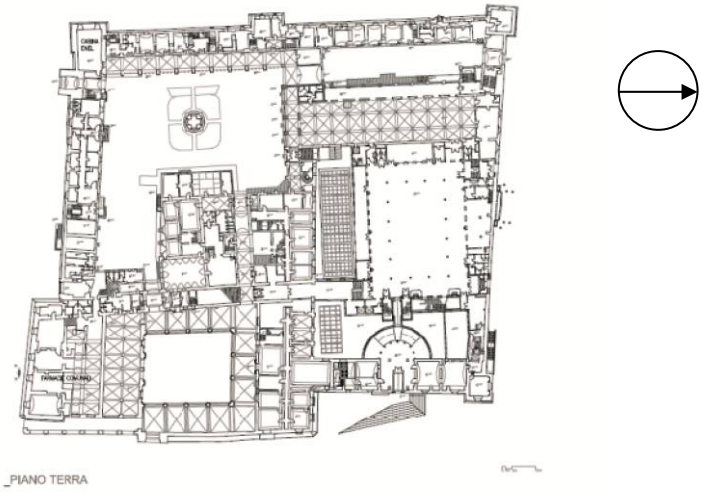
Relation with neighbouring buildings	Location in the most ancient part of the historic city centre, between Maggiore Square and ancient Via Emilia, where the original core of the “roman urbs” was located,; The urban system of squares made by Maggiore, Nettuno and Re Enzo Squares is the place where the most prestigious monuments and buildings of the city and the representative offices of the most important city institutions concentrate. Maggiore Square represents the civic community of Bologna, is dominated by the impressive facade of San Petronio Basilica which stands in front of “Palazzo del Podestà” and is concluded by the 16th century colonnade of “portico dei Bianchi” which connects the Square to Galvani Square.
Quarter/town/surrounding	The Palace is located in the historical centre of Bologna, in the core of an ancient formation where the original Roman urbs used to be.
location/orientation/ accessibility	The northern view is towards the ancient Via Emilia (now known in that stretch, as via U. Bassi). Maggiore Square, on which the main facade of the Palace overlooks, is the hub of the public life in the city, where the public and religious festivities are celebrated.
Development plans	As the building and its site are strictly bound by the protection constraints as object of architectural, historical and cultural heritage value, only renovation and ordinary maintenance development plans are admitted.
Certificates/reports/regulations on energy efficiency	In the year 2005 the Decree 192 (updated in 2006 and 2009), and the Government Decree 28/2011 have implemented at Italian level the EU Directive 2002/91/EC on Energy Performance of Building (EPBD) and Directive 2009/28/EC

	regarding the promotion of RES use. EPBD regulation has been adopted as local legislation at regional level for a few Regions in Italy, among which Emilia Romagna Region (DAL 156/2008). Decree 28/2011 has been recently incorporated in EPBD regulation by Emilia Romagna Region (DGR 1366/2011). The National and Regional regulation of EPBD is not applied if the respect of minimum energy performance requirement compromise the Cultural heritage value of the Historical Building.
Historical context	Part of historical monumental complex.
Necessary data for PHPP calculation available: Monthly mean averages of temperatures and solar radiation?	The last version of PHPP (V8.4) provides climate data for Bologna. The existing data are sufficient to achieve the objective of the calculation: the evaluation of design alternatives. If comparison with real consumption of specific year is the aim, related climate data should be used
Particular architectural solutions according to the local climate	Local traditional dimming and shadowing solutions: use of the "Bolognese" tent in the entire façade facing Maggiore Square (East) and in the facades of the main courtyard, consisting of an outside tent, red-brick coloured, mounted on metal slides; wooden window shades in the secondary courtyards and along the side walls on the South and West sides.
Overshadowing	No overshadowing effect on the roof surface are detected in the area considered of our study.
Nearby areas for organizing the onsite retrofit works	The Palace is located in the historical centre of Bologna, in the core of an ancient formation where the original Roman *urbs* used to be. The northern view is towards the ancient Via Emilia (now known in that stretch, as via U. Bassi). Maggiore Square, on which the main facade of the Palace overlooks, is the hub of the public life in the city, where the public and religious festivities are celebrated. In the Buildings are present areas for organizing the on-site retrofit works.
Use during the retrofit works	The building is still being used as the renovation and refurbishment works concern only a portion of it, corresponding to the “Coat of Arms” Room. Therefore every part and zone of the building can be accessed except for the “Coat of Arms” Room which is closed to public and currently scuffled for the refurbishment works.

Local climate date	
Climate zone	E
Climate area	3F
Degree days	2.259
Coordinates:	Lat N 44° 29‘ - Long E 11° 20'

Altitude	54 m
Average wind speed	1,60 m/s (max 3,20)
Prevailing wind direction	South/West

Building plan showing the north



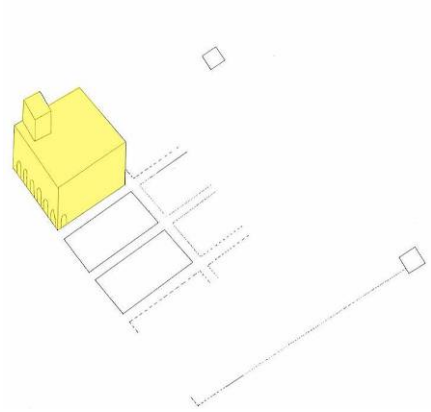
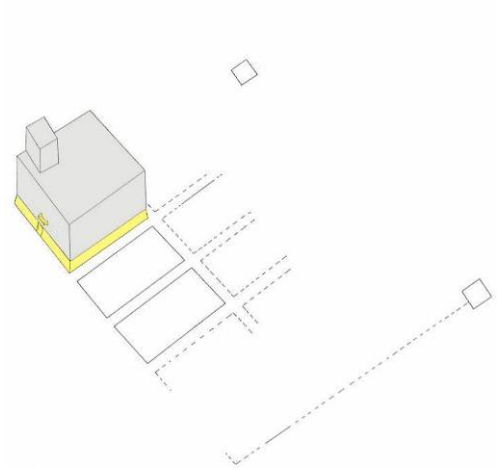
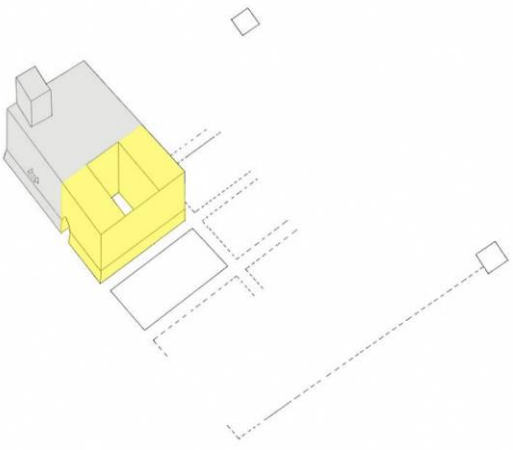
Winter climate data		Summer climate data	
Winter design temperature	- 5°C	Temperature: dry/wet bulb	dry/wet bulb: 33/22 °C
HR max (Nov.-Dec.)	95% (Nov.- Dec.)	HR	43%
Heating day per year	183 (15 Oct.- 15 Apr.)	Daily temperature range	12 °C

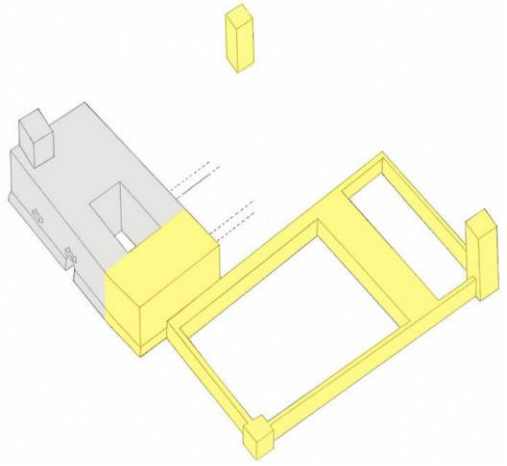
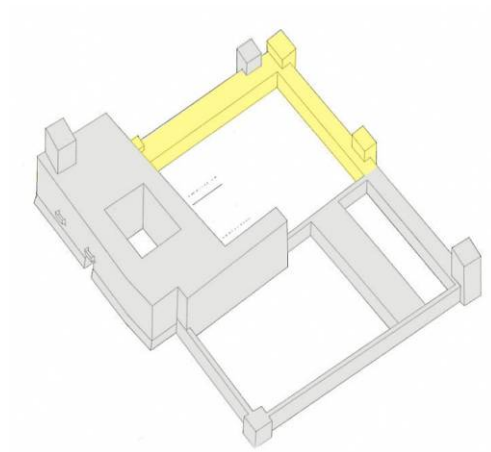
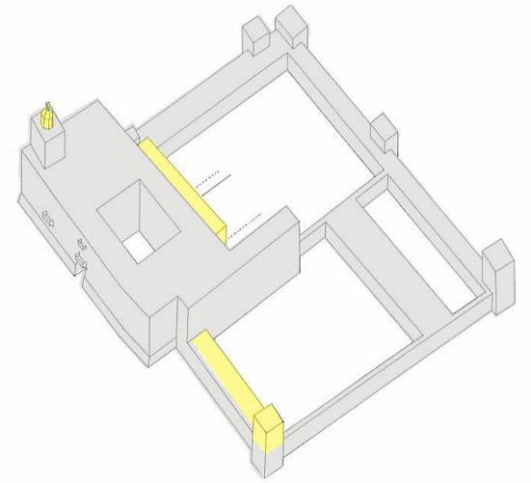
Available data for the project	Weather data recorded at the station of Bologna - Borgo Panigale and communicated by the service "IdroMeteoClima" of the ARPA of the region Emilia Romagna allow to define the current local weather trend.
Reference statistic data from “common database” (e.g. Meteonorm)	**Reference data - static system** UNI 10349 **Reference data - dinamic system** Energyplus database
Reference climate data	Weather data recorded at the station of Bologna - Borgo Panigale and communicated by the service "IdroMeteoClima" of the ARPA of the region Emilia Romagna allow to define the current local weather trend.
Data measured from local weather station	yes

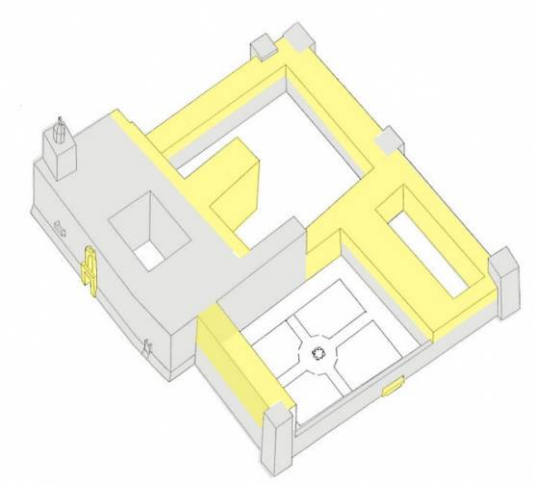
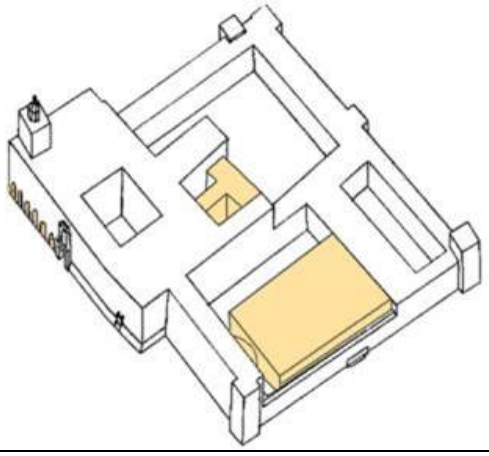
Measured climate data	yes

0.3.2 Report on history of the building

History of the building	
Use of building in time	The original nucleus of the building was the so called Biada Palace, used for the storage of grain. This has been then expanded over the centuries to become the institutional headquarter of the city. It was protected by walls and towers, located at the four corners of the quadrilateral perimeter, with entries in the middle. The building has hosted different institutions and functions in several historical phases. Since 1336 The Palace hosted the city Government, then the papal legation, and later on it testifies the Cisalpine Republic period. Nowadays it is the seat of the city municipality and of prestigious Museums, such as the Morandi Museum and the Arts Municipal Collections, which houses paintings and furnishings from the Middle Ages to the 19th century. Some information has to be given in order to sum up the additions and structural changes made over time, mostly repairs and renovations. The actual structure of D'Accursio Palace is the result of several interventions, beginning with the construction of the original thirteenth-century nucleus of the so called Biada Palace, which was initially used as a corn deposit. It was protected by walls and defensive and lookout towers, which were located at the four corners of the quadrilateral, and at intermediate access points. Already in 1365, to defend his power, Cardinal Legate erected crenelated walls interspersed with towers. In 1425, following a fire, the part of the building that faces Maggiore Square was completed by the architect Fioravanti in a typical local late-Gothic style. In 1508, the walls were reinforced around the main nucleus with white and red merlons (the same colours of the city vessel). Inside, in the main courtyard, the western body of the palace was built with of a porch whose architecture was similar to the one of the previous century, and with a "ribbed" staircase used to let horses go up to the second floor. In the phase between 1513 and 1796, when the city was ruled by a mixed government composed by a senate appointed by the citizens and a Cardinal directly designated by the Pope, the Palace hosted the apartments of the Cardinal Legate, one at the ground floor and another at the second, where a chapel was built during the second half of year 1500 by Galeazzo Alessi and then frescoed by Prospero Fontana. At the end of the sixth century, the building showed the consistency it has nowadays, apart from the area of the botanical garden, where the Stock room was built in 1886. Therefore, the architectural style is obviously not homogeneous. The fourteenth part overlooking Maggiore Square has a very severe style without decorations. The fifteenth century part of the building has a different battlement and has marble mullioned windows. Everything is united by a large portal designed by Alessi in mid-1500 constituted by double pillars in sandstone with a statue of Pope Gregory XIII in the middle (reformer of the calendar). The sides of the palace are still closed as a fortress of solid bricks.

Historical summary table **History of the buildings** Construction phases			
First phase of construction:	1295	Original nucleolus of the Building (Palazzo della Biada)	 Palazzo della Biada in 1295 (Origin of Palazzo d'Accursio)
Second phase of construction (first extension):	1340	Palazzo Grande di Taddeo Pepoli	 Palazzo della Biada in 1336 (First addition)  Taddeo Pepoli's Palazzo Grande in 1340
Third phase of construction	1425	Palatium Apostolicum (1365-1425) Construction of the	

		crenellated walls with towers	 Palatium Apostolicum des Andrion de la Roche at 1365
Fourth phase of construction	1436	Construction of the Cortile degli Svizzeri. Reinforcements of the walls	 Palatium Apostolicum with Cortile degli Svizzeri in 1436
Fifth phase of construction	1513	Completion of the cardinal lagate apartments (fistrs and second floor)	 Palatium Apostolicum in 1513 defined also as Giulio II's Palace
Sixth phase of construction	1585	Construction of the buildings around the Cortile degli Svizzeri	

			 Palatium Apostolicum in 1585
Seventh phase of construction	1886	Construction of the Stock room in the area of the botanical garden named Sala Borsa	
Restoration phases			
First restoration	1885	Palazzo della Biada front restauration	
Second restoration	1933	Restoration front with the substitution of old windows	
Third restoration	1936	Realization Municipal collections inside to Giulio's palace	
Fourth restoration	1939-1943	Restoration ovest front	
Other comments			

0.3.3 Building consistency

Building consistency	
Description state of the building	The building does not have any particular structural problem. On the other hand, there are some problems for the management of the plants network due to the antiquated status of these. Moreover, some roof parts are damaged causing rain water infiltrations and thermal dispersions.
Description construction method	The whole construction is in brick bearing walls with two or three heads of bricks. The building materials are typical of the area: as said, brick for the bearing structures (two or three heads), sandstone for the decorations and with some exceptions marble for the embellishment of the architecture, while the roof structure is entirely made of wood (beams, trusses..).
Description shape	Courtyard historic building
Description of facades and roof	All the buildings facades facing the exterior are made of bricks with decorative parts in marble. The roofs have a wooden structure with major and secondary beams, covered by terracotta tiles and by copper layers only for the bodies facing the monumental courtyard.
	
Number of floors above ground	5 floor (Ground floor, 1st under floor, 1st floor, 2nd under floor, 2nd floor).
Number of basement floors	2 floor
Covered area	11.826 m2
Numbers of rooms	1.376

Gross area	44.935 m2
Net area	35.025 m2
Heated surface	35.025 m2
Gross volume	276.800 m3
Heated volume	158.258 m3

Occupancy rate (number of inhabitants/users)	485 employees; 1.000 visitors per day.
Occupancy time (h/week, d/month)	Offices area (From Monday to Friday 6:00-18:00); (Saturday 7:00-16:00); Museum areas and public access (Everyday 6:30-18:00)

Building Services (as- is-state)	
Heating system	Operating plants in the building D'Accursio Palace, including the Stock Room, is provided with two heating power stations (called "Palace Power Station", and "Stock Room Power Station") and an autonomous generator, with a distinct location than the others (informally called "CALDAIETTA", "small boiler"). While the ground floor and the first floor mezzanine of the south exposed offices are heated by the "small boiler", the first floor and the second floor mezzanine of the same offices and the Arts Municipal Collections are heated by the generators of the heating power stations that produce warm water located inside D'Accursio Palace. The area covered by the study is equipped with a thermal station called "CT Palace" containing four heat generators (two produces warm water and two produces vapor) and a autonomous heat generator defined "small boiler". While the ground floor and the first floor mezzanine of the south exposed offices are heated by the "small boiler", the first floor and the second floor mezzanine of the same offices and the Arts Municipal Collections are heated by the generators of the heating power stations that produce warm water located inside "D'Accursio" Palace. Technical features of the plants Current heating system of the building are based on cast iron radiators. The "CT Palace" main heating system is controlled and regulated by an external probe, this does not permit temperature monitoring suitable of the interiors; for this reason, many workers are equipped with electric heaters that control and manage independently. The heating power station called "Palace", contains four generators of heating: two of them produce warm water, whose temperature can reach the 90 °, and the remaining two produce vapour. These generators work for several locals that have different heating needs in winter: because of this, some throttles have been installed at the end of every single distribution system of each area, in order to provide regulation according to the function of the heated interiors and to their use. Since autumn 2007 the City Hall of D'Accursio Palace is being heated with the so called "white gasoil" – or "Gecam"Â, gasoil emulsified with water (90% gasoil

and 10% water). The delivery temperature estimated for the water produced by the heating generators is 70°-75° while the return one corresponds to 60-65°; this information is being constantly monitored by a computer located inside the “Palace” power station.

The two heating generators do work simultaneously, the warm water produced is sent to the mixers and then to the several collectors connected to the delivery installations in the various areas of D’Accursio Palace. The same happens for the heating generators producing vapour. The heating generators that produce warm water are regulated by an external sonda located between the first floor mezzanine and the first floor on the north looking facade, and this does not permit temperature monitoring of the interiors. The warm water generators, indeed, are regulated by an internal sonda located in a single room.

These sporadic monitoring cause a wide dissatisfaction among the workers, mainly because the areas of the building that have a better solar exposure have a high comfort while the other ones are very cold and force many office employees to use stoves. The Council Room and the adjacent rooms are heated by means of the actual radiators that use both the warm water heating generators and partially the heat pump, provided with an inverter, able to warm and to cool as well.

The "Small boiler" is regulated by means of a thermostat placed in the ground floor offices, independently adjusted by the occupants. The ground floor of the considered offices (actual Headquarters of the Municipal Police) and the first floor above are warmed by a small condensation boiler of 28 kW, which makes this area heating-autonomous.

This installation is regulated by means of a thermostat placed in the ground floor offices, and works together with an inverter provided heat pump (brand: DAIKIN, model: RXYQ5M7W1B) which produces both heating and cooling and can be turned on manually.

This heating generator, informally called “Caldaietta”, little boiler, warms the Municipal police offices that are open during the whole week 24 hours a day, and the upper floor as well, even if it would not be necessary on weekends, and at night as it hosts the headoffices of the Municipal Council staff, which works following a normal timetable.

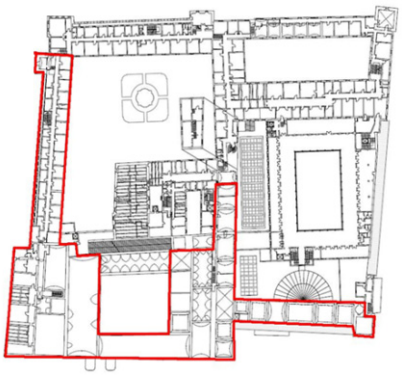
Distribution system

In the study areas there are:

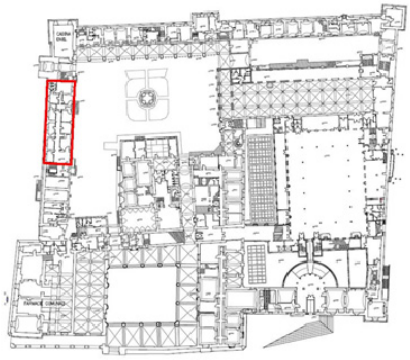
- 74 radiators heated by "CT Palace"
- 31 radiators heated by "Small boiler"
- 15 electric heaters with a power 1500 W/each

Water temperature of the heating system: 70-75°C

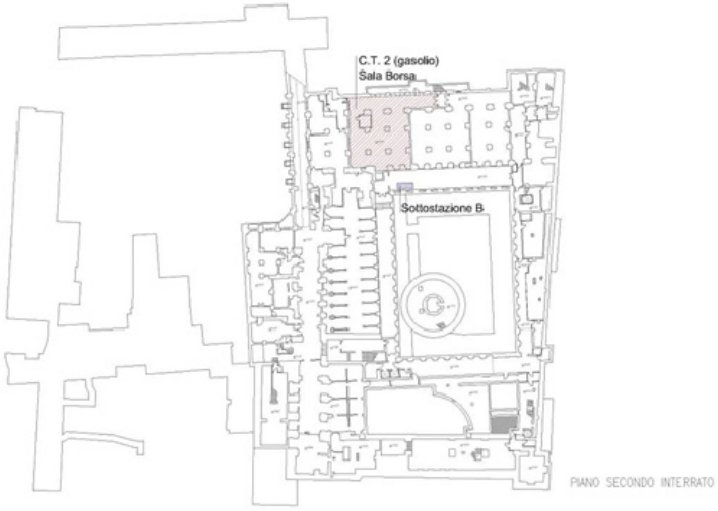
Generator located in the Palace power station



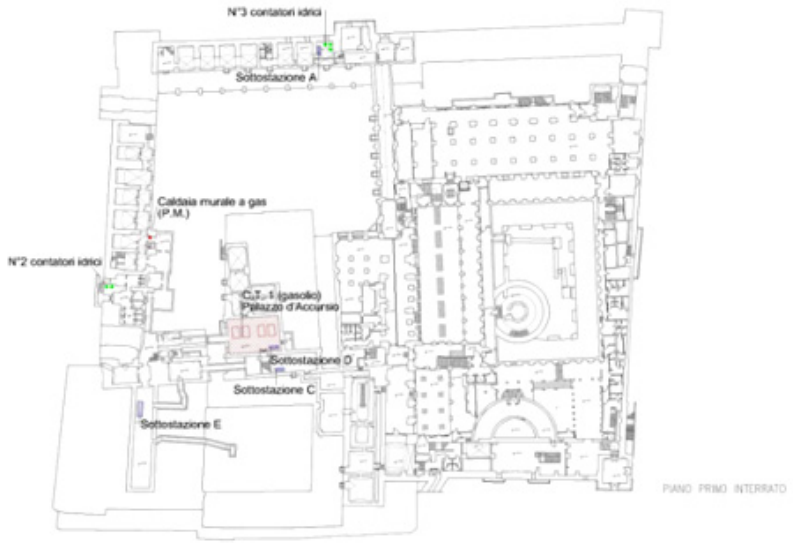
and indicative perimeter of area warmed

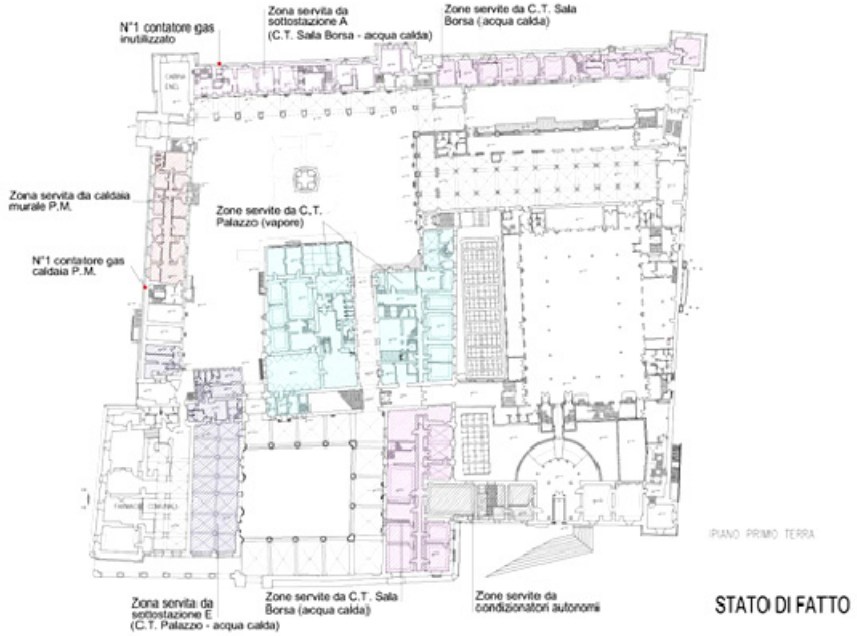


Small boiler (caldaietta) and the indicative perimeter of warmed area



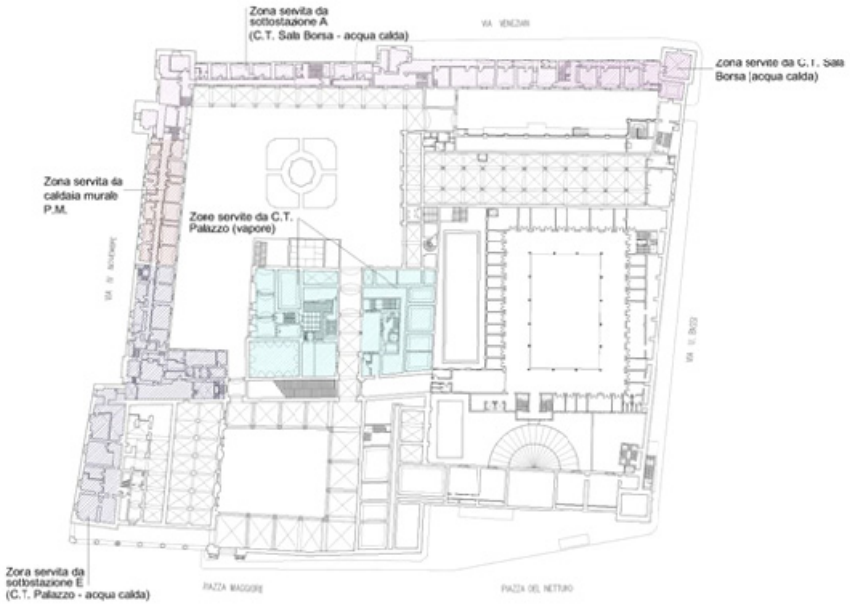
Second Underground Floor



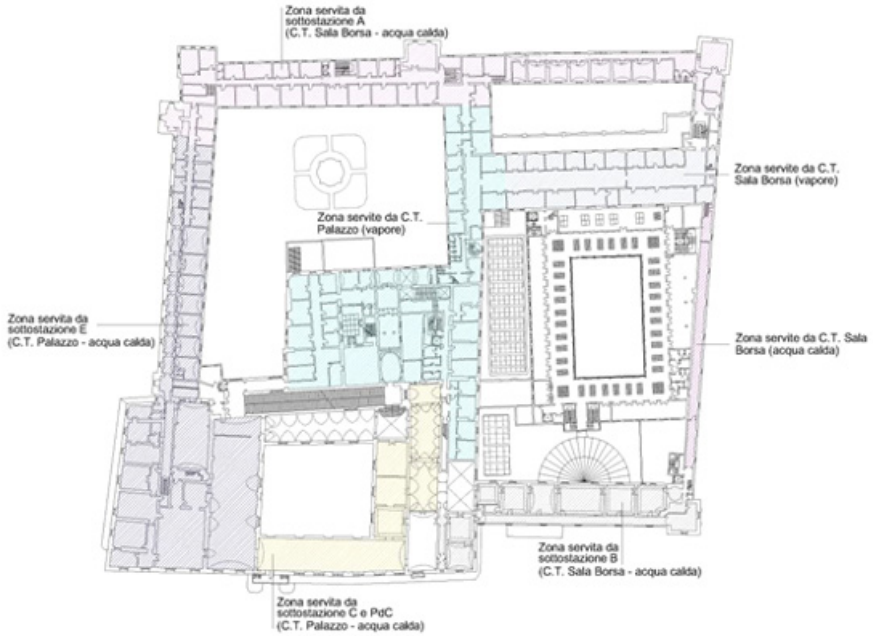


First Underground Floor

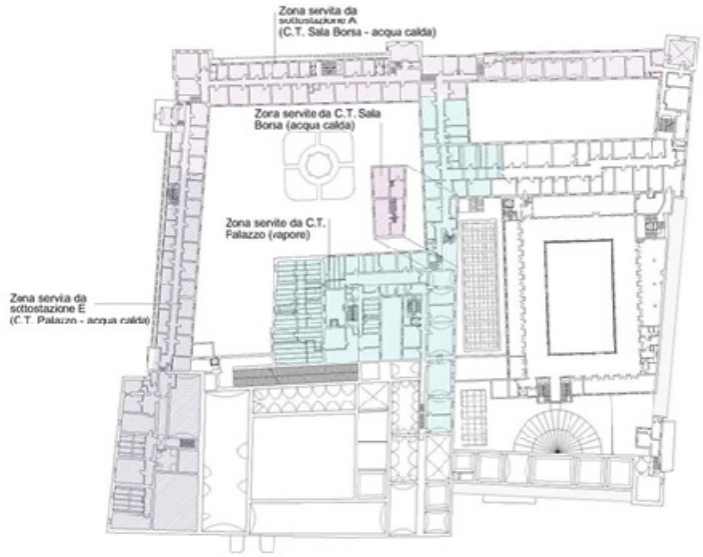
Ground Floor



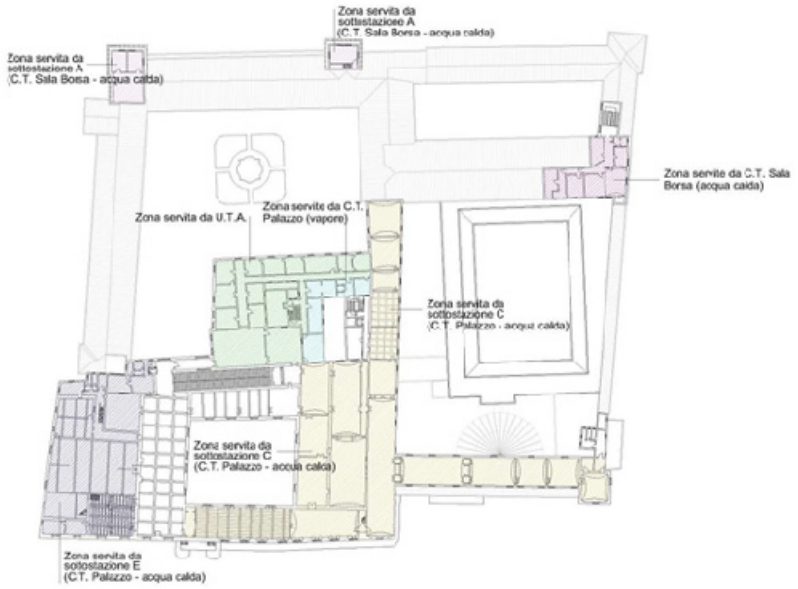
First Mezzanine Floor



First Floor



Second Mezzanine Floor

	 Second Floor
Plant room	The main plant room corresponding to the CT Palace Generator stands at the first Under-ground Floor. Small boiler is installed and located in the office area at the ground Floor hosting the Municipal Police.
Electrical System	D'Accursio Palace is equipped with electrical boxes (low voltage) that divide the building into areas and floors, connected to a cabin Enel (medium voltage) placed outside.
Ventilation System	No Mechanical Ventilation system is installed for control the quality of the air. There isn't a system of controlled natural ventilation, the windows are opened directly by the occupants according to the their needs.
Cooling System	Current cooling system of the building (air based system, radiant floor, etc.): independent heat pump inverter with split, fans and portable air conditioner are present in the office area. Heat pumps with inverters that can be turned on manually both in winter and spring have been installed in several points of the building. Because of the type of use it's very difficult to predict the Energy consumes, that will be hypotheses only after completing a list of the installed heat pumps. Characteristics of local terminals : in the study areas there are nine splits of heat pump inverter with a power 1100 W each. The systems mentioned above are controlled and regulated manually by the individual worker. There is no thermal energy storage system/tank in the building.
Wastewater disposal	The water used comes from the aqueduct. For the disposal of water there isn't differentiation between white water and black water.
Renewable Energy	Actually no renewable energy sources is used in the building. During the years 2009 and 2010 all the palace was included on green electricity energy procurement. No solar thermal or PV installation are installed.
Artificial Lighting	The census of the functioning lights has not been made yet, and because of this it's not possible still to give any precise indication about the type of installation and its consumption. Current luminaires (type, e.g. reflector-diffuser, optics, etc., and position) inside the building are fed by the general line, the cabin and some external electrical panel of the whole building, recently rehabilitated. From the cabinet at the terminal there are different solution that reflect the time of installation. The general

	lines, including the adaptation of the cabin and some external electrical panel, were rehabilitated in 2005. The Municipal Collection electric system has been completely redeveloped in the 1980s while the local police office system was completely renovated in 2008. Over the years, there have been also partial work redevelopment of the electrical plants in individual parts of the building. No external luminaires (e.g. facade illumination) is installed. There isn't empty available casings for electrical wires.
Use of Daylight	Openings in walls, in the roof are available. Only a few corridors and service rooms are without windows.
DHW production	For the production of Domestic Hot Water are used boiler with electric resistance, placed in the bathrooms.
Chimney/ducts	There are external ducts available.

Building Potential	
Potential for energetic use	No potential for energy production. The wide thickness of the perimeter walls guarantees a good level of thermal inertia, but only in case of optimization of the buildings thermal envelope performance (infiltration and thermal dispersion limitation).
Subterranean floors and basements and the possibility of air exchange with upper floors/roof	There aren't subterranean floors that can be used for this purpose.
Possible heat exchange with the surrounding ground	Not Possible
Possible use of energy sources on the building or from nearby, possible application of "smart grids"	Not Possible
Possibility of installation of geothermal collectors (dimension)	Not Possible
Possibility of de-/central ventilation system (available space/wiring etc.)	Only in some specific portions of the building where the physical and visual impact of the technical installations (cables, systems, wiring) can be limited.
Transferability of (energetic) refurbishment solutions to other buildings	The refurbishment purposed solutions concerning the roof, the windows and the lighting, can be applied to the other many public historical protected buildings present in the town having same or similar architectonic and structural features. In particular for what is concerned with the window frames substitution, this solution can be transferred as well to all other historic buildings only where the existing ones are damaged and only with frames or other components with the same features (shape, colour, material) of the original substituted ones.

0.3.4 Building Energy consumption

Energy bills	The data referring to D'Accursio Palace's thermal consuming (including CT Palace Power Station and CT Stock Room) have been provided by BGP (Public Municipality Building Estate manager).
Documentation of former energy audits	No former energy audits carried out
Measured energy consumption as-is-state	For a general overview of the range of the consumes, in the following tabs are reported both thermal and electric consumes data. Both the data referring to total consumes and to singular consumes derived from every generator serving the areas included in the study have been analyzed and surveyed. Overall consumption data for the whole Palace surveyed across different seasons are provided in the following tabs.

The areas of Palazzo d'Accursio Palace focuses on the following ones:

- Arts Municipal Collections: at 2nd floor.
- South facing Offices: (Municipal police offices at ground floor, P1 first floor mezzanine – first floor P1 – and P2 second floor).

While the ground floor and the first floor mezzanine of the south exposed offices are heated by the "small boiler", the first floor and the second floor mezzanine of the same offices and the Arts Municipal Collections are heated by the generators of the heating power stations that produce warm water located inside D'Accursio Palace.

In particular the thermal consuming data for the areas heated by the "CT Palace" thermal station are recalled below, according to the different seasons of survey:

- Season 2007/2008: 19,87 kWh/mc, 109,74 kWh/mq, (DD 2152,5)
- Season 2008/2009: 20,47 kWh/mc, 113,09 kWh/mq, (DD 2238,1)
- Season 2009/2010: 21,15 kWh/mc, 116,82 kWh/mq, (DD 2405,7)
- Season 2010/2011: 19,54 kWh/mc, 107,96 kWh/mq, (DD 2300,8)
- Season 2011/2012: 20,94 kWh/mc, 115,70 kWh/mq, (DD 2.295,7)

The thermal consuming data for the Offices areas heated by the "Small boiler" thermal station are recalled below, according to the different seasons of survey:

- Season 2007/2008: 31,16 kWh/mc, 99,07 kWh/mq, (DD 2162,8)
- Season 2008/2009: 32,06 kWh/mc, 101,93 kWh/mq,(DD 2238,1)
- Season 2009/2010: 31,21 kWh/mc, 99,22 kWh/mq, (DD 2405,7)
- Season 2010/2011: 30,91 kWh/mc, 98,25 kWh/mq, (DD 2300,8)
- Season 2011/2012: 31,160 kWh/mc, 99,19 kWh/mq, (DD 2300,8)

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Total consumption of Palazzo d'Accursio

Gecam (White Diesel)	Years	Degree Days (DD)	Consumption (lt)	Consumption (kWh)
	season 2007/2008	2.152,5	278.497	2.674.180
	season 2008/2009	2.238,1	286.988	2.755.712
	season 2009/2010	2.405,7	296.450	2.846.568
	season 2010/2011	2.301	318.971	3.062.819
	Season 2011/2012	2.405,7	341.765	3.281.691
GAS	**Years**	**Degree Days (DD)**	**Consumption (mc)**	**Consumption (kWh)**
	season 2007/2008	2.152,5	5.128	49.204
	season 2008/2009	2.238,1	5.276	50.624
	season 2009/2010	2.405,7	5.136	49.281
	season 2010/2011	2.300,8	5.085	48.798
	season 2011/2012	2.405,7	5.127	49.201

Electricity	Years	Consumption (kWh)
	2007	3.429.851
	2008	3.296.794
	2009	3.286.083
	2010	3.011.260
	2011	2.931.342
	2012	2.890.682

0.4 Constraint condition and protection

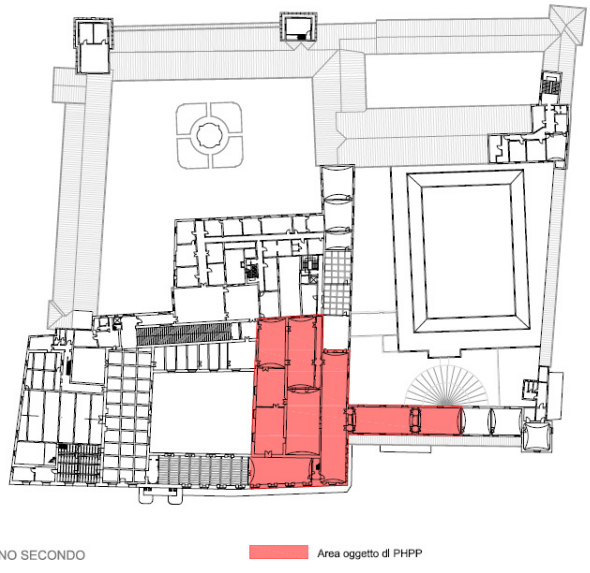
Constraint condition and protection	
Description of building safety with regards statics/structural problems - compliance with local regulations	See section 1.2
Certificates/reports/regulations on statics	The intervention that has been carried out in the "Sala Urbana" is defined as "non relevant intervention for what is concerned with public utility" by Regional Government Decree (DGR) n. 687 of 2011. A formal Declaration signed by the project Director and an Explanatory Technical Survey have been released together with the graphic material as is requested by the current Regulations for interventions of remaking of the secondary warping, of the board, of the panels, and of the outer envelope, of wooden or steel roofs, with an overall eventual weight increase inferior or corresponding to 10% respect to the present conditions. The Explanatory Technical Survey contains the information in relation to the building typology and explicitly indicates the dimensions and functions of the intervention and the context in which it has been carried out.
Description of building safety with regards dangerous materials (to remove)- Compliance with local regulations	During the roof refurbishment works a layer of guano droppings left by the pigeons was removed.
Certificates/reports/regulations on dangerous materials	No dangerous material are present in the building.
Description of building safety with regards fire protection - compliance with local regulations	The building is good in terms of safety of fire.
Certificates/reports/regulations on fire protection	Ministry Decree of 22nd/2/2006 on fire prevention "Technical regulation for fire prevention within design, construction and functioning of buildings or indoor spaces dedicated to offices" Ministry Decree nr. 569 of 20th/5/1992 on fire prevention in historic buildings "Safety rules for fire prevention and protection in historic buildings hosting museums, galleries, expositions and exhibitions";
Description of building safety with regards seismic safety - compliance with local regulations	The renovation project has included a significant improvement of the seismic performance of the upper walls by means of metal plates located in order to tighten the structure holding the roof. Besides this, the intervention of renovation inside Palazzo D'Accursio's "Sala urbana" has include the following actions:

	- Insertion of a curb in light steel (12 kg circa of weight) and some series of armed brick walls; - Vertical threaded boards for connecting the edges of the roof trusses to the walls below; - Wooden boarding and steel drilled tape (RothoBlass type) as groundwater upwind; - Insertion of wooden screws (HBS type) in the nodes of the trusses for reinforcing the existing connections and for fixing the new secondary warping to the principal one;
Certificates/reports/regulations on seismic safety	Guidelines for the evaluation and reduction of seismic risk in cultural heritage – alignment to the new Technical Code for buildings" Act nr. 26 of 2nd/12/2010 First Minister Directive Guideline for the evaluation and reduction of the seismic risk in cultural heritage of 12th/10/2007
Description of building safety with regards noise protection - compliance with local regulations	The classification of the building is based on the existing national and regional codes as well also for the evaluation of the acoustic comfort, and in particular: • At national level the Framework Law n. 477/95 and its executive decrees DPCM 14/11/97 and DMA 16/3/98, • At regional level LR 9/5/2011 and "Direttiva regionale 2053/2001". • At local level "Acoustic classification of Bologna communal territory" ODG n°42 of 20/1/2010. The review of the documents related to the acoustic classification of the city of Bologna, which represents one of the main tools of governance of the territory as well of protection from noise, evidenced that the zone where the building is located belongs to the Acoustic Class n. III called "Mixed type areas" and, besides that, is also part of the airport acoustic classification_"Zone A". The official documents that deal with this topic refer to the prescriptions given by the Regional Code n°2053/2001 "Dispositions on noise pollution" and on the National Law n°477/95 and to its Executive Orders. In particular, the Acoustic Zoning, following the article n.5 of the National Law n°477/95, contains the subdivision of the territory in five acoustic classes that correspond to the first five ones defined by DPCM 14/11/1997 with the limits of noise compatible with each use. These acoustic classes are named by the existing norms as "Territorially Homogeneous Units" (UTO). The fourth Acoustic Class, called "areas with intense human activity": areas with intense vehicular traffic and high population density, with high presence of commercial activities, offices, crafts, nearby main roads and railways, port areas, areas with limited presence of industries. For every acoustic class, following the indications of DPCM 14/11/1997, for every acoustic class are given specific edge-values of sonic emission, that is the "attention values"

	and the "quality values", distinct for day time (6:00 AM÷10:00 PM) and night time (22:00 PM÷6:00 PM). For every acoustic class, following the indications of DPCM 14/11/1997, for every acoustic class are given specific edge-values of sonic emission, that is the "attention values" and the "quality values", distinct for day time (6:00 AM÷10:00 PM) and night time (22:00 PM÷6:00 PM). The absolute edge-value of emission has been defined referring to the "continuous equivalent sonic level" (LAeq) measured in dB (decibel) during the whole daytime or night time period. The sonic level, measured in indoor residential spaces is due to the presence of external sources (road-railway traffic, railway, street yards, etc..) and of indoor activities, within the same space or in adjacent ones. At the following URL further specification on the urban acoustic classification of Bologna can be found: http://www.comune.bologna.it/ambiente/servizi/6:345
Certificates/reports/regulations on noise protection	The classification of the building is based on the existing national and regional codes as well also for the evaluation of the acoustic comfort, and in particular: • At national level the Framework Law n. 477/95 and its executive decrees DPCM 14/11/97 and DMA 16/3/98, • At regional level LR 9/5/2011 and "Direttiva regionale 2053/2001". • At local level "Acoustic classification of Bologna communal territory" ODG n°42 of 20/1/2010.

0.5 Selected area of intervention

0.5.1 Functional Area 1- Municipal Collections

Functional area consistency	
Description 	Selected area is dedicated to the art collections of the city with paintings and furniture related to different ages. This area has problems related to the maintenance of movable goods kept inside, with critical issues related to the hygrometric control and mixed construction characteristics. The area can be accessed by the public from h 9 am to h 6 pm. It isn't provided with any air conditioning.
Number of rooms	9 rooms selected (14 rooms are devoted to the Municipal Collection)
Heritage aspects	Selected area is dedicated to the art collections of the city with paintings and furniture related to different ages, hosting both important pieces of art and fresco decoration, therefore being part of the most valuable heritage of the Palace.
Second floor 	

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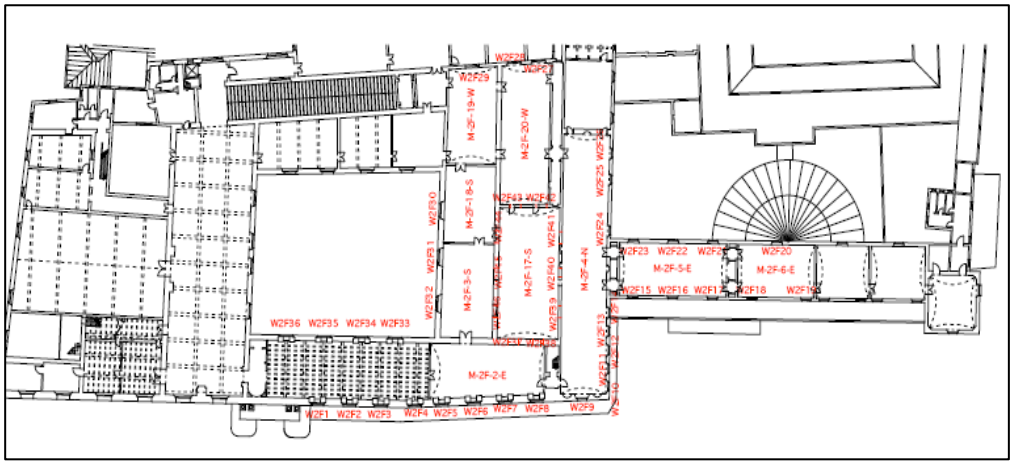


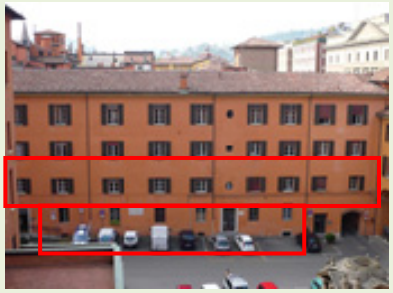
Second Floor Plan detail

Height interpolated average net (m):	6,51 m
Surface area (Gross/Net) heated (mq):	1.073,69 m^2
Volume (gross/net) heated (mc):	6.990,76 m^3
Opening to the public (from/to; hours /day; temperature set-up):	09:00-18:00
Hours of working (from/to, hours/ day; temperature set-up):	Monday-Sunday 06.30-18:00
Hours of air conditioning (from/to; hours/day; temperature set-up)	No air conditioning

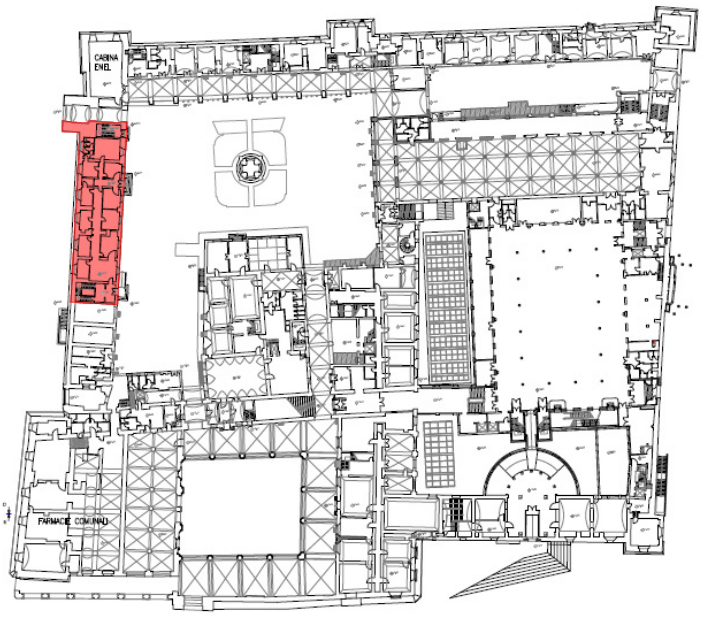
Consumes (CT Palace Thermal Station): Sub area 1 : Municipal Collection – Second floor

Gecam (White Diesel)	**Years**	**Degree Days (DD)**	**Consumption (lt)**	**Consumption (kWh)**
	season 2007/2008	2.152,5	14.465	138.891
	season 2008/2009	2.238,1	14.906	143.126
	season 2009/2010	2.405,7	15.397	147.845
	season 2010/2011	2.300,8	14.229	136.633
	season 2011/2012	2.405,7	15.246	146.397
Electricity		**Consumption (kWh)**		
		57.637		

0.5.2 Functional Area 2 – Pusterla Tower – Municipal Police Offices

Functional area consistency	
Description 	Selected area is located in the Southern Wing of the building part bordering the "Pit Courtyard". This area includes the ground floor and the first under-floor. The ground floor actually hosts the Municipal Police Headquarters Offices, that are operative 24 hours/day during the whole week.The first under-floor hosts the offices and reunion spaces for the local Political Assembly Groups of the City Council and the Municipal Council Staff, which works following a normal timetable. For what is concerned with the technical systems operating in the area, this portion of the building is heated with a small condensation boiler of 28 kW, informally called "Caldaietta" ("Small Boiler"), that affects the ground floor together with part of the first under floor, which makes this area heating-autonomous. The reason is that the headquarters of the Municipal Police, being on duty during the whole 24 hours day length, need to use this boiler continuously.
Number of rooms	45 rooms (23 GF, 22 1st under-floor)
Heritage aspects	Selected area is provided with consistent heritage value, as it forms part of the ancient part of the building with particular constructive features.

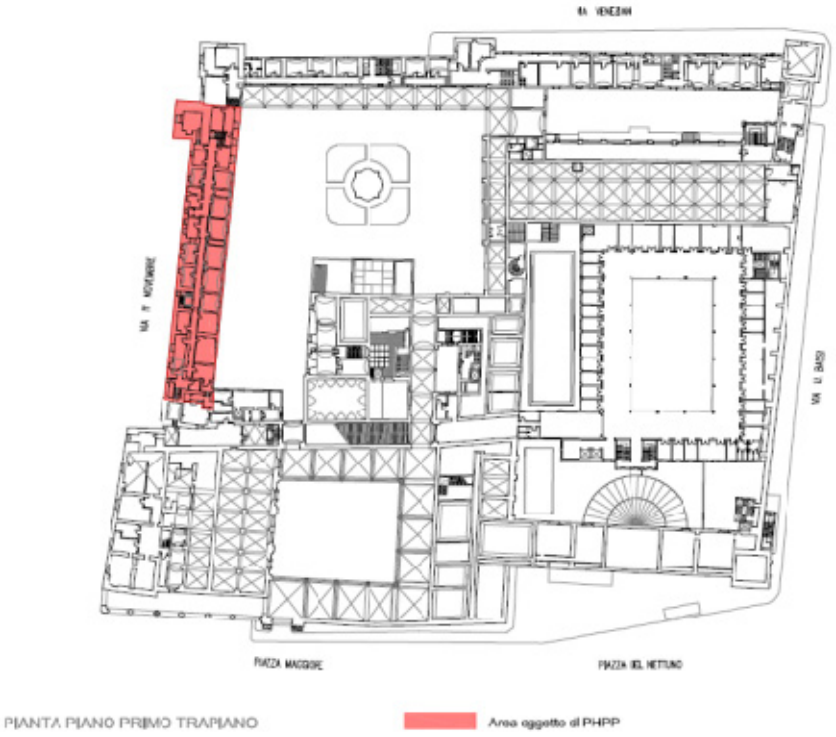
Ground floor



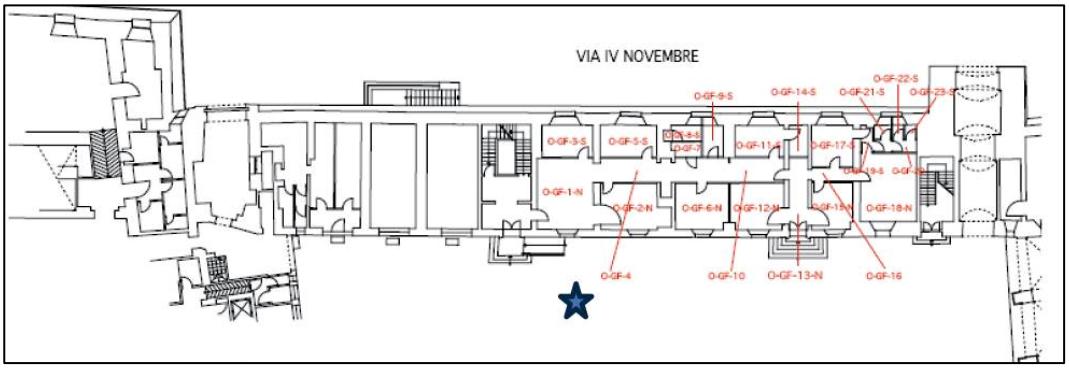
PIANTA PIANO TERRA

Area oggetto dl PHPP

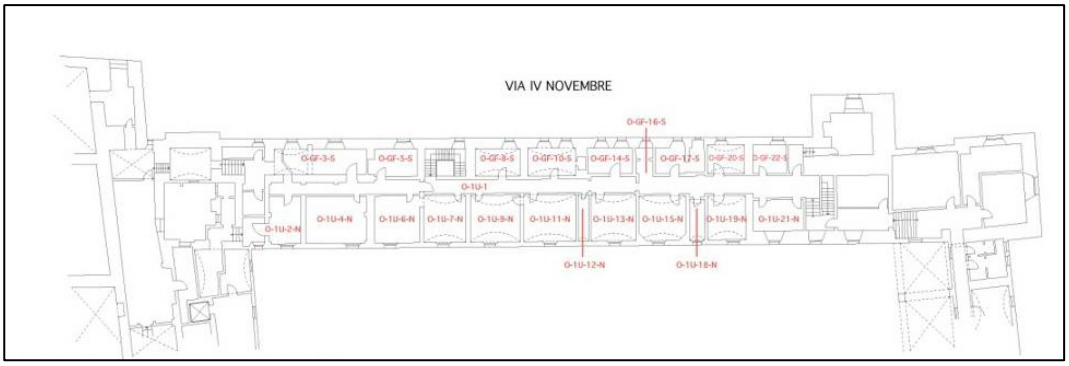
1st Under Floor



Selected rooms



Ground Floor Plan detail



First Mezzanine Floor Plan detail

Height interpolated average net (m):	3,18
Surface area (Gross/Net) heated (mq):	496,66 m2
Volume (gross/net) heated (mc):	1.578,96 m3
Opening to the public (from/to; hours /day; temperature set-up):	Mon-Sun 00:00-24:00
Hours of working (from/to, hours/ day; temperature set-up):	Mon-Sun 00:00-24:00
Hours of air conditioning (from/to; hours/day; temperature set-up)	Heat pomp (Daikin, model RXYQ5M7W1B)
Comments	Central access

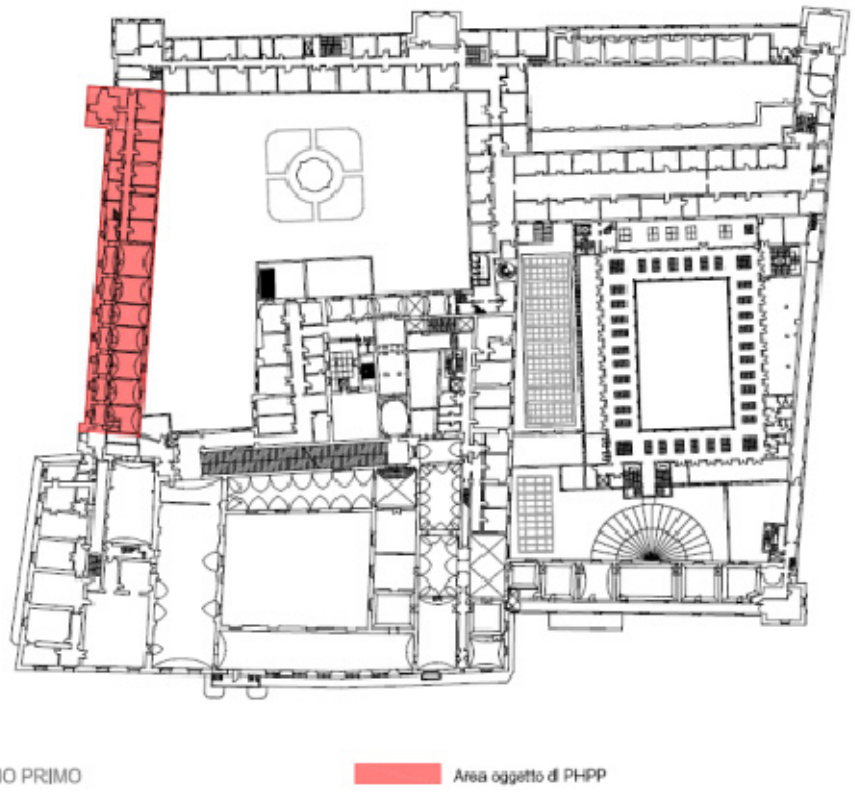
Consumes (CT Small Boiler thermal station): Sub area 2a Municipal Police GF and offices 1 under floor

GAS	**Years**	**Degree Days (DD)**	**Consumption (mc)**	**Consumption (kWh)**
	season 2007/2008	2152,5	5.128	49.204
	season 2008/2009	2238,1	5.276	50.624
	season 2009/2010	2405,7	5.136	49.281
	season 2010/2011	2300,8	5.085	48.798
	season 2011/2012	2405,7	5.127	49.201
Electricity*		**Consumption (kWh)**		
		58.252		

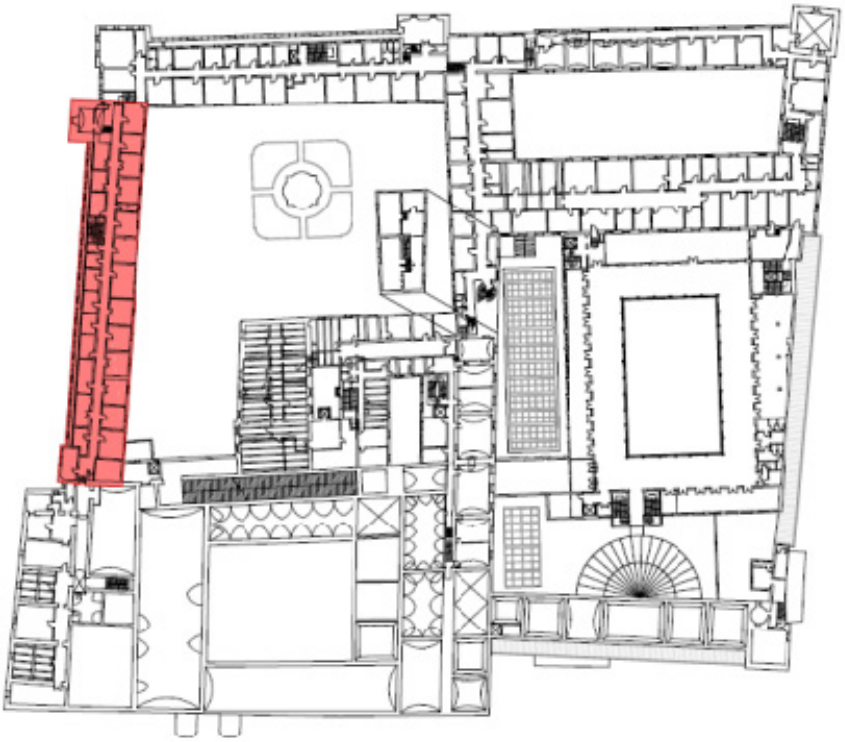
0.5.3 Functional Area 3 – Pusterla Tower – Municipal Offices

Functional area consistency	
Description 	Selected area is located in the Southern Wing of the building part bordering the so-called “Pit Courtyard” (“Cortile del Pozzo”). In particular this functional area includes the first floor and the second under-floor of the already mentioned South Wing. These actually host the Municipal Offices, open to the public from Monday to Friday from 09:00 to 18:00. These spaces are heated during the week from Monday to Friday from 06.00 to18.00 and only on Saturday from 07.00 to 16.00.
Number of rooms	49 rooms (20 1st floor, 29 2nd under floor)
Heritage aspects	Selected area is provided with consistent heritage value, as it forms part of the ancient part of the building, with particular constructive features.

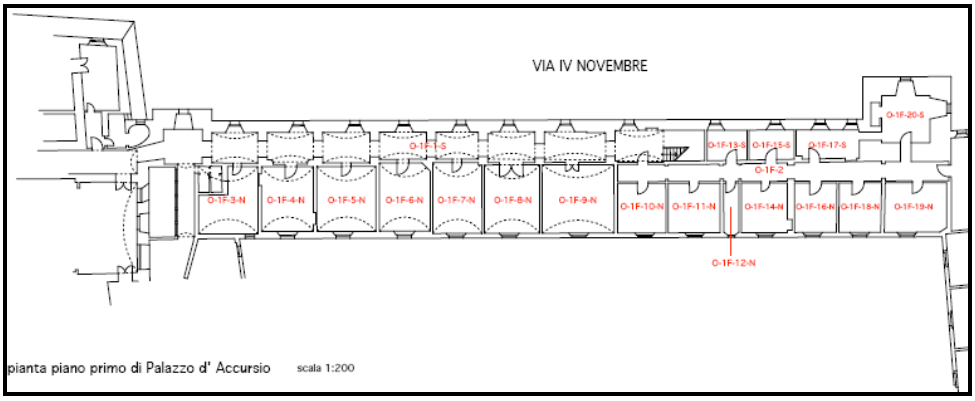
1St Floor



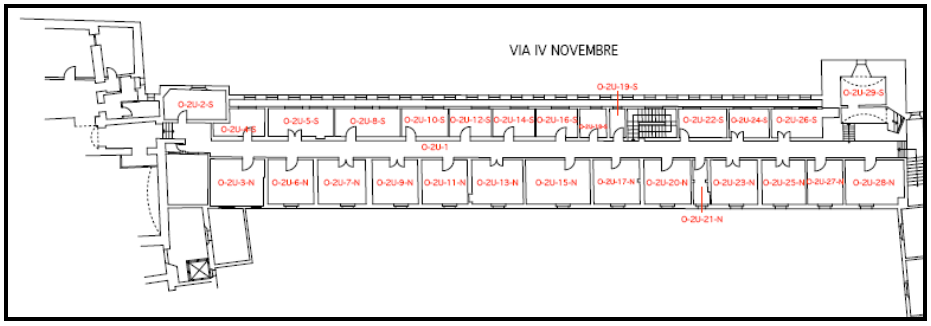
2nd Under Floor



Selected rooms



First Floor Plan detail



Second Under Floor Plan detail

Height interpolated average net (m):	3,31
Surface area (Gross/Net) heated (mq):	1.074,74 m2
Volume (gross/net) heated (mc):	3.696,55 m3
Opening to the public (from/to; hours /day; temperature set-up):	Mon-Fri 09:00-18:00
Hours of working (from/to, hours/ day; temperature set-up):	Mon-Fri 06.00-18.00 – Saturday 07.00-16.00
Hours of air conditioning (from/to; hours/day; temperature set-up)	No air conditioning
Comments	Central access

Consumes (CT Palace thermal station): Sub area 2b Municipal offices 1st floo and 2under floor

Gecam (White Diesel)	**Years**	**Degree Days (DD)**	**Consumption (lt)**	**Consumption (kWh)**
	season 2007/2008	2.152,5	7.649	73.442
	season 2008/2009	2.238,1	7.882	75.682
	season 2009/2010	2.405,7	8.142	78.177
	season 2010/2011	2.300,8	7.524	72.248
	season 2011/2012	2.405,7	8.062	77.411
Electricity*		**Consumption (kWh)**		
		43.134		

1 Report on status pre-intervention

1.1 Analysis of architectural elements

1.1.1 Thermal envelope

General description of Palazzo D'Accursio –Functional area 1 – Municipal Collections

The materials used for building the palace are typical of the area: brick for the bearing structures, with two or three heads; sandstone for the decorative pieces; and with some exception marble to embellish the architecture (present only in the lancet windows of the facade on the Maggiore Square).

The attics of the first and second floor of the Palace that overlooks the East side are mostly made of brick arches, with screeds of lime, sand and fill to the sides made of brick debris or stones. The ceilings on the second floor are made of thin plaster arches or sometimes of a wooden structure on which lays a wooden plank about 3 cm thick.

The parts which were added from the fifteenth to the nineteenth century generally have flat wooden floors, with primary and secondary wooden structure and screed made of limestone, sand and small brick debris, while the last buildings dating from the twentieth century have mixed floors in brick-concrete.

Throughout the building there is an attic, in some parts accessible through wooden walkways, with wooden frame and planks, or brick tiles. The roof is made of brick, with the exception of part of the roof on Maggiore Square, Which has a roof of copper plates.

The windows, also of great size, are all wooden, single glazed, with the exception of the Sala Borsa library, restored in 1980/90, where the old windows were largely replaced with new ones, with better air, temperature, water, etc, tightness.

The dimming systems are two:

- use of the "Bolognese" tent in the entire façade facing Maggiore Square (East) and in the facades of the main courtyard. It consists of an outside tent, red-brick coloured, mounted on metal slides;
- wooden window shades in the secondary courtyards and along the side walls on the South and West sides.

The thickness of the majority of the wall is not constant throughout the different portion of the building. In the office area there are walls with different thickness from 110 cm to 30,5. In particular in the Museum area the thickness is between 76 and 43 cm.

In particular, it is found that in the examined South area, the South-facing walls of the ground floor and first floor have a thickness of about 90-100 cm, while the remaining have a thickness of about 40cm. By the Municipal Collections, the external wall that overlooks the East side (Maggiore Square) has a thickness of about 40cm, while the one overlooking the West side has a thickness of about 25-30cm.

Heritage aspects

The thermal envelope is composed by walls built in traditional Bolognese full bricks with dimensions 28,2 cm x 14 cm x 6 cm. All of Bologna's historical buildings have been constructed using this typology of bricks since the Middle Ages.

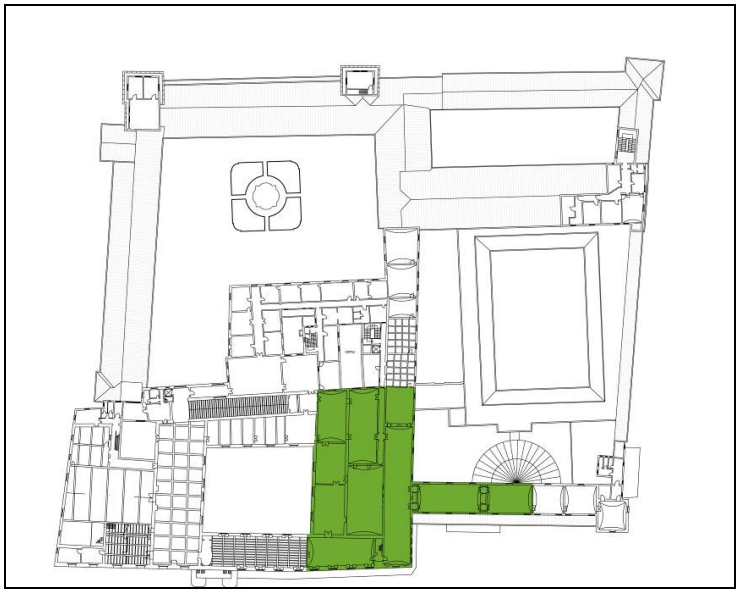
Analysis of Building envelope - bottom:

General description	
Description	The attic of the study area is characterized by surfaces covered with traditional marble stone.
Framing/construction scheme	All the masonry wall is based on solid bricks with different dimensions, roof structures and framing are wooden.
Total dimension	Functional Area 1 gross heated area: 1.073,69 sqm;
Specification of potentials and limitations	
Heritage aspects	The surfaces are paved with traditional marble stone, even if laid down in 1935, shall be preserved. Therefore the temporary removal of the floors covering e.g. to install a heating system is not possible.
Installation of insulation (covering of surfaces, room height)	Walls surfaces cannot be altered by insulation or any other coating for protection constraints. The only surfaces coatings that can be modified by philological renovation interventions are East and South facing vertical enclosures directly bordering the exterior that are at present covered with a layer of strongly deteriorated plaster, made of a mixture of a concrete base of the 30s, therefore with non-philological procedures that would instead entail a lime based mixture.
Additional openings, breaches in the ceilings	From some investigations in the Museum area there are some openings/holes which might be used for wiring or pipes (e.g. 10cm diameter).

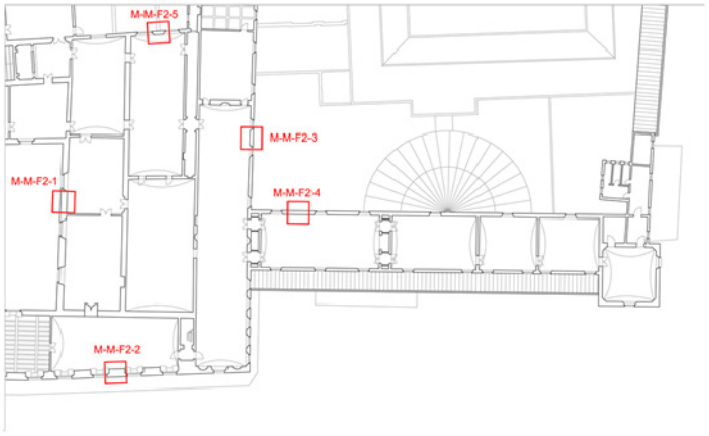
Deliverable D6.2 Documentation of each study case

Analysis of building envelope - top:

General description
Identification of different areas/elements and of relevant points

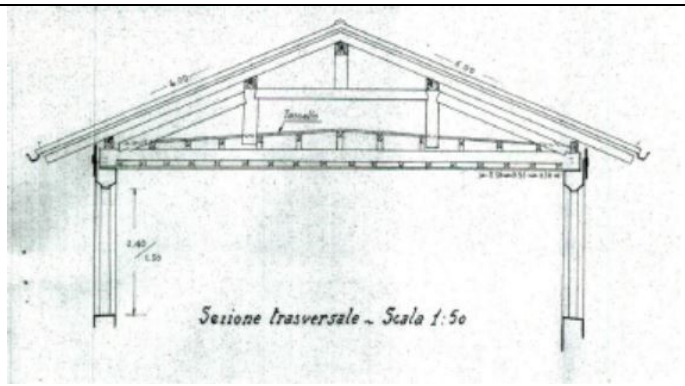


General plant of the Second Floor of Palazzo d'Accursio showing the area covered by the Municipal Collections of PHPP



Extract of the Municipal Collections of being PHPP with an indication of the walls catalogued in the carried out survey of the study area

Description	This area covering roof's structure is wooden with main beams and trapezoidal trusses. The roof intrados ceiling is decorated. Critical issues are related to the damages present within the roof section causing water infiltrations menacing the ceiling decorations conservation as well as thermal dispersion.
Documentation of skylights	There are no skylights in the studied area.
Structural scheme of the roof, indication of maximum load allowed	Roof has a wooden structure. The cross section below has been reconstructed during the last maintenance intervention completed in 1935 and clearly shows "Coat of arms" room roof structure with thick transversal logs joined by thinner ones.

	
Overshadowing of roof areas, cause and impact	No overshadowing effect on the roof surface are detected in the area considered by our study.
Membranes (waterproofing/breather/vapour control layer) applied	No membrane (waterproofing/breather/vapour control layer) are applied.
Roof/ceiling top floor	
Heritage Value	The ceiling of "Coat of Arms "- Sala Urbana Room is filled and enriched by many artistically valuable decorations.
Preservation of the surface/roofing	In the Sala Urbana the most worrying issues of preservation regard the diffuse detachments of the decorative paintings of the room; also some water infiltrations together with some hot areas in the upper side of East and South walls individuated by the IRT inspection have been spotted.
Covering through installation of solar technologies, available space - also on the inner side of the roof covering (solar thermal/air collectors)	No space available for solar technologies installations, also for constraint given by existing legal regulation codes for historic buildings.
Possibility for additional openings/skylights	Principles of protection given by the Authority for Cultural Heritage state that the opening of slots or skylights in the roof is not allowed.
Application of insulation (inside/outside) - elevation possible?	No application of insulation layers can be done on the inner surface. The application of new insulation in wood fiber layers has been already studied and carried out in the implementation of the roof refurbishment intervention. No possibility of further elevation.
Installation of mirrors/heliostats for improvement of daylight	No mirror/heliostat can be installed for constraints by Principles of protection given on historic buildings by the Authority for Cultural Heritage.
Specification of potentials and limitations	
Heritage value in general	The global building heritage value is quite unique for its rooted traditional and ancient architecture and the composite character of its styles and composing layers. The studied functional area is dedicated to the art collections of the city with paintings and furniture related to different ages.

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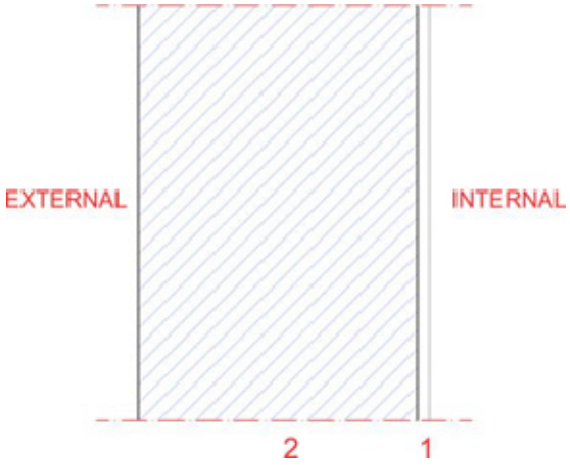
Conservation/changing of wall surfaces (outside), historic plaster, historic wall paintings by e. g. installation of insulation etc.	Absolutely none of the wall surfaces can be altered in any way, whether they face the exterior or internal courtyard, and even if they don't present any feature of decoration.
Possibility of installation of additional shading system (typology, integration in glazing/box type window) (c.f. rooms)	The only shading elements that are present in the building are the curtains in textile (e.g. those facing Via IV Novembre), that can be substituted if necessary only with newer ones made of the same textile and in the same size/color . No additional shading system can be installed.
Changing of window shape, materials and colours (with regard to window sashes and frame) (c.f. rooms)	The shape and dimensions of the windows in the facades are bound by the Principles of protection given by the Authority for Cultural Heritage.
Conservation/changing of window glazing/glass visual appearance (c.f. rooms)	The Principles of protection given by the Authority for Cultural Heritage prescript to keep the original window infixes and shading elements in every external perimeter wall. In case of substitution, which is admitted only if the original components cannot be repaired, the new inserted elements must have same partition, material, color and shape of the previous.
Possibility of additional layer inside (c.f. rooms)	No additional layer can be placed inside for the presence of decorated ceilings and for Historical Heritage Protection constraints.
Constrains regarding wall thickness	The thickness of the majority of the wall is not constant throughout the different portion of the building. In the Museum area the thickness is between 76 and 43 cm. Also in the office area there are walls with different thickness from 110 cm to 30,5. The thickness has to be preserved and kept as is.
Possibility for covering with solar technologies, available spaces	No possibility of covering with solar technologies installation for Historical Heritage Protection constraints.
Possibility of additional openings/holes for installation (for wiring or pipes e.g. 10cm diameter)	From some investigations in the Museum area there are some openings/holes which might be used for wiring or pipes (e.g. 10cm diameter).
Conservation/changing of window recesses, cornices and plastic elements	The Principles of protection given by the Authority for Cultural Heritage prescript to keep the original window shape, dimensions, infixes and components in every wall. In case of substitution of the components, which is admitted only if the original components cannot be repaired, the new inserted elements must have same partition, material, color and shape of the previous.
Changing on the window size (enlarge/reduce, limitations)	No change possibility fort the windows size, for Historical Heritage Protection constraints.
Constrains regarding installation alignment of window	The existing asset and alignments among windows on facades must be kept and preserved as they are for Historical Heritage Protection constraints.

Possibility of additional window openings in exterior walls (max. size/limitations)	The opening of new/additional windows in exterior walls is forbidden and not allowed for Historical Heritage Protection constraints.

Façade 1: South west façade-wall M-M-F2-1

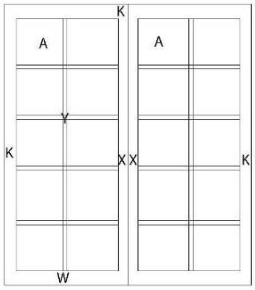
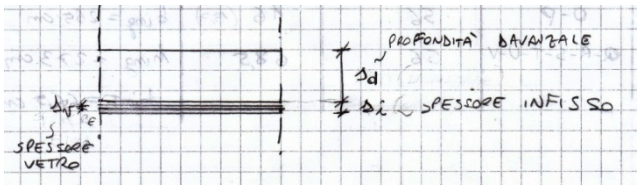


Description

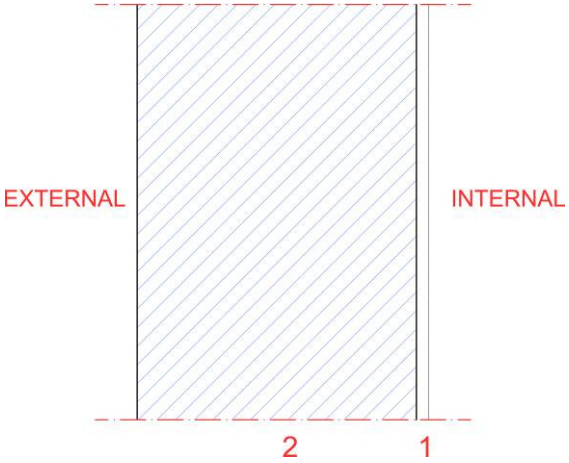
South west facade overlooking the internal principal courtyard/patio, built in full solid 5 heads brick masonry, with a 76 cm total thickness, with no external plaster layer, built in the construction phase around 1580.

LAYER	CONDUCTIVITY [W/mK]	RESISTANCE [m^2K/w]	SPECIFIC HEAT [J/kgK]	DENSITY [kg/m3]
1 Internal lime plaster	0.8	0.025	1000	1600
2 Solid brick wall facing	0.810	0.914	840	1800
3 External plaster	-	-	-	-
Total thickness				**76 cm**
Transmittance calculated				**0.881 W/m2K**
Transmittance measured on site				**0.642 W/m2K**

Type of façade	Not plastered masonry façade.
Balcony	None

Eaves	Yes
Conservation state of the façade: humidity or other visible stain/deterioration on walls	There are signs of rising damp in some parts of the building.
Openings/hol,es usable for wiring or pipes (e.g. 10cm diameter)	From the investigations done in the Museum study area there are some openings/holes which might be used for wiring or pipes (e.g. 10 cm diameter). The analysis and audits are in progress.
Membranes (waterproofing/breather/vapour control layer) applied	No waterproofing/breather/vapour control layer layer applied.
Documentation of windows	
	
	
Surface area part 1	
Construction	Façade built in solid 5 heads brick masonry.

Façade 2: wall M-M-F2-2



Description

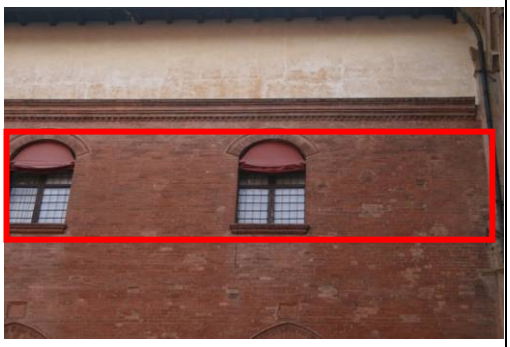
Masonry wall, built in the phase around 1580, exposed to South-East.

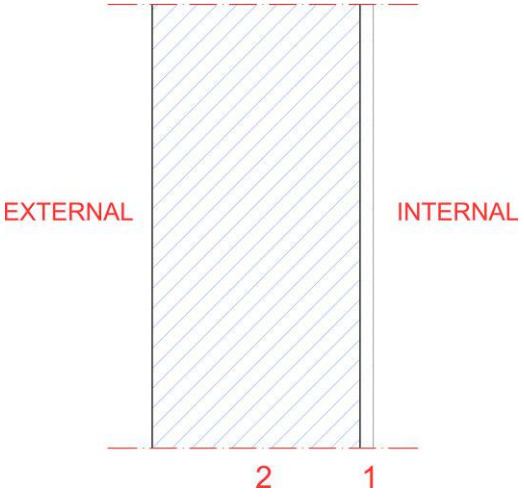
LAYER	CONDUCTIVITY [W/mK]	RESISTANCE [m^2K/w]	SPECIFIC HEAT [J/kgK]	DENSITY [kg/m3]
1 Internal lime plaster	0.800	0.025	1000	1600
2 Solid brick wall facing	0.810	0.864	840	1800
3 External plaster	-	-	-	-
Total thickness	**72 cm**			
Transmittance calculated	**0.921 W/m^2K**			
Transmittance measured on site	**0.771 W/m^2K**			

Type of facade	Not plastered masonry facade.
Balcony	None
Eaves	Present
Conservation state of the façade: humidity or other visible stain/deterioration on walls	There are signs of rising damp in some parts of the building.
Openings/hol,es usable for wiring or	From the investigations done in the Museum study

pipes (e.g. 10cm diameter)	area there are some openings/holes which might be used for wiring or pipes (e.g. 10 cm diameter). The analysis and audits are in progress.
Membranes (waterproofing/breather/vapour control layer) applied	No waterproofing/breather/vapour control layer applied.
Documentation of windows	
Construction	Facade built in solid 5 heads brick masonry.

Façade 3: wall M-M-F2-3





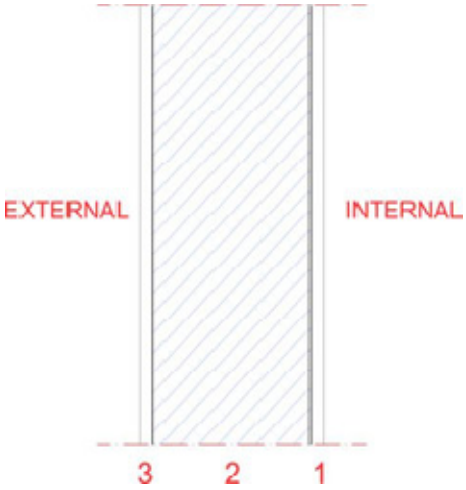
Description

Masonry wall, built in the phase around 1560, exposed to North-East.

LAYER	CONDUCTIVITY [W/mK]	RESISTANCE [m^2K/w]	SPECIFIC HEAT [J/kgK]	DENSITY [kg/m3]
1 Internal lime plaster	0.800	0.025	1000	1600
2 Solid brick wall facing	0.810	0.568	840	1800
3 External plaster	-	-	-	-
Total thickness				**50 cm**
Transmittance calculated				**1.228 W/m^2K**
Transmittance				**0.869 W/m^2K**

	measured on site	
Type of facade	Facade built masonry, with solid 5 heads brick masonry.	
Balcony	None	
Eaves	Present	
Conservation state of the façade: humidity or other visible stain/deterioration on walls	There are signs of rising damp in some parts of the building.	
Openings/hol,es usable for wiring or pipes (e.g. 10cm diameter)	From the investigations done in the Museum study area there are some openings/holes which might be used for wiring or pipes (e.g. 10 cm diameter). The analysis and audits are in progress.	
Membranes (waterproofing/breather/vapour control layer) applied	No waterproofing/breather/vapour control layer applied.	
Documentation of windows		
Construction	Facade built in solid 5 heads brick masonry.	

Façade 4: wall M-M-F2-5

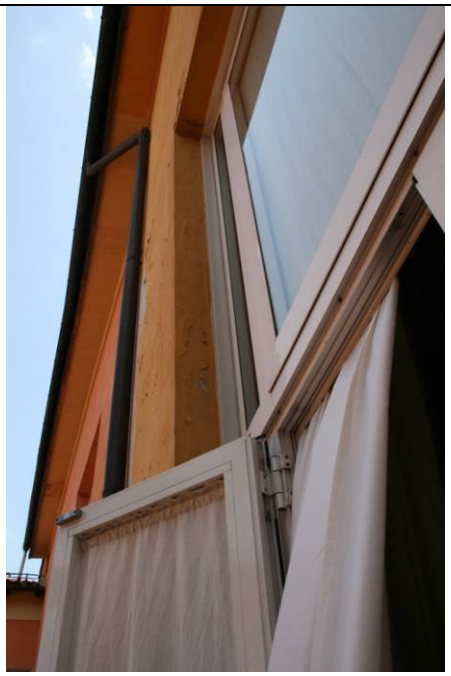


Description

Wall built in the phase around 1580, exposed to North-West.

LAYER	CONDUCTIVITY [W/mK]	RESISTANCE [m^2K/w]	SPECIFIC HEAT [J/kgK]	DENSITY [kg/m3]
1 Internal lime plaster	0.800	0.025	1000	1600
2 Solid brick wall facing	0.810	0.481	840	1800
3 External plaster	1.000	0.020	1000	1800
Total thickness				**43 cm**
Transmittance calculated				**1.378 W/m^2K**
Transmittance measured on site				**1.348 W/m^2K**

Type of facade	Plastered façade built in masonry.
Balcony	None
Eaves	Present
Conservation state of the façade:	There are signs of rising damp in some parts of the

humidity or other visible stain/deterioration on walls	building.
Openings/hol,es usable for wiring or pipes (e.g. 10cm diameter)	From the investigations done in the Museum study area there are some openings/holes which might be used for wiring or pipes (e.g. 10 cm diameter). The analysis and audits are in progress.
Membranes (waterproofing/breather/vapour control layer) applied	No waterproofing/breather/vapour control layer applied.
Documentation of windows	
Construction	Facade built in solid 5 heads brick masonry.

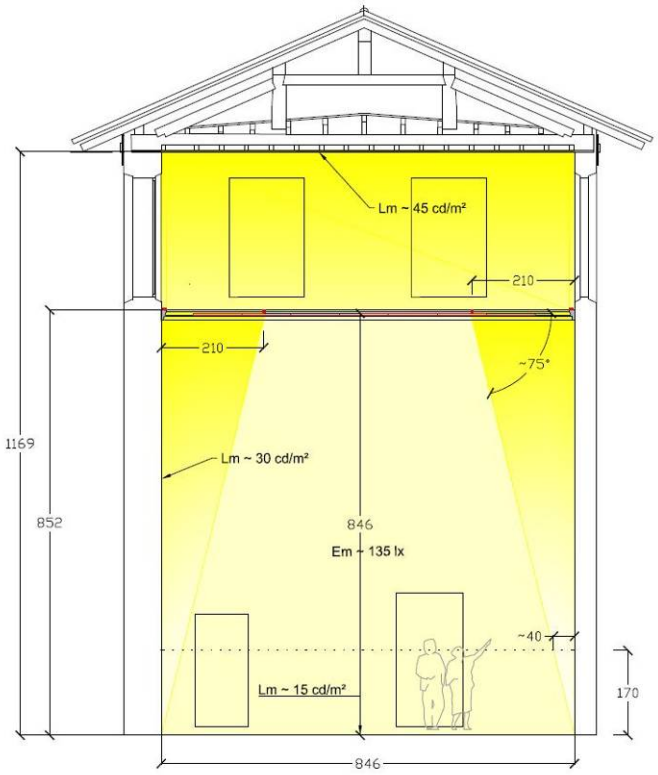
1.1.2 Rooms and room units

Floor/ selected area 1

Sala Urbana– M-2F-17-S

View from below of Sala Urbana's frescoed ceiling

View from below of Sala Urbana's frescoed ceiling and perimeter longitudinal wall.

Description	The Room is part the Museum/art collections area of the building, with valuable paintings and furniture related to different ages. It stands at the second floor of palazzo d'Accursio, at the core of Functional Area 1. The room is filled and enriched by fresco decorations present on the internal walls and ceiling.
Height interpolated average net (m)	11,69 m 
Surface area	143,82
Volume (gross/net) heated (m^3)	1.681,25
Number of rooms	1

Description of room	
Name/ room number	Sala Urbana/ **M-2F-17-S**
Room group	Municipal Collections
Construction phase	1564

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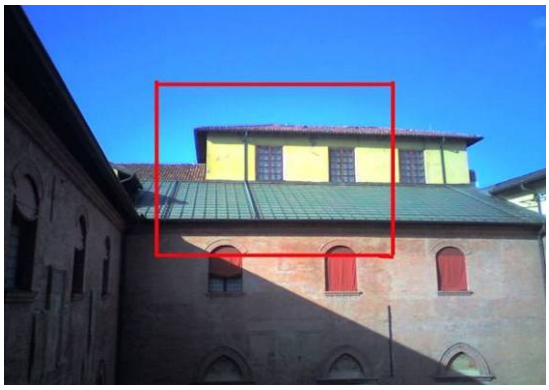
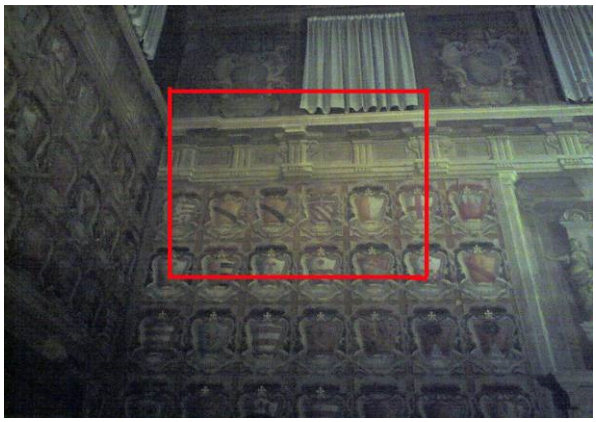
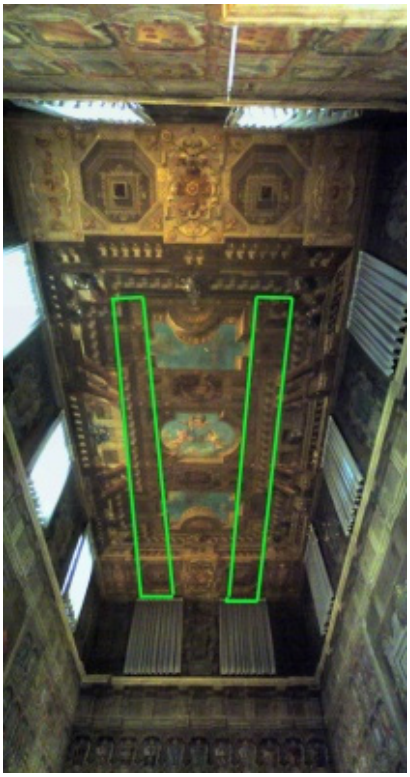
Description	 The Room is part the Museum/art collections area of the building, with valuable paintings and furniture related to different ages. It stands at the second floor of palazzo d'Accursio, at the core of Functional Area 1. The room is filled and enriched by fresco decorations present on the internal walls and ceiling.
Dimension	height interpolated average net: 11,69 m
Design Phase	To stop and solve the decay conditions an energetic retrofit proposal of Sala Urbana was elaborated and carried on as described at sections 2.7 and 3.1, 3.2 and 3.3.
Description of design phase	See section 2.7, 3.1, 3.2 and 3.3
Description conditions	The fresco decorations on the ceiling are in evident decay due to rainwater infiltrations through the deteriorated roof covering.
Actual/planned use	The room is closed to the public for safety reasons.
Mobile equipment	No mobile equipment disposable in the Room.
Present room conditions: temperature, air humidity (measured room climate as-is-state)	Winter period (14,21 °C; 30,9 UR) Ext. (4,14 °C; 61,6 UR) Summer period (30,9 °C; 37,5 UR) Ext. (30,5 °C; 25 UR)
Daylight potential	The room has no skylights but windows adjacent to the exterior in the top East and South facing facades.

