D 6.2 Documentation of each study case
CS3 Palazzina della Viola, Bologna (Italy)
Delivered at M42

EUROPEAN COMMISSION

DG Research and Innovation

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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

Project Acronym	3ENCULT
Project Title	Efficient ENergy for EU Cultural Heritage
Project Coordinator	Alexandra Troi EURAC research, Viale Druso 1, 39100 Bolzano/Italy Alexandra.troi@eurac.edu
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Case study 3 presentation

0.1 General Information

Location	
	
Name and location of building	Palazzina della Viola, Bologna, Italy
Previous locality names	/
Legal investigation	Ownership: Alma Mater Studiorum - Università di Bologna Local legislation: Urban Building Regulation Protection status: the building is qualified as *building of historical and architectonic interest* in the Urban Regulation Code and therefore admits only respectful interventions of renovation and maintenance. Development plans: the building is placed in the “Comparto Filippo Re” of Bologna, between the old city walls and the Botanic Garden. The urban context is under redevelopment and the rehabilitation of this area is part of the Agreement between the University and the Municipality of Bologna.
Heritage administration	The subject in charge of the object, qualified as *building of historical and architectonic interest* in the Urban Building Regulation Code, is the local Authority for Cultural Heritage.
Responsible Planner/ Architect	

Local case study team	LCS-Team of CS3 - Palazzina della Viola: UNIBO (scientific guidance), UNIBO (building owner), Soprintendenza per i Beni Architettonici di Bologna & Soprintendenza per i Beni Artistici di Bologna, Architect(s) in charge of the conservation intervention
Name and company of surveyor	Camilla Colla, Elena Gabrielli, Marco Giuliani (UNIBO-DICAM); Giacomo Paci (UNIBO – DEI)
Comments	*At the moment (2013) the building is used as headquarters of the International Relationships Department of the University of Bologna

General description incl. building problems

Date of construction	1497 by Giovanni II Bentivoglio
Architect/Artist/other persons	Frescoes and painted wooden ceiling by Amico Aspertini, Prospero Fontana and Innocenzo da Imola (15th and 16th C.)
Architectural style	Renaissance
Typology of building	Light building, load bearing masonry with ceilings made of steel, wooden beams and brick elements
Original objective	Hunting hut
present use	None (at the beginning of 3ENCULT project, Oct. 2010)
expected use in the future	University
Construction materials	brick masonry, wood, steel

Construction method	Masonry construction
Short description of building	This isolated building, built in 1497 as little hunting hut, has a quadrangular plan (4 floors,300 m2 per floor, around 4240 m3 of total volume) and 3 façades (partly plastered) lightened by a double open gallery. The structure is load bearing masonry walls and ceilings made of steel beams and brick elements. This listed building is enriched at the ground and 1st floor, by frescoes and painted wooden ceilings (15th and 16th C.), attributed to Amico Aspertini and Prospero Fontana. The building was the College for the University of Bologna students who came from Piedmont (a northern region of Italy) from 1540 to 1797; in 1803 it was acquired together with the land plot around it by the Government of the Italian Republic to host the Faculty of Agriculture and the Botanical Garden. The building has been object of rehabilitation intervention at the beginning of 1900. After WWII, the N-W corner of the building was rebuilt because destroyed by a bombardment. Several other partial remakes date from the last 60-70 years. Rehabilitation preservation interventions and functional requalification has been started at the end of 2010.
Number of Axes	/
Shape of roof	Pitched roof
Internal access	not specified
Status quo	Current use (at the beginning of 3ENCULT project, Oct.2010): None, under refurbishment after several years of abandon. Refurbishment planning: rehabilitation preservation interventions and functional requalification (16-months: Nov. 2010 - March 2012) Expected use*: offices of the International Relationships Department of the University of Bologna at the ground floor and spaces for congresses and events at the 1st floor
Overall conservation status	Status of conservation (Oct. 2010, prior to the rehabilitation interventions): several structural problems, conservation problems for the frescoes (related to indoor humidity, temperature and lighting) and problems related to energy efficiency have been detected (e.g. wide surface of windows, windows with single glazing). Cracks on walls and ceilings, salt rising in masonry walls, lack glazing, broken windows are visible.
Actual European energy standard	No available standards for historical buildings.
building problems with regards humidity	Presence of humidity at the underground and ground level
building problems with regards salts	/

Planned activities within the project	
Diagnosis	- Visual inspection -Geometric and dimensional survey integration (plan view, section, volumes, etc.) - Material, decay and crack pattern survey - Window frames survey - Survey of the heating/cooling/lighting systems - Survey of openings in ceilings/floors - Monitoring of crack opening - Measurements of Air T and RH in rooms; measurements of superficial temperature on walls - Mapping of air T and RH - IR thermography investigations for energetic aims - IR thermography investigations of air fluxes - IR structural investigations, both superficial and under-plaster to identify the masonry pattern - Ground penetrating radar (GPR) survey for structural and energetic purposes - U-value measurements - Blower Door test - Daylight measurements
Planned solutions	Rehabilitation preservation interventions and functional requalification to be performed keeping the original integrity of every architectonic, artistic and decorative elements of the building as prescribed by the Urban Building Regulation Code.
Monitoring system	**WSN Wireless Sensor Network for monitoring and controlling building environment** **Monitoring concept:** - Indoor climate: air temperature, air humidity and light intensity for each ground and first floor room. Surface temperatures on constructional critical points of the thermal envelope (e.g. external corner, window, air streams, …) - Outdoor climate: solar radiation, outdoor temperature, outdoor relative humidity - Historical surfaces: near field climate, surface temperatures. Wall vibration detection **Approach**: 1) Monitoring as-is-state: monitoring of selected rooms to detect light intensity, air temperature and relative humidity.

	2) During interventions: monitoring of selected rooms to detect wall vibration intensity, light intensity, air temperature and relative humidity. 3) Monitoring after interventions. 4) Monitoring after conclusion refurbishment works: monitoring of selected rooms, when in use, to detect air temperature, relative humidity and light intensity to interact with the building management system in order to increase the energy efficiency of the building.
Simulation	- PHPP calculations (as-is-state) - Modelling of the most critical parts of the building - Performance assessment of existing windows
Transfer to urban scale concept	For its characteristics of light masonry building (reduced thickness of walls), methodology and findings from Palazzina della Viola could be transferred to other “minor architecture” (private housing)
Others	Search for archive information (photos, drawings, history); search for information about the existing heating system