Outer wall 1	
	
Description	The thermo gram test has been repeated during a warmer day, and the most interesting feature is the high temperature area indicated by the green arrow; during test 27 the same zone appeared colder, so this could identify a thermal bridge between the outside and the room (green arrow in Test 27). The same area has also been inspected by IRT from the outside and it is still warmer (green arrow in the test done at 17:14) than the surrounding areas, leading to the conclusion that probably identify a cavity; a high thermal resistance component, e.g. wood beam would not appear colder during the March measurement, while a concrete one would show a reversed thermal behavior. Finally, a close up photo of the outside of the wall shows no evident anomalies.
Interior wall 1	
West wall	
Description	West wall of Sala Urbana is only partially exposed to the external cold air, which is clearly visible in the two areas Ar1 and Ar2. The room ceiling is supported by a wood structure, clearly visible in the thermogram, with large beams crossing the room transversally. Also, two warmer zones are observed that could correspond to a layer of insulation (Ar3 and Ar4), for example a second layer of wood beams. A cold area is indicated by the white arrow and could be due water leaks.

Interior wall 2	
North wall	
Description	Wall is characterized by diffused small colder areas, that could be ascribed to slight differences in plaster or decoration composition. More interesting is the presence of a closed aperture (area Ar1 and upper green arrow) positioned between the window and the commemorative plate; however, note how the temperature gradient is limited to some tenths of a degree. Also the plate shows a relatively higher temperature in its upper part, and this could be due to a local detachment, but it looks more like a reflection from room lamps.
Ceiling	
	
Description	In the thermograms the structure of the roof is clearly visible, with thick transversal logs joined by thinner ones. An interesting feature of the roof is represented by two large

	warmer areas (green shapes in the following Tests); they seem to identify stripes of insulation material, or a second roof on top of the visible one. When the same shapes are superimposed on a photo of the roof, there appear no relationship with painted decoration, so the influence of different pigments is to be excluded (tests of 18/03/2011). On July 20, 2011, the same thermograms of 18/03/2011 have been recorded, obtaining the same results: there appear some very hot spots, whose origin is not understood yet (see tests of May 27).
Floor	
Label	
Description	Realized in polychrome marbles by craftsmen expert in the cut and treatment of marble stone.
Technical equipment	
Label	The existing installation consists of alone standing removable luminairies.
Lighting devices/luminaires	

Potential and Limitations regarding the room	
Heritage value of room and its equipment in general	The Room is part the Museum/art collections area of the building, with valuable paintings and furniture related to different ages. The room is filled and enriched by fresco decorations present on the internal walls and ceiling.
Possibility of additional window openings in exterior walls (max. size/limitations)	No additional openings allowed for Historic Heritage Protection constraint.
Possibility of additional layer inside ---> see also facade level	The placing of additional layers on the internal surface of the room is not allowed by the constraints of Protection for the presence of decorations.
Possibility of installation of additional shading system (typology, integration in glazing/box type window) c.f. facade	No need of further shading installations for this room; no additional shading allowed for Historic Heritage Protection constraint.
Conservation/changing of installations (like heaters and lighting)	The changing and substitution of the existing lighting systems in the room has been studied. The room isn't provided with heaters.
Conservation/changing of wall surfaces (outside), historic plaster, historic wall paintings by e. g. installation of insulation etc. c.f. facade.	The East and the South facing vertical enclosures directly bordering the exterior are at present covered with a layer of strongly deteriorated plaster; it is made of a mixture of a concrete base of the 30s , therefore with not philological procedures that would instead entail a lime based mixture. Thus on these facades the treatment of the outer walls surfaces with plaster substitution has been studied elaborating and then selecting specific intervention hypothesis as described in the 2. Design section.
Conservation/changing of window recesses, cornices and plastic elements ---> see also facade level	The Principles of protection given by the Authority for Cultural Heritage prescript to keep the original window shape, dimensions, infixes and components in every wall. In case of substitution of the components, which is admitted only if the original components cannot be repaired, the new inserted elements must have same partition, material, color and shape of the previous.
Constraints regarding wall thickness, c.f. facade	The thickness has to be kept as is for Historic Heritage Protection constraint.
Possible breaches/openings, running of cables/tubes	There is no possibility of breaches/openings for this room.
Changing of window shape, materials and colours (with regard to window sashes and frame) ---> see also facade level	Windows shape, materials and colors have to be kept as they are for Historic Heritage Protection constraint. Windows components can be substituted if damaged but only with components of the same type, material, and color.
Conservation/changing of window glazing/glass visual	The Principles of protection given by the Authority for Cultural Heritage prescript to keep the original window

appearance ---> see also facade level	infixes and shading elements in every external perimeter wall. In case of substitution, which is admitted only if the original components cannot be repaired, the new inserted elements must have same partition, material, color and shape of the previous. Glasses can be eventually substituted with thicker or with camera type newer glasses for energy efficiency improvement.
Elimination, changing, moving of internal partitions	All the original walls and partitions with historical value must be maintained and restored.

1.2 Structural analysis and assessment of moisture

Building safety	
Description of building safety with regards statics/structural problems - compliance with local regulations:	There are no static or structural problems. In general, Palazzo D'Accursio does not show important structural deficiencies.
Certificates/reports/regulations on statics:	The intervention that has been carried out in the "Sala Urbana" is defined as "non relevant intervention for what is concerned with public utility" by Regional Government Decree (DGR) n. 687 of 2011. A formal Declaration signed by the project Director and an Explanatory Technical Survey have been released together with the graphic material as is requested by the current Regulations for interventions of remaking of the secondary warping, of the board, of the panels, and of the outer envelope, of wooden or steel roofs, with an overall eventual weight increase inferior or corresponding to 10% respect to the present conditions. The Explanatory Technical Survey contains the information in relation to the building typology and explicitly indicates the dimensions and functions of the intervention and the context in which it has been carried out.
Description of building safety with regards dangerous materials (to remove) - compliance with local regulations:	During the inspection of the roof a layer of guano droppings left by the pigeons has been detected among the beams.
Certificates/reports/regulations on dangerous materials:	Guano is not a dangerous material but will be removed during the roof refurbishment works.
Description of building safety with regards fire protection - compliance with local regulations:	The building is good in terms of safety of fire
Certificates/reports/regulations on fire protection:	There aren't certificates because the Administration is designing a global project of the Palace for the fire protection.
Description of building safety	Seismic regulations are evaluated with the Guideline for

with regards seismic safety - compliance with local regulations:	seismic safety of protected building given by the National Ministry of Cultural Heritage and it complies with local regulations. The renovation project has included a significant improvement of the seismic performance of the upper walls by means of metal plates located in order to tighten the structure holding the roof. Besides this, the intervention of renovation inside Palazzo D'Accursio's "Sala urbana" has include the following actions: - Insertion of a curb in light steel (12 kg circa of weight) and some series of armed brick walls; - Vertical threaded boards for connecting the edges of the roof trusses to the walls below; - Wooden boarding and steel drilled tape (RothoBlass type) as groundwater upwind; - Insertion of wooden screws (HBS type) in the nodes of the trusses for reinforcing the existing connections and for fixing the new secondary warping to the principal one;
Certificates/reports/regulations on seismic safety:	There is a certificate about the intervention of Urban Room.
Description of building safety with regards noise protection - compliance with local regulations:	The classification of the building is based on the existing national and regional codes as well also for the evaluation of the acoustic comfort, and in particular: •At national level the Framework Law n. 477/95 and its executive decrees DPCM 14/11/97 and DMA 16/3/98, •At regional level LR 9/5/2011 and "Direttiva regionale 2053/2001", •At local level "Acoustic classification of Bologna communal territory" ODG n°42 of 20/1/2010.. The review of the documents related to the acoustic classification of the city of Bologna, which represents one of the main tools of governance of the territory as well of protection from noise, evidenced that the zone where the building is located belongs to the Acoustic Class n. III called "Mixed type areas" and, besides that, is also part of the airport acoustic classification "Zone A".
Certificates/reports/regulations on noise protection:	The official documents that deal with this topic refer to the prescriptions given by the Regional Code n°2053/2001 "Dispositions on noise pollution" and on the National Law n°477/95 and to its Executive Orders. In particular, the Acoustic Zoning, following the article n.5 of the National Law n°477/95, contains the subdivision of the territory in five acoustic classes that correspond to the first five ones defined by DPCM 14/11/1997 with the limits of noise compatible with each use. These acoustic classes are named by the existing norms as "Territorially Homogeneous Units" (UTO). The *fourth Acoustic Class, called "areas with intense human*

	activity": areas with intense vehicular traffic and high population density, with high presence of commercial activities, offices, crafts, nearby main roads and railways, port areas, areas with limited presence of industries. For every acoustic class, following the indications of DPCM 14/11/1997, for every acoustic class are given specific edge-values of sonic emission, that is the "attention values" and the "quality values", distinct for day time (6:00 AM÷10:00 PM) and night time (22:00 PM÷6:00 PM). For every acoustic class, following the indications of DPCM 14/11/1997, for every acoustic class are given specific edge-values of sonic emission, that is the "attention values" and the "quality values", distinct for day time (6:00 AM÷10:00 PM) and night time (22:00 PM÷6:00 PM). The absolute edge-value of emission has been defined referring to the "continuous equivalent sonic level" (L_{Aeq}) measured in dB (decibel) during the whole daytime or night time period. The sonic level, measured in indoor residential spaces is due to the presence of external sources (road-railway traffic, railway, street yards, etc..) and of indoor activities, within the same space or in adjacent ones. At the following URL further specification on the urban acoustic classification of Bologna can be found:http://www.comune.bologna.it/ambiente/servizi/6:3457/6780/
Description of building problems with regards humidity:	In general the presence of humidity is very limited, although it must be remembered that IRT will show it only in the presence of superficial evaporation, otherwise it could pass unnoticed to this type of investigation. The IRT investigation of Palazzo D'Accursio has required several measurement sessions during the period February-July 2011, due to the complexity of the structure and also because only the passive approach has been chosen, due to very large surfaces to be explored; different environmental situations have allowed to put in evidence many hidden structural characteristics of the building, along with a series of problematic spots.
Description of building problems with regards salts:	No problems evidenced concerned with salts.

The project has been developed, where possible, by non-invasive and completely reversible diagnostic and monitoring analysis to increase the level of knowledge of the building and to assess its performance, through:

- GPR radar tests for masonry stratigraphy;
- Infrared Thermography (IRT) for structural analysis and moisture assessment;
- Blower door test;
- U-value determination;
- Monitoring trough WSN.
-

1.2.1 GPR radar tests for masonry stratigraphy

(UNIBO – Camilla Colla, Elena Gabrielli)

This test has realized by UNIBO in the Municipal Collection area in September- October 2011. Here below are reported the position and the lengths of the radar survey.

The GPR radar tests have been performed in 6 different testing days (September 7th, October 10th - 11th and October 13th-15th, 2011) and a consistent number of survey lines have been considered.

Data have been acquired in reflection mode by using a GSSI SIR-3000 system and different medium (900 MHz) to high (2.0 GHz) frequency antennas.

In the following images, the positions and lengths of the radar survey lines collected with both antennas are reported together with photos of the data acquisition phases.

Fig.1: GPR survey lines acquired with a 900 MHz antenna

Fig. 2: GPR lines collected with a 900 MHz antenna; the position of the radargrams reported in Fig. 3 and Fig. 4 are highlighted in red and green respectively

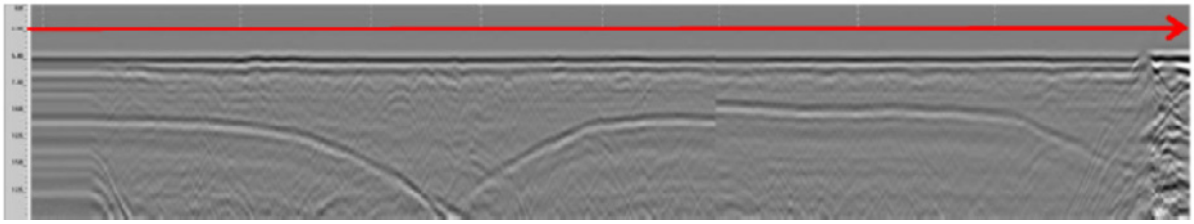


Fig. 3: “Sala Urbana”, raw radargram collected with a 900 MHz antenna along an East-West survey line 16.73m long, at 4.53m from the South wall (File 109-110-11)

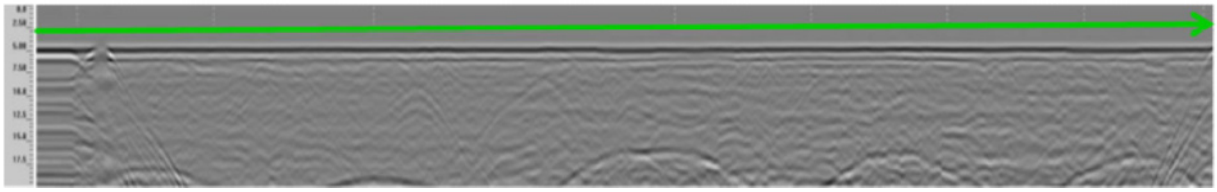


Fig. 4: “Sala Urbana”, raw radargram collected with a 900 MHz antenna along an East-West survey line 16.73m long, at 6.53m from the South wall (File 112-113-114-115)

1.2.2 Infrared Thermography (IRT) for structural analysis and moisture assessment

(ARTEMIS – Enrico Esposito, Antonio del Conte)

Radiant heat flow depends on many characteristics of the materials and of environment surrounding the examined structural component. Generally speaking, differences in recorded thermograms may depend on:

1. Surface characteristics (e.g. smoothness/roughness, presence of humidity)
2. Surface materials
3. Substrate materials
4. Presence of discontinuities in the substrate (including structural defects, e.g. voids)

These characteristics may be present simultaneously, so IRT investigation is not simple, especially in the data analysis phase. Different sequences of images should be acquired in different thermal situations, e.g. with cold surfaces, radiated surfaces and cooling surfaces, so to be able to separate all mentioned contributions.

For example, when looking at an apparently uniform plaster, an intervention with different plaster will show up even at ambient temperature, while a defect will generally appear only after thermal excitation of the surface: taking measurements with and without thermal excitation may help to understand which type of inhomogeneity we are observing.

Heat will flow from warm areas to cold ones, and will accumulate in the presence of a local increase in thermal resistance, so that a local increase in temperature will be recorded; this behavior will be immediately observable by IRT and thermograms may be used to individuate both structural characteristics and defects. Attention must be paid to surface characteristics, especially surface color, that will directly influence surface emissivity; for this reason, observations should be made on homogeneous parts of the surface, or after local emissivity correction if possible.

The IRT investigation of Palazzo D'Accursio has required several measurement sessions during the period February-July 2011, due to the complexity of the structure and also because only the passive approach has been chosen, due to very large surfaces to be explored; different environmental situations have allowed to put in evidence many hidden structural characteristics of the building, along with a series of problematic spots. In general the presence of humidity is very limited, although it must be remembered that IRT will show it only in the presence of superficial evaporation, otherwise it could pass unnoticed to this type of investigation.

In the following we will present the results of all IRT measurements divided by building areas that are of interest for 3ENCULT; only a selection of results will be shown, the most important ones out of a total of about 400 thermograms.

In Figure 5 and following ones we present some aerial photos of the building where main different investigated locations are individuated, along with maps of the Collections of Art and offices with the correct identification of the rooms, both as established by the LCS Team and as found in the Web site of the Collections.

Here below we summarize the conclusion that we reach during the Infrared Thermography realized in the areas of Palazzo d'Accursio selected for the 3ENCULT project.

A full IRT survey of the areas of Palazzo D'Accursio, relevant to the 3ENCULT Project, has been conducted, with a series of in-situ tests in the period February-July 2011, with a short leg in November 2013.

The tests have been aimed at 1. detection of critical areas of the building, in terms of structural defects, hidden characteristics or other anomalies, such as superficial delaminations; 2. inspection in terms of building energy performance, with the inspection aimed at verifying the presence of thermal bridges, lack of insulation, water leaks and other characteristics that could lead to lack of thermal insulation and favor heat exchange between the inside and outside of the building.

In general, Palazzo D'Accursio does not show important structural deficiencies (but consider the results for Sala Urbana), at least by IRT inspection, and also its performance in terms of thermal

bridges and infiltrations seems satisfactory; as regards the latter observation, we must put in evidence that the tests that have been performed are not able to identify some characteristics, like the presence of air leaks between, e.g. the room and the attic, but, after inspecting the rooms and the external facades of D'Accursio the overall behavior seems similar to other buildings of the same period. However, specialized measurements are needed to quantify thermal behavior of the structures, like thermal transmissivity and air leaks, and IRT inspection will be regularly repeated to monitor ongoing situation.

In more detail we may individuate some results for the following rooms:

SALA DEI PRIMITIVI: supporting wood structure of the roof well individuated, brick room walls seem quite homogeneous, only some small cracks detected in the roof. No trace of water leaks or other sign of deterioration.

GALLERIA VIDONIANA: IRT inspection allowed to visualize the different wood structures of the roof as visible from the Gallery and from the attic.

SALA DEGLI SVIZZERI: most interesting finding of the IRT inspection is the visualization of a regular series of hidden structures in the upper part of the West wall, whose origin and consistency has been individuated from photos of the restoration works of the '30s. Also some detachments have been individuated and some water infiltration detected.

SALA URBANA: most worrying results regard the diffuse detachments of the decorative paintings of the room; by IRT alone it is not possible to assess the risk of falling of the supporting plasters, but a more detailed inspection is recommended, especially before the start of the foreseen renovation works of the roof. Also some probable water infiltrations have been spotted and, in the upper part of the East and South walls, some very hot areas are evident, but no sure explanation of such a temperature gradient is still assessed, like for the small circular hot spots seen in March, May and July.

In **THE OFFICE**, IRT inspection has put in evidence the structural details of roofs and walls, and only in one office a damp patch has been individuated. In the offices also the humidity content of masonries has been qualitatively evaluated by a hand-held capacitive sensor; obtained values are quite low, typical of a "dry" wall, and also on the outside brick layer values are very low. A hand-held capacitive sensor for humidity content of walls T650 gives values ranging from 0 to 200, with 100 being the usual threshold value for excessive humidity, and obtained average values are 55 and 65 respectively. IRT examination shows cold areas in proximity of the window and TROTEC measures values from 80 to 100. Humidity concentrates, as it happens usually, in corners, but values are still in a safe region for structure conservation.

In the following pages we introduce the IRT tests conducted in different period of the year 2011 with the support of two infrared camera FLIR ThermaCAM B400 and FLIR B335.

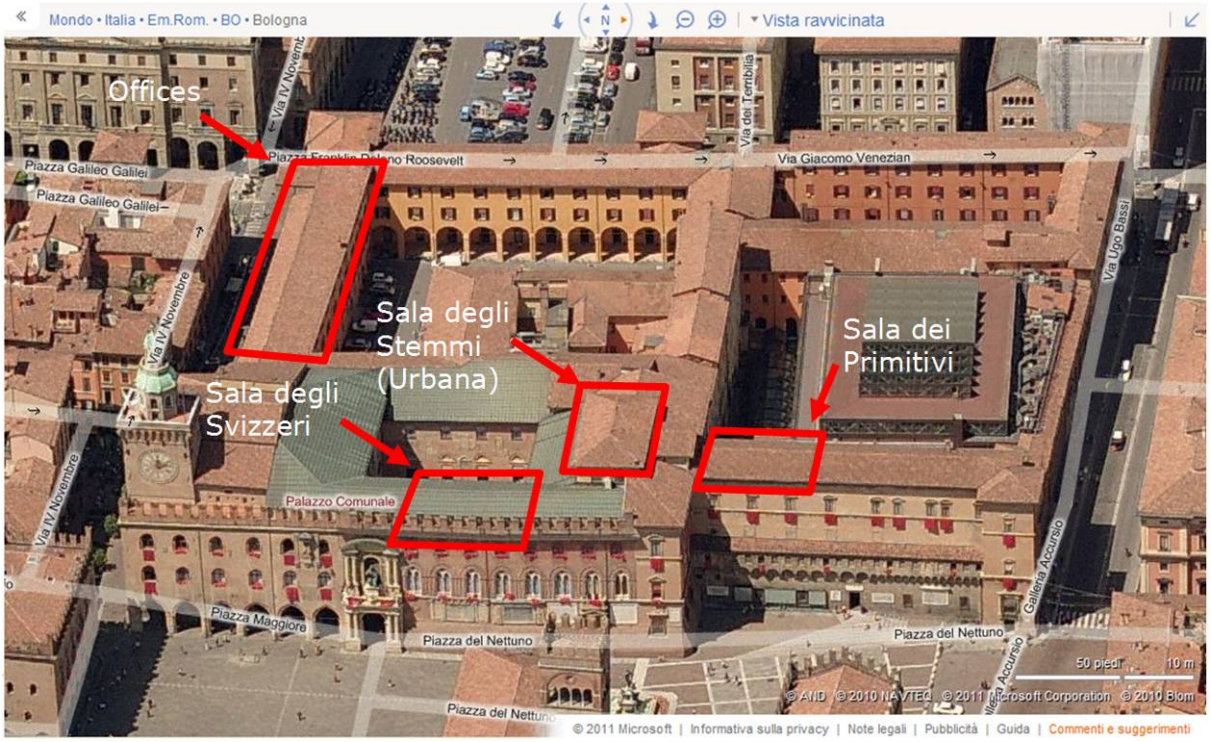


Fig.5: Aerial view of Palazzo D'Accursio, East façade

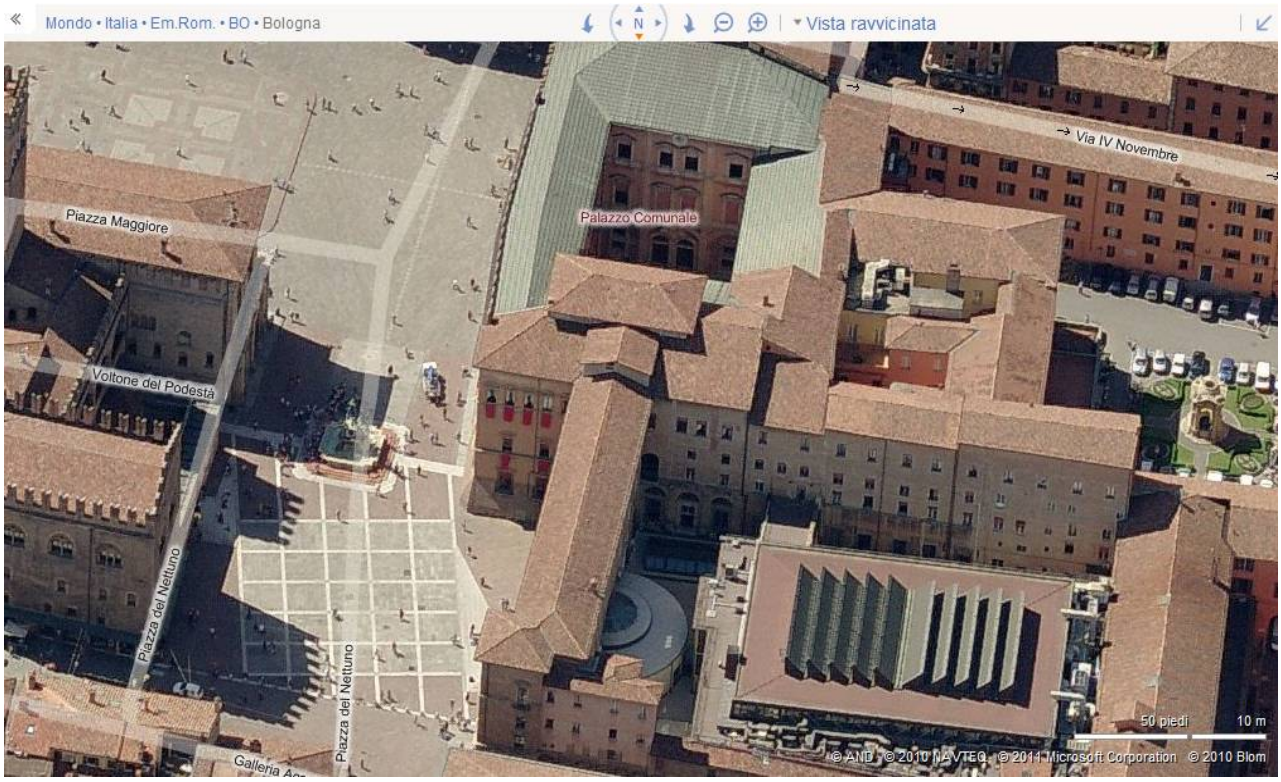


Fig. 6: Aerial view of Palazzo D'Accursio, North façade.

ROOM M-2F-17-S (SALA URBANA)

In the following figure we indicate the positions of performed tests.

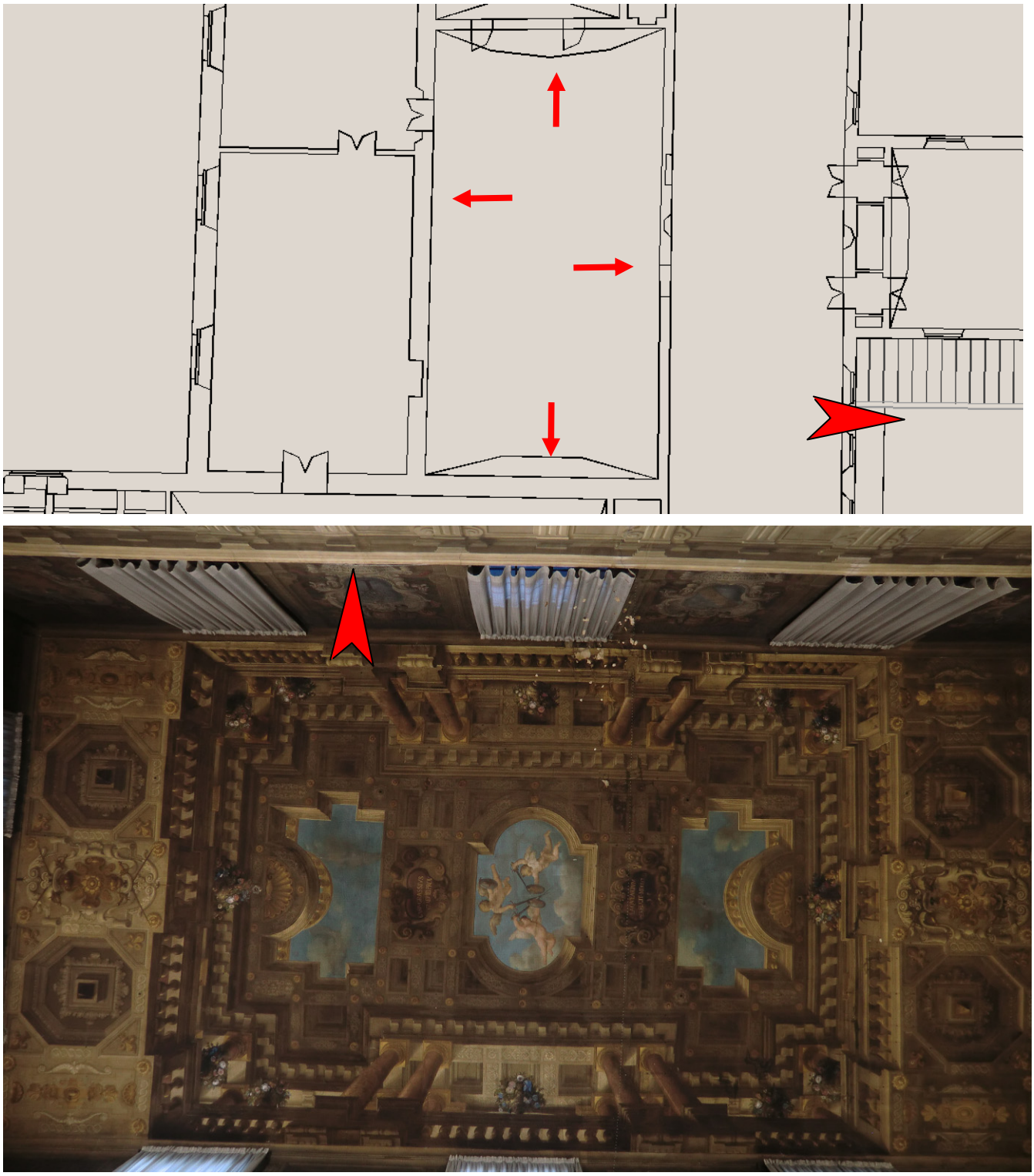
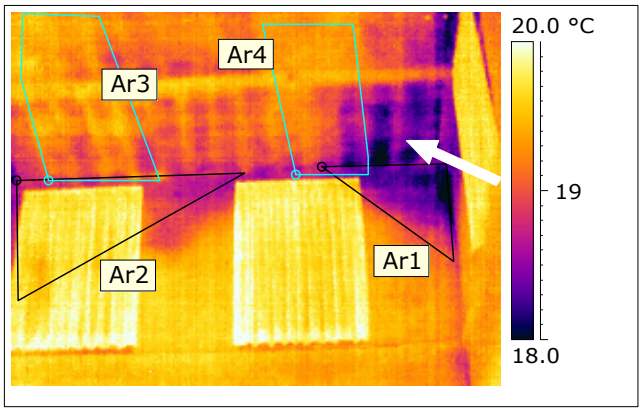


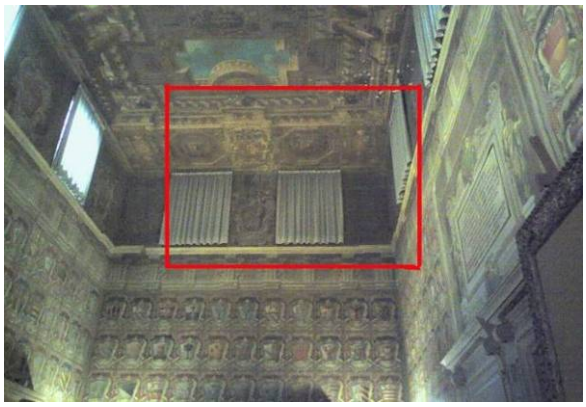
Figure 7: Positions of IRT tests in Sala Urbana and photo of the room

West wall

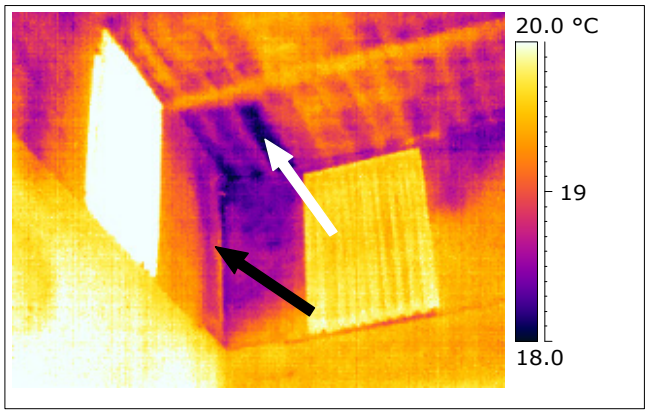
Test 13. **Captured at: Sala Urbana**

Date & Time: 18/03/2011 12:55:33





Comment: West wall of Sala Urbana is only partially exposed to the external cold air, which is clearly visible in the two areas Ar1 and Ar2. The room ceiling is supported by a wood structure, clearly visible in the thermogram, with large beams crossing the room transversally. Also, two warmer zones are observed that could correspond to a layer of insulation (Ar3 and Ar4), for example a second layer of wood beams. A cold area is indicated by the white arrow and could be due water leaks.

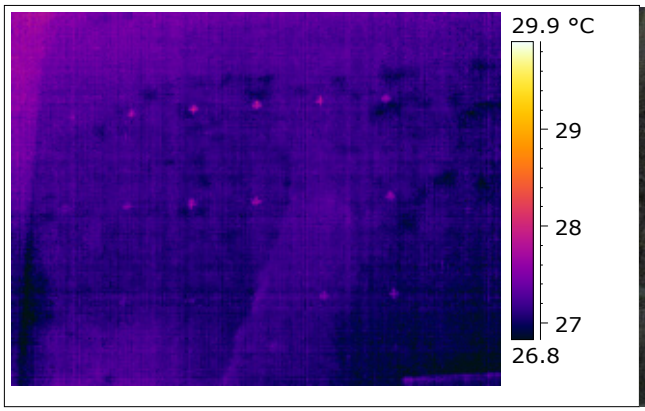


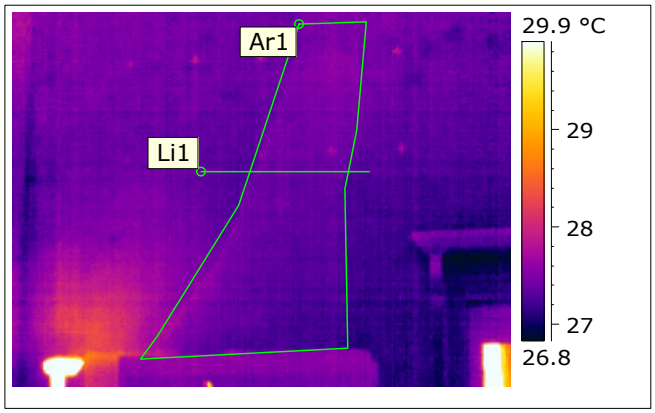
Comment: the white arrow aims at a damp area or otherwise a lack of insulation. The black arrow aims at South wall and identifies a cold area probably due to water leaks, although a similar trace is visible also at the opposite side of the same wall.

Test 14. **Captured at: Sala Urbana**

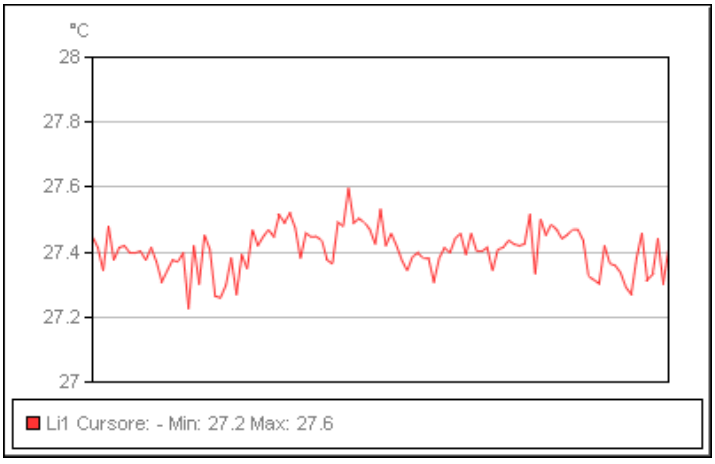
Date & Time: 08/04/2011 14.42.30

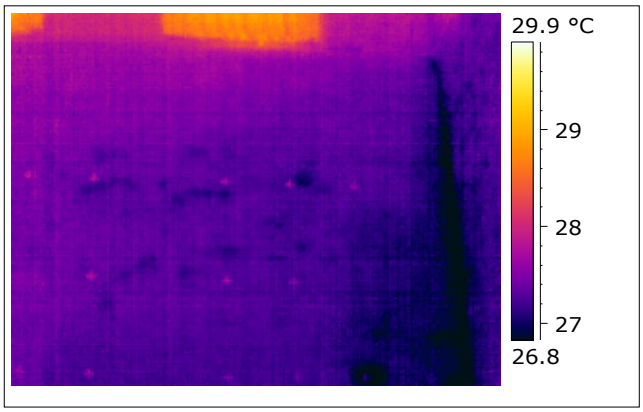
Immagine.Nome file IR_12691.jpg

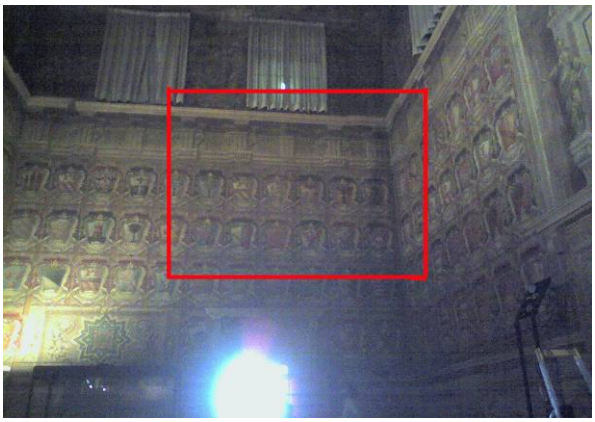


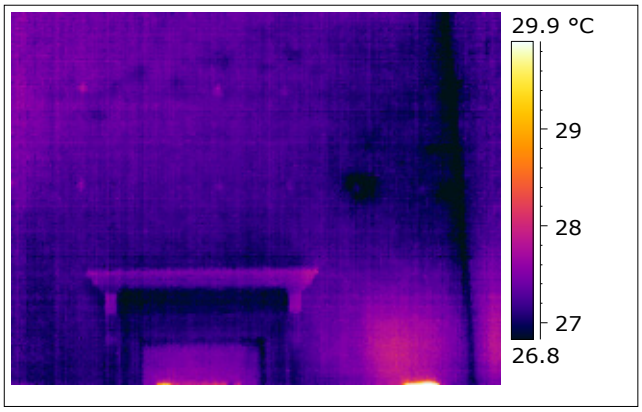


Describe







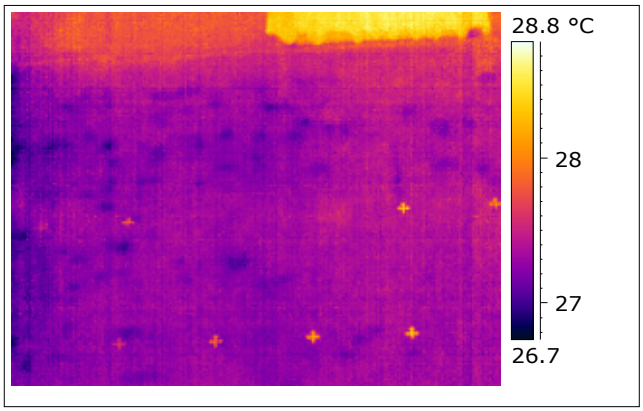


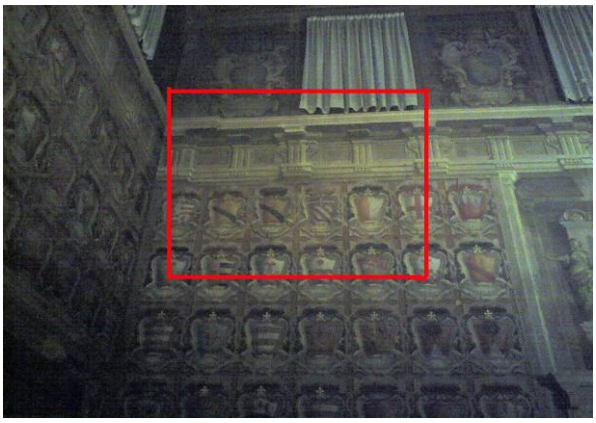
Comment: areas Ar1 are slightly warmer than the rest of the wall and this identifies a large detached portion of the plaster. Also area Ar2 is interesting to observe because it does not show the small colder irregularities of the lower part of the wall; possible explanations are: 1. a different plaster 2. the influence of the different superficial decoration 3 a diffused detachment. We must also consider that Ar2 coincides with a portion of the wall facing into the attic of the building, so that thermal transmission characteristics are completely different from the lower part of the wall.

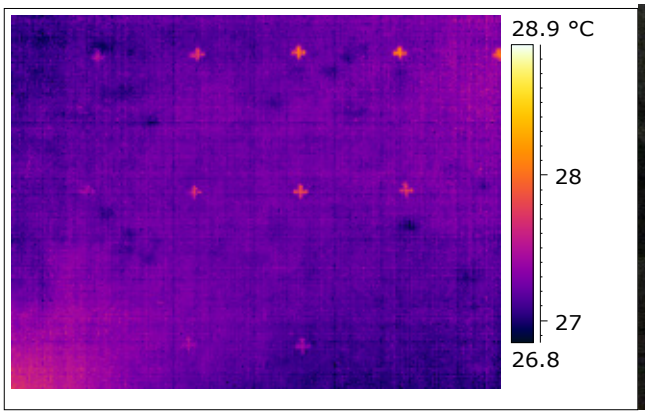
North wall

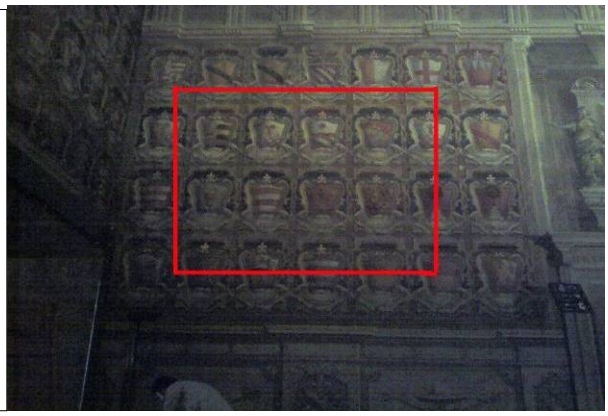
Test 15.

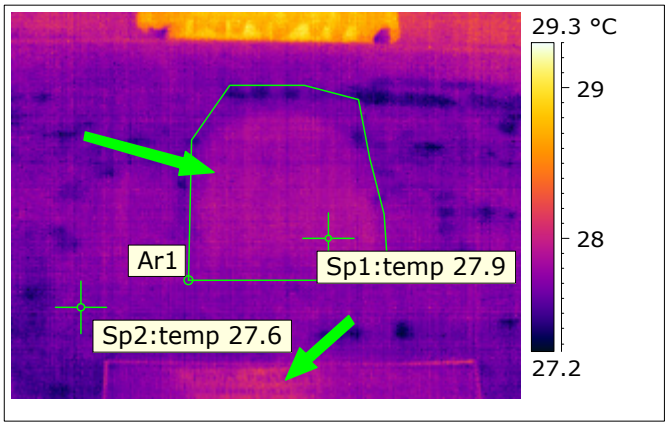
Date & Time: 08/04/2011 14.47.02

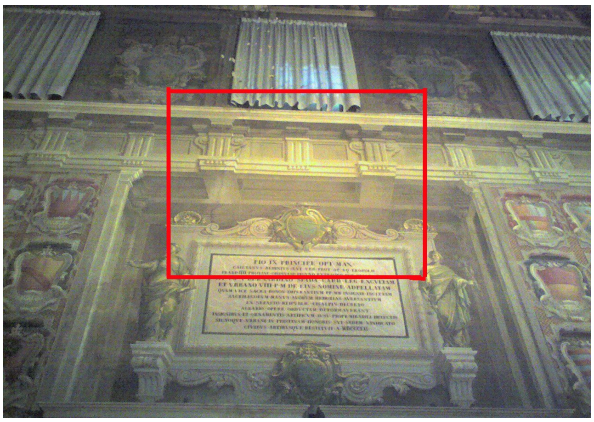












Comment: wall is characterized by diffused small colder areas, that could be ascribed to slight differences in plaster or decoration composition. More interesting is the presence of a closed aperture (area Ar1 and upper green arrow) positioned between the window and the commemorative plate; however, note how the temperature gradient is limited to some tenths of a degree. Also the plate shows a relatively higher temperature in its upper part, and this could be due to a local detachment, but it looks more like a reflection from room lamps.

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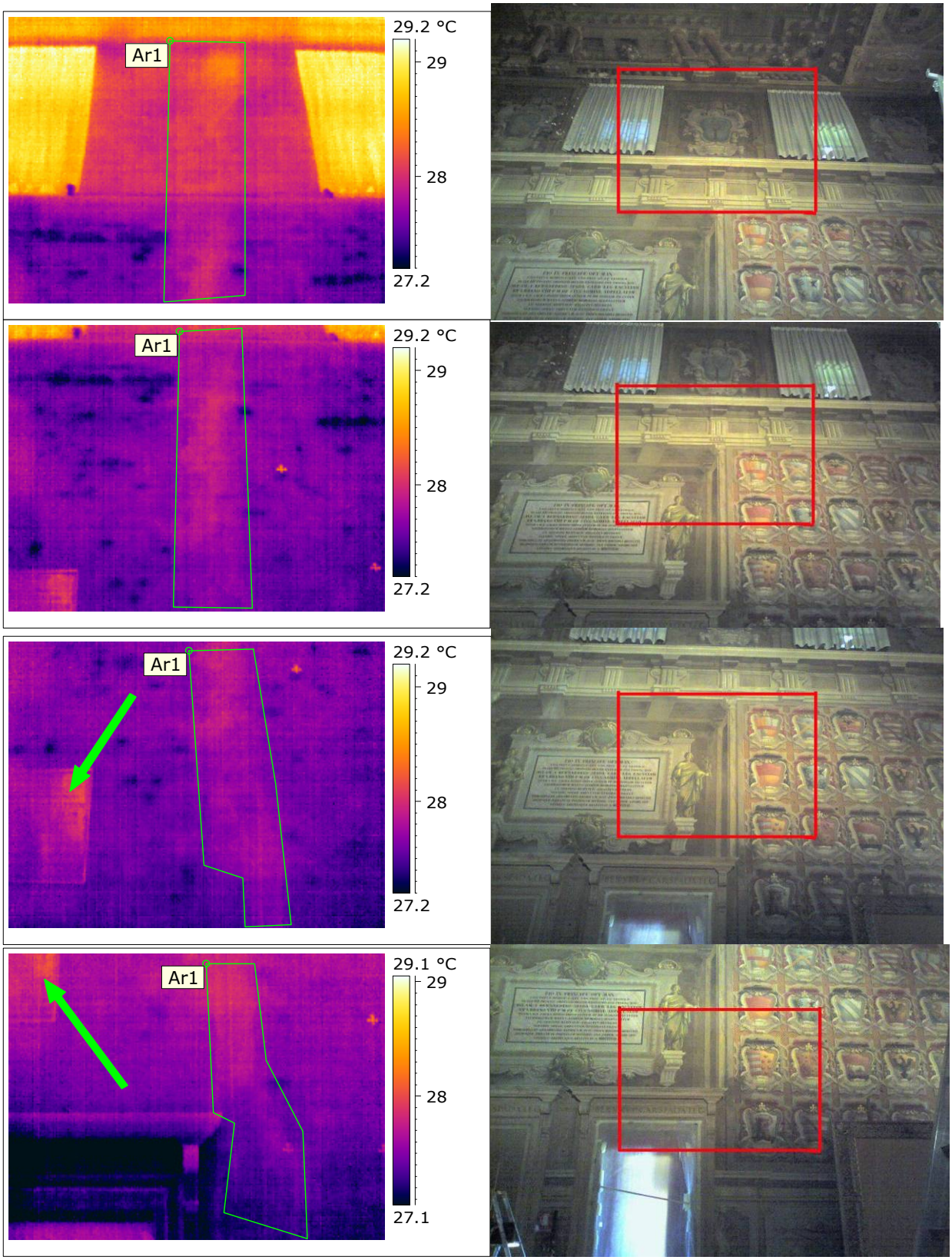
Test 16.

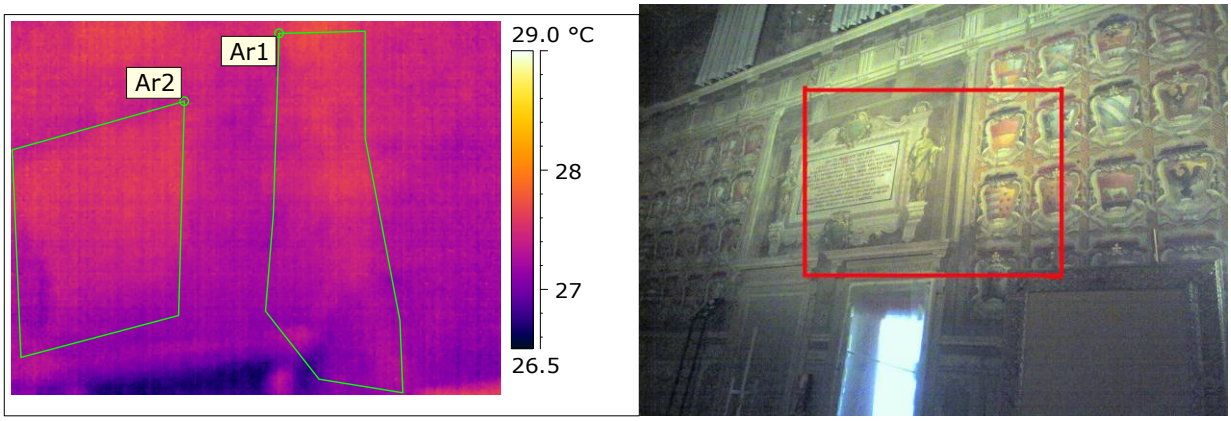
Date & Time: 08/04/2011 14.49.18



Comment: areas Ar1 identify a large plaster detachment running from the roof down to the room entrance; this detachment has been manually checked and confirmed.

Test 17.

Date & Time: 08/04/2011 15.10.24



Comment: also the plate shows a higher temperature, but the reason of this gradient is to be better understood by further examination.

In Figure 8 we show a photo of the North wall, where two visible cracks limit the area identified in Test 15 and follow the detachment seen in Test 16.

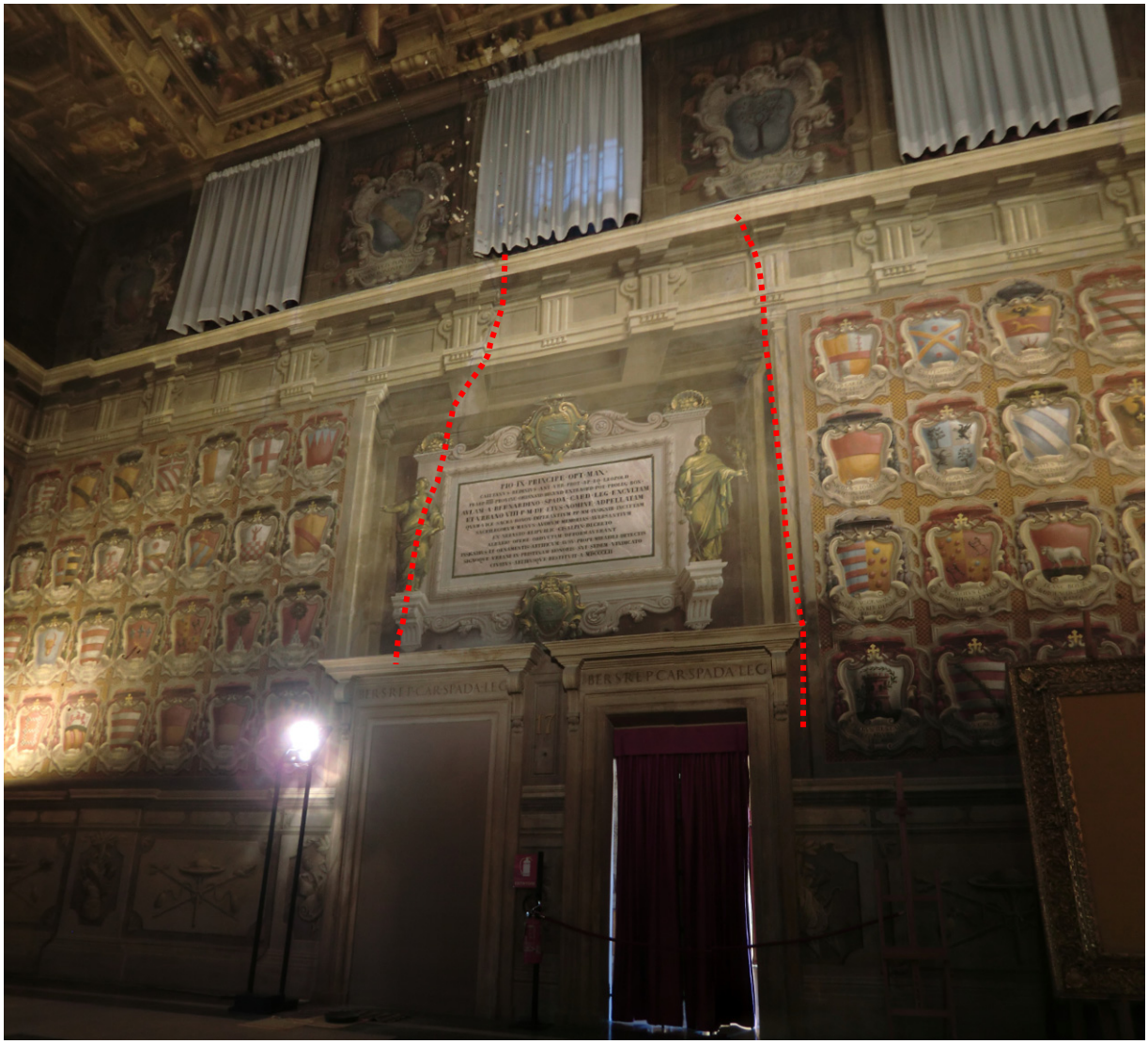
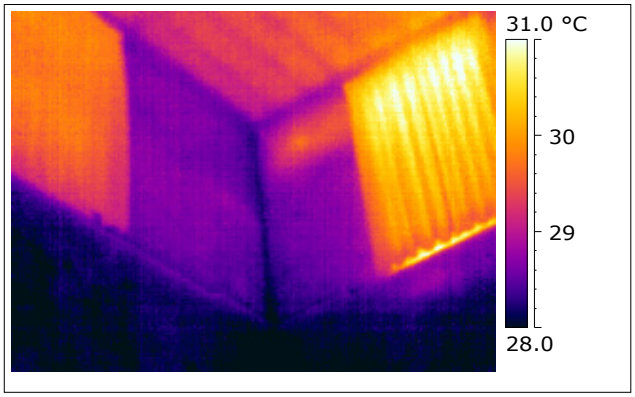


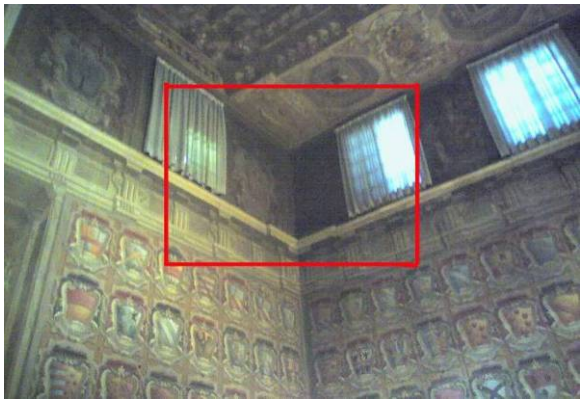
Figure 8: Photo of the Sala Urbana North wall, identification of cracks

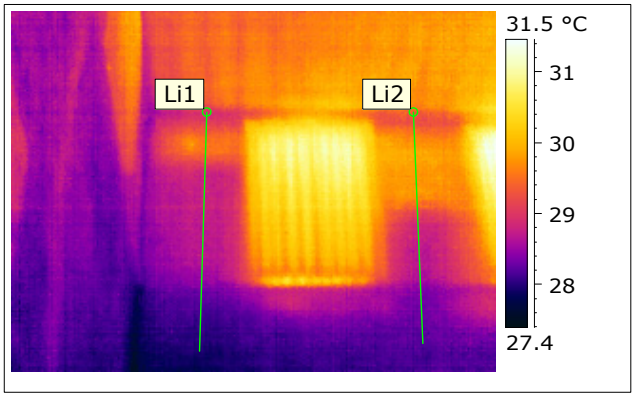
East wall

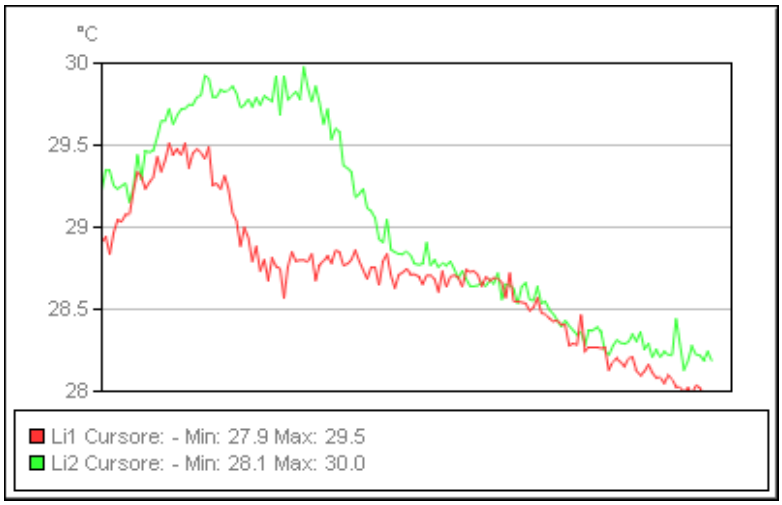
Test 18.

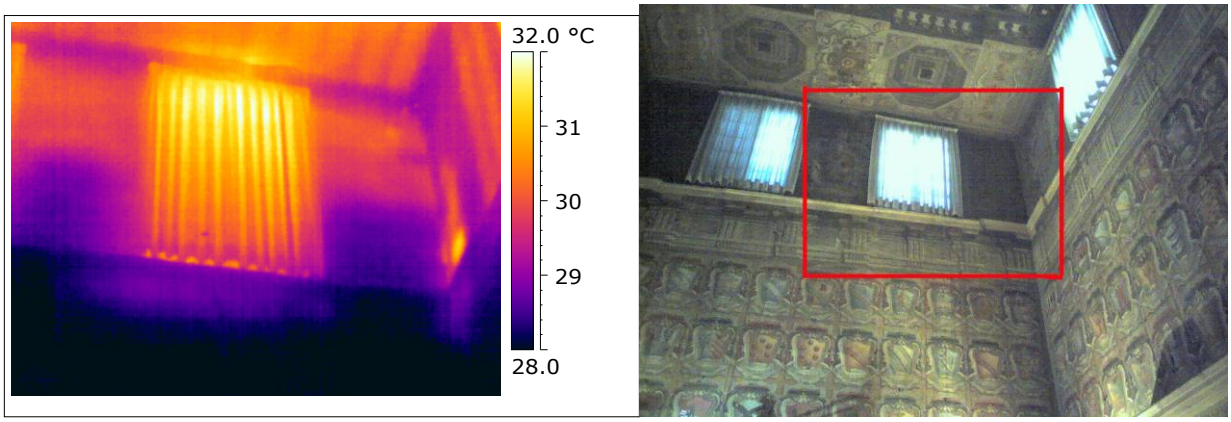
Date & Time: 08/04/2011 15.21.42







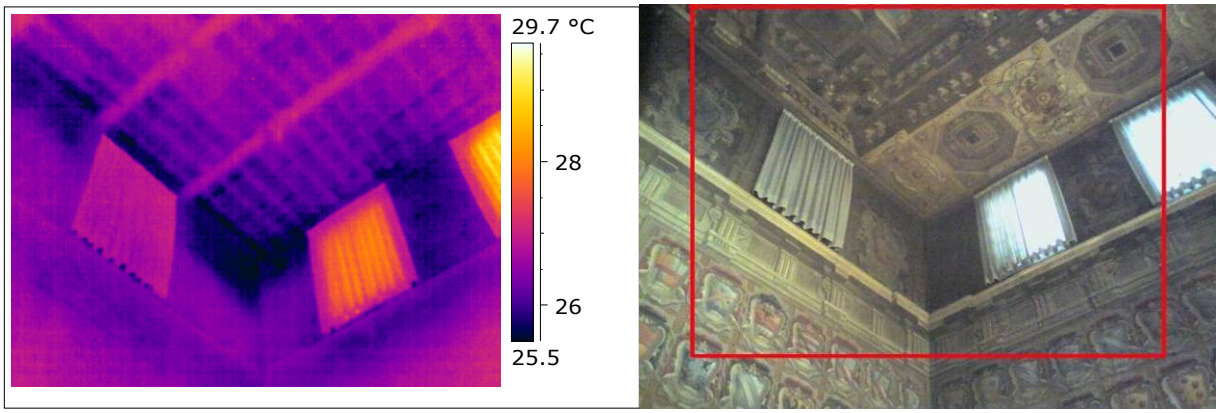




Comment: the evident warmer areas do not seem to be due to diffused detachments, their shape is too regular; and there seems to be no external structures that could explain such anomalies (e.g. air conditioning heat exchangers). Direct inspection and local demolition of external plaster would be required to understand such anomalies.

Test 19.

Date & Time: 18/03/2011 12:38:23



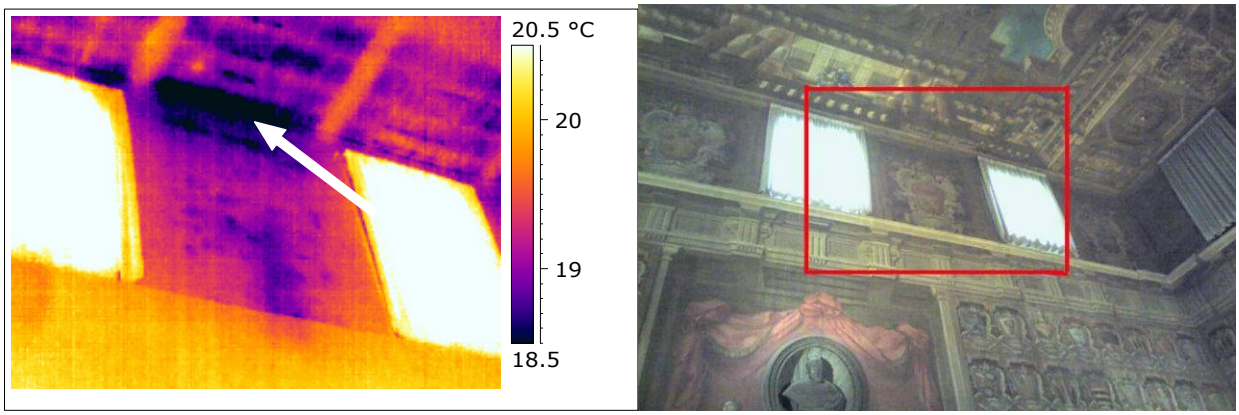
Comment: the same area has been inspected during a colder day in March, and in this case we have that the same zones are colder; this could suggest that we are observing a structure that offers a lower heat resistance, due to:

1. structural thinning (not probable);
2. different materials (to be investigated further);
3. presence of a cavity (not probable).

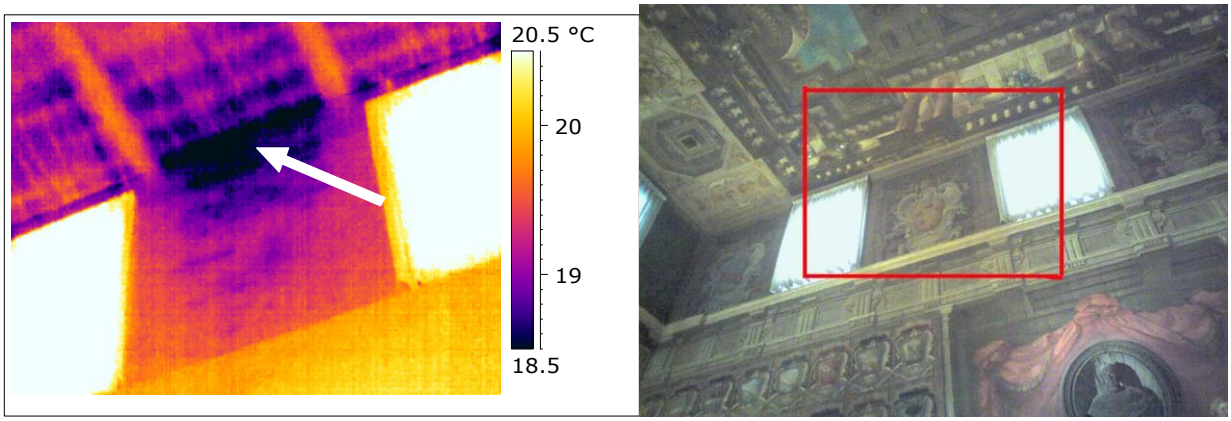
South wall

Test 20.

Date & Time: 18/03/2011



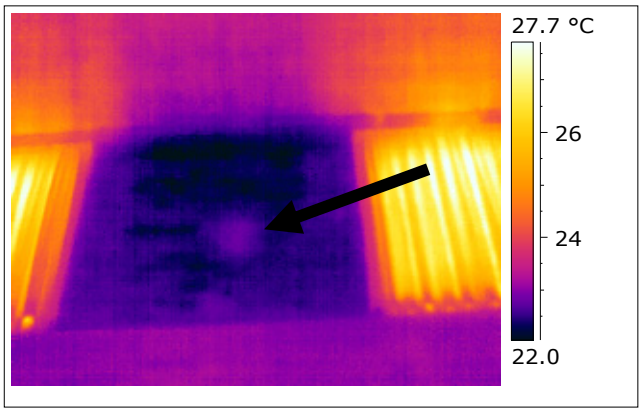
Comment: the white arrow aims at a damp area or otherwise a lack of insulation.

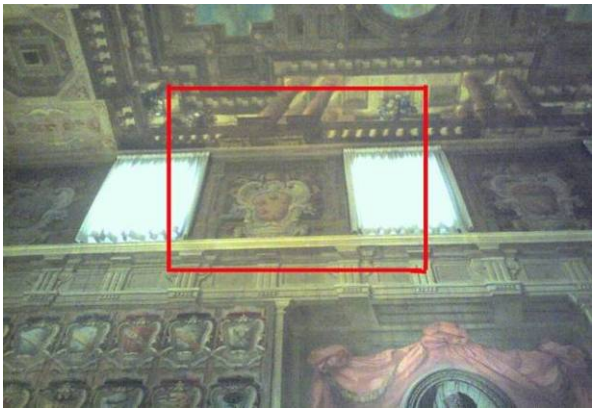


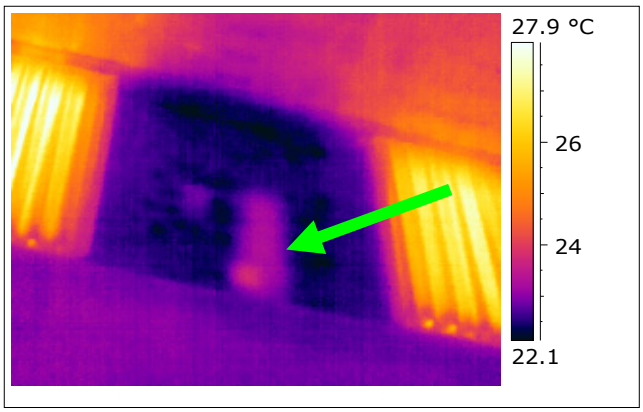
Comment: the white arrow aims at a damp area or otherwise a lack of insulation.

Test 21.

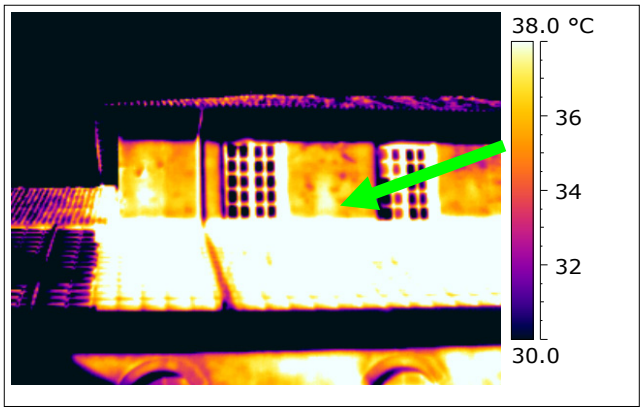
Date & Time: 29/03/2011 17:08:10







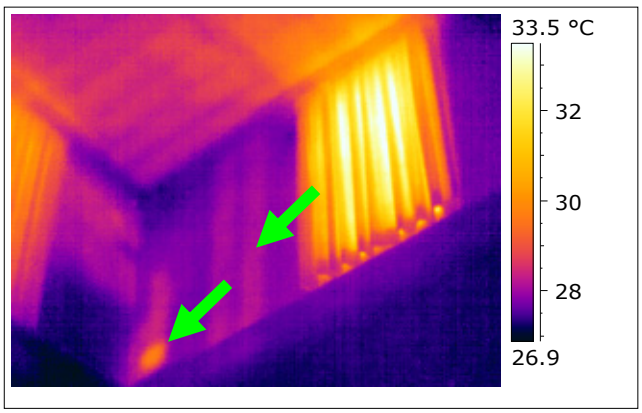
Date & Time: 29/03/2011 17:14:35



Comment: Test 21 has been repeated during a warmer day, and the most interesting feature is the high temperature area indicated by the green arrow; during Test 27 the same zone appeared colder, so this could identify a thermal bridge between the outside and the room (green arrow in Test 21). The same area has also been inspected by IRT from the outside and it is still warmer (green arrow in the test done at 17:14) than the surrounding areas, leading to the conclusion that probably identify a cavity; a high thermal resistance component, e.g. wood beam would not appear colder during the March measurement, while a concrete one would show a reversed thermal behavior.

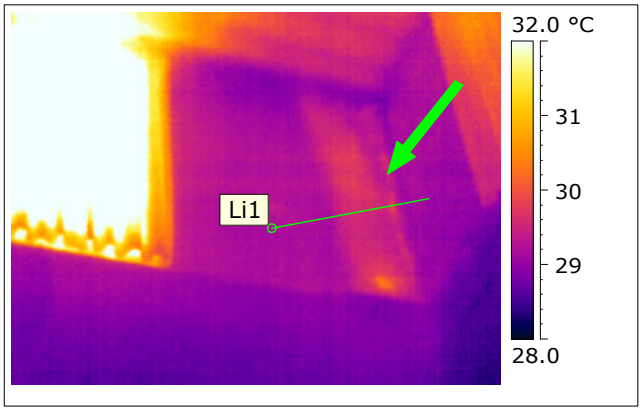
Test 22.

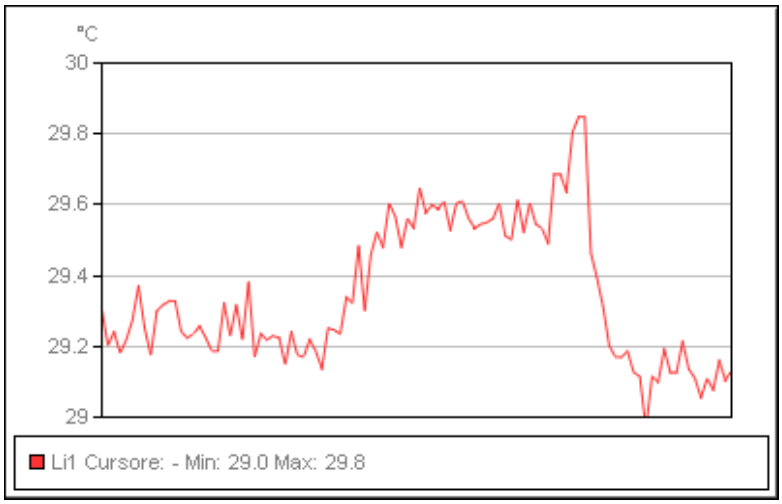
Date & Time: 08/04/2011 14.39.45



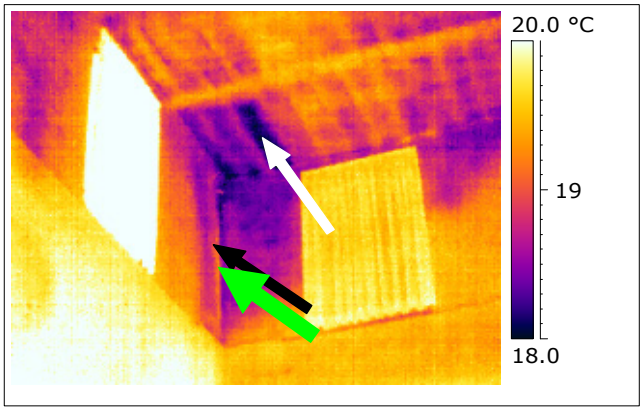
Test 23.

Date & Time: 08/04/2011 15.23.57



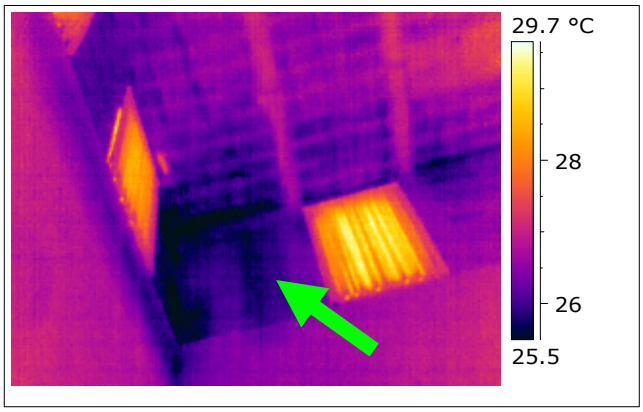


Test 24. Date & Time: 18/03/2011

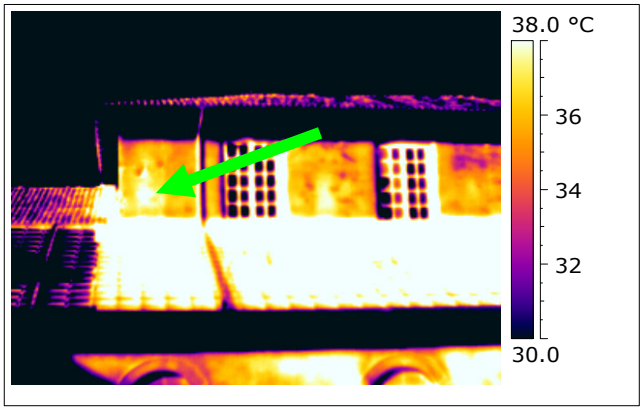


Test 25.

Date & Time: 18/03/2011 12:38:02



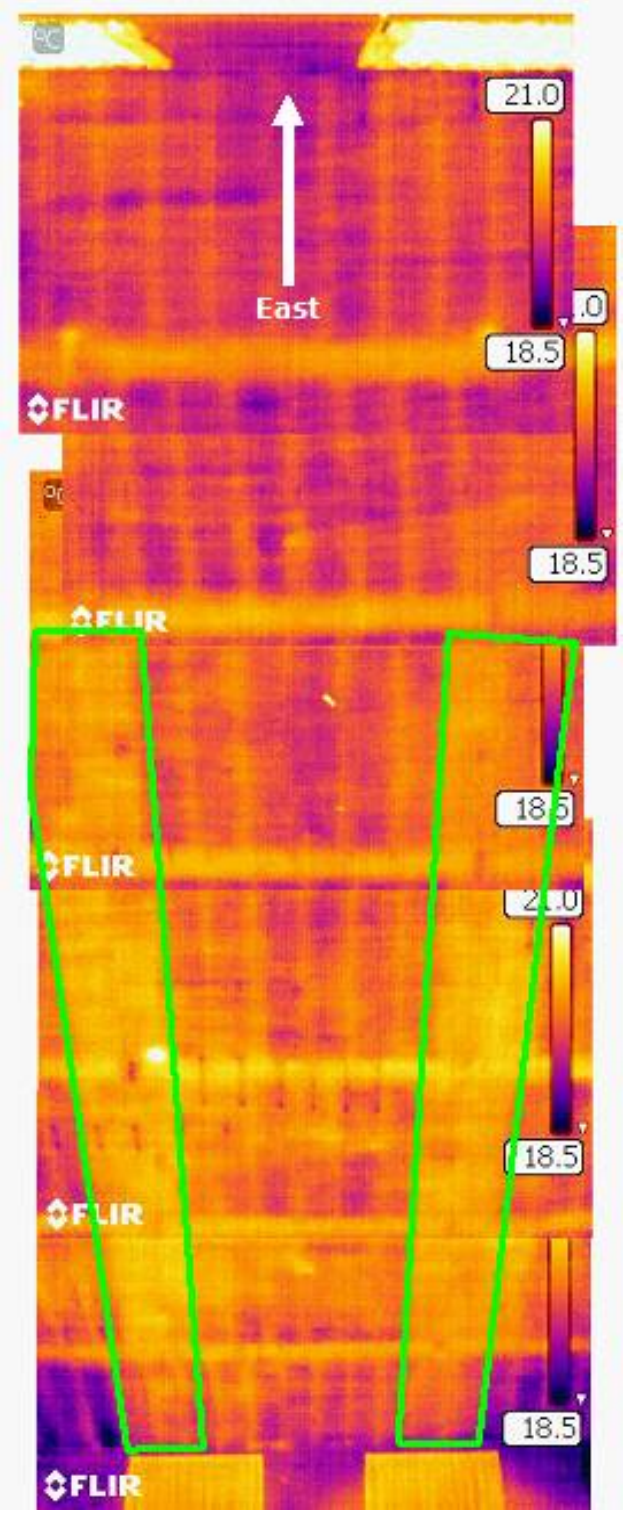
Date & Time: 29/03/2011 17:14:35

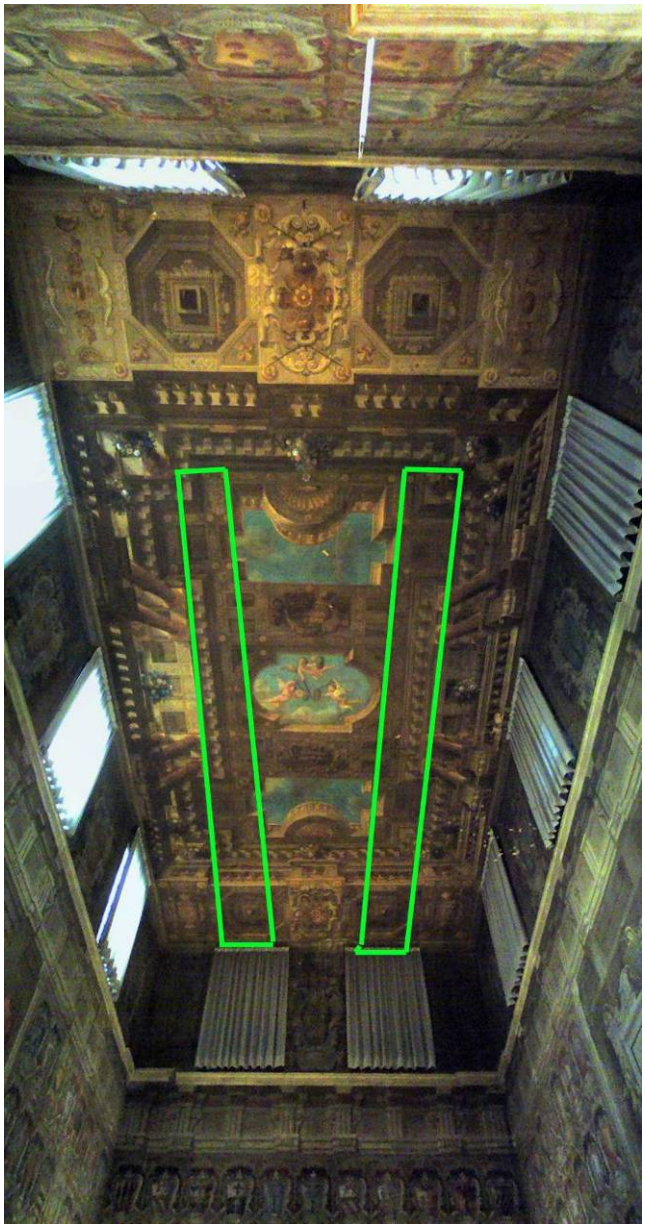


Comment: also the left (Test 20) and right (Test 21) parts of the wall present warmer areas, that are colder during the March measurements (cold air outside). Again, this can be explained as seen with Test 21, but a closer inspection would be needed; also observe the presence of a crack put in evidence by the line Li1. The hottest spots could be due to metal parts inserted in the masonry. The right upper part of the wall seen from outside shows a hot area.

Roof

In the thermograms the structure of the roof is clearly visible, with thick transversal logs joined by thinner ones. An interesting feature of the roof is represented by two large warmer areas (green shapes in the following Tests); they seem to identify stripes of insulation material, or a second roof on top of the visible one. When the same shapes are superimposed on a photo of the roof, there appear no relationship with painted decoration, so the influence of different pigments is to be excluded (tests of 18/03/2011).

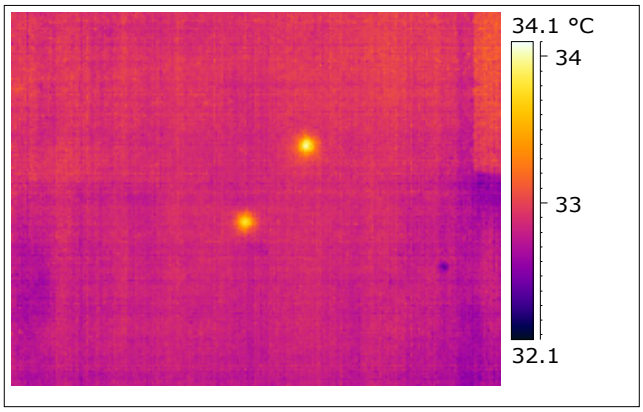


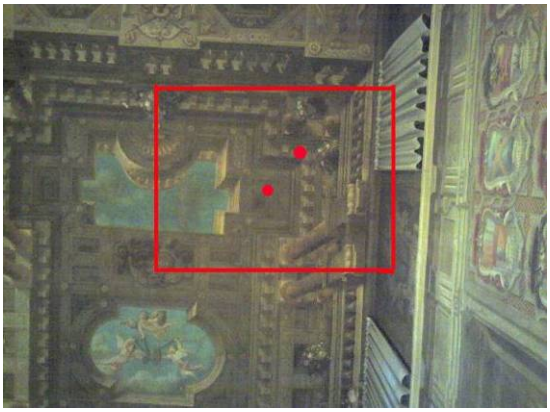


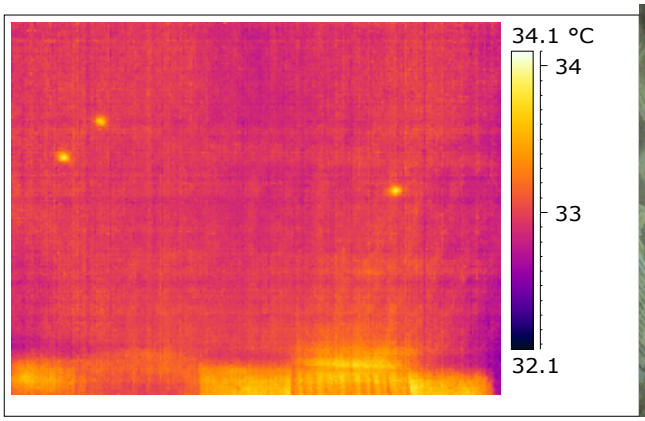
Deliverable D6.2 Documentation of each study case

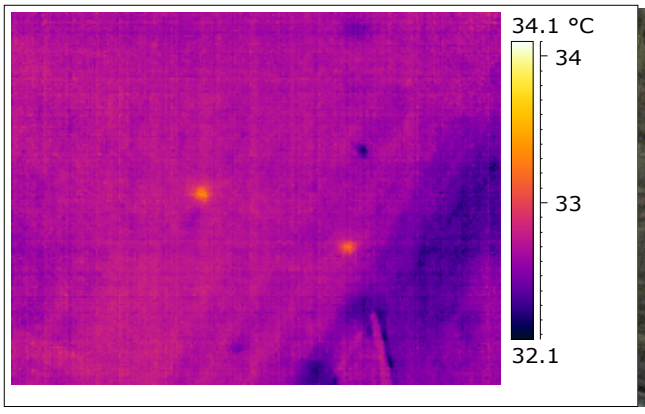
On July 20, 2011, the same thermograms of 18/03/2011 have been recorded, obtaining the same results: there appear some very hot spots, whose origin is not understood yet (see tests of May 27).

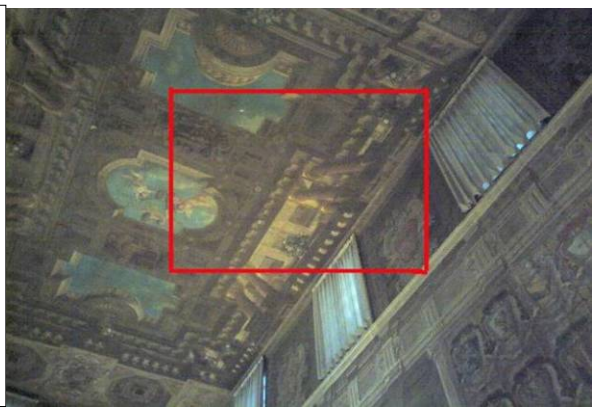
Date & Time: 2011-05-27







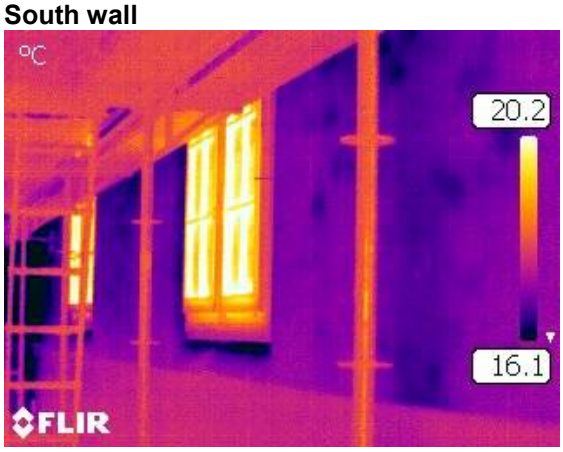


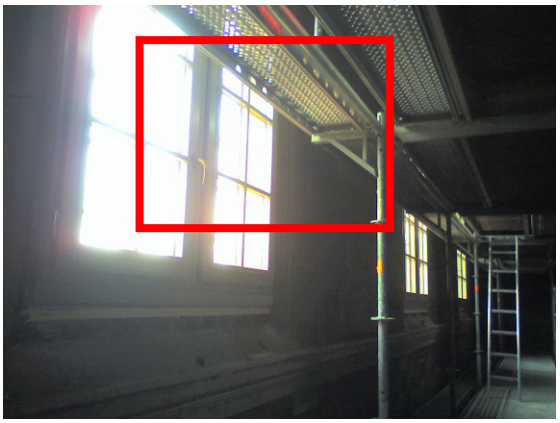


Comment: in the Sala Urbana room, on May 27 a series of hot spots have been recorded, whose origin is unknown. They are not objects laying on the protection net, could be the result of sun rays passing through some small apertures in the roof, but no certain explanation has been found. In the case of the first thermogram, their positions have been superimposed on the digital photo of the ceiling.

Date & Time: 2013-11-12, 14:10

South wall





West wall

Comment: in the Sala Urbana room, on November 12, 2013, a series of thermograms have been recorded aiming at showing the insulation degree of the newly installed windows; it is evident how around the windows there is a lower temperature and a lesser degree of insulation but no air infiltration is appearing. The situation has been greatly improved afterwards by the insertion of foam and a metal sealing frame.

1.2.3 Blower door test

(PAEA –Emiliano Zanichelli, UNIBO – Camilla Colla))

This is an extract of the technical report realized for Comune di Blogna in order to evaluate with the Blower Door Test the determination of air permeability of the two selected area of Palazzo d'Accursio Buildings. All the test are performed following the indication insert in the UNI EN 13829:2002.

The tests were carried out with the instrument : Minneapolis Blower Door and DG700E with serial number 6375-105.

The realization of the test takes place in two steps:

1- In the first phase a difference of pressure difference of 50 Pa (or the highest that can be possibly reached in case a 50 Pa difference could not be reached) between indoor and outdoor environment is been created; during this phase the building body enclosure is analyzed searching for the non-hermetic points that cause the major losses of thermal gain due to ventilation.

2- In the second phase, a decreasing depression is being generated, starting from values of 70 Pa circa (or the highest that can be possibly reached in case a 70 Pa difference could not be reached, in case of great volumes and/or of a very low air impermeability), going to a final value of 10 Pa. For every step the air volumes lost through the permeability points are detected and noted and an index estimating the air quantity entered in an hour time is calculated (n50), referred to a pressure difference of 50 Pa.

The final result represents the number of hourly internal air volume renewals that is obtained through the leaks in the building enclosure body, the sum of which defines the total loss, expressed in cm2(leakage area).

Blower Door test in the Municipal collection

Calculation surfaces

The analyzed building presents itself as part of an historic building located inside the historic center.

Because of the high volume and the low level of air impermeability we chose to divide the tested area in four zones in order to reach significant pressure differences all the same. The several parts have been separated from each other, by closing and belting the existing doors and sealing the openings that were not provided with doors using synthetic canvas installed by means of specially designed frames (the ones that are indicated with an "O" in the map below). The different areas are highlighted in the map below:

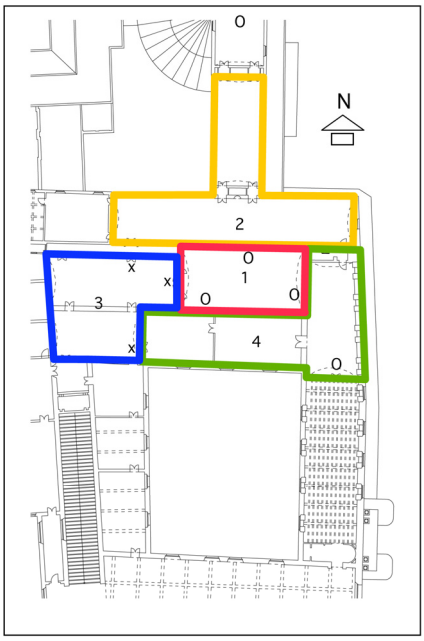
Sub area 1 - "Coat of arms" room;

Sub area 2 - "Vidonian" Room, "Primitivi" Room, Room "1500";

Sub area 3 - Room 19, Room 20;

Sub area 4 - Room Aemilia Ars and adjacent ones.

The "X"es in the map indicate the openings where the mechanic fan used for the several tests was put. The net volume of the different tested zones has been derived from on-site measurements.



Considered sub-areas

Boundary conditions

The adopted method in order to define the level of air permeability of the building's enclosure body is the test method "A" (test on building in use), following the norm UNI EN 13829:2002

Detection of the points with highest loss

Using the Minneapolis Blower Door (model nr. 4) the building environment has been depressed at a constant value of 50 Pa (when reachable) ; then the local points of the tested building's enclosure body that, for extension and intensity could cause the highest air infiltrations from the outside environment,

The measured infiltration resulted being very high and concentrated in particular:

- Near windows shutters: all the shutters have great dimensions, with wood frames without seals, sometimes visibly deformed and with difficult closure. The infiltrations are located both between window and frame and between frame and walls.
- Near installations pipelines located under the pavement beside the perimeter walls.
- Near upper floors docks in those rooms where these are coffered and made of wood (leaks among the beans can be seen by naked eye)

Detection of the points with highest loss

With the boundary conditions previously depicted, four permeability to air tests were done on the diverse zones using Blower Door obtaining the results that are reported below.

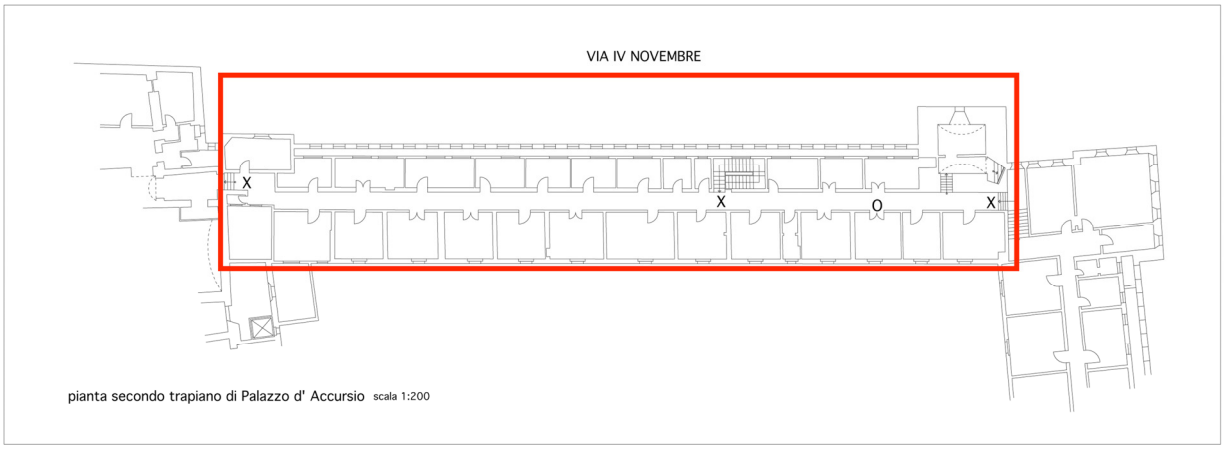
SubArea Blower-door-test	n50 = V50/V (1/h)
Sub area 1 - "Coat of arms" room	**2,52**
Sub area 2 - "Vidonian" Room, "Primitivi" Room, Room "1500"	**4,40**
Sub area 3 - Room 19, Room 20	**2,38**
Sub area 4 - Room Aemilia Ars and adjacent ones	**14,69**

Blower Door test in the Office area

Calculation surfaces

The building object of analysis presents itself as part of an historic fabric located inside the historic centre. The part of the building analyzed by the test it's been separated from the adjacent ones, by closing and belting the existing doors (signaled with an 'x' in the plant). Because of problems related to the windows dimensions the mechanical fan has been installed on an internal door (signaled with an 'o' in the plant) opening the external room window towards the zone to be tested.

The net volume of the several test areas has been derived from "on site" measurements.



Boundary conditions

The method used for determining the building's external body enclosure permeability to air filtering is the type 'A' (test on a building being used), following the norm UNI EN 13829:2002.

Detection of highest loss points

Using the Minneapolis Blower Door (Model 4) the building has been depressed at a constant value of 50 Pa (when this could be reached); therefore the points that, both because of extension and intensity, could cause the highest air infiltration from the outside were forsaken and detected in every room.

The infiltrations that were found resulted having a very high intensity, concentrating especially next to window shutters.

Below are shown in detail some measurements done with anemometer on a window shutter chosen as sample: shutter W2F69, located on the building's side that overlooks IVth of November road inside room nr 40.

Between the two opening doors have been detected infiltrations whose average value corresponds to 1,5 m/s with growing values that sometimes each the maximum of 2,5-2,9 m/s, meaning the imperfect closure due to frame deformation.

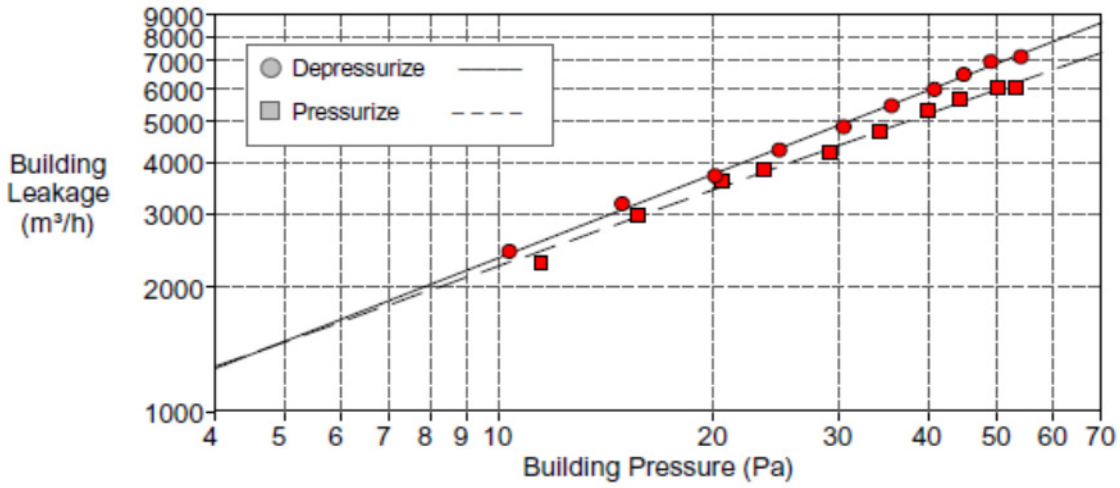
Between the frame and the wall both on left and right side can be found infiltrations with an average value of 0,2 m/s.

Between the frame and the wall on the right side, we do have an average value of 0,1 m/s, while on the left side the conditions are even worse with an average infiltration value of 0,7 m/swith peak values that are higher than 1 m/s in the upper part.

Between the lower part of the left door knocker of the window and the frame we do have an average value of 1,5-2 m/s with a peak of 3,8 m/s nearby the closure; between the inferior part of the right knocker door of the window and the frame we do have an average value of 0,1 m\s with increasing values going towards the external corner and a peak value of 0,4 m/s nearby the closure.

Between the inferior side of the frame and the lower wall we have a value of 0,1 m\s.

In the right part of the window shutter the second glass (counted from the upside) is leaked, and in that leak we have an infiltration value of 6,4 m\s.



Test results

With the boundary conditions previously depicted, four tests have been done on the air permeability, using Blower Door in the several zones obtaining the results that are listed below.

SubArea Blower-door-test	n50 = V50/V (1/h)
1 - An Office at second floor	**4,68**

1.2.4 U-Value determination

ARTEMIS – Enrico Esposito and UNIBO Marco Giuliani

Different U-value measurements of exterior wall have been conducted in a direct way in accordance to the norm ISO 9869 (CEN, 1994), in order to compensate the lack of existing documentation on the actual state of the building and to obtain a sufficiently reliable estimation of the heat losses of the structure, keeping in mind that the physical characteristics of masonry's components are different from masonry's components currently used, thus the scheduled values should not be used. As reported elsewhere in this document the discrepancy between measured value and calculated one (through the standard value of material) is high, especially for thicker walls. The U-value measurements positions are reported below, on the plan and sectional views of the building (Figure 9 and 10). The measurement positions have been chosen considering different aspects regarding the building structure, the presence of inaccessible points and the presence of frescoes. An example of data elaboration is reported in figure 11 where Average Method and Black-box Method are applied. Values obtained are much closed, addressing that the estimated value is correct and the reliability of the methods. The heat losses via the floor and the ceiling have been determined through the numerical calculation of the transmittance value and not following the norm ISO 9869. The floor component isn't very important because the first plant was heating in the same way and with the same system of second plant. The heating loses via the ceiling has more importance but the direct measure need more time to implement for difficulties to organize it due to presence of frescoes and other technical aspect.

Transmittance measure plan of Municipal Collection

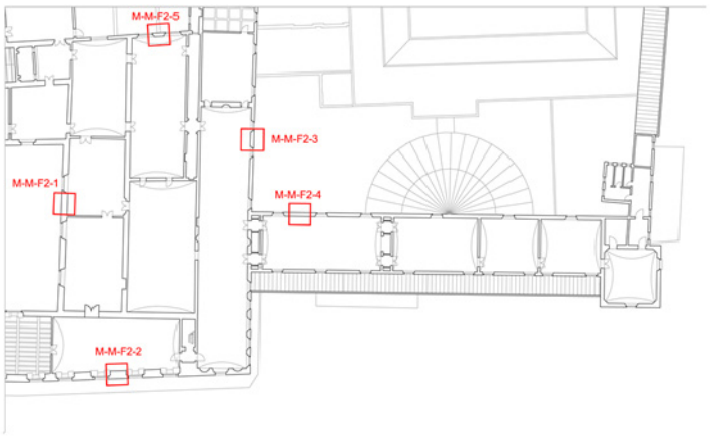


Fig. 9 – Plan view of the Museum plant, with the position of U-value measurements

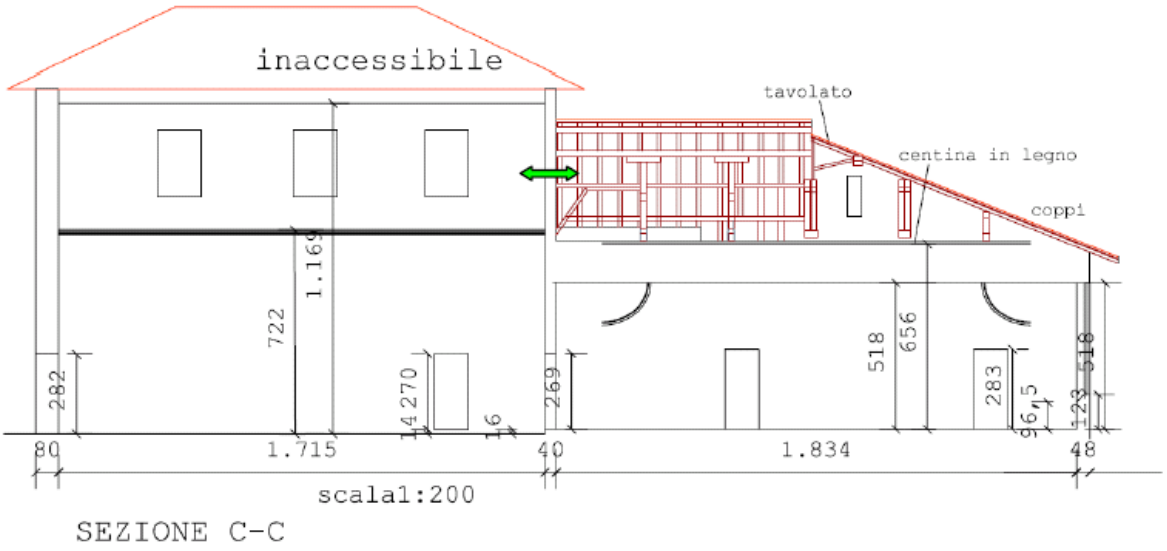
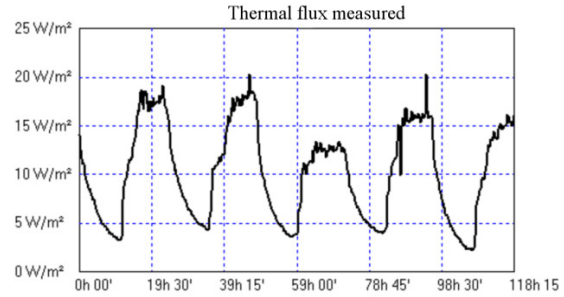
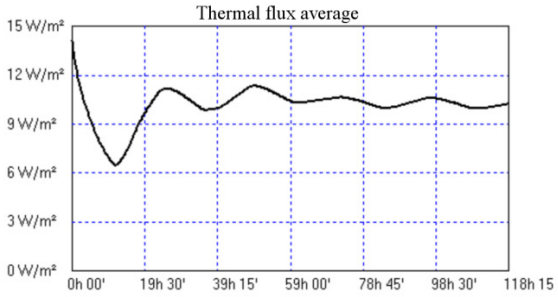
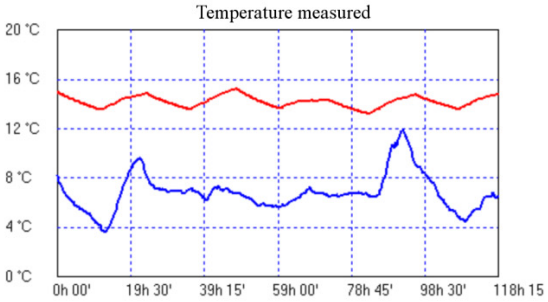
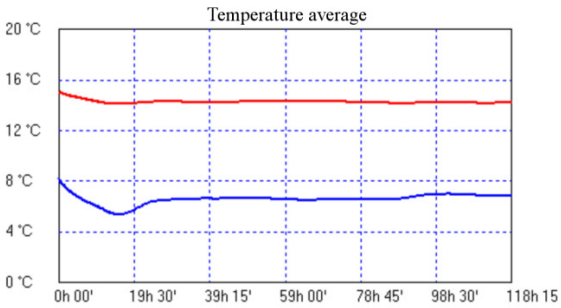


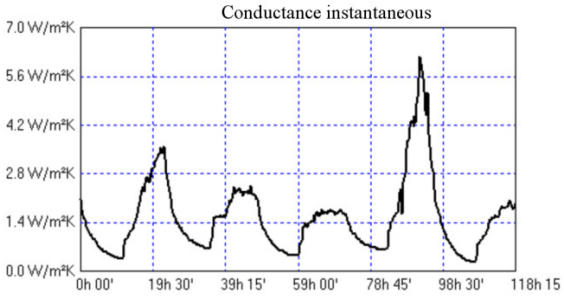
Fig. 10 – section view of the attic, with the position of U-value measurements.

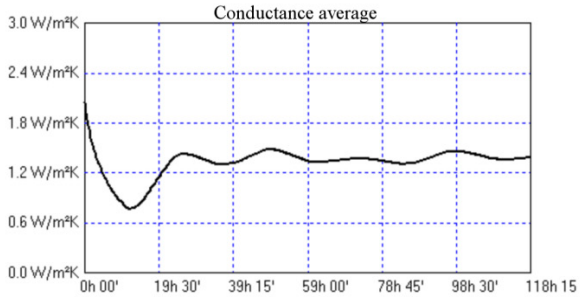












Results of data elaboration

Moving Average Method		
Thermal Flux	10.2453	W/m2
Temp int	14.1912	°C
Temp ext	6.7972	°C
Conductance	1.3856	W/m2K
Blackbox Method		
Conductance	1.3751	W/m2K
Standard Dev	0.0417	W/m2K

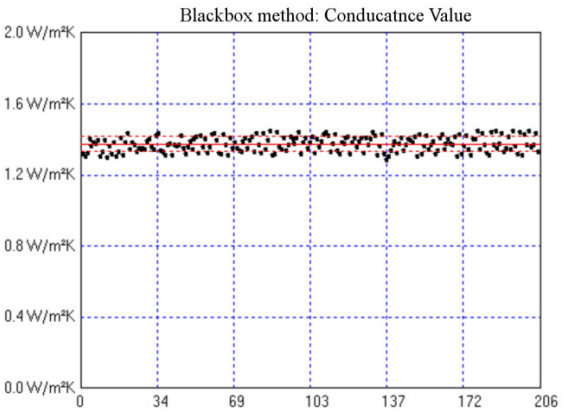


Fig. 11 - Example of data elaboration

1.3 Hygrothermal and environmental monitoring

Hygrothermal monitoring of the building was carried out through a WSN and a IEQ (Indoor Environmental Quality) Audit for characterization of micro-climatic conditions carried with portable instrumentation, both in the Museum and in the Office areas:

- WSN: monitoring has been going on since February 2011 to April 2012 and in the picture below we have a summarizing graph of the results obtained for air temperature and RH inside Sala Urbana and in its attic, where it is evident that the present situation is not favourable for artworks conservation.
- IEQ Audits were performed in winter and summertime period. Through the two monitoring campaigns realized in February 2012 and July 2012 were identified the levels fixed in each indoor room using thermo-hygrometric, visual, acoustic parametric value and the derived calculated parameters of comfort. Results concerning thermo-hygrometric wellbeing in Urban room showed values of satisfactory comfort for winter time (respectively PMV=-0,29 PPD=6,74).

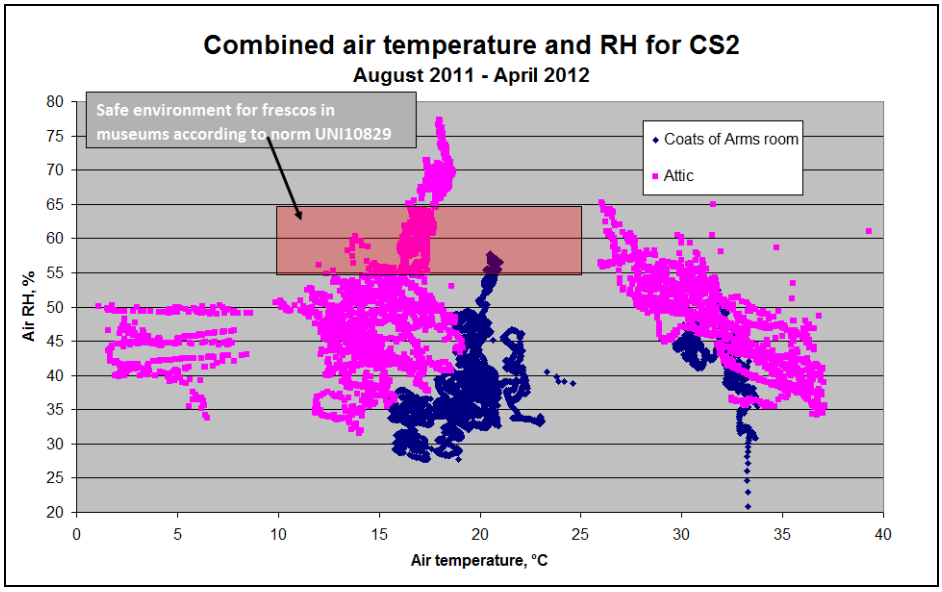


Figure 12 - Combined air temperature and RH, Source: [Esposito, E. 2012], © Artemis

In addition, in the Municipal Collection area, the pre-intervention indoor climate conditions were repeatedly monitored by UNIBO's researchers in different seasons and with open/closed windows/doors by means of digital thermohygrometer and analogue thermohygrographer to obtain psychrometric maps at different heights above the floor (Figure 13). Moreover, the climatic variations in Sala Urbana during and after intervention in summer/autumn 2013 were monitored by means of a Wireless Sensor Network made of 2 nodes for T, RH, light, vibration detection (Figure 14).

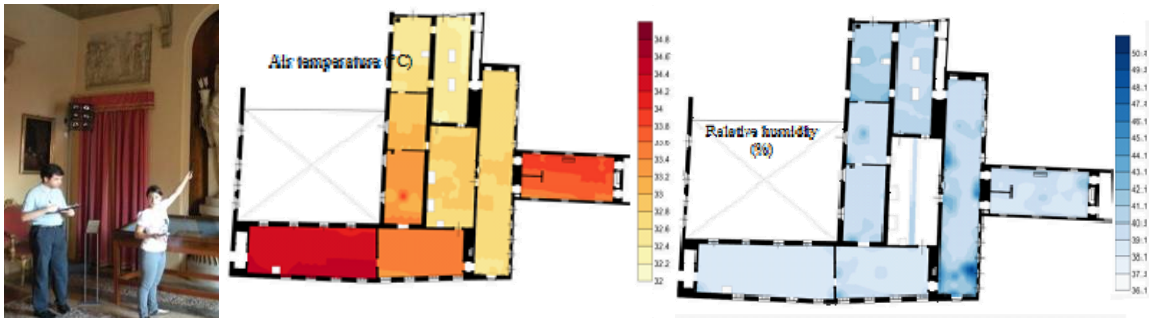


Figure 13:Data acquisition for psychrometric maps, Municipal Collections, in a hot August day with closed windows, and output maps. Source: [Colla C., 2012], © DICAM Dept., University of Bologna

Figure 14: WSN monitoring of microclimatic conditions during refurbishment works: laptop and node 0 on the West wall of "Sala Urbana" (left), WSN node 1 in the roof space above the room (centre) example of monitor data (right), Source: [Colla C., Paci G., 2013], © DEI & DICAM Dept., University of Bologna

1.3.1 Monitoring results through WSN

(Artemis - Enrico Esposito, Antonio del Conte, UNIBO- Marco Giuliani)

Results are not presented entirely in this report but only relevant graphs (see Annex 8, all results are reported in Excel files uploaded on the Project Dropbox folder prepared by COBO an in the Team site). In the following pages we will present relevant remarks about results and only some examples of graphs and WSN installation, divided by location, Civic Collections and offices, and monitoring period.

TEST INSTALLATION

In the days 25-28/02/2011 two different small WSNs have been installed in Collezioni Comunali, specifically in Sala dei Primitivi and in the attic of Galleria Vidoniana, see Figure 15.

WSNs were formed by:

Network 01

4 Memsic MDA300 nodes (01…04) with on-board air temperature and humidity sensors; node 4 was also equipped with a Cantherm CWF4B103G3380 thermistor to measure surface temperature and a Omron D6F-V03A1 MEMS flow sensor to measure air velocity.

Network 02

3 Memsic MTS400 nodes with on board air temperature and humidity sensors, luxmeter, pressure sensor, two-axis accelerometer (MTS01….03).

Both WSNs sent data to a Memsic MIB520 gateway that interfaced the WSNs to a laptop where data were stored and displayed; at the end of data acquisition, data have been exported to Excel for analysis and graphics.

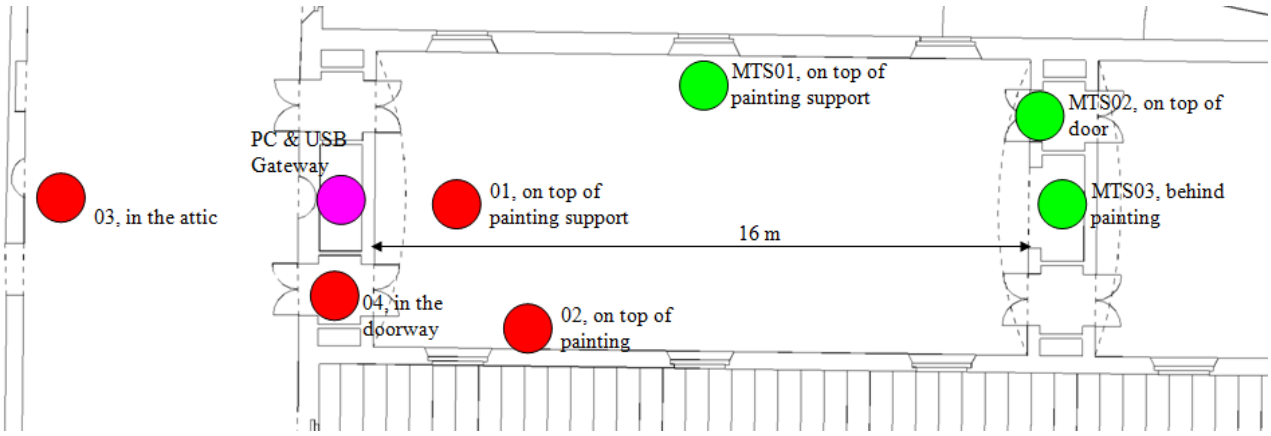


Figure 15: Plan of pilot Wireless Sensor Networks installed in Collezioni Comunali and photos of installed nodes positions.

Results

Battery consumption is a fundamental feature of WSN nodes, because it will influence the maintenance interval of the network. Installed nodes are consuming batteries (two standard AAA ones) at a rate of about 0.1 mV/per reading, see Figure 16, giving a total of 9000 readings (full charged batteries at 3.3 V); this means that a reading rate of 1 minute will give a life span of about 1 week, while a rate of 1 hour will give a life span of about 1 year; these values are too limited and the final WSN should guarantee a life span of at least 2 years with a reading interval of 5 minutes.

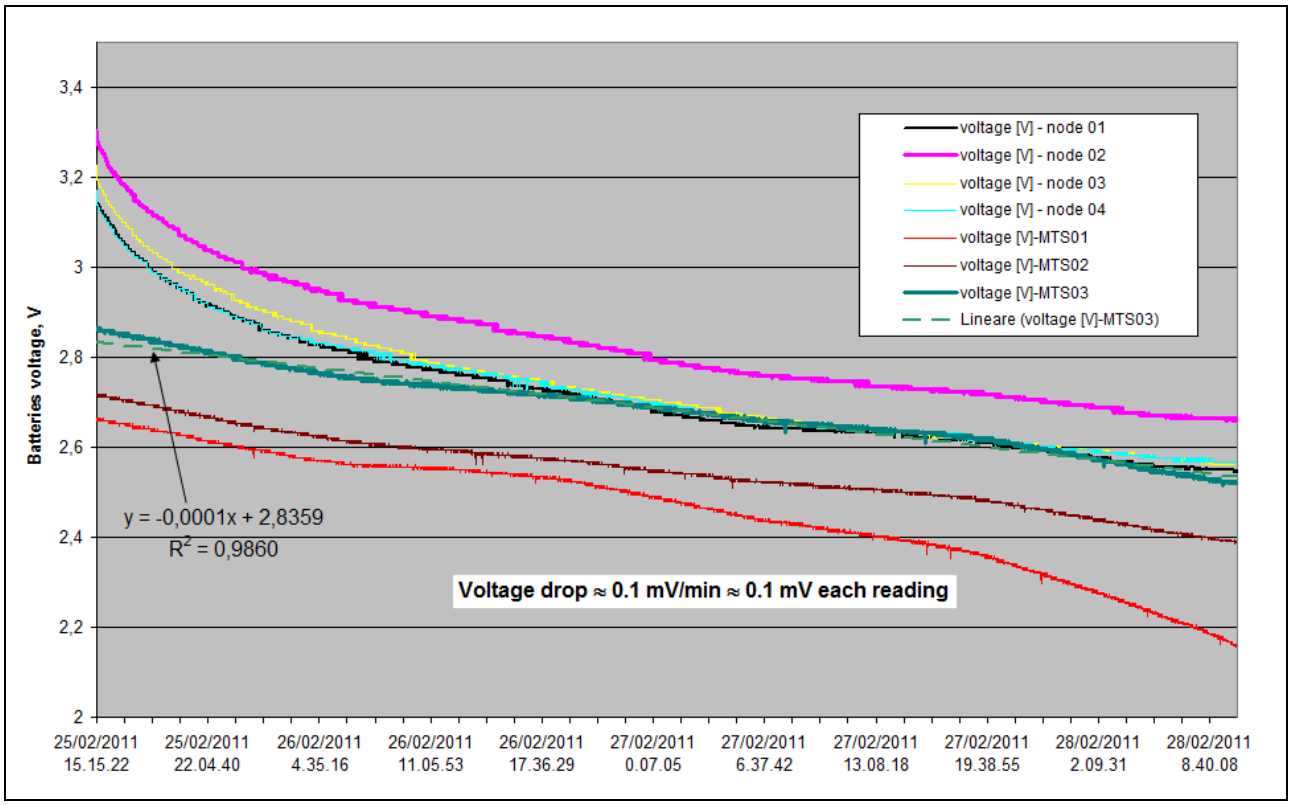


Figure 16: Battery consumption for Memsic nodes.

Air temperature and humidity are plotted in Figure 17; we observe that humidity values, apart for the sensor in the attic, oscillates in the range 30-50%, with maxima occurring in correspondence of temperature minimum values. Also temperatures range is limited to 13-19 °C, with a variation of about 2 °C for single sensors.

As a reference, the Italian norm UNI 10829:1999 gives some indications for optimal values of thermo/hygrometric parameters:

- Books and documents: 13-18°C, RH 50-60%
- Painting on canvas: 19-24°C, RH 40-55%
- Wood furniture, wood sculptures and painting on wood 19-24°C, RH 50-60%

Temperature is normally too low for optimal conservation of artworks exposed in Collezioni Comunali, while RH is generally acceptable, although variations of RH are far too large. Note also how the temperature peak is reached slightly after the Collezioni close in the evening (see the graph for light level of MTS01). Surface temperature variations are more limited with respect to air ones, a behaviour due to thermal inertia phenomena.

In Figure 18 we show the values for air velocity (at the entrance of Sala dei Primitivi) and ambient pressure; as easily predictable, air velocity follows temperature trend with peaks in the range of 0.2 m/s, while air pressure is quite stable and compares well with data collected at Bologna airport during the same days.

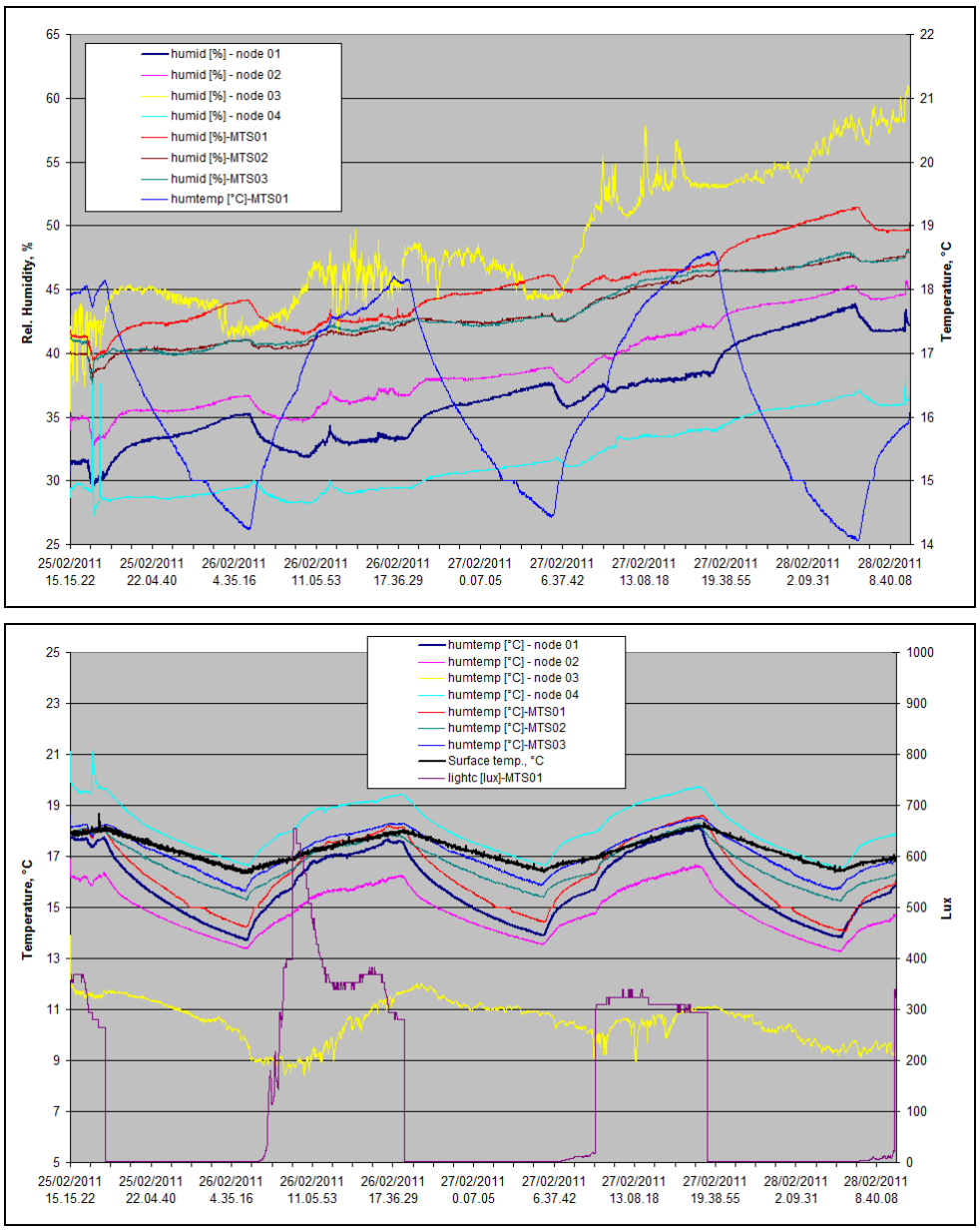


Figure 17: Air humidity and air temperature.

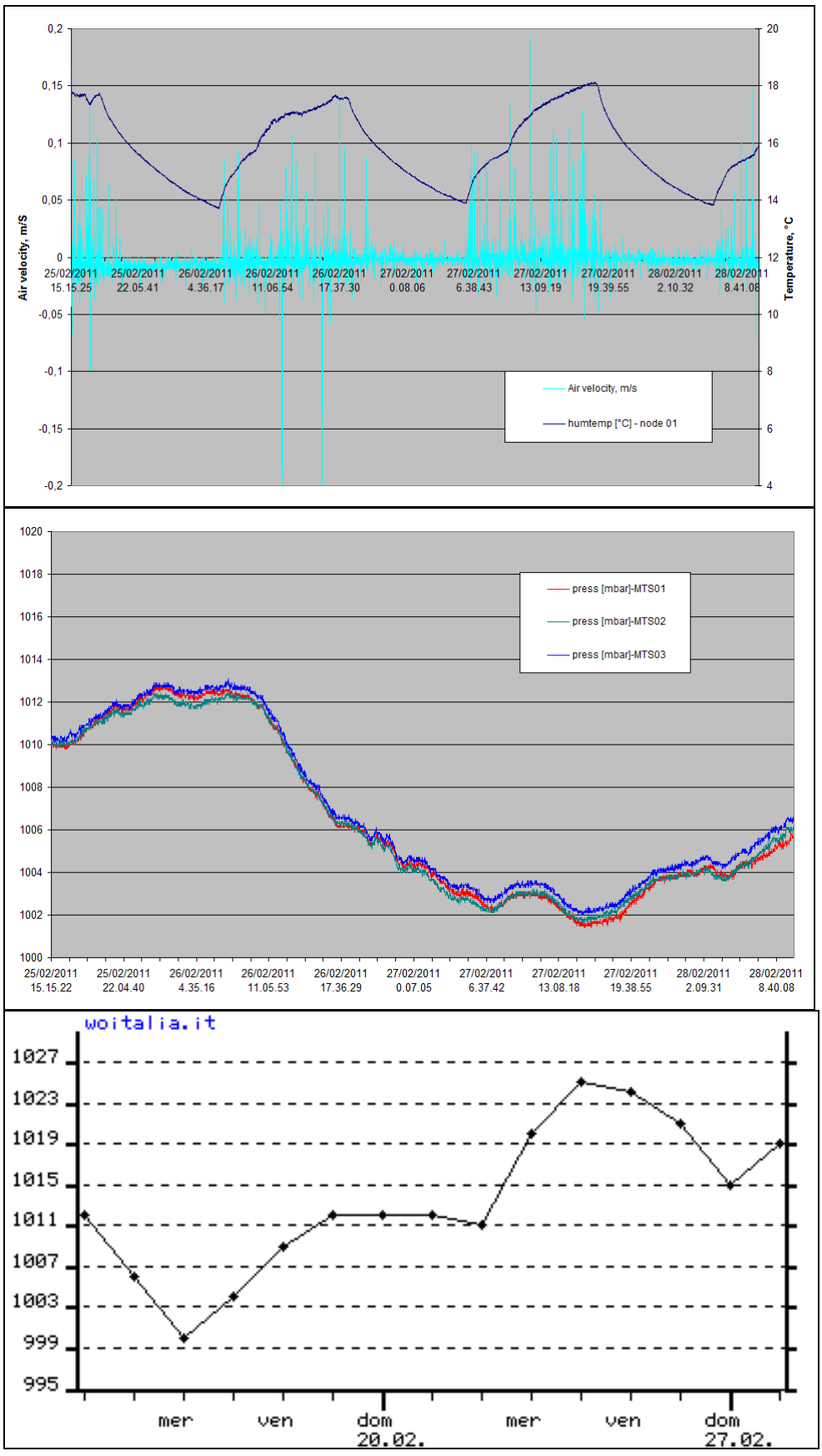


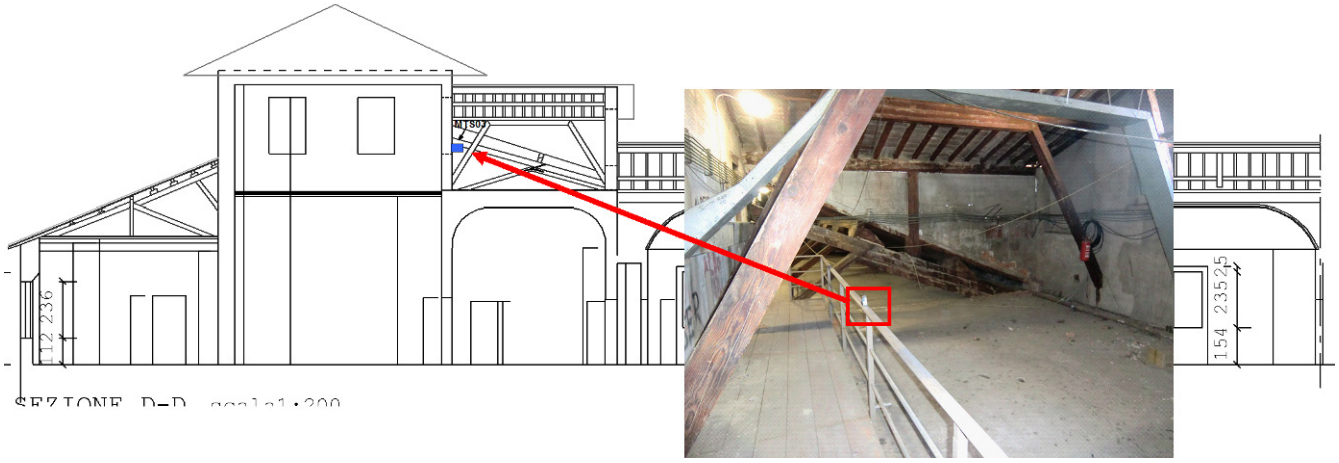
Figure 18: Air velocity and ambient pressure.

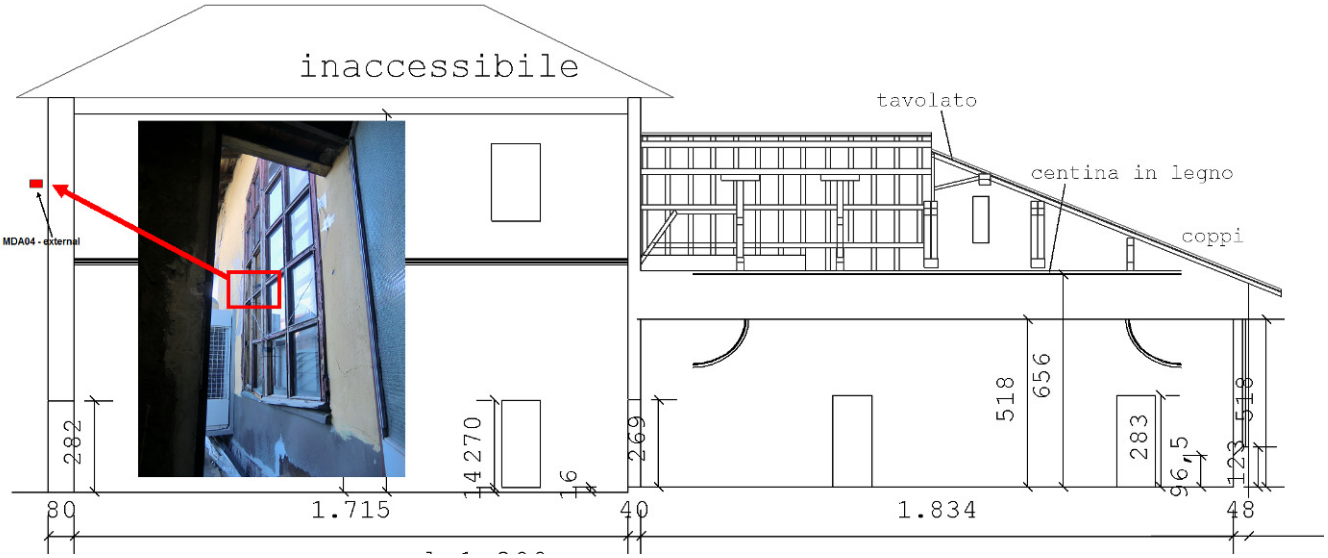
Deliverable D6.2 Documentation of each study case

CIVIC COLLECTIONS

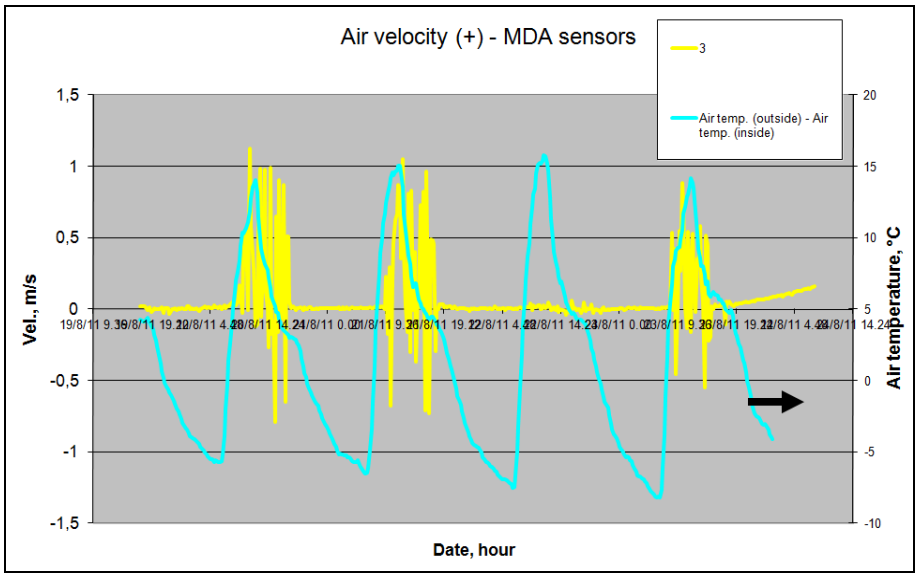
August 2011

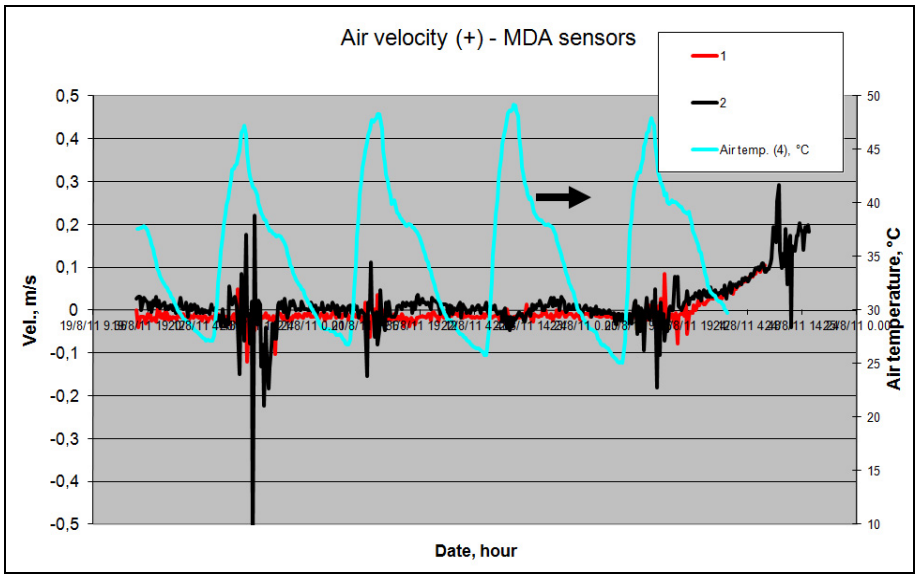
Map of nodes

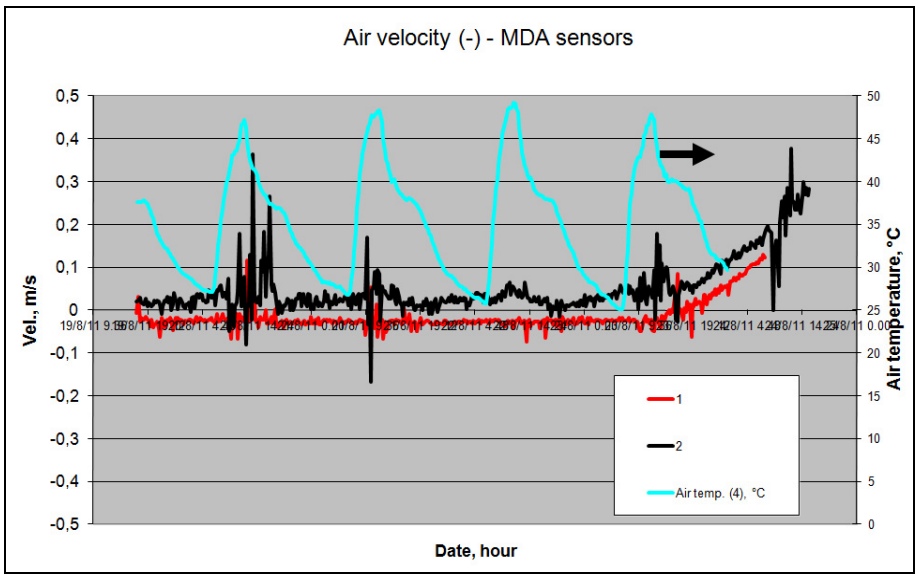




Positions of nodes MTS03, MDA01…04.



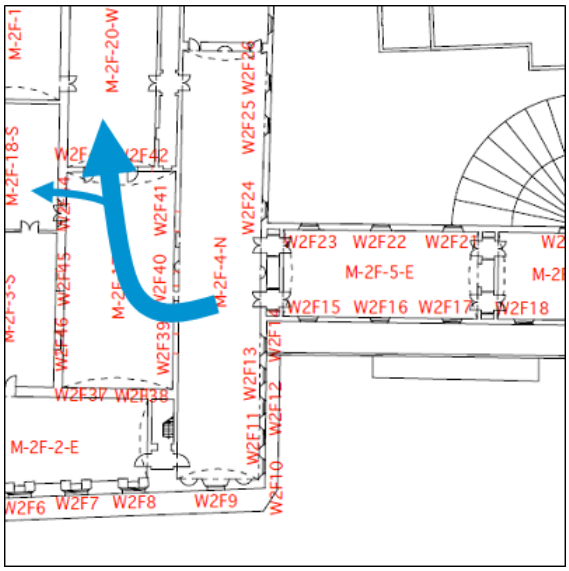




August 2011 - Graphs of data from monitoring in Civic Collections.

Remarks

1. Employed WSN used the Memsic devices tested for the first prototype installation;
2. Air temperature inside Sala Urbana is almost constant, with a daily variation of about 1 °C and a ratio between average and maximum/minimum values of about 6.5%;
3. Air humidity is quite stable during single days, changing quite abruptly from one day to another; this behavior, however, is consistent with data recorded by the reference weather station;
4. Node in the middle of Sala Urbana (MTS01) has an average temperature higher of about 1 °C with respect to MDA nodes, placed close to the room entrances; also recorded air humidity is slightly higher for the MTS01 node;
5. Data referring to the outside environment show a daily oscillation of about 22 °C, while in the attic temperature varies of about 5 °C; it must be pointed out that the node on the outside of Sala Urbana was close to the external part of an air conditioning system, but this seems to have little if no influence on measured data;
6. Surface temperatures show a similar behavior, with daily oscillations inside Sala Urbana lower than 0.5 °C;
7. It is quite interesting to note how recorded data follow quite closely those downloaded by the “ilmeteo” weather station, at least as a daily trend;
8. Air velocity is relatively high in correspondence of the entrance towards Galleria Vidoniana (MDA03), reaching a value of about 1 m/s, with much lower values for MDA01 and MDA02. The “+” sign means that air is entering the room, the “-“ sign indicating the opposite situation: looking at the graphs it seems that there is a net positive air flow entering the room but the different dimensions of doors and the presence of tents should be taken into account; anyhow, considering the relatively high “-“ flow through node 2, the flow is probably going from Vidoniana to Room 20 through Sala Urbana and this depends on the windows opening operated by the Collections guardians (see graph below);



9. Thermal inertia can be roughly evaluated from the graphs and, to ease this task, two relevant cases for the Collections and the offices have been extracted from the graphs shown before, see Figure 19 and Figure 24. Delay of propagation of the thermal wave is in the order of 6-7 hours, but attenuation is 2.5 times greater for the Civic Collections compared to the offices, see Figure 21; however, these results are a first approximation, and sometimes have been obtained results that are difficult to explain; more reliable ones will be obtained after the full installation of the final WSN.

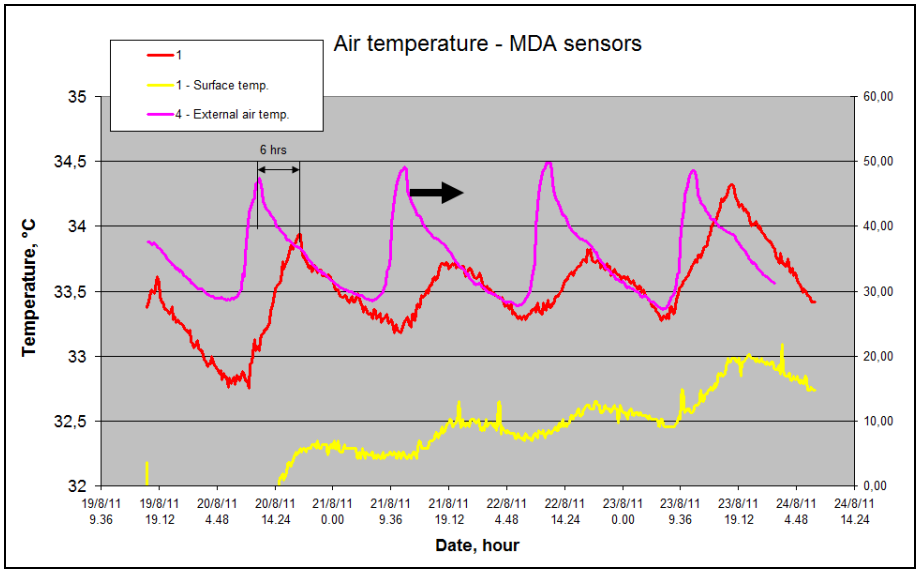
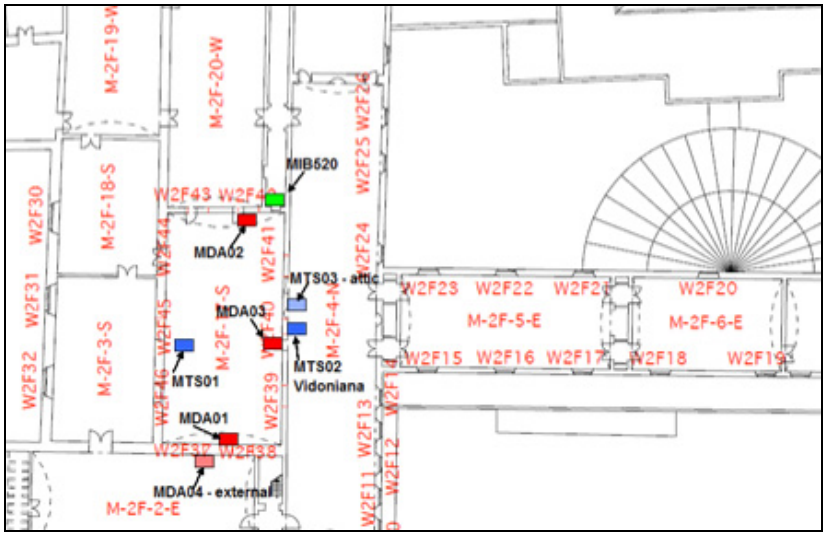


Figure 19: Graphs used for thermal inertia evaluation (Sala Urbana, sensor MDA01 and MDA04).

September 2011



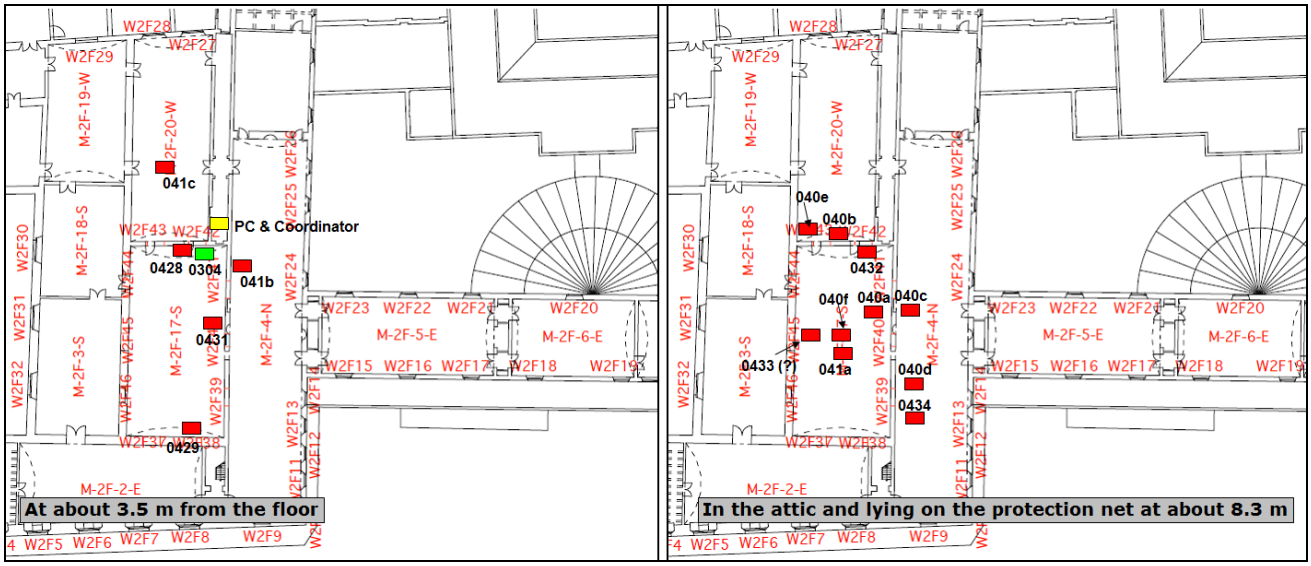
Map of nodes

Remarks

1. Employed WSN used the Memsic devices tested for the first prototype installation;
2. Air temperature inside Sala Urbana is almost constant, with a daily variation of about 1 °C;
3. Air humidity is quite stable around a value of about 45%, with peaks of 50% on 03/09 and 10-11/09;
4. Data referring to the outside environment show a daily oscillation of about 17 °C, while in the attic temperature varies of about 4 °C; it must be pointed out that the node on the outside of Sala Urbana was still close to the external part of an air conditioning system, but this seems to have little if no influence on measured data;
5. Surface temperatures show a similar behavior, with daily oscillations inside Sala Urbana lower than 0.5 °C;
6. It is quite interesting to note how recorded data follow quite closely those downloaded by the “ilmeteo” weather station, at least as a daily trend;
7. As regards air velocity, we have results similar to the measurements in August.

Deliverable D6.2 Documentation of each study case

October-November 2011



Map of nodes

Remarks

1. Since the installation of October, a new WSN has been employed, made of nodes supplied by I.Co. (Italy) (see Annex 1);
2. Air temperature inside the room is almost constant, with a daily variation ranging from 0.5 to 1.0 °C, for all nodes wherever they are placed;
3. Maximum difference among temperatures measured at nodes at 3.5 m is about 2 °C and it raises to 3°C at 8.3 m (including the attic);
4. When comparing temperatures at different levels and sites, we have a maximum ΔT of 3 °C between the nodes above the Vidoniana (040c) and Sala Urbana (0304); the difference with nodes above Room 20 (node 040b) is limited to 2 °C;
5. *Note that, with the exception of node 040f, temperatures inside the Sala Urbana do not significantly vary between 3.5 and 8.3 m*;
6. External temperatures, as measured by the official weather station of Bologna, have an average variation of about 5 °C and this data compare quite well with the values measured by the nodes external to the offices; daily variations in the attic are limited to about 1.5 °C;
7. Measurements should always be considered including their uncertainty: for example, in Figure 20 we show a comparison between two nodes at 3.5 m and one node at 8.3 m, and we see that the two nodes at the same height have an almost imperceptible difference, and that the difference with the colder node (040f) is greatly reduced;
8. In Sala Urbana and adjacent rooms (Vidoniana and Room 20) air humidity is quite stable during single days, changing of about 20% from a 45% value to a 55% value in ten days, following quite closely the trend of external humidity. Again, the only exception is node 040f, with an almost constant +10% RH with respect to other nodes in Sala Urbana; nodes in the attic recorded higher values of RH, again a +10 % RH, especially the one above Vidoniana; this node is exposed to the North and this explains the highest RH and lower temperatures it is recording;

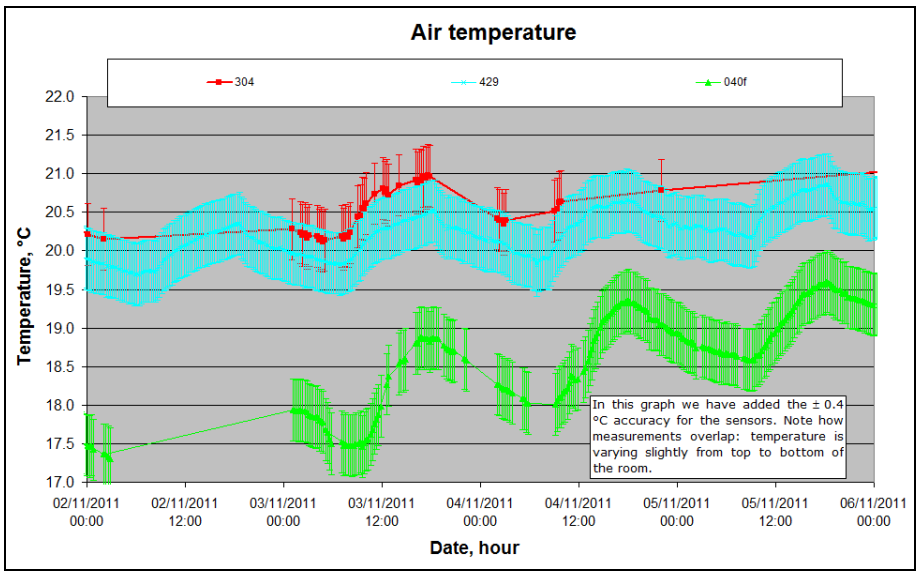
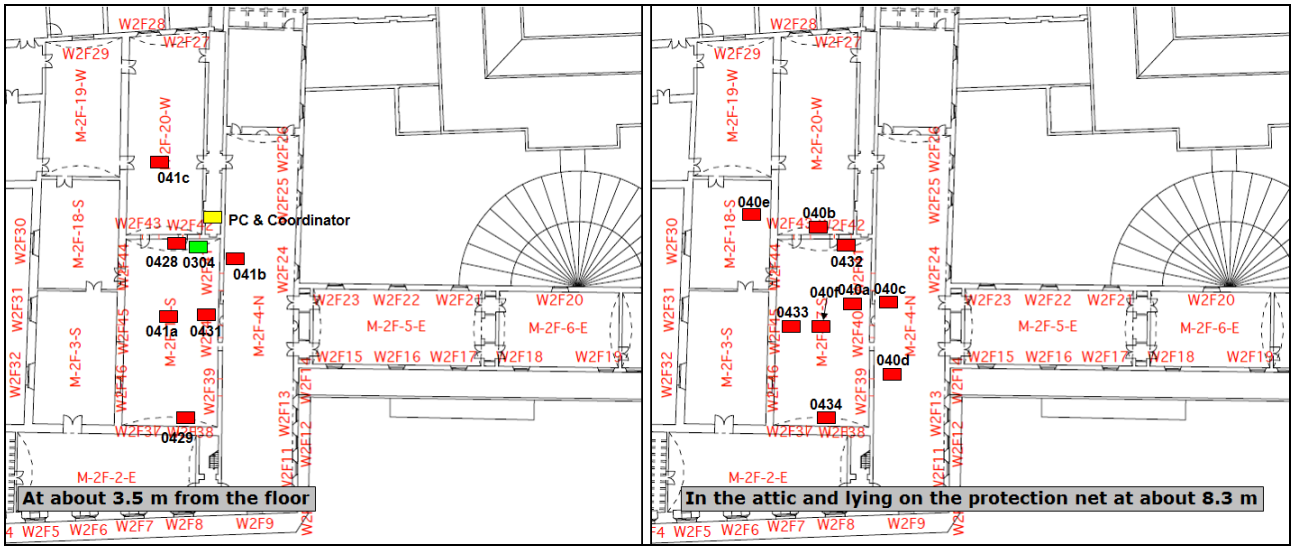


Figure 20: Graphs used for measurement comparison.

December 2011



Map of nodes

Remarks

1. The difference between the 3.5 m and the 8.3 m temperature is about 0.5 °C, i.e. they are almost coincident, especially if we consider the measurement uncertainty (refer for an example to Figure 21). We must also consider that node 0304 is close to a powerful lamp, so its always slightly higher temperature is due to this influence;
2. Day variation for nodes inside the Sala Urbana ranges from 0.5 °C to 1 °C, so remains quite limited, especially when compared to the external variation measured by official weather stations, which reaches an average value of about 9 °C; external temperatures have also been measured by a node in the offices (0406), which shows a reduced day variation of about 7 °C: in winter, external temperatures as supplied by the official weather station are usable as regards the maximum values, but tend to underestimate the minimum values in the centre of Bologna;
3. Nodes in the Vidoniana Gallery and in Room 20 show a day variation of about 2 °C, while nodes in the attic stay in the range of about 1 °C. The node with the greatest variation is the one in the attic of Room 18 (040e), exposed to the South and under a copper roof, reaching as high a value as 7 ° C;
4. Air humidity showed almost constant and low values, in the range 25-40%, much lower than the external one; only the node in the North part of the attic recorded values around 50%.

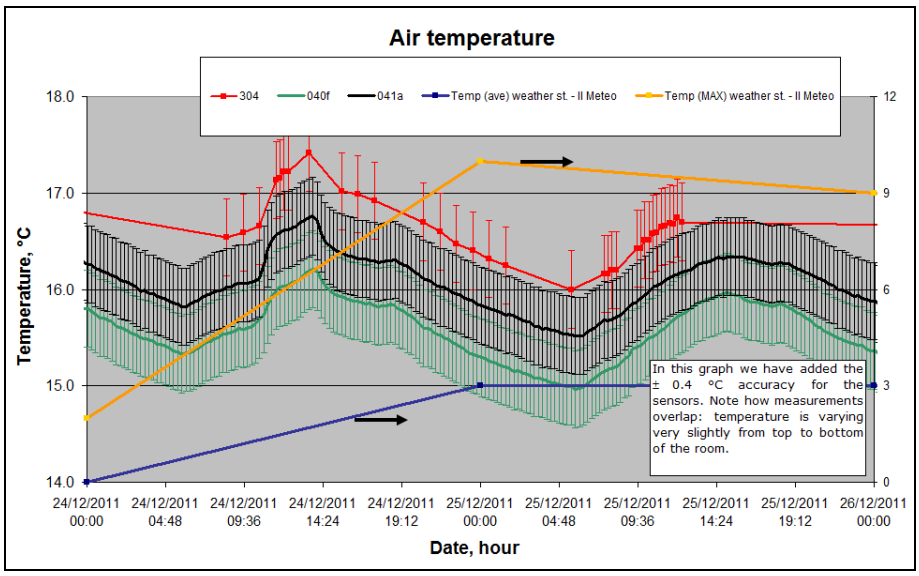
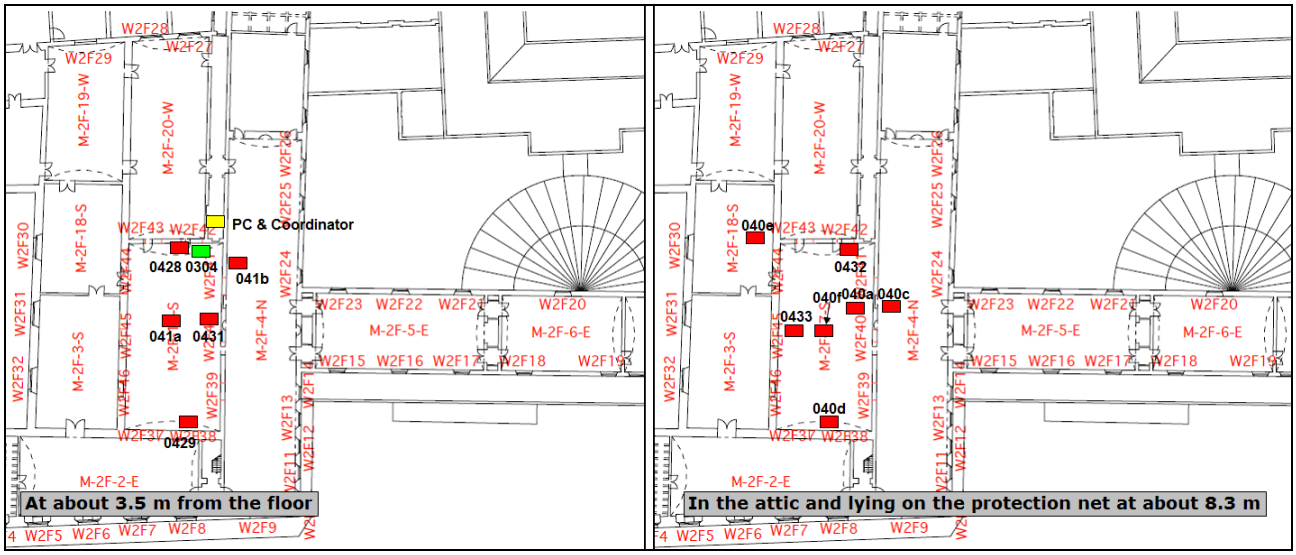


Figure 21: Graphs used for measurement comparison.

February 2012



Map of nodes

Remarks

1. The difference between the 3.5 m and the 8.3 m temperature is about 0.5 °C, i.e. temperatures are almost coincident, especially if we consider the measurement uncertainty (refer for an example to Figure 22). We must also consider that node 0304 is close to a powerful lamp, so its always slightly higher temperature is due to this influence;
2. Day variation for nodes inside the Sala Urbana ranges from 1.0 °C to 1.8 °C, with an average of 1.5 °C, so remains quite limited, especially when compared to the external variation measured by the official weather stations and local one, which reaches average values of about 12.9 °C and 12 °C respectively;
3. Node in the Vidoniana Gallery shows a day variation of about 2 °C, while nodes in the attic stay in the range of about 3 °C. The node with the greatest variation is the one in the attic of Room 18 (040e), exposed to the South and under a copper roof, reaching as high a value as 7 ° C;
4. Air humidity showed almost constant and low values, in the range 30-40% (nodes at 3.5 and in the Vidoniana) and 34-45% (nodes at 8.3 m); in the second case we have two relevant exceptions: node in the attic above Vidoniana (040c) oscillates in the range 45-60% and node 040e (above Room 18) oscillates in the range 25-40%; they clearly reflect their opposite positioning at the North and at the South, especially the node 040e that is under a copper roof.

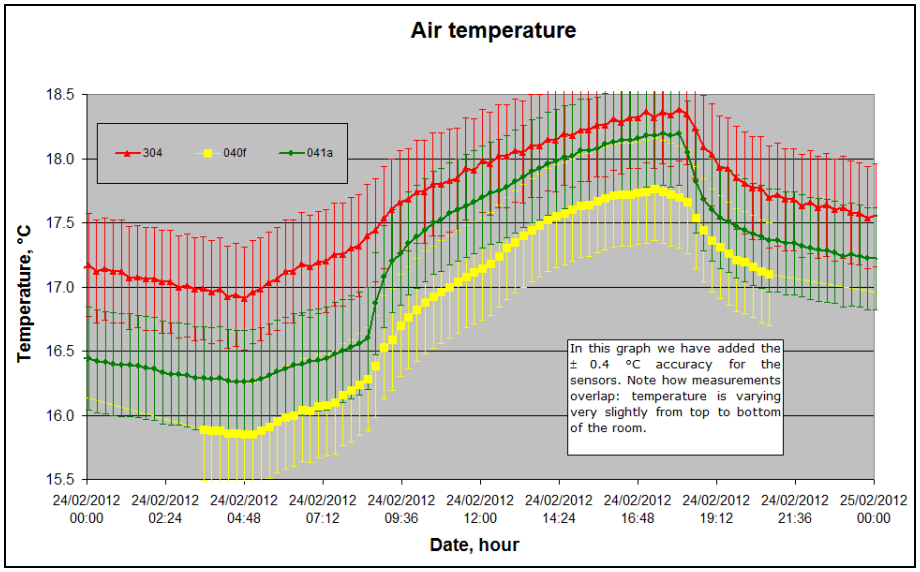
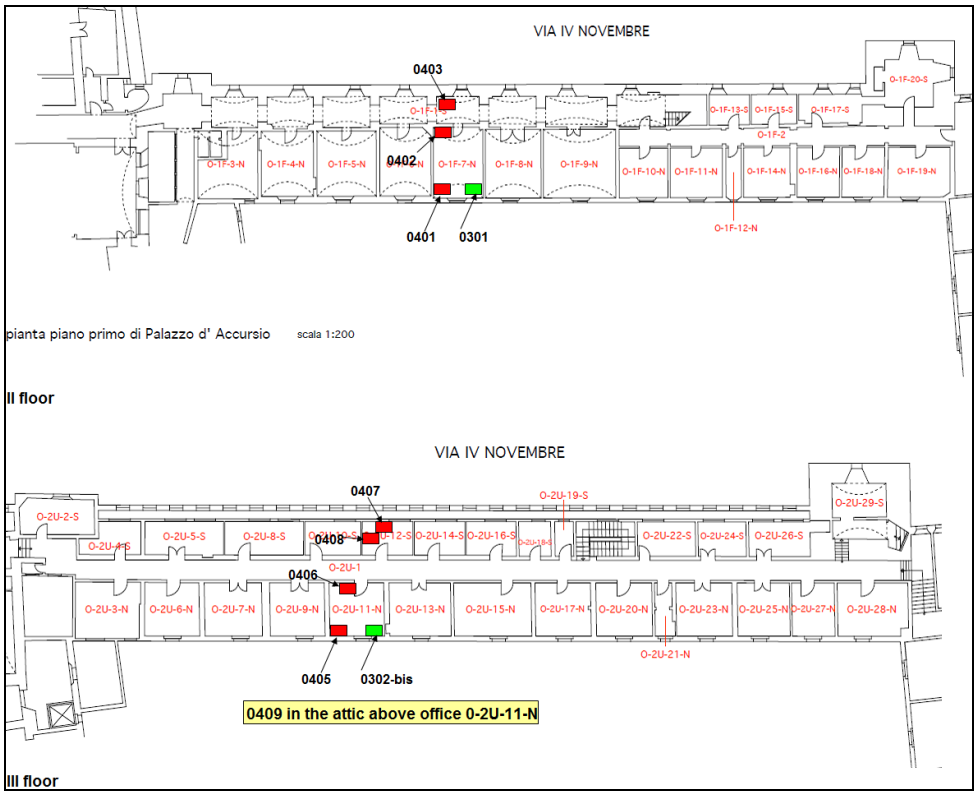


Figure 22: Graphs used for measurement comparison.

OFFICES

August 2011



Map of nodes

Figure 23: Positions of node 0407 with attached sensors.

Remarks

1. In the offices the WSN has always been made of I.CO. (ITALY) nodes;
2. Data collected in the offices are more difficult to analyze due to the presence of air conditioning systems, frequent opening and closing of windows and doors, so that temperature maxima and minima may appear at hours greatly differing from the external ones. Temperature and humidity daily oscillations are quite similar to those found in the Civic Collections, with external temperature range limited to about 12 °C; external temperature variation is reduced compared to the Civic Collections because one sensor was placed on the North façade and the other one on the South, but in the shadow of the merlons curtain. Inside offices we have a daily variation of about 2.5 °C, unless there is a portable air conditioning system, which increase the variation to about 3 °C (see nodes 0407 and 0408); along internal corridors, temperature variation is in the order of 1 °C, close to sensor's measurement uncertainty. There is no discernible difference for air temperature among sensors in the same room, especially if considering sensors uncertainty. Air humidity varies between 25 and 45% (19-28/08), with daily oscillations of about 3%, following quite closely the variation of RH as measured by the official weather station at Bologna airport (due to problems with employed sensors, it has not been possible to measure correctly the local external RH of air outside the offices).
3. In the graph of Figure 24 we show a rough estimation of the thermal inertia measured for office 0-2U-11-N (compare with Figure 19).

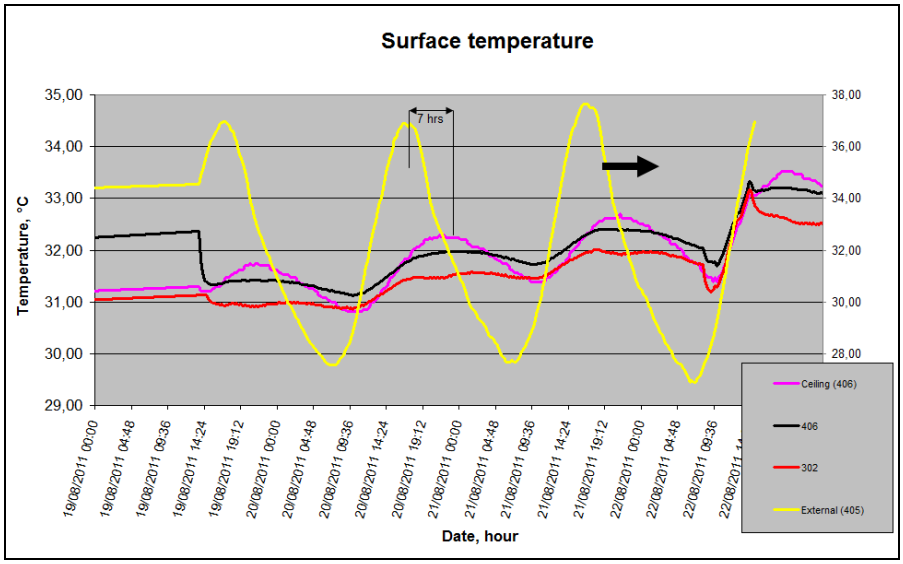


Figure 24: Graphs used for thermal inertia evaluation (office 0-2U-11-N).

Deliverable D6.2 Documentation of each study case

September 2011

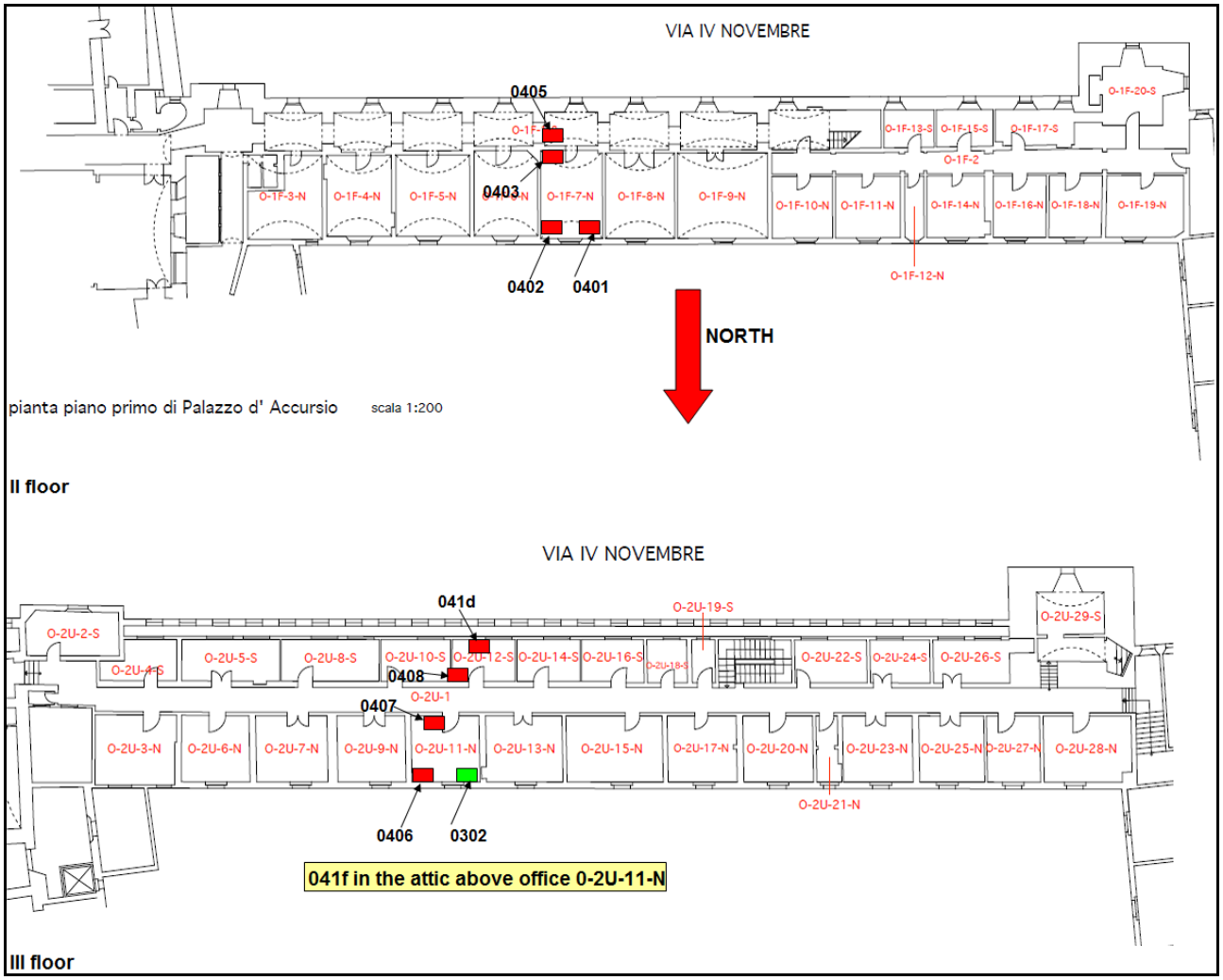
Map of nodes – same of August

Remarks

1. Outside temperature variations vary quite evidently when considering first and second week of September, passing from 8 °C to 14°C, following quite closely the measurements of the official weather station of the city of Bologna; inside temperatures remain quite constant with small daily oscillations (< 1 °C, except node 0407) and do not vary significantly among sensors in different places and different rooms;
2. Air RH varies from 40 to 64 % with very limited daily oscillations. Values for sensors 0407 and 0408 follow quite closely the trend of air RH as measured by the reference weather station and this can be explained by the behavior of the clerk in the office, with frequently opens/closes the window.
3. Node 0407 is placed on a wall facing to South, partially screened by a curtain of merlons, and close to a window and a portable air- conditioner: most probably for these reasons its daily oscillations are more relevant when compared to other nodes.

Deliverable D6.2 Documentation of each study case

November 2011



Map of nodes

Remarks

1. Daily oscillations of outside temperature vary from about 11 °C at the official weather station at the airport of Bologna to 7 °C on the north prospect (node 0406 external sensor) to more than 20 °C on the South prospect, but in this latter case it was found out that the sun was heating the thermistor sensor directly, so data are to be discharged;
2. In the attic (sensor 041f) daily oscillations are in the range of about 3 °C;
3. In the offices of the II floor, temperature oscillates daily of about 1 °C, while at the III floor oscillations cover a range of 2-4 °C, in the offices exposed to North and South respectively; it is also interesting to note that temperature distribution inside rooms is not uniform: for example, in room O-1F-7-N, sensor on the wall exposed to North register a temperature that is about 2.5 °C lower than node 0403, fixed on the wall dividing the office from the internal corridor (this office is rarely used as a meeting room); a difference of 2 °C is observed in the office O-2U-12-S, while in office O-2U-11-N it is limited to about 1 °C. Also temperature in the corridor varies of about 1 °C at the II floor and about 2 °C at the III floor (see Figure 25 for a cross sections of temperatures at III floor);
4. Air humidity values ranged from 35 to 45% (inside offices), raising to 60% in the attic and 80% outside (estimated), with daily variations of a few %.

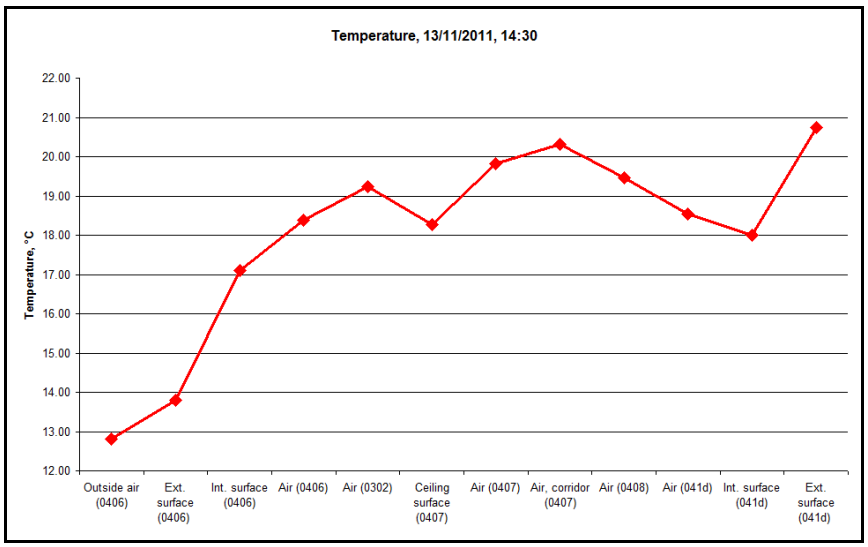
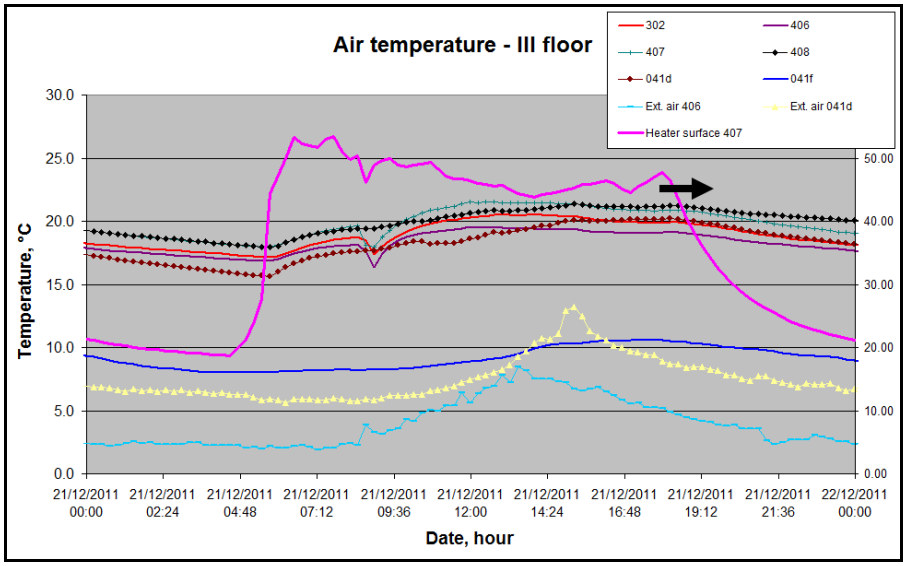


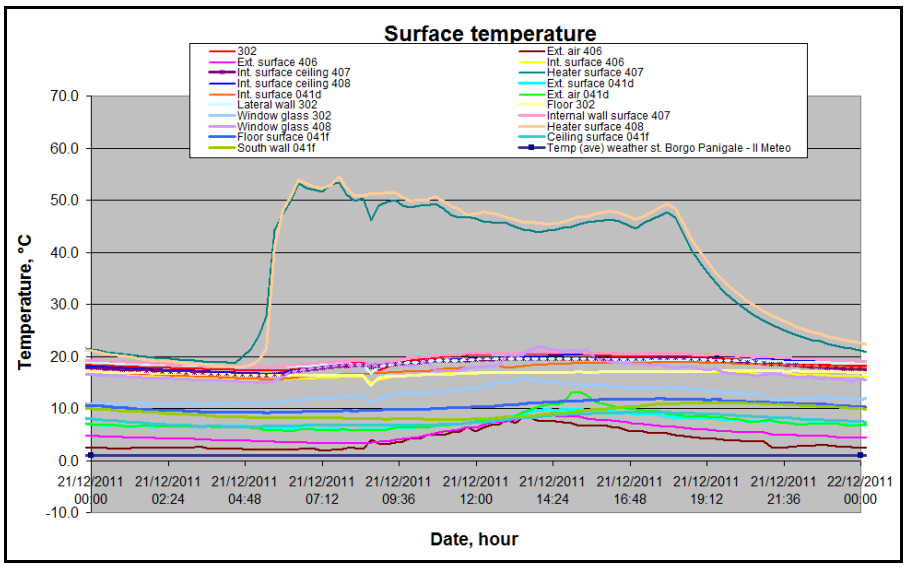
Figure 25: Example of temperatures across the offices at III floor.

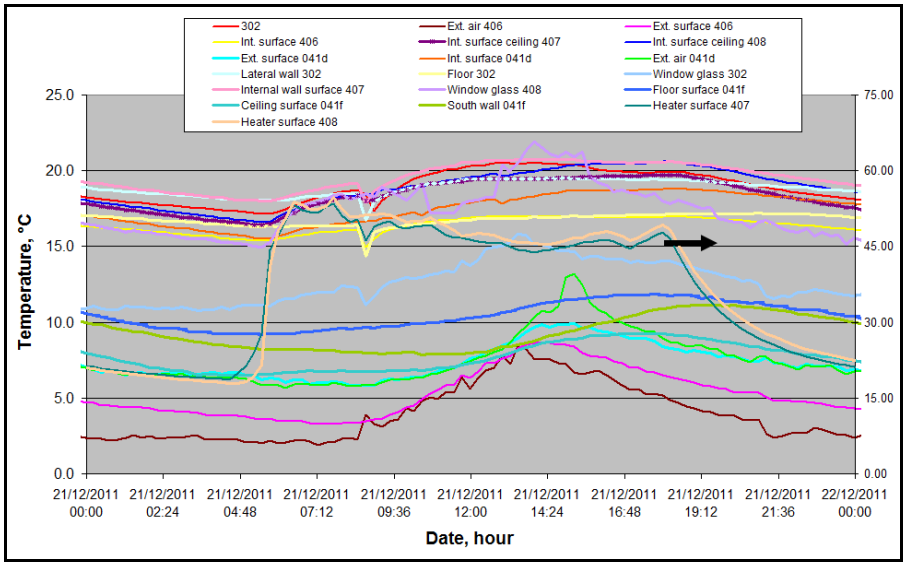
Deliverable D6.2 Documentation of each study case

December 2011 – January 2012

Map of nodes – Same as November







December 2011 / January 2012 - Graphs of data from monitoring in the offices.

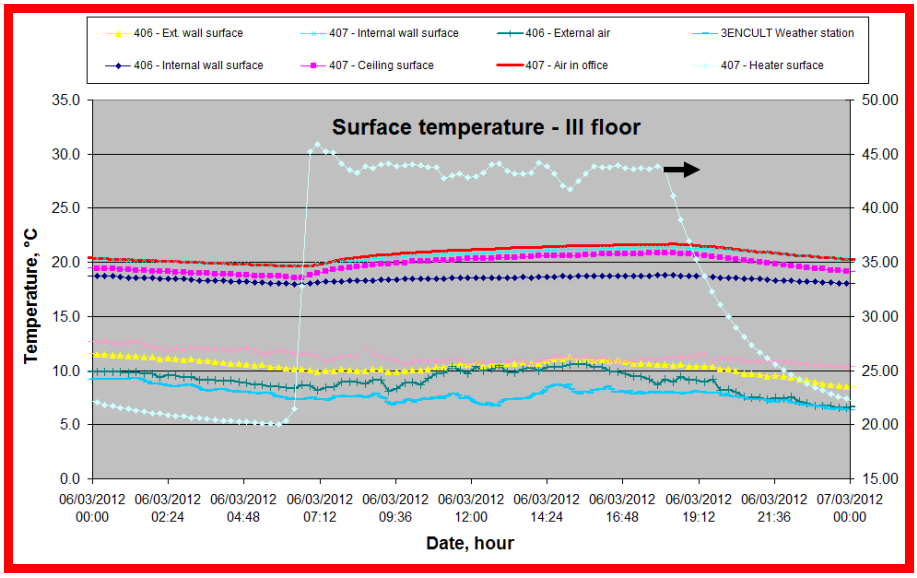
Remarks

1. Daily oscillations of outside temperature vary greatly during the observed period: for example, at the official weather station at the airport of Bologna they oscillate between 8 and 14 °C; sensors for external air at the North (0406) and at the South (041d) show an average daily oscillation of about 7 °C,
2. In the attic (sensor 041f) daily oscillations are in the range of about 2.5 °C;
3. In the offices of the II floor, temperature oscillates daily of about 1.5 °C, while at the III floor oscillations cover a range of 2.5-4 °C, in the offices exposed to North and South respectively, although a more detailed statistical analysis would be needed; it is also interesting to note that temperature distribution inside rooms is not uniform: for example, in room O-1F-7-N, sensor on the wall exposed to North register a temperature that is about 2.5 °C lower than node 0403, fixed on the wall dividing the office from the internal corridor (this office is rarely used as a meeting room); a difference of 2 °C is observed in the office O-2U-12-S, while in office O-2U-11-N it is limited to about 1.5 °C;
4. A detail of one day (21/12/2011) allows to observe how air temperature changes with the heaters activity: they are turned on at about 04:30 in the morning, reach their maximum temperature at about 06:30 and are turned off at about 18:00 in the evening. For example, in the office O-2U-11-N the peak temperature (21.52 °C) is reached at 12:30, while in office O-2U-12-S the peak temperature (21.24 °C) is reached at 15:30. Similar observation can be made also for surface temperatures.
5. Air humidity values ranged from 20 to 40% (inside offices), raising to 40-60% in the attic and 70% outside (estimated), with daily variations of a few %.

Deliverable D6.2 Documentation of each study case

March 2012

Map of nodes – Same as November / Office O-2U-11-N empty since mid February



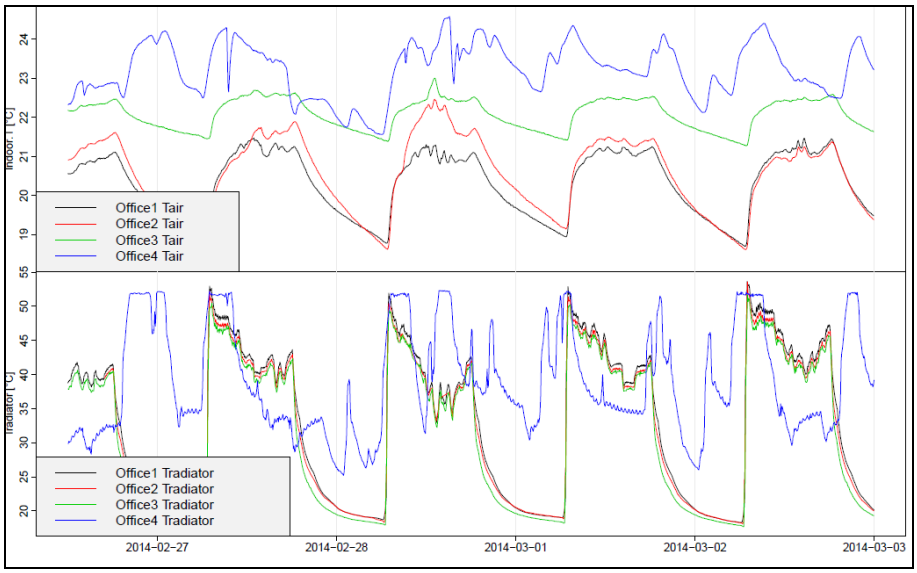
March 2012 - Graphs of data from monitoring in the offices.

Remarks

Since February, 22nd, 2012, a weather station has been installed on top of Palazzo D'Accursio (see § Annex 1 - 7.2 "PLANNING OF THE INSTALLED SENSORS") and more interesting comparisons can be made: for example we may observe how external air temperature measured by node 0406 is clearly raised during the heating hours of the office, and this is not due to external air temperature raise, because we see that, during the same hours, it stays quite constant (see graph with red frame).

February-March 2014

Since February 2014 the WSN has been reinstalled in the Offices area, along with a domotic sensors network (see Annexes) and a completely renovated weather station (see again Annexes for a general description and technical details). Monitoring is still going on and in the picture below we show an example of data from offices of the II floor.



Deliverable D6.2 Documentation of each study case

Conclusions from pre-intervention monitoring

Different types of WSNs have been installed in two different areas of D'Accursio Palace to acquire environmental and energetic data on a period going from August 2011 to March 2014. Areas of interest are the Civic collections of Art and Municipality offices, along Via IV Novembre, at the second and third floor. Proposals for networks topologies have been presented in July 2011 but actual implementations have been adapted to overcome technical difficulties and new requirements from COBO. In this document we have not reported the transmittance measurements (U value) and accompanying monitoring done by a separate WSN.

As regards the CIVIC COLLECTIONS it has been observed that air temperature and RH values inside the Sala Urbana, on a daily basis, are practically constant throughout all the examined periods; average temperature and RH of air vary with the seasons, but the huge thermal mass of the room smooths out variations on short time periods; in many cases, differences are below the uncertainty of employed sensors, and also differences among sensors at different heights are practically negligible (see Table 2 for a summary of results).

These observations will be employed for the future implementation of monitoring WSNs: for example, less nodes could be used with more sensible (and costly) sensors. From a conservation point of view, there exist a number of standards, codes and recommendations that fix and/or indicate preferred values for environmental quantities; in Italy, the most diffused norm is UNI 10829 "Beni di interesse storico e artistico - Condizioni ambientali di conservazione - Misurazione ed analisi", but also important are the UNI 10969 "Beni Culturali – Principi generali per la scelta e il controllo del microclima per la conservazione dei Beni Culturali in ambienti interni", UNI-EN 15757 "Conservazione dei Beni Culturali - Specifiche concernenti la temperatura e l'umidità relativa per limitare i danni meccanici causati dal clima ai materiali organici igroscopici", UNI-EN 15758 "Conservazione dei Beni Culturali - Procedure e strumenti per misurare la temperatura dell'aria e quella della superficie degli oggetti". Using the air temperature and RH limits indicated in UNI 10829 for frescoes, covering all walls of Sala Urbana, we retraced the graphs summarizing data collected in the period August 2011- April 2012 and we see that RH values are almost always too low, while temperatures are quite too high in summer (see Figure 12).

Table 2: Summary of monitoring results (August 2011 – February 2012).

Air temperature daily excursion (°C)					
Period	August. 2011	September 2011	Oct. - Nov. 2011	December 2011	February 2012
Location					
Sala degli Stemmi	1	1	1	1	1.5
Attic	5	4	1.5	1	3
External	22	17	5	7	12
Ratio Sala/Ext	4.55%	5.88%	20.00%	14.29%	12.50%
Ratio Sala/Attic	20.00%	25.00%	66.67%	100.00%	50.00%
Ratio Attic/Ext	22.73%	23.53%	30.00%	14.29%	25.00%
Air temperature average values (°C)					
Period	August. 2011	September 2011	Oct. - Nov. 2011	December 2011	February 2012
Location					
Sala degli Stemmi	33	31	20.2	16.4	18
Attic	34.6	30.2	17.3	11	14.1
External	35.7	28.5	13.2	4.2	12.8
Slope (°C/day)					
Sala degli Stemmi	0.08				
Attic	0.11				
External	0.12				

As regards the OFFICES, data show greater variations when compared to the Collections, mainly due to people changing the equilibrium of the rooms by opening/closing doors/windows and by the small thermal inertia of the rooms themselves. Also the presence of small air conditioning systems has great influence and, in summer, thermal inversion can be clearly observed. In the offices there are not conservation problems, but only people comfort must be considered. Also, inside the rooms temperature distribution is not as uniform as it is for Sala Urbana, so a greater number of nodes must be employed to fully study the environment variations. To get a more detailed view of all these complex events, a fully featured domotic network has been installed and comparative data analysis will greatly increase the understanding of the energetic behaviour of the building.

1.3.2 IEQ – Indoor Environmental Quality Audit

(ICIE – Sandra Dei Svaldi, Mena Viscardi)

In this chapter we report the results derived from the IEQ audit performed in winter and summer period

The field of energetic diagnosis activities cannot be identified only with the fulfilment of the levels of control of the building's energy dispersion and technologies efficiency. In fact it's necessary to verify that, in parallel to the performances derived from the right use of energy, the basic needs of individuals comfort and healthiness inside an indoor environment.