0.2 Building Assessment

Cultural Value (Specific valuable aspects)	
Architectural historical value	Singular light masonry building, defined as a “jewel of the Renaissance art”, characterized by a quadrangular plan, with three glazed facades, frescoes and painted ceilings.
Cultural historic value	The building is socially representative and has an high historical value, as it is dated from the 15th C. and it is enriched by frescoes and painted wooden ceilings attributed to Amigo Aspertini, Prospero Fontana and others (15th – 16th C.)
Context value	Different architectural style from the others building of the same quarter (mainly from 1900).
Social value	The building is socially representative as presents walls and ceilings decorated or painted at *frescoes*.
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 this code, the building is qualified as *building of historical and architectonic interest* and therefore admits only respectful interventions of renovation and maintenance.
Limits and prescriptions arising from Area Regulations	/

Limits and prescription determined by the owner	/
Preservation concept	/
Others	

Documentation	
diagrams/drawings	See §1.1.
expertises/reports	CS3_ReportPreIntervention_Airtightness.pdf, CS3_ReportPreIntervention_Basement.pdf, CS3_ReportPreIntervention_InternalPartition.pdf, CS3_ReportPreIntervention_Windows.pdf, CS3_ReportPreIntervention_PsychrometricMaps.pdf, CS3_ReportPreIntervention_StructuralAnalysis&MoistureAssessment.pdf, CS3_ReportPreIntervention_U-value.pdf
files/correspondence	
guidelines/specifications	
photographs/images	CS3_SitePlan.pdf
publications/press	

0.3 Detailed description

0.3.1 Urban Context and Local climate data

Urban Context	
Building plan showing the north 	
Relation with neighbouring buildings	isolated building
Quarter/town/surrounding	The site is located in via Filippo Re, near the old city walls of Bologna. It is an university area with a high rate of students' participation with pedestrian and vehicular traffic. Via Filippo Re is a dead-end street and it is characterized by University buildings surrounded by public parks.
location/orientation/ accessibility	• Conservation aspects: The building is located in the "Comparto Filippo Re" of Bologna between the old city walls and the Botanic Garden. The site is characterized by the presence of other historic buildings(mainly from 1900) connected by pedestrian paths and parking for university staff. Buildings are surrounded by green areas with trees. • Energy-related aspects: Self-contained building, South-East oriented, shaded by trees on all sides except the South side.
Development plans	Urban Building Regulation code.
	no file associated
Certificates/reports/regulations on energy efficiency	

	no file associated
Historical context	• Conservation aspects: A XV century building defined a "jewel of the Renaissance art", characterized by three glazed facades and located just outside the gates of the old city walls. The architectural style of the Palazzina della Viola is completely different from the others buildings of the same quarter. • Energy-related aspects:
Key figures as e.g. % of historic buildings, renovation rate	no file associated
Necessary data for PHPP calculation available: Monthly mean averages of temperatures and solar radiation?	yes
Particular architectural solutions according to the local climate	Use of red Bolognese curtains
Overshadowing	The building is shaded by trees on all sides except the South side (main facade) where there is a meadow. Trees partially shade the roof.
Nearby areas for organizing the on site retrofit works	
Use during the retrofit works	

Local climate date			
Climate zone	E		
Climate area	3F		
Degree days	2259		
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		
Winter climate data		Summer climate data	
Winter design temperature	-5°C	Temperature: dry/wet bulb	33/22°C

HR max (Nov.-Dec.)	95%	HR	43%
Heating day per year	183	Daily temperature range	12°C
Other		Other	

Available data for the project	Statistical data: Meteonorm (Bologna - Borgo Panigale (airport) weather station)
Reference statistic data from “common database” (e.g. Meteonorm)	yes Energyplus Database
Reference climate data	
Data measured from local weather station	yes
Measured climate data	
Comments	Data needed for PHPP-calculation: Regional data used in PHPP database refer to Milan. This is allowed by the similarities between these cities and it is on the safe side because Milan has slightly more extreme climatic conditions than Bologna. PHPP V8.4 provides data also for Bologna Climate.

0.3.2 Report on history of the building

History of the building	
Use of building over time	The Palazzina della Viola was built in 1497 by Giovanni II Bentivoglio at the city boundaries for his son Annibale as hunting hut and place of delight. It owes its name to the violets blooming in the meadows. In 1505, after an earthquake, the Bentivoglio family took refuge in the building and one year after it was plundered by Bentivoglio enemies. After the Annibale’s death, in 1540, the building was sold to the Felicini family and used before as Literary Academy of “Viridario” and after as Academy of “Desti”. Few years later, the Cardinale Bonifacio Ferrerio bought it and the Palazzina became a student residence since 1797 where it was expropriated during the Napoleonic era. Actually, the 17th C. was a period of negligence for the Palazzina since the building was abandoned several times and some bad interventions were done in the middle of 17th C: the loggia at the 1st floor was closed to

	obtain rooms, some frescoes were covered with plaster or tapestry and others frescoes were damaged. In 1803 the building passes to the Italian Government and later it becomes the Headquarters of the Agriculture Faculty and Botanical Gardens. In 1907 the "Cassa di Risparmio" of Bologna financed the renovation: the loggia at the 1st floor was reopened by demolish the non-load bearing walls and the frescoes behind the plaster were recovered. Minor interventions were also done in 1928. After the WWII long refurbishment works were done to repair the damages caused by the bombing of June 22nd , 1944. In detail, the N-E side was rebuilt, the porch on the main façade and the superior loggia were recomposed and restored and the damaged walls were repaired. Later on the frescos were also restored.

Archive photo, front view of Palazzina in 1922

Construction phases	
	not specified
Other comments	

0.3.3 Building consistency

Building consistency	
Description state of the building	The building presents some structural problems as cracks in walls, ceilings and floor at different levels, especially in the South-West side. Other structural problems are related to the wooden roof structures, made of both ancient, original and new timber elements and mainly due to water leakages. Moisture and salt rise is also visible on walls.
Description construction method	It is a load-bearing masonry structure of quadrangular plan. The ceilings, originally timber beams ceilings, were partially substituted for metal beam ceilings with hollow fired-clay elements or for on-site cast prestressed concrete beams with hollow fired-clay elements.
Description shape	Self-contained building
Description of facades and roof	The building presents three glazed facades. The main facade (South-East) presents a porch at the ground level with a loggia on the upper level. The roof structure is made of wooden beams, partly original and partly new. The roof is made with 40mm thick terracotta elements covered with a waterproof membrane on which the roof tiles have been laid.
 	