In order to evaluate the level of comfort inside most significant rooms for the present experimentation,, we started a two monitoring campaigns in winter and summer conditions using an integrated system of certified tools for the measuring and evaluation of indoor micro-climate. The two campaigns have the purpose to identify the present performances offered by the building across several seasons together with the elements that will permit to forecast the evolving of those performances after the execution of the scheduled interventions.

Through the monitoring campaigns realized the 17 February 2012 and the 18 July 2012 were identified the levels fixed in each indoor room using thermoigrometric, visual, acoustic parametric value and the derived calculated parameters of comfort: The Predicted Mean Vote Index (PMV) and the Predicted Percentage Dissatisfied Index (PPD).

The monitoring could not affect the entire area studied by the energetic analysis. Therefore the most indicative points of measure for the analysis were identified, so that the observations done could be representative both of extremely critical and intermediate conditions.

Figures 26: Technical equipment used

Monitored parameters

The condition of thermal comfort, even called "thermoigrometric wellness", can be defined, at a psychological level, as the psychophysical condition where the individual expresses satisfaction towards the thermic

environment, or, at a thermic-sensorial level, as the neutral condition where the individual doesn't suffer either the sensation of heat or cold.

The environmental parameters monitored for evaluating the thermal and hygrometric comfort are essentially the following:

- **Air temperature** (it has fit the making of the planned activities, and it must stand within adequate levels without presenting wide gradients of difference both in space and time)
- **Air speed** (it must stand within adequate levels in order to avoid the generating of noxious air flows, referring to winter time hygrometric comfort needs)
- **Medium radiant temperature** (it expresses the value of temperature due to the radiation on the internal surfaces of the examined indoor environment)
- **Operating temperature** (value that expresses precisely the level of indoor thermal comfort and is derived from the right combination of air temperature and medium radiant temperature)
- **Relative humidity** (the level of moisture must stay inside the range of apt minimum and maximum values referring to both winter and summer time hygrometric comfort needs)
- **Surface temperature** (the temperatures of the internal environment surfaces must stay in a range of apt values , in order to contain the discomfort due both to radiation and to excessive airflow convections).

The environmental parameters that were used for evaluating visual comfort are:

- The medium indoor lightning
- The indoor lightning

These two must be measured contemporarily and compared in order to determine the daylight medium factor ηm.

The environmental parameter used for evaluating acoustic comfort is the following:

- The continuous level of sonic pressure (in singular spaces, for induced noise, must be compatible with physiological needs related to the scheduled activities).

Data elaboration

The following step was the data elaboration phase. Some information that are necessary for the process need the anticipated elaboration of basic data in order to provide objective elements of evaluation. The indoor comfort was evaluated through the calculation of the integrated indexes, the PMV and the PPD realized with the support of software "InfoGAP Evoluto" realized by LSI (application for "moderate environment").

Thermal comfort

The thermal comfort is defined by ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers INC) as a condition of psycho-physical wellbeing of the individual in relation to the environment where he/she lives and work. It can be evaluated using integrated indexes that consider both microclimate environmental parameters (TA, Tr, Va, rh) and energy consumption (metabolic consumption MET) due to working activity, as well as the kind of clothing commonly used (thermal insulation CLO).

In this case, as we are dealing with a kind of thermally moderate indoor environment the PMV (Predicted Mean Vote) index is the one that most of others shows the influence of the previously mentioned physical and physiological variables, indicating the average feedback on thermal comfort expressed through scores by a group of individuals in the same environment.

From it is derived a second index, called PPD (Predicted Percentage of Dissatisfied) which provides a percent esteem of the number of unsatisfied individuals in relation to particular microclimate conditions.

Both these indexes are fixed by the UNI EN ISO 7730 norm of year 2006 ("Ergonomic character of thermal environments - analytic determination and interpretation of thermal comfort through the calculation of PMV and PPD indexes and local thermal comfort criteria").

These norm suggests PMV values included in a range between + 0,5 and -0,5, in order to consider the analyzed indoor space thermally comfortable, that corresponds to a percentage of unsatisfied users (PPD) inferior to 10%.

PMV	PPD%	THERMAL ENVIRONMENT EVALUATION
+3	100	Very warm
+2	75,7	Warm
+1	26,4	Slightly warm
-0,5<PMV<+0,5	<10	Thermally acceptable
-1	26,8	Cool
-2	75,4	Cold
-3	100	Very cold

Through using the proper tools, we identified the seven fundamental parameters in order to develop the evaluation.

- Dry air temperature (°C)
- Wet air temperature (°C)
- Radiant temperature (°C)
- Air speed (m/s)
- Turbulence (%)
- Relative humidity (%)
- Atmospheric pressure (kPa)

Visual comfort

The evaluation of lighting comfort has been developed referring to national norms, and in particular to regional and urban codes for residential buildings:

- At national level DM 5/7/75 and Quaderno N°2 of CER (Ministry of Public Works);
- At regional level LE n°48 9/11/84 and the Manual NTR;
- Al local level RUE (Regolamento Urbanistico Edilizio) of Bologna (Requirement E4.7 – natural lighting control and technical card dE4.7)

All these norms consider the average daylight factor as “the ratio between the indoor average lighting and the lighting of open air exposed surface in the same conditions of time and space without sun’s direct radiation.

$$\eta_m = E_{im}/E_{em}$$

with E_{im} representing the value of lighting within the analyzed zone, and E_{em} being the average value of outdoor lighting previously measured. Both national and regional norms state that the average daylight factor expressed in percentage in indoor spaces must be higher or equal to 2%.

$$\eta_m \geq 2\%$$

In order to determine ηm we made two sessions of measurement of indoor lighting Ei and outdoor lighting Ee contemporarily with two luxmeters in three different points of two spaces, at a distance of 0,90 m from the pavement and 1,50 m from the walls provided with windows and superior to 0,60 m from all the other walls.

Acoustic comfort

We based ourselves on the existing national and regional codes as well also for the evaluation of the acoustic comfort, and in particular:

- At national level the Framework Law n. 477/95 and its executive decrees DPCM 14/11/97 and DMA 16/3/98,
- At regional level LR 9/5/2011 and Direttiva regionale 2053/2001,
- Al local level "Acoustic classification of Bologna communal territory" ODG n°42 of 20/1/2010..

The review of the documents related to the acoustic classification of the city of Bologna, which represents one of the main tools of governance of the territory as well of protection from noise, evidenced that the zone were the building is located belongs to the Acoustic Class n. III called "Mixed type areas" and is part of the airport acoustic classification _Zone A. The official documents that deal with this topic refer to the prescriptions given by the Regional Code n°2053/2001 "Dispositions on noise pollution" and on the National Law n°477/95 and to its Executive Orders.

In particular, the Acoustic Zoning, following the article n.5 of the National Law n°477/95, contains the subdivision of the territory in five acoustic classes that correspond to the first five ones defined by DPCM 14/11/1997 with the limits of noise compatible with each use.

These acoustic classes are named by the existing norms as "Territorially Homogeneous Units" (UTO).

The *fourth Acoustic Class, called "areas with intense human activity"*: areas with intense vehicular traffic and high population density, with high presence of commercial activities, offices, crafts, nearby main roads and railways, port areas, areas with limited presence of industries.

For every acoustic class, following the indications of DPCM 14/11/1997, for every acoustic class are given specific edge-values of sonic emission, that is the "attention values" and the "quality values", distinct for day time (6:00 AM÷10:00 PM) and night time (22:00 PM÷6:00 PM).

The edge-values to be respected in the zone in which is located the analyzed building are the ones that are evidenced in red in the table below.

Classificazione del territorio		Valori limite di immissione sonora	
		Periodo diurno	Periodo notturno
I classe	Aree particolarmente protette	50 dB(A)	40 dB(A)
II classe	Aree prevalentemente residenziali	55 dB(A)	45 dB(A)
III classe	Aree di tipo misto	60 dB(A)	50 dB(A)
IV classe	Aree di intensa attività umana	65 dB(A)	55 dB(A)
V classe	Aree prevalentemente industriali	70 dB(A)	60 dB(A)

Valori limite di immissione sonora

The absolute edge-value of emission has been defined referring to the "continuous equivalent sonic level" (L_{Aeq}) measured in dB (decibel) during the whole daytime or night time period.

The sonic level, measured in indoor residential spaces is due to the presence of external sources (road-railway traffic, railway, street yards, etc..) and of indoor activities, within the same space or in adjacent ones.

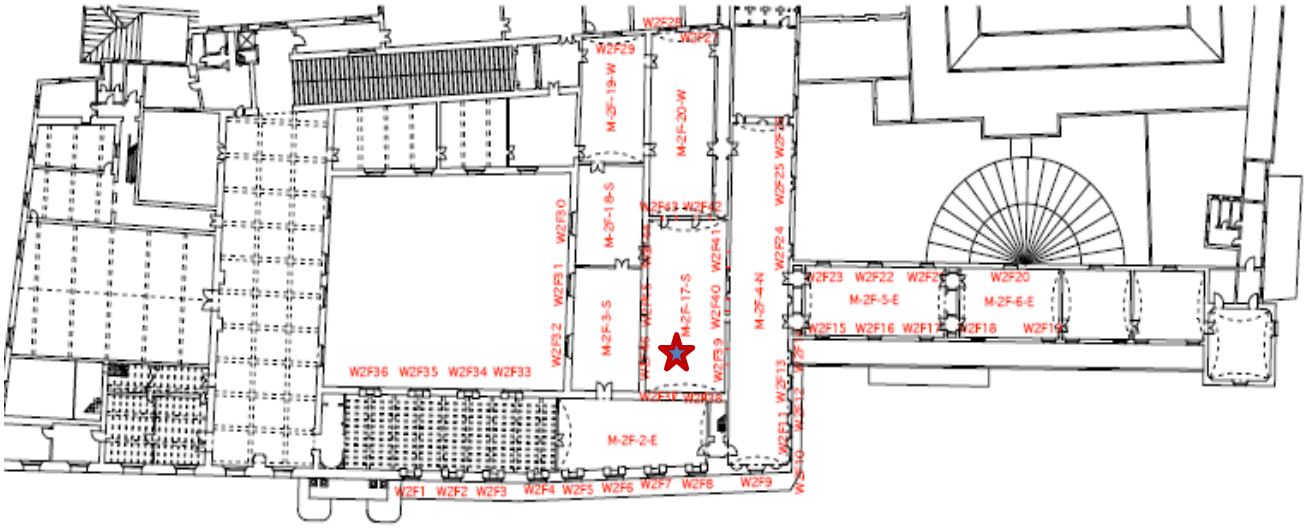
Deliverable D6.2 Documentation of each study case

Survey forms and the evaluation report of the indoor microclimate

Below are the survey forms and evaluation reports of the microclimate, processed, relating to four areas considered to be representative in terms of the functions performed, the location in the field of 'building (ground and exposure) and the rules' use by the user.

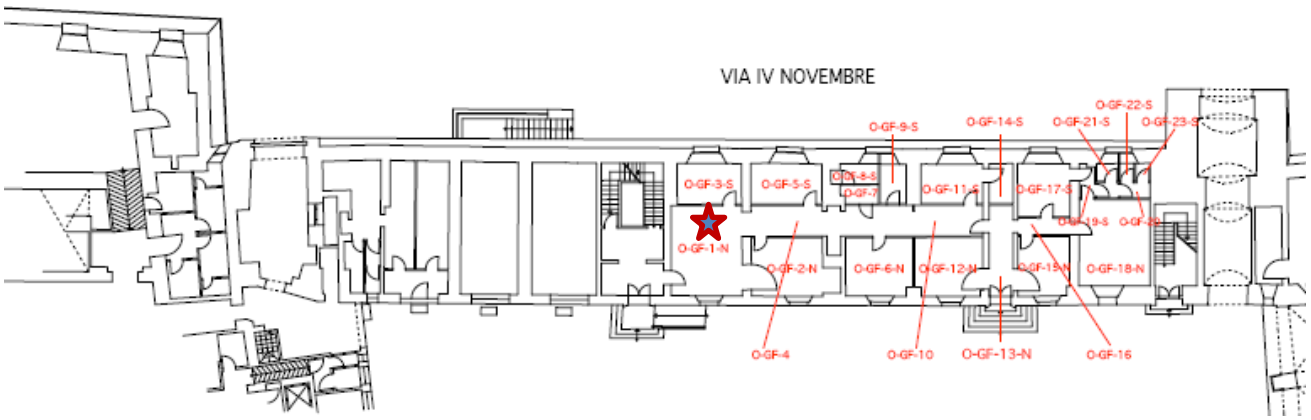
Identification of representative environments:

Municipal Collection: Second Floor



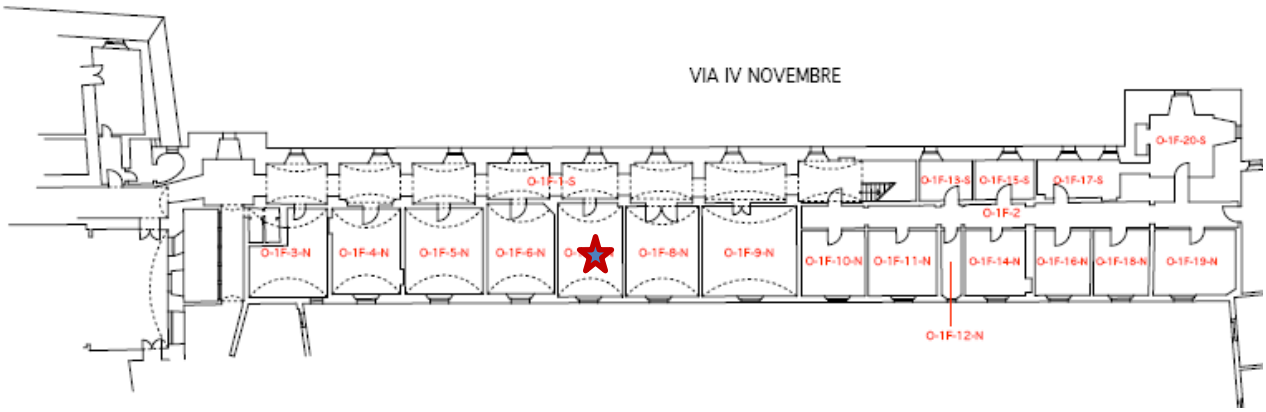
Room selected: **M 2F 17 S**

Municipal Policy Offices: Ground Floor



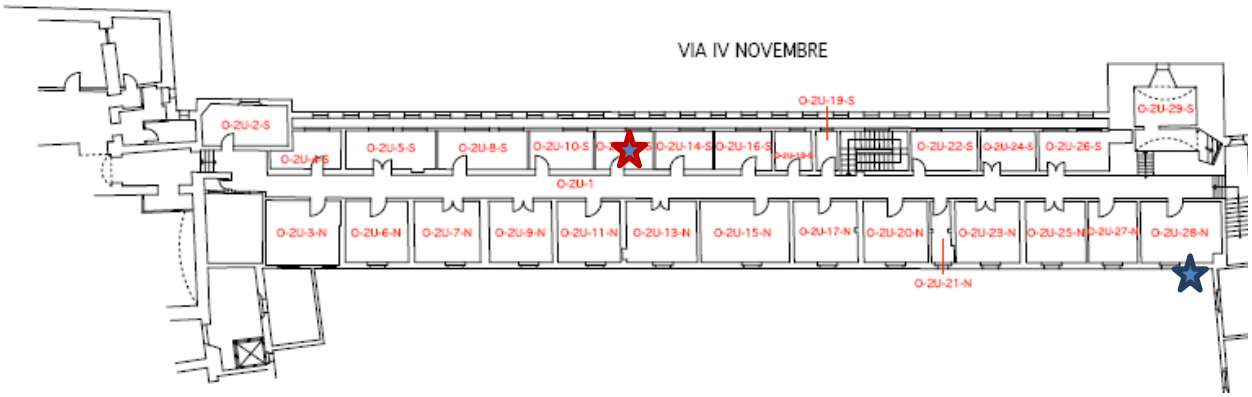
Room selected: O GF 1 N

Municipal Offices: First floor



Room selected: O 1F 7 N

Municipal Offices: Second Under Floor

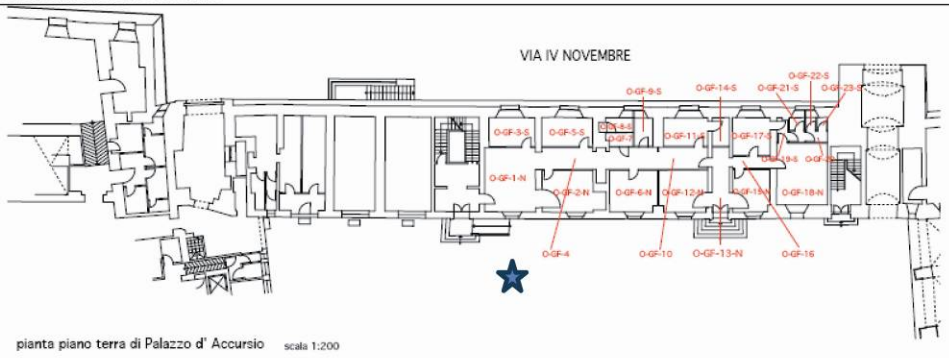


Room selected: O 2U 12 S

WINTER PERIOD

Parametri termoigrometrici

Identificazione locale

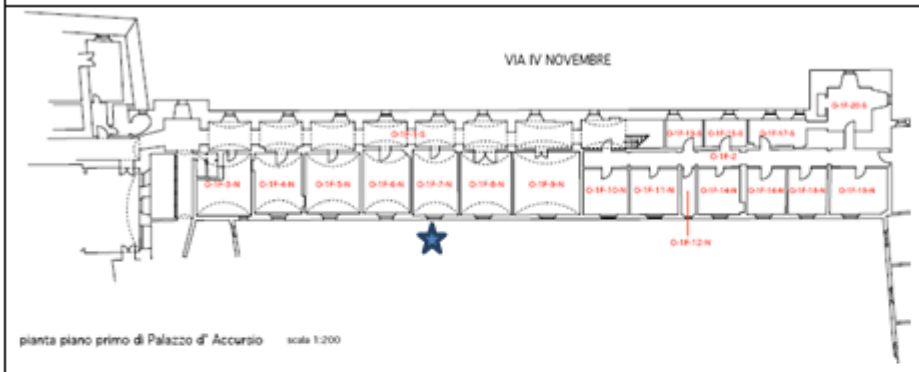


Htot,stanza=3,12m

N° stanza	O GF 1 N
Piano	PT Piano terra
Utilizzo	Sala d'attesa
Ora INIZIO	9:55
Rilievo n.	004/001

CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,72	Uscita 1 – TEMP. AMB	T_{umid} (°C)	13,60
	$WBGT_I$	15,93		$WBGT_I$	15,87
	$WBGT_E$	15,96		$WBGT_E$	15,72
Uscita 2 - PSICROMETRO	T_{sec} (°C)	21,43	Uscita 2 - PSICROMETRO	T_{sec} (°C)	19,70
	T_{umid} (°C)	11,99		T_{umid} (°C)	11,69
	UR (%)	27,8		UR (%)	32,2
	T_{PR} (°C)	2,08		T_{PR} (°C)	2,64
Uscita 4 - GLOBO	T_{glob} (°C)	21,13	Uscita 4 - GLOBO	T_{glob} (°C)	21,16
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0,00	Uscita 5 - ANEMOMETRO	V_a (m/sec)	0,00
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	0,0
	DR (indice)	0		DR (indice)	

CENTRO STANZA, h: 2,00 m			Condizioni ambientali esterne (Rilievon°004/002 e 004/003)		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,83	Uscita 1 – TEMP. AMB	T_{umid} (°C)	2,39
	$WBGT_I$	16,04		$WBGT_I$	4,59
	$WBGT_E$	16,19		$WBGT_E$	4,03
Uscita 2 - PSICROMETRO	T_{sec} (°C)	22,62	Uscita 2 - PSICROMETRO	T_{sec} (°C)	4,14
	T_{umid} (°C)	12,68		T_{umid} (°C)	1,66
	UR (%)	26,7		UR (%)	61,6
	T_{PR} (°C)	2,57		T_{PR} (°C)	-2,55
Uscita 4 - GLOBO	T_{glob} (°C)	21,28	Uscita 4 - GLOBO	T_{glob} (°C)	9
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0,00	Uscita 5 - ANEMOMETRO	V_a (m/sec)	0,55
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	54,3
	DR (indice)	0		DR (indice)	100

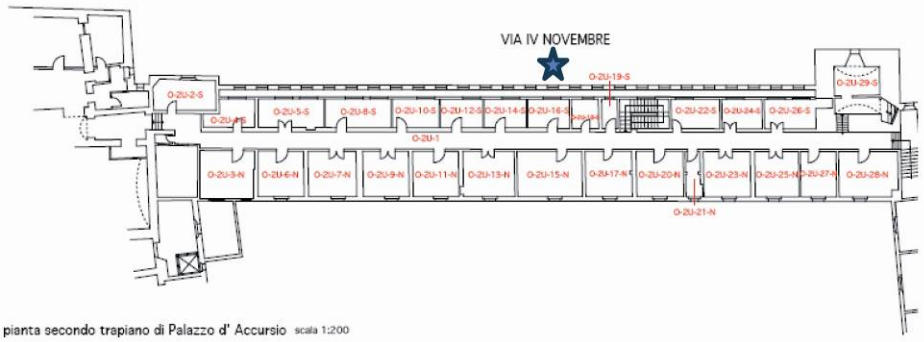
Parametri termoigrometrici		
Identificazione locale		
 pianta piano primo di Palazzo d' Accursio scala 1:200 Htot stanza = 3,44 m Nota Presenza dei sensori 3EnCult sulla : parete esterna n° 0402 parete interna n° 0403 parete interna n° 0401 (a sinistra della finestra)	N° stanza	O 1F 7N
	Piano	P2° Piano primo
	Utilizzo	Sala Riunioni (Sala Verde)
	Data Ora INIZIO	17/2/2012 11:40
	Rilievo n.	007/001

CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,64	Uscita 1 – TEMP. AMB	T_{umid} (°C)	13,49
	$WBGT_I$	16,07		$WBGT_I$	15,96
	$WBGT_E$	16,08		$WBGT_E$	15,92
Uscita 2 - PSICROMETRO	T_{sec} (°C)	21,55	Uscita 2 - PSICROMETRO	T_{sec} (°C)	21,28
	T_{umid} (°C)	12,76		T_{umid} (°C)	11,65
	UR (%)	31,90		UR (%)	26,4
	T_{PR} (°C)	4,19		T_{PR} (°C)	1,21
Uscita 4 - GLOBO	T_{glob} (°C)	21,74	Uscita 4 - GLOBO	T_{glob} (°C)	21,70
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	0
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	0
	DR (indice)	0		DR (indice)	0

CENTRO STANZA, h: 2,60 m			, h: m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,72	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	16,12		$WBGT_I$	
	$WBGT_E$	16,20		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	22,43	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	12,76		T_{umid} (°C)	
	UR (%)	28,2		UR (%)	
	T_{PR} (°C)	3,13		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	21,74	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	0		DR (indice)	

Parametri termoigrometrici

Identificazione locale



pianta secondo trapiano di Palazzo d' Accursio scala 1:200

Htot,stanza = 3,12 m

Nota
Presenza dei sensori 3EnCult su:
parete interna n° 0408
parete esterna n° 041D (oppure O)

N° stanza	O 2U 16 S
Piano	P3° Secondo trapiano
Utilizzo	Ufficio
Ora INIZIO	13:50
Rilievo n.	/

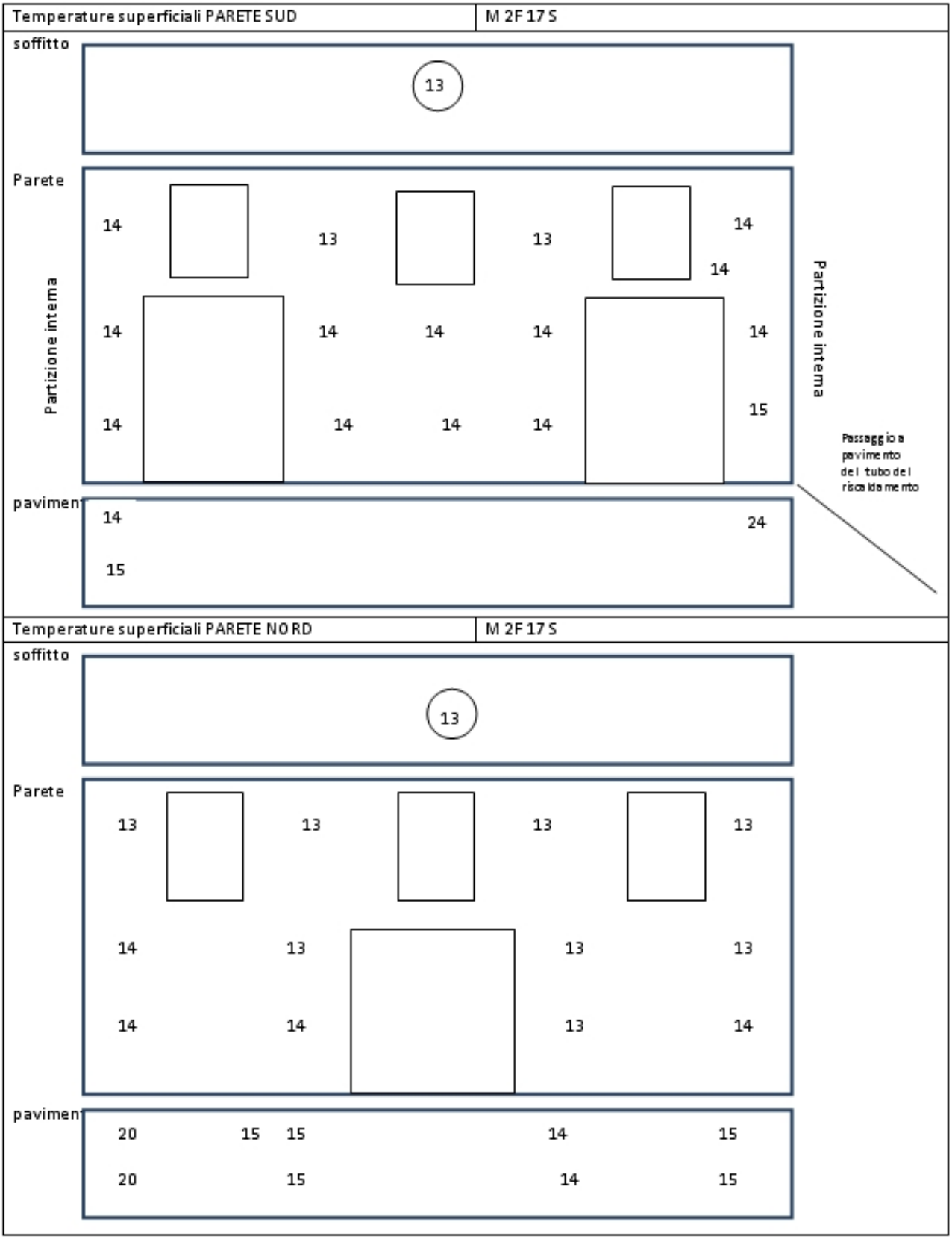
CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,26	Uscita 1 – TEMP. AMB	T_{umid} (°C)	13,18
	$WBGT_I$	15,72		$WBGT_I$	15,67
	$WBGT_E$	15,69		$WBGT_E$	15,58
Uscita 2 - PSICROMETRO	T_{sec} (°C)	21,20	Uscita 2 - PSICROMETRO	T_{sec} (°C)	20,43
	T_{umid} (°C)	11,00		T_{umid} (°C)	10,73
	UR (%)	21,90		UR (%)	23,90
	T_{PR} (°C)	-1,30		T_{PR} (°C)	-0,05
Uscita 4 - GLOBO	T_{glob} (°C)	21,47	Uscita 4 - GLOBO	T_{glob} (°C)	21,36
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	0
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	0
	DR (indice)	0		DR (indice)	0

CENTRO STANZA, h: 2,30 m			, h: m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	13,33	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	15,71		$WBGT_I$	
	$WBGT_E$	15,87		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	22,59	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	11,88		T_{umid} (°C)	
	UR (%)	22,10		UR (%)	
	T_{PR} (°C)	-0,11		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	21,24	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	0		DR (indice)	

Parametri termoigrometrici					
Identificazione locale					
 pianta piano secondo di Palazzo d' Accursio Collezioni scala 1:200			N° stanza		M 2F 17 S
			Piano		Piano Secondo
			Utilizzo		Sala espositiva chiusa al pubblico
			Data		17/2/2012
			Ora INIZIO		15:40
Htot,stanza = 11,73 m			Rilievo n°		012/001

CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	9,62	Uscita 1 – TEMP. AMB	T_{umid} (°C)	9,54
	$WBGT_I$	11,20		$WBGT_I$	11,16
	$WBGT_E$	11,18		$WBGT_E$	11,13
Uscita 2 - PSICROMETRO	T_{sec} (°C)	14,71	Uscita 2 - PSICROMETRO	T_{sec} (°C)	14,64
	T_{umid} (°C)	7,63		T_{umid} (°C)	7,55
	UR (%)	30,9		UR (%)	31,2
	T_{PR} (°C)	-2,18		T_{PR} (°C)	-2,18
Uscita 4 - GLOBO	T_{glob} (°C)	14,21	Uscita 4 - GLOBO	T_{glob} (°C)	14,94
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	0
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	0
	DR (indice)	0		DR (indice)	0

CENTRO STANZA, h: 2,50 m			, h: m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	9,46	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	11,14		$WBGT_I$	
	$WBGT_E$	11,12		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	14,87	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	7,66		T_{umid} (°C)	
	UR (%)	30,5		UR (%)	
	T_{PR} (°C)	-2,26		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	15,06	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	0	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	0	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	0		DR (indice)	


Temperature superficiali PARETE SUD
M 2F 17 S
soffitto
13
Parete
14
13
13
14
14
Partizione interna
14
14
14
14
14
14
14
14
14
14
15
Partizione interna
Passaggio a pavimento del tubo del riscaldamento
pavimen
14
24
15
Temperature superficiali PARETE NORD
M 2F 17 S
soffitto
13
Parete
13
13
13
13
14
13
13
13
14
14
13
14
pavimen
20
15
15
14
15
20
15
14
15

Statistic elaboration

Device Babuc number: **1865**

Survey n° **012/001 del 17/02/2012**

N° room M 2F 17 S

Used parameters:

Energy metabolism:	1.359 met	79. W/m^2
Thermal insulation of the clothing:	1.51 clo	0.2341 m^{2}C/W
Mechanical efficiency:	0 %	

Statistics of the surveyed environmental variables:

Grandezza	Media	Minima	Massima	Dev. Stand.
ta °C	14.86	14.86	14.86	0.00
tw °C	9.72	9.11	10.34	0.87
tg °C	15.09	15.09	15.09	0.00
RH %	49.00	43.40	54.60	7.92
tr °C	15.16	15.16	15.16	0.00
va m/s	0.00	0.00	0.00	0.00
var m/s	0.11	0.11	0.11	0.00
TU %	0.00	0.00	0.00	0.00

Statistics of the elaborated indexes:

Grandezza	Media	Minima	Massima
pa kPa	0.83	0.83	0.83
to °C	15.01	15.01	15.01
PMV	-0.29	-0.29	-0.29
PPD %	6.74	6.74	6.74
PD %	0.00	0.00	0.00
DR %	0.00	0.00	0.00

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The main index processed for these areas in the **winter period** are:

	PMV	PPD	
OFFICES AREA			
Room O GF 1 N	0,27	6,55	Thermal comfort achive
Room O 1F 7 N	0,11	5,26	Thermal comfort achive
Room O 2U 16 S	0,01	5	Thermal comfort achive
MUSEUM AREA			
Room M 2F 17S	-0,29	6,74	Thermal comfort achive

The PMV Predicted Mean Vote Index need to be (-0,5<PMV<+0,5)

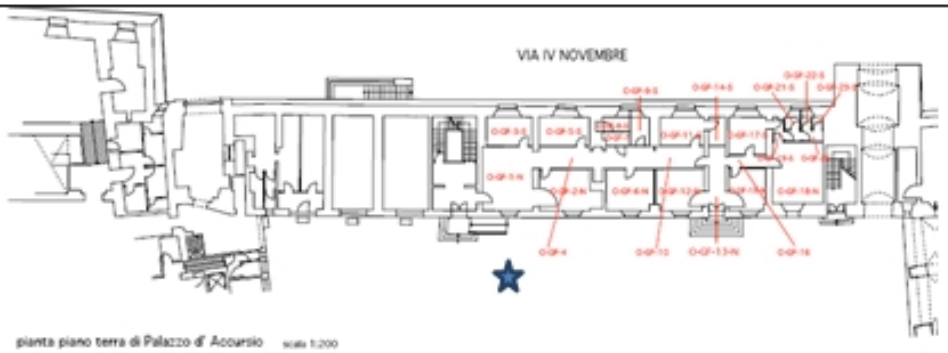
The PPD Predicted Percentage Dissatisfied Index need to be <10

This data is only an extract of IEQ audit. The whole document of IEQ Indoor Environmental Quality audit are available in a separate document.

SUMMER PERIOD

Parametri termoigrometrici

Identificazione locale



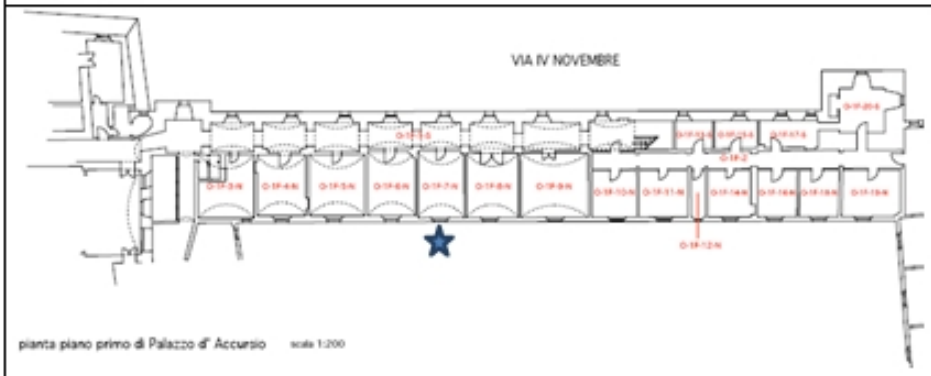
N° stanza	0 GF 1 N
Piano	PT Piano terra
Utilizzo	Sala d'attesa
Data	18/7/2012
Ora INIZIO	17:29
Rilievo n.	010/001

Note: condizionatore acceso a 26°C, finestre chiuse, porta ufficio 0-GF-3-S aperta,
guardiola (0-GF-2-N) con fori nel vetro, guardiola con finestra aperta, no

Htot,stanza=3,12m

CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	21,05	Uscita 1 – TEMP. AMB	T_{umid} (°C)	21,20
	$WBGT_I$	22,91		$WBGT_I$	22,62
	$WBGT_E$	22,59		$WBGT_E$	22,33
Uscita 2 - PSICROMETRO	T_{sec} (°C)	24,05	Uscita 2 - PSICROMETRO	T_{sec} (°C)	23,05
	T_{umid} (°C)	15,63		T_{umid} (°C)	15,21
	UR (%)	39,3		UR (%)	41,10
	T_{PR} (°C)	9,23		T_{PR} (°C)	9,12
Uscita 4 - GLOBO	T_{glob} (°C)	27,09	Uscita 4 - GLOBO	T_{glob} (°C)	25,82
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	/
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	/
	DR (indice)	/		DR (indice)	/

CENTRO STANZA, h: 2,00 m			Condizioni ambientali esterne (.....)		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	20,36	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	21,87		$WBGT_I$	
	$WBGT_E$	21,78		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	24,47	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	15,60		T_{umid} (°C)	
	UR (%)	36,3		UR (%)	
	T_{PR} (°C)	8,61		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	25,36	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	/		DR (indice)	

Parametri termoigrometrici					
Identificazione locale					
 pianta piano primo di Palazzo d' Accursio scala 1:200				N° stanza	0 1F 7N
				Piano	P2° Piano primo
				Utilizzo	Sala Riunioni (Sala Verde)
Htot,stanza = 3,44 m				Data	18/7/2012
				Ora INIZIO	15:31
Nota I sensori 3EnCult sono stati rimossi. Finestre aperte nel corridoio lato sud. Luxmetro esterno posizionato a sud.				Rilievo n.	005/001
CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	24,55	Uscita 1 – TEMP. AMB	T_{umid} (°C)	24,23
	$WBGT_I$	25,84		$WBGT_I$	25,62
	$WBGT_E$	25,85		$WBGT_E$	25,58
Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,90	Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,32
	T_{umid} (°C)	17,98		T_{umid} (°C)	18,09
	UR (%)	31,6		UR (%)	34,40
	T_{PR} (°C)	10,42		T_{PR} (°C)	11,15
Uscita 4 - GLOBO	T_{glob} (°C)	28,86	Uscita 4 - GLOBO	T_{glob} (°C)	28,74
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	/
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	/
	DR (indice)	/		DR (indice)	/

CENTRO STANZA, h: 2,60 m			Porta chiusa, h: 1,50 m		
Uscita 1 – TEMP.AMB	T_{umid} (°C)	24,09	Uscita 1 – TEMP. AMB	T_{umid} (°C)	23,93
	$WBGT_I$	25,59		$WBGT_I$	25,43
	$WBGT_E$	25,59		$WBGT_E$	25,44
Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,86	Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,86
	T_{umid} (°C)	18,01		T_{umid} (°C)	17,82
	UR (%)	32		UR (%)	31
	T_{PR} (°C)	10,51		T_{PR} (°C)	10,05
Uscita 4 - GLOBO	T_{glob} (°C)	28,82	Uscita 4 - GLOBO	T_{glob} (°C)	28,74
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	/
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	/
	DR (indice)	/		DR (indice)	/

Parametri termoigrometrici					
Identificazione locale					
 pianta secondo trapiano di Palazzo d' Accursio				N° stanza	0 2U 12 S
				Piano	P3° Secondo trapiano
				Utilizzo	Ufficio
Nota Presenza dei sensori 3EnCult disattivati. Ventilatore a pale acceso, finestra accostata al centro, presenza di condizionatore tipo Pinguinospento. Htot,stanza = 3,12 m				Data Ora INIZIO	18/7/2012 16:32
				Rilievo n.	008/001

CENTRO STANZA, h: 1,50 m			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	18,59	Uscita 1 – TEMP. AMB	T_{umid} (°C)	19,63
	$WBGT_I$	21,80		$WBGT_I$	22,45
	$WBGT_E$	21,76		$WBGT_E$	22,45
Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,97	Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,97
	T_{umid} (°C)	17,59		T_{umid} (°C)	17,67
	UR (%)	29,40		UR (%)	29,8
	T_{PR} (°C)	9,37		T_{PR} (°C)	9,60
Uscita 4 - GLOBO	T_{glob} (°C)	29,24	Uscita 4 - GLOBO	T_{glob} (°C)	29,05
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	/
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	/
	DR (indice)	/		DR (indice)	/

CENTRO STANZA, h: 2,30 m			h: m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	18,51	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	21,66		$WBGT_I$	
	$WBGT_E$	21,65		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	28,90	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	17,75		T_{umid} (°C)	
	UR (%)	30,50		UR (%)	
	T_{PR} (°C)	9,82		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	/29,01	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	0		DR (indice)	

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Parametri termoigrometrici					
Identificazione locale					
 pianta piano secondo di Palazzo d' Accursio Collezioni scala 1:200 Htot,stanza = 11,73 m				N° stanza	M 2F 17 S
				Piano	Piano Secondo
				Utilizzo	Sala espositiva chiusa al pubblico
				Data Ora INIZIO	18/7/2012 12:15
				Rilievo n°	001/001
CENTRO STANZA, h: 1,50 m (rilievo effettuato alle 12:40)			CENTRO STANZA, h: 0,20 m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	23,35	Uscita 1 – TEMP. AMB	T_{umid} (°C)	24,43
	$WBGT_I$	27,15		$WBGT_I$	26,21
	$WBGT_E$	27,14		$WBGT_E$	26,20
Uscita 2 - PSICROMETRO	T_{sec} (°C)	30,71	Uscita 2 - PSICROMETRO	T_{sec} (°C)	30,75
	T_{umid} (°C)	20,47		T_{umid} (°C)	18,55
	UR (%)	37,5		UR (%)	28,1
	T_{PR} (°C)	13,91		T_{PR} (°C)	10,14
Uscita 4 - GLOBO	T_{glob} (°C)	30,90	Uscita 4 - GLOBO	T_{glob} (°C)	30,90
Uscita 5 - ANEMOMETRO	V_a (m/sec)		Uscita 5 - ANEMOMETRO	V_a (m/sec)	/
Uscita 6 - ANEMOMETRO	Tu (%)		Uscita 6 - ANEMOMETRO	Tu (%)	/
	DR (indice)			DR (indice)	/

CENTRO STANZA, h: 2,50 m			CENTRO STANZA, h: 4,00 m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	23,51	Uscita 1 – TEMP. AMB	T_{umid} (°C)	24,01
	$WBGT_I$	25,71		$WBGT_I$	26,12
	$WBGT_E$	25,70		$WBGT_E$	26,12
Uscita 2 - PSICROMETRO	T_{sec} (°C)	30,82	Uscita 2 - PSICROMETRO	T_{sec} (°C)	31,02
	T_{umid} (°C)	19,74		T_{umid} (°C)	19,17
	UR (%)	33,5		UR (%)	30,4
	T_{PR} (°C)	12,91		T_{PR} (°C)	11,62
Uscita 4 - GLOBO	T_{glob} (°C)	30,98	Uscita 4 - GLOBO	T_{glob} (°C)	31,09
Uscita 5 - ANEMOMETRO	V_a (m/sec)	/	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	/	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	/		DR (indice)	

Deliverable D6.2 Documentation of each study case

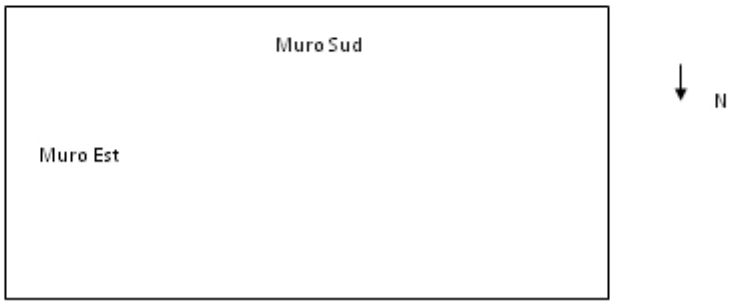
RILIEVO ESTERNO (Rilievo 003/001)			CENTRO STANZA, h: 4,00 m		
Uscita 1 – TEMP. AMB	T_{umid} (°C)	19,13	Uscita 1 – TEMP. AMB	T_{umid} (°C)	
	$WBGT_I$	23,27		$WBGT_I$	
	$WBGT_E$	23,01		$WBGT_E$	
Uscita 2 - PSICROMETRO	T_{sec} (°C)	29,94	Uscita 2 - PSICROMETRO	T_{sec} (°C)	
	T_{umid} (°C)	18,21		T_{umid} (°C)	
	UR (%)	29,1		UR (%)	
	T_{PR} (°C)	10,03		T_{PR} (°C)	
Uscita 4 - GLOBO	T_{glob} (°C)	32,79	Uscita 4 - GLOBO	T_{glob} (°C)	
Uscita 5 - ANEMOMETRO	V_a (m/sec)	2,93	Uscita 5 - ANEMOMETRO	V_a (m/sec)	
Uscita 6 - ANEMOMETRO	Tu (%)	6,3	Uscita 6 - ANEMOMETRO	Tu (%)	
	DR (indice)	79,6		DR (indice)	

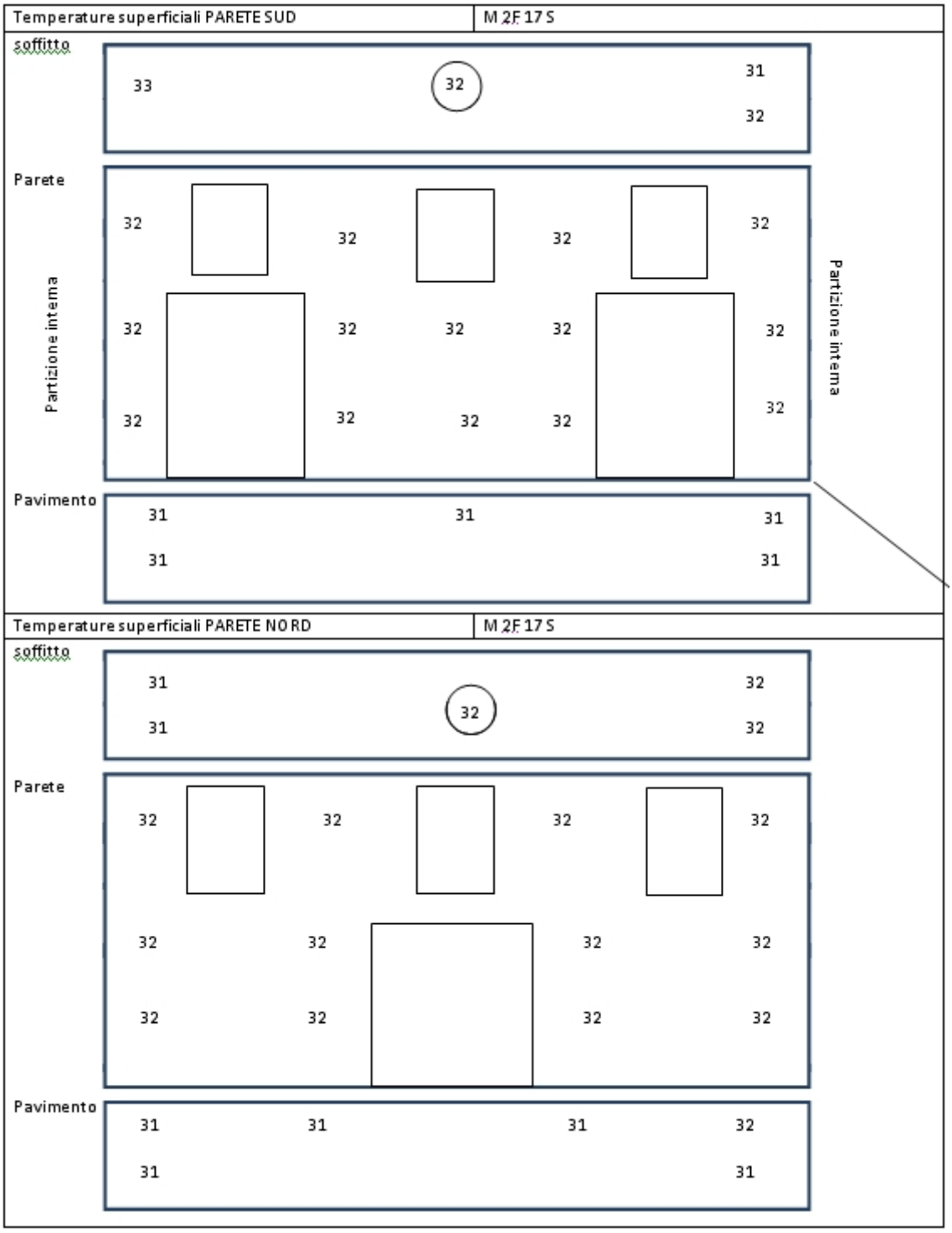
Parametri acustici (Rilievo del 01/08/2012) Nota: presenza visitatori

Identificazione locale

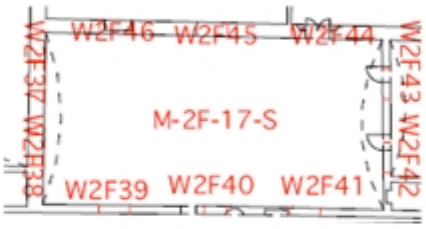
pianta piano secondo di Palazzo d' Accursio Collezioni scala 1:200

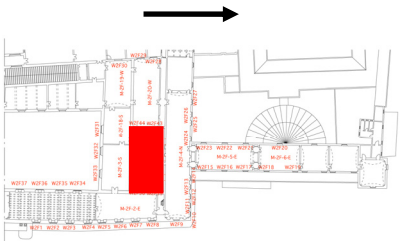
N° stanza	M 2F 17 S
Piano	Piano Secondo
$L_{Aeq\ int}$ (dB) Muro Sud	43,4
	41,5
	42,2
	42,5
$L_{Aeq\ iest}$ (dB) Muro Sud	52,2
	55,7
	51,2
	49,2
$L_{Aeq\ int}$ (dB) Muro Est	43,4
	42,9
	43,1
	42,9
$L_{Aeq\ iest}$ (dB) Muro Est	60,2
	59,1
	61,9
	62,5




Temperature superficiali PARETE SUD
M 2F 17 S
soffitto
33
32
31
32
Parete
Partizione interna
Partizione interna
Pavimento
Temperature superficiali PARETE NORD
M 2F 17 S
soffitto
Parete
Pavimento

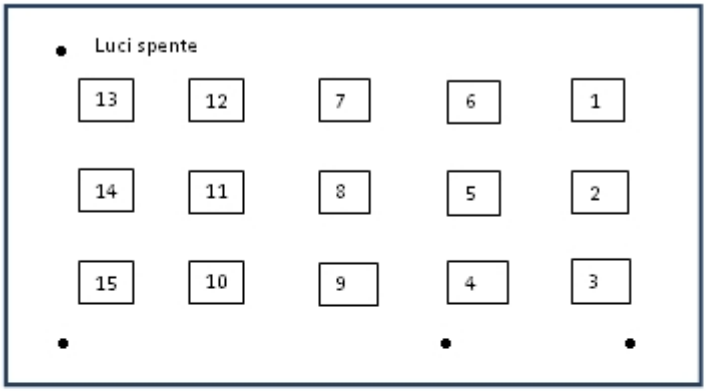
Rilievo del 01/08/2012 _Stanza M 2F 17 S





LUCI SPENTE

Parametri illuminotecnici (h: 0,80 cm) Nota: finestre lato sud colpite dal sole per metà		Illum INT (lux)	Illum EST (klux)
Pianta	1	2	48-52
	2	2	"
	3	3	"
	4	2	"
	5	2	"
	6	5	"
	7	2	"
	8	2	"
	9	2	"
	10	2	"
	11	2	"
	12	2	"
	13	2	"
	14	2	"
	15	2	"



Statistic elaboration

Device Babuc number: **1865**

Survey n° **001/001** ***del*** **18/07/2012**

Used parameters:

Energy metabolism: 1,359 met 79 W/m2

Thermal insulation of the clothing: 0,5 clo 0,0775 m2C/W

Mechanical efficiency: 0 %

Statistics of the surveyed environmental variables:

Grandezza	Media	Minima	Massima	Dev. Stand.
ta °C	30.82	30.47	31.09	0.11
tw °C	19.70	18.62	27.35	1.34
tg °C	30.97	30.86	31.09	0.06
RH %	33.45	28.00	78.20	7.40
tr °C	31.06	30.90	31.31	0.09
va m/s	0.10	0.10	0.10	0.00
var m/s	0.21	0.21	0.21	0.00
TU %	40.00	40.00	40.00	0.00

Statistics of the elaborated indexes:

Grandezza	Media	Minima	Massima
pa kPa	1.49	1.49	1.49
to °C	30.92	30.92	30.92
PMV	1.71	1.71	1.71
PPD %	62.43	62.43	62.43
PD %	3.02	3.02	3.02
DR %	2.29	2.29	2.29

Summary of results for the summer period

The main index processed for these areas are:

	PMV	PPD	
OFFICES AREA			
Room O GF 1 N	0,15	5,46	Thermal comfort achieve
Room O 1F 7 N	1,07	29,35	Thermal comfort **not achieve**
Room O 2U 12 S	1,12	31.48	Thermal comfort **not achieve**
MUSEUM AREA			
Room M 2F 17S	1.71	62.43	Thermal comfort **not achieve**

The PMV Predicted Mean Vote Index need to be (-0,5<PMV<+0,5)

The PPD Predicted Percentage Dissatisfied Index need to be <10

This data is only an extract of IEQ audit. The whole document of IEQ Indoor Environmental Quality audit are available in a separate document.

1.4 Results derived from the application of PHPP

(UNIBO - Marco Giuliani)

In this section we report the main results obtained by the application of the PHPP calculation model on those parts of the building which are considered by the analysis. Annex 1 shows the complete calculation report related to the elaboration made by the Passive House Planning Package (PHPP) software package.

The present report also illustrates the calculation assumptions taken for the energy simulations, due to the need to limit the analysis to a portion of the building itself.

Before turning to the results obtained by the application of the Protocol PHPP are reported remarks made upstream to make the protocol applicable to the case study.

The most relevant initial problem is given from an inadequate availability of documentation on building for the recovery of reliable data necessary for the calculation, starting from the drawings, system layout and operation schedule. The case study is a building of considerable size, consisting of multiple zones, different for types of use, ranging from administrative offices, museum rooms to various services for citizens. The building is the result of subsequent actions of expansion of the original plant. The choice of areas representative of the entire palace is done considering a variety of issues, including also the evaluation of the applicability of PHPP. In fact, this protocol is generally applied to whole buildings to assess the energy exchanges with the external environment. Under certain conditions it is possible to evaluate the energy balance of portions of buildings, considering the energy exchange between portions of the same building insignificant, using adiabatic constrains.

This is the strategy that is adopted in this case study. Then, two areas are selected, structurally homogeneous, characterized by different orientation and construction and by destination of use. As result two PHPP calculation are provided for the two areas referred to as “Office Area” and “Municipal Collections”.

The calculation took into account the indications provided by PHI and in particular have been taken the following choices:

• A review of the drawings are done, through an architectural survey. The drawings of the municipal collections have been partially integrated with some sections because they are very poor and however should be expanded.

• The attics are excluded from Boundary Balance because they are no-heated areas.

• For windows a specific survey activity was carried out for two specific aims. First is the recovery of the basic characteristics, necessary for inclusion in the PHPP calculation, where the transmittance values were estimated on the indications of PHI -. Second is the developing of the database of information for the Municipality to fill the lack of information on the building. The different types of finishing glass surfaces were not considered due to lack of available data. External shading effects from others building, overhangs and vertical elements are considered. The bars, covering the windows are considered as indicated in the guidelines of PHPP: omitted from the glass surface and considered increasing the thickness of the frames on all 4 sides.

• Transmittance values of the walls are carried out in accordance with ISO 6946 (CEN, 2007). The characterization of external walls is also provided though in-situ measurement of Transmittance value according with ISO 9869 (CEN, 1994). More details are available in section 3.1.1.

• Blower door test is performed to measure the airtightness level of the building according to ISO 9972 (CEN, 2006). The results of presurization test are used in the calculation to estimate the air permeability f the building.

• The thermal bridges are not analysed at this stage

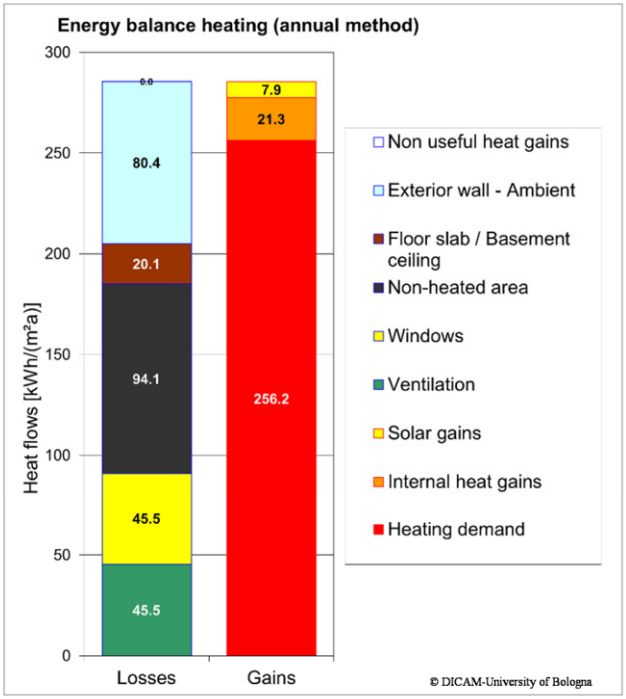
• Equipment, light and interior load are determined through the use of result of energy audit performed on the building.

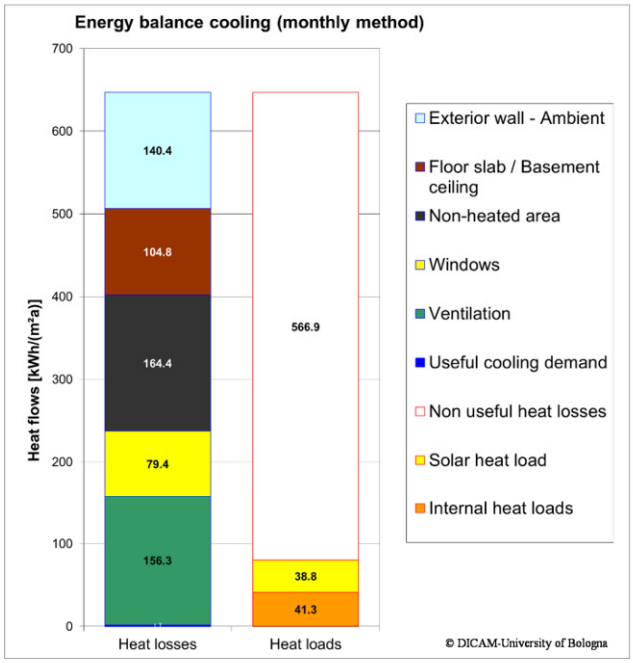
Results

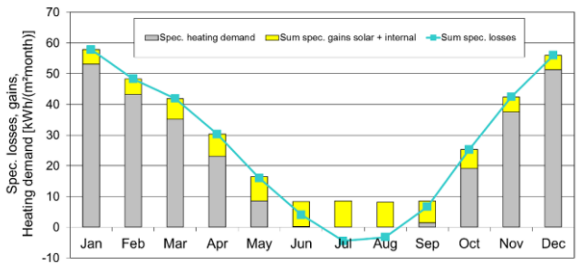
As you can see in the pictures below and in more detail in “ANNEX 1” is that the “Municipal Collections” and “Office area” of Palazzo D'Accursio are far away from achieving the passive house standard.

PHPP in the Municipal Collections

The results of the application of the PHPP analysis showed that the energy losses are distributed across the entire envelope. The main components are concentrated in the attic, included in the non-heated area, and external walls. The blower door test showed a relatively poor airtightness with a mean air change rate of 5.9 1/h. Therefore the losses due to infiltration, contained in the ventilation component, are considerable. Also the transmission heat losses through the windows are relevant, due to the presence of several and large windows in each external surface. During summer the building is cooled by natural ventilation through the windows. The reference component shows high value. Due to high value of losses on the entire envelope, the estimated hours of overheating has low value. The reliability of this value is doubtful as the monitored data show that indoor temperature is over 30°C for long part of the summer. It is well know that static tool has high uncertainty in the estimation of cooling load.

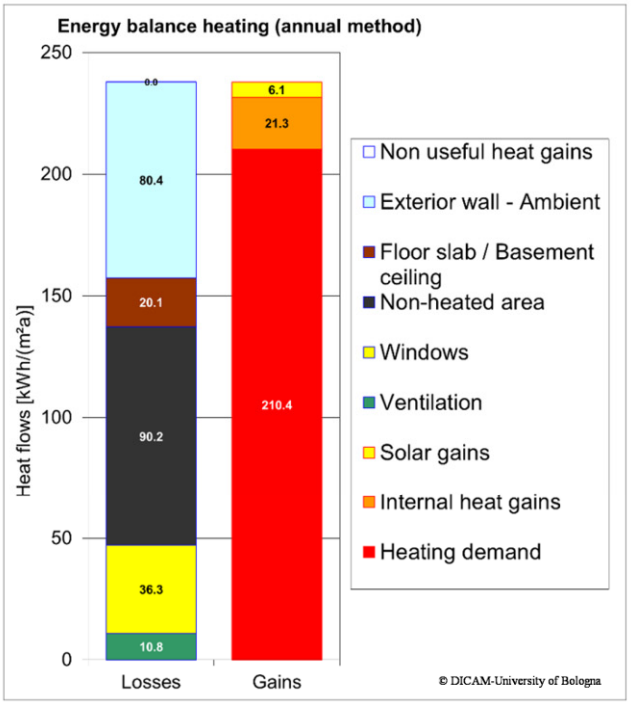


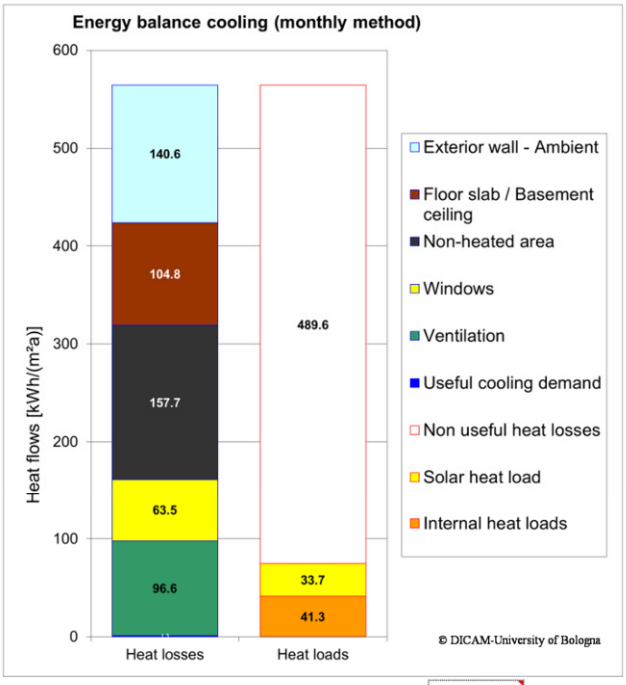


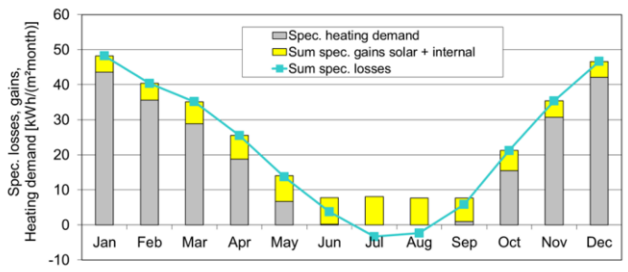


	Treated floor area	1015.0	m²
Space heating	Heating demand	273	kWh/(m²a)
	Heating load	124	W/m²
Space cooling	Overall specif. space cooling demand	2	kWh/(m²a)
	Cooling load	19	W/m²
	Frequency of overheating (> 25 °C)	1.7	%
Primary energy	Heating, cooling, auxiliary electricity, dehumidification, DHW, lighting, electrical appliances	543	kWh/(m²a)
	DHW, space heating and auxiliary electricity	439	kWh/(m²a)
	Specific primary energy reduction through solar electricity		kWh/(m²a)
Airtightness	Pressurization test result n_{50}	5.9	1/h

Compared to the pre-intervention scenario, the results of the post-intervention PHPP showed that the losses to the non-heated area (attics) and through the windows decreased in accordance with the implemented measure. Also ventilation losses decreased due to an improvement of the air-tightness. Looking at the global assessment the estimated heating and cooling demand decreased by 50 kWh/m2a (19%) and 1 kWh/m2a (50%).





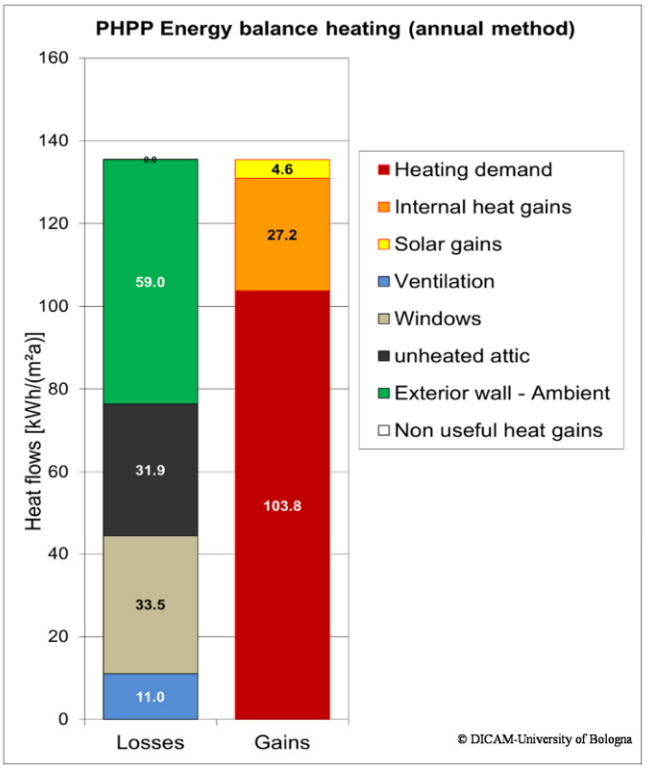


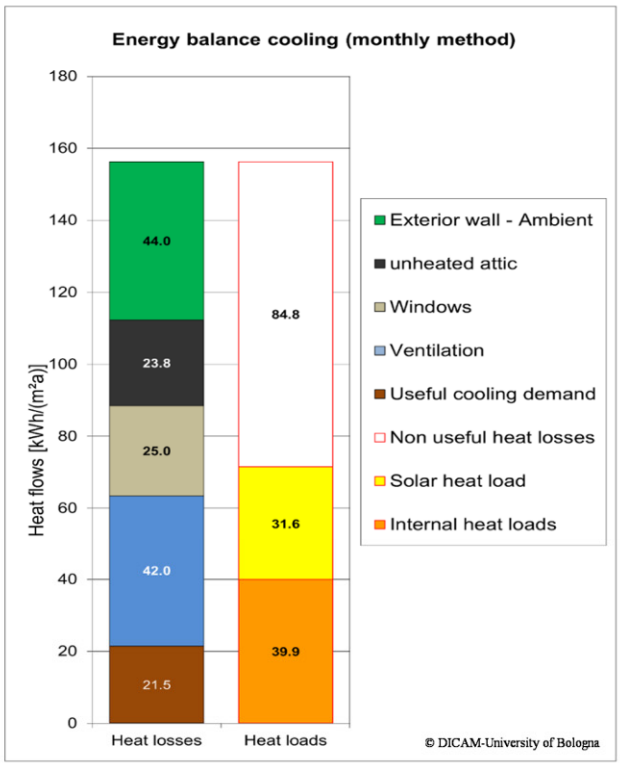
	Treated floor area	1015.0	m²
Space heating	Heating demand	223	kWh/(m²a)
	Heating load	86	W/m²
Space cooling	Overall specif. space cooling demand	1	kWh/(m²a)
	Cooling load	6	W/m²
	Frequency of overheating (> 25 °C)	1.0	%
Primary energy	Heating, cooling, auxiliary electricity, dehumidification, DHW, lighting, electrical appliances	472	kWh/(m²a)
	DHW, space heating and auxiliary electricity	370	kWh/(m²a)
	Specific primary energy reduction through solar electricity		kWh/(m²a)
Airtightness	Pressurization test result n_{50}	2.5	1/h

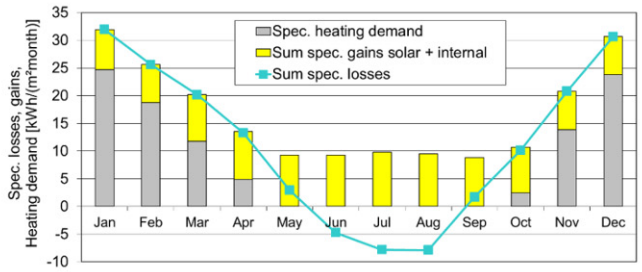
PHPP in the Offices Area

The main losses components of the “Office Area” are the exterior walls, then windows and unheated attic components. The overall heating consumption is much lower than Museum area, as the building is massive and with smaller indoor space. The internal gains are higher as the building is used as office. During summer the indoor temperature is controlled by natural ventilation through manually operable windows. According to that, the ventilation component during summer is considerable. This strategy seems not be sufficient to guarantee the comfort condition and the calculation of hours of overheating by PHPP shows high value.

All the result of PHPP, should be consider not as a good estimation of the absolute value of the energy balance but with the aim of compare pre and post retrofit result. One of the aim of 3encult is the verification of the capability of tools to simulate historical building. In this case the discrepancy of heating demand with consumption data is very high. Uncertainties are present also in the real consumption data, but the level of discrepancy does not justify all of that. Modeling a complex building like that is not easy task and the development of procedures are necessary. An approach of modeling is developed starting from the problems adressed in this project and it is presented in (Giuliani, 2014).







Space heating	Heating demand	**100**	**kWh/(m²a)**
	Heating load	**66**	**W/m²**
Space cooling	Overall specif. space cooling demand	**21**	**kWh/(m²a)**
	Cooling load	**44**	**W/m²**
	Frequency of overheating (> 25 °C)	23.9	%
Primary energy	Heating, cooling, auxiliary electricity, dehumidification, DHW, lighting, electrical appliances		**kWh/(m²a)**
	DHW, space heating and auxiliary electricity	184	kWh/(m²a)
	Specific primary energy reduction through solar electricity		kWh/(m²a)
Airtightness	Pressurization test result n_{50}	**4.7**	**1/h**

1.5 Overall rating

A comprehensive report focused on the surveys and analysis carried out in the Municipal Collections Area and in the Offices area highlights the following issues:

- Municipal Collections area: the “Municipal Collections” area is far away from achieving the passive house standard: surveys revealed a high incidence of losses in this area due to doors and windows, energy losses are distributed over the entire envelope and the main components are concentrated on the attic, contained in non-heated area, external walls and infiltration, the latter is contained in the ventilation component. Also the energy lost through the windows is relevant, due to the present of several and large windows on each external surface.
- Offices area: infiltrations that were found resulted having a very high intensity, concentrating especially next to window shutters;the main losses stem from the high glazed surface and high number of windows disposed to North due to the shape of the wing of the palace and for the type of fixtures present.

For what is concerned with the thermal aspects, we must highlight that the old heating plants and the distribution of the radiators are not able to provide heating addressing properly the different zones and activities that are carried out in the building. Because of this, a not proper fruition of the air conditioning devices both in summer and winter conditions can be found, with a consequent high consume of electric energy.

Deliverable D6.2 Documentation of each study case

The diagnosis was performed through a detailed analysis of the electrical systems and use frequencies, recorded during two surveys, carried out at the beginning and the end of the project. During the first survey, conducted in November 2011, a total consumption of 164.635 kWh/year emerged, while in the second observation, made in November 2013, the consumption turned out to be 159.027 kWh/year.

The high electricity consumption (106 kWh/m²) is mainly due to the use of individual air conditioners in summer and of small electric stoves to improve comfort inside the offices in winter. This is due to the fact that the current heating and cooling systems installed are inadequate. The decline of consumption from 2007 to 2013 is mainly due to a significant transition to the use of fluorescent lamps.

The results of the consumes calculations referred to heating, and therefore for the production of thermal Energy in D'Accursio Palace, seem extremely low if compared to the average value encountered in other historical builgings present in the Bologna territory and with respect to the PHPP calculation.

For what is concerned instead with the consume of electric energy, the data derived from the 2007-2010 billing show a very high consume if compared to the data found out in the Energetic Plan of the Municipality of Bologna for buildings with the same use.

This anomaly could be due to the following reasons:

- Inside D'Accursio Palace have been installed several heat pumps, some of which are responsible of the full heating of interior spaces (e.g. Sala Rossa) while others (installed in spaces where also radiators are placed) are activated manually by the occupants of these also in the winter season and not only in summertime;
- Both the personnel working at the Offices and in the Municipal Collections, in order to improve the thermal comfort, uses electric stoves in winter and fans/air coolers in summer. This is due to the fact that the building is not heated homogeneously for the presence of one only thermal probe which regulates the internal temperatures;
- For the production of warm water for bathroom are used boilers with electric resistances, located in bathrooms ;
- The Morandi museum requiring a constant temperature and a continuous control of moisture across all the hours of the day, uses for that purpose air treatment unities (UTA) with electric resistances.

To conclude, it is reasonable to think that the high electric energy consume (at the opposite of the consumes of Methane and Gecam) could be due to the fact that a significant part of the thermal energy demand and the whole of the warm sanitary water production demand are satisfied with technologies operating through electricity.

2 Design

2.1 Interventions needed

The energetic retrofit proposal of Palazzo D'Accursio's "Coat of Harms" Room of the Bologna Municipal Collections was originated by the willingness of the Local Authority to integrate an intervention of extremely necessary non ordinary maintenance of the Room, vital in order to resolve the ceiling's frescos decay due to the rainwater infiltrations through the deteriorated roof covering, with energetic refurbishment interventions able to respond properly to the double requirement of improving internal comfort the Room – where there is no air conditioning – during the winter and summer period while protecting the fresco decorations on the walls and ceiling from direct sunlight by reducing massively the ultraviolet radiations and providing protection from the infrareds.

The actions to be taken within the Municipal Collections area were orientated primarily to the execution of works relating to the "Coat of Arms" Room, called also "Sala Urbana", whose urgency was justified by the surveyed advanced conditions of decay. Work focused primarily on the replacement of the roof with waterproofing and replacement of existing windows.

In the realization of these maintenance operations, we introduced the aspect of energy saving, which normally would not have been applied to historic buildings protected by the Cultural Heritage Preservation Authority. Design objectives included the application of the legal limitations that prevent building components and envelope energy from losses.

The needed interventions and the retrofit actions individuated for the "Coat of Arms" Room have been varied in different procedures, each one essentially corresponding to a different specific choice of the materials to be used in order to build up the technological packets and abacus.

2.2 Simulation

(ICIE – Sandra Dei Svaldi, Mena Viscardi)

Before intervention, in the as-is state diagnosis phase, both PHPP Protocol and Design Builder Modelling were applied to the present case-study.

PHPP Protocol

PHPP is applied to both area, “Office Area” and “Municipal Collection Area”, for the as-in-state condition. It is applied to museum area also for the Post-intervention scenario. The results of the PHPP calculation is presented in section 1.4, section 6 annex 1 and section 7 annex 2.

DB Simulation-Municipal Collections Area

An energetic model of the Municipal Collections Area was elaborated using Design Builder (an informatics software for the analysis in dynamic conditions developed with the ENERGY PLUS engine). Modeling and analysis were performed in 7 steps, from digital rebuilding of the examined area, to the simulation of the thermal and physical characters of the building components, ending with the definition in the model of the kind of HVAC and the type of regulators. Using DB the solar gains, the internal gains, the energy losses through the building envelope and for ventilation, both in winter and summer time, were calculated, estimating the energy need for heating in winter time and the one for cooling and lighting referred to summer time. The solar gains through the external building envelope are shown in the graph below as a excerpt from the results.

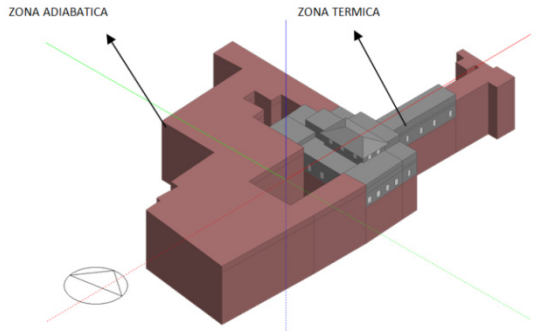


Figure 27:Energetic 3d model of the building (as is state), Source: [Viscardi, M.; Dei Svaldi, S. 2012] ICIE

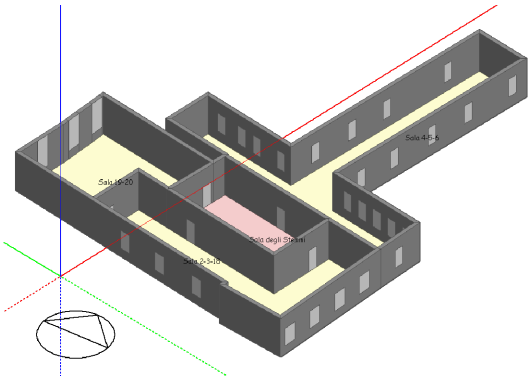


Figure 28: Energetic 3d model of the PHPP area (as is state), Source: [Viscardi, M.; Dei Svaldi, S. 2012] ICIE

In the elaboration of the intervention hypothesis phase, after evaluating singularly the interventions for the energetic retrofit, an Effectiveness Analysis in dynamic regime has been carried out in three phases in order to determine the most performing combination of windows and window frames solutions in relation to the need of improving Room’s internal comfort, in particular :

- Elaboration of 4 energetic DB simulations referred respectively to: as-is state conditions and window frames substitution hypothesis scenario a), b), c); review of the obtained results compared to the as-is state; first choice of hp c) as the most satisfactory in relation to priority target of protecting the frescos from UV radiations and infrared rays; final choice of combining scenario c) solar control and low emissive glasses with only low emissive ones (of the other two previous hypothesis) for north and west facing windows.
- On the basis of the simulation done, was defined the pack of the internal comfort improving interventions on the opaque parts: the analysis of 5 intervention hypothesis with DB obtained combining the technological options studied in the previous chapter referred to windows substitution, roof and ceiling refurbishment, plaster remake. A comparison was performed among the results of the 5 hypothesis and of the as-is state simulations in winter/summer time, followed by a winter-

summer combined evaluation and the individuation of Hp n.3 as the most performing across the whole year.

- Test of performance of the structure consequent to the plaster substitution, test of the building's envelope and "Coat of Arms" Room performance consequent to substitution of the existing with an already mixed thermo-plaster fiber reinforced with cork (grain size 0-3 mm), lime, diatomic powders and hydraulic binding agent: the simulated improvements of the thermal performance of the Room walls did not justify in terms of overall comfort increase the adoption of this project option.

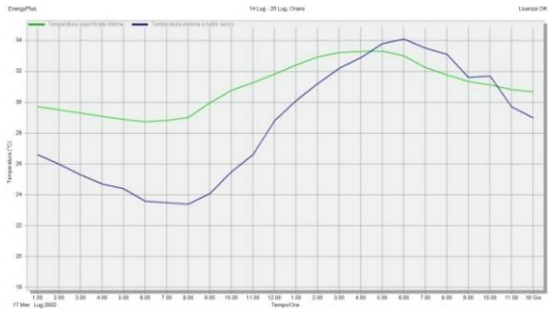


Figure 29: External temperature (in blue) and internal surface temperature of the window (in green) on the 17th of July, Source: [Viscardi, M.; Dei Svaldi, S. 2012]ICIE

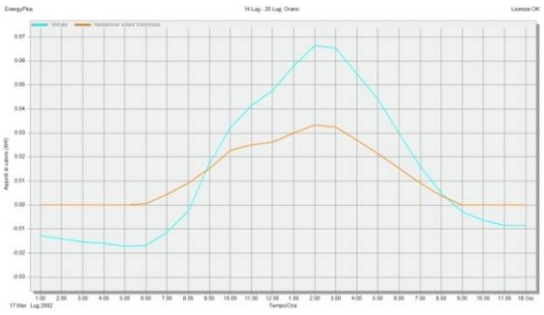


Figure 30: Solar radiation transmitted through the glass (in orange) and the heat stream through the window (in light blue) on the 17th of July,Source: [Viscardi, M.; Dei Svaldi,S. 2012] ICIE

DB Simulation-Offices Area

A simulation in the Offices area was also elaborated using Design Builder.

The studied area , in particular is located in the south wing of the so-called "Pit Courtyard" ("Cortile del Pozzo") and faces Via IV Novembre. It is made of 4 floors, whose functional destination is organized as follows:

- Ground Floor –Bologna Municipal Police Offices;
- First Mezzanine Floor – Municipal Assemblies Offices;
- First and Second Mezzanine Floors – Municipal Offices;

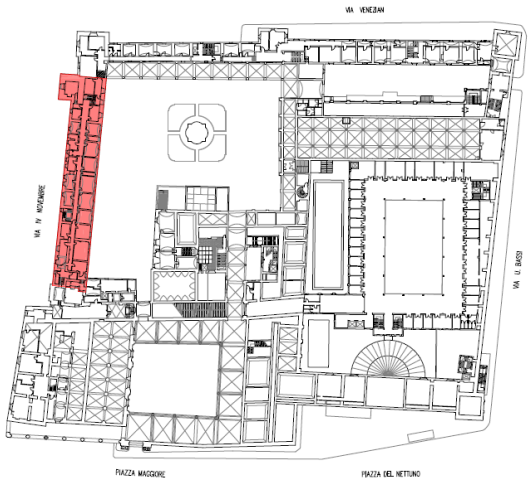


Figure 31 Identification of the study areas

Modeling and analysis were performed in 7 steps, from digital rebuilding of the examined area, to the simulation of the thermal and physical characters of the building components, ending with the definition in the model of the kind of HVAC and the type of regulators. Using DB the solar gains, the internal gains, the energy losses through the building envelope and for ventilation, both in winter and summer time, were calculated, estimating the energy need for heating in winter time and the one for cooling and lighting referred to summer time. The solar gains through the external building envelope are shown in the graph below as a excerpt from the results.

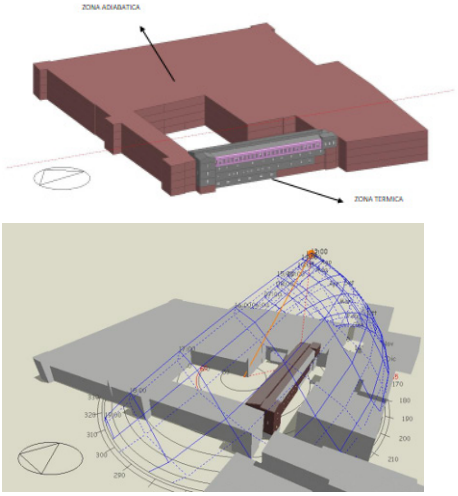


Figure 32: Energetic 3d model of the building e analisi solare (as is state), Source: [Viscardi, M.; Dei Svaldi, S. 2012] ICIE

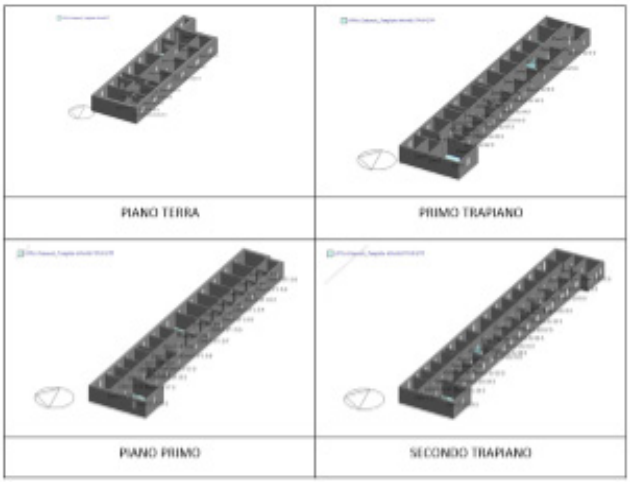
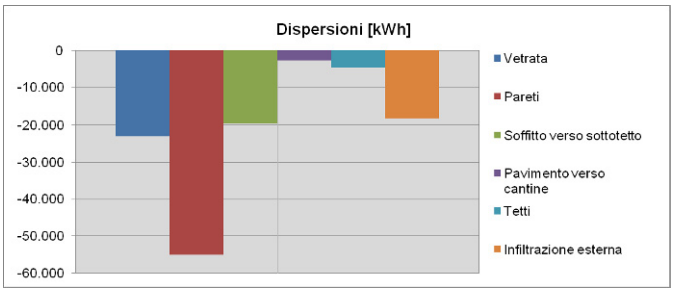


Figure 33:Zone termiche individuate (as is state), Source: [Viscardi, M.; Dei Svaldi, S. 2012], ICIE

At first the solar gains, the internal gains, the dispersals through the envelope and through ventilation were individuated, referring to the period going from 15th October to 15th April ("winter season") and to the period going from 16th April to 14th October ("Summer Season").

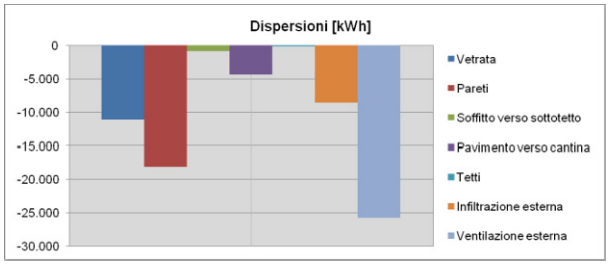
Then, the analysis of the Energy demands for the haeating in winter conditions and for cooling in summer conditions, as well as that concerning the gas consumes for heating and the elecetric Energy consume, mainly due to lighting and air-cooling was performed.



Winter dispersions (kWh) (as is state) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

Consumi di energia elettrica	kWh
Illuminazione	20.618,82
Strumentazione ufficio	50.759,78
Apparecchiature per la climatizzazione (stufette)	3.338,49
ACS	1.866,12
Totale	**76.583,21**

Electric Energy consumptions in winter (kWh) (as is state) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE



Summer dispersions (kWh) (as is state) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

Consumi di energia elettrica	kWh
Illuminazione	10.281,16
Strumentazione ufficio	50.652,11
Apparecchiature per la climatizzazione (ventilatori)	710,82
Condizionatori	13.741,81
ACS	1.864,39
Totale	**77.250,29**

Electric Energy consumptions in summer (kWh) (as is state) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

According to the analysis performed with this software the net energy demand for heating corresponds, in the as is state, to **39.088,89 kWh**; the gas consumption only for heating is esteemed in 49.367,43 kWh. Data in detail are reported in the following tabs:

Electric energy consumptions	kWh
Lighting	20.618,82
Office equipments	50.759,78
Equipment for air-conditioning (little stoves)	3.338,49
ACS	1.866,12
Total	**76.583,21**

Electric energy consumptions	kWh
Lighting	10.281,16
Office equipments	50.652,11
Equipment for air-conditioning (fans)	710,82
Air conditioners	13.741,81
ACS	1.864,39
Total	**77.250,29**

Hypotyzed solutions

Based on the results of diagnoses, monitoring and simulation, the issues should be determined in order to find the probabilistic solutions. The retrofit actions that have been evaluated were the following:

- Windows substitutions;
- Substitution of the courtains in textile facing Via IV Novembre, with or without tele-control;
- Lamps substiution;
- Coat insulation of the walls of the north-west facades facing the “Pit Courtyard” (“Cortile del Pozzo”);
- Insulation of the ceiling of the Second Mezzanine Floor from the extradox;
- Insulation of the floors external attics.

Those interventions have been varied in different ways, essentially corresponding to five intervention hypothesis:

- A HYPOTHESIS: Frames substitution + technical not teleoperated courtains + controlled lights
- A1 HYPOTHESIS: Frames substitution + technical teleoperated courtains + controlled lights
- B HYPOTHESIS: North west facade walls coat insulation;
- C HYPOTHESIS: Ceiling insulation towards the under-roof void and of the external floor attic;
- D HYPOTHESIS: (A1+B+C)

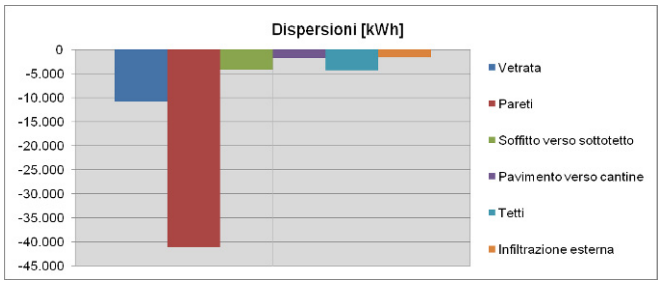
Expected results

Also for the project hypothesis the solar gains, the internal gains, the dispersions through the envelope or for ventilation have been reported both referring to winter and summertime periods.

Therefore the heating in winter condition and cooling in summer condition net energy demands analysis has been performed, including gas consumptions for heating and electric energy consumption mainly due to lighting and cooling.

Deliverable D6.2 Documentation of each study case

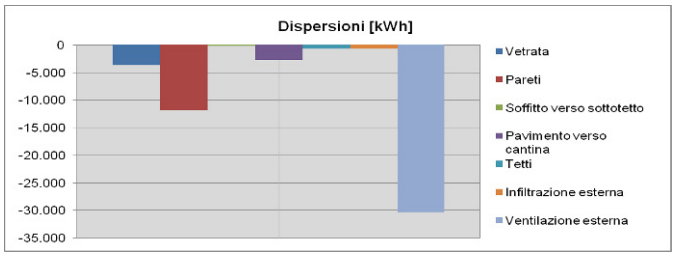
Following the application of the D hypothesis, the most complete, a reduction of the net energy demand for heating going from 39.088,89 kWh to **33.609,55 kWh** is estimated, with the gas demand only for heating going from 49.367,43 kWh to 42.434,31 kWh .



Winter dispersions (kWh) (project hypothesis) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

Consumi di energia elettrica	kWh
Illuminazione	3.749,96
Strumentazione ufficio	50.759,78
ACS	1.866,12
Totale	56.375,86

Electric Energy consumption in winter (kWh) (project hypothesis) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE



Summer dispersions (kWh) (project hypothesis) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

Consumi di energia elettrica	kWh
Illuminazione	1.931,34
Strumentazione ufficio	50.652,11
Condizionatori	13.120,53
ACS	1.864,39
Totale	67.568,37

Electric energy consumption in summer (kWh) project hypothesis) [Viscardi, M.; Dei Svaldi, S. 2012]
© ICIE

Electric Energy consumptions	kWh
Lighting	3.749,96
Office equipments	50.759,78
ACS	1.866,12
Total	**56.375,86**

Electric Energy consumptions	kWh
Lighting	1.931,34
Office equipments	50.652,11
Air conditioners	13.120,53
ACS	1.864,39
Total	**67.568,37**

2.3 Planned solution

The energetic retrofit interventions that have been planned in order to test their capacity to fulfill the given targets, considering the present constraint conditions, are the following:

1. Roof refurbishment(Insulation of the interior covering ceiling from the extrados of the roof)
2. Windows substitutions;
3. Roof refurbishment;
4. Plaster remake.

These interventions have been varied in different procedures, each one essentially corresponding to a different specific choice of the materials to be used in order to build up the technological packets and abacus. Follows a detailed description of the hypnotized interventions.

2.3.1 Roof refurbishment

Among the energetic retrofit interventions analyzed in relation to the present case study, the substitution of the existing roof is a priority.

Currently there are abundant rainwater infiltrations through the roof, leading to the decay of the walls underneath, detachment of the frescos at the intrados of the ceiling, emerging of moulds in the lateral decorated walls; the intervention of extraordinary maintenance is therefore necessary.

The adoption of a ventilated roof system for the refurbishment of the roof permits to increase the energetic performances of the Room both in winter and summer time.

By choosing to adopt a proper thickness of transpiring insulation and a properly dimensioned ventilation chamber, the ventilated roof permits to insulate from the cold the space underneath in the winter period (lowering of the value of thermal transmittance) and to obtain also a good performance in the summer period (control of the values of periodic transmittance and displacing of the thermal wave); it favors the condensation dispersal thanks to the internal air stream, guarantees a longer duration of the used materials and effectiveness of the applied insulation. The studied insulating materials, apt to this kind of use, are two:

• The glass wool, a natural product which shows good insulating and physical properties. The glass wool is fire resistant, chemically neutral, non-absorbing, light, flexible, simple to be worked and resistant to aging. Because of its features of moisture vapor transmission rate, thermal and acoustic insulation, mechanical resistance to compression and optimal reaction to fire, the glass wool is proper for the application in ventilated roofs. In the examined case, the use of a panel in mineral insulation “BAC CF N Roofine G3” with an 8 cm thickness and a density of 30 kg/m3, laid down between two layers of 1,9 cm thick OSB panels with the function of increasing the volume of the roof and therefore improve its acoustic insulation and the performance in summer time. The overall thickness of this insulating packet is , therefore, of 11,8 cm.

• The wood fiber, material of plant origin produced from the manufacturing of conifer tree wood (spruce, larch, pines) derived from wastes and remains of saw mills and woods keeping, from which panels of different thicknesses, formats and densities are made.

The wood fiber is apt to applications of this kind because, thanks to its structure with open pores, it permits an excellent transpiration and the passing of vapor, is an hygroscopic material (able to regulate humidity) and, thanks to the high density, permits a very high thermal wave displacement 8and therefore the protection of the internal spaces for summer heat).

The analyzed version of ventilated roof entails the exploitation of a double layer of insulating panels in wood fiber “Pavatherm”, with juxtaposed joints with a 4 cm displacement for each one and with a density (volume mass) corresponding to only 140 kg/m3, on which another layer of wood fiber “Natur isolant” only 1,9 cm thick of higher density (220 kg/m3) is laid down, whose aim is to distribute in the best way on the panel the weight of the upper roof (important precaution due to the panel rigidity. In this case the overall thickness of the insulating pack corresponds to 9,9 cm.