Number of floors above ground	3
Number of basement floors	1
Covered area	500 m^2 each floor
Numbers of rooms	38
Gross area	1310 m^2
Net area	1061 m^2
Heated surface	833 m^2
Surface cooled	752 m^2
Heated volume	3561 m^3

Other comments	/

Occupancy rate (number of inhabitants/users)	The building was not in use for many years before the rehabilitation works.
Occupancy time (h/week, d/month)	/
Target energy demand heating/cooling	/
Other comments	/

Building Services (as- is-state)	
Heating system	The heating system used in the past consisted in a gas-oil boiler (THERMITAL TH-NG 200) that was located in the underground floor. Different kind of radiator are present, some of them are hidden into the ceilings but the majority was placed below windows. Some vents related to AHU no longer present are located in the large room at the first floor. The distribution system is made of iron and copper pipes. The oldest pipes have a layer of canopy and lime.
Plant room	/
Electrical System	Electric installations were almost completely removed. No technical information is available.
Ventilation System	A ventilation system was used as heating system in the first floor. It is not sure if the system was or not used also for ventilation, treated air, night ventilation. No information is available and the type of control is unknown.
Cooling System	There was not a cooling system. The only system used in the past for cooling was represented by the transom windows at the ground floor.
Wastewater disposal	No information available
Renewable Energy	None
Artificial Lighting	Different types of luminaires and lamp types; presence of external luminaires. No technical data available. No information about Depict control strategy (on-off-switcher, dimmer, control panel, bus system, occupancy sensor, daylight sensor, etc.
Use of Daylight	Openings in the roof. In some rooms, both at the ground floor and first floor, there are no windows; daylight comes from glazed doors

DHW production	For the production of domestic hot water was probably used a boiler (no technical information available).
Chimney/ducts	An historical chimney in the large hall at the first floor (no longer in use).

Building Potential	
Potential for energetic use	Unique building, defined as a *jewel of Renaissance art*.
Subterranean floors and basements and the possibility of air exchange with upper floors/roof	One basement
Possible heat exchange with the surrounding ground	
Possible use of energy sources on the building or from nearby, possible application of “smart grids”	
Short description/overview on space available for building services/combustible/installations	
Possibility of installation of geothermal collectors (dimension)	
Possibility of de-/central ventilation system (available space/wiring etc.)	
Transferability of (energetic) refurbishment solutions to other buildings	
Others	

0.3.4 Building Energy consumption

Energy bills	No data available.
Documentation of former energy audits	No former energy audits have been carried out.
Measured energy consumption as-is-state	No data. The building wasn't in use for several years and previous data are not available. no file associated

Building Energy consumption			
Electricity	**Years**		**Cost (€) (average cost €/kWh)**
	2008		
	2009		
	2010		
Diesel	**Year**	**Consumption (l)**	**Cost (€) (average cost €/l)**
	2008		
	2009		
	2010		
Gas	**Years**	**Consumption (mc)**	**Cost (€) (average cost €/mc)**
	2008		
	2009		
	2010		
Gecam	**Years**	**Consumption (l/mc)**	**Cost (€) (average cost €/mc)**
	2008		
	2009		
	2010		

0.4 Constraint condition and protection

Constraint condition and protection	
Description of building safety with regards statics/structural problems - compliance with local regulations	During the rehabilitation and refurbishment interventions, works have been undertaken in order to improve the safety performance of the building taking into account seismic risk.
Certificates/reports/regulations on statics	Certificates about static regulations have been the care of the technical office of the University as project Director. All was accomplished as requested by the current regulations for interventions. 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	No dangerous material are present in the building.
Certificates/reports/regulations on dangerous materials	No such certificates required given that dangerous material are not present in the building.
Description of building safety with regards fire protection - compliance with local regulations	Fire extinguisher and all required equipment for protection from fire risks have been provided and installed as from up-to-date Italian laws.
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	In relevant parts of the ceilings between ground and first floor, during the renovation project, the structural performance with regard to seismic safety has been significantly improved by means of more complete anchoring of the ceilings with the respective perimeter walls. In the structural nodes of the timber elements of the roof, trusses, tightening between the elements has been improved by fastening. This was aimed at improving the box behavior of the building.
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	No such certificates required given that the building is located in a quiet place without acoustic disturb.
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.

Some constraints were also related to the historical and architectural value of the Palazzina della Viola and to the presence of ancient frescoes.

0.5 Selected area of intervention

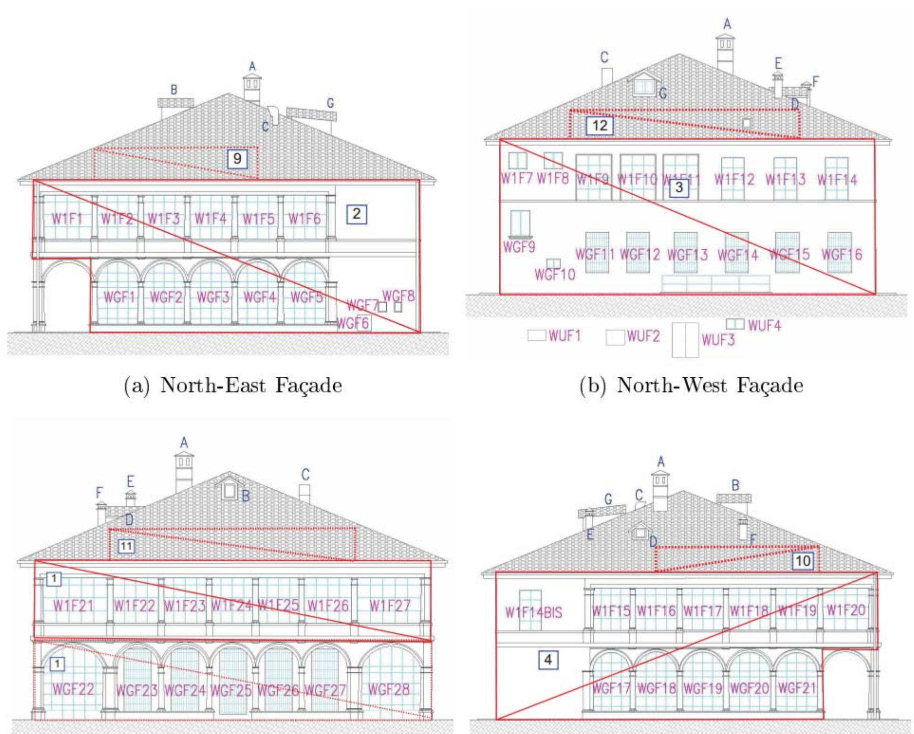
The whole building has been studied and has undergone refurbishment and rehabilitation works.

1 Report on status pre-intervention

1.1 Analysis of architectural elements

1.1.1 Thermal envelope

General description
The whole building of Palazzina della Viola has been studied and subjected to rehabilitation and refurbishment interventions. It is a self-contained, isolated building of quadrangular plan. It has a load-bearing masonry structure with ceilings where the original timber beams were partly present and partly substituted with metal beams and hollow fired-clay elements or prestressed concrete beams with hollow fired-clay elements. More details and characteristics of the architectural elements are reported in the tables below, divided according to their types/functions. As an example and as an anticipation, the balance boundaries selected for PHPP evaluation (see annex I) are herein reported for the 4 façades.



(a) North-East Façade (b) North-West Façade

(c) South-East Façade (d) South-West Façade

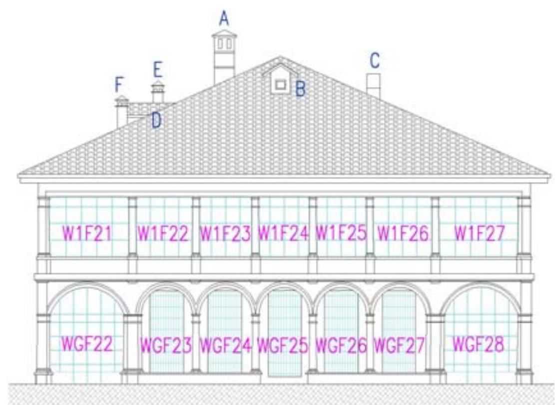
Balance boundaries assumed for PHPP calculations: elevations

Heritage aspects
This listed building has an high cultural and architectural value and for its peculiarity it was defined a jewel of the Renaissance art.

Special care has to be taken during rehabilitation intervention due to the presence of frescoes and painted timber ceilings from 15th-16th C attributed to Amico Aspertini and Prospero Fontana.

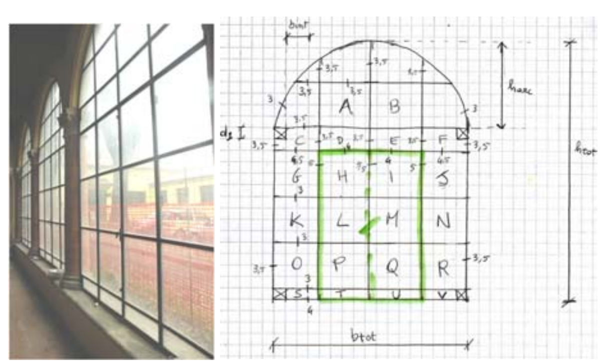
Façade 1: #feld_1_1#

Description	Main façade, South-East
Type of façade	Porch at the ground floor & glazed façade at the 1st floor
Balcony	no
Eaves	
Conservation state of the façade: humidity or other visible stain/deterioration on walls	The porch protects the rooms of the ground floor.
Openings/holes usable for wiring or pipes (e.g. 10cm diameter)	none

Membranes (waterproofing/breather/vapour control layer) applied	none
Documentation of windows	Very many types of windows can be recognized; they are of different materials (wood, steel...) and from different ages. Moreover different types of glasses can be identified: normal (thin, thick), printed (stripes, different shapes and size of prints) and coloured (milk). All the exterior windows are characterized with clear glasses, single or double. Dimension of frames, glasses, depths, and other main characteristics were collected following the directive of PHPP and in order to produce a good amount of information necessary to understand and maintain the history of building and to analyse correctly the energy balance. 

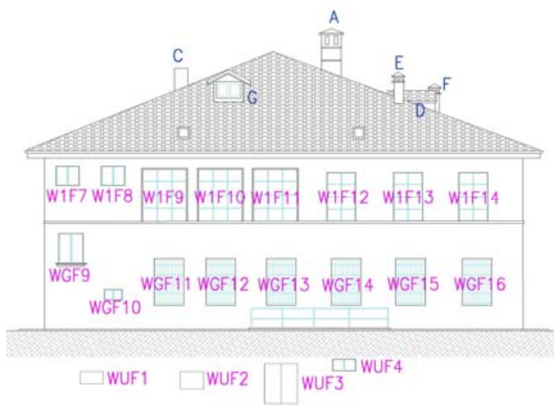
	 WGF28  W1F27
Surface area part 1	Façade area: 193,76 m2
Surface area part 2	Windows area: 104,18 m2

Façade 2: #feld_1_1#	
	
Description	North-East side
Type of facade	Double glazed façade

Balcony	no
Eaves	/
Conservation state of the façade: humidity or other visible stain/deterioration on walls	high level of humidity in air and wall
Openings/holes usable for wiring or pipes (e.g. 10cm diameter)	/
Membranes (waterproofing/breather/vapour control layer) applied	none
Documentation of windows	A complete documentation of the windows of this façade was collected following the same procedure showed for the South-East façade. Here examples of drawings, sketch and photos taken during the measurements of the windows of the North-East façade are reported.   Photo and sketch WGF1, ground floor

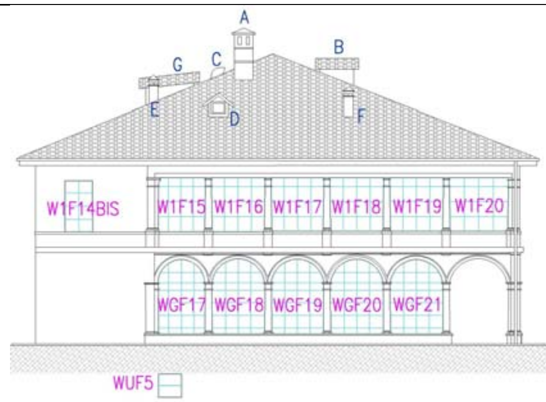
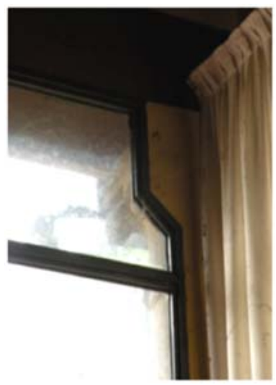
	 WGF6, ground floor  W1F2, first floor
Surface area part 1	Façade area: 176,92 m2
Surface area part 2	Windows area: 85,48 m2

Façade 3: #feld_1_1#	
	
Description	North-West side

Type of facade	
Balcony	No
Eaves	
Conservation state of the façade: humidity or other visible stain/deterioration on walls	high level of humidity in air and wall
Openings/holes usable for wiring or pipes (e.g. 10cm diameter)	/
Membranes (waterproofing/breather/vapour control layer) applied	none
Documentation of windows	A complete documentation of the windows of this façade was collected following the same procedure showed for the main façade. Window codes for North-West façade (rear):  W1F9
Surface area part 1	Façade area: 187,71m2

Surface area part 2	Windows area: 56,02m2

Façade 4: #feld_1_1#	
 view from the South corner	
Description	South-West side
Type of facade	Double glazed façade
Balcony	no
Eaves	
Conservation state of the façade: humidity or other visible stain/deterioration on walls	high level of humidity in air and wall
Openings/holes usable for wiring or pipes (e.g. 10cm diameter)	/
Membranes (waterproofing/breather/vapour control layer) applied	none
Documentation of windows	A complete documentation of the windows of this façade was collected following the same procedure showed for the South-East façade. Window codes for S-W façade:

	 
Surface area part 1	Façade area: 182,09m2
Surface area part 2	Windows area 90,62m2

1.1.2 External walls

The thicknesses of the main walls are reported in figures 1.1 and 1.2, but it is necessary to underline that the thickness of the majority of the walls, especially the older ones, is not constant throughout the building, also because the plaster thickness is uneven. The measurements reported for each wall, resulted from measures in multiple locations of the same wall, with an approximation of about ± 0.5 cm.