The thickness of the analyzed insulations has been determined trying to respond to two necessities:

- To obtain low thermal transmittances;

- To respect the constraint (RUE of the Bologna Municipality, art. N. 57 IS 1.1) of heighten the roof top of 20 cm maximum;

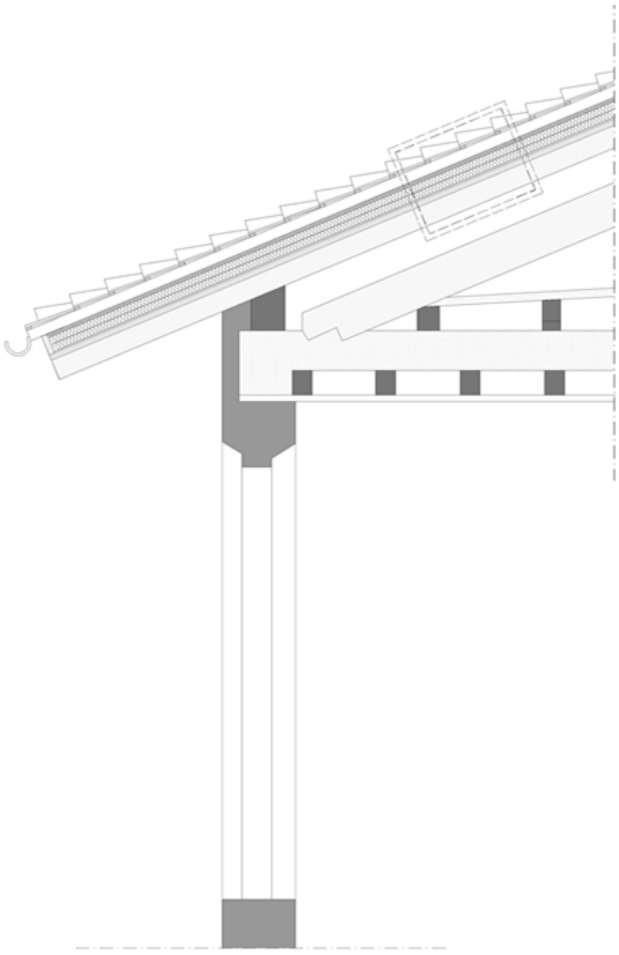
In the following lines are reported the features of the two current status and project hypothesis.

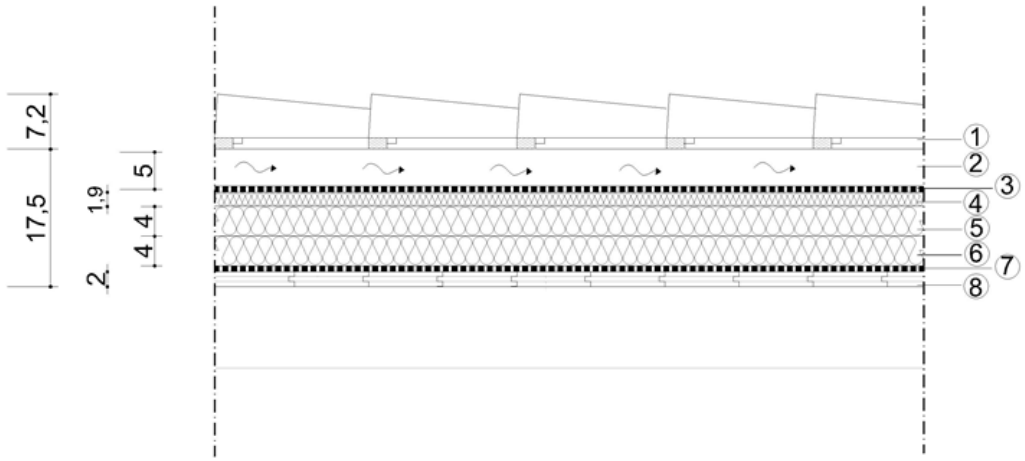
Analyzing the value of the pack thermal transmittance, takes place the passage from a value of 1,960 W/m2K of the current status to a value of 0,398 W/m2K corresponding to the same ventilated roof but using wood fiber.

The performance in summertime has been evaluated analyzing the values of periodic transmittance, attenuation and thermal wave displacement factor determined through the use of a simulation software in almost stationary conditions 8Edilclima). The value of periodic thermal transmittance, i.e. passes from a value of 2,251 W/m2K of the current status to a value of 0,307 W/m2K in the state of project using glass wool and of 0,326 W/m2K using wood fiber. The highest thermal wave displacement is obtained using wood fiber insulation thanks to which from a value of – 1,397 W/m2K of the current status we pass to a value of -4,775 W/m2K in the state of project.

In both the analyzed project solutions the values of thermal transmittance can be further improved using a thicker insulation , always considering that two of the main constraints of the project are represented by the limitation of the weights that insist on the covering structures and by the respect of the constraint of roof top heightening of 20 cm maximum.

The thickness of the insulation therefore will be determined when the knowledge frame of the present structures will be in the conditions to be completed.





1. Copertura in tegole di argilla
2. Intercapedine d'aria s. 50 mm
3. Telo impermeabilizzante sottotegola s. 0.4 mm
4. Pannelli in fibra di legno (densità 220 kg/m3) s.19 mm
5. Pannelli in fibra di legno (densità 140 kg/m3) s. 40 mm
6. Pannelli in fibra di legno (densità 140 kg/m3) s. 40 mm
7. Barriera all'aria e freno al vapore a diffusione igrovariabile s. 0.2 mm
8. Assito in Legno di pino flusso perpendicolare alle fibre s. 20 mm

2.3.2 Windows substitution

The first intervention considered is the substitution of the present windows and window frames.

"Sala Urbana" does have nr. 10 window frames: 3 + 3 in the North and South facing facades and 2 + 2 in the East and West facing facades. The window frames in the East and South facing facades are adjacent to the exterior and do present a second external window frame of the same typology.

The window frames in the West and North facing facades, instead, are adjacent to the roof attic of other rooms of the Municipal Collections and are single.

The present windows, provided with a simple wooden frame and a single glass 2 mm thick, are in an evident state of decay. All the windows do have internal curtains in clear color.

The application of wooden/aluminum frame window frames (in laminar pine with the internal surface varnished in dark brown color), with Uf=1,372 W/m2K associated to different "glass packets" was considered as option.

In particular the choice has been to analyze the effects obtained through the application of different solutions of windows summarized below :

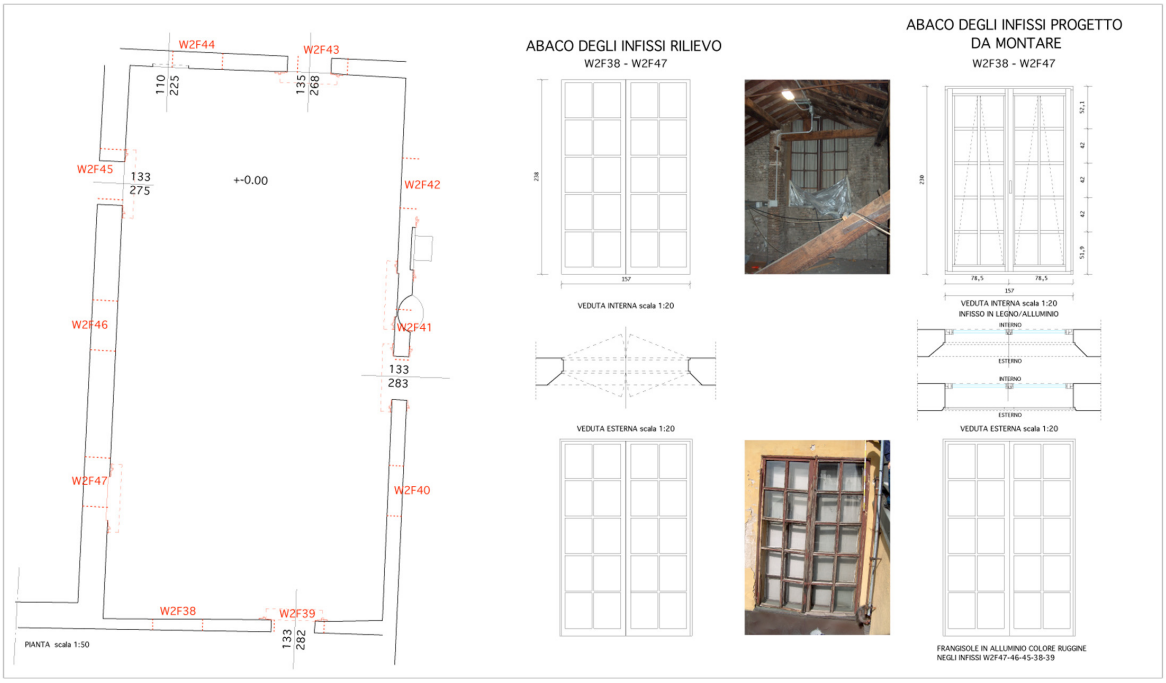
1) A triple glass 3 + 3 be/12argon/3 + 3be (offered performances: Ug=0,7w/m2K and g=33);
2) A double insulating glass 5 + 5be/16argon/4 + 4 (offered performances: Ug=1w/m2K and g=27);
3) A double insulating glass 4 + 4be/16argon/4 + 4 (offered performances: Ug=1w/m2K and g=26);

In every option has been taken in consideration the use of low emission and solar control glass, that is with a good solar factor, "g", pursuing the target of protecting the fresco decorated walls; the third solution involving the use of a selective glass that permits also to tear down the UV radiations.

It is expected that the frames, with overturned doors, can be provided with automatic openings activated on the basis of the ratio between the internal and the external temperature value; the opening at night favors the activation of a chimney effect which is able to guarantee a natural cooling of the Room and at a certain degree also of the adjacent spaces in summer months. On the southern and northern side external the positioning of brise soleil has been planned provided with anti-intrusion grids whose design recalls in the shape the present external window shutters.

An energetic analysis has been carried out referring to the current status and to the state of project.

Follow the features of the window frames and of the glass type in the current status and the three project hypothesis.



2.3.3 External walls insulation

The East and South facing vertical enclosures directly bordering the exterior are at present covered with a layer of strongly deteriorated plaster; it is made of a mixture of a concrete base of the 30s, therefore with non-philological procedures that would instead entail a lime based mixture.

Two intervention hypothesis have been considered, both implying the substitution of the functional layer, in the first case with **a** thermo-insulating plaster and in the second with **a** traditional lime-based plaster. Both solutions allow the control of the present thermal fields connected to the presence of deteriorated infra bricks cement layers.

The use of a lime made plaster in substitution of the present one is for sure the most respectful solution in relation to the characters of the walls on which the intervention is carried out.

The use of a thermo-insulating plaster guarantees an improvement of the indoor comfort conditions both in winter time and in summer time thanks to the function that it can perform in insulating the walls from the exterior; the thermo-insulating plaster allows the transpiration through the wall avoiding the formation of moulds.

In the examined case the choice focused on the use of the thermo-insulating plaster named “Diathonite Evolution”, an already mixed thermo-plaster fiber reinforced with cork (grain size 0-3 mm), lime, diatomic powders and hydraulic binding agent.

It is a completely natural compost, ideal for contests where eco-sustainable material are needed, ready to use, therefore it can be applied in a fast and efficient way on existing walls.

With the laying of only three centimeters of plaster the thermal transmittance value is halved, passing from being 1,633 W/m^{2}K in the current status to 0,788 W/m^{2}K in the state of project. The planned thickness could be even increased as a consequence of the positive resolution of the negotiation procedure that is being carried on with the Bologna Architectural and Landscape Heritage Preservation Authority . In the following

part are reported the features of the constructive pack both in the current status and in the state of project (concrete plaster substitution with thermo insulating or lime plaster).

2.3.4 Project energy simulations for achieving the most efficient solution for conservation

After individuating and evaluating singularly the punctual interventions for the energetic retrofit of the case in exam, an Effectiveness Analysis at system level has been carried out, using the energetic simulation software at a dynamic regime Design Builder (with Energy Plus motor); the analysis has been divided in three phases through which it has been possible to determine the most performing combination of the windows and window frames solutions in relation to the priority to protect the frescos from the direct radiation of solar rays (tearing down UV radiations and protection from the infrareds) and in relation to the need to obtain an improvement of the internal comfort of the Room, not directly served by air-conditioning equipment, during summer and winter time.

Follows the description of the three phases of the Effectiveness Analysis.

Individuation of the glass type that best protects the frescos from direct solar radiation (1st step)

By using the Design Builder Software four simulations of the entire environmental system have been done:

- Current status, with pine wooden window frames and clear glass 2 mm thick;
- HP Project a) substitution with new wooden/aluminum frames with Uf=1,372 W/m2K (in laminar pine with the internal surface varnished in dark brown color and the external in aluminum varnished in dark brown color) and triple insulating glass 3 + 3be/12 gas argon/4/12 gas argon/3+3be (Ug=0,7 W/m2K and g=33), highly performing in winter time.
- HP Project b) substitution with new wooden/aluminum frames Uf=1,372 W/m2K (laminar pine with the internal surface varnished in dark brown color and the external in aluminum varnished in dark brown color) and double insulating glass layered 5+5be/16argon/4+4 (Ug=1 W/m2K and g=27);
- HP Project c) substitution with new wooden/aluminum frames Uf=1,372 W/m2K (laminar pine with the internal surface varnished in dark brown color and the external in aluminum varnished in dark brown color) and double insulating glass layered 4+4be16argon/4+4 (Ug=1 W/m2K and g=27)), highly performing in summer time.

The results achieved from the analysis of the three project hypothesis compared to the current status highlight that, in relation to the priority target of protecting the frescos from the UV radiations and the infrared rays the best performance is obtained through the positioning of glasses that do have the characteristics individuated in hypothesis HP c.

In front of a performance that is for the remaining aspects quite similar to the one guaranteed by the other two solutions, this glass choice permits a noticeable limitation of the solar gains in summer time, going from 1658,80 kWh of the current status to 282,12 kWh of the project hypothesis.

A further convenience of the HP c if compared to the HP a hypothesis is due to the fact that the chosen triple glass in this one, being heavier, presents higher criticalities and consuming in the motioning in time and has a much higher cost.

In the beginning, was considered the application of the same glass for all the windows. Successively, was contemplated the use of glass with a lesser thickness for windows facing the attic (north and west); a window frame leaning out towards the interior, in fact, doesn't have to provide solar control but must only be low emissive; for these windows was analyzed the hypothesis of a low-emissive but not selective glass.

From the analysis done it is tested that in the two cases (selective glass on 10 window frames, selective glass for east-west facades and only insulating low-emissive glass for north-south facades) the performances reached are quite similar in summer and winter time; the main differing aspect happens in the dispersions through the windows in winter time that result to be higher in comparison to the dispersions obtained using only one typology of window frame offering a lower performance (due to the higher transpiration of the window frames towards the interior) with the same values of the other components, among which the internal temperature. In summer, instead, the combined solution of the two window frames performs in a better way avoiding the injection of further heat in the environment.

So, if the solution designed for HP c is applied only on the window frames leaning out towards the exterior using lighter glass types in the windows facing the attic, it improves even more its performance in terms of "optimal levels in function of the costs", as the EPBD2 suggests.

Definition of the pack of interventions on the roof that permits an improvement of the energetic and internal comfort conditions of the room (2nd step)

After defining the most effective window solution (frame and glass), five intervention hypothesis have been analyzed using the Design Builder Software, obtained combining the technological solutions studied in the previous chapter.

Follow the five hypothesis analyzed at system scale (in bold the technological solution that differs from the one of the previous hypothesis):

HP1	High efficiency window frames (selected in phase 1)
	Ventilated and insulated roof with glass wool + a double layer of panels oriented fibers (OSB)
	Insulation of the roof from its extrados with glass wool
	Remake of the external façade plaster using traditional lime plaster

HP2	High efficiency window frames (selected in phase 1)
	Ventilated and insulated roof with wood fiber
	Insulation of the roof from its extrados with glass wool
	Remake of the external façade plaster using traditional lime plaster.

HP3	High efficiency window frames (selected in phase 1)
	Ventilated and insulated roof with wood fiber
	Remake of the external façade plaster using traditional lime plaster.

HP4	High efficiency window frames (selected in phase 1)
	Ventilated and insulated roof with glass wool + double layer of panels with oriented fibers (OSB)
	Remake of the external façade plaster using traditional lime plaster.

HP5	High efficiency window frames (selected in phase 1)
	Remake of the external façade plaster using traditional lime plaster.
	Insulation of the roof from its extrados with glass wool

On the basis of the energetic analysis conducted on a dynamic field, the HP3 and HP4 intervention hypothesis, very similar to each other, result to be the most succeeding and satisfying. Between the two we consider to be more suitable for the case in exam the HP3 which uses the wood fiber as roof insulating material and doesn't need further OSB layers to increase its thermal mass. Therefore it results to be faster and easier to be laid down together with a more limited weight (47 kg/m2 of the ventilated roof with wood fiber against the 63 Kg/mq of the ventilated roof with glass wool); the wood fiber reveals to be efficient most of all in summer thanks to a volume mass that permits a significant displacement of the thermal wave (the periodic thermal transmission goes from a value of 2,251 W/m2K of the current status to a value of 0,326 W/m2K) besides good acoustic properties; it is an hygroscopic material , useful feature in environments that are sensitive to humidity, and is ideal for contests where eco-sustainable material are needed.

From the diagram comparison between the curve evolution of the superficial exterior and interior temperature of the covering roof in the current status and in the project at the 17th of July (see following diagrams) is highlighted in fact that the daily displacement increases in the project hypothesis.

Across the whole year the intervention solution valuable as the most effective turns out to be the following:

HP3	window frames with wooden/aluminum window frames (in laminar pine with the internal surface varnished in dark brown color and the external in aluminum varnished in dark brown color), with Uf=1,372 W/m2K and double insulating glass 4 + 4be/16 gas argon/4+4 with Ug=1 W/m2K and g=26, total reduction of UV radiation (Uw=1,3 W/m2K as defined by the prospect c.3 of the norm UNI/TS 11300-1)
	Ventilated Insulated roof with wood fiber
	Remaking of the plaster of the external façade with plaster based on traditional lime

Test of the performance of the walls consequent to the plaster substitution (3rd step)

Once individuated the HP3 as the most efficient intervention hypothesis, it has been tested, as last analysis, the way in which the performance of the structure changes locating on the external facades, in the place of a traditional lime based plaster, an already mixed thermo-plaster fiber reinforced with cork (grain size 0-3 mm), lime, diatomic powders and hydraulic binding agent

From the analysis of the obtained data through the energetic simulations done in the winter and summer period, it has been evidenced a slight improvement in the performance of the external walls consequent to the thermo-plaster insulation.

In the winter period, in fact, the heat dispersions reduce themselves going from a value of -1664,39 kWh per year to a value of -1232,43 kWh per year; in the summer period, instead, the external walls increase their collaboration with the structure in expelling the heat from the interior going from a gain of -73,16 kWh per year to a value of -255,16 kWh per year.

It is proper to point out that, even if the solution with thermo-plaster produces in wintertime improvements in terms of heat dispersion through the walls of -431,96 kWh per year and in summer time improvements in terms of heat expulsion of 182,00 kWh per year, these values do not bring a significant improvement in the overall performance of the "Sala urbana", able to justify this project choice, especially if we consider the realization costs of a thermo-insulating plaster (the "optimal level referred to the costs" suggested by norm EPBD" is not achieved); besides this, given the traditional lime – made plaster higher compatibility with the historical walls compared to a cork-made thermo-plaster, the making of a traditional lime-made plaster for the exterior is considered to be more proper.

2.4 Transfer to urban scale concept

In Bologna, historic buildings, which have to comply with specific restrictions, differ one from the other either by their historic-architectural interest (art. 149 of the urban building regulation; these buildings are recognized as "cultural heritage" by the national law) or by their historic - modern architectural interest (early twentieth century till nowadays) as they are indicated in the urban plan (PSC) map (available in the Municipality's internet site).

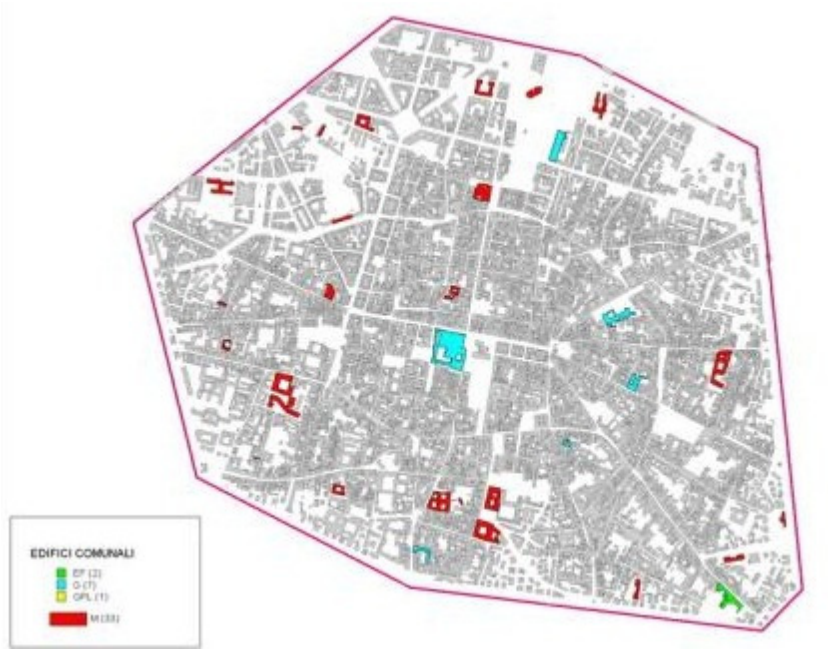
Deliverable D6.2 Documentation of each study case

The following figure shows Bologna's historic center with its 4 different administrative zones: Porto, San Vitale, Santo Stefano and Saragozza. The figure also shows the prevalent buildings' age for the different census areas of the city.

Legend

Color	Building age
	Low-density area
	Before 1920
	1920-1945
	1946-1961
	1962-1971
	1972-1981
	1982-1991
	1992-2001

Among historic buildings, those having a public use (including municipal ones) are indicated in the next figure (pink).



Among public buildings, municipal ones are shown in the next figure, different colors identifying the specific fuel used (*red=Methane, blue=diesel, green=fuel oil*).

The table below sums up some data regarding the historical center from an energetic point of view (all buildings, not just the ones owned by the Municipality).

	Number of buildings	**Volume** [m^3]
BUILDINGS IN GENERAL	10,480	28,446,272
SCHOOL BUILDINGS (public and municipal)	322	1,051,500

The gas (methane) consumption of these users sum up to 63,834,345 m^3 (52,692 toe), which equals to 13% of the total consumption of gas (methane) in Bologna. The specific consumption equals 305 kWh/m^2.

Research has shown that it is possible to obtain improvements in the energy performance in buildings of historical value, preserving and keeping to unaffected typical materials and featuring the monumental buildings

The town planning building regulation (RUE) foresees conservative standards on buildings whose historical and architectural interest is indisputable, while for buildings prior to 1949, which may have elements of historical - cultural and testimonial value, it requires, in the case of intervention, in-depth analyzes aimed at verifying the presence and the actual value of such elements.

Throughout the municipal area, the monumental buildings of architectural interest are approximately 1300 and the historical buildings are more than 10 times as much (about 13,600). We can therefore say that buildings of historical and architectural interest represent a total of about 36% of the total housing stock.

In addition, the municipal structural plan identifies areas of historic interest, replacing the traditional image of the city center (enclosed within the circle of walls) with the historic city, consisting of the oldest formation of the urban fabric of the (the ancient core of the medieval plant, the new city built at the end of 1800 inside and outside the fourteenth century walls, behind and beyond the railroad). While working on a building of historic interest it is at first necessary to thoroughly study the building, in order to have all the historical information and all the data required to assess both the overall merit and the single elements. With respect to the particular strengths and overall findings of the study in order to improve the energy performance of the documental- historical building, the architects might foresee:

- ventilation and cover insulation systems extended to the entire coverage within a maximum fixed thickness, so as to avoid obvious distortions of the historical building elements;
- solar and photovoltaic panels installed on the secondary slopes (only for documental buildings) (ie those that are not facing the public street) of the less prestigious shells (ie that do not have still intact decorative elements or historic structures);
- thickening of the external walls in areas lacking evidence of artistic and architectural elements (face-to- view wall hangings, frames, string courses, paintings, tombstones, in general, any other form of decoration);
- the replacement of external fixtures, maintaining the same scores and colors of the original ones, with the possibility of changing the materials only when all the windows of the building are replaced.

2.5 Information for on-site retrofit works

Description of nearby areas for organizing the on-site retrofit works	In the Buildings are present areas for organizing the on-site retrofit works.
How is the building/building part used during the retrofit works?	The building is still being used as the renovation and refurbishment works concern only a portion of it, corresponding to the "Sala Urbana". Therefore every part and zone of the building can be accessed except for this room which is closed to public and currently scuffled for the refurbishment works.

2.6 Intervention Hypothesis

The interventions and the retrofit actions that have been evaluated and carried on by the Municipality of Bologna, owner of the building, were the following:

- *Roof refurbishment*: the substitution of the existing roof and the adoption of a ventilated roof. Insulating of the roof is realized with packet in wood fiber with an insulating packet 9,9 cm thick, made of a double layer of insulating panels in wood fiber "Pavatherm" (4+4 cm) and a layer of wood fiber "Natur isolant" (1,9 cm).
- *Punctual seismic improvement*: Through consolidation perimeter through integration of new brick because in many places there are ancient chimneys that weakened the structure and reinforcement with metal edgebanding. We consolidated a wooden truss with insertion of metal bars and epoxy resins.
- *Window substitution*: application of wooden/aluminium window frames, associated to double insulating glass type based on stratification glass with argon inside (4 + 4be/16argon/4 + 4 (Ug=1W/m2K and g=26). The glass selected is selective (in the winter periods retain the heat and in the summer periods reflect it) in such a way as to avoid the UV rays which produce the bleaching effect of the frescoes, thus limiting the solar gain and bright.
- *Automation and control of the Urban Room*: with domotic system that control automatically the windows and the curtains opening and adjusting light intensity in relation to the uses. The domotic system is realized with Konnex standard.
- *Plaster remake*: substitution of the present external plaster layer with a traditional lime-based plaster.
- *Frescoed ceiling renovation*: insertion of an insulation layer at the extrados of the frescoed ceiling using adjusting light intensity in relation to the uses. Pre consolidation of the paint surface with Japanese paper and subsequent cleaning.
- *Artificial lighting* : refurbishment of the artificial lighting with a LED Wall washer system for improved efficiency.

3 Implementation

The works for the maintenance of Sala Urbana began in April 2013. Sala Urbana is the highest part of the whole palace building complex; it is made of a small tower surrounded by other buildings. In order to be able to work in safe conditions, it was necessary to build a scaffold along the main facade (facing Piazza Maggiore) and to create a connecting walkway to get to Sala Urbana. In order to be able to support the metal structure of the scaffolding along the perimeter walls, it was chosen to lay it down using the surrounding roofs as anchorage points, placing props on them at the backing points in the wooden structure, at the intrados.

The scaffolding was provided with a roof covering the entire room extension, in order to make it possible to remove the existing roof avoiding the decorated ceiling underneath to be damaged in case of rain.

In addition to the external one an internal scaffold was assembled inside the room, in order to sustain the entire decorated ceiling and avoid the fall of the painting layer, after a pre- consolidation of this.

The interventions targeting safety have had an economic impact corresponding to almost one third of the sum total of the works.

The works were mainly of two types:

- static consolidations of the walls and of the wood structure in order to comply with the anti-seismic norms and standards ;
- new roof package and installation of new window frames for energy efficiency improvement.

In this phase the metal structure that holds the metal bars, to which the room's lighting system are connected, was also assembled, by hanging it at the roof structure. These interventions lasted 6 months.

After this phase we proceeded to launch the tender targeting the the companies specialized in fresco renovation. The renovation works are now in progress. The provision of lighting bodies has been already completed and technicians are assembling the new lighting system.

The official opening of Sala Urbana to the public is expected for June 2014.

3.1 Roof substitution

The roof had to be completely replaced and it was considered to be enough to realize a ventilated roof, because normally the insulation is introduced in the last opaque element facing the outside. In this case it was necessary to use a transpiring insulating material suitable for summer periods, having a low thermal diffusivity (thermal conductivity / density x specific heat, such as insulating materials based on wood fiber). With this arrangement was obtained, therefore, a low thermal transmittance periodic Yie, value that indicates the transmittance during the day, which should be no> 0.20 W/m2K.

The best insulating materials with these characteristics were individuated in those in wood fiber, with the maximum thermal conductivity being around 0.043 to λ [W / (mK)]. For the isolation of the floor, the minimum thickness of the insulation was established in 8 cm, assisted by the panel of wood fiber, cloth transpiring waterproof, air chamber allowing ventilation, and a wooden partition as a finish. In this case the overall thickness of the insulating pack corresponds to 9,9 cm. The thickness of the analyzed insulations was determined trying to respond to two necessities: to obtain low thermal transmittances and to respect the constraint of heighten the roof top of 20 cm maximum (RUE of the Bologna Municipality, art. N. 57 IS 1.1).

With the laying of only three centimetres of plaster the thermal transmittance value is halved, passing from being 1,633 W/m2K in the current status to 0,788 W/m2K in the state of project.

During the intervention we carried out the consolidation of perimeter walls through integration of new brick because in many places there were ancient chimneys that weakened the structure. We chose to do a curb metal around the walls with anti-seismic function. We consolidated a wooden truss with insertion of metal bars and epoxy resins.

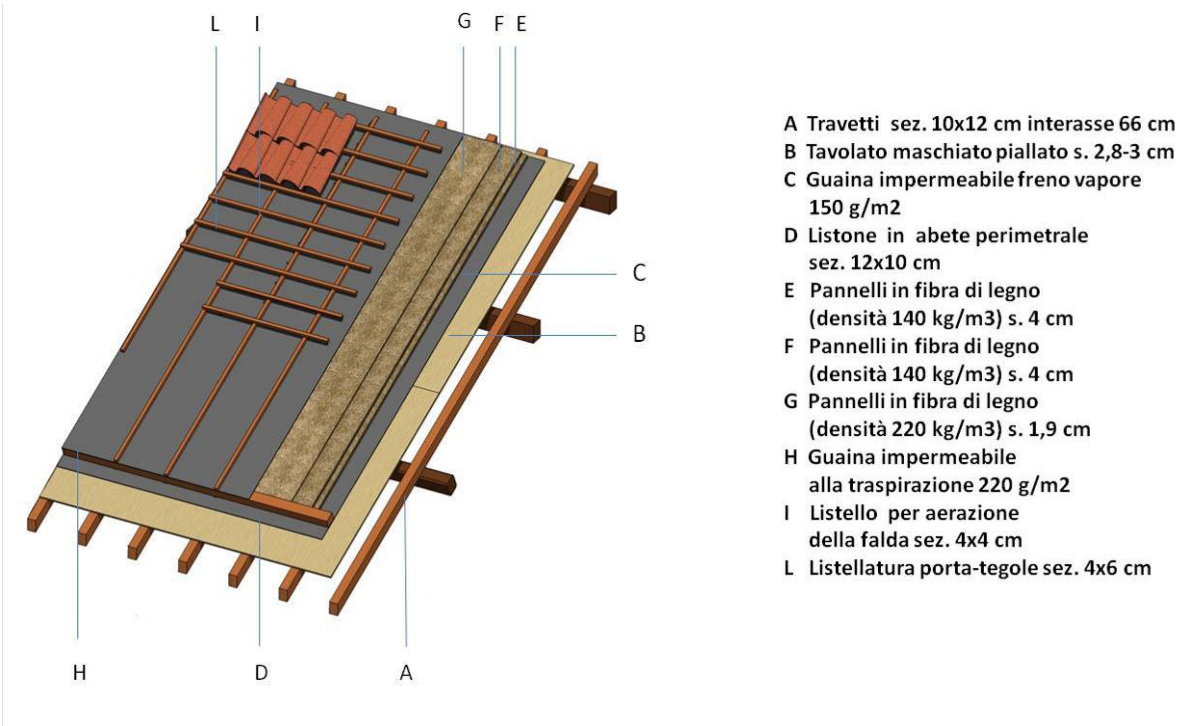


Figure 34: Assonometry of the realized roof constructive solution, Source: [Viscardi, M.; Dei Svaldi, S. 2012], ICIE

Figure 35-36: Deterioration of the wooden structure of the roof

Figure 37-38: ancient chimneys and intervention of consolidation of the masonry

Fig. 39-40: wooden truss gear and consolidation with steel bars and resins

Fig. 41-42: metal curb for the consolidation of perimeter walls

Fig. 43-44: replacement of the wooden beams and installation of insulation on the roof

Fig. 45-46: Test for the renovation of frescoes

3.2 Windows substitution

In case of replacement of windows in Zone E, the limit established by law is 2.2 W/m2K.

This value provides a better performance of glazed openings, without exceeding its performance that should be at the expense of comfort especially as regards the contribution of the windows facing south which would produce excessive heat in summer creating a greenhouse effect, even for windows oriented to the west and east, is suspected to be observed the same criterion. As for windows oriented to the north you can use a window with improved performance. It's necessary to use selective glass to reflect and protect the frescoes from the sun, but at the same time retaining heat in the winter period.

For windows facing south which have a double frame, we have replaced them with a windows single frame that maintains the same design. It can be positioned flush with external does not change the design on the façade (keep in mind that at present lacks counter the window) with the application of a drip for rain swing. Given the limits imposed by the design of the window (which does not allow the use of significant thickness of the profiles) and the possible limitations that may be encountered in fixation to the wall (but heavy-performance windows can be anchored to masonry / plaster deteriorated), it is suggested to obtain the same performance limits of the frame by pushing further the performance of the glass instead of the profiles, but with particular attention to the seals and the thermal break.

Fig. 47-48: View of the external and internal old windows

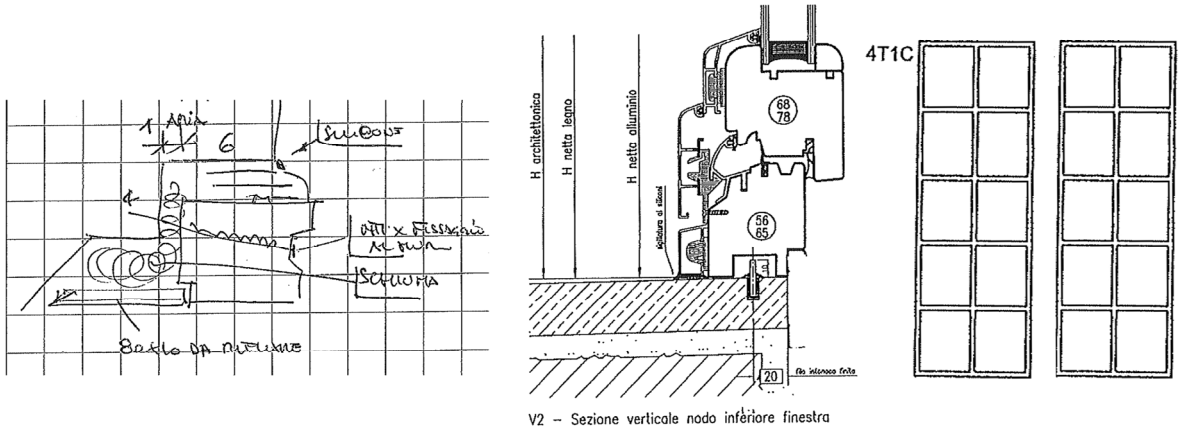
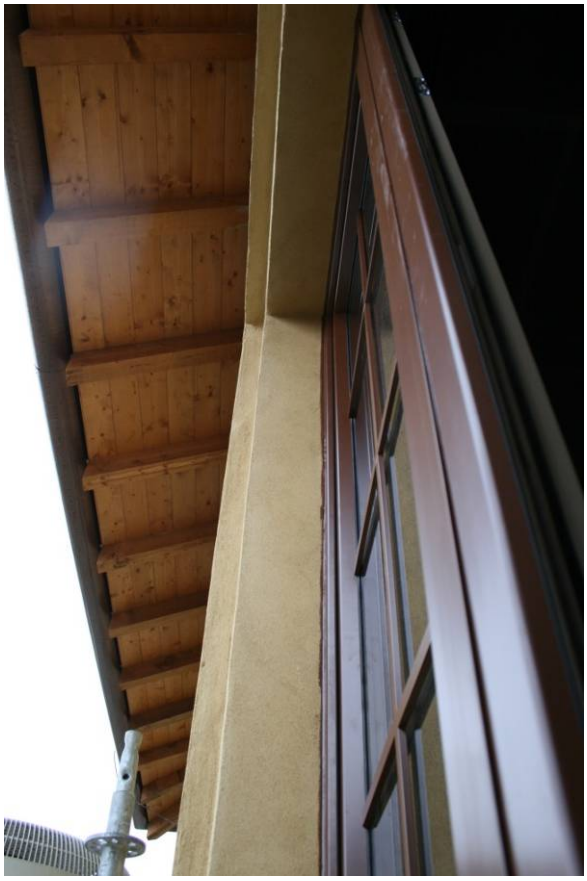


Fig. 49. Scheme and section detail of the new window frames



For windows facing east and west: we have replaced the windows while keeping the existing design, leading to a total transmittance of the window equal to Uw = 2.2 W/m2K (with reduced thickness of the frame, which could be around to 70 mm). To get this performance should be the window with double glazing and cavity (16 mm) the introduction of gas (type: Argon), to increase performance.

The glass selected are selective (in the winter periods and retain the heat in the summer periods reflect it) in such a way as to avoid the UV rays which produce the bleaching effect of the frescoes, thus limiting the solar gain and bright.

For windows oriented to the north: it is recommended to replace the frames, which while maintaining the current design will lead to overall transmission of the frame of Uw = 1.9 W/m2K. The glass also in this case will have to be selective.

Given the nature of the historic building, the type of window should be wood , but to address the maintenance issue, we have chosen a window with a wood frame coloured in grey and outside with an aluminium coating with thermal break, treated with brown colour.

The windows, with double opener have been provided with automatic openings activated on the basis of the ratio between the internal and the external temperature value; the opening at night favour the activation of a chimney effect which is able to guarantee a natural cooling of the Room and at a certain degree also of the adjacent spaces in summer months.

Figure 50: External window before and after the interventions, Source: [Faustini, F. M. 2012-2014], © Municipality of Bologna.

3.3 Motorizing, automation and control

The project of substitution of the present window frames, their inaccessibility caused by their height from ground level and the information collected during the monitoring of the indoor microclimate

conditions in particular in summertime have contributed to the decision of installing in the “Urban” room a microclimate general control system able to activate the automatic opening of the transom windows with the aim of generating a natural ventilation following specifically conceived performance scenarios. Therefore the installation of a domotic equipment was planned (Bus) with Konnex technology in order to coordinate all the automatic devices in the field.

The target is to achieve a flexible and expandable tool that can lead to support the development of a new strategy of preservation of the cultural heritage, still in progress, able to exploit all the technological opportunities that will emerge during the project.

Solutions that contemplate the automatic opening of windows in summer time have been simulated and tested in the project for cases in which the interior temperature doesn’t exceed of 3 grades the exterior (natural cooling).

The performance of the windows shutters automatic opening scenarios will therefore be directly conditioned by the values of the environmental parameters like temperature and humidity, both internally and externally to the room, by the air speed survey and by an external meteorological station in order to have all the necessary data in order to evaluate the differences among internal and external air temperatures, in particular in order to highlight the rain and wind speed conditions that determine the shutters non-opening or closure.

The planned system will therefore be able to:

1. determine the condition of the window, intended as open or close window;
2. permit the regulation of the opening grade of the window, calculating the opening percentage of the window shutter;
3. permit the manual unlock of the windows preventing the automatic functioning;
4. be provided with a proper number of temperature and humidity probes, for different heights, in order to measure the internal climate conditions of the room;
5. be programmed with specific scenarios activation boundary-levels at the specified temperature and pressure conditions.
6. be provided with a meteorological station located outside the room;

It is necessary to plan a simultaneous automatic movement of the curtains positioned on the windows to be moved in order not to let them be an obstacle to the opening and closing operations of the window shutters. We specify that the curtains type will have to be kept with horizontal opening.

The proposal of installing in this room a system provided with these characters is derived from the necessity of keeping a microclimate for the preservation of the walls paintings layers that would have for sure been altered in the hypothesis of substituting the existing shutters and window frames, with highly efficient ones for what is concerned with energy consume, without being able on the other side to intervene with natural air turnover and with mechanical controlled ventilation that would have been much more impacting considering the presence on every wall of frescoes and decorations.

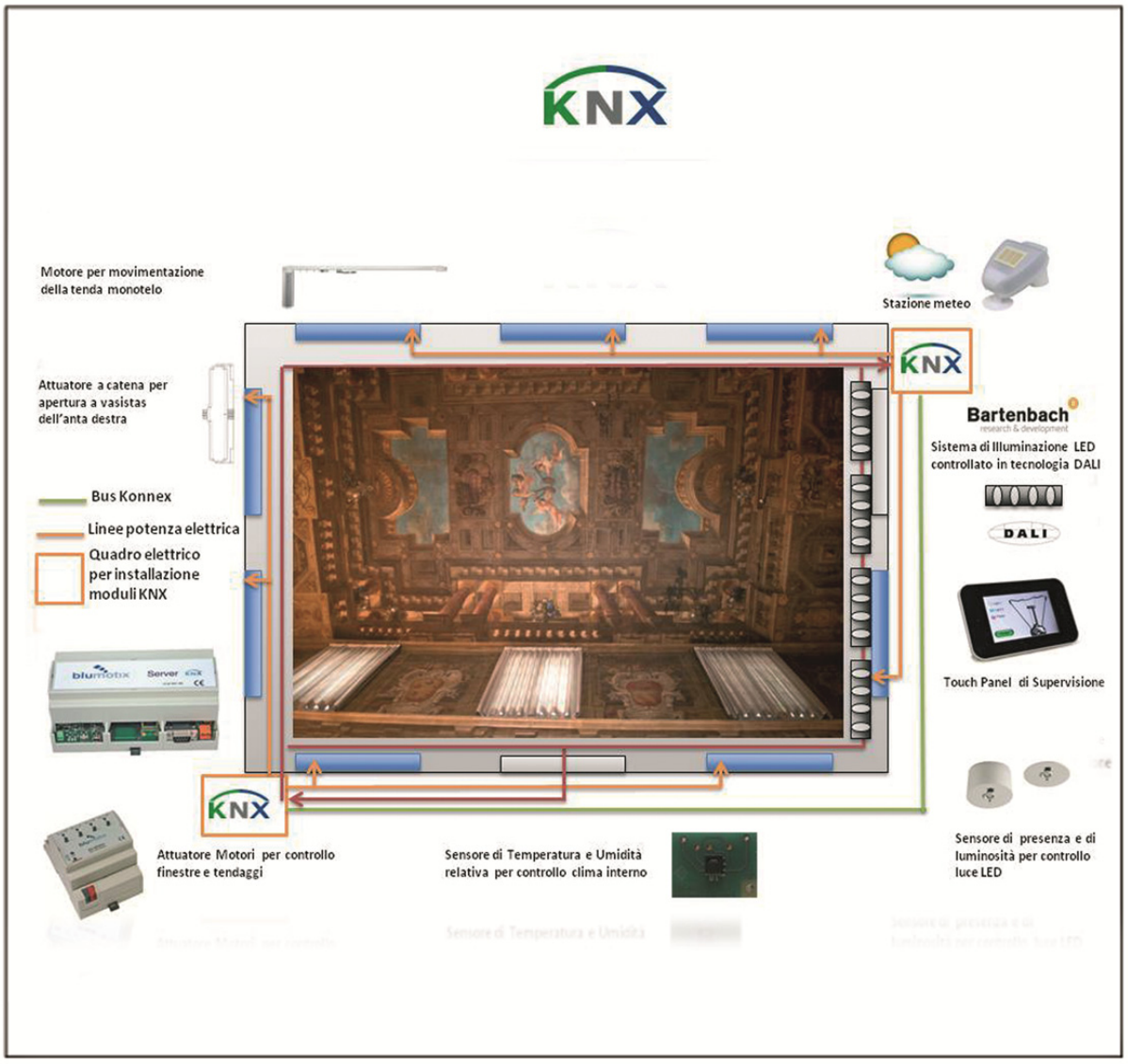


Figure 51: Domotic system installed in the Sala Urbana

3.4 Experimental artificial lighting system

The main goal of the efficient lighting installation in Palazzo D' Accursio is to provide visual comfort to the viewer of the frescoes and retarded deterioration of materials. "Sala Urbana" in Palazzo D' Accursio represents a very common room category in listed buildings: Its dimensions are enormous, the exhibition is the room itself i.e. the frescoes on the walls. The existing installation consisting of alone standing luminairies was absolutely not glare-free, resulting luminance distribution were far beyond the well-established and recommended ratios and absolute levels. For intervention a frame in 8.5m height was considered to hide the – linear - ceiling luminaries. Conservational authorities together with 3encult developed the idea of using this cornice also for hiding anchors, which would hold cables and attached luminaires. During pre-diagnosis this first idea was replaced by hanging a double-T-bar structure from two available anchors in the wooden roof structure. These two points came out during refurbishing of ceiling frescoes. The bar will bear the 3encult wall-washer (www.projektleuchten.de). The slight difference between both ideas appears in marginally poorer illumination homogeneity for the second approach. This reversible installation balances the trade-off between perfect illumination and conservation considerations (reversibility) and offers visual comfort, i.e. glare-free and well balanced lighting levels on the walls and ceiling. The luminaire itself will be nearly invisible, because of its small dimensions and its specific light intensity distribution.

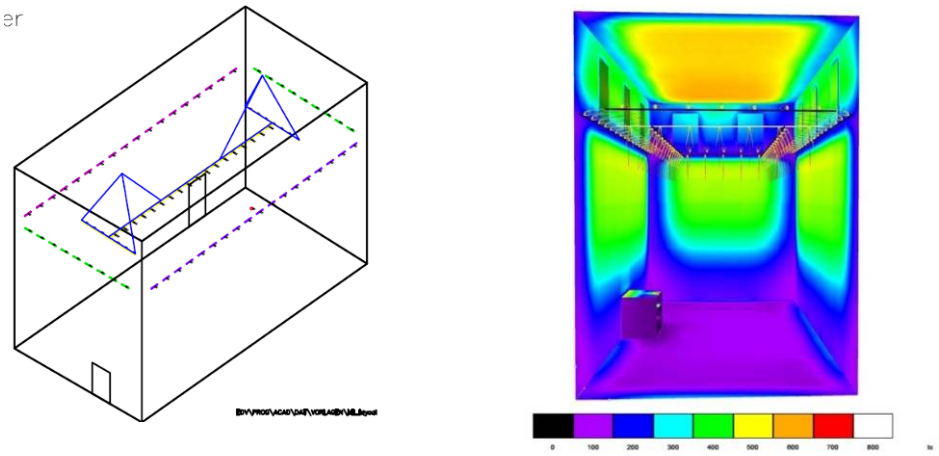


Figure 52: Artificial lighting simulations, Source: [Weitlaner, R. 2013], © Bartenbach GmbH

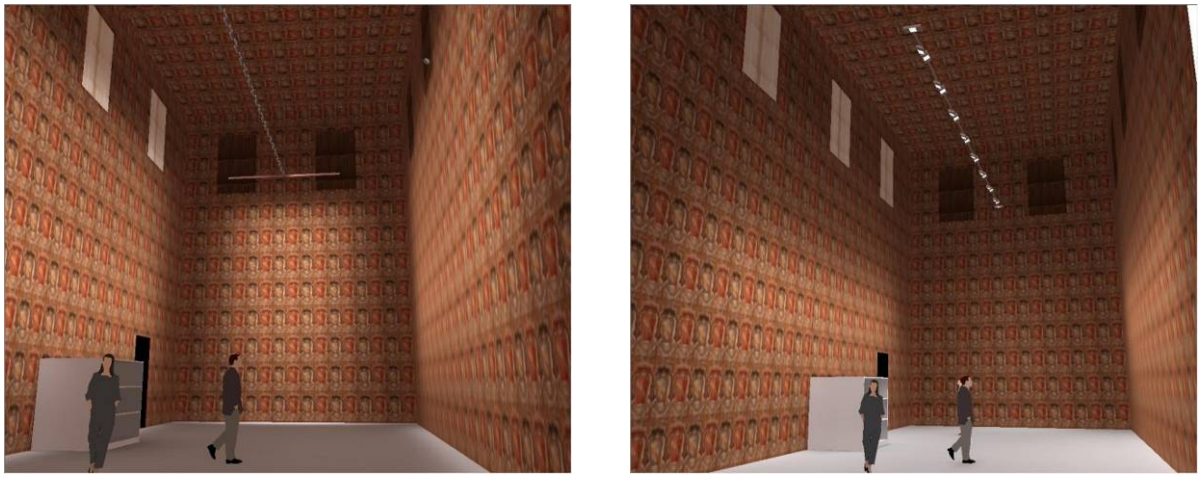
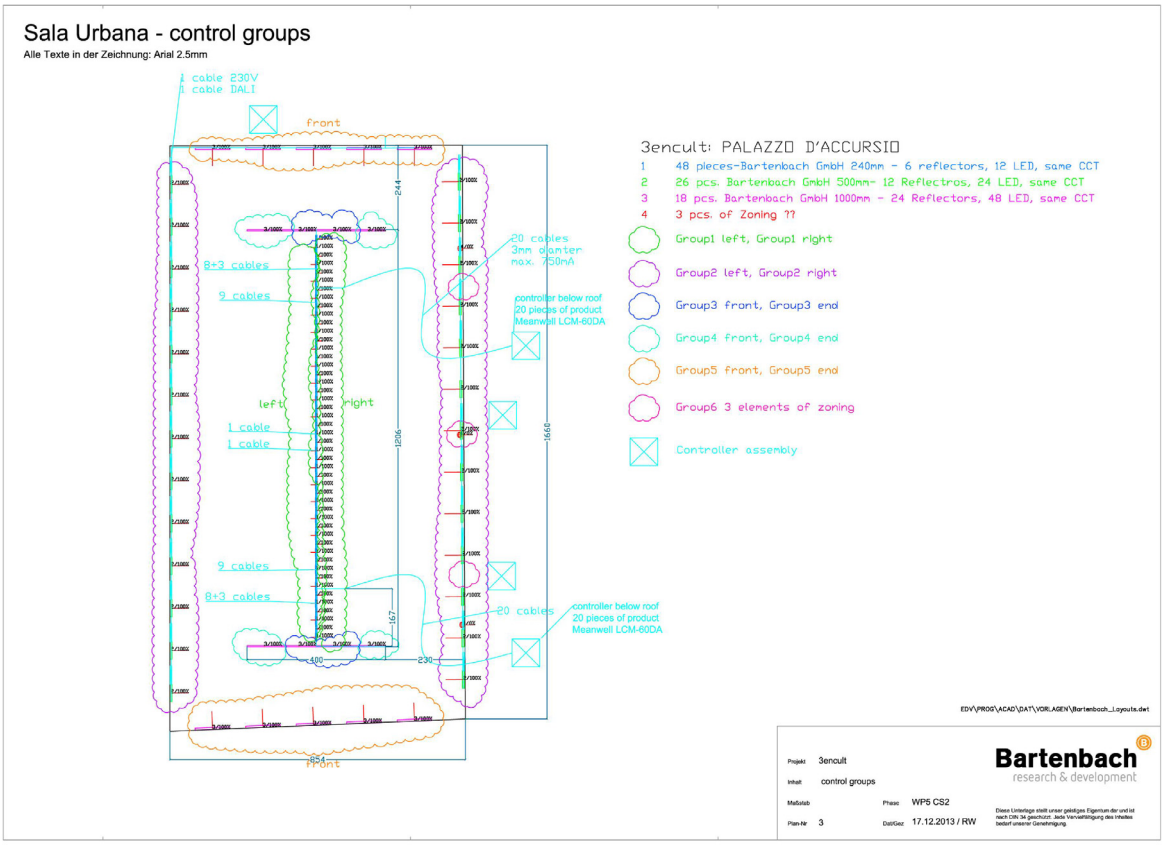


Figure 51:© Bartenbach GmbH 3encult wallwasher installation (no glare, invisible) in comparison to an arbitrary square museum luminaire, which is causing glare.



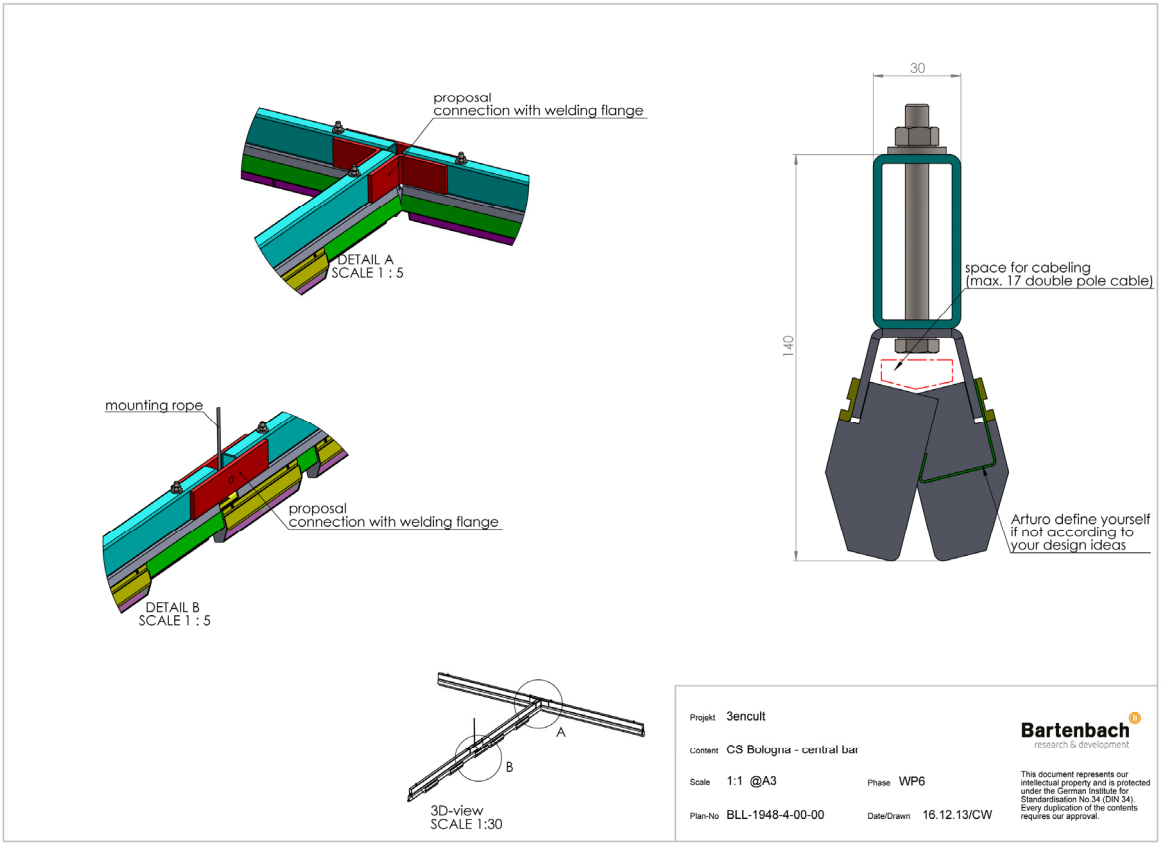


Fig. 53-54: Control groups disposition and details of the lighting supporting structure

Figure 55: 3Encult wallwasher in rectangular housing.

Figure 56: anchoring structure for hanging the bar for central lighting

Figure 57 : test of lighting

4 Post evaluation

4.1 Evaluation of the energy consumption

4.1.1 Measured energy consumption

Several measuring surveys were conducted before the renovation intervention. .Reported data were measured with reference to the electricity, gas and Gecam consumes for the whole “D’Accursio” Palace.

For what is concerned with the electric consumes, the lack of specific data referred to the individual studied areas, has requested the elaboration of a questionnaire targeted to collect information about the fruition of the spaces object of interest, the level of comfort encountered and felt by the occupants, an abacus of the present electric devices and the consequent mode of use of these. After an inspection and on the basis of the collected data, a list of the devices used in those areas has been built, with the related consume associated to each device (in some cases only estimated, while in others duly registered) and with the working hours declared by the same users; thus for every device the annual consume has been calculated.

The sum of the calculated consumes, therefore, conduced us to the assessment of the annual consume of electric energy for the considered areas. Here it is necessary to point out that the answers quality to the questionnaire resulted to be incomplete and allowed only an assessment of the effective electric consume, because of the Municipal Council break up with the consequent transfers of many workspaces that have taken place in the last years and are still on-going. It is believed to be proper in the next future months to proceed with a new questionnaire expecting more complete and reliable answers.

The audit campaign had as its object of study the areas occupied by the offices and rooms used as a museum housing the municipal collections. The diagnosis was performed through a detailed analysis of the electrical apparatuses and methods of use, recorded during two survey, made at the beginning and the end of the project. During the first survey, conducted in November 2011, has emerged as a total consumption of **164.635 kWh/year**, distributed as follows:

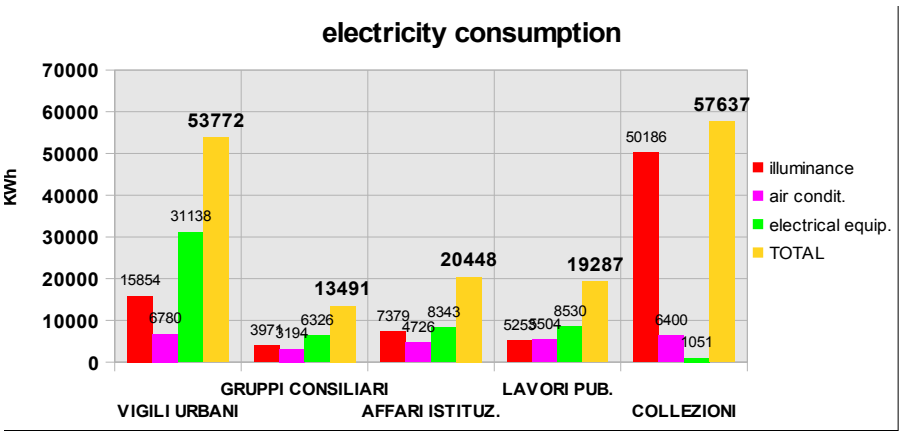


Figure 58: Electricity Consumption graph - November 2011, Source: [Tutino, F. 2013], © Municipality of Bologna

The second observation, made in November 2013, made it possible to estimate a total consumption of **159.027 kWh/year**, broken down according to the following uses:

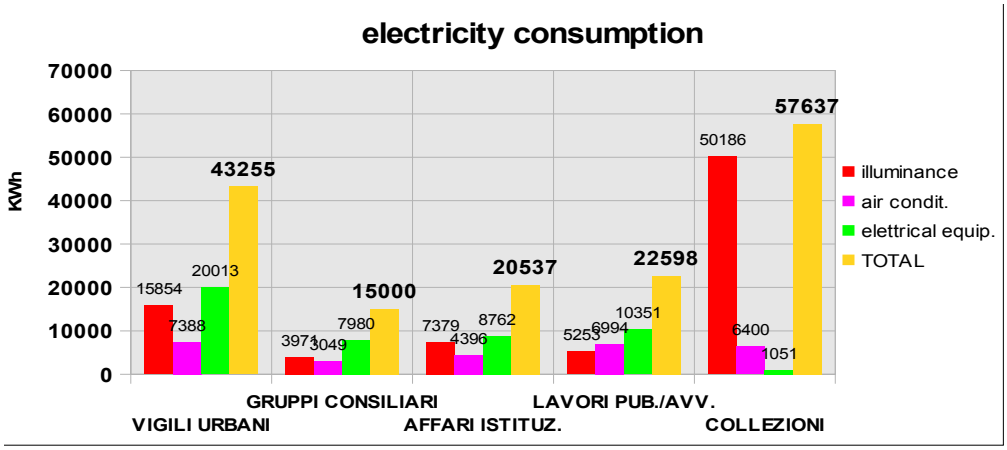


Figure 58: Electricity Consumption graph – November 2013, Source: [Tutino, F. 2013], © Municipality of Bologna

The consumption electrical due to the equipment, which rose from 55 387 kWh/year to 48 157 kWh/year , with a decline of 16 % is mainly attributable to the reduction of the stations found in offices, increased from 84 to 80 units. Consumption for air conditioning instead saw an increase of 6 %, from an initial guess of 26,604 kWh/ year to 28,227 kWh/year, in this case due to the higher number of detected devices in the second relief, while the illumination is observed a significant changes towards fluorescent lamps.

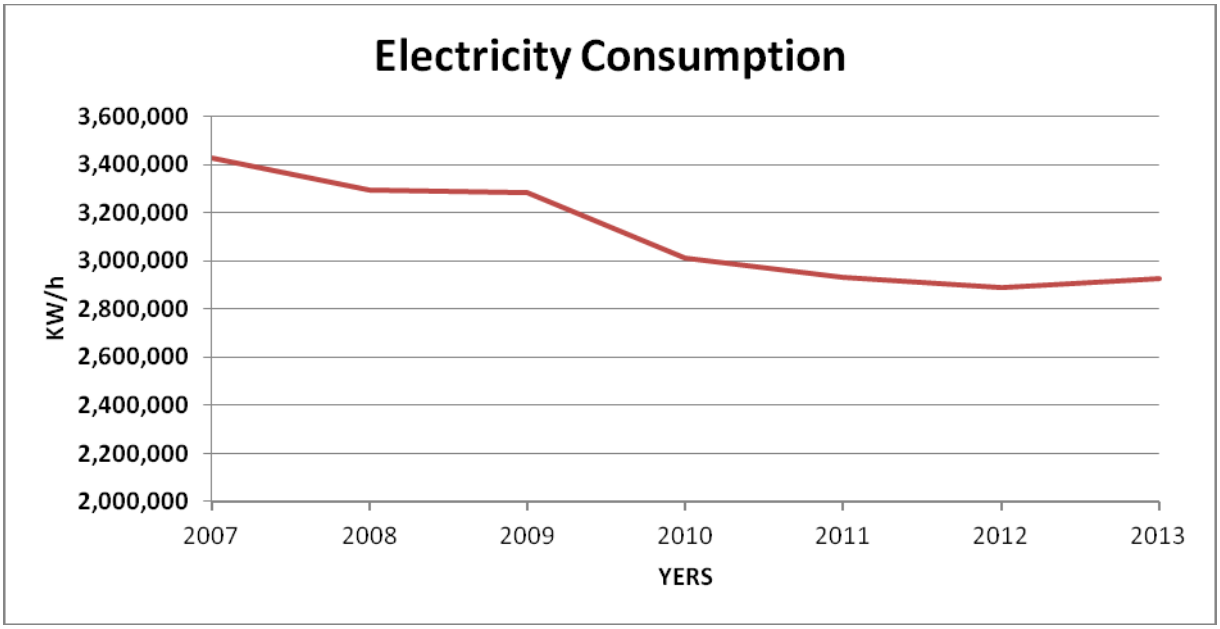


Figure 59: Electricity Consumption graph, Source: [Tutino, F. 2013], © Municipality of Bologna

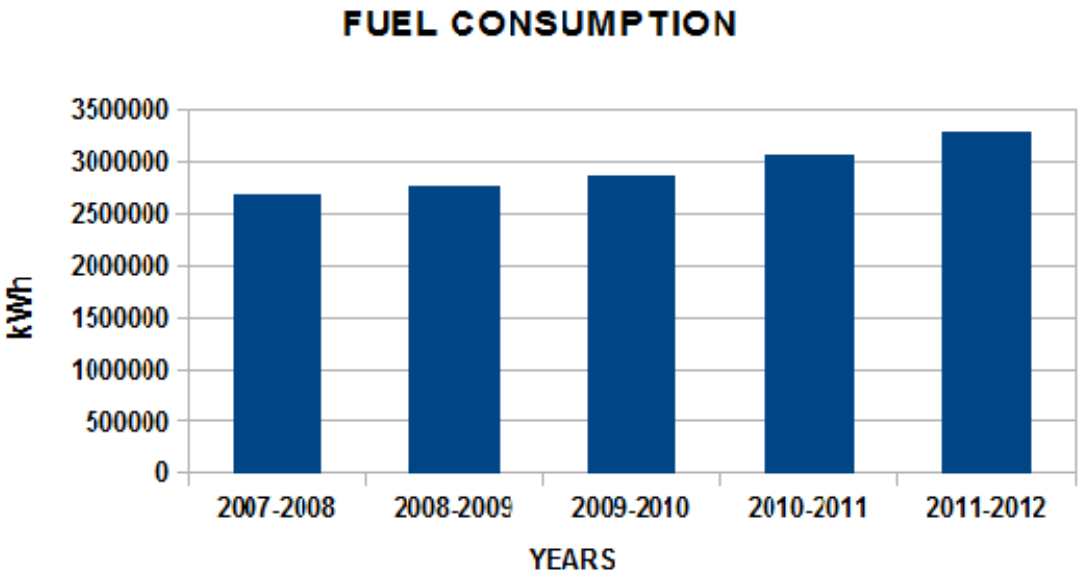


Figure 60: Fuel Consumption graph, Source: [Tutino, F. 2013], © Municipality of Bologna

Despite the positive result of savings recorded during the years of monitoring, the consumption values obtained are still very high (106 kWh/m2), considering that not all the rooms in the building are occupied on a regular basis.

The higher consumption compared to the average for public building estimated in the last Municipal Energy Plan developed in 2007 for public buildings, could be partly justified by the presence of a large number of heat pumps probably used in winter and some utilities for public lighting affected the overall load.

The average “business as usual” electricity consumption would be not more than 30 kWh/m2 year for public building, and should be reduced at least to 20 kWh/m2.

The possibility to achieve savings also much higher than mentioned before is evidenced by the refurbishment of the special lighting system made possible with the design of Bartenbach GmbH, partner of 3encult project. The transition from the pre-existing system of lights using halogen lamp to a system of wall wash LED lighting system has reduced power engaged of over 30%. Considering too the control system of the light flux with presence sensors, **the saving is expected up to 53%** . Moreover the quality of illumination will improve and the ratio lumen/watt will shift from 11 to 80 with the new innovative wall wash adopted in the refurbished Urban Room.

4.1.2 PHPP Calculated energy consumption

First interesting observation comes form the consumption data, Table (section 4.1.1), where the variability over 4 year is ±10% respect to the average which has value generally much lower that expected, and the years which have lower number of Degree Day (GG) have higher consumption.

Possible deductions considering just this data are: other sources of energy have been used for heat the building, like heat pumps, which are present in part of the building; or the strategy of control adopted.

The calculation of PHPP is presented in section 1.4. of this document. The most interesting result of this first comparison is that there is a considerable difference between heating consumption and estimated heating demand: 110kWh/m^{2}a (+78%). In this case the difference between them is unacceptable For the improvement of the heating demand estimation, the thermal set points of the plants are analysed using monitored temperature data and it results that temperature set point of 20 is correct. To obtain similar data of consumption the set points should be 15 but it is clear inconsistent.

All the result of PHPP, should be consider not as a good estimation of the absolute value of the energy balance but with the aim of compare pre and post retrofit result. One of the aim of 3encult is the verification of the capability of tools to simulate historical building. In this case the discrepancy of

heating demand with consumption data is very high. Uncertainties are present also in the real consumption data, but the level of discrepancy does not justify all of that. Modeling a complex building like that is not easy task and the development of procedures are necessary. An approach of modeling and analyse historic building is developed starting from the problems adressed in this project and it is presented in (Giuliani, 2014).

4.1.3 Calculated energy consumption by Design Builder (Energy plus)

An energetic model of the Municipal Collections Area was elaborated using Design Builder (an informatics software for the analysis in dynamic conditions developed with the Energy plus engine). Modelling and analysis were performed in 7 steps, from digital rebuilding of the examined area, to the simulation of the thermal and physical characters of the building components, ending with the definition in the model of the kind of HVAC and the type of regulators. Using DB the solar gains, the internal gains, the energy losses through the building envelope and for ventilation, both in winter and summer time, were calculated, estimating the energy need for heating in winter time and the one for cooling and lighting referred to summer time.

The basic steps we referred to for the elaboration of the energetic model and for the project analysis are the following:

- building's geometry and openings modeling;
- creation of thermal zone;
- insertion in the model of shadows generating elements;
- geographical location of the building and local climate and weather data loading (in the Tab "Location");
- assigning to the building's surfaces and external enclosure its physical characters (given in the Tabs "Construction" and "Glazing")
- adding the thermal charges and correspondent schedules (in Tab "Activity");
- definition of the installations characters (in Tab HVAC).

1st step

As the aim of this study is to evaluate the energetic performance of the wing of D'Accursio Palace hosting the Municipality Collections, we proceeded to re-build the examined area extracting from the rest of the model the Museum spaces to be analyzed, considering the walls facing other Museum spaces with the same temperature, oriented towards the heated spaces adjacent to the simulated building, as if they were adiabatic.

2nd step

Four thermal zones were defined (same for the Blower Door Test) with the same use profiles, with the same identifying names of the rooms:

- Room 19-20
- Room 2-3-18
- Room 4-5-6
- Room of the Sala Urbana

The last one is actually closed to the public because of roof infiltrations.

3rd step

The non thermal blocks were added, in order to provide shadows to the analyzed volumes, in order to evaluate correctly the effects of shadows brought by other buildings. Then other intermediate areas like attics were inserted, as a separation between the indoor thermal zones and the outdoor environment with a much lower temperature.

4rth Step

Then we proceeded to reproduce the external context of the building, loading the weather data that corresponds to Bologna and setting the alignment on North, essential for the solar analysis of the model (latitude, longitude, height).

5° Step

The following step was defining in detail the thermal and physical characters of the several building components (walls, ceilings, pavements, shutters) using the information given by the present study; in particular for the solid components, the necessary materials have been virtually rebuilt, defining the relative physical properties such as conductivity [w/mK], specific heat [J/kgK] and density [kg/m3].

6th Step

At this step we developed the description of the activities, the spaces use profiles and the defining of the internal electrical and thermal pressures and charges.

7th Step

In the end after modeling the building, we defined the kind of HVAC and the type of regulators. We took the information from the point 3.1.3 “Analysis of technical systems” of the present document.

Using the Design builder Software we calculated the solar gains, the internal gains, the energy losses through the building external enclosure body and for ventilation, both in winter and summer time.

The analysis of energy need for heating has been developed for winter time and the energy need for cooling and lighting has been done referring to summer time.

As part of the Results of the dynamic simulation for winter season the Winter-time Heat balance for the Municipal collections Area is reported below:

Winter-time Heat balance for the Municipal collections Area	
Losses	[kWh]
Windows	- 5.748,28
Walls	- 27.653,25
Roofs	- 48.785,75
External infiltrations	- 318.526,57
Free Gains	
Lighting	24.395,19
Heating/cooling equipment (fan)	0,00
Heating/cooling equipment (electric heating)	6.039,80
Electric equipment (cameras)	570,72
Occupation	60.260,0
Solar gains through the windows	3.671,19
Net Energy need for heating	305.776,92
Primary Energy need for heating	**391.351,52**

The total consumption of primary Energy for heating, resulting from the analysis done with this software has been estimated in 391.351,52 kWh, corresponding to 417 kWh/mq.

4.1.4 Briefly Summarizing word

As resulting from the post-intervention monitoring and evaluating session we have surveyed that after the installation of the new windows and the construction of the new roof, daily oscillations turned out to be reduced and internal microclimate is less prone to follow the trend of the external one, thus obtaining a more stable environment.

4.2 Evaluation of the construction´s situation

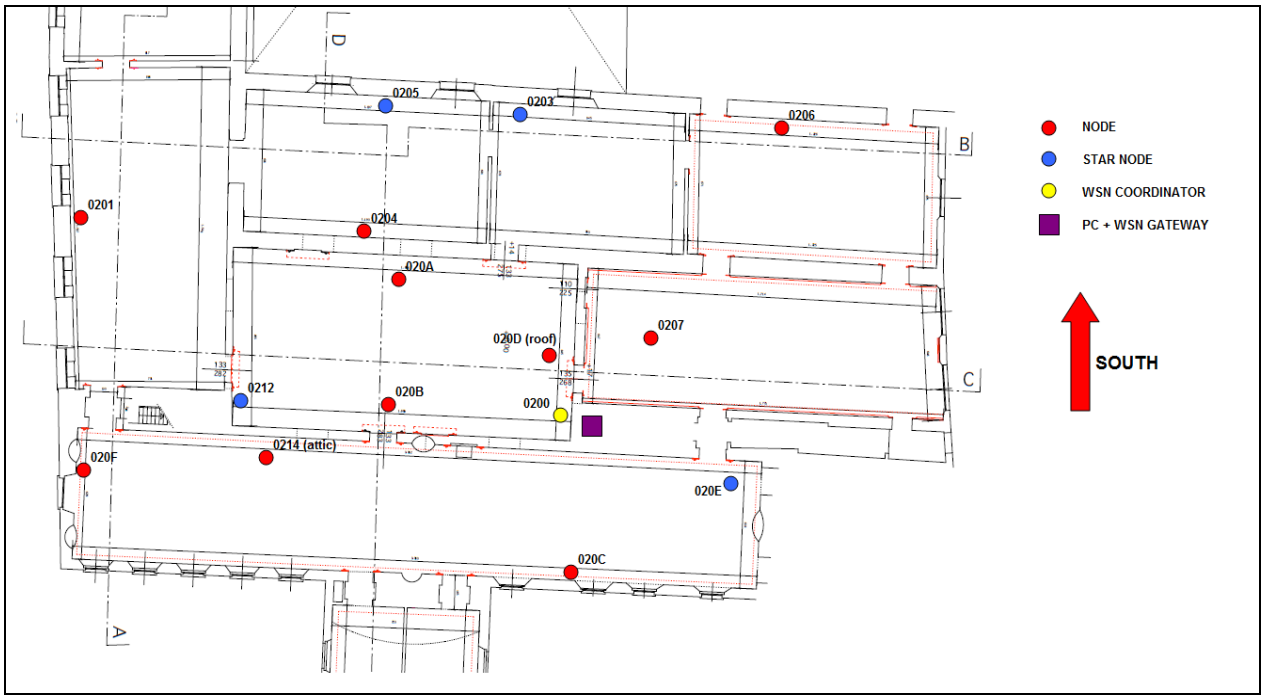
4.2.1 Evaluation of monitoring data into the construction

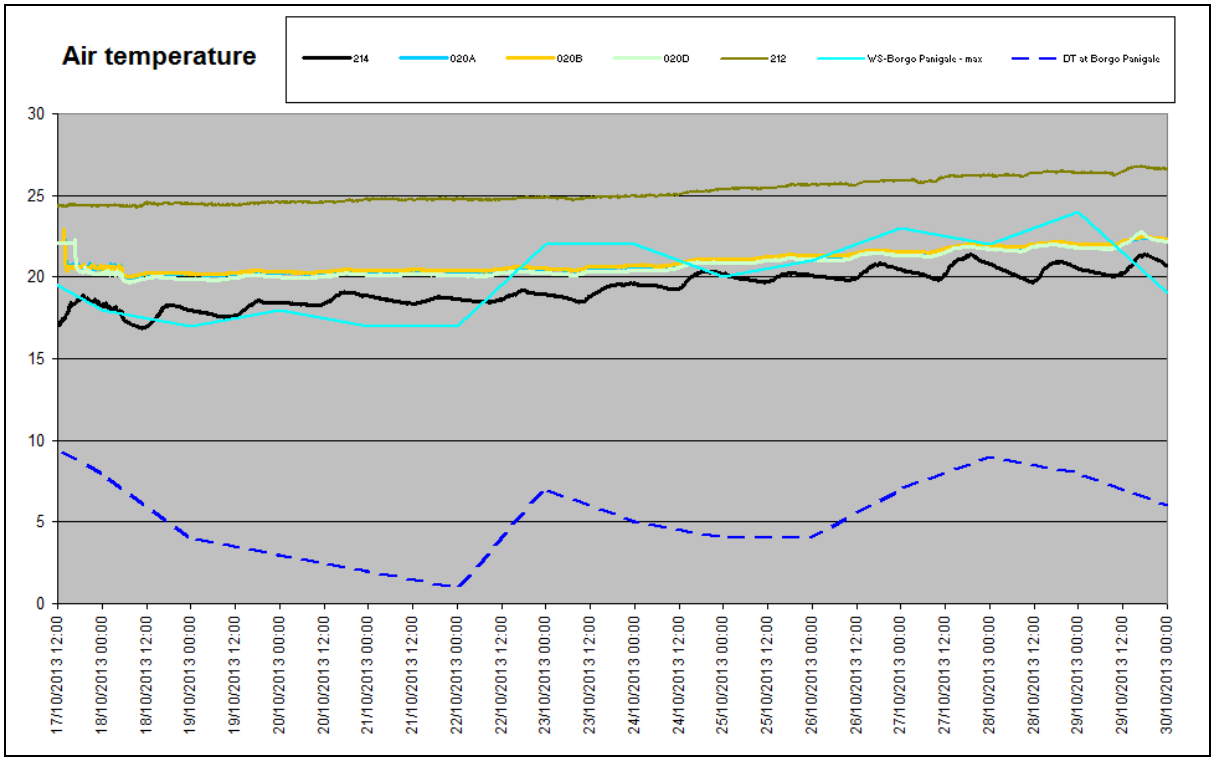
Sala Urbana has been monitored during the periods 17/10/2013-21/11/2013 and 21-30/12/2013 and results are compared with those acquired in the periods 28/10/2011-08/11/2011 an 21-30/12/2011 to verify the effects of the renovation works (described in other reports), especially of the installation of the new high performance windows.

In the following pages we will show graphs of air temperature and relative humidity (RH), including also data from the local weather station or from the national weather service (Weather Station - WS in Borgo Panigale).

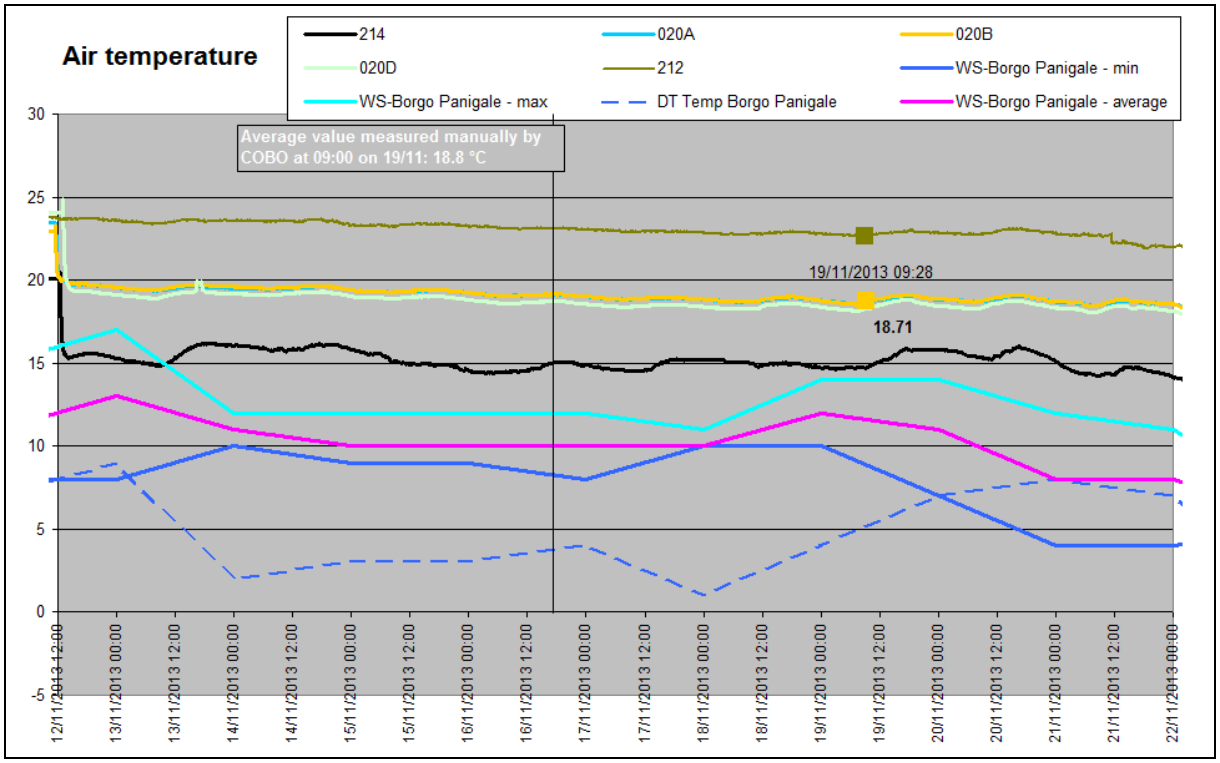
Monitoring in the period 17/10/2013-21/11/2013.

Map of nodes (node 0214 is in the attic and node 020D is tied to the scaffoldings at about 9 m from the floor).



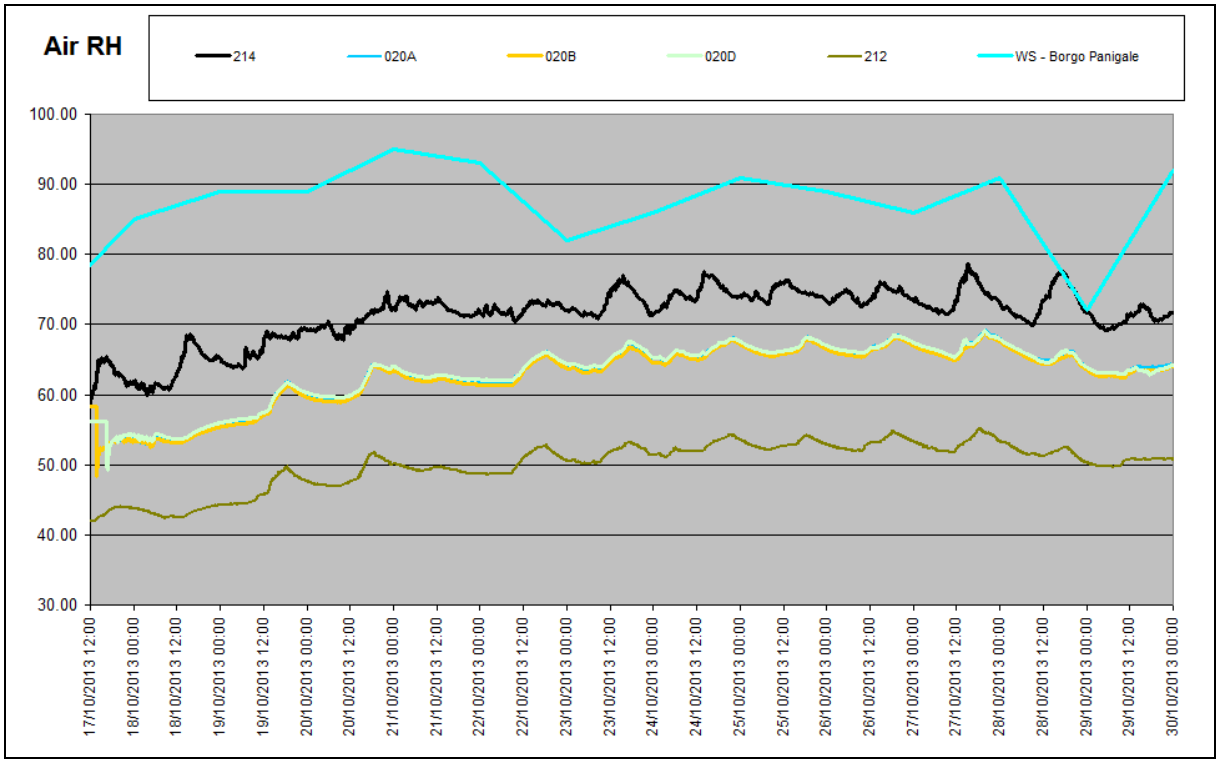


During the days preceding the new windows installation, se graph above, we notice a daily variation of temperature inside the Sala Urbana of about 0.2 °C, comparable to nodes accuracy. The variation in the attic is around 1 °C, in the outside about 7 °C (dotted blue line) and the difference between external and internal temperature varies around 2 °C. Probably node 0212 indicates an average higher temperature because it is positioned in proximity of lamps used for the restoration work, but this situation should be checked further. Notice how the internal temperature trend follows quite closely the trend of external temperature.

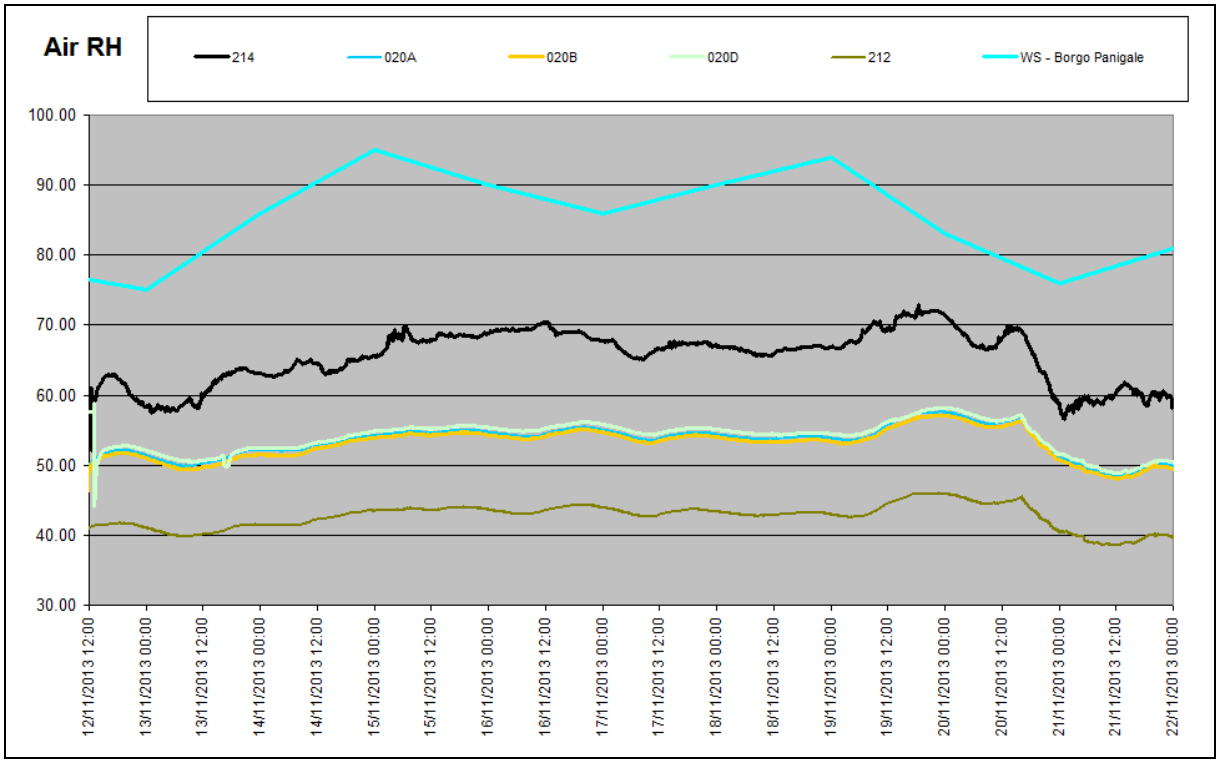


After the new windows installation, we notice a daily variation of temperature inside the Sala Urbana of about 0.2 °C (see graph above), comparable to nodes accuracy. The variation in the attic is around 0.7 °C, in the outside about 4 °C (dotted blue line) and the difference between external and internal

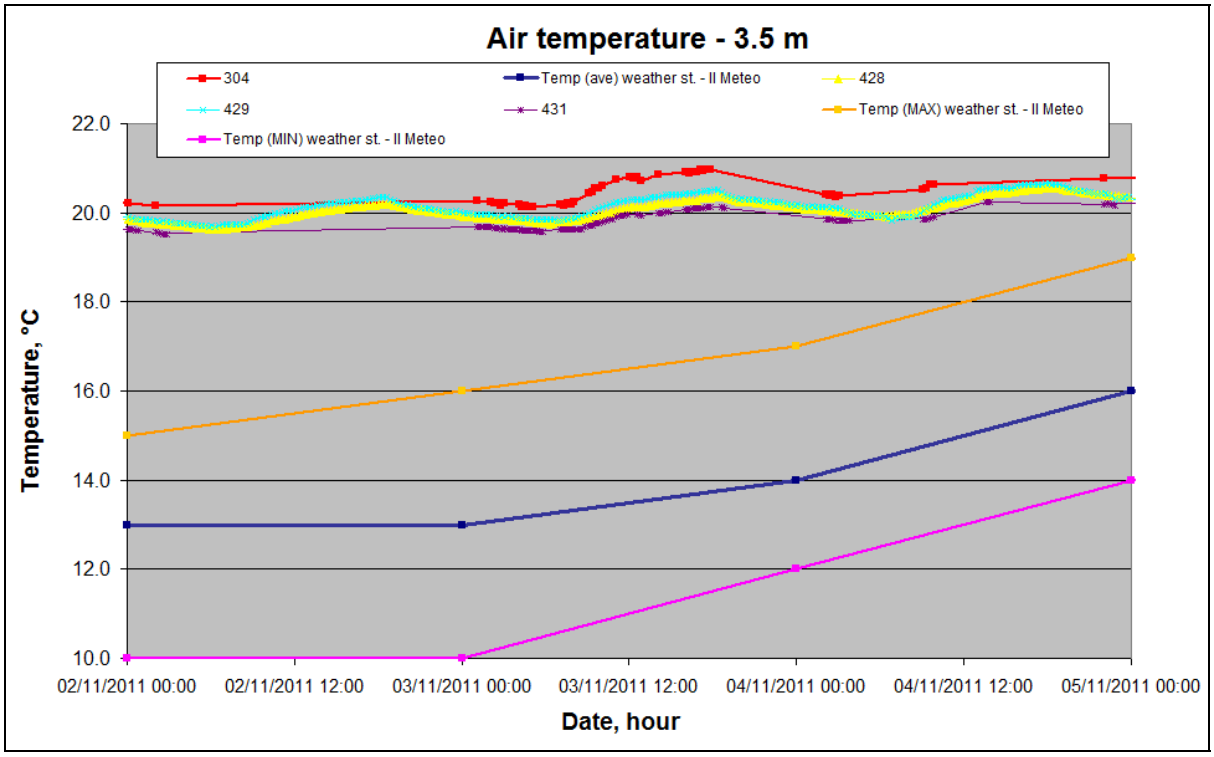
temperature reaches 7 °C. Notice how the internal temperature tends to decrease very slightly while the external one gets lower and then starts rising and then decreases again (in the attic stays almost completely constant): this behavior in different from the one observed before windows installation and could represent a more favorable thermal environment for the conservation of artworks.

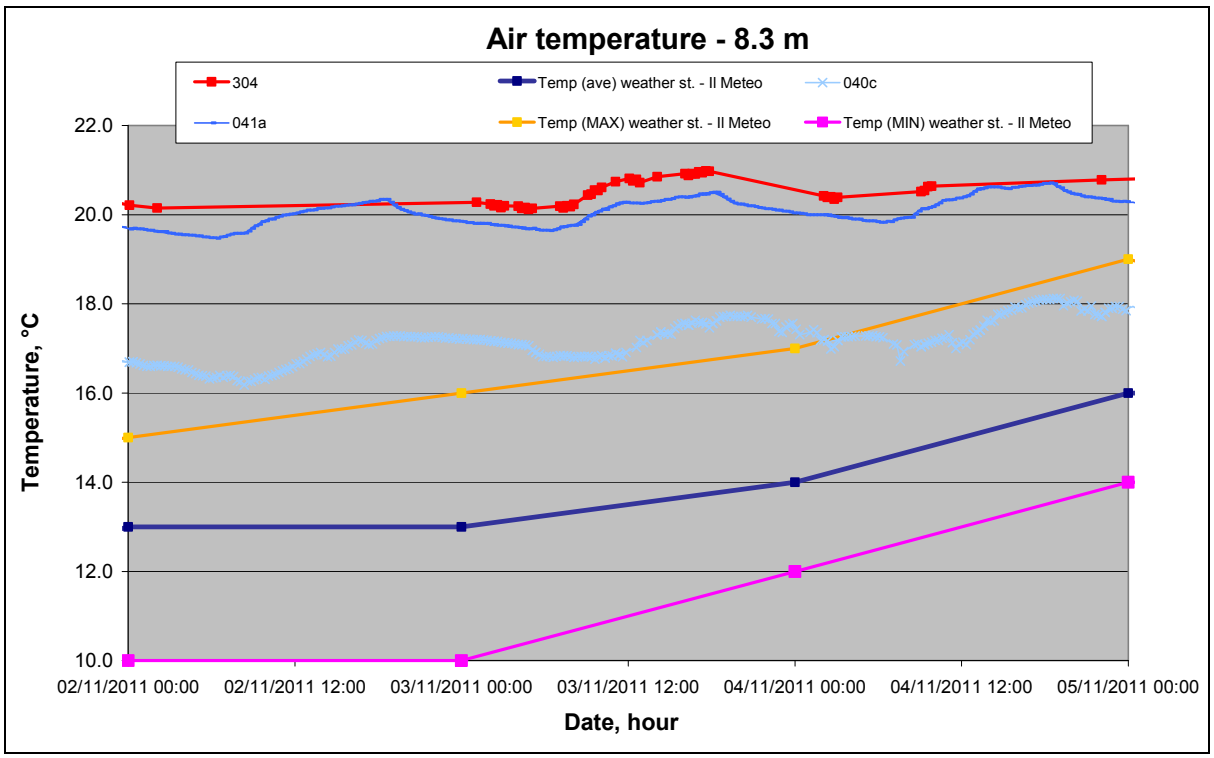


During the days preceding the new windows installation, we notice a daily variation of RH inside the Sala Urbana of about 3 %, comparable to nodes accuracy. The variation in the attic is around 5%, in the outside can reach 15%. As absolute values, inside Sala Urbana RH stays around 65%, in the attic oscillates between 70-75%, in the open outside air oscillates around 80-95%.