All bearing walls of the Palazzina are made of solid masonry and their thermal characteristics are reported in §1.2. Some existing cavity related to the presence of old chimneys have also been found. No membrane for humidity control transportation was present into the walls.

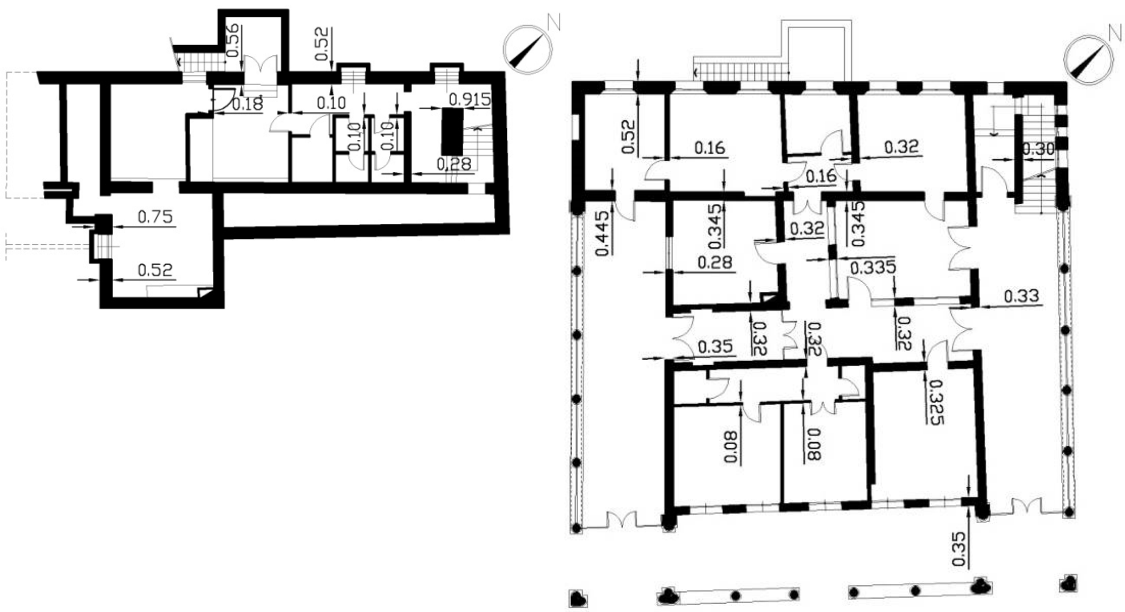


Fig. 1.1 – Plan view of underground and ground floor showing the thicknesses of the walls

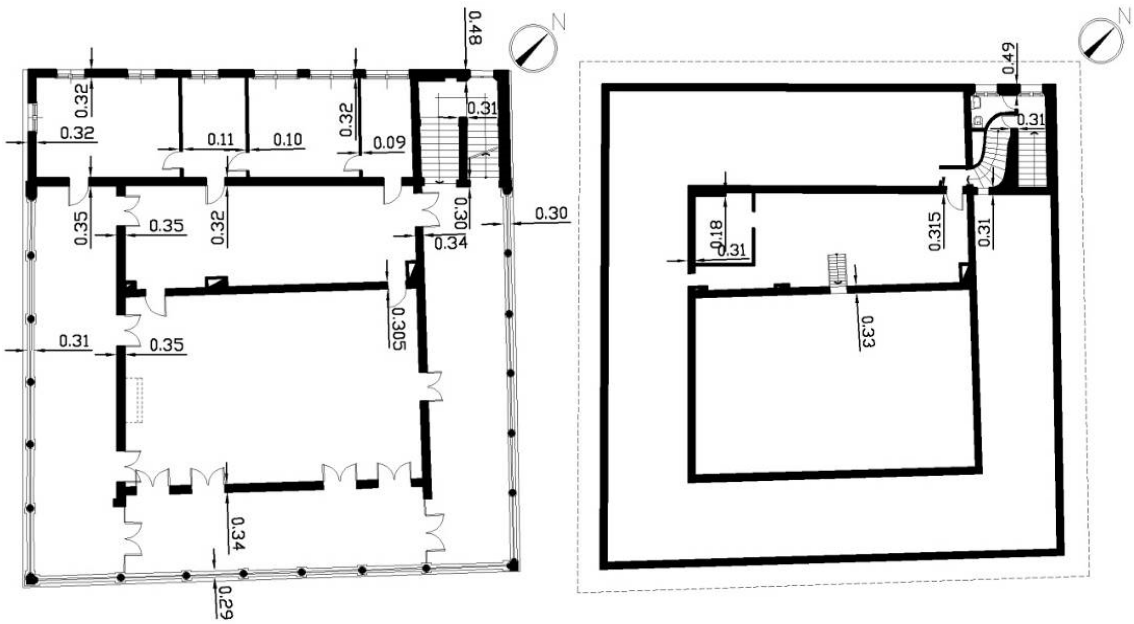


Fig. 1.2 – Plan view of first floor and second floor showing the thicknesses of the walls

1.1.3 Windows

The Palazzina della Viola is characterized by a large amount of windows with a percentage of windows area related to the total surface area very high.
In the following images, some example photos are reported to show the different types of windows frames and glasses installed in the building. Note that all the exterior windows are characterized with clear glasses, single or double, while interior doors and windows have often printed glasses

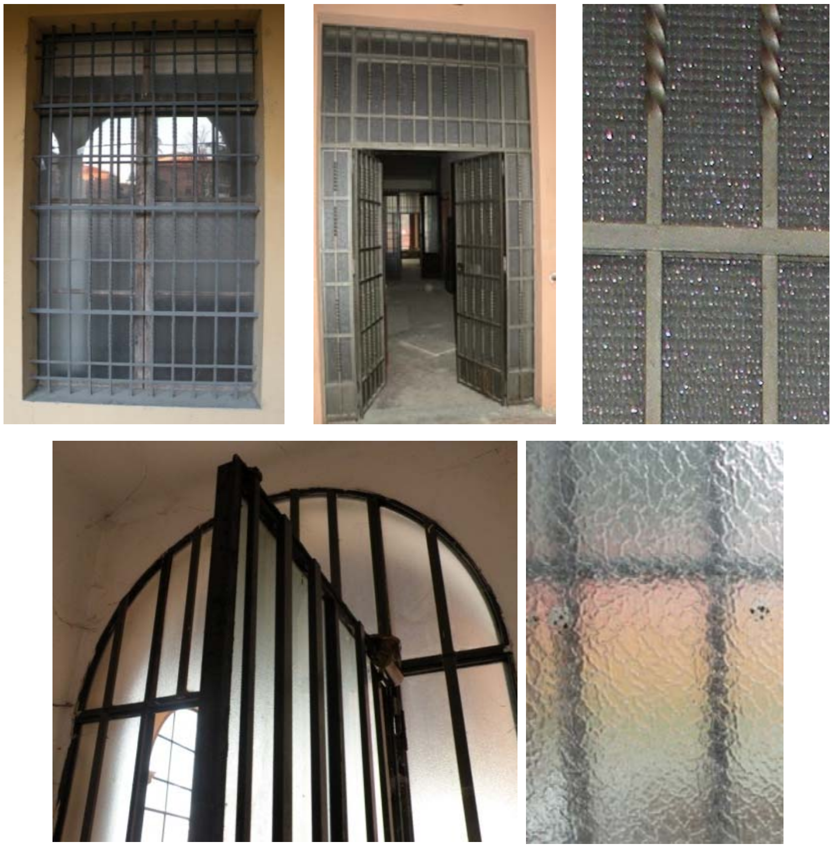


Fig. 1.3– Different types of windows (windows frames and glazing) installed in the building at the ground floor (view from the exterior and interior)

Fig. 1.4–Details of the window frames of the first floor

Fig. 1.5– Internal glazed doors

Geometrical survey of windows

The dimensions and characteristics of the windows frame were measured and reported in detailed drawings.

An example for two windows, one at the ground floor and one at the first floor is reported in the following images.