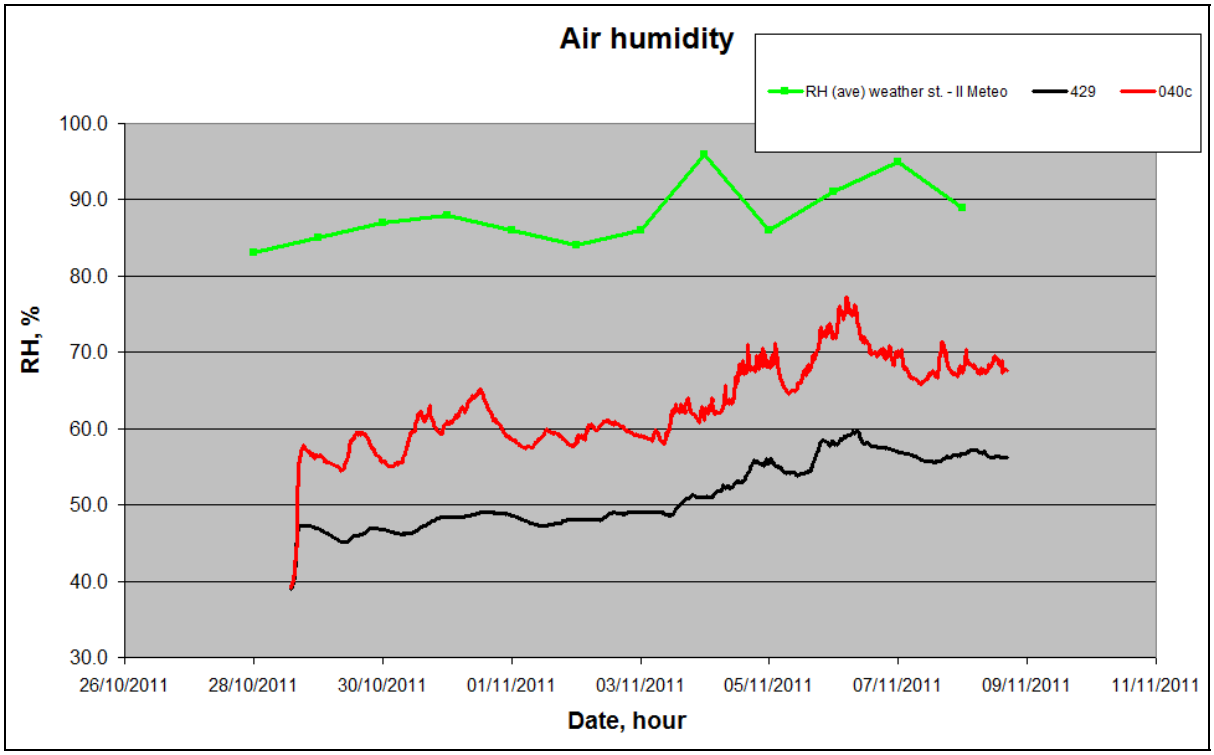


After the new windows installation, we notice a daily variation of RH inside the Sala Urbana below 1%. The variation in the attic stays around 5%, although only on some days, at the outside can reach 20%. As absolute values, inside Sala Urbana RH stays around 55%, in the attic oscillates between 60-70%, in the open outside air oscillates around 75-95%. We notice that, while the external RH values are comparable to the ones observed before window installation, the inside values are lower and noticeably more stable.





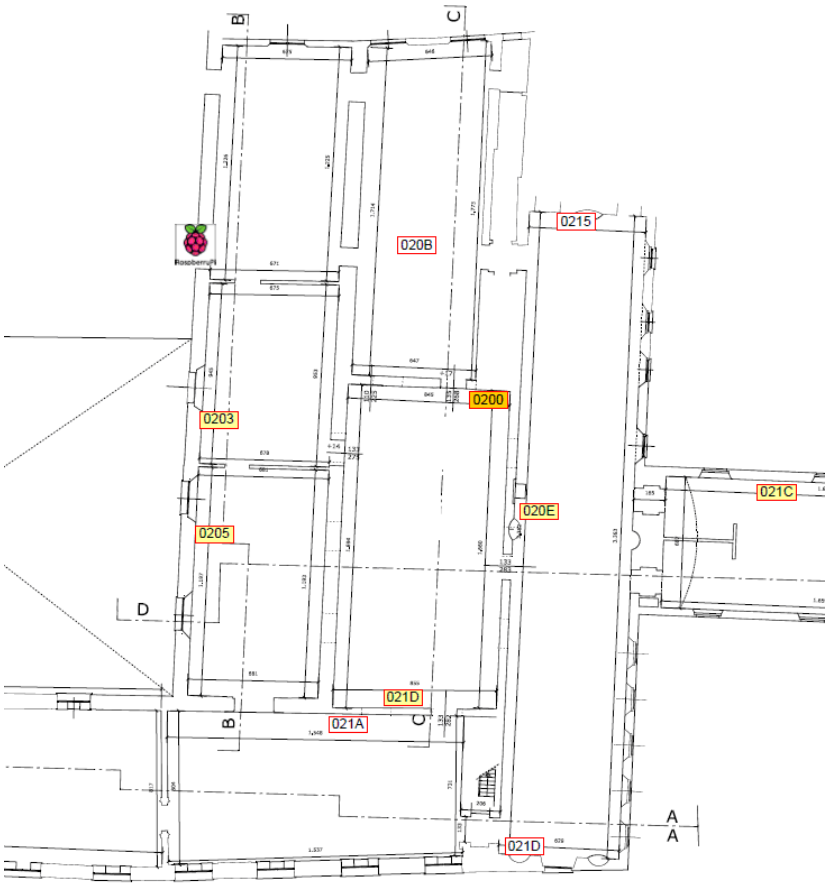
In 2011, we notice a daily variation of temperature inside the Sala Urbana of about 0.8 °C. The variation in the attic is around 1 °C, in the outside about 5 °C and the difference between external and internal temperature varies around 4-5 °C. Although with a much lower gradient, notice how the internal temperature trend follows quite closely the trend of external temperature.

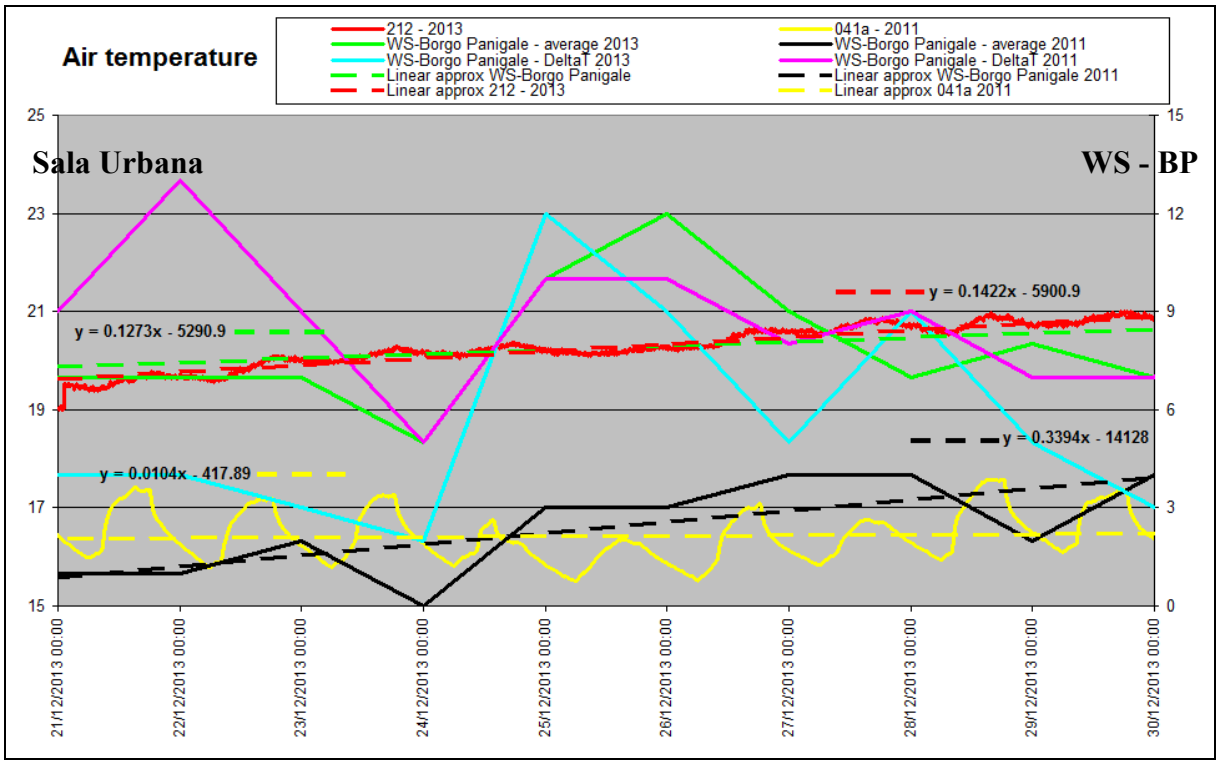


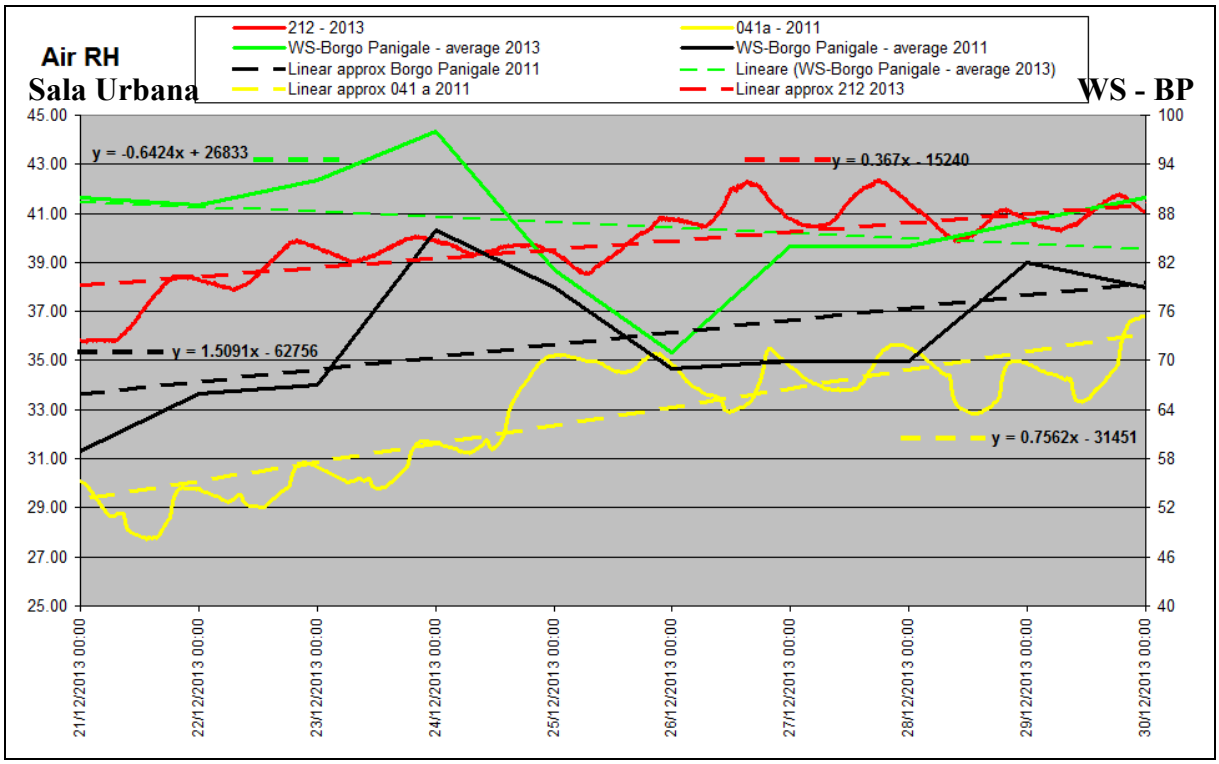
Although the external RH values are comparable to those of 2013, it is quite evident how the values inside Sala Urbana, which on the average stay at the same level than in 2013, are much more sensitive to external variations.

Monitoring in the period 21/12/2013-30/12/2014.

Map of nodes







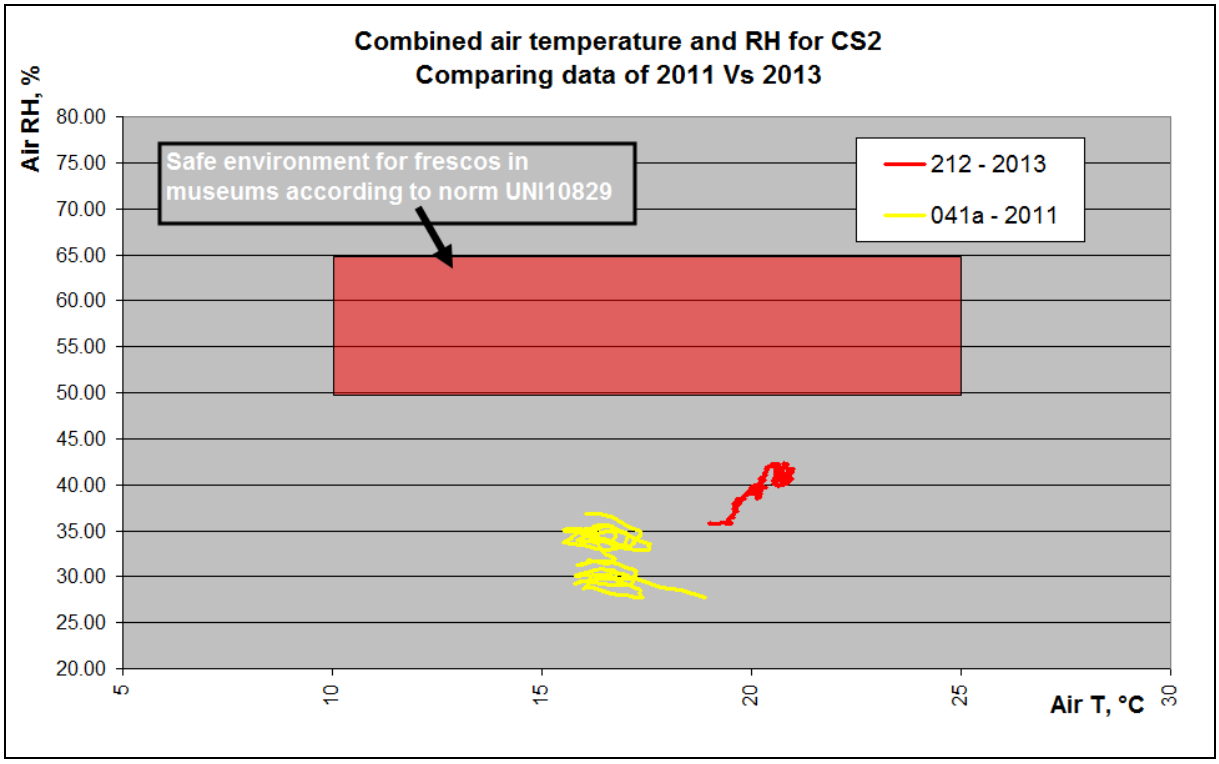
Situation in December is different: we observe that temperature trend inside Sala Urbana is following the external temperature one, while in 2011 internal temperature trend was almost flat; however, daily oscillation in 2013 is not noticeable, while in 2011 it was about 1.5 °C. As regards air RH, both in 2011 and 2013 inside/outside trends were quite similar, max daily oscillation was about 5%, but we see that inside value was not growing as much as outside one when comparing data of 2011 and 2013.

Conclusions

From a general point of view, we observe that air temperature and RH in Sala Urbana are stable before and after the installation of the new window, with daily variations comparable (if not less than) to the accuracy of the employed measuring sensors.

However, as a result from this first monitoring session in October-November 2013 we can state that after the installation of the new windows and the construction of the new roof daily oscillations are reduced and internal micro-climate is less prone to follow the trend of the external one, thus obtaining a more stable environment. In December 2013 the situation is different, i.e. the internal climate follows more closely the external one, but with much reduced daily oscillations; we must also take into consideration that in December the construction yards inside and outside Sala Urbana were getting dismantled, so situation was much more variable that the normal one. Most stabilizing effect can be ascribed to the windows, but we must consider that the monitoring should be extended at least to the next summer season to verify the behavior of the components under heavy external heating.

In the picture below we show a cumulative graph of RH/Temp recordings and we see that the present situation (red line) is slightly improved with respect to the past one (yellow line) in terms of conservation environment.



4.2.2 Briefly Summarizing word

As a result from the simulation and monitoring sessions we can state that after the installation of the new windows and the construction of the new roof, daily oscillations are reduced and internal microclimate is somehow less prone to follow the trend of the external one, thus obtaining a more stable environment.

4.3 Evaluation of Impact on cultural heritage value

4.3.1 Impact on building fabric

The roof of Urban Room is composed of 6 wooden trapezoidal trusses, and on the centre there is the ridge beam with 4 cantonal.

The perimeter wall is formed by three heads brick.

The situation during the construction phase was the following:

- the perimeter wall was statically weakened by the presence of numerous chimneys that once flowed in the highest part of the building;
- the coupling between the chain and the strut of a truss was completely deteriorated and marciscente and no longer able to withstand the loads of the structure;
- the cannucciato, typical local structure, consisting of a cross-linked wood hung on the structure of the covered, on which is nailed to a layer of reeds, in some place was weakened;
- inside the room, the ceiling of the paint film, whose support is precisely the cannucciato, the points of greatest infiltration of water had separated by the support, in other places they had created the "empty pockets" that needed to be "re -adhere "to the media
- The wooden window frames, fitted surely in 1935 and perhaps replaced after 1945, were completely deteriorated and no longer functional.

The comparison of the historical value of the building imposes a duty to maintain as much as possible the original materials of the ancient structures, while ensuring the security and stability.

Regarding the first point we proceeded closing with new brick flues, and the last section of masonry, along the horizontal joints, were inserted steel rods for reinforcing the masonry. Along the last course of bricks was fixed a metal plate connected wood trusses by bolting, effectively creating a curb connection that connects the four sides of the wall. In this way, while keeping the brick structure, has been done to improve the seismic structure of the "tower" room Urbana.

The consolidation of the wooden truss occurred on site. The "healthy" part of the wooden structure was retained, while the degraded one was crushed and demolished.

To integrate the missing part have been inserted four steel bars along the strut in wood, to a depth of about 30 cm , has built a small permanent formwork of the shape of the strut and is proceeded with the casting of a resin to strong resistance , thus creating a plug- in resin and metal bonded to the original structure.

Working in this way , the structure of the original one has been covered , the joists were replaced only secondary.

The slight curvature of the ridge beam has remained as such , and once completed the full intervention insulation covered on the outside you can still see the curvature of the ridge beam .

The cannucciato has been established both on the upper side , and on the inner side of the room. On the side of the pool, in the most critical point, was spread a mortar added with ethyl silicate , while the interior has been done through the adhesion of Japanese paper mixed with liquid consolidation. During working on the roof, the decorated ceiling was propped up and in the next step we proceeded with the filling of empty bags through injections of mortars with acrylic resins with additives.

The windows have been replaced as quite recent and not considered to be of historic value. We fitted double glazed windows high performance, with flap opening on one side to allow for air circulation during the summer months, the design of the squares of the frame has been maintained as the original, as well as the exterior colour, dark brown. Originally there were two windows, one inside and one outside. Not to alter the external appearance, and at the same time allow the passage of air with the automatic opening of new fixtures, was mounted an outer frame without glasses, with only a network construction and bird scarers, maintaining the same design of the quadrature.

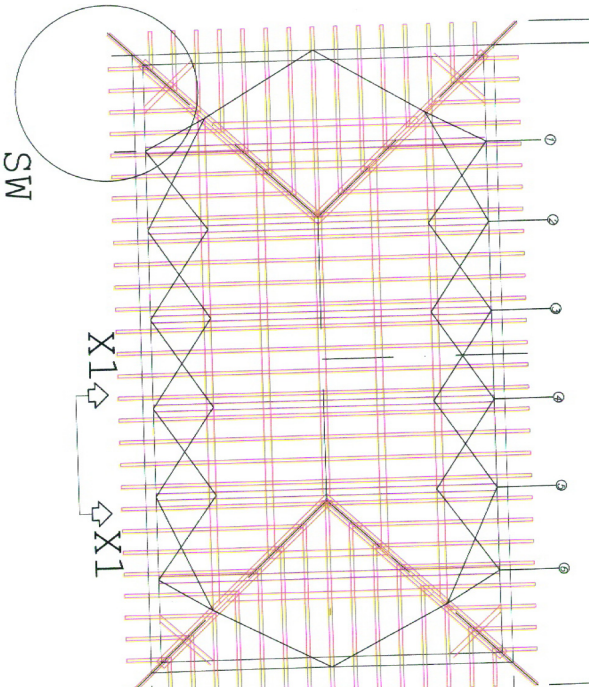


Fig. 61: Scheme plan of the refurbished roof with indication of the perimeter masonry walls and of the steel reinforcement elements inserted

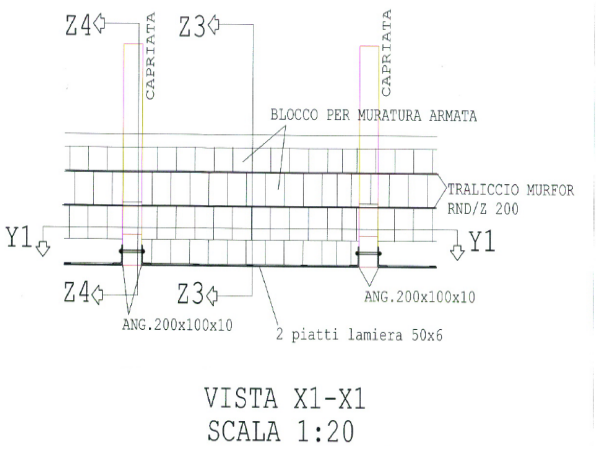


Fig. 62: Detail section X1-X1 with indication of the steel reinforcement elements inserted

4.3.2 Impact on the appearance

The goals that we wanted to achieve with the surgery were:

- improving the microclimate inside;
- reduction of heat loss;
- consolidation and structural seismic strengthening of the supporting structure;
- conservation and preservation of the original materials;
- preservation and consolidation of the paint film;
- unalterable of the external fronts.

These objectives were all met and the only appearance (improvement) that is found is the new plaster to look brighter , composed of lime-based mortar with natural pigments, as it was done in ancient times.

4.3.3 Reversibility of measures

The concept of reversibility, compared with the paper of the restoration of 1972, is changing over time, and it is the same as the Italian legislation acknowledging some aspects, such as the criterion of "seismic improvements" in which the rule has taken reference interventions to enable static profits, but at the same time non-invasive, necessary for the adjustment to the safety standards applicable to buildings with modern materials.

Over the years, it was found that the total reversibility is sometimes impossible, just for interventions in the past; the concept now is the non-invasiveness of the added technology and respect for the historical materials. If, in a restoration, you are in front of old works made with materials that aren't compatible, it's appropriate for them to be removed and replaced with others that are considered "compatible".

In our case, removing the plaster cement fits perfectly in this logic, as the concrete laid on ancient materials causing salinization processes and degradation of the materials. Removing the cement plaster replacing with lime plaster is considered an intervention of respect and conservation of the building because it is an original material.
The same applies to the removal of the wooden frames. Those fixtures were installed after 1945, with poor materials, and their manufacture hadn't particular historical value, were also completely degraded and could not be any restoration.The structural consolidation on the walls, the restoration of the frescos, the insulation of the roof and the artificial lighting system have high reversibility. The graft resin runs on the strut of the structure of the covered was a way to not completely replace the entire wooden truss, maintaining the original material, as well as the consolidation of the masonry has resulted in the addition of metal bars. The consolidation of cannucciato was performed with natural lime-based mortars, acrylic resins are added, but the installation was preceded by laying a network of plastic fiber , which will eventually be removed. Inside the room, the injections on the paint film and the cannucciato are based on lime mortar, compatible material, and the pre-consolidation performed with Japanese paper was removed with ethyl acetate.

4.3.4 Overall rating

The Urban hall in the Accursio palace was closed to the public for about 10 years. The hall was built by Pope Urban VIII in 1664 and was part of the apartment of Cardinal Legate. The hall was the conclusion of the public representative path where there were meetings between the most important men.

When the work will finish, citizens will be able to appreciate the extraordinary artistic value of the room, a kind of tower inside the palace , whose walls are completely covered with Sala Urbana and the ceiling shows a quadrature performed by the master Colonna.

The new lighting will be able to exploit all the decorations without creating shadow cones , and while not intervening with new installations, the internal microclimate will be better.

The museum will have a great room open to the public, where is possible also do conferences, presentations of books or works of art , reclaiming a representative and symbolic area of the city.

5 Summary and conclusion

Building history: The actual structure of D'Accursio Palace is the result of several interventions: the original nucleus of the building was the so called Biada Palace, protected by a square perimeter of walls and used for the storage of grain. This has been then expanded over the centuries to become the institutional headquarter of the city. In 1336 it became the residence of the Elders, thus hosting the city government. In the following phase, in-between 1365 and 1508, it was renovated and expanded by architect Fioravante Fioravanti, crenellated walls interspersed with towers were erected, together with the completion of the building façade in front of Maggiore Square and of the western body of the Palace, with contributions coming from several architects including Donato Bramante; in between 1513 and 1886, the renovation and further extension interventions included the completion of Cardinal Legate's private apartments and Galeazzo Alessi's Chapel.

Constraints conditions and Protection: The building is qualified as building of historical and architectonic interest in the Urban Building Regulation Code, and it is classified among the buildings protected by the National Law of Conservation of Historical Heritage. The regulation admits only respectful interventions of renovation and maintenance. In particular, the Regulation Code prescripts to preserve the original integrity of every architectonic, artistic and decorative element of it, in particular it allows:

- the consolidation with substitution of un-repairable parts without modifying the position and height of major walls, lofts, ceilings, stairs;
- the insertion of essential technological installations, respecting the previously given constraints;
- the reversibility of each intervention

Electricity consumption audit- Update to 2013: The diagnosis was performed through a detailed analysis of the electrical systems and use frequencies, recorded during two surveys, carried out at the beginning and the end of the project. During the first survey, conducted in November 2011, a total consumption of 164.635 kWh/year emerged, while in the second observation, made in November 2013, the consumption turned out to be 159.027 kWh/year.

The high electricity consumption (106 kWh/m²) is mainly due to the use of individual air conditioners in summer and of small electric stoves to improve comfort inside the offices in winter. This is due to the fact that the current heating and cooling systems installed are inadequate. The decline of consumption from 2007 to 2013 is mainly due to a significant transition to the use of fluorescent lamps.

Analysis and non-destructive tests: Pre and during intervention diagnoses have foreseen the combination of different approaches and several non-destructive techniques in the whole Municipal Collection area. The structural and energetic integrated approach developed by the DICAM Dept. of Bologna University has included: (I) GPR radar tests for investigating the masonry construction stratigraphy; (II) Infra-Red Thermography (IRT); (III) Blower Door Test; (IV) U-Value tests; (V) Daylight test using photometric equipment. These tests showed the presence of thermal bridges in the ceiling and the presence of cavities inside the walls (chimneys). The blower door test showed where the major air infiltrations take place (windows and ceiling). The daylight test tells us that the Urban room is poorly illuminated and that luminance levels on the walls are below recommended levels.

IRT test in Sala Urbana before interventions: In the IRT tests, the structure of the roof is clearly visible, with thick transversal logs joined by thinner ones. An interesting feature of the roof is represented by two large warmer areas (green shapes in the following Tests); they seem to identify stripes of insulation material, or a second roof on top of the visible one. When the same shapes are superimposed on a photo of the roof, there appear no relationship with painted decoration, so the influence of different pigments is to be excluded (tests of 18/03/2011). On July 20, 2011, the same thermo grams of 18/03/2011 have been recorded, obtaining the same results: there appear some very hot spots, whose origin is not understood yet (see tests of May 27).In the Sala Urbana room, on May 27 a series of hot spots have been recorded, whose origin is unknown. They are not objects laying on the protection net, could be the result of sun rays passing through some small apertures in the roof, but no certain explanation has been found. In the case of the first thermo gram, their positions have been superimposed on the digital photo of the ceiling.

IRT for structural analysis: most worrying results regard the diffuse detachments of the decorative paintings of the room; by IRT alone it is not possible to assess the risk of falling of the supporting plasters, but a more detailed inspection is recommended, especially before the start of the foreseen renovation works of the roof. Also some probable water infiltrations have been spotted and, in the upper part of the East and South walls, some very hot areas are evident, but no sure explanation of such a temperature gradient is still assessed, like for the small circular hot spots seen in March, May and July.

U-Value determination in historical building: Different U-value measurements of exterior wall have been conducted in a direct way in accordance to the norm ISO 9869 (CEN, 1994), in order to compensate the lack of existing documentation on the actual state of the building and to obtain a sufficiently reliable estimation of the heat losses of the structure, keeping in mind that the physical characteristics of masonry's components are different from masonry's components currently used, thus the scheduled values should not be used.

Hygrothermal and environmental monitoring: Hygrothermal monitoring of the building was carried out through a Wireless Sensor Network (WSN) and an IEQ (Indoor Environmental Quality) audit for characterization of micro-climatic conditions performed with portable instrumentation, both in the Museum and in the Office areas:

- WSN: monitoring has been going on since February 2011 to March 2014. The results obtained before the interventions for air temperature and RH inside Urban Room and in its attic, showed that the situation is not favorable for artworks conservation. Different types of WSNs have been installed in two different areas of D'Accursio Palace to acquire environmental and energetic data on a period going from August 2011 to March 2014. Areas of interest are the Civic collections of Art and Municipality offices, along Via IV Novembre, at the second and third floor. Proposals for networks topologies have been presented in July 2011 but actual implementations have been adapted to overcome technical difficulties and new requirements from COBO. In this document we have not reported the transmittance measurements (U value) and accompanying monitoring done by a separate WSN.
- IEQ Audits were performed in winter and summertime periods. Through the two monitoring campaigns were identified the levels fixed in each indoor room using thermo-hygrometric, visual, acoustic parametric value and the derived calculated parameters of comfort. Results concerning thermo-hygrometric wellbeing in Urban room showed values of satisfactory comfort for winter time (respectively PMV=-0,29 PPD=6,74).

In addition, in the Municipal Collection area, the pre-intervention indoor climate conditions were repeatedly monitored by UNIBO's researchers in different seasons and with open/closed windows/doors by means of digital thermohygrometer and analogue thermohygrographer to obtain psychrometric maps at different heights above the floor.

Moreover, the climatic variations in Sala Urbana during and after intervention in summer/autumn 2013 were monitored by means of a Wireless Sensor Network made of 2 nodes for T, RH, light, vibration detection

PHPP calculation results: A PHPP calculation was applied twice to the Municipal Collections Rooms as one of the, structurally homogeneous, chosen areas and as representative of the whole building. The results evidenced not surprisingly that the "Municipal Collections" area is far away from achieving the Passive House standard.

The results of the application of the PHPP analysis showed that the energy losses are distributed across the entire envelope. The main components are concentrated in the attic included in non-heated area, and external walls. The blower door test showed a relatively poor airtightness with a mean air change rate of 5.9 1/h. Therefore the losses due to infiltration, contained in the ventilation component, are considerable. Also the transmission heat losses through the windows are relevant, due to the presence of several and large windows in each external surface.

Compared to the pre-intervention scenario, the results of the post-intervention PHPP showed that the losses to the non-heated area (attics) and through the windows decreased in accordance with the implemented measure. Also ventilation losses decreased due to an improvement of the air-tightness. Looking at the global assessment the estimated heating and cooling demand decreased by 50 kWh/m^{2}a (19%) and 1 kWh/m^{2}a (50%).

Deliverable D6.2 Documentation of each study case

Design Builder Modelling (as-is state): An energetic model of the Municipal Collections Area was elaborated using Design Builder. Modeling and analysis were performed in 7 steps, from digital rebuilding of the examined area, to the simulation of the thermal and physical characters of the building components, ending with the definition in the model of the kind of HVAC and the type of regulators. Using DB the solar gains, the internal gains, the energy losses through the building envelope and for ventilation, both in winter and summer time, were calculated, estimating the energy need for heating in winter time and the one for cooling and lighting referred to summer time.

Methodological procedure and project: The energetic retrofit proposal of Palazzo D'Accursio's Urban Room of the Bologna Municipal Collections was originated by the willingness of the Local Authority to integrate an intervention of extremely necessary non ordinary maintenance of the Room, vital in order to resolve the ceiling's frescos decay due to the rainwater infiltrations through the deteriorated roof covering, with energetic refurbishment interventions. These respond properly to the following double requirement: (I) improving internal comfort the Room – where there is no air conditioning – during the winter and summer period; (II) protecting the fresco decorations on the walls and ceiling from direct sunlight by reducing massively the ultraviolet radiations and providing protection from the infrareds.

The needed interventions and the retrofit actions individuated for the "Coat of Arms" Room are been varied in different procedures, each one essentially corresponding to a different specific choice of the materials to be used in order to build up the technological packets and abacus.

Works will focus primarily on the replacement of the roof with waterproofing and replacement of existing windows. After evaluating singularly the interventions for the energetic retrofit, an Effectiveness Analysis in dynamic regime has been carried out with alternative solutions and the relative impact in the building.

Interventions realized: The following works have been realized in the Sala Urbana:

- *Roof refurbishment*: substitution of the existing roof by a ventilated roof with wood fibre insulation.
- *Punctual seismic improvement:* The perimeters walls were consolidated by inserting new bricks in the section portions in which the pre-existing chimneys had weakened the structure. Moreover the perimeter structure was reinforced by a banding of metal bars. A wooden truss was stabilized by inserting metal bars and epoxy resins.
- *Window substitution*: application of wooden/aluminium window frames with double low-E glazing.
- *Automation and control of the Sala Urbana:* with a domotic system that automatically controls windows and curtains adjusting the light intensity depending on the current room use.
- *Plaster remake*: substitution of the present external plaster layer with a traditional lime-based plaster.
- *Frescoed ceiling renovation*: insertion of an insulation layer at the extrados of the frescoed ceiling using natural plaster with resins . Pre consolidation of the paint surface with Japanese paper and subsequent cleaning.
- *Artificial lighting* . refurbishment of the artificial lighting with a LED wall washer system for improved efficiency.

IRT test and environmental monitoring after interventions: WSN monitoring: Sala Urbana has been monitored during the period 17/10/2013-21/11/2013. The results have been compared with those acquired in the period 28/10/2011-08/11/2011 to verify the effects of the renovation works, especially the ones resulting from the installation of the new high performance windows.

As a result from this monitoring session we can state that after the installation of the new windows and the construction of the new roof, daily oscillations have been reduced and internal microclimate is less prone to follow the trend of the external one, thus obtaining a more stable environment

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7 Annex 1 - Description of the monitoring system

7.1 Monitoring Concept

After a survey in Palazzo D'Accursio in November 2010, a first plan for installation of wireless sensor network was prepared and three areas were selected:

1. Museo Morandi
2. Collezioni Comunali
3. Offices in the south side of the building.

People responsible for Museo Morandi and Collezioni Comunali have been interviewed and positions and numbers of sensors have been agreed; other sensors can be installed after interaction with other WPs but, especially for Museo Morandi further installations are quite difficult to be accepted by the Museum representatives. At the end of February, COBO communicated that a new section of Collezioni Comunali would be of interest for 3ENCULT, the large room called Sala Urbana, due to renovation works that should take place during the project. For this reason, it has been decided to shift sensors from Museo Morandi to this room. For the same reason, it has been decided to check U values in Sala Urbana, although great difficulties arised due to the presence of decorative work on all walls. In December 2010 a monitoring plan has been supplied and in February 2011 a first test installation has been done. The area of the offices has been selected to be used as a test bench for the validation of simulation tool prepared under WP2; the rationale behind this decision is that the offices area is less prone to installation difficulties due to the artistic values of surfaces and/or spaces.

7.2 Planning of the installed sensors

(Artemis - Enrico Esposito, Antonio del Conte, UNIBO, Marco Giuliani)

With respect to the December proposal, in July 2011 a new planning for nodes of the WSN installation has been prepared and described in the following.

In the Collections, end devices (nodes) should be placed at an average height of about 3 to 3.5 m, except for the Hall of Sala Urbana, where we will have three "layers":

1. one above the architraves of the doors (height = 3.5 m),
2. one above the safety net (height = 8.3 m),
3. one in the attic

In Figure 63 we show a section and a plan scheme of the foreseen positions for nodes installation (for the offices see Figure 64).

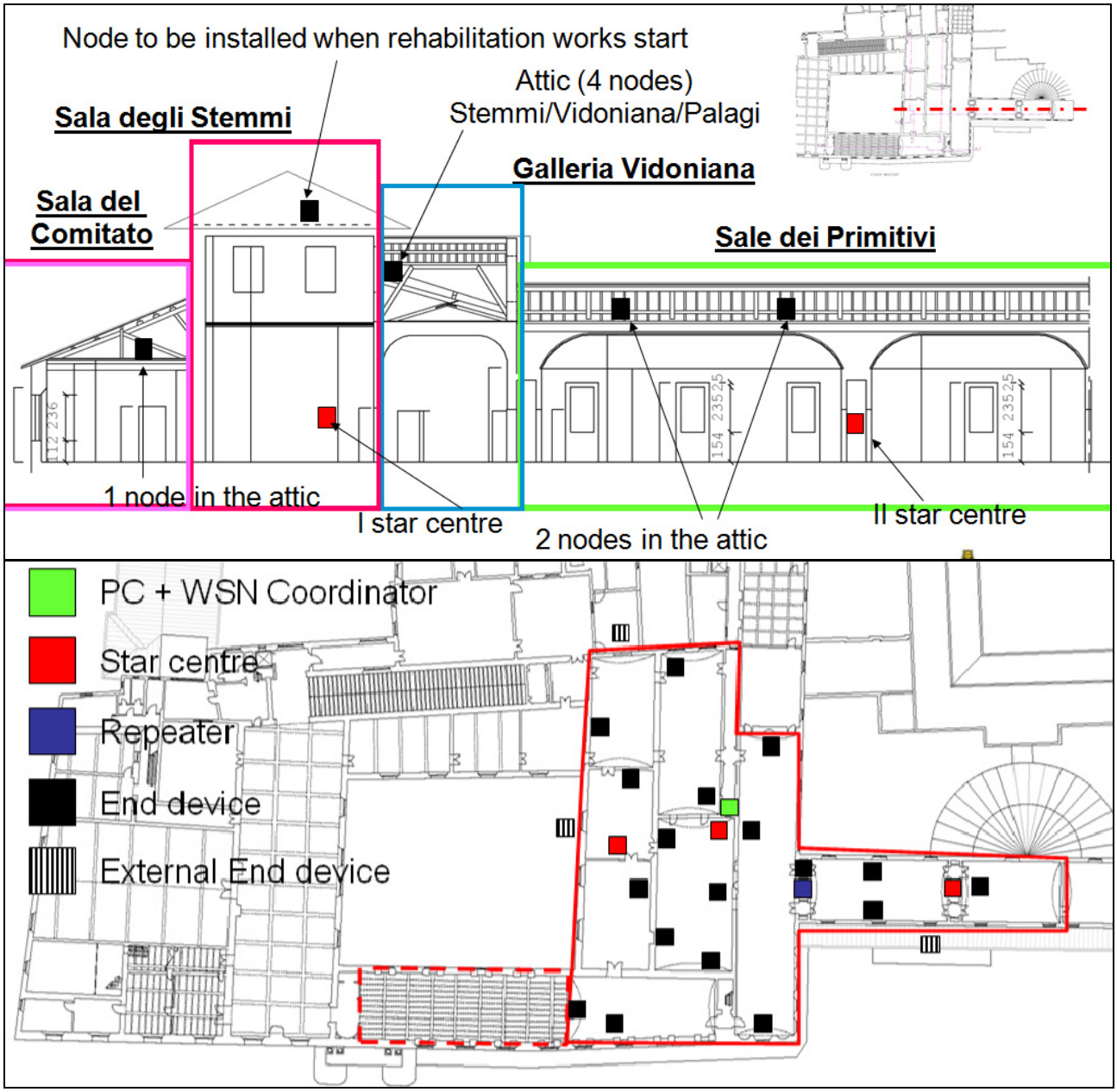
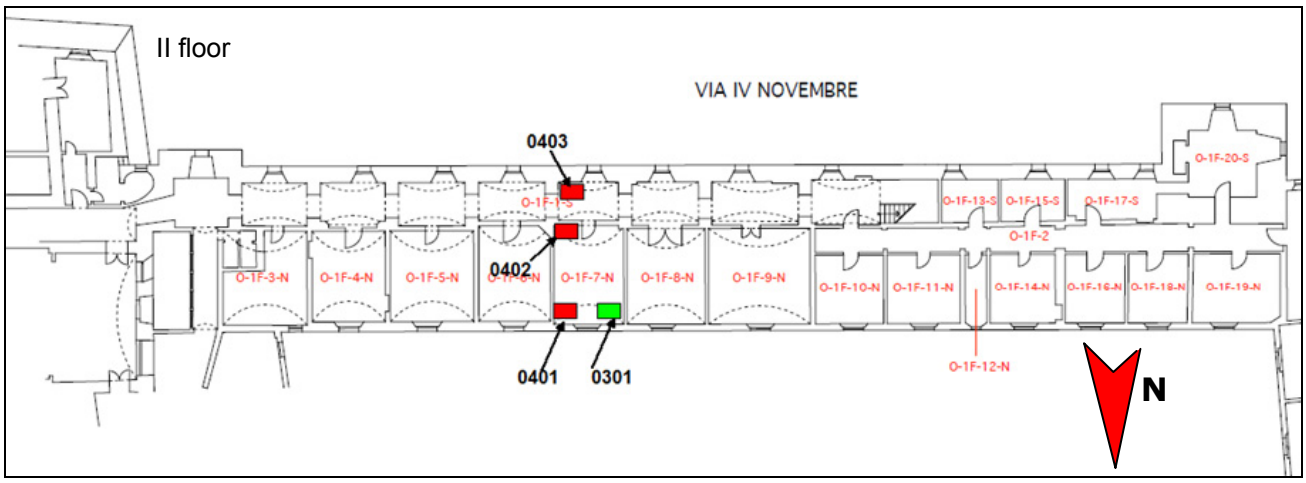


Figure 63: WSN nodes localization for Civic Collections.



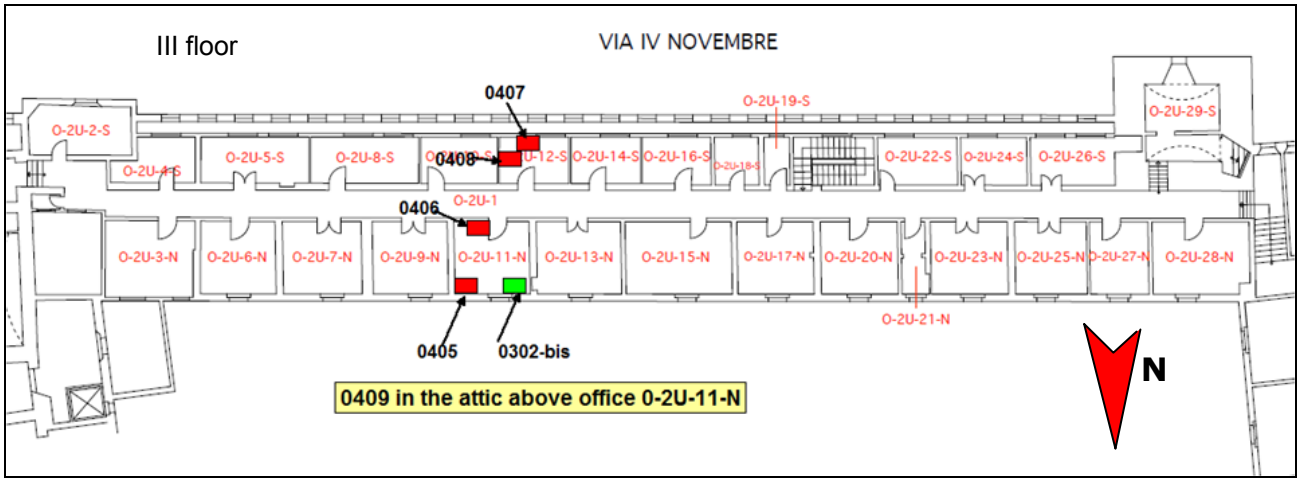
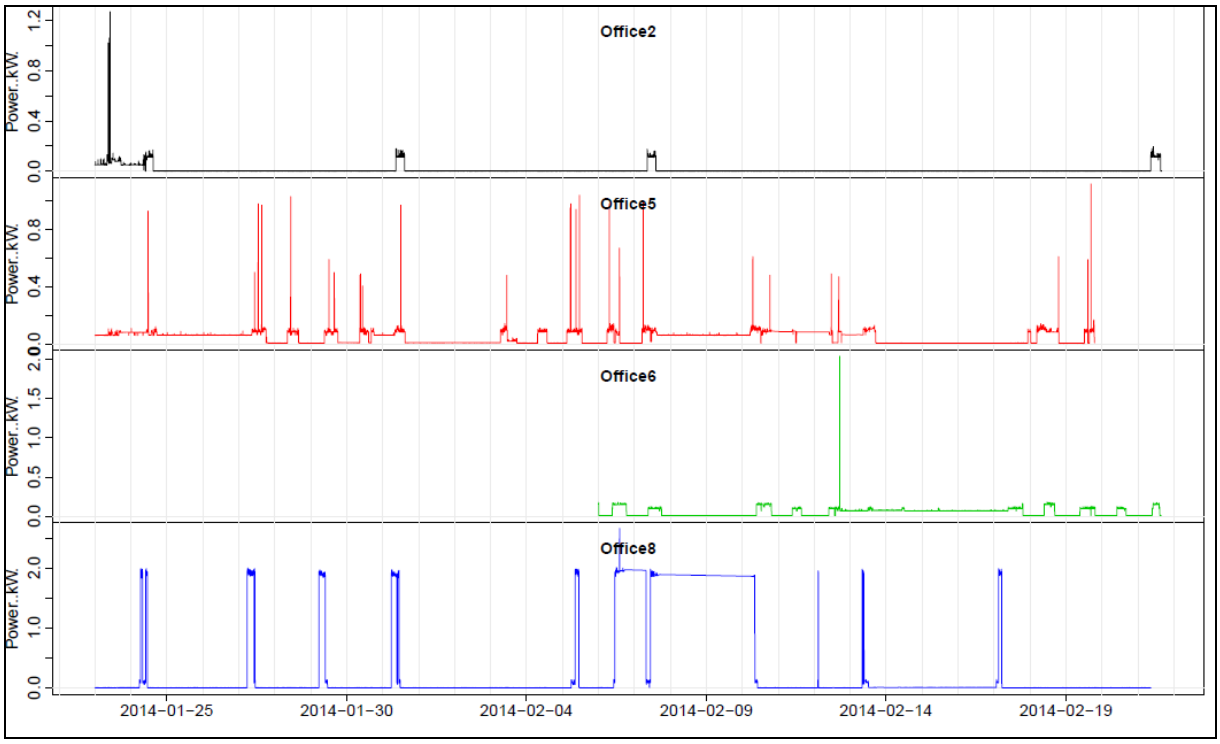


Figure 64: WSN nodes localization for the offices.

Each node will acquire air temperature and humidity by internal sensors, and, moreover, a set of sensors to be connected at the nodes inputs has been individuated and acquired; a summary of technical data of the utilized nodes and sensors is reported in Appendix A. *As we will report in the section dedicated to results, actual positions and number of nodes changed during time due to changing requirements and technical difficulties related to the transmissions paths exceeding the nodes capability*.

In February 2014 a Z-Wave domotic network has been installed in the offices area to acquire parameters that are quite difficult to be monitored by a standard WSN network, mainly electrical consumptions; although feasible, the interfacing of power monitoring sensors to the existing WSN would have required extensive interfacing works and so a network that is natively born to implement such a task has been selected, acquired and installed (see Appendix A for technical details). *Acquired data are still under analysis* and in this report we will only show the photos below, with the "Virtuoso2 gateway and installations of a reed contact and a measuring/actuating plug.

Data are stored in a internal database of the "Virtuoso" gateway and must be manually extracted by the operator to be analyzed and presented (in the graph below we see an example from the plus of four offices). Data are currently under evaluation and will give the main comparative and validation results for the modeling of the building in WP2.



In February 2012 also a weather station has been installed on top of Palazzo D'Accursio, see Figure 65. The external sensors (air temperature and RH, pressure, wind speed and direction) of the weather station communicate wirelessly with a base station placed in the Collections: till February 2014 it has been left in the same small room that hosts the WSN PC and gateway (see MIB520 in map of nodes of the August 2011 period), but it gave numerous malfunctions due to the difficulty of establishing a stable radio link, so a complete new strategy has been adopted in February 2014. Since that month the base station has been moved to room 19 (see Figure 66) and, to acquire data, a Raspberry Pi micro-computer has been acquired and programmed (see 7.4 for technical details of the implemented solution). The new solution has been seamlessly working since 03/02/2014 and a graph of acquired data is shown in Figure 67, where we also show the results from the reference weather station in Borgo Panigale: it is quite evident how the 3ENCULT weather station follows quite accurately the reference one.

Figure 65: weather station position (Bing maps) and installation on top of Palazzo D'Accursio.

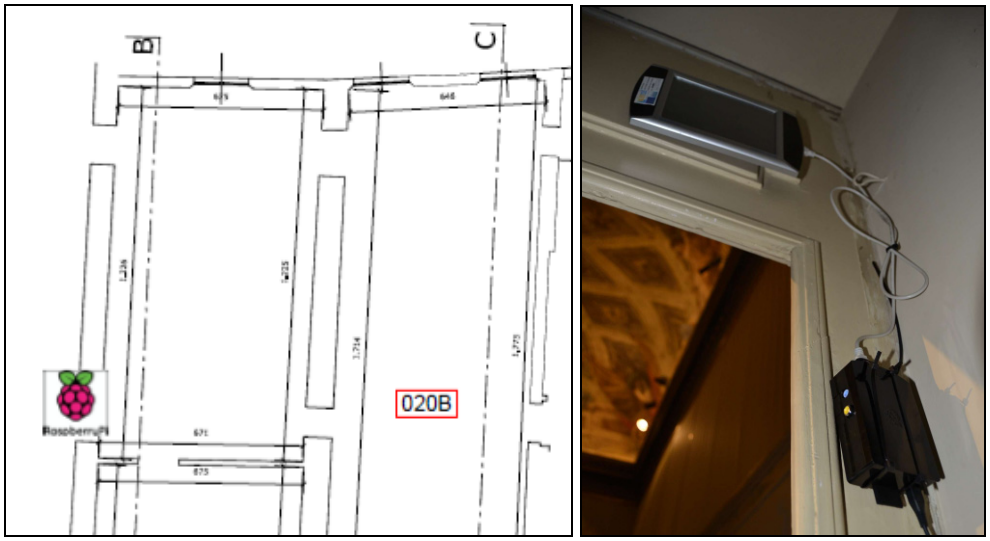


Figure 66: weather station receiving station and Raspberry PC in room 19 of Municipal Collection.

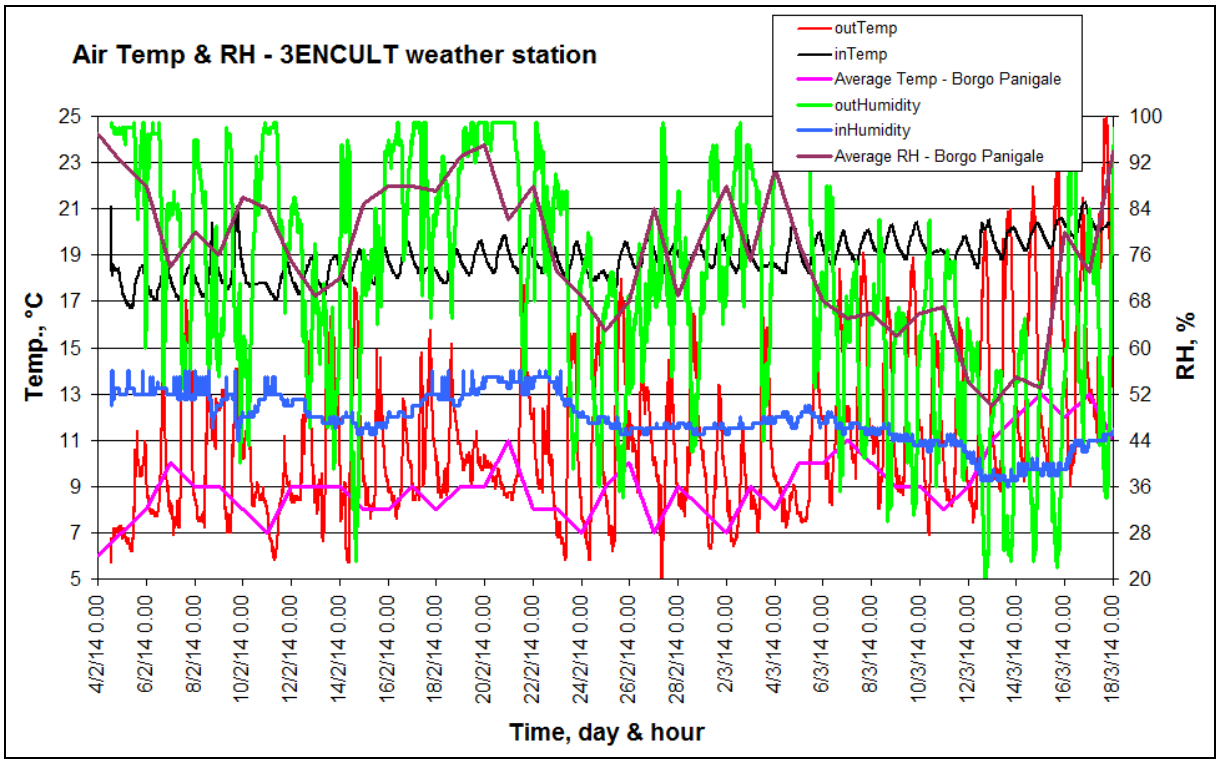


Figure 67: weather data acquired by the 3ENCULT station in the period February-March 2014.

7.3 Accessibility to monitoring data

(Artemis - Enrico Esposito, Antonio del Conte, UNIBO, Marco Giuliani)

Following requirements expressed in conjunction with WP4, all data are stored in a SQL based database, specifically a MySQL database has been implemented; data dump and transformation to other SQL standards or spreadsheet formats (CSV, XLS, TXT) is straightforward and can be implemented by open source tools. Local PCs for data storage has been linked to the central 3ENCULT server by a HSDPA modem with a contract to a GSM national operator (Civic Collections) or by LAN access (offices, still to be granted by COBO). Local PCs are also accessible for direct control and management by “TeamViewer”, a free (for not commercial use) tool for remote access (http://www.teamviewer.com/en/index.aspx) that is capable of working thru all eventual network blocks usually found in Public Administration sites, see a screenshot in Figure 68.

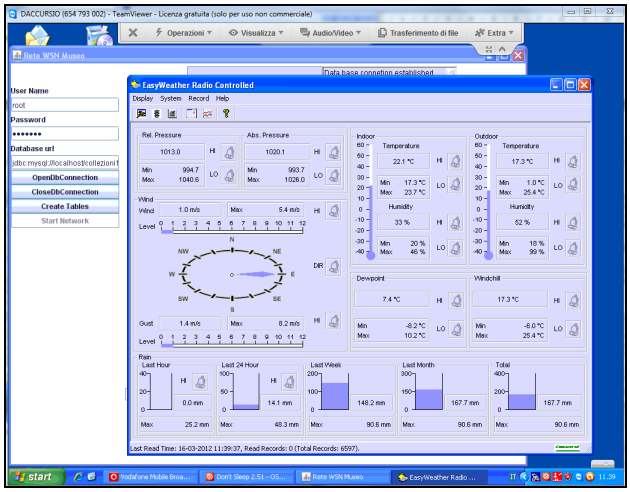


Figure 68: A screenshot of the PC used in the Civic Collections while under control by TeamViewer.

7.4 Technical specifications of WSN nodes, sensors and weather station

(Artemis - Enrico Esposito, Antonio del Conte, UNIBO, Marco Giuliani)

I.Co. (Italy) DEVICES
A state-of-the-art commercial system has been acquired, with the following characteristics:

- Dimensions: 90x59x35 mm, see Figure 69
- Integrated omnidirectional antenna
- 7 analog input modules (0-2.5 V) for NTC sensors with a resolution of 0.6 mV;
- Selectable low pass analog filter at 50 Hz;
- Supply voltage 5 V/100 mA;

- T and RH sensors on board (Sensirion SHT11, see description for Memsic nodes):
    - Resolution of 0.01°C / 0.05%RH (typ.)
    - Accuracy of +-0.4°C / +-3%RH (typ.)

- "Clip on" terminals for external sensors
- Powering: 1 3.6V battery
- Sleep mode current: < 0.1μA
- Selectable acquisition rate (5 minutes min, 30 minutes max)
- Radio transmitter
    - 2.4 GHz IEEE802.15.4 compliant
    - Sleep mode current: < 0.1uA
    - Interoperability with all 2.4 GHz standard devices
    - Very low Packet Error Rate
    - Encrypted data transmission

Nodes are hierarchically divided into:

- Coordinators
- Repeaters
- Star centre
- Acquisition node

The network does not use the so-called "multi-hop" technology in order to save battery energy but is based on a "Extended star" topology, see Figure 70.

Figure 69: Photos of WSN nodes

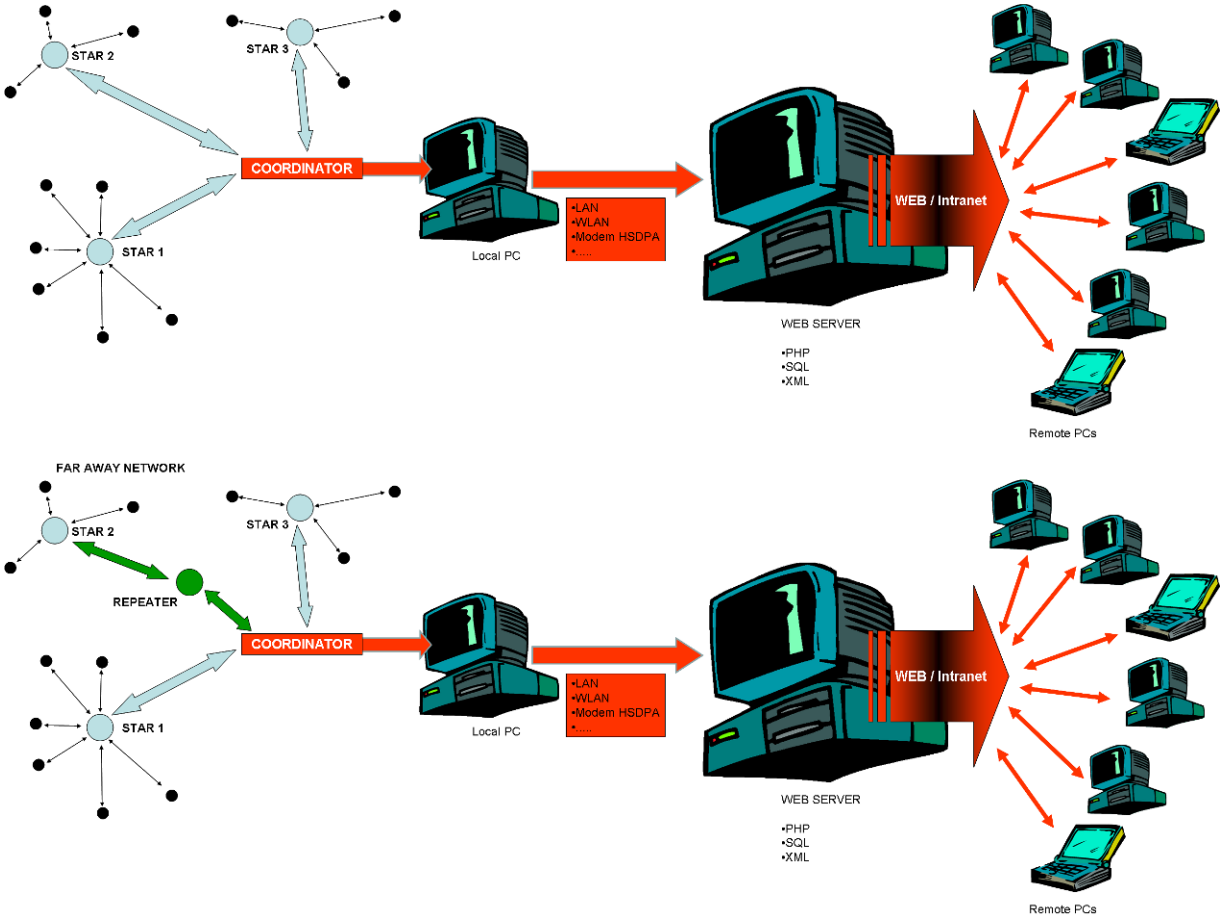


Figure 70: Network “Extended star” topology, with and without Repeater node(s).

MEMSIC (China/USA) DEVICES

MTS400

- Onboard Temperature & Humidity, Barometric Pressure and Ambient Light Sensors

Barometric Pressure Sensor

- Model: Intersema MS5534AM
- Pressure range and resolution: 300-1100 mbar; 0.01 mbar
- Accuracy: ± 1.5% at 25°C

Ambient Light Sensor

- Model: TAOS TSL2550D
- Spectral responsivity: 400-1000 nm,

Relative Humidity & Temperature

- Model: Sensirion SHT11
- Humidity range; resolution: 0-100% RH; 0.05% RH
- Absolute RH accuracy: ± 3.5% RH
- Temp. accuracy: ± 0.5°C @ 25°C

- Compatible with IRIS/MICAz/MICA2 Processor/ Radio Boards

MDA300

Developed at UCLA's Center for Embedded Network Sensing (CENS), the MDA300 is a data acquisition board that also includes an onboard temperature/humidity sensor (Sensirion SHT15). With its multi-function direct user interface, the MDA300 offers a convenient and flexible solution to those sensor modalities commonly found in areas such as environmental and habitat monitoring as well as many other custom sensing applications.

- Sensirion SHT15
  - Humidity range; resolution: 0-100% RH; 0.05% RH
  - Absolute RH accuracy: ± 2% RH
  - Temp. accuracy: ± 0.3°C @ 25°C
- 7 single-ended or 3 differential ADC channels (resolution 0.6 mV)
- 4 precise differential ADC channels
- 6 digital I/O channels with event detection interrupt
- 2.5, 3.3, 5V sensor excitation and low-power mode

SENSORS

Thermistor

Model: Cantherm CWF4B103G3380

Resistance in Ohms @ 25°C:	10kΩ
B25/50:	3380K
Operating Temperature:	-55°C ~ 125°C
Resistance Tolerance:	±2%
B Value Tolerance:	±2%

Air humidity (RH)

Model: Honeywell HIH-4030

Accuracy:	3.5 %
Repeatability:	±0.5 %
Settling time:	70 ms

Air velocity

Model: Omron D6F-V03A1

Operating temperature:	-10 ÷ 60 °C
Flow Range:	0 ÷ 3 m/s @ 25°C, 1 atmosphere

WEATHER STATION AND RASPBERRY Pi MICROCOMPUTER

The weather station installed on Palazzo D'Accursio is a PCE-FWS 20 (also known as Fine Offset WH\080/81) and it offers the following specifications:

- Touch screen panel
- USB port for connection to PC
- All the weather data from the base station and weather history data with user adjustable measuring intervals can be recorded and uploaded to your PC
- Rainfall data (inches or millimeters): 1-hour, 24-hour,one week,one month and total since last reset.
- Wind chill and Dew point temperature display (°F or °C)
- Records min. and max. wind chill and Dew point with time and date stamp
- Wind speed (mph, m/s, km/h, knots, Beaufort)
- Wind direction display with LCD compass
- Weather forecast tendency arrow
- Weather alarm modes for: a) Temperature b) Humidity c) Wind chill d) Dew point e) Rainfall f) Wind speed g) Air pressure h) Storm warning
- Forecast icons based on changing barometric pressure
- Barometric pressure (inHg or hPa) with 0.1hPa resolution
- Wireless outdoor and indoor humidity (% RH)
- Records min. and max. humidity with time and date stamp
- Wireless outdoor and indoor temperature (°F or °C)
- Records min. and max. temperature with time and date stamp
- Receive and displays the radio controlled time and date (WWVB, DCF version available)
- 12 or 24-hour time display
- Perpetual calendar
- Time zone setting
- Time alarm
- High light LED backlight
- Wall hanging or free standing
- Synchronized instant reception
- Low power consumption (over 2 years battery life for transmitter)

Set includes:

- Base station to be installed internally
- Four outdoor sensors: thermo-hydro transmitter, wind speed sensor, wind direction sensor and rain sensor

Specifications:

- Outdoor temperature range: -40.0 °C to + 65.0 °C (-40 °F to +149 °F), resolution 0.1 °C, accuracy 1 °C
- Indoor temperature range: 0 °C to + 50.0 °C (32 °F to +122 °F), resolution 0.1 °C, accuracy 1 °C
- Outdoor RH range: 10% to 99%, 1 % resolution, accuracy 5 %
- Rain volume display: 0 - 9999mm (show OFL if outside range), resolution : 0.3mm (if rain volume < 1000mm), 1mm (if rain volume > 1000mm)
- Wind speed: 0~100mph (show OFL if outside range)
- Measuring range air pressure: 27.13inHg - 31.89inHg, resolution: 0.01inHg
- Transmission range up to 100m (330 feet)
- Power consumption: a) Receiver: 3 x AA alkaline batteries (not included) b) Sensor WH7: 2 x AA alkaline batteries (not included)
- Transmission frequency: 433MHz,868MHz

As illustrated in the following photos, the weather station is linked via USB to a Raspberry microcomputer where data are stored.

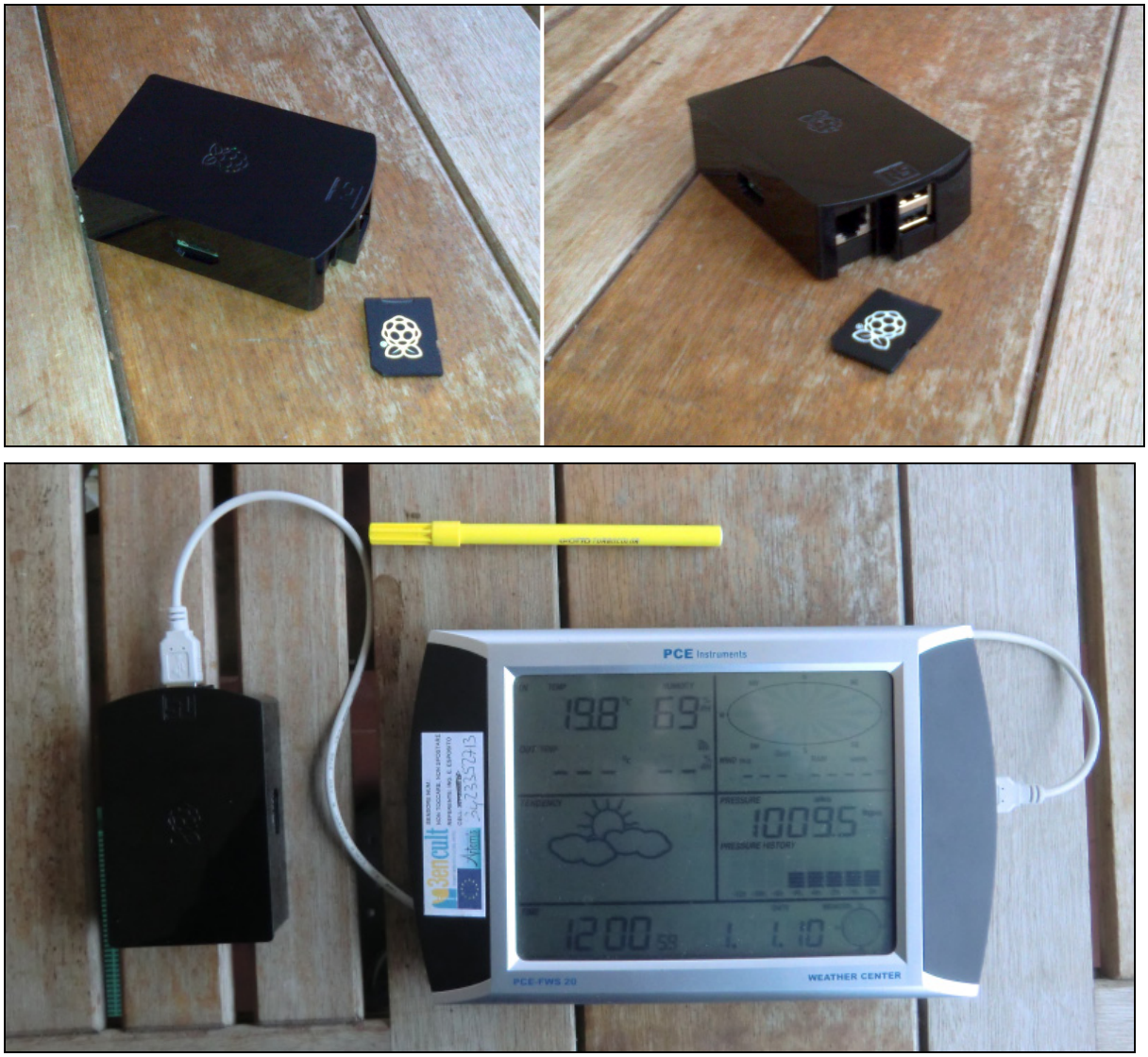


Figure 71: Weather station with USB linked Raspberry microcomputer.

The Raspberry Pi (http://www.raspberrypi.org/) is a credit-card-sized single-board computer (it measures 85.60mm x 56mm x 21mm, with a little overlap for the SD card and connectors which project over the edges and weighs 45g) developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools.

The Raspberry Pi is manufactured in two board configurations through licensed manufacturing deals with Newark element14 (Premier Farnell), RS Components and Egoman. These companies sell the Raspberry Pi online at about 35$, excluded case and power supply.

The Raspberry Pi has a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, and was originally shipped with 256 megabytes of RAM, now upgraded to 512 MB and it does not include a built-in hard disk or solid-state drive, but uses an SD card for booting and persistent storage.

The Foundation provides Debian and Arch Linux ARM distributions for download. Tools are available for Python as the main programming language, with support for BBC BASIC (via the RISC OS image or the Brandy Basic clone for Linux), C, Java and Perl.

The device is powered by 5 V micro USB. Exactly how much current (mA) the Raspberry Pi requires is dependent on what you hook up to it. Usually a 1.2A (1200mA) power supply will provide you with

ample power to run your Raspberry Pi. Typically, the model B uses between 700-1000mA depending on what peripherals are connected, and the lower performance model A can use as little as 500mA with no peripherals attached. The maximum power the Raspberry Pi can use is 1 Amp. If you need to connect a USB device that will take the power requirements of the Raspberry Pi above 1 Amp then you must connect it to an externally powered USB hub. The power requirements of the Raspberry Pi increase as you make use of the various interfaces on the Raspberry Pi. The GPIO pins can draw 50mA safely (that is 50mA distributed across all the pins! An individual GPIO pin can only safely draw 16mA), the HDMI port uses 50mA, the camera module requires 250mA, and keyboards and mice can take as little as 100μA or over 1000mA.

Figure 72: Raspberry Pi computer Model-B Rev1.

Raspberry hardware

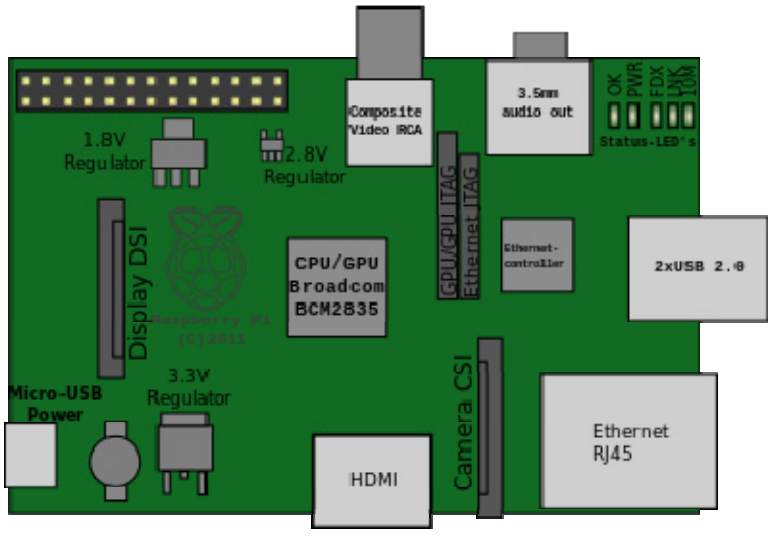


Figure 73: Location on the PCB of connectors and major ICs.

Initial sales were of the Model B, with Model A following in early 2013. Model A has one USB port and no Ethernet controller, and costs less than the Model B with two USB ports and a 10/100 Ethernet controller.

Though the Model A does not have an 8P8C (RJ45) Ethernet port, it can connect to a network by using an external user-supplied USB Ethernet or Wi-Fiadapter. On the model B the Ethernet port is provided by a built-in USB Ethernet adapter. As is typical of modern computers, generic USB keyboards and mice are compatible with the Raspberry Pi

The Raspberry Pi does not come with a real-time clock, so an OS must use a network time server, or ask the user for time information at boot time to get access to time and date for file time and date stamping. However, a real-time clock (such as the DS1307) with battery backup can be added via theI²C interface.

Performance & Overclocking

The Broadcom SoC used in the Raspberry Pi is equivalent to a chip used in a modern cellphone. While operating at at 700 MHz by default, the Raspberry Pi provides a real world performance roughly equivalent to the 0.3 GFLOPs of a 300MHz Pentium II of 1997-1999 on CPU level. TheGPU however provides 1Gpixel/s, 1.5Gtexel/s or 24 GFLOPs of general purpose compute and the graphics capabilities of the Raspberry Pi are roughly equivalent to the level of performance of the Xbox of 2001. The Raspberry Pi chip operating at at 700 MHz by default, will not become hot enough to need a heatsink or special cooling.

The LINPACK single node compute benchmark results in a mean single precision performance of 0.56 GFLOPs and a mean double precision performance of 0.41 GFLOPs for one Raspberry Pi Ver. B board. A cluster of 64 Raspberry Pi Ver. B computers, labeled "Iridis-pi", achieved a LINPACK HPL suite result of 1.14 GFLOPs (n=10240) at 216 Watts for c. 4,000 $US.

Most Raspberry Pi devices can be overclocked to 800MHz and some even higher to 1000 MHz. Via the Raspbian Linux distro the overclocking options on boot can be done by a software command running “sudo raspi-config” without voiding the warranty. In case of issues, the overclocking settings can be reduced until stability is restored, or one can put an appropriately sized heatsink on it.

Raspbian

After cycling through several recommendations since just before the hardware was first made available, the Raspberry Pi Foundation created the New Out Of Box System (NOOBS) installer, and as of July 2013 suggests using it to install the Debian-derived Raspbian.

Raspbian is a Debian-based free operating system optimized for the Raspberry Pi hardware. It is the current recommended system, and was officially released in July 2012, although it is still in development. It is free software and maintained independently of the Raspberry Pi Foundation. It is based on ARM hard-float (armhf)-Debian 7 'Wheezy' architecture port with the LXDE desktop environment, but optimized for the ARMv6 instruction set of the Raspberry Pi, which lacks Jazelle RCT/ThumbEE, VFPv3 and the NEON SIMD extension. It provides some available deb software packages, pre-compiled software bundles. A minimum size of 2 GB SD card is required for Raspbian, but a 4 GB SD card or above is recommended. The downloaded Raspbian Wheezy image file has to be unzipped and then written to a suitable SD card, formatting it for use (Artemis srl installed Raspbian on its Raspberry Pi Model B).

Data are collected by the Raspberry using a Python based software called **weewx**.

weewx - http://www.weewx.com/ - is a free, open source, software program, written in Python, which interacts with your weather station to produce graphs, reports, and HTML pages. It can optionally publish to weather sites or web servers. It uses modern software concepts, making it simple, robust, and easy to extend. It includes extensive documentation. The project is hosted at SourceForge.

weewx is small, with under 10,000 lines of code, and well-documented, with over 6000 lines of comments and runs under most versions of Linux, as well as Mac OS X and Solaris. Many users are running on the Raspberry Pi..

Key features:

- Support for many popular weather stations;
- Uploads to weather sites including WeatherUnderground, PWSweather.com, CWOP, WOW, and AWEKAS;
- Uploads to your website using FTP or rsync;
- Extensive celestial almanac;
- Ability to create or modify skins (the look and feel of your weather site);
- Support for localization;
- Simple, but extensible templating system;
- Native support for US or Metric unit systems;

- Support for sqlite or MySQL databases;
- Calibration corrections;
- Filtering of anomalous values;
- An easy to understand, simple, extensible micro-kernel architecture;
- Ability to extend weewx with new services and reports.

Weewx uses a sqlite3 database to store data and it can be easily managed by the Mozilla Firefox SQLite Manager add-on. There are two databases used by weewx, which can be implemented either by using SQLITE3, an open-source, lightweight SQL database, or MySQL, an open-source, full-featured database server, or some combination of the two of them. The archive database, given symbolic name 'archive_database' is a big flat table, one record for each archive interval, keyed by dateTime, the time at the end of the archive interval, while the statistical database, given symbolic name 'stats_database', consists of a separate table for each observation type (that is, one for 'outTemp', one for 'barometer', etc.), each containing one record per day, keyed by the start time of the day. The important thing to remember is that the archive database contains a record for every archive interval and, as such, represents the current conditions at the time of the observation. By contrast, the statistical database represents the aggregation of conditions over a day. That is, it contains the daily minimum, maximum, and the time of the minimum and maximum, for each observation type. As you can imagine, the statistical database is much smaller because it represents only a summary of the data.

The archive database is used for both generating plot data and in template generation (where it appears as tag $current). The statistical database is used only in template generation (where it appears as tags $day, $week, $month, $year, and $rainyear, depending on the aggregation time period).

Z-WAVE DOMOTIC NETWORK

The Z-Wave protocol is an interoperable wireless RF-based communications technology designed specifically for control, monitoring and status reading applications in residential and light commercial environments.

Z-wave offers the following features:

- Low Powered RF communications technology that supports full mesh networks without the need for a coordinator node;
- Operates in the sub-1GHz band; impervious to interference from Wi-Fi and other wireless technologies in the 2.4-GHz range (Bluetooth, ZigBee, etc.);
- Designed specifically for control and status apps, supports data rates of up to 100kbps, with AES125 encryption, IPV6, and multi-channel operation;
- The physical and media access layers (MAC and PHY) are described by ITU-T G.9959 specification;
- Full interoperability through layer 5 with backwards compatibility to all versions;
- Successfully bridged and trialed with OpenADR, SEP 1, SEP 1.1 and other Smart Energy protocols;
- Shares the same position in the NIST / SGIP Catalog of Standards as the IEEE 802.11 and 802.15 and 802.16 families.

Each Z-Wave network may include up to 232 nodes, and consists of two sets of nodes: controllers and slave devices. Nodes may be configured to retransmit the message in order to guarantee connectivity in the multipath environment of a residential house. Average communication range between two nodes is 30.5 m (100 ft), and with message ability to hop up to four times between nodes, this gives enough coverage for most residential houses.

As of 2013, Z-Wave is supported by over 160 manufacturers worldwide that offer more than 900 different products certified by the Z-Wave Alliance - http://www.z-wavealliance.org/.

Topology and routing

Each Z-Wave network is identified by a Network ID, and each device is further identified by a Node ID. The Network ID is the common identification of all nodes belonging to one logical Z-Wave network and has a length of 4 bytes (32 bits) and is assigned to each device, by the primary controller, when the device is "included" into the Network. Nodes with different Network ID's cannot communicate with each other. The Node ID is the address of a single node in the network and has a length of 1 byte (8 bits). It is not allowed to have two nodes with identical Node ID on a Network.

Z-Wave uses a source-routed mesh network topology, and has one Primary Controller and zero or more Secondary Controllers that control routing and security. Devices can communicate to one another by using intermediate nodes to actively route around and circumvent household obstacles or radio dead spots that might occur. A message from node A to node C can be successfully delivered even if the two nodes are not within range, providing that a third node B can communicate with nodes A and C. If the preferred route is unavailable, the message originator will attempt other routes until a path is found to the C node. Therefore, a Z-Wave network can span much farther than the radio range of a single unit; however, with several of these hops a slight delay may be introduced between the control command and the desired result.

In order for Z-Wave units to be able to route unsolicited messages, they cannot be in sleep mode. Therefore, battery-operated devices are not designed as repeater units. A Z-Wave network can consist of up to 232 devices, with the option of bridging networks if more devices are required.

As a source-routed static network, Z-Wave assumes that all devices in the network remain in their original detected position. Mobile devices, such as remote controls, are therefore excluded from routing. In later versions of Z-Wave, new network discovery mechanisms were introduced. So-called "explorer frames" can be used to heal broken routes caused by devices that have been moved or removed. Explorer frames are broadcast with a pruning algorithm and are therefore supposed to reach the target device, even without further topology knowledge by the transmitter. Explorer frames are used as a last option by the sending device when all other routing attempts have failed.

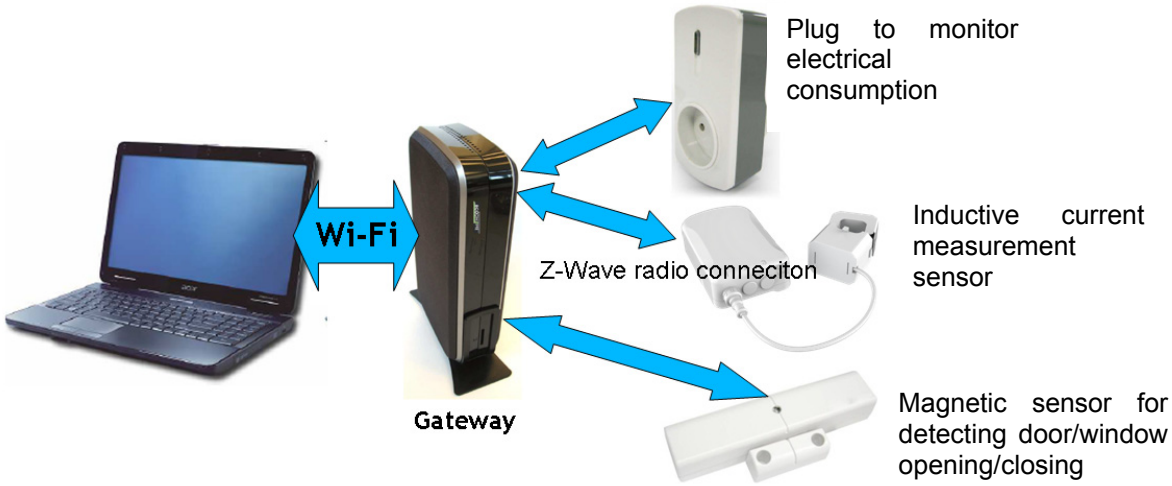


Figure 74: A Z-Wave domotic network schematic.

In Palazzo D'Accursio a full featured Z-Wave network has been installed in the offices area, including the following sensors:

”Virtuoso” gateway: it is a self-contained Linux-based PC that collects data from sensors

Actuating and measuring plug

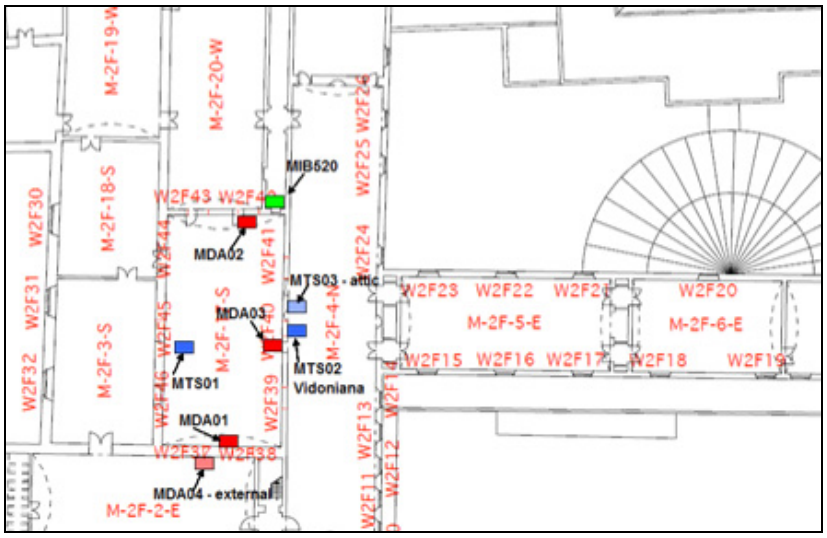
Inductive current measuring sensor (3-phase, 380 V)

Magnetic (reed) sensor for windows/doors opening/closing detection

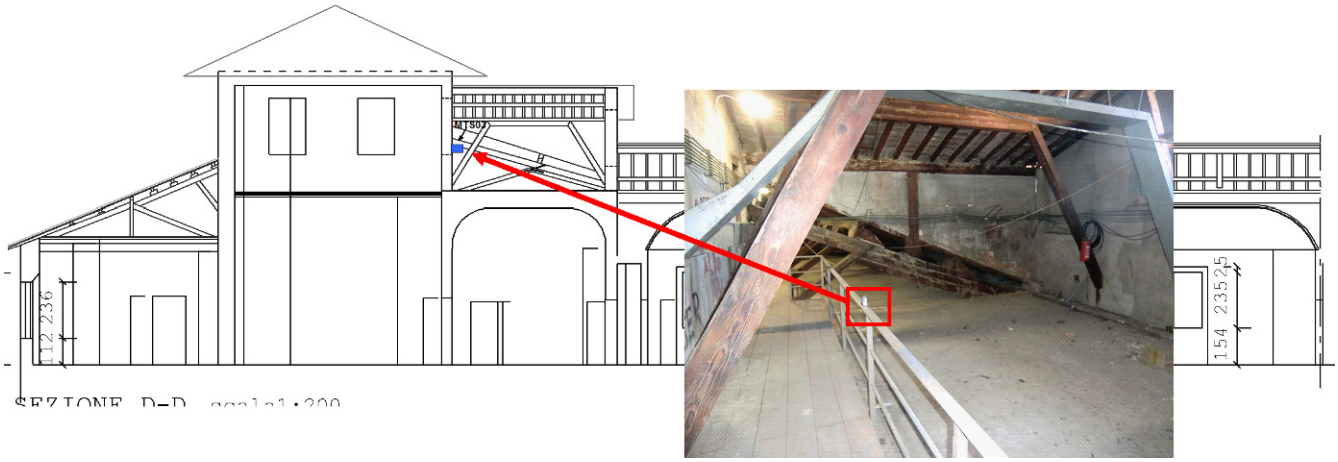
8 Annex 2 – WSN monitoring results

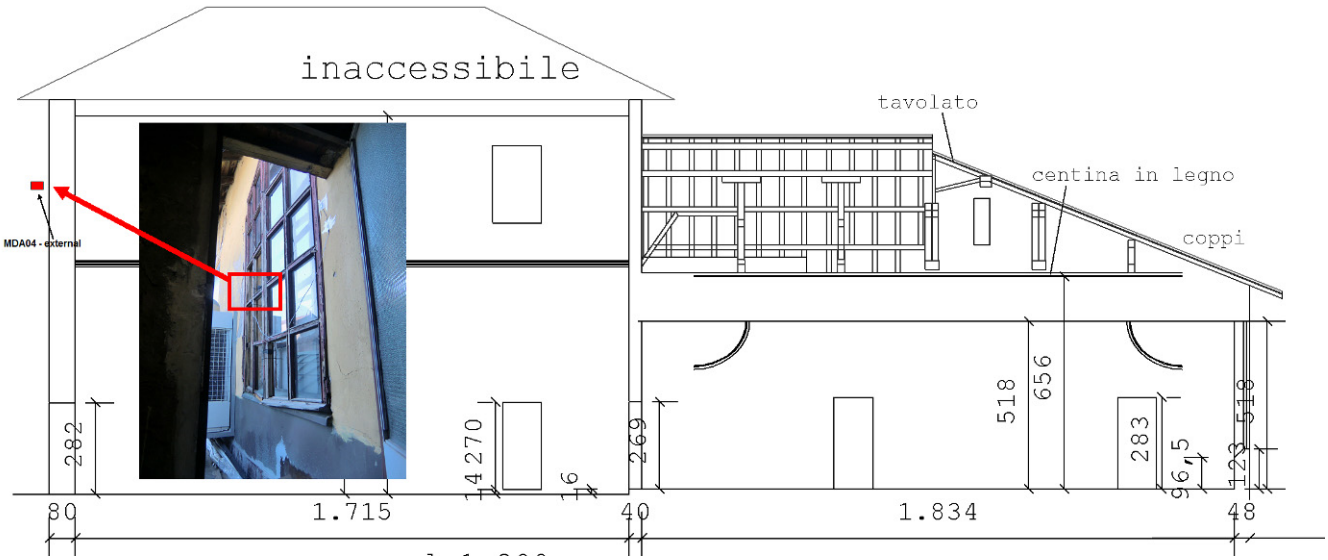
CIVIC COLLECTIONS

August 2011

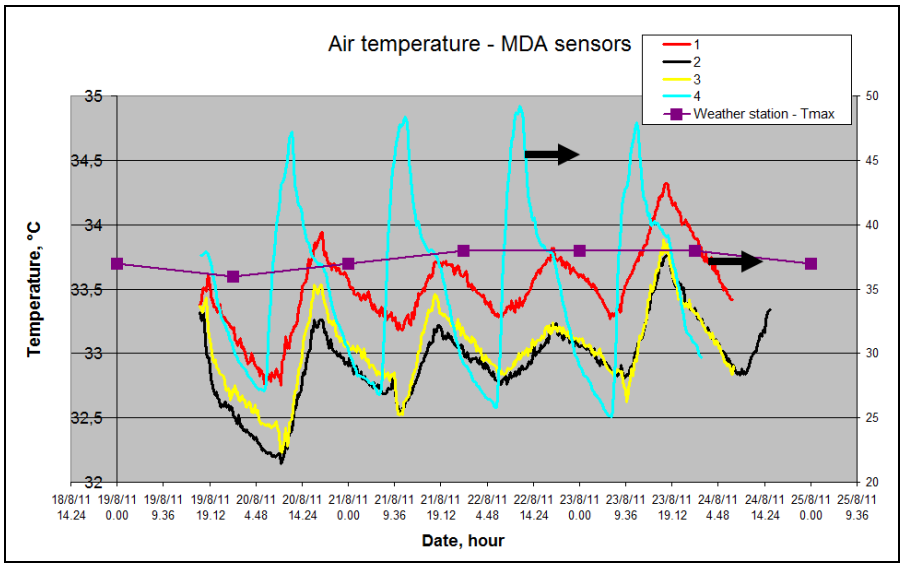


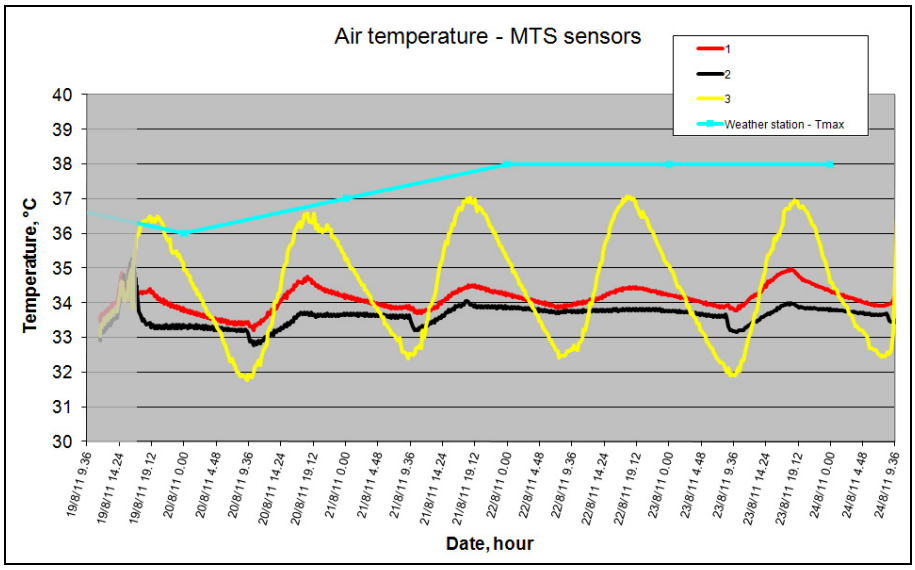
Map of nodes

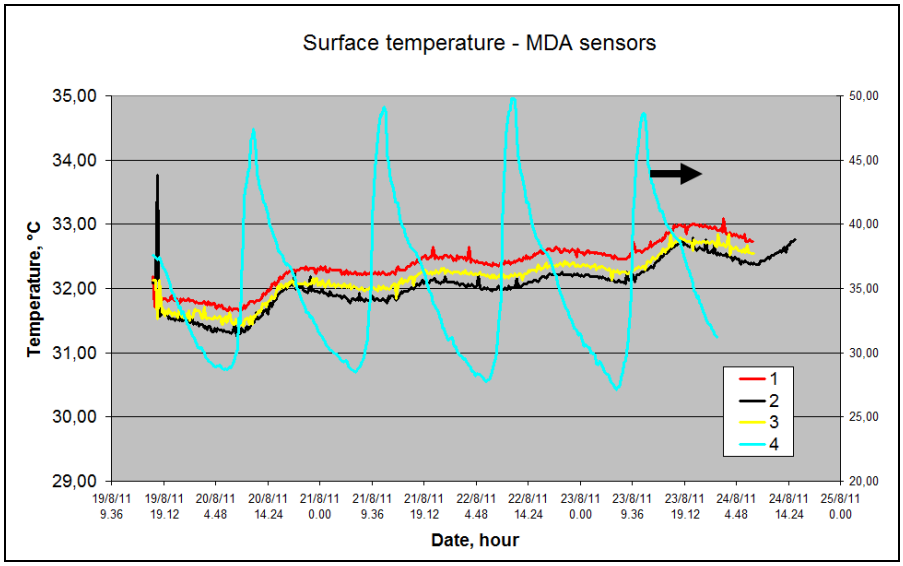


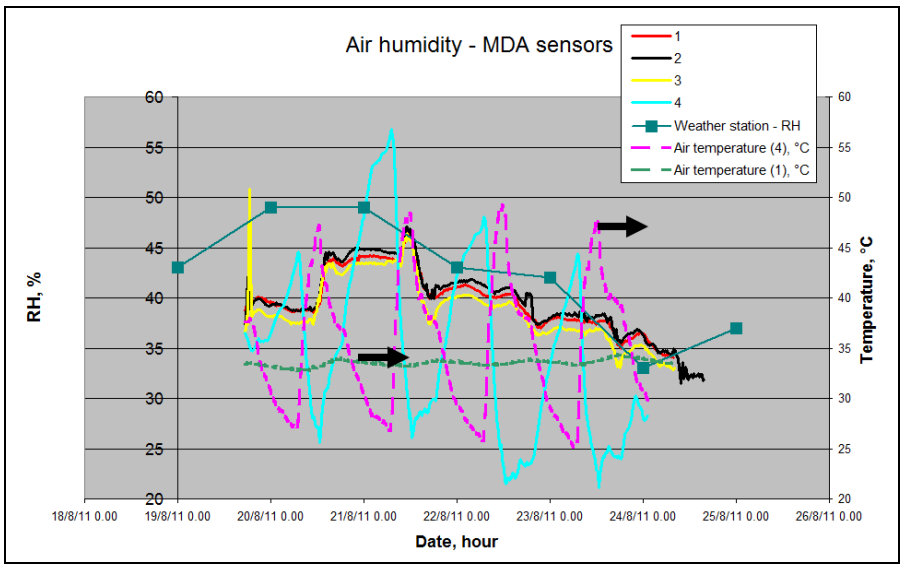


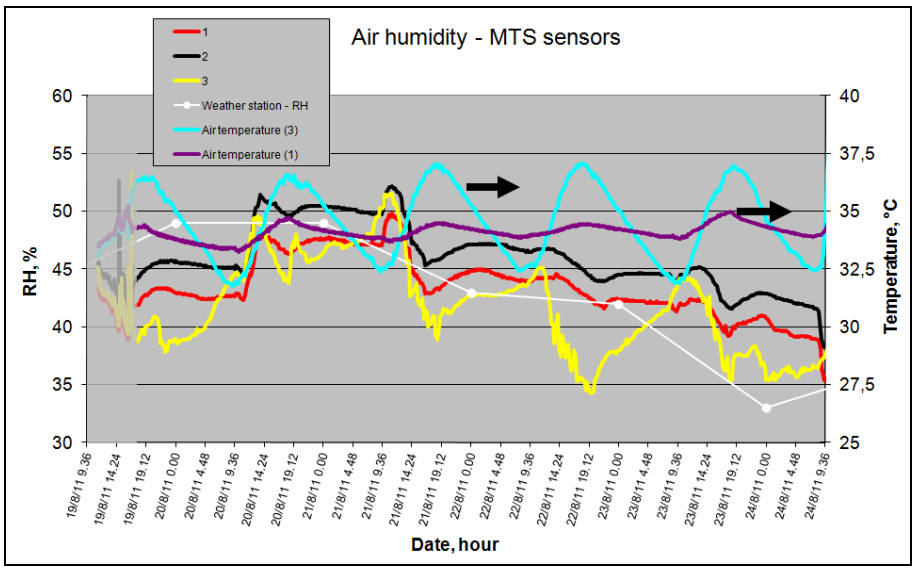
Positions of nodes MTS03, MDA01…04.



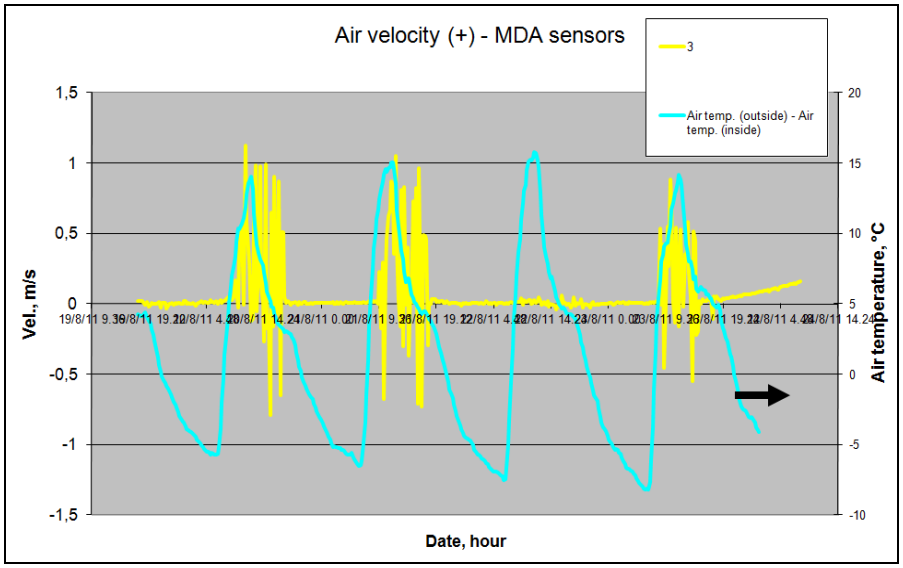


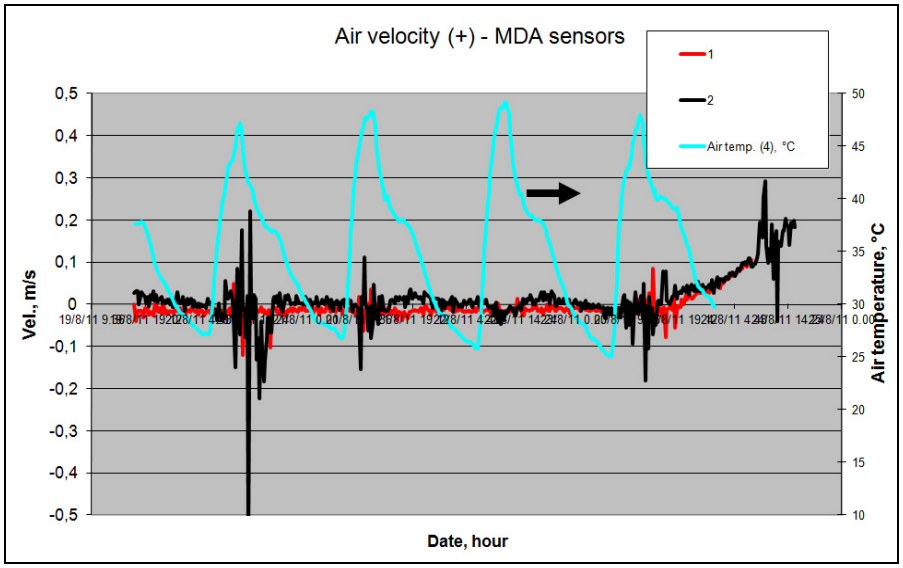

Surface temperature - MDA sensors
Temperature, °C
Date, hour
1
2
3
4

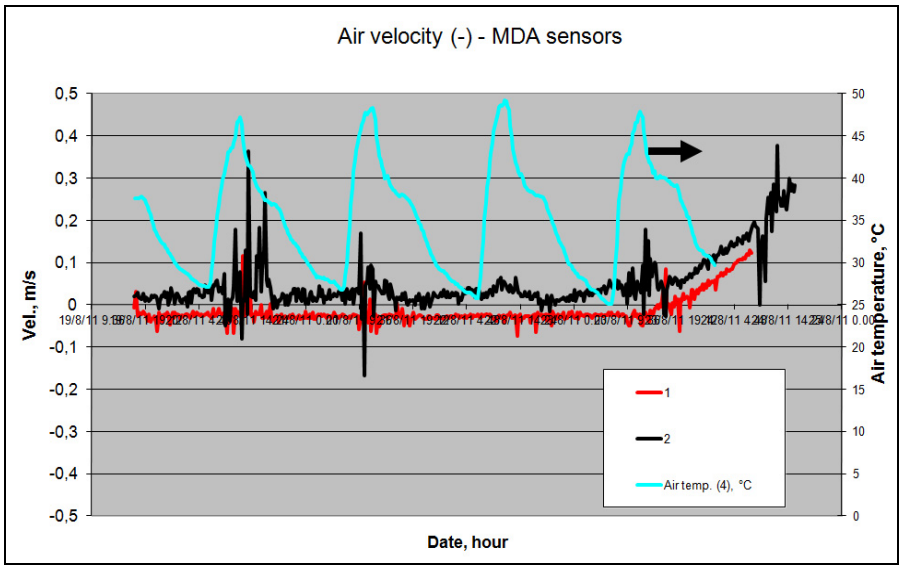

Air humidity - MDA sensors
RH, %
Temperature, °C
Date, hour
1
2
3
4
Weather station - RH
Air temperature (4), °C
Air temperature (1), °C


Air humidity - MTS sensors
RH, %
Temperature, °C
Date, hour
1
2
3
Weather station - RH
Air temperature (3)
Air temperature (1)

Deliverable D6.2 Documentation of each study case

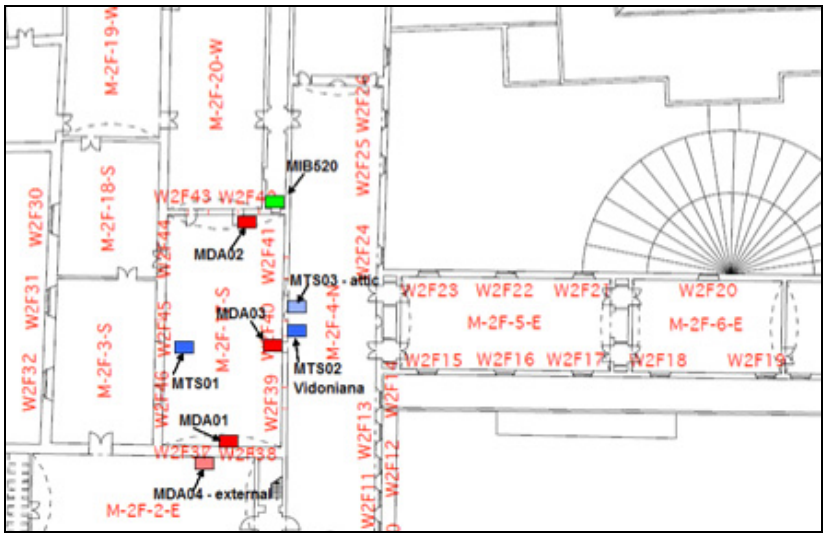




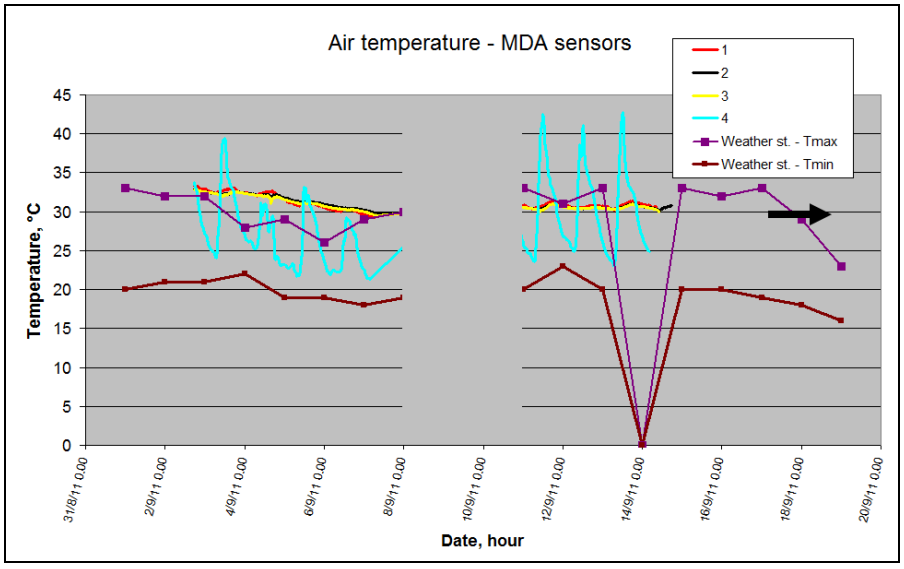


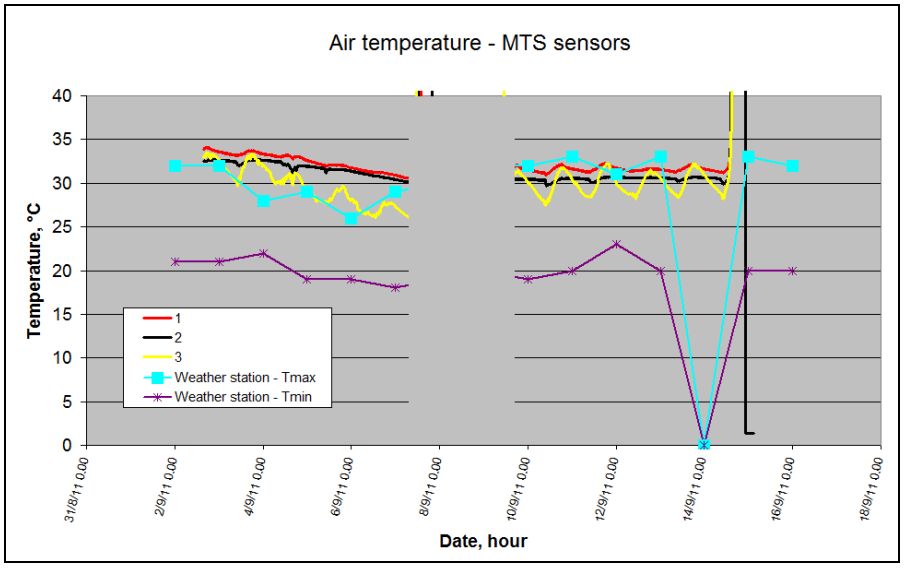
August 2011 - Graphs of data from monitoring in Civic Collections.

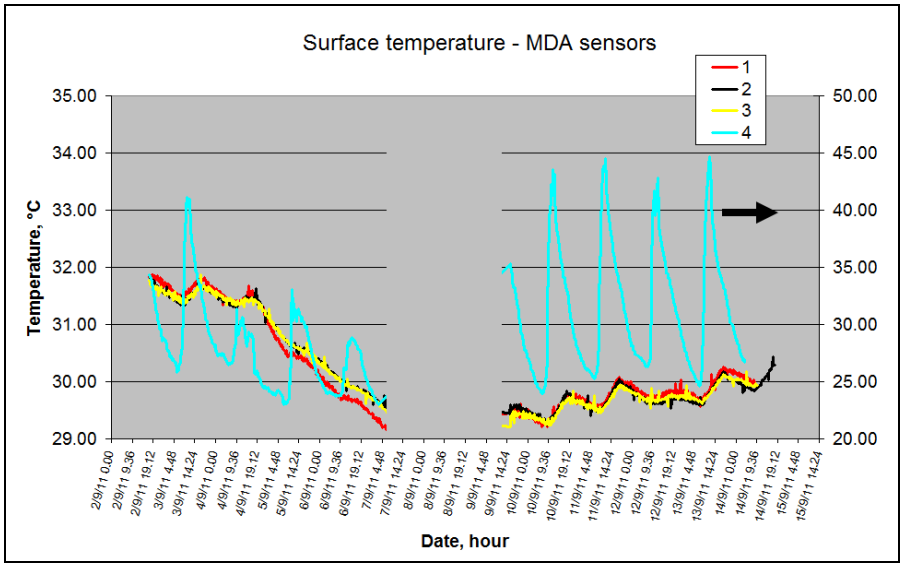
September 2011

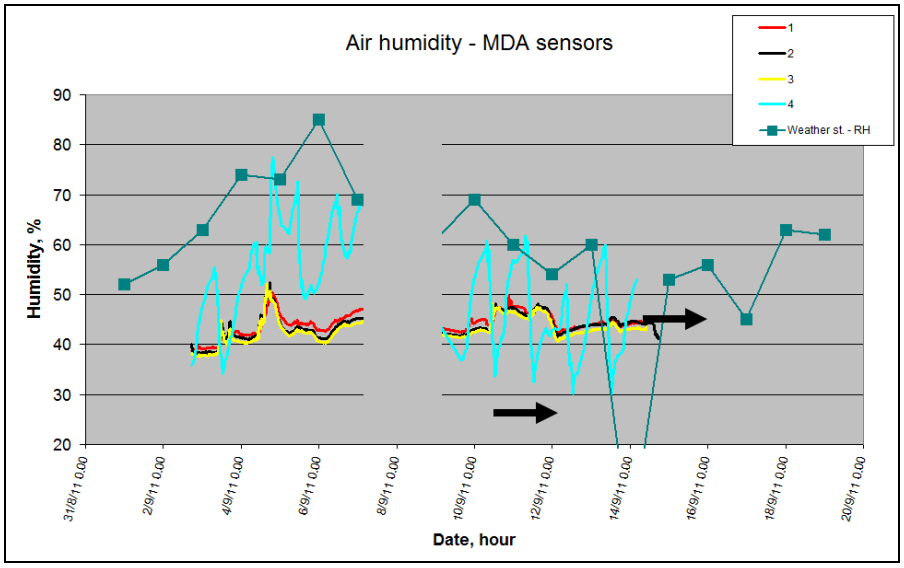


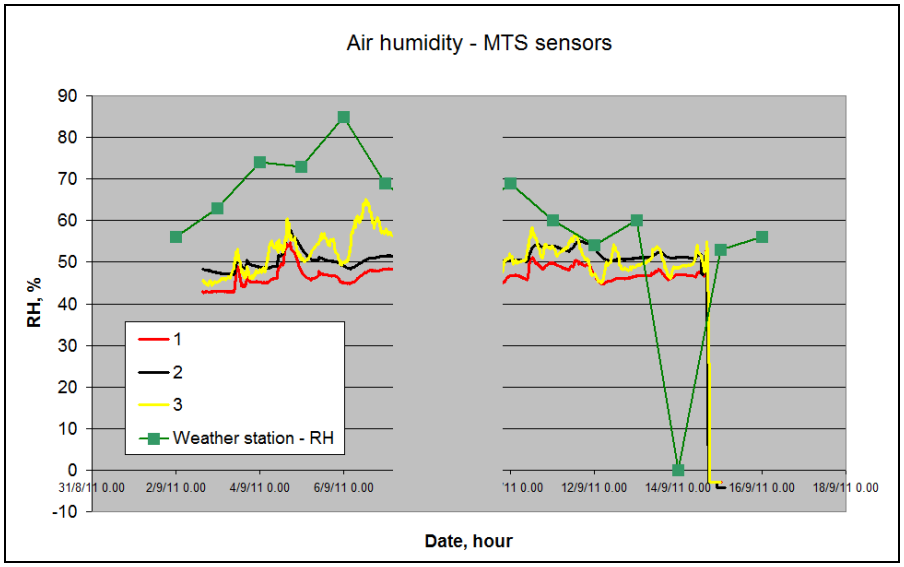
Map of nodes







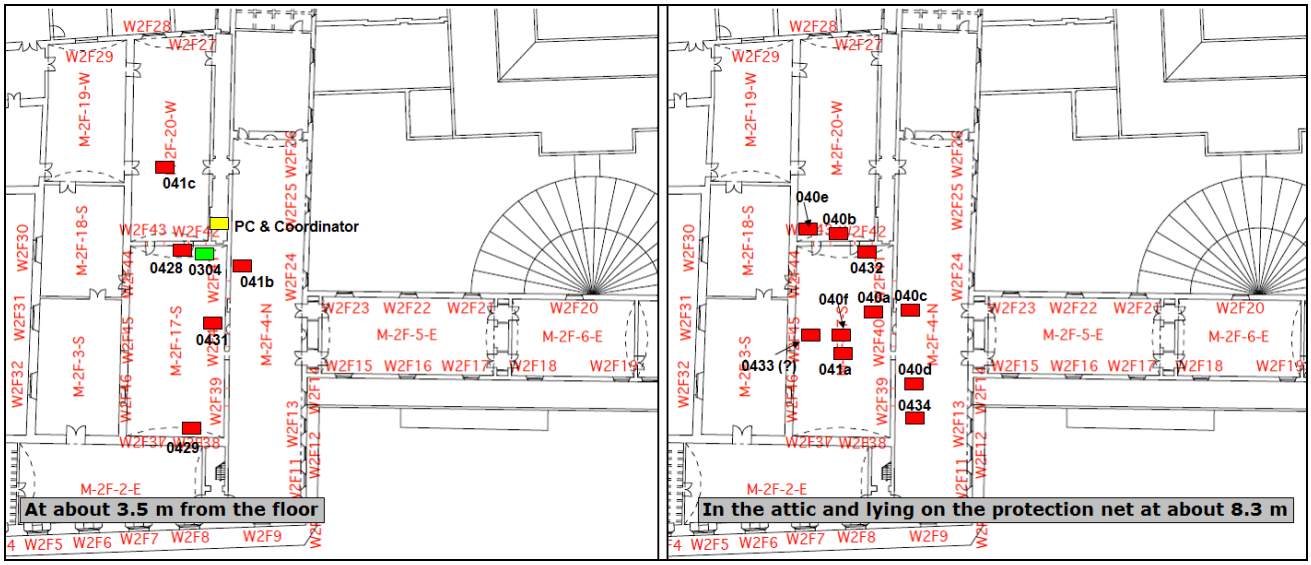




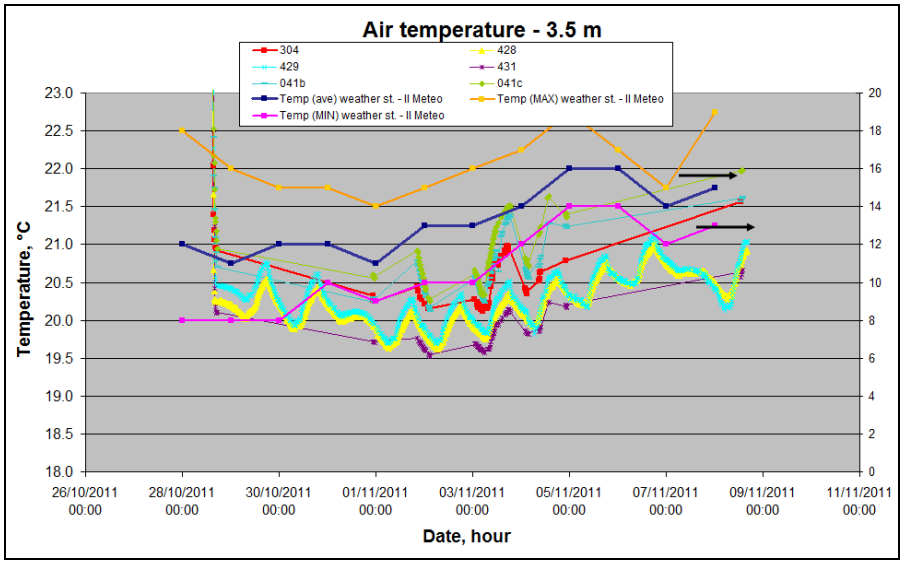
September 2011 - Graphs of data from monitoring in Civic Collections.

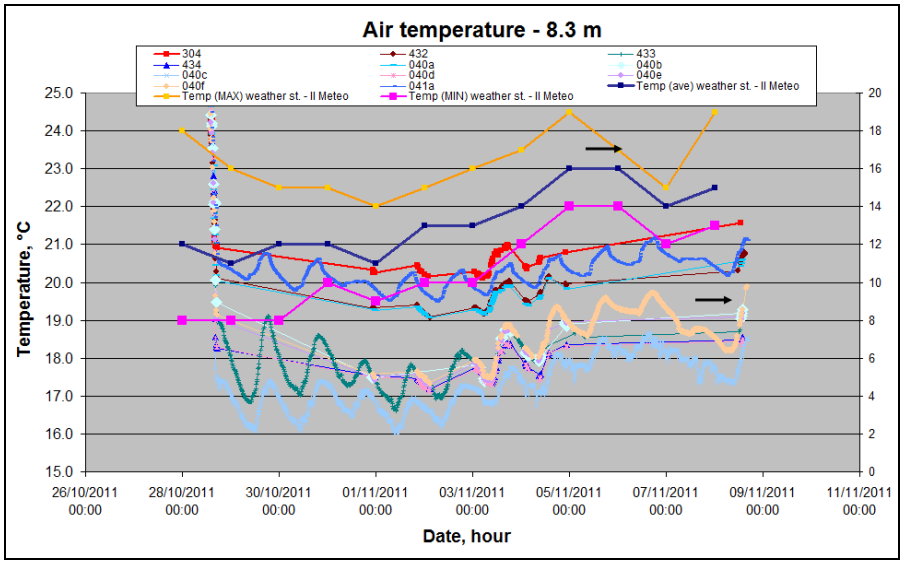
Deliverable D6.2 Documentation of each study case

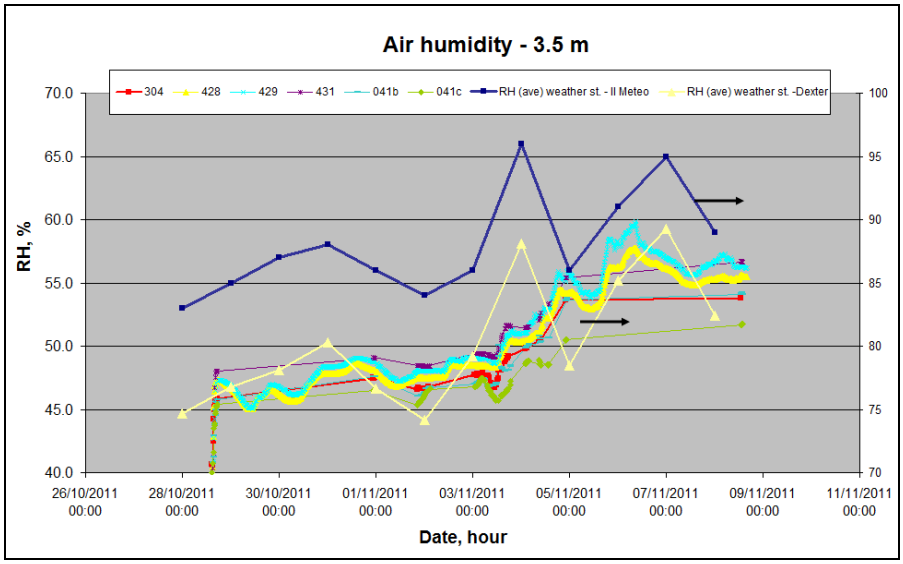
October-November 2011

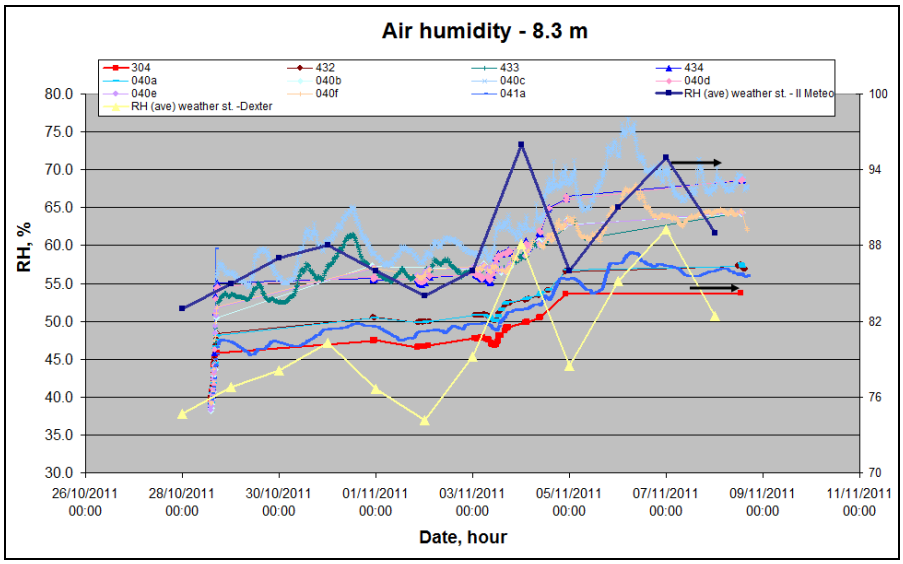


Map of nodes





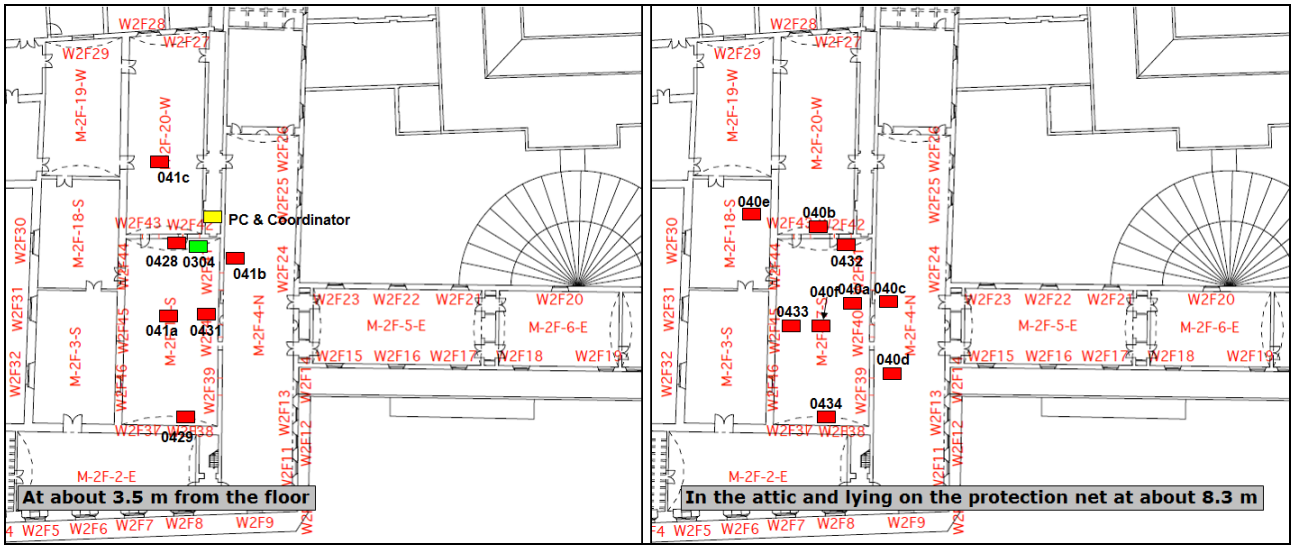




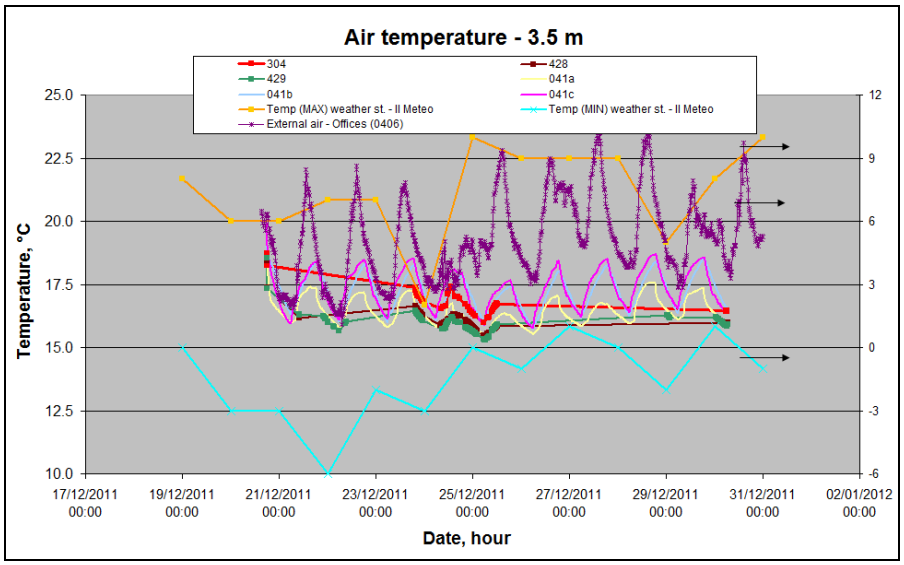
October-November 2011 - Graphs of data from monitoring in Civic Collections.

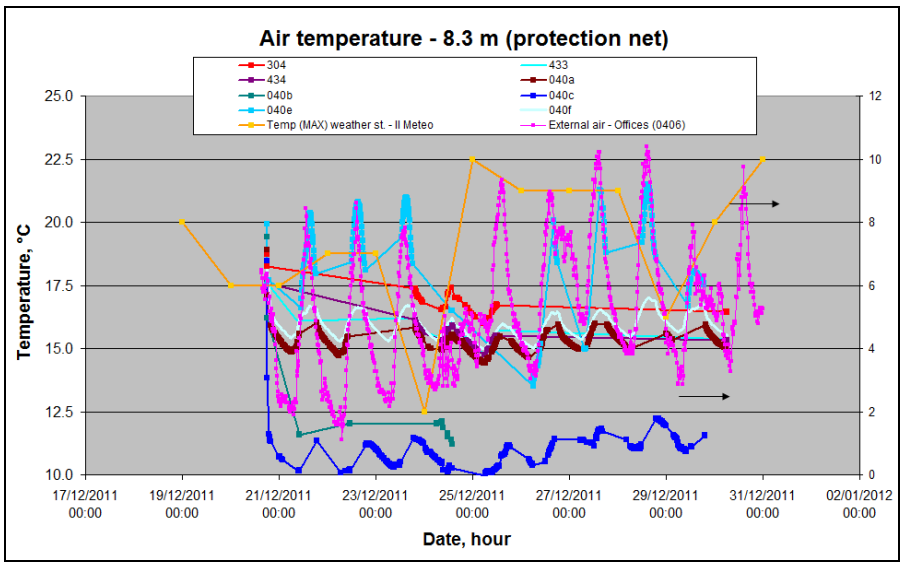
Deliverable D6.2 Documentation of each study case

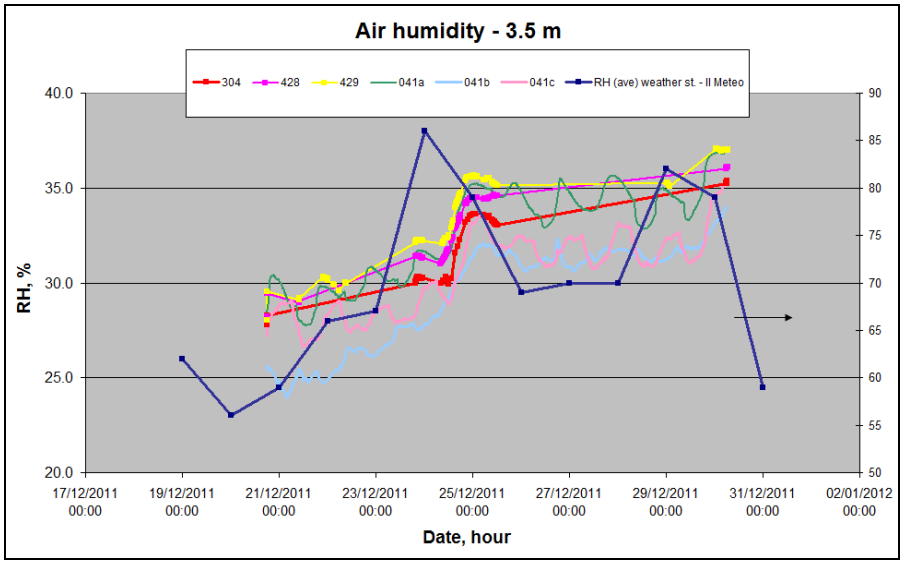
December 2011

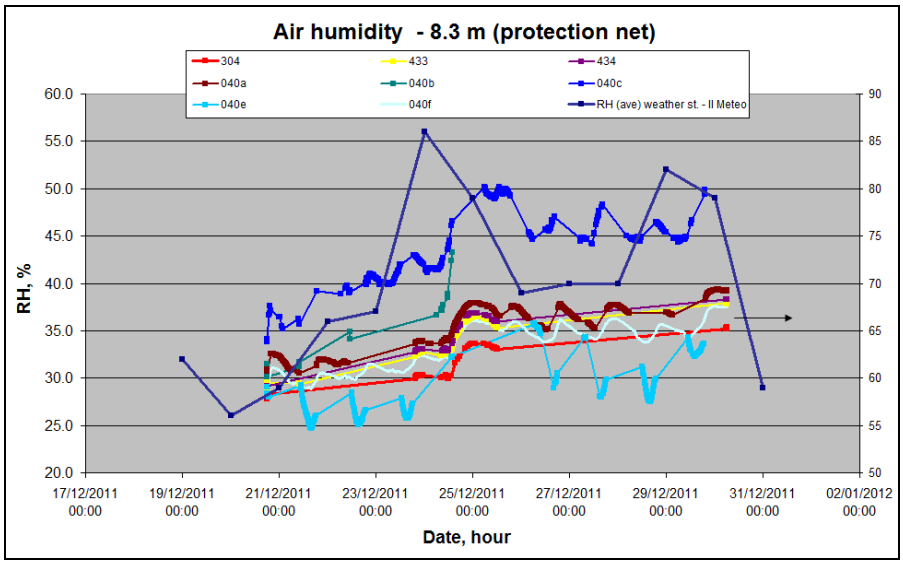


Map of nodes





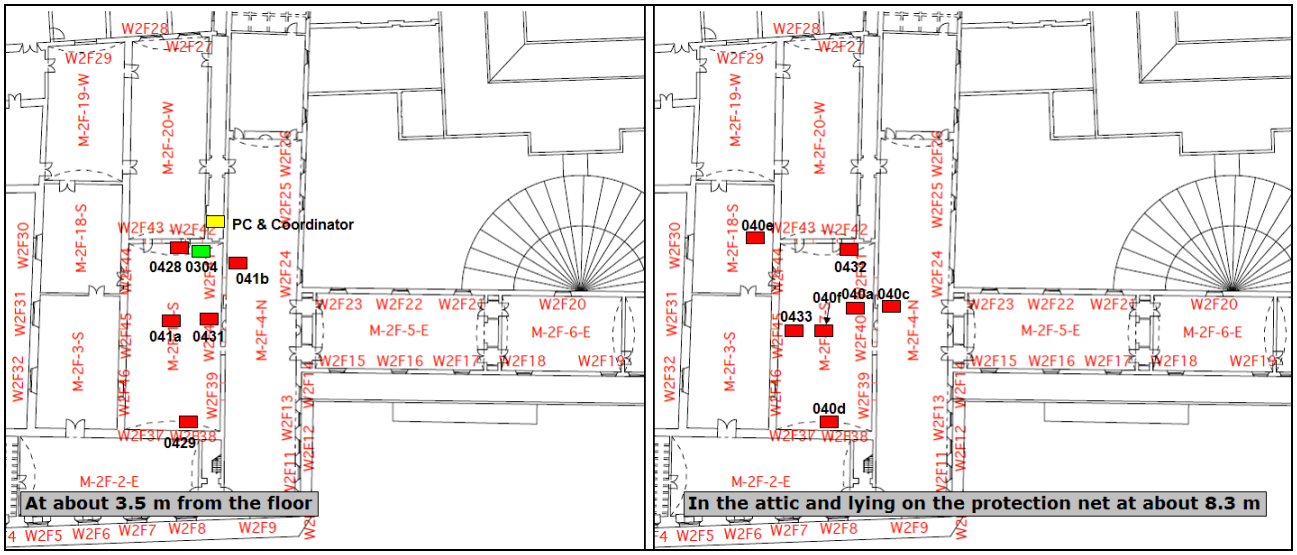




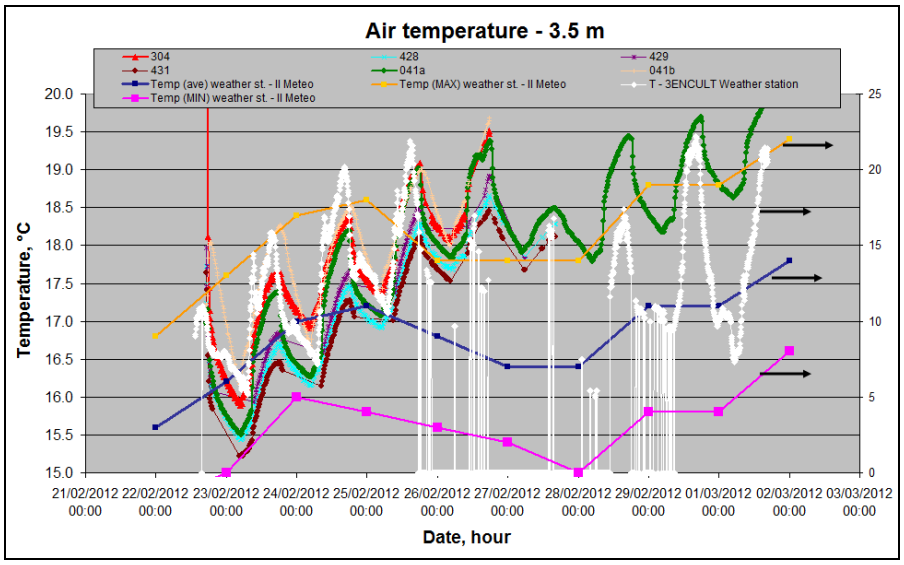
December 2011 - Graphs of data from monitoring in Civic Collections.

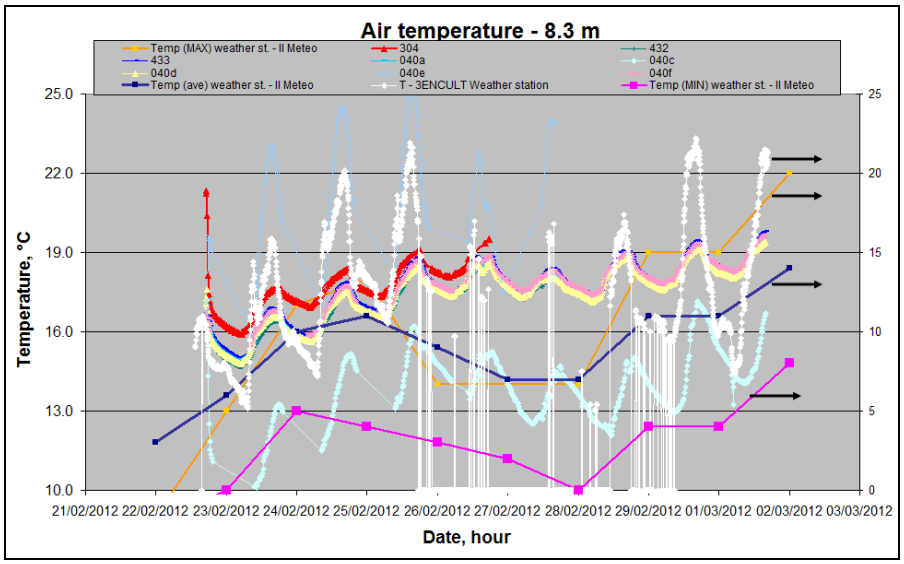
Deliverable D6.2 Documentation of each study case

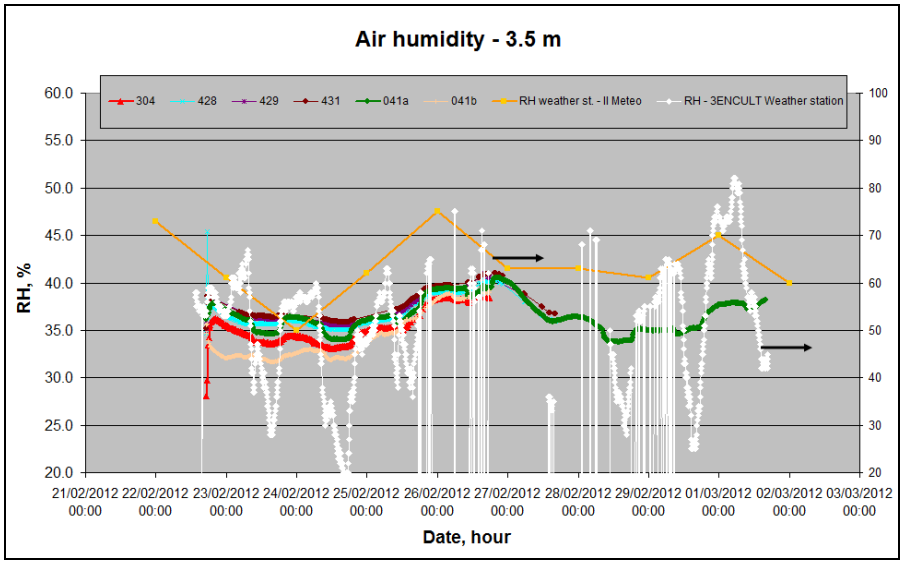
February 2012

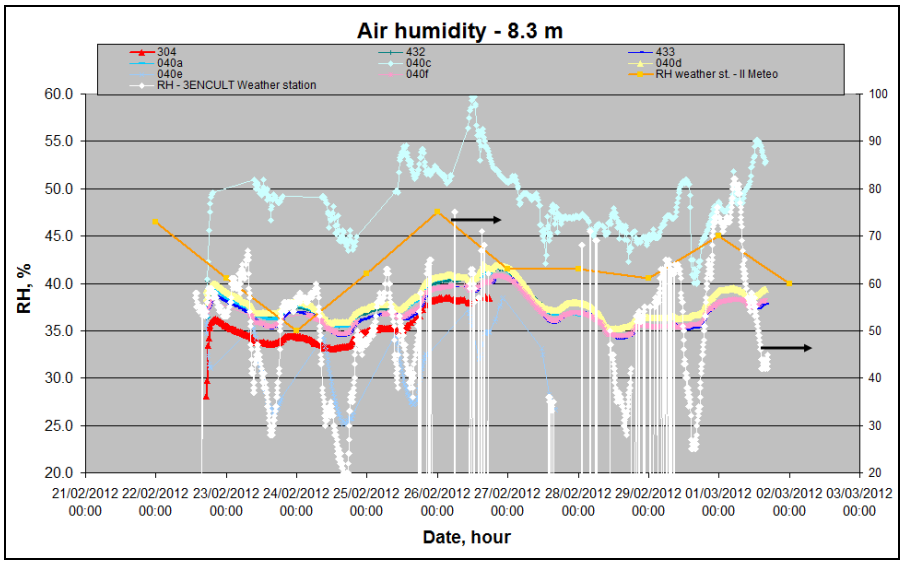


Map of nodes









February 2012 - Graphs of data from monitoring in Civic Collections.

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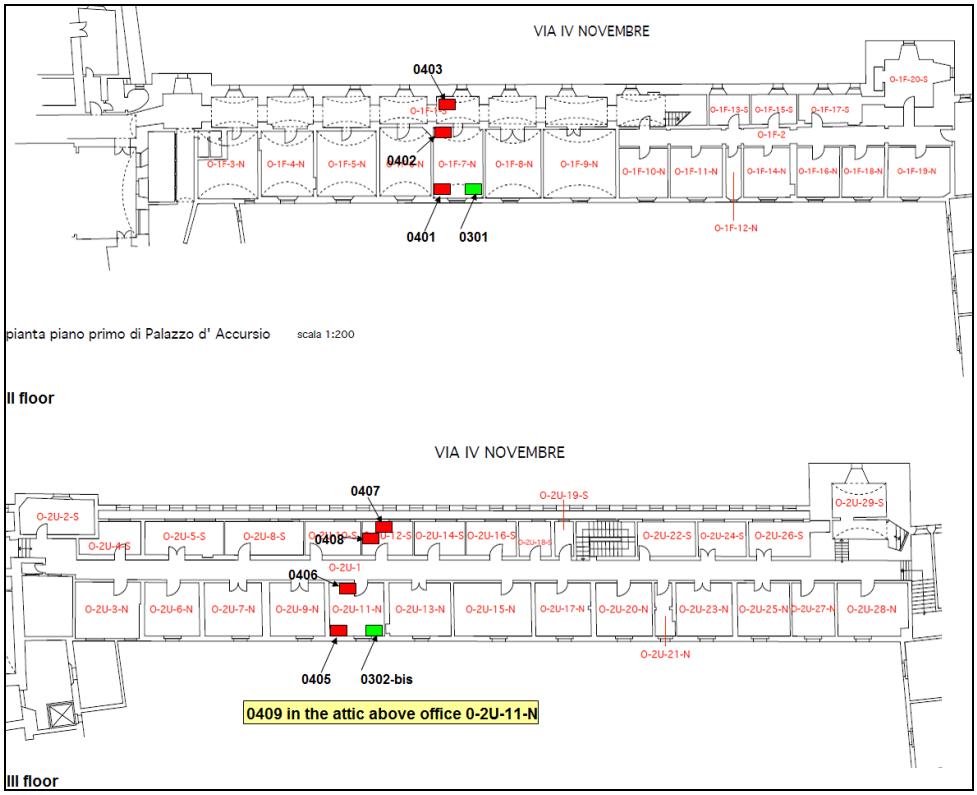
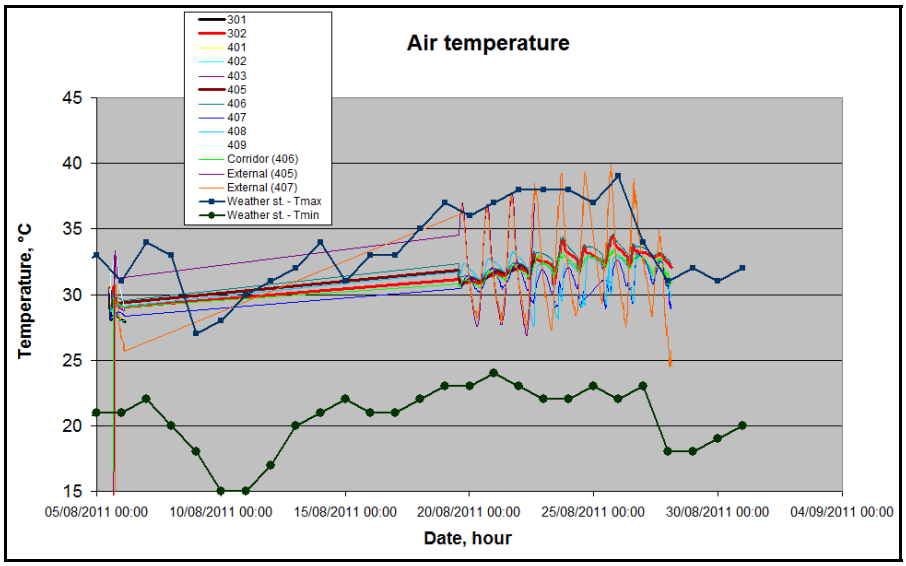
OFFICES

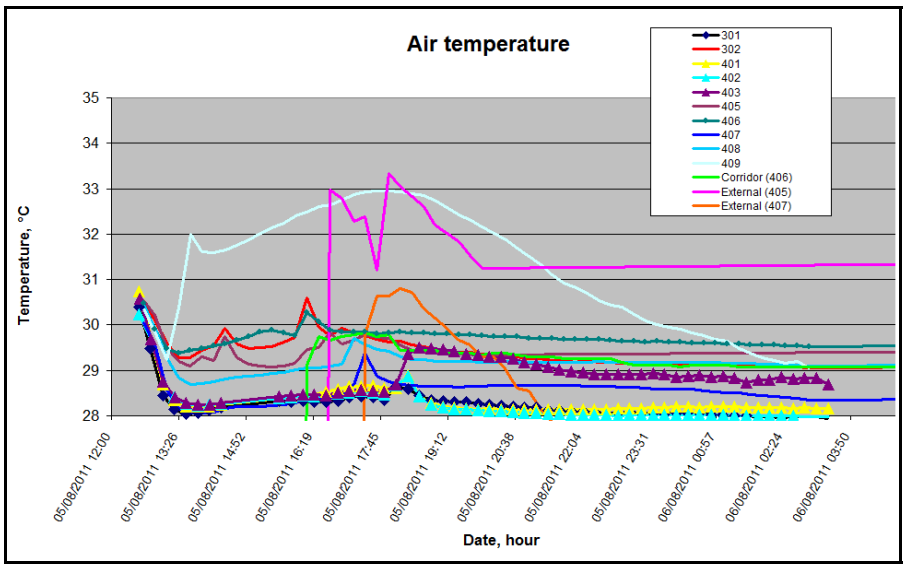
August 2011

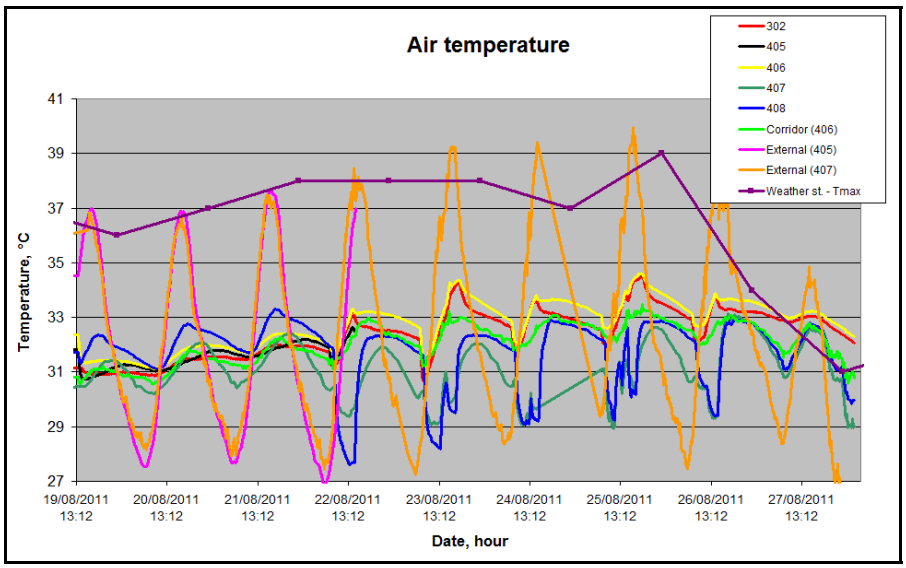


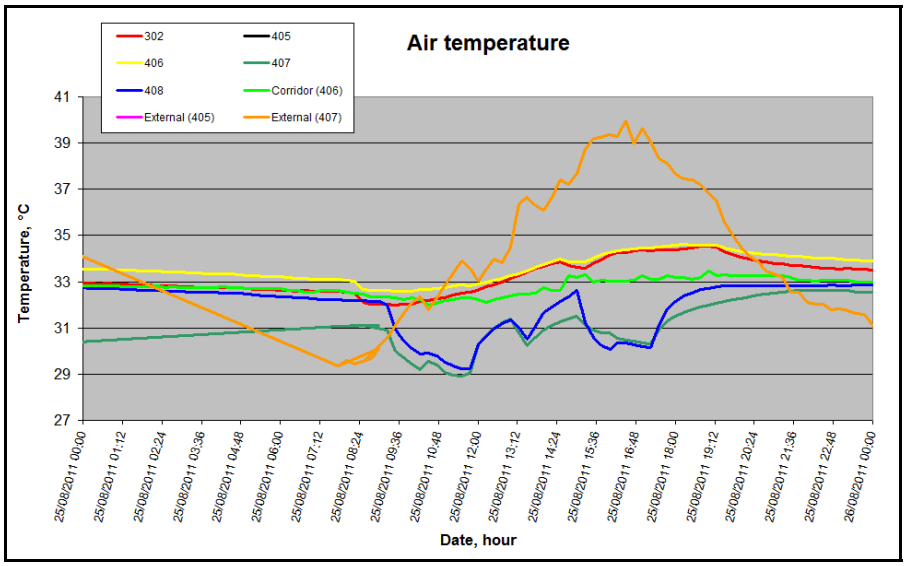
Map of nodes

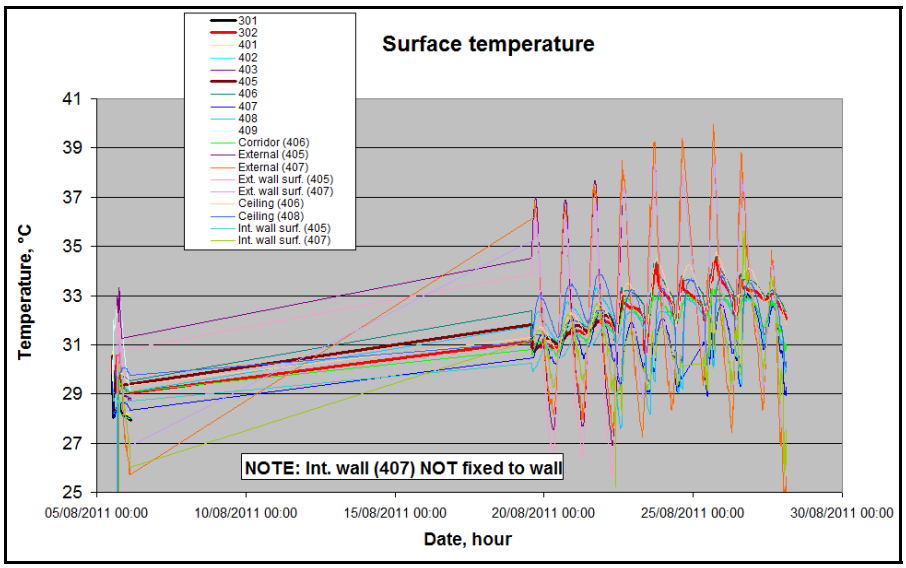
Positions of node 0407 with attached sensors.

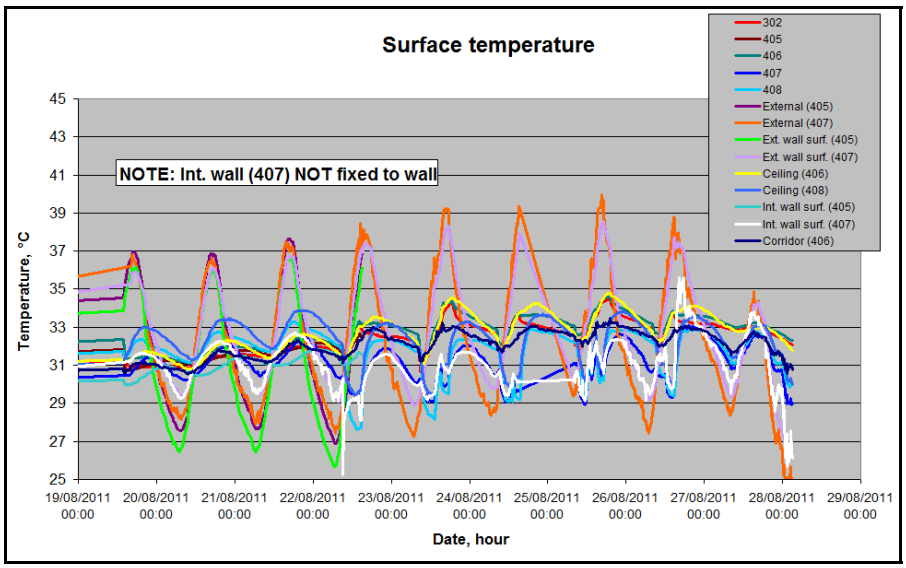

Air temperature
301
302
401
402
403
405
406
407
408
409
Corridor (406)
External (405)
External (407)
Weather st. - Tmax
Weather st. - Tmin
Temperature, °C
45
40
35
30
25
20
15
05/08/2011 00:00
10/08/2011 00:00
15/08/2011 00:00
20/08/2011 00:00
25/08/2011 00:00
30/08/2011 00:00
04/09/2011 00:00
Date, hour

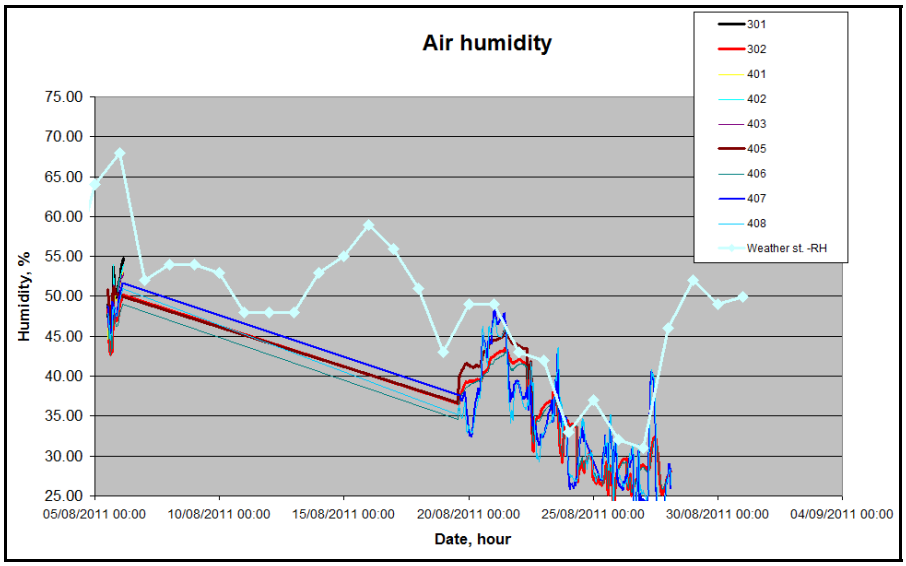

Air temperature
301
302
401
402
403
405
406
407
408
409
Corridor (406)
External (405)
External (407)
Temperature, °C
35
34
33
32
31
30
29
28
05/08/2011 12:00
05/08/2011 13:26
05/08/2011 14:52
05/08/2011 16:19
05/08/2011 17:45
05/08/2011 19:12
05/08/2011 20:38
05/08/2011 22:04
05/08/2011 23:31
06/08/2011 00:57
06/08/2011 02:24
06/08/2011 03:50
Date, hour

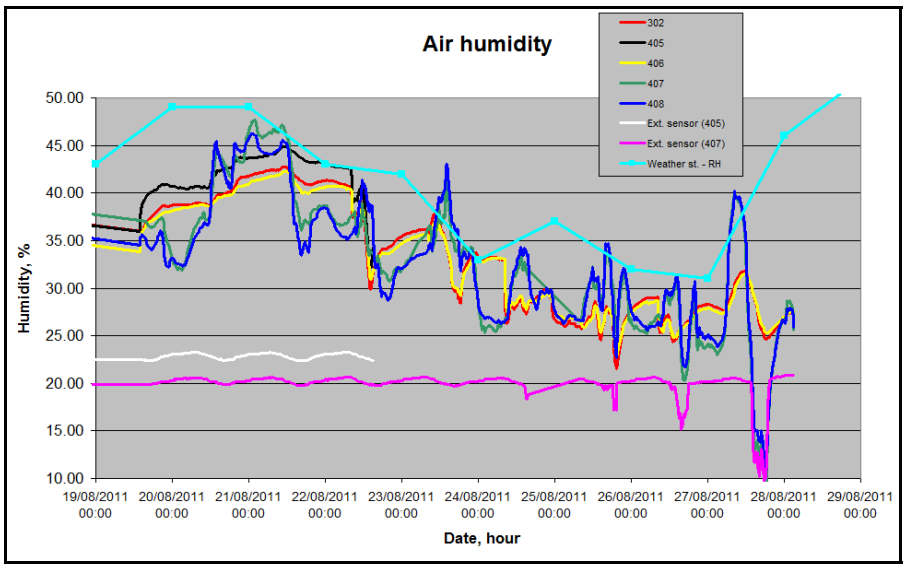

Air temperature
302
405
406
407
408
Corridor (406)
External (405)
External (407)
Weather st. - Tmax
Temperature, °C
41
39
37
35
33
31
29
27
19/08/2011 13:12
20/08/2011 13:12
21/08/2011 13:12
22/08/2011 13:12
23/08/2011 13:12
24/08/2011 13:12
25/08/2011 13:12
26/08/2011 13:12
27/08/2011 13:12
Date, hour


Air temperature
302
405
406
407
408
Corridor (406)
External (405)
External (407)
Temperature, °C
Date, hour


Surface temperature
301
302
401
402
403
405
406
407
408
409
Corridor (406)
External (405)
External (407)
Ext. wall surf. (405)
Ext. wall surf. (407)
Ceiling (406)
Ceiling (408)
Int. wall surf. (405)
Int. wall surf. (407)
NOTE: Int. wall (407) NOT fixed to wall
Temperature, °C
Date, hour


Surface temperature
302
405
406
407
408
External (405)
External (407)
Ext. wall surf. (405)
Ext. wall surf. (407)
Ceiling (406)
Ceiling (408)
Int. wall surf. (405)
Int. wall surf. (407)
Corridor (406)
NOTE: Int. wall (407) NOT fixed to wall
Temperature, °C
Date, hour



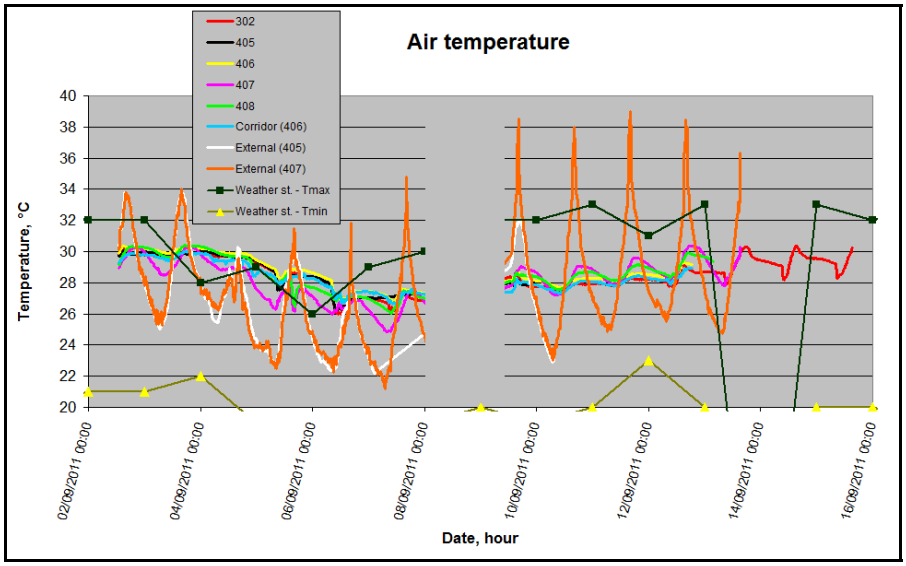


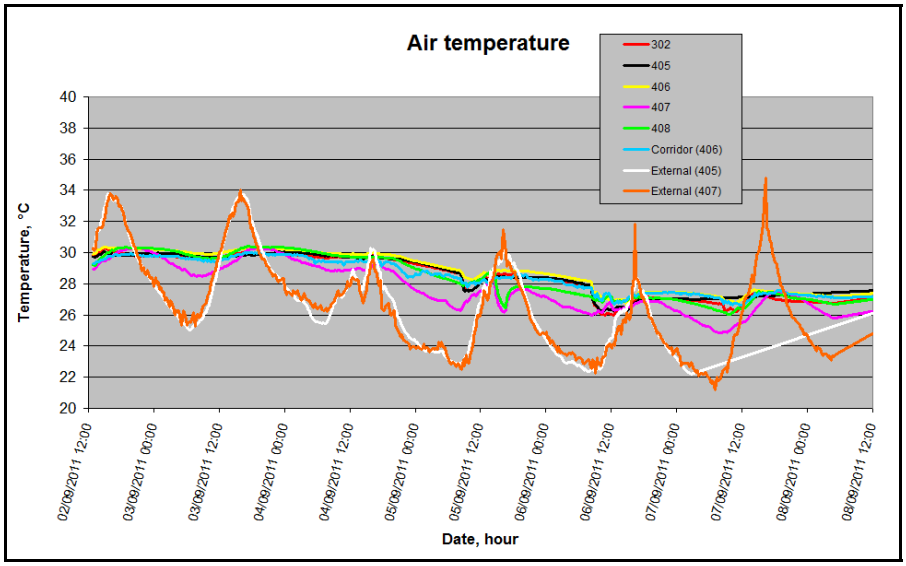
August 2011 - Graphs of data from monitoring in the offices.

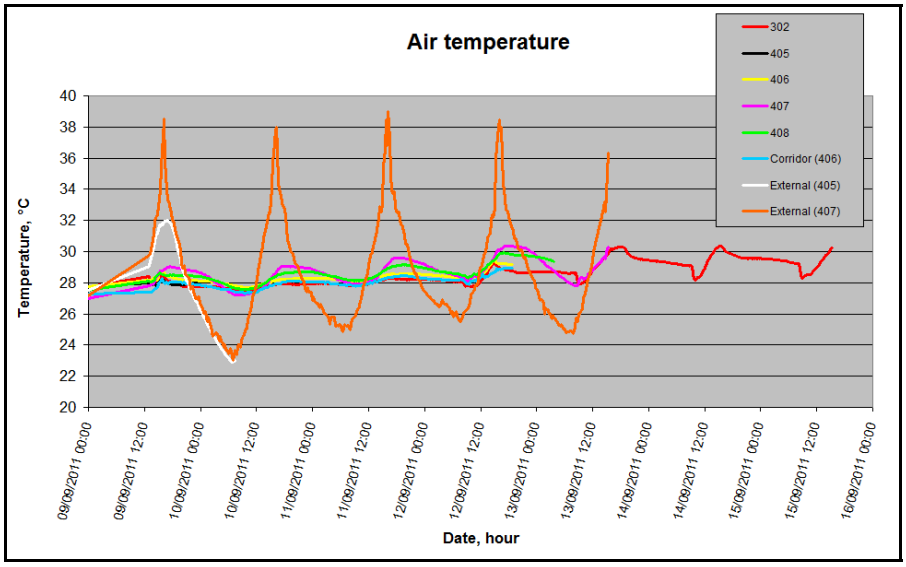
Deliverable D6.2 Documentation of each study case

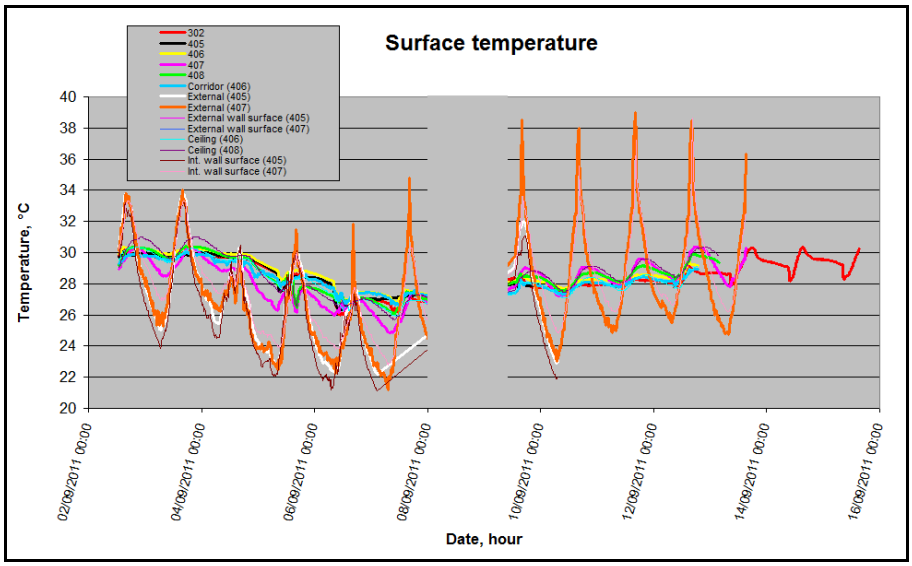
September 2011

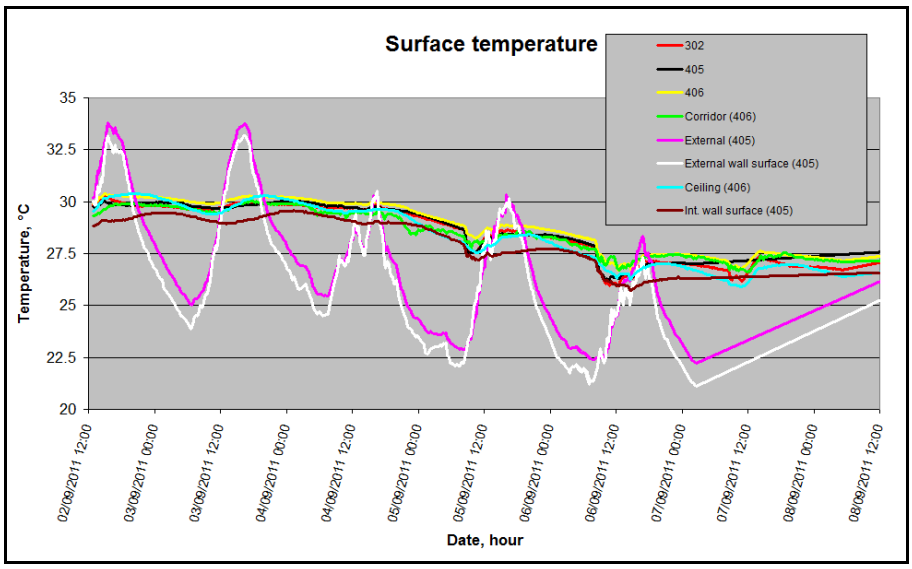
Map of nodes – same of August

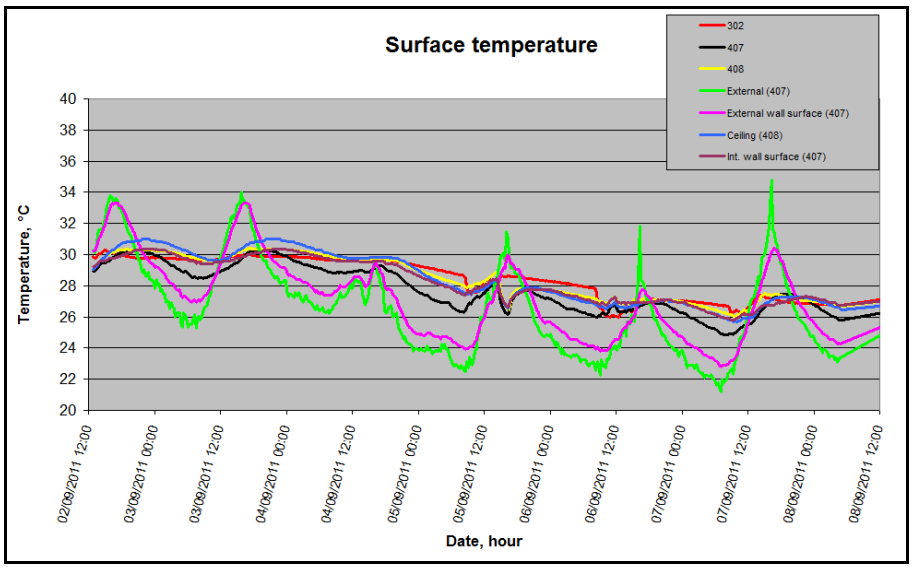


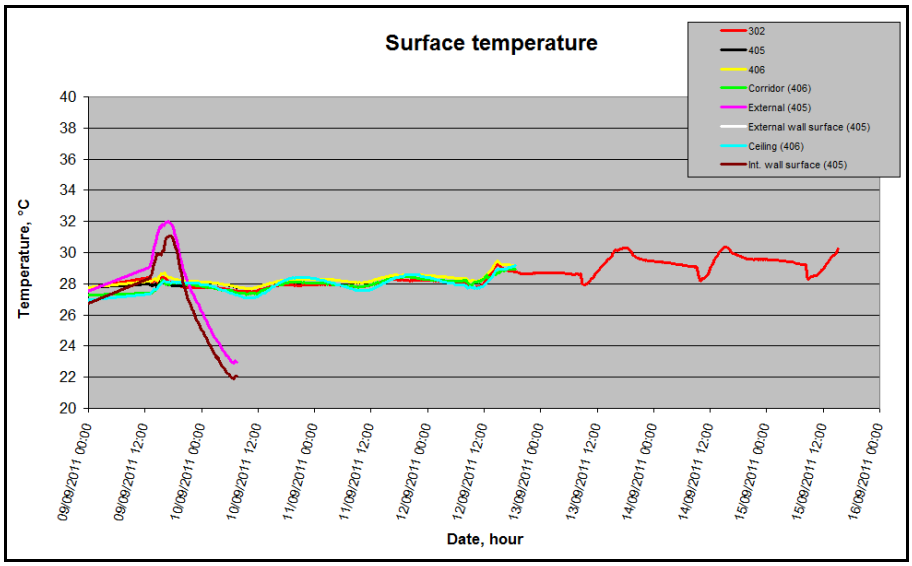


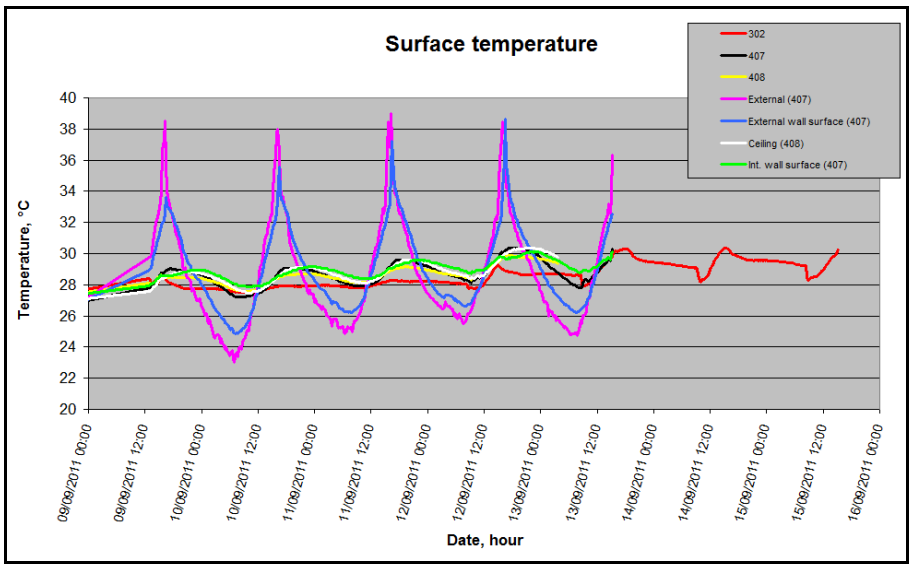


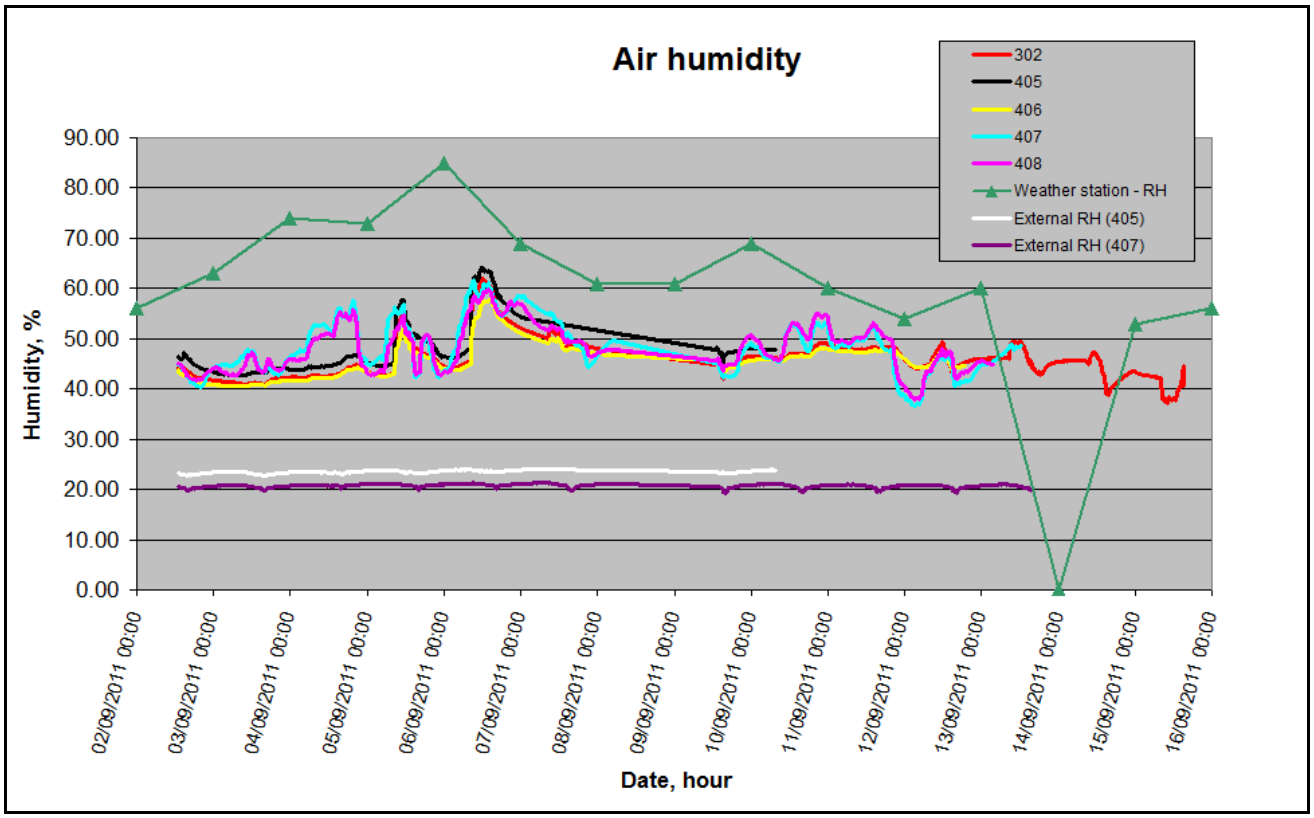

Surface temperature
302
405
406
407
408
Corridor (406)
External (405)
External (407)
External wall surface (405)
External wall surface (407)
Ceiling (406)
Ceiling (408)
Int. wall surface (405)
Int. wall surface (407)
Temperature, °C
Date, hour


Surface temperature
302
405
406
Corridor (406)
External (405)
External wall surface (405)
Ceiling (406)
Int. wall surface (405)
Temperature, °C
Date, hour


Surface temperature
302
407
408
External (407)
External wall surface (407)
Ceiling (408)
Int. wall surface (407)
Temperature, °C
Date, hour


Surface temperature
302
405
406
Corridor (406)
External (405)
External wall surface (405)
Ceiling (406)
Int. wall surface (405)
Temperature, °C
Date, hour

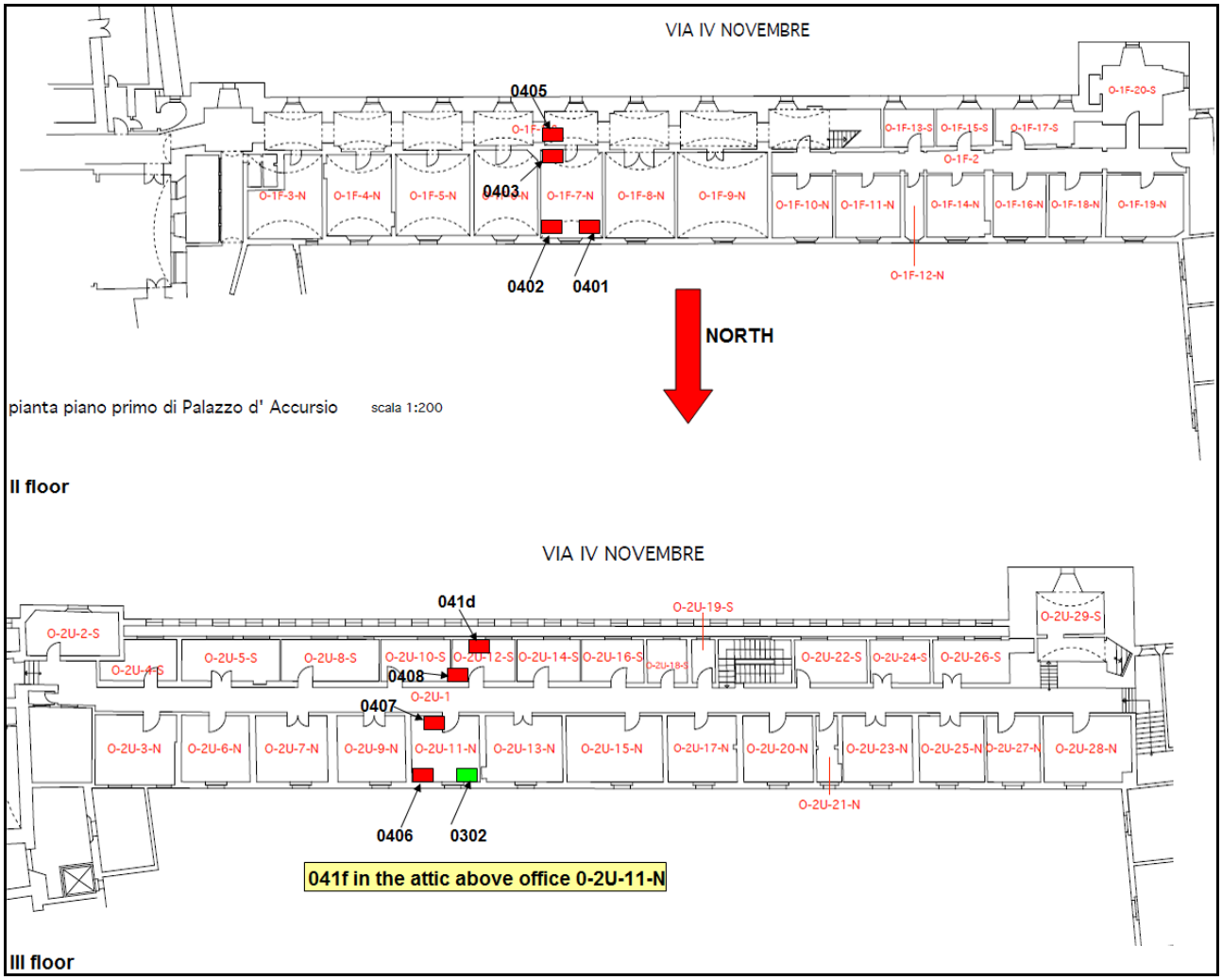

Surface temperature
302
407
408
External (407)
External wall surface (407)
Ceiling (408)
Int. wall surface (407)
Temperature, °C
Date, hour



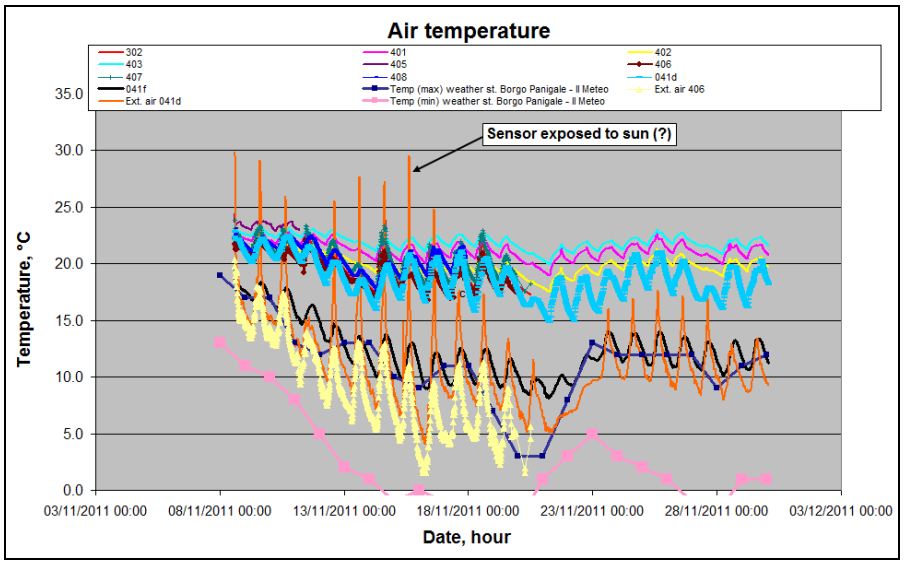
September 2011 - Graphs of data from monitoring in the offices.