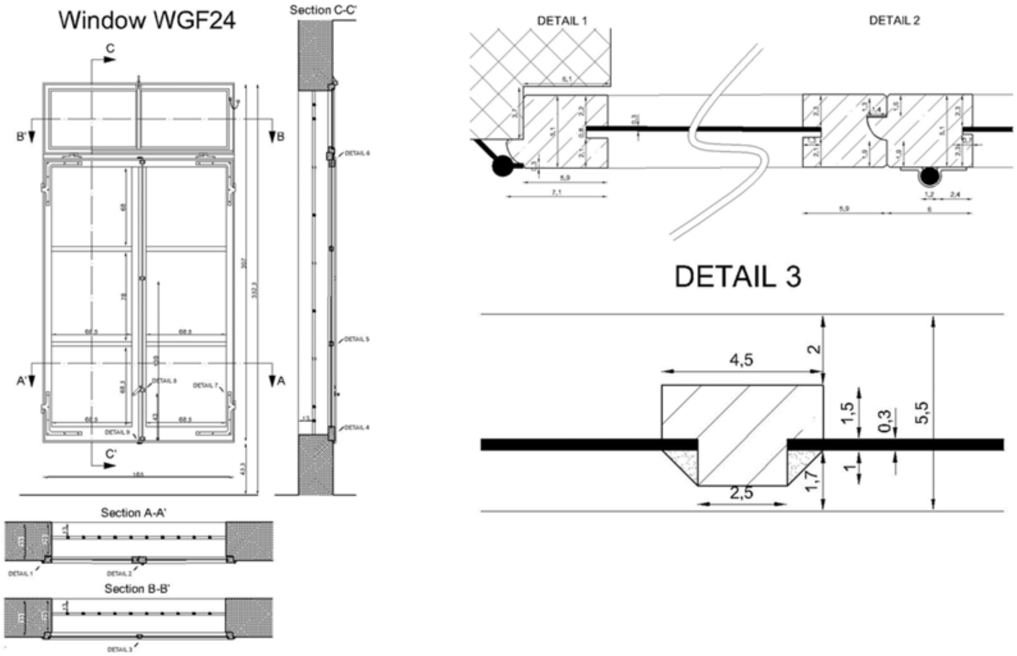


Fig. 1.6 – Geometrical details of window WGF24

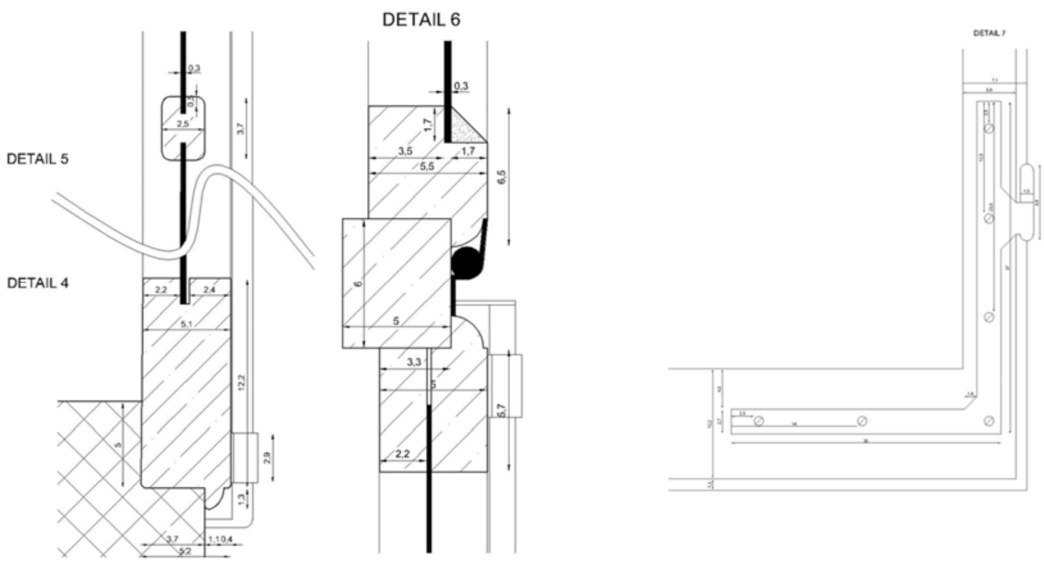


Fig. 1.7– Details of window WGF24

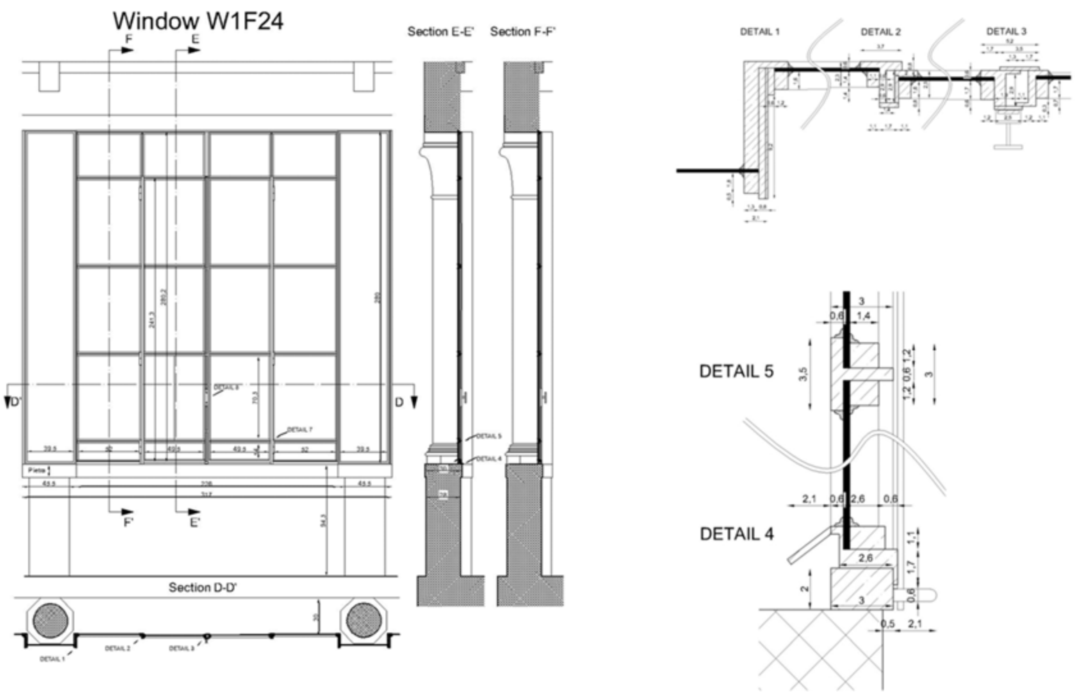


Fig. 1.8 – Geometrical details of window W1F24

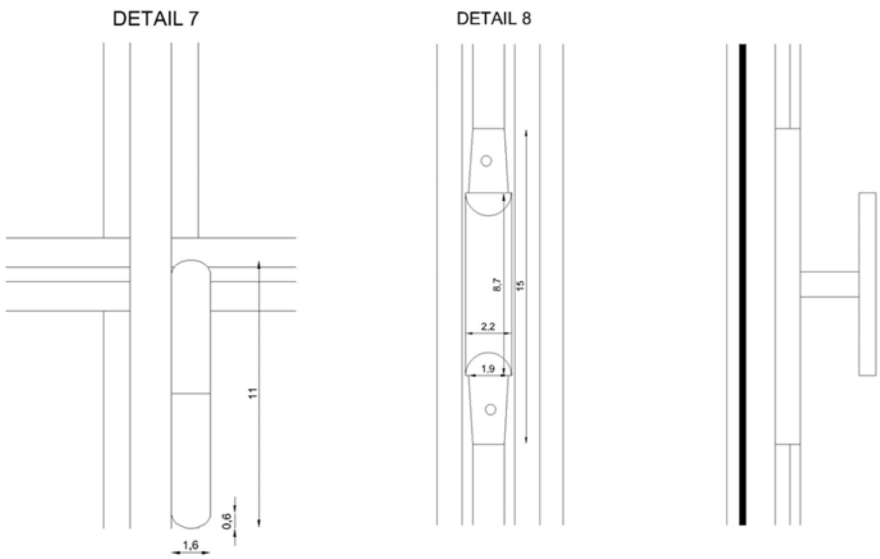


Fig. 1.9– Details of window W1F24

<u>Numerical simulation of as-in-state conditions of window frames</u>

The study of performance of old windows was carried out by ARUP. The numerical simulation had considered so far two different, representative, windows of the South façade, one at the ground floor and one at the first floor.

The purpose of the study was to characterize the actual thermal behaviour of components and the interaction with the room climate conditions.

The renovation project included the restoration of existing windows, not allowing for the replacement (due to heritage protection constraints). It will therefore be interesting to study the consequence of this design choice.

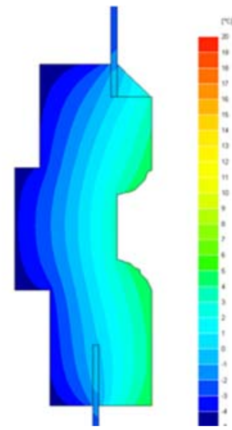
WGF24 – Detail 6:

Environmental Conditions:

- Internal Temp.: 8°C (from psychrometric map)
- External Temp.: -5°C

Ψ-value: 2.70 W/mK

Min. Internal Surface Temp.: -1.3 °C



Environmental Conditions:

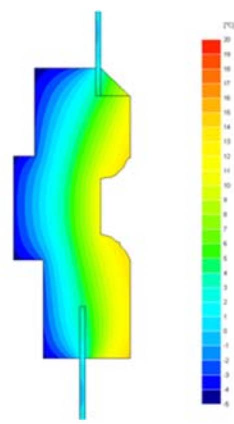
- Internal Temp.: 20°C (design temperature)
- External Temp.: -5°C

Ψ-value: 2.70 W/mK

Min. Internal Surface Temp.: 2.5 °C

Dew point temp. (20°C; 50% RH): 9.3 °C

➢ ***Formation of Condensation***



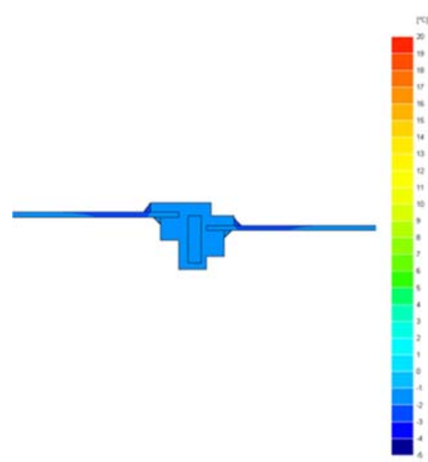
W1F24 – Detail 2:

Environmental Conditions:

- Internal Temp.: 8°C (from psychrometric map)
- External Temp.: -5°C

Ψ-value: 2.64 W/mK

Min. Internal Surface Temp.: -1.9 °C



Environmental Conditions:

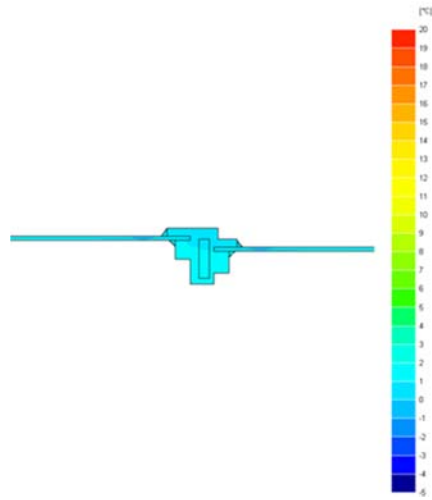
- Internal Temp.: 20°C (design temperature)
- External Temp.: -5°C