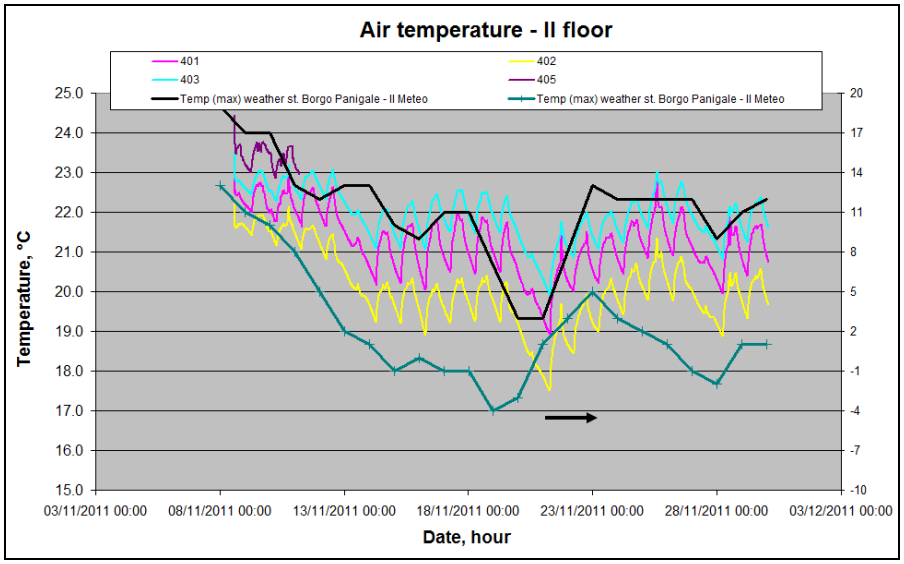
Deliverable D6.2 Documentation of each study case

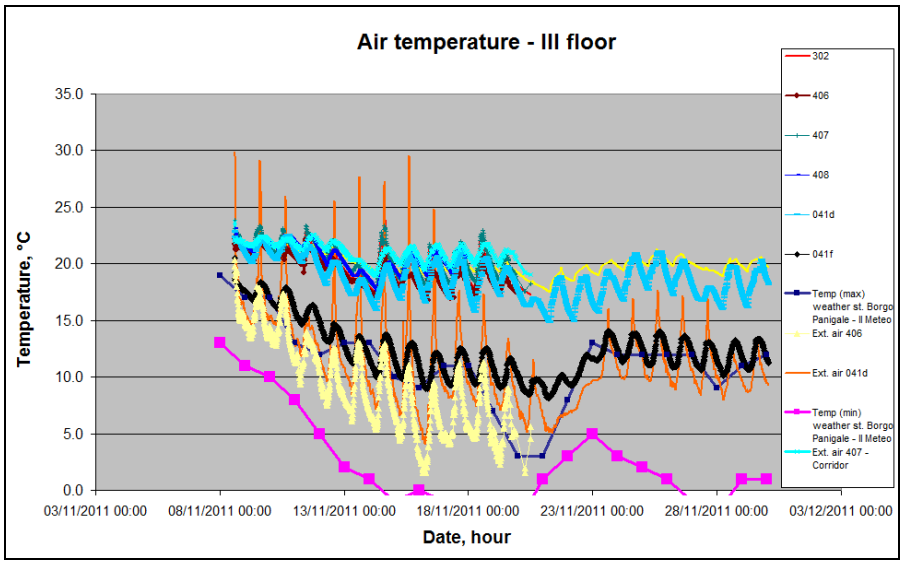
November 2011

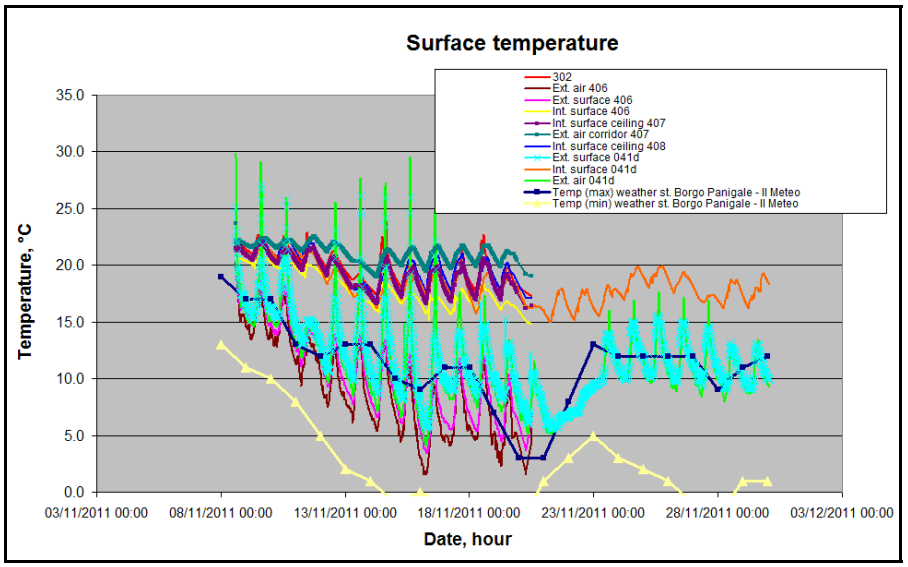


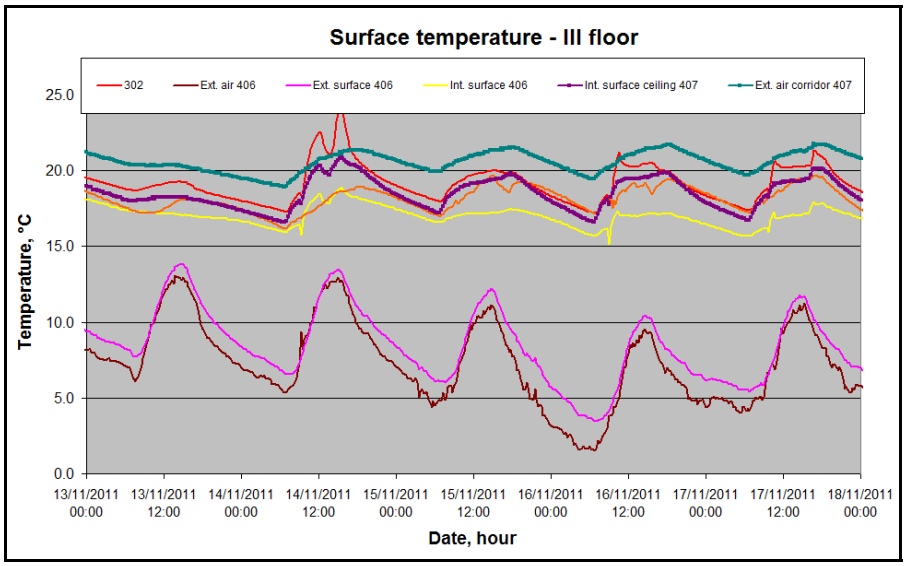
Map of nodes




Air temperature - II floor
401
402
403
405
Temp (max) weather st. Borgo Panigale - Il Meteo
Temp (max) weather st. Borgo Panigale - Il Meteo
Temperature, °C
Date, hour
03/11/2011 00:00
08/11/2011 00:00
13/11/2011 00:00
18/11/2011 00:00
23/11/2011 00:00
28/11/2011 00:00
03/12/2011 00:00


Air temperature - III floor
302
406
407
408
041d
041f
Temp (max) weather st. Borgo Panigale - Il Meteo
Ext. air 406
Ext. air 041d
Temp (min) weather st. Borgo Panigale - Il Meteo
Ext. air 407 - Corridor
Temperature, °C
Date, hour
03/11/2011 00:00
08/11/2011 00:00
13/11/2011 00:00
18/11/2011 00:00
23/11/2011 00:00
28/11/2011 00:00
03/12/2011 00:00


Surface temperature
302
Ext. air 406
Ext. surface 406
Int. surface 406
Int. surface ceiling 407
Ext. air corridor 407
Int. surface ceiling 408
Ext. surface 041d
Int. surface 041d
Ext. air 041d
Temp (max) weather st. Borgo Panigale - Il Meteo
Temp (min) weather st. Borgo Panigale - Il Meteo
Temperature, °C
Date, hour
03/11/2011 00:00
08/11/2011 00:00
13/11/2011 00:00
18/11/2011 00:00
23/11/2011 00:00
28/11/2011 00:00
03/12/2011 00:00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Ext. surface 406
Int. surface 406
Int. surface ceiling 407
Ext. air corridor 407
Temperature, °C
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20.0
15.0
10.0
5.0
0.0
13/11/2011 00:00
13/11/2011 12:00
14/11/2011 00:00
14/11/2011 12:00
15/11/2011 00:00
15/11/2011 12:00
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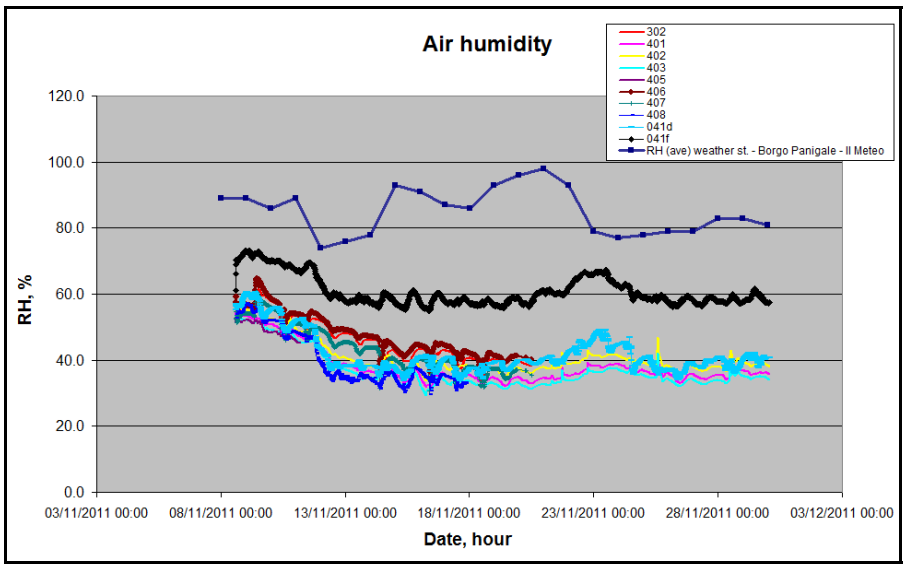
17/11/2011 12:00
18/11/2011 00:00
Date, hour


Air humidity
302
401
402
403
405
406
407
408
041d
041f
RH (ave) weather st. - Borgo Panigale - Il Meteo
RH, %
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100.0
80.0
60.0
40.0
20.0
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03/11/2011 00:00
08/11/2011 00:00
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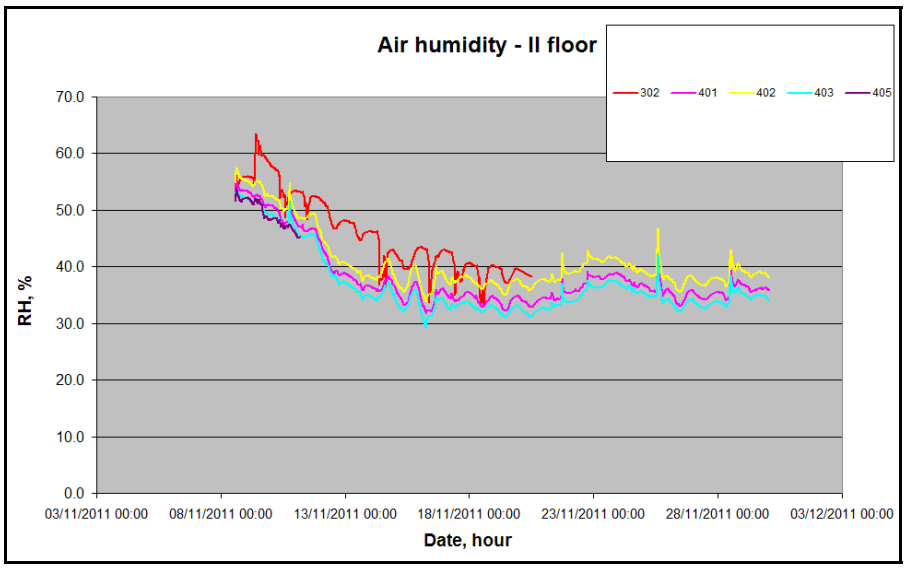
03/12/2011 00:00
Date, hour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402
403
405
RH, %
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50.0
40.0
30.0
20.0
10.0
0.0
03/11/2011 00:00
08/11/2011 00:00
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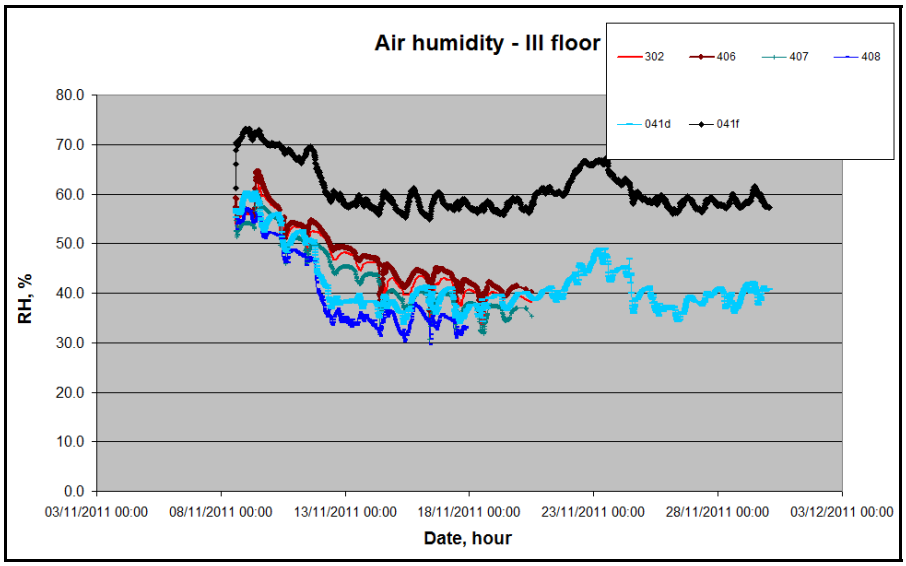
18/11/2011 00:00
23/11/2011 00:00
28/11/2011 00:00
03/12/2011 00:00
Date, hour

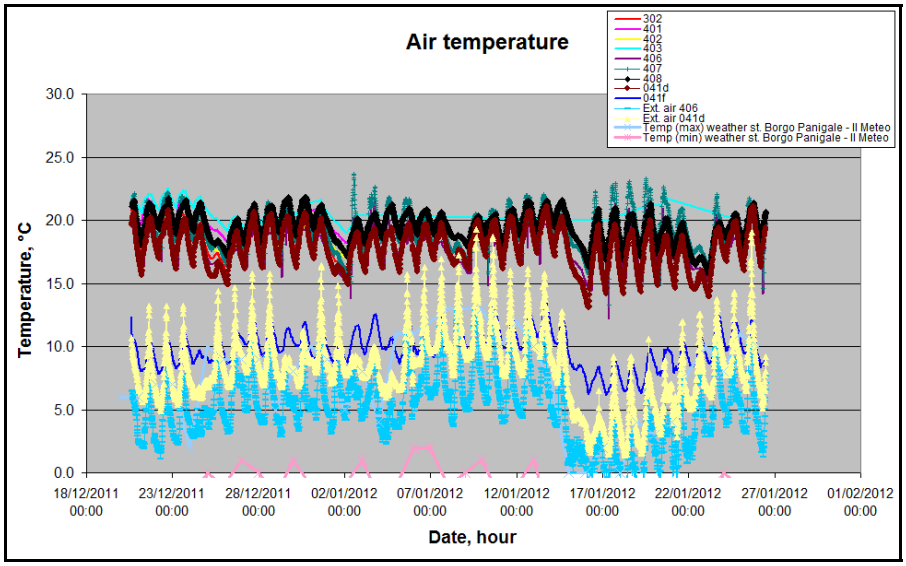


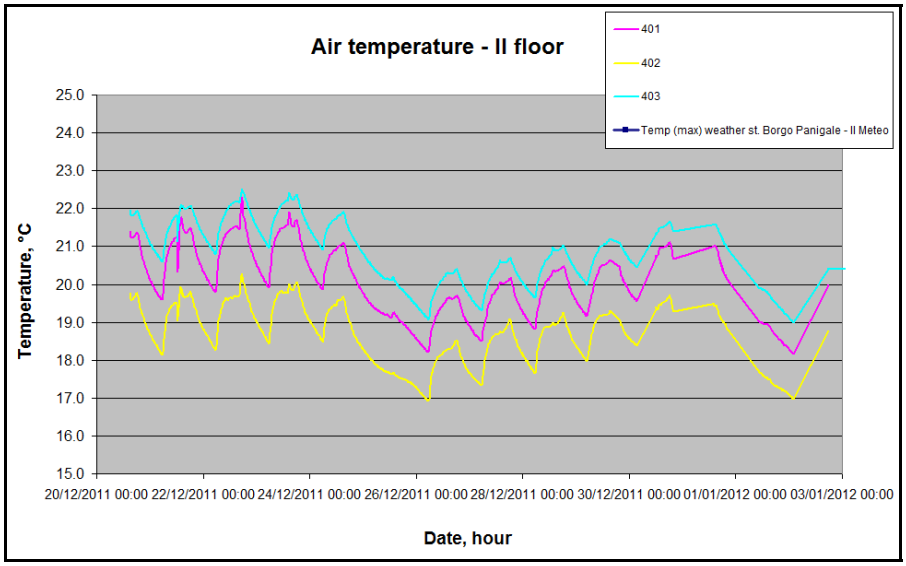
November 2011 - Graphs of data from monitoring in the offices.

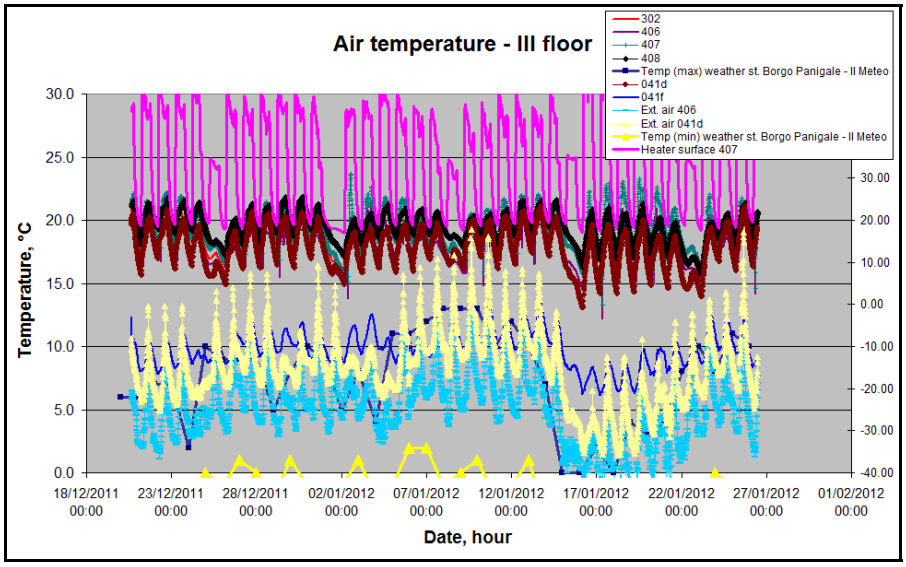
Deliverable D6.2 Documentation of each study case

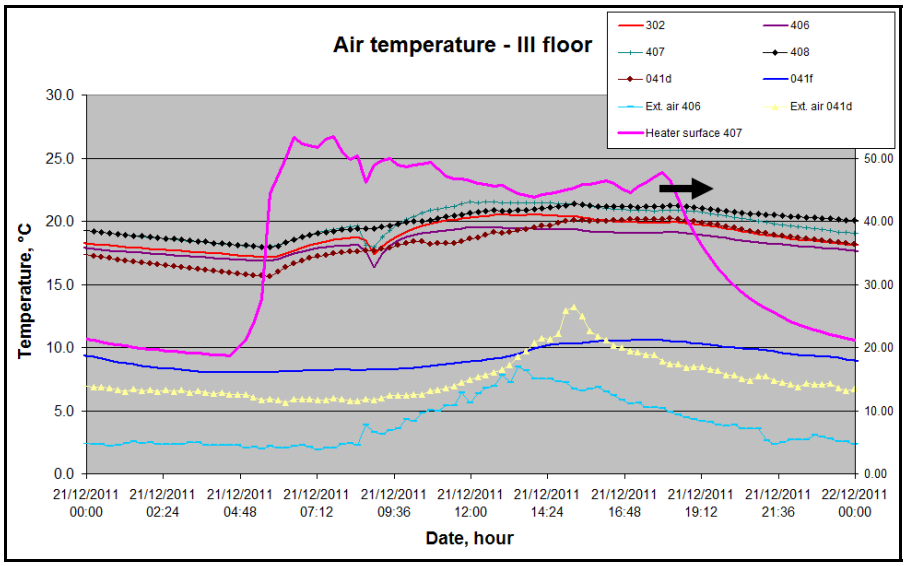
December 2011 – January 2012

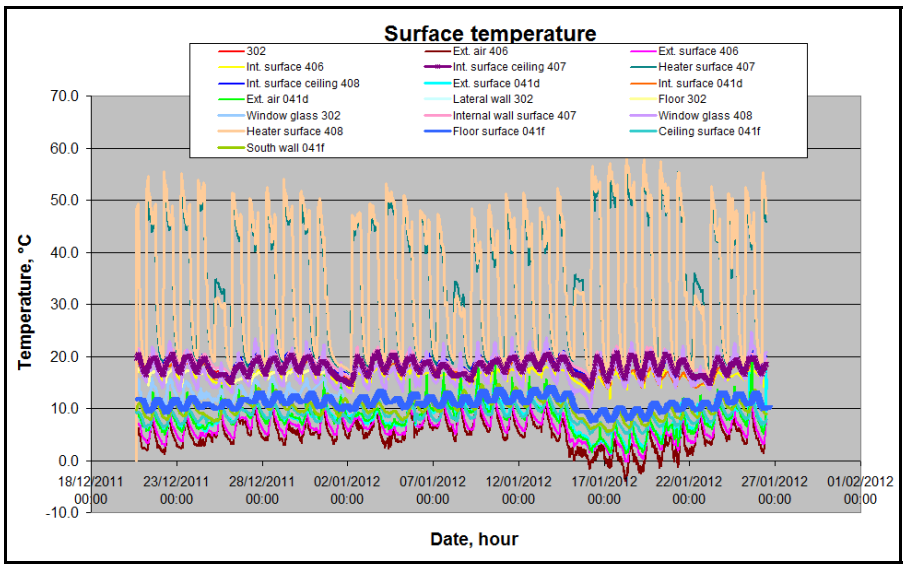
Map of nodes – Same as November

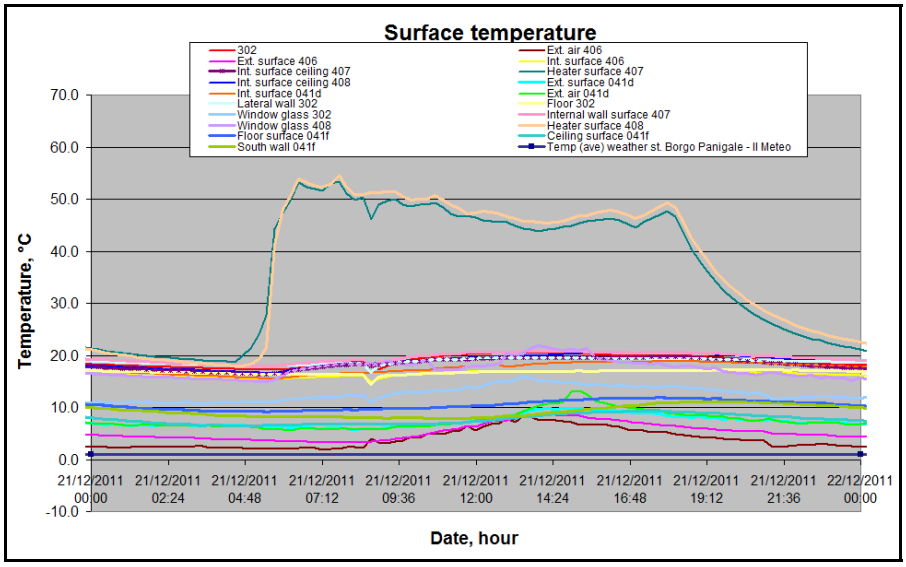


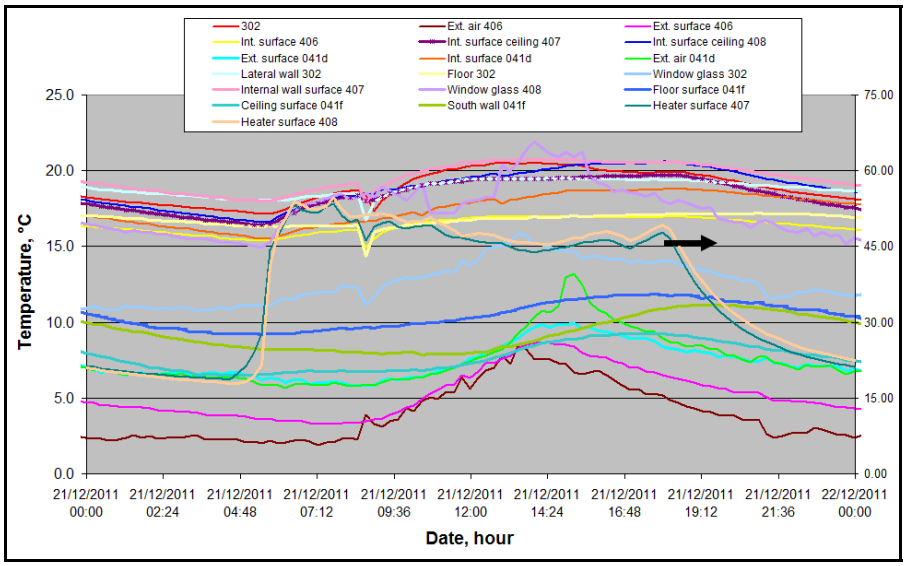


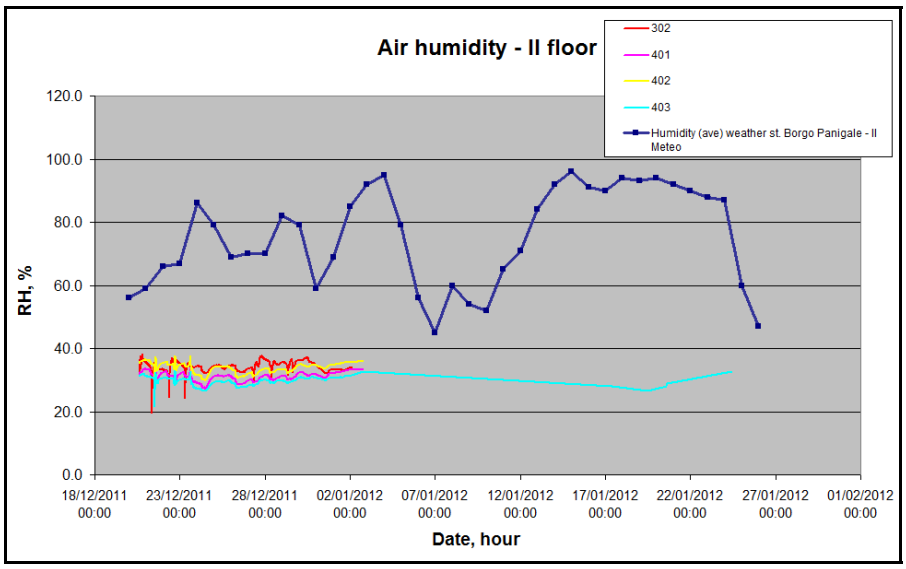


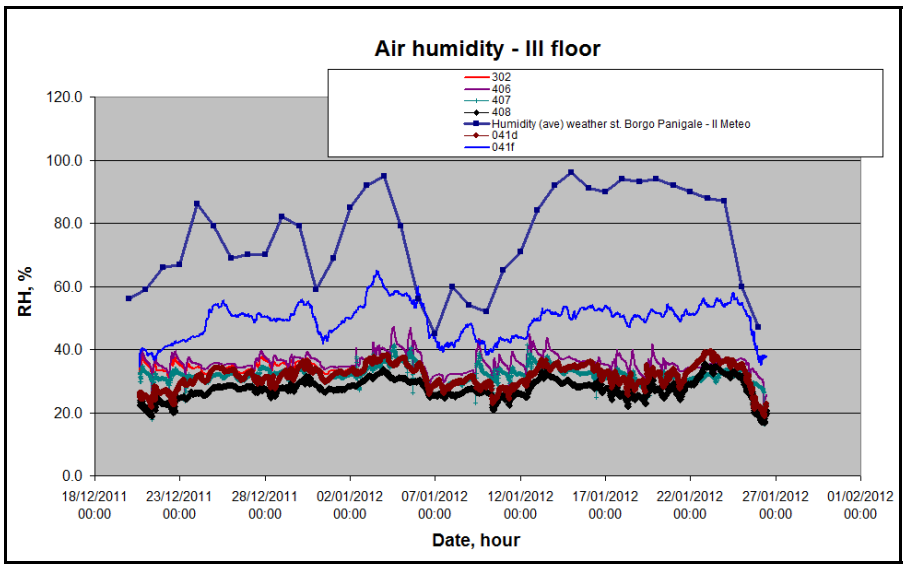

Air temperature - III floor
302
406
407
408
041d
041f
Ext. air 406
Ext. air 041d
Heater surface 407
Temperature, °C
Date, hour


Surface temperature
302
Ext. air 406
Ext. surface 406
Int. surface 406
Int. surface ceiling 407
Heater surface 407
Int. surface ceiling 408
Ext. surface 041d
Int. surface 041d
Ext. air 041d
Lateral wall 302
Floor 302
Window glass 302
Internal wall surface 407
Window glass 408
Heater surface 408
Floor surface 041f
Ceiling surface 041f
South wall 041f
Temperature, °C
Date, hour


Surface temperature
302
Ext. air 406
Ext. surface 406
Int. surface 406
Int. surface ceiling 407
Heater surface 407
Int. surface ceiling 408
Ext. surface 041d
Int. surface 041d
Ext. air 041d
Lateral wall 302
Floor 302
Window glass 302
Internal wall surface 407
Window glass 408
Heater surface 408
Floor surface 041f
Ceiling surface 041f
South wall 041f
Temp (ave) weather st. Borgo Panigale - Il Meteo
Temperature, °C
Date, hour





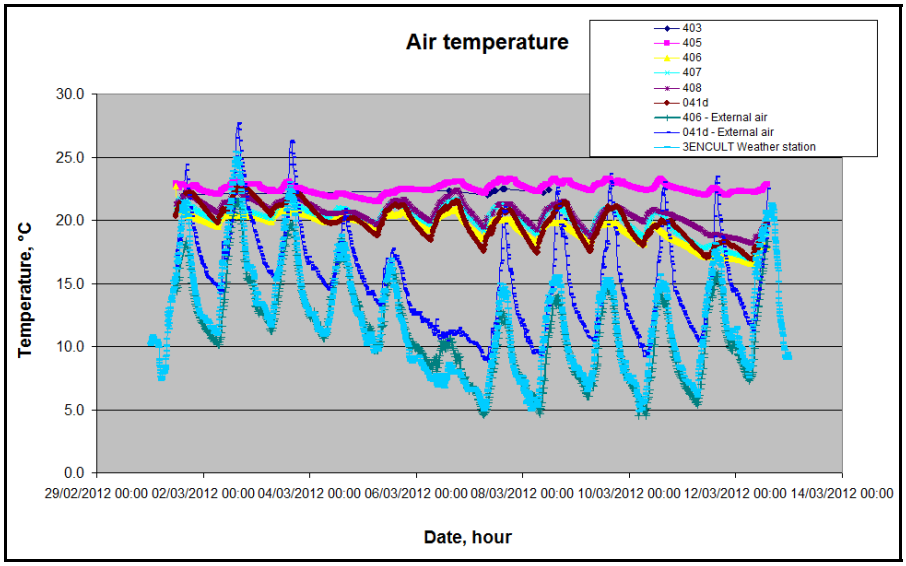


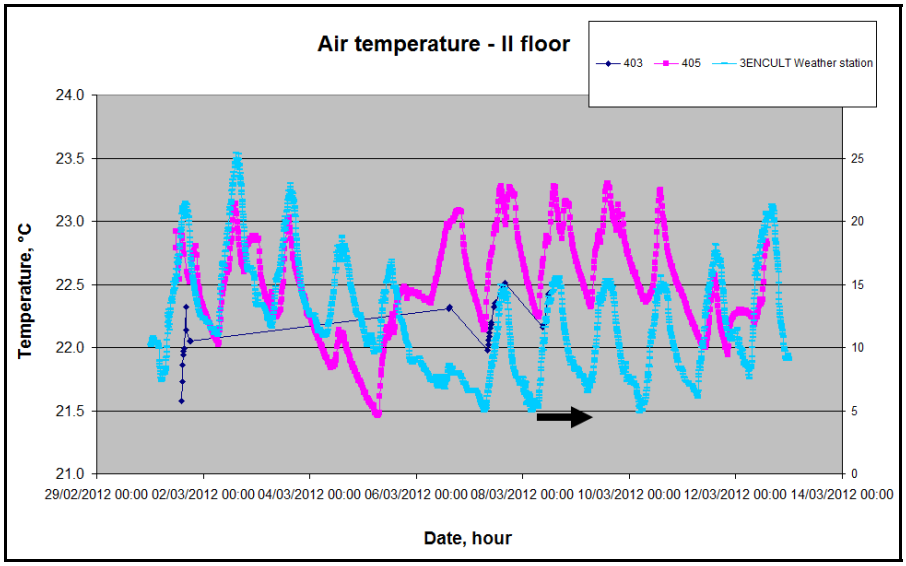
December 2011 / January 2012 - Graphs of data from monitoring in the offices.

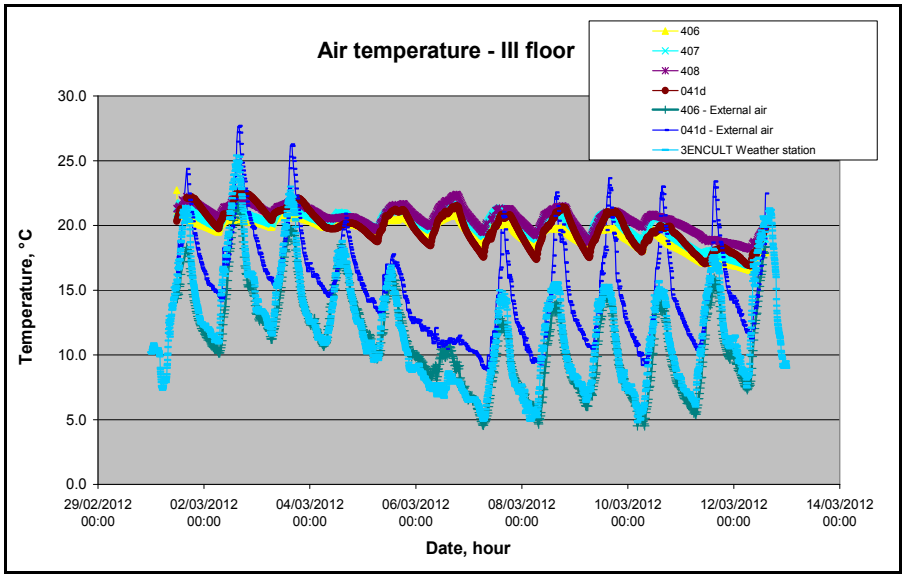
Deliverable D6.2 Documentation of each study case

March 2012

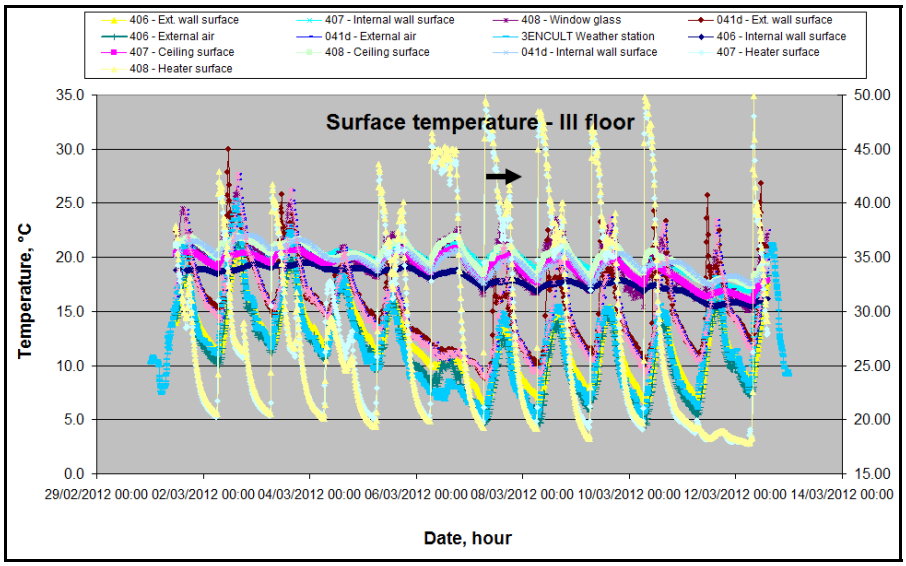
Map of nodes – Same as November / Office O-2U-11-N empty since mid February

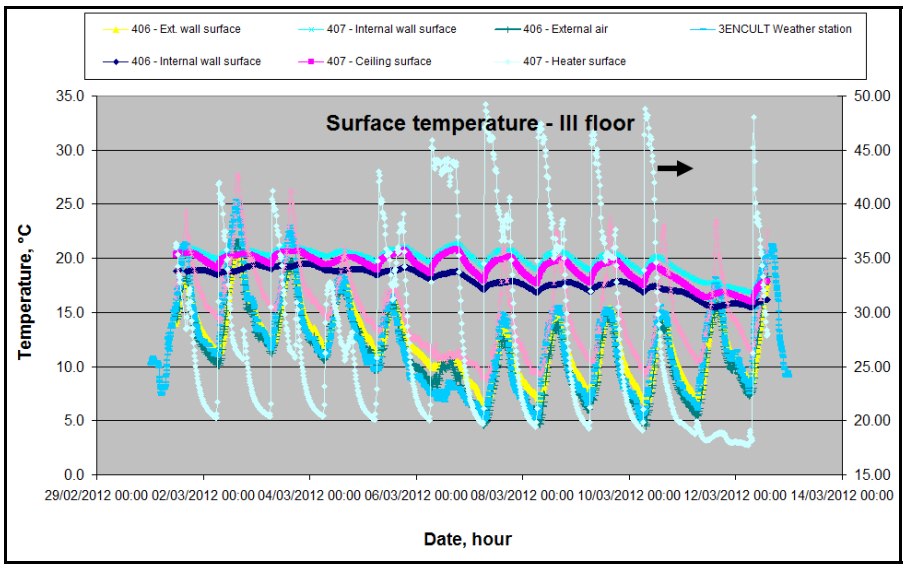


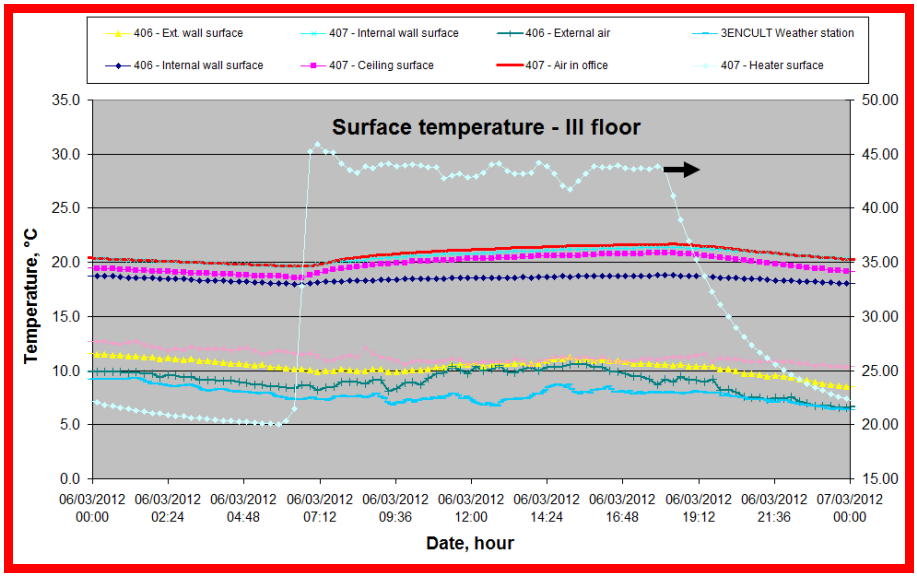




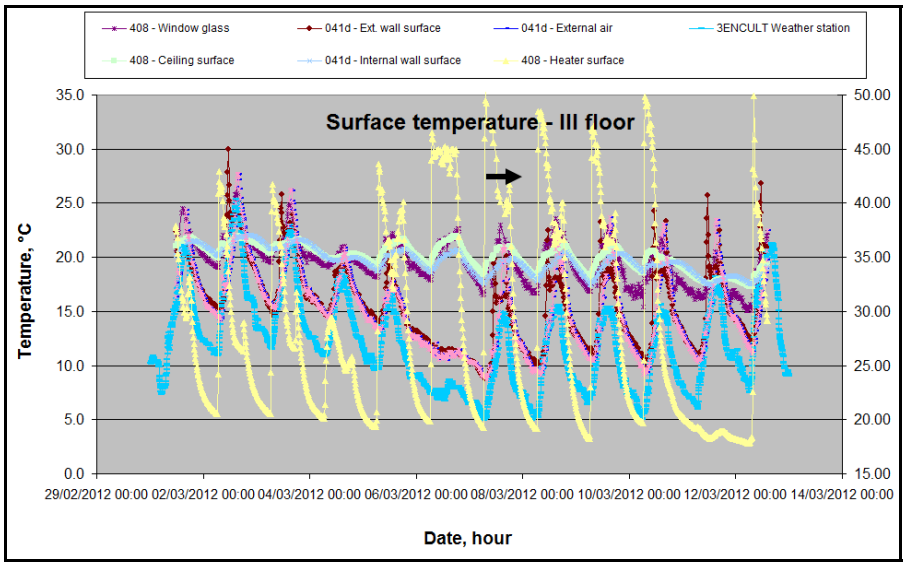
Deliverable D6.2 Documentation of each study case

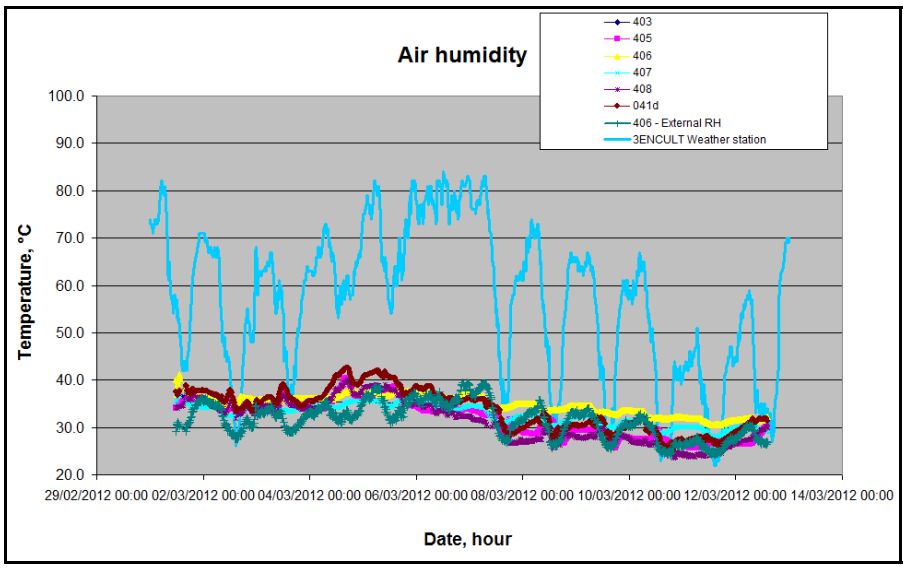


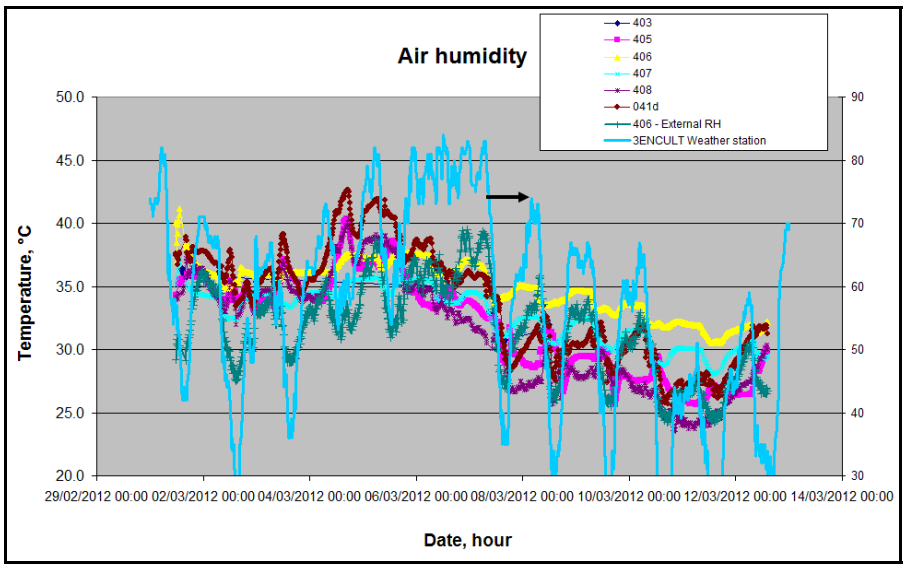


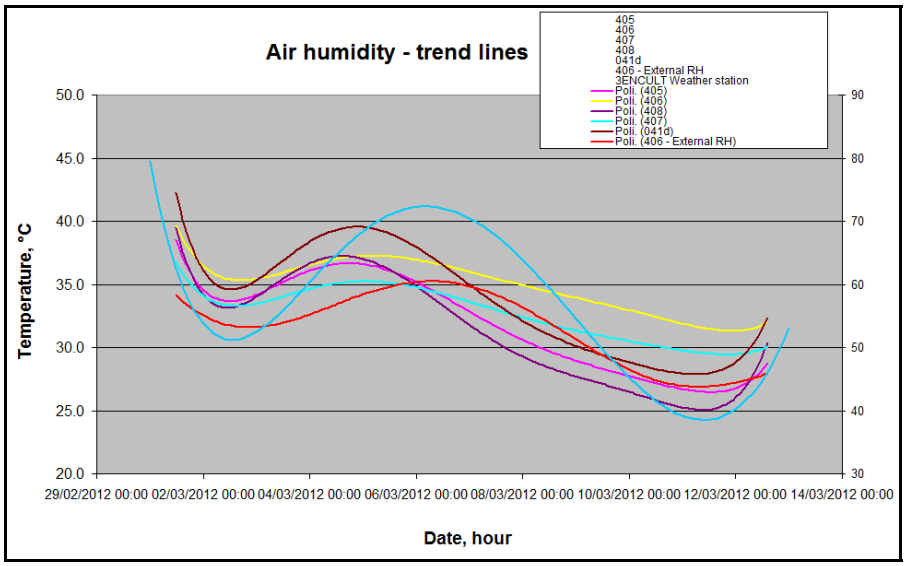


Deliverable D6.2 Documentation of each study case









March 2012 - Graphs of data from monitoring in the offices.

9 Annex 3 - Case Study organisation

9.1 Local Case Study Teams (LCS teams)

The Bologna LCS-Team of Palazzo d'Accursio is composed by the following 3 ENCULT partners

- **COBO - Municipality of Bologna** representative of the owner of the Palazzo d'Accursio with the involvement of the International Relations department and the quality department of the city with different sector:
    - Public work sector with the responsible of historical building and monuments;
    - Environment and Urban Green sector with the responsible of energy office;
    - City planning sector with the responsible of the urban interventions
- **UNIBO** – Alma Mater Studiorum University of Bologna with DEIS (Department of electronics, computer sciences and Systems) and DICAM (Structural, transport, Hidraulic, Survey and Territory Engineering)
- **ARTEMIS** srl

The Palazzo d'Accursio case study team intends to include other stakeholder representative of different aspect that this case study

- **Manutencoop** representative of the Facility manager of the building;
- **IBC** – Istituto per I Beni artistici, culturali e naturali (requires identification of the sector to be involved) representatives from the regional cultural heritage administration/council;
- **Cultural Heritage Superintendence** (requires identification of the sector to be involved) representatives from the local cultural heritage administration/council;
- **ICIE_Larcolcos** Laboratory for representative of Construction platform of the High Technology Network of the Emilia Romagna Region.

9.1.1 LCST formalisation

EURAC has provided two templates for such agreements (WP6_20101004_P01_LCS template_final.doc and WP6_20101004_P01_NDA_Case study.doc), which can be found on the teamsite http://teamsites.eurac.edu/renene/3encult

It is important to include here also the most vital points the agreement should deal with. It is necessary to make sure that all partners have the following points in mind:

- access rights;
- provision of technical information;
- liability;
- confidentiality;
- link to Consortium Plan and time schedule.

10 Annex 3 - PHPP calculation

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
DEPARTMENT OF CIVIL, CHEMICAL, ENVIRONMENTAL,
AND MATERIALS ENGINEERING

3encult Project: CS2
Deliverable 6.2, Annex 1:
PHPP calculation of Palazzo D'Accursio

Author:
Ing. Giuliani Marco

April 18, 2014

Contents

Chapter 1

PHPP Municipal Collection

This document resumes the PHPP calculation for "Municipal Collection" area of Palazzo D'Accursio. All the information regarding the calculation is provided in order to better understand how the calculation is performed

Contents

1.1 Building characteristic and selection

Palazzo D'Accursio is big and very complex building as describe in Deliverable D.6.2 inside 3encult project. In order to perform the PHPP calculation two areas are selected. This selection allow to analyze two different destination of use, moreover the areas selected present different feature. For the application of PHPP the first step is the analysis of the building and the definition of the Treated floor Area and the Balance Boundary, these are outlined below.

1.1.1 Balance Boundary

The Boundary Balance is traced with red lines. Some parts are denoted by the dotted line because they are not in the foreground, but they belong to the same view. This is done to make the meaning clear. The different zones are identified with a number, corresponding with ID number used in sheet "Areas" of PHPP.

Municipal Collection Subdivision

	Denomination	Area
		m^2
1	Facade est P.Maggiore	193
2	Facade est tower	40
3	Facade est Primitivi	232
4	Facade Sud Courtyard	103
5	Facade Sud tower	119
6	Partition Wall Sud-Morandi	107
7	Partition Wall Sud-Svizzeri	68
8	Facade west tower	40
9	Facade west Primitivi	232
10	partition wall West	49
11	Facade West	115
12	Facade North	200
13	partition wall-North	70
14	partition wall-North Primitivi	57
15	Facade north tower	89
16	Basement ceiling-partion wall	1188
17	WoodCeiling-WoodCopperRoof	168
18	GypsumCeiling-TradRoof	280
19	GypsumWoodCeiling-TradRoof	565
20	SalaStemmi	175

Figure 1.1: The Table resume the surface that describe the balance boundary.

The drawings that describe the building are limited and some photo are used to better describe the definition of the boundary. The following drawings and images give a detail description of the Balance Boundary assumes for the PHPP calculation. Each surface has an identification index that correlate the drawing with the Table in 1.1.

1.1.2 Treated Floor Area (TFA)

The areas are presented with green color on the Figure 1.7. Have been applied following the indication of the PHPP manual. More details are available in the tables 1.6.

1.2 PHPP calculation

The calculation took into account the indications provided by PHI and in particular have been taken the following choices:

- A review of the drawings is done, through an architectural survey. The drawings of the municipal collections have been partially integrated with some sections

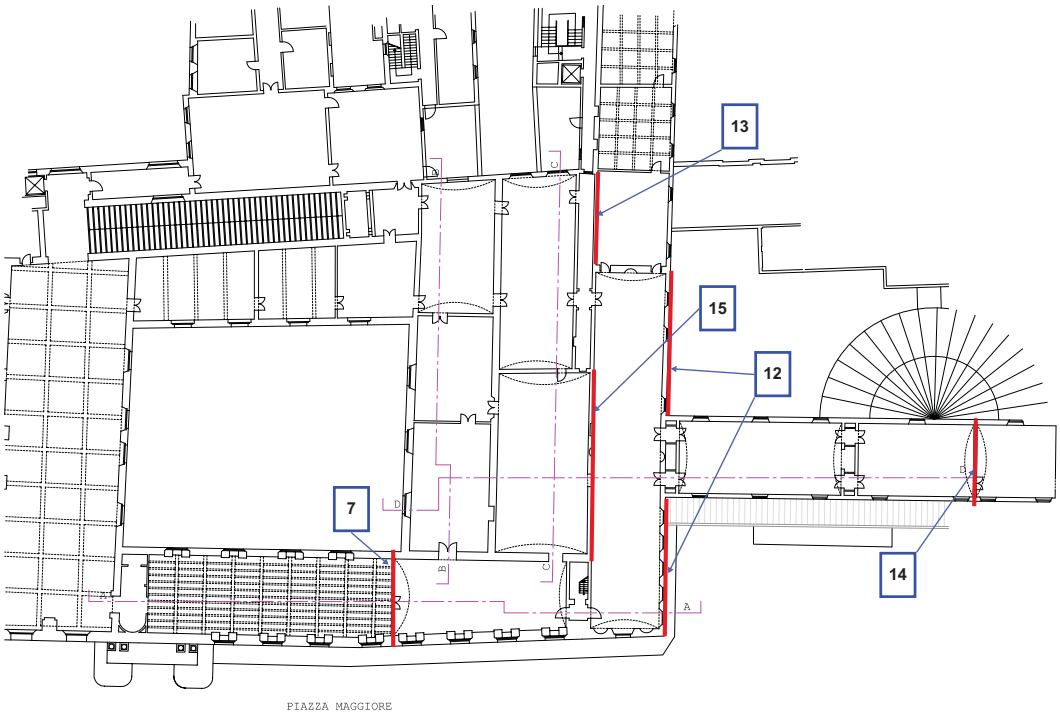


Figure 1.2: The figure shows the plan of the part of the building where the PHPP is applied. The figure resume also the position of same surface

because they are very poor and however should be expanded.

- The attics are excluded from Boundary Balance because they are no-heated areas.

- For windows a specific survey activity was carried out for two specific aims. First is the recovery of the basic characteristics, necessary for inclusion in the PHPP calculation, where the transmittance values are estimated on the indications of PHI. Second is the developing of the database of information for the Municipality to fill the lack of information on the building. The different types of finishing glass surfaces were not considered due to lack of available data. External shading effects from others building, overhangs and vertical elements are considered. The bars, covering the windows are considered as indicated in the guidelines of PHPP: omitted from the glass surface and considered increasing the thickness of the frames on all 4 sides.

- Transmittance values of the walls are carried out in accordance with ISO 6946 [1]. The characterization of external walls is also provided though in-situ measurement of Transmittance value according with ISO 9869 [2]. More details are available in deliverable D.6.2.

(a) Main Square Façade

(b) North Façade with section

Figure 1.3: Subdivision of selected part of building: North and East Façade.

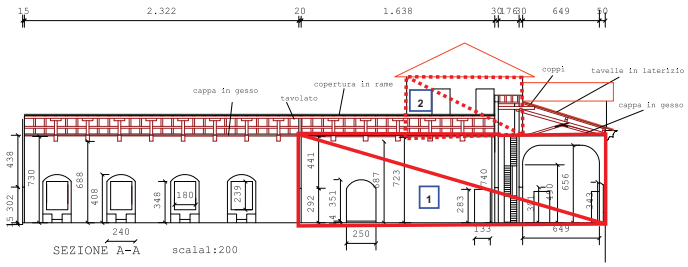
- Blower door test is performed to measure the airtightness level of the building, according to ISO 9972 [3]. The results of pressurization test are used in the calculation to estimate the air permeability of the building.
- The thermal bridges are not analysed at this stage.
- Equipment, light and interior load are determined through the use of result of energy audit performed on the building.

1.2.1 PHPP calculation for "as-in-state" scenario

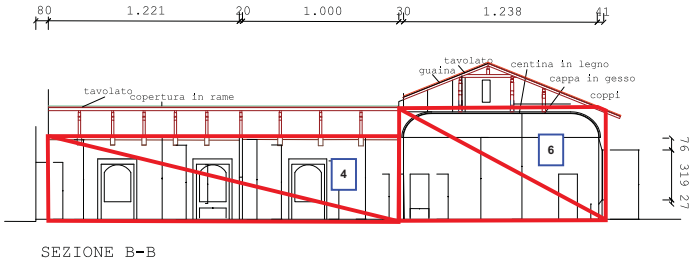
The results of the application of the PHPP analysis 2.10 showed that the energy losses are distributed across the entire envelope. The main components are concentrated in the attic, included in the non-heated area, and external walls. The blower door test showed a relatively poor airtightness with a mean air change rate of 5.9 1/h. Therefore the losses due to infiltration, contained in the ventilation component, are considerable. Also the transmission heat losses through the windows are relevant, due to the presence of several and large windows in each external surface. During summer the building is cooled by natural ventilation through the windows. The reference component shows high value. Due to high value of losses on the entire envelope, the estimated hours of overheating has low value. The reliability of this value is doubtful as the monitored data show that indoor temperature is over 30Â°C for long part of the summer. It is well know that static tool has high uncertainty in the estimation of cooling load. The monthly method for the estimation of heating demand has a discrepancy of 6% (16 kWh/m2a) compare to annual method.

1.2.2 PHPP calculation for "retrofit" scenario

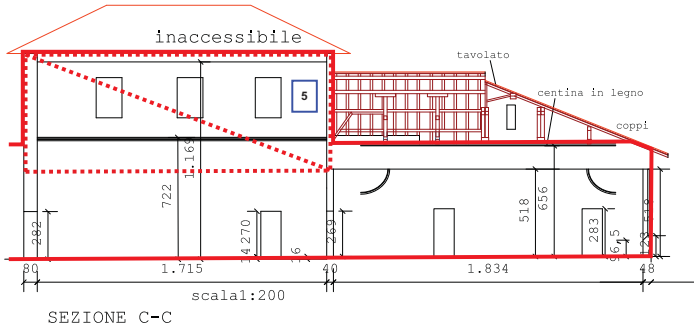
Compared to the pre-intervention scenario, the results of the post-intervention PHPP 1.9 showed that the losses to the non-heated area (attics) and through the windows decreased in accordance with the implemented measure. Also ventilation losses decreased due to an improvement of the air-tightness. Looking at the global assessment the estimated heating and cooling demand decreased by 50 kWh/m2a (19%) and 1 kWh/m2a (50%). The monthly method for the estimation of heating demand has a discrepancy of 6% (12 kWh/m2a) compare to annual method.



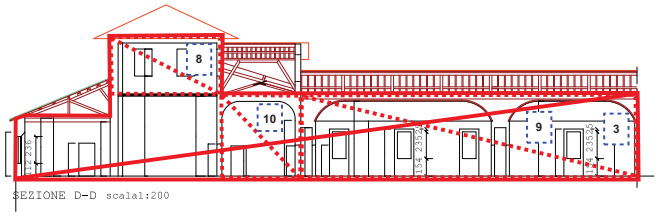
(a) Section A-A



(b) Section B-B



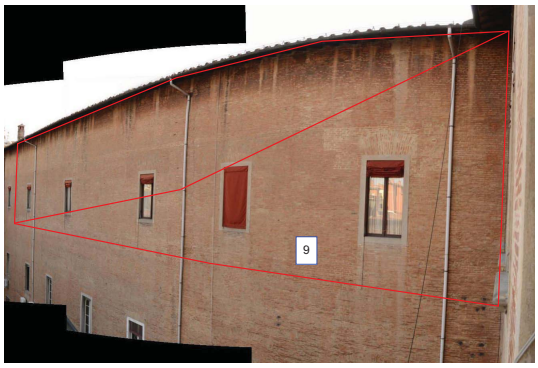
(c) Section C-C



(d) Section D-D

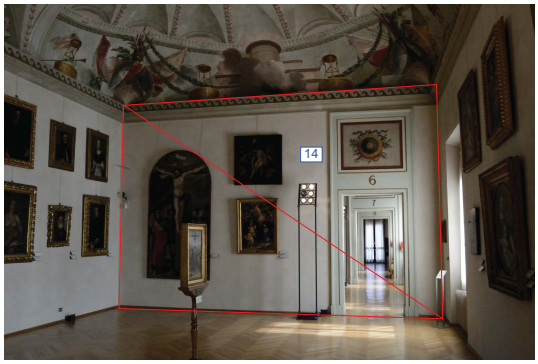
Figure 1.4: Sections of Municipal Collection

(a) South Façade



(b) West Façade

(c) Adiabatic partition wall



(d) Adiabatic partition wall

Figure 1.5: Surfaces of balance boundary.

Municipal Collection TFA

Room	TFA	Height	Volume
	m^2	m	m^3
2F1	117.8	7.28	857.58
2F2	82	5.25	430.50
2F3	64.6	5.25	339.15
2F4	81.5	6.56	534.64
2F5	112	6.56	734.72
2F6	142.7	11.69	1668.16
2F7	208	6.56	1364.48
2F8	115	5.8	667.00
2F9	75	5.8	435.00
2F10	1.86	3.45	6.42
2F11		2.65	0.00
2F12	6.18	4	24.72
2F13	8.76	4.55	39.86
TOT	1015.40		7102.23

Figure 1.6: The Table resumes the surface that describe the TFA of Municipal collection.

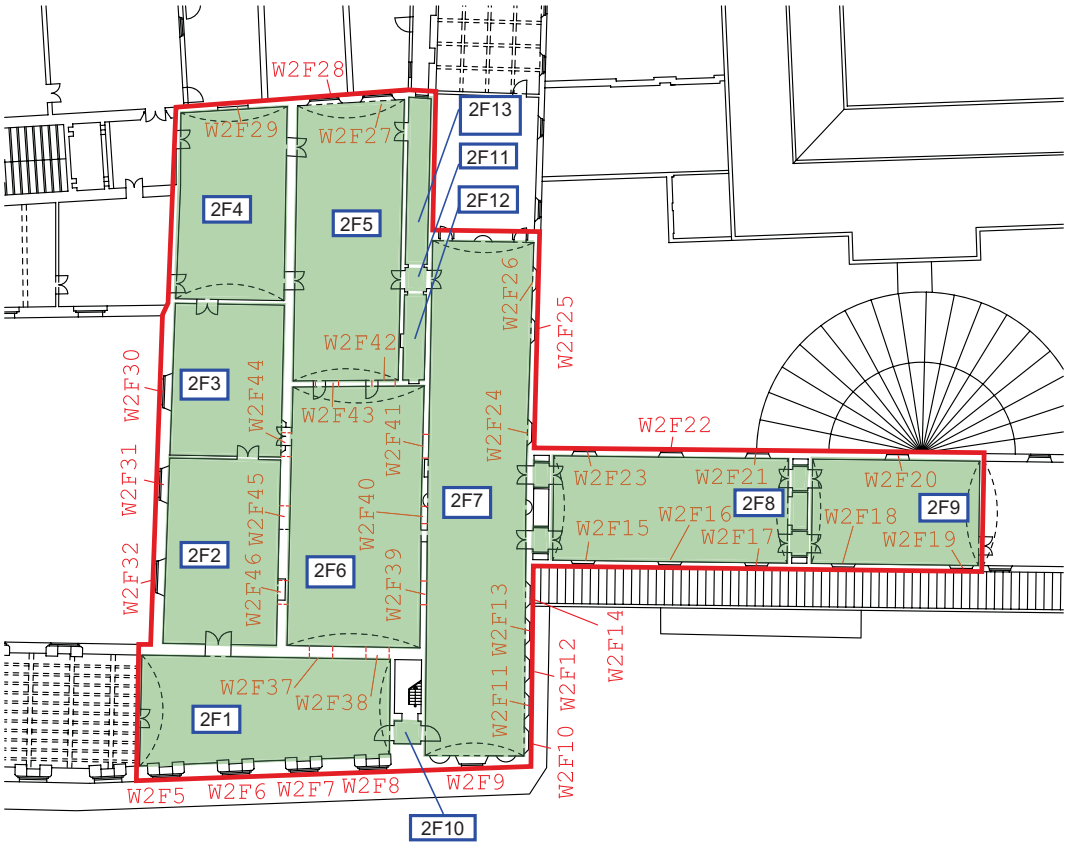


Figure 1.7: Collection plan with TFA identification code.

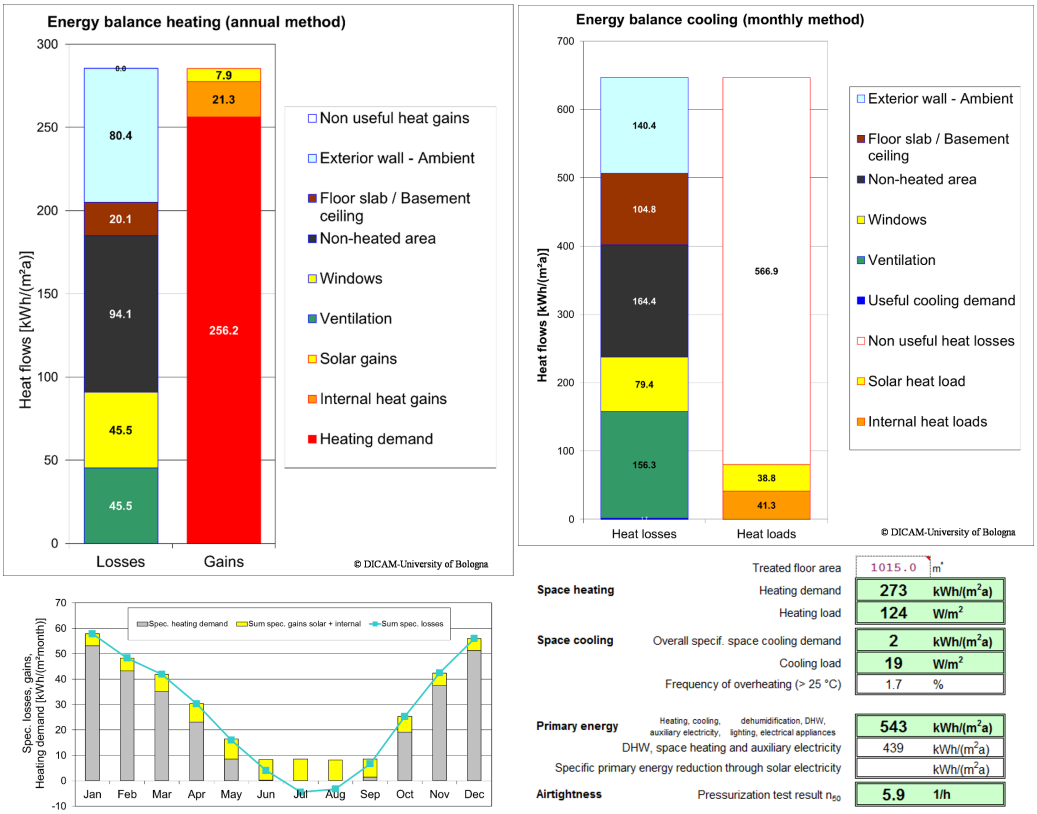


Figure 1.8: PHPP calculation for pre-intervention scenario.

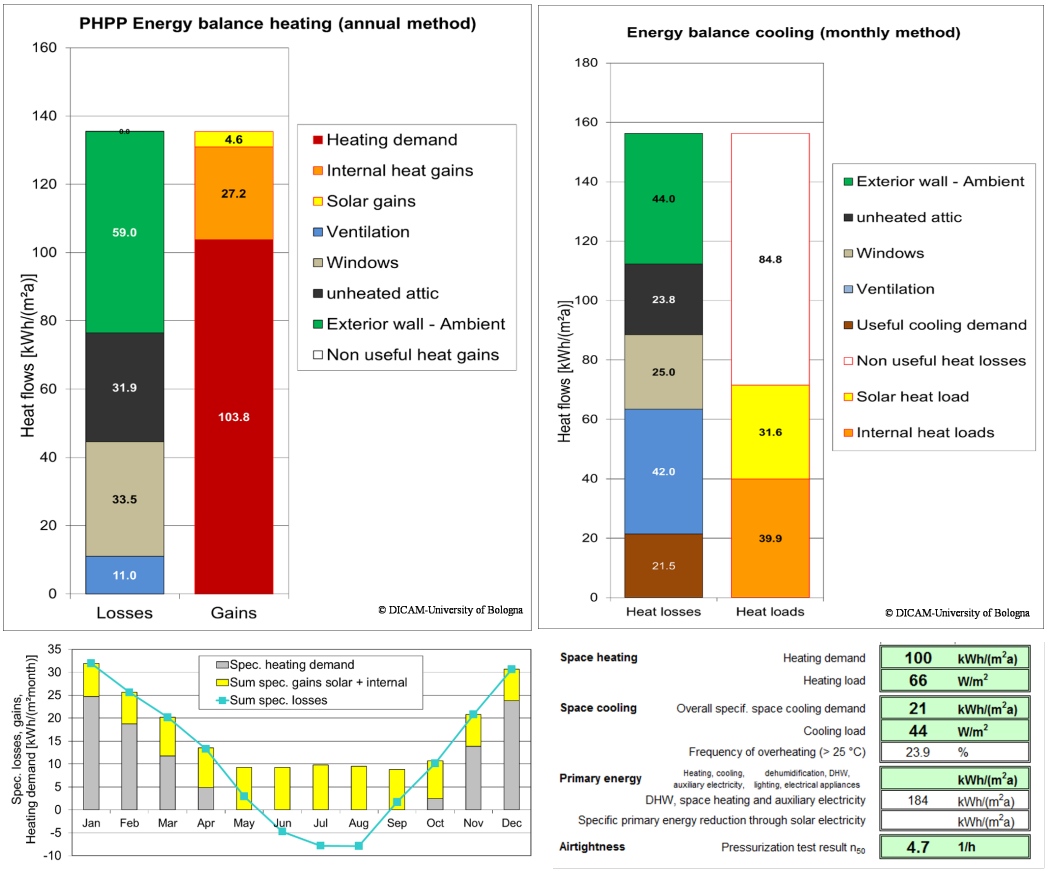


Figure 1.9: PHPP calculation for pre-intervention scenario.

Chapter 2

PHPP Office Block

This document resumes the PHPP calculation for Office area of Palazzo D'Accursio. All the information regarding the calculation is provided in order to better understand how the calculation is performed

Contents

2.1 Building characteristic and selection

Palazzo D'Accursio is big and very complex building as describe in Deliverable D.6.2 inside 3encult project. In order to perform the PHPP calculation two areas are selected. This selection allow to analyze two different destination of use, moreover the areas selected present different feature. For the application of PHPP the first step is the analysis of the building and the definition of the Treated floor Area and the Balance Boundary, these are outlined below.

2.1.1 Balance Boundary

The Boundary Balance is traced with red lines. Some parts are denoted by the dotted line because they are not in the foreground, but they belong to the same view. This is done to make the meaning clear. The different zones are identified with a number, corresponding with ID number used in sheet "Areas" of PHPP.

Balance boundary Office Areas

	Denomination	Area
		m^2
2	Prospetto nord	866.5
	Prospetto Sud	944.77
8	Prospetto Sud_3F	214.92
10	Prospetto Sud_GF	102.03
9	Prospetto Sud_1F to 2F	451.7
1	Prospetto Sud_tower	107
11	Prospetto Est_tower	70
12	Prospetto Ovest_tower	68.14
3	Sezione est	110
4	Sezione ovest	126.5
6	Celing - Ambient	639.6
7	Basement ceiling P Terra	319
14	Basement ceiling Interrato	305
	Exterior Door	
13	Sezione Nord-partition wall	39.68
15	Basement ceiling 3F	56.8

Figure 2.1: The Table resume the surface that describe the balance boundary.

The following drawings give a detail description of the Balance Boundary assumes for the PHPP calculation. Each surface has an identification index that correlate the drawing with the Table in 2.1.

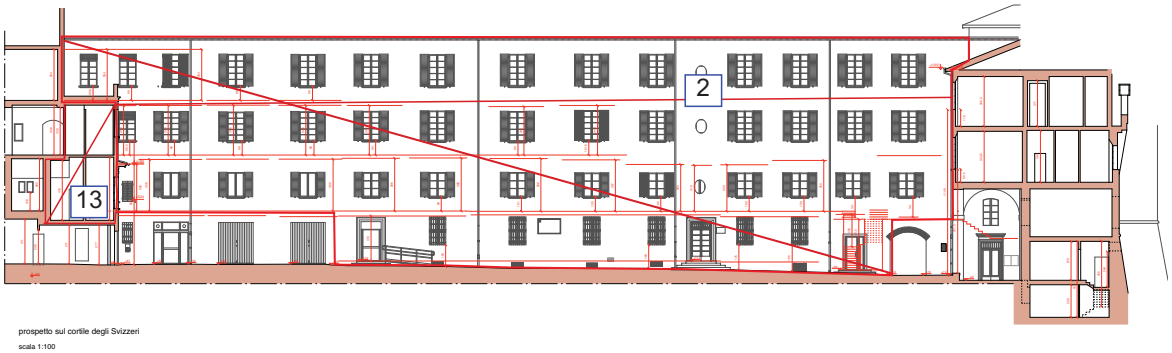
2.1.2 Treated Floor Area (TFA)

The areas are presented with green color on the Figure 2.8 2.9. It is the standard representation of TFA, following the indication of the PHPP manual. More details are available in the tables 2.5 2.6 2.7, used to calculate the TFA starting from the analysis of each room.

2.2 PHPP calculation

The calculation took into account the indications provided by PHI and in particular have been taken the following choices:

(a) South Façade



(b) North Façade with section

Figure 2.2: Subdivision of selected part of building: North and South Façade.

- A review of the drawings is done, through an architectural survey. The drawings of the municipal collections have been partially integrated with some sections because they are very poor and however should be expanded.

- The attics are excluded from Boundary Balance because they are no-heated areas.

(a) Section 1-1

(b) Section 2-2

(c) Section 3-3

(d) Section 6-6

Figure 2.3: Sections of Office Building.

- For windows a specific survey activity was carried out for two specific aims. First is the recovery of the basic characteristics, necessary for inclusion in the PHPP calculation, where the transmittance values are estimated on the indications of PHI. Second is the developing of the database of information for the Municipality to fill the lack of information on the building. The different types of finishing glass surfaces were not considered due to lack of available data. External shading effects from others building, overhangs and vertical elements are considered. The bars, covering the windows are considered as indicated in the guidelines of PHPP: omitted from the glass surface and considered increasing the thickness of the frames on all 4 sides.

- Transmittance values of the walls are carried out in accordance with ISO 6946 [1]. The characterization of external walls is also provided though in-situ measurement of Transmittance value according with ISO 9869 [2]. More details are available in

deliverable D.6.2.

- Blower door test is performed to measure the airtightness level of the building, according to ISO 9972 [3]. The results of pressurization test are used in the calculation to estimate the air permeability of the building.
- The thermal bridges are not analysed at this stage.
- Equipment, light and interior load are determined through the use of result of energy audit performed on the building.

2.2.1 PHPP calculation for "as-in-state" scenario

The main losses components of the "Office Area" are the exterior walls, then windows and unheated attic components. The overall heating consumption is much lower than Museum area, as the building is massive and with smaller indoor space. The internal gains are higher as the building is used as office. During summer the indoor temperature is controlled by natural ventilation through manually operable windows. According to that, the ventilation component during summer is considerable. This strategy seems not be sufficient to guarantee the comfort condition and the calculation of hours of overheating by PHPP shows high value.

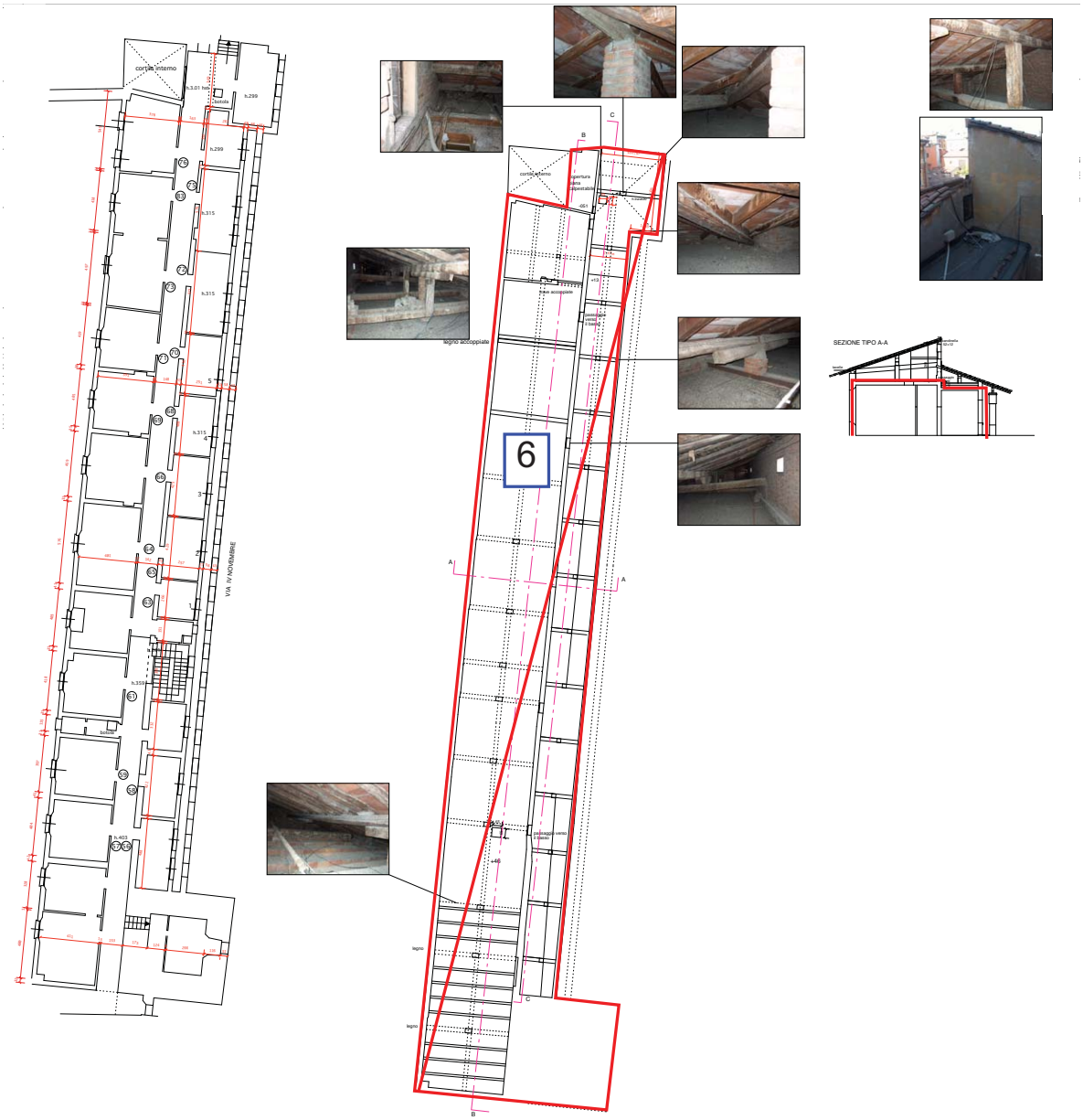


Figure 2.4: The figure shows the attic of the building with the most relevant features.

OFFICE1° FLOOR						OFFICE GROUND FLOOR				
Room	Area	height	Volume	TFA		Room	Area	height	Volume	TFA
	4,23	2,99	12,6477	4,23			10,4	3,13	32,552	10,4
	6,7	2,9	19,43	6,7			10,3	3,13	32,239	10,3
	3,7	3,62	13,394	3,7			4	3,12	12,48	4
	6,5	3,59	23,335	6,5			6	3,12	18,72	6
	1,66	2,68	2,2244	0,83			9,2	2,83	26,036	9,2
	8,8	3,59	31,592	8,8			1,3	2,83	1,8395	0,65
	10,36	3,6	37,296	10,36			1,9	2,83	2,6885	0,95
	10,1	3,4	34,34	10,1			1,2	3,13	1,878	0,6
	11,6	3,3	38,28	11,6			2,05	3,13	6,4165	2,05
	11,2	3,1	34,72	11,2			1,6	3,13	2,504	0,8
	2,54	3,14	7,9756	2,54			1,68	3,13	2,6292	0,84
	7,2	3,12	22,464	7,2			0,85	3,13		0
	3,9	3	11,7	3,9			3,3	3,13	10,329	3,3
	9,13	3	27,39	9,13			0,85	2,66		0
	8,12	3,63	29,4756	8,12						
	16,87	4,35	73,3845	16,87						
Stairs	9,60									
	2,19	3,27	7,1613	2,19			7,4	3,14	23,236	7,4
	3	3,27	9,81	3			8,6	3,13	26,918	8,6
	2	3,27	6,54	2			24,5	3,13	76,685	24,5
	6,33	3,26	20,6358	6,33			17	2,41	40,97	17
	4	3,26	13,04	4			1,2	2,58	1,548	0,6
	22,5	3,58	80,55	22,5			0,95	2,41		0
	14,3	3,58	51,194	14,3			14,5	2,11	30,595	14,5
	17	3,6	61,2	17			14,4	2,81	40,464	14,4
	17,2	3,66	62,952	17,2			11	3,13	34,43	11
	19,7	3,68	72,496	19,7			23	3,14	72,22	23
	20,1	3,66	73,566	20,1						
	3,25	2,88	9,36	3,25						
	17,1	3,57	61,047	17,1						
	17,5	3	52,5	17,5						
	2,68	3,19	8,5492	2,68						
	2,85	3,19	9,0915	2,85						
	15,35	3	46,05	15,35						
	13,9	3,53	49,067	13,9						
	15,36	4,35	66,816	15,36						
Corridor1	11,3	3,62	40,906	6,78		Corridor 1	18,4	2,41	44,344	11,04
Corridor 2	4,3	3,61	15,523	2,58		Corridor 2	8	2,81	22,48	4,8
Corridor 3	17	2,49	42,33	10,2		Corridor 3	3,26	2,83	9,2258	1,956
Corridor 4	4,9	3,57	17,493	2,94		Corridor 4	4,6	2,41	11,086	2,76
Corridor 5	11,6	2,49	28,884	6,96		Corridor 5	4,75	3,2	15,2	2,85
Corridor 6	7,4	3,52	26,048	4,44						
Corridor 7	2,87	3,65	10,4755	1,722						
Corridor 8	10,6	4,12	43,672	6,36						
Tot	395,7		1335,575	358,112		Tot	176,29		599,7135	193,496

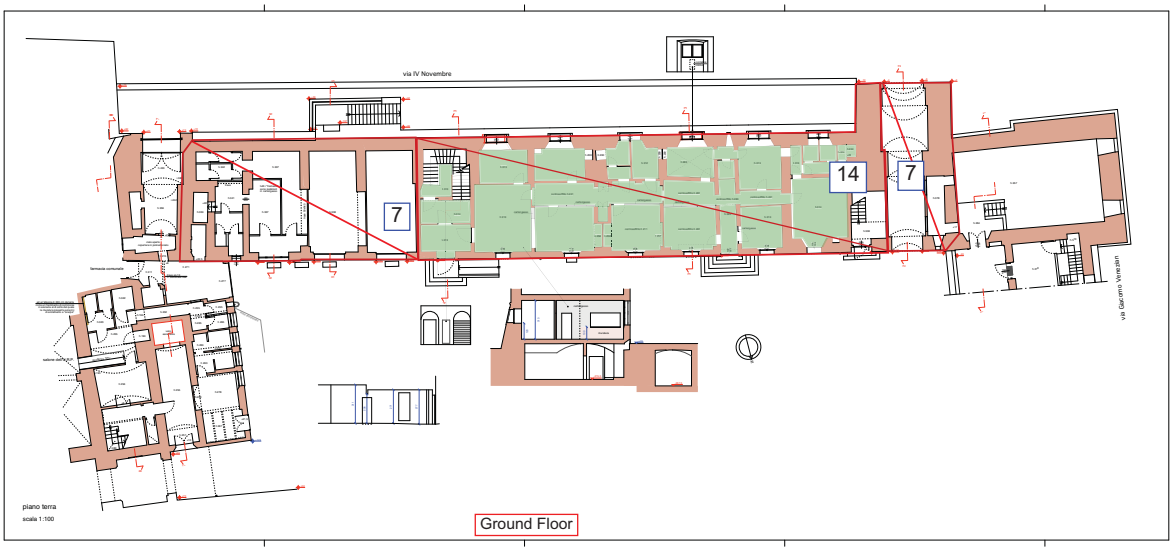
Figure 2.5: The Table resumes the surface that describe the TFA of Ground and First floor of office building.

	OFFICE 2° FLOOR						
	Room	Area	height 1	vault radius	width	Volume	TFA
Room Via 4 Novembre side		10,44	1,15	1,53	2,6	21,5664	10,44
		9,9	1,15	1,5	2,46	20,07936	9,9
		10,4	1,15	1,475	2,6	20,84541	10,4
		9,66	1,15	1,48	2,4	19,36661	9,66
		9,8	1,15	1,45	2,44	19,32834	9,8
		10,8	1,15	1,41	2,71	20,88306	10,8
		13,5	1,15	1,42	2,65	23,91849	13,5
		9,55	1,15	1,41	2,77	19,63293	9,55
		10,2	3,56			36,312	10,2
		9,11	3,57			32,5227	9,11
		13,8	3,56			49,128	13,8
		4,28	3,56			15,2368	4,28
		21,5	4,64			99,76	21,5
						0	
Room Courtyard's side		0,79	2,43			1,9197	
		0,81	3,38			2,7378	
		2,4	3,4			8,16	2,4
		22,3	3,43			76,489	22,3
		22,8	3,43			78,204	22,8
		26	3,46			89,96	26
		22,1	3,45			76,245	22,1
		22,6	3,44			77,744	22,6
		26,3	3,45			90,735	26,3
		32,7	3,36			109,872	32,7
		15,8	3,44			54,352	15,8
		16	3,49			55,84	16
		2	3,43			6,86	2
		1,78	2,66			4,7348	0,89
		15,7	3,42			53,694	15,7
		14	3,42			47,88	14
		15,35	3,42			52,497	15,35
		15,52	3,54			54,9408	15,52
	corridor 1	1	2,4			2,4	
	corridor 2	34,9	3,4			118,66	20,94
	corridor 3	11	3,55			39,05	6,6
	ToT	464,79				1419,697	402,54

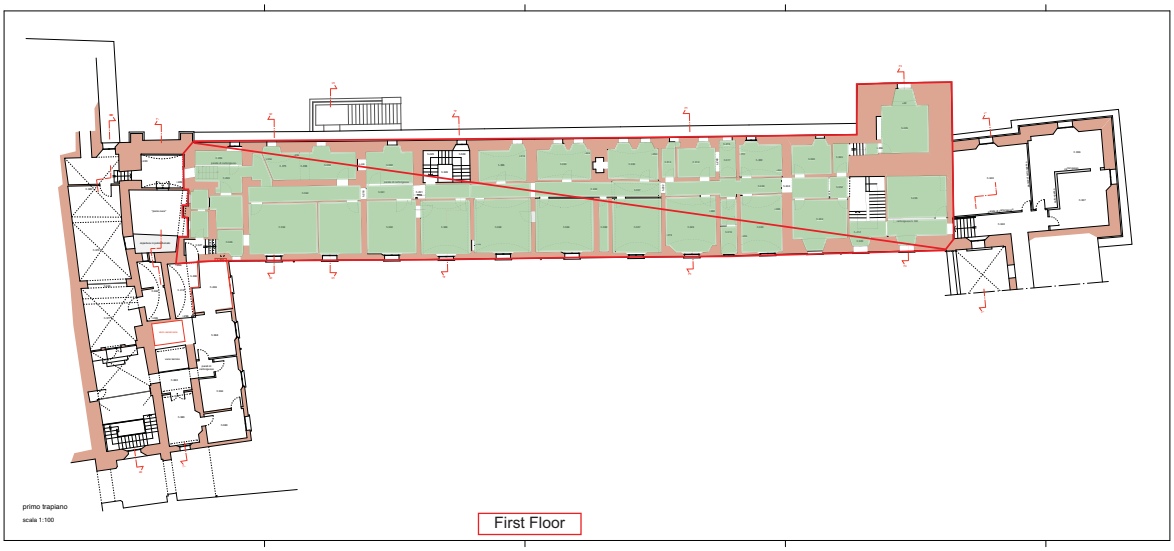
Figure 2.6: The Table resumes the surface that describe the TFA of Second floor of office building.

OFFICE 3° FLOOR						
	Room	Area	height	Volume	Volume of BDT test	TFA
Room Via 4 novembre side		14,9	2,99	44,551	44,551	14,9
		9	2,99	26,91		9
		14,56	3,14	45,7184		14,56
		14,14	3,14	44,3996	44,3996	14,14
		10,34	3,16	32,6744		10,34
		10,18	3,16	32,1688	32,1688	10,18
		10,66	3,16	33,6856	33,6856	10,66
		10,8	3,17	34,236	34,236	10,8
		6,8	3,18	21,624	21,624	6,8
		0,97	2,11	2,0467	2,0467	0
		2,64	3,18	8,3952	8,3952	2,64
	Stairs	8,94		45	45	
		7,5	3,15	23,625	23,625	7,5
		11	3,15	34,65	34,65	11
		9,5	3,12	29,64	29,64	9,5
		11,8	3,5	41,3	41,3	11,8
		4,7	4	18,8	18,8	4,7
Room Courtyard's side		19,3	3,54	68,322		19,3
		16,1	3,57	57,477	57,477	16,1
		19,3	3,59	69,287	69,287	19,3
		15,88	3,58	56,8504		15,88
		16,25	3,6	58,5	58,5	16,25
		18,2	3,6	65,52	65,52	18,2
		23,2	3,62	83,984	83,984	23,2
		16,45	3,6	59,22	59,22	16,45
		16,73	3,58	59,8934	59,8934	16,73
		2,61	3,57	9,3177	9,3177	2,61
		2,05	2,7	5,535	5,535	2,05
		16,22	4,05	65,691	65,691	16,22
		16,26	3,98	64,7148	64,7148	16,26
		13,35	3,98	53,133	53,133	13,35
		19,56	3,98	77,8488	77,8488	19,56
	Corridor 1	14	3	42	42	8,4
	Corridor 2	69,2	3,58	247,736	247,736	41,52
	Corridor 3	24,8	4	99,2	99,2	14,88
Tot		497,9		1602,0758	1444,229	392,18

Figure 2.7: The Table resumes the surface that describe the TFA of Third floor of office building.

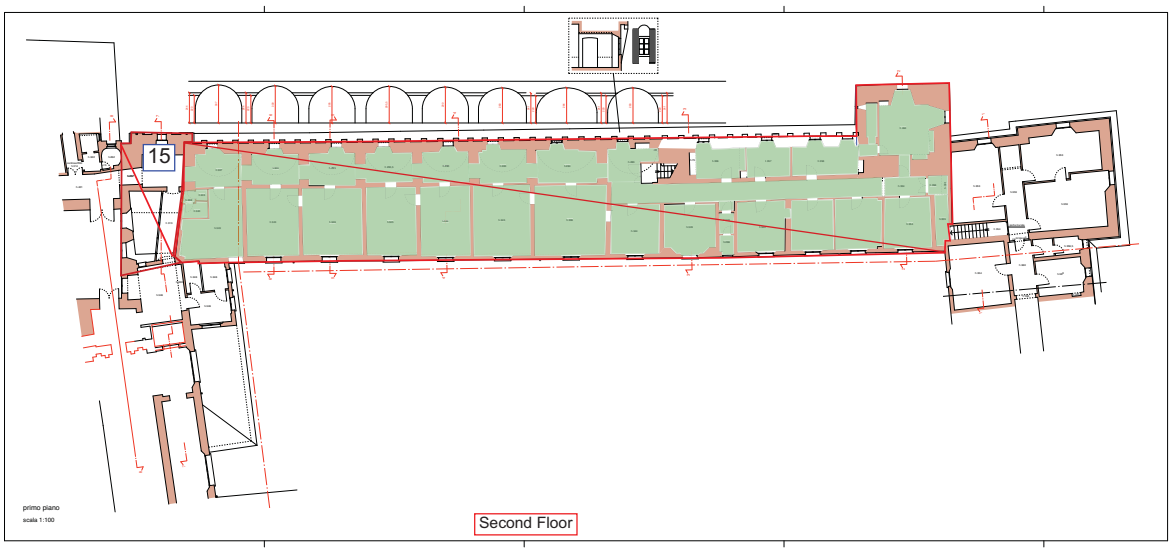


(a) TFA Ground Floor

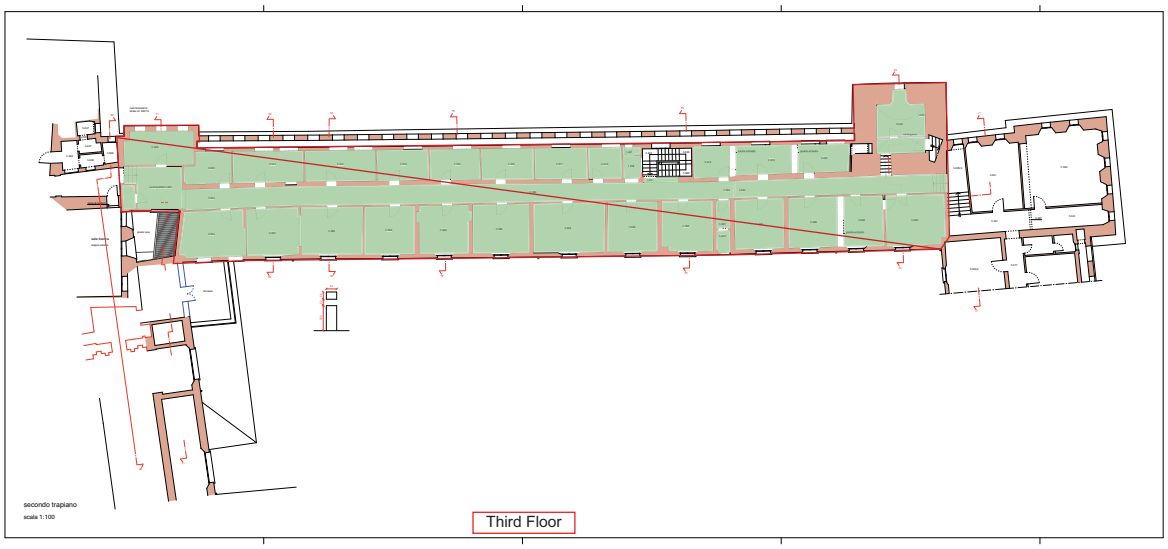


(b) TFA First Floor

Figure 2.8: Treated floor Area of Office building.



(a) TFA Second Floor



(b) TFA Third Floor

Figure 2.9: Treated floor Area of Office building.

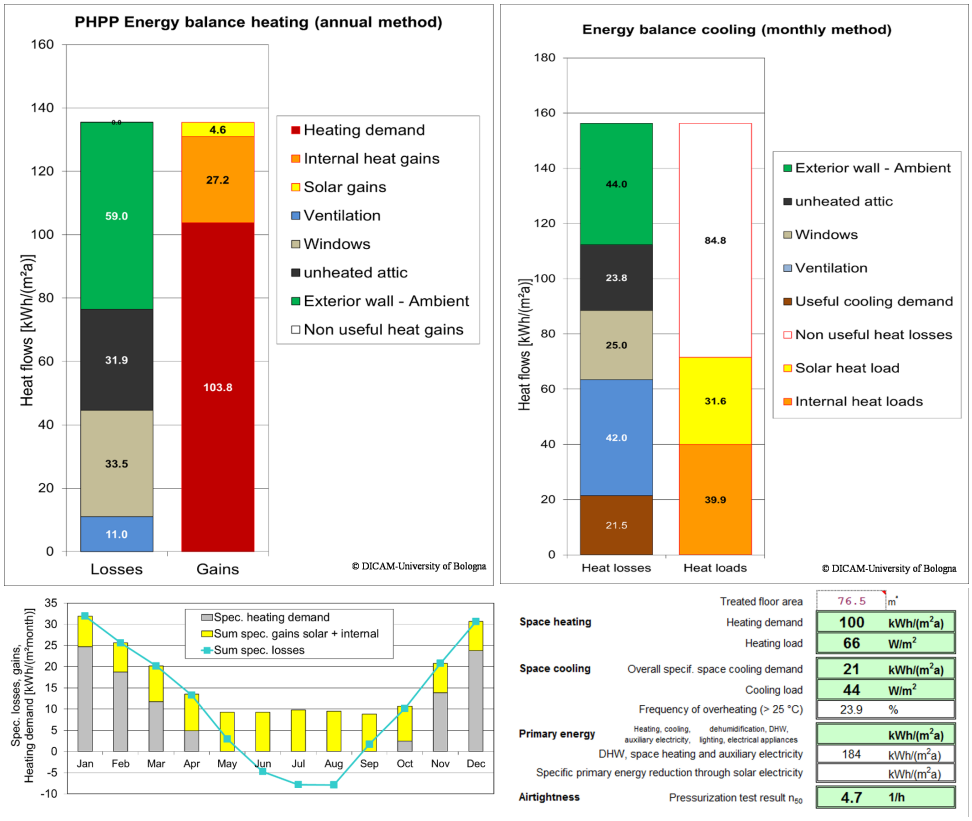


Figure 2.10: PHPP calculation for pre-intervention scenario.

References

[1] CEN. En iso 6946 - building components and building elements - thermal resistance and thermal transmittance - calculation method. *European Committee for Standardization*, 2007.

[2] CEN. En iso 9869 thermal insulation - building elements - in-situ measurement of thermal resistance and thermal transmittance. *European Committee for Standardization*, 1994.

[3] CEN. Iso 9972 thermal performance of buildings - determination of air permeability of buildings - fan pressurization method. *European Committee for Standardization*, 2006.