Ψ-value: 2.64 W/mK

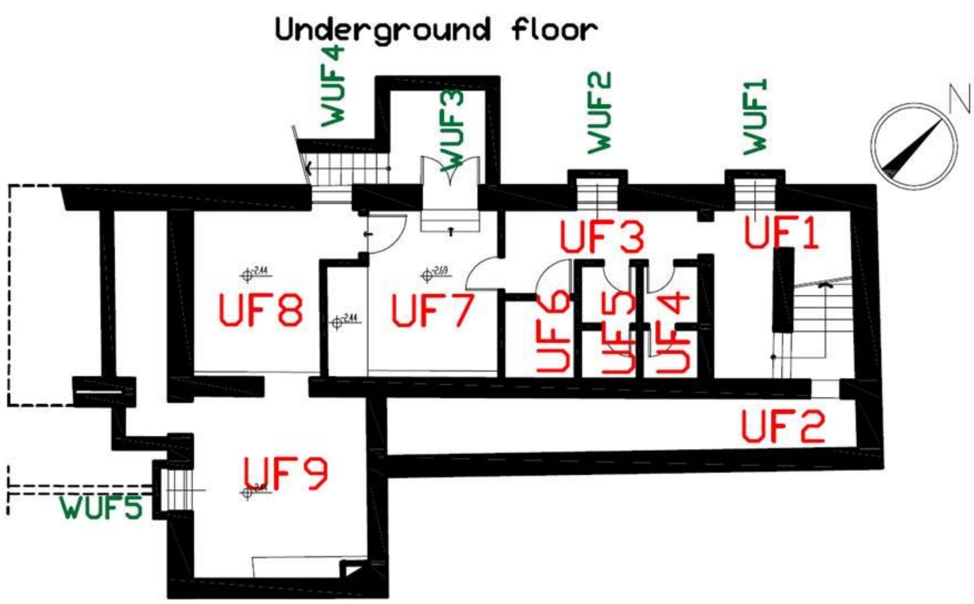
Min. Internal Surface Temp.: 1.0°C

Dew point temp. (20°C; 50% RH): 9.3 °C

➢ ***Formation of Condensation***

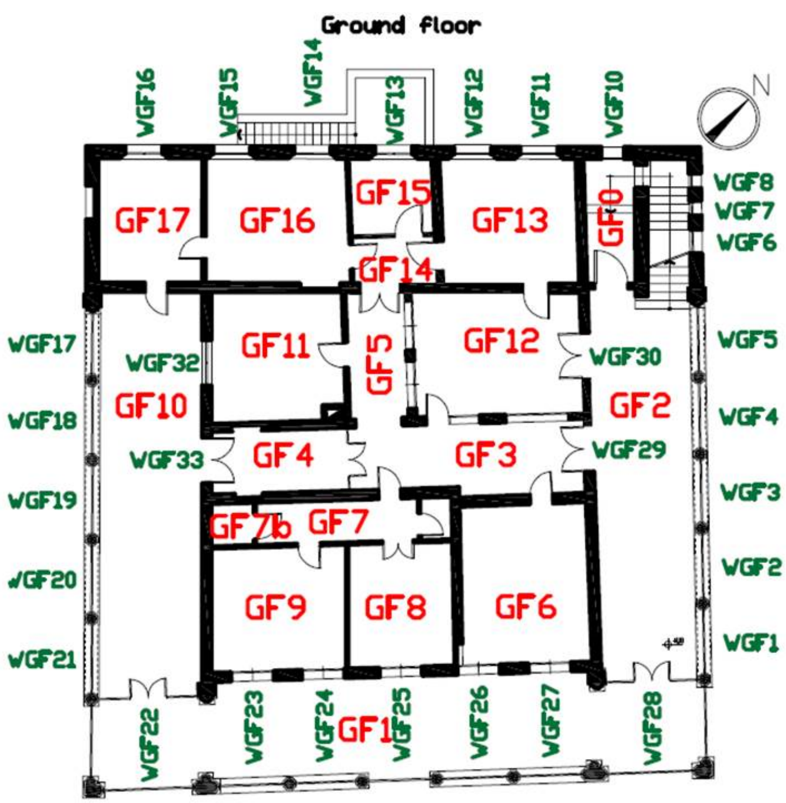


1.1.4 Rooms and room units

Underground floor (name of floor/selected area)	
	
Description	Underground floor Almost all the building has no foundations and there is a layer of gravel about 50 cm below the floor (this can be determined

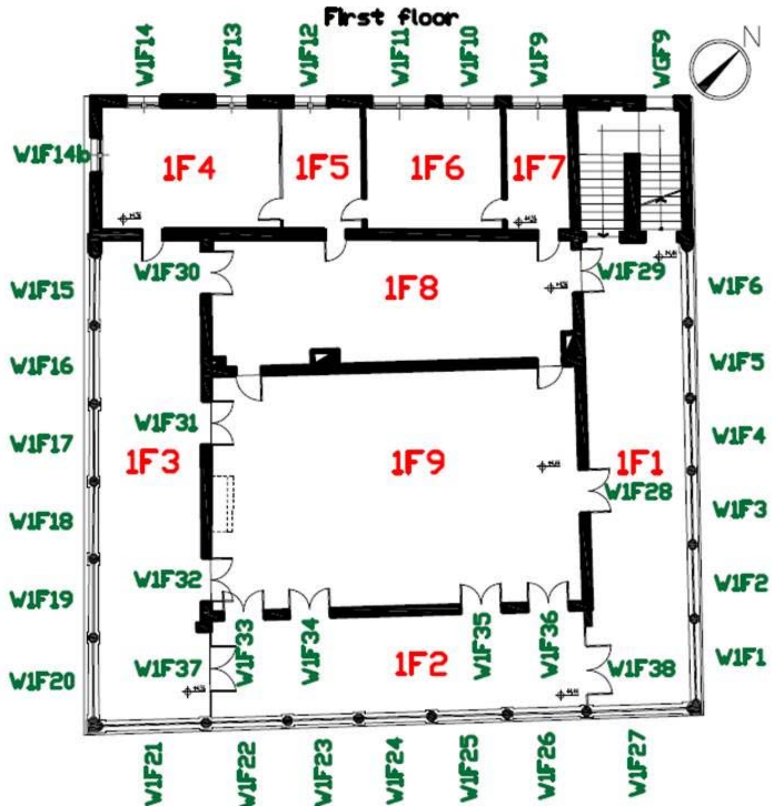
	by the destructive openings carried out on the floor of the building's ground level in several places). At the rear side of the building is instead present a basement that serves in part as a foundation. From this, an access to a vaulted opening can be gained, that shows the shape of the building underground structure. The presence of voids under the building partially filled with earth and gravel has to be noticed. In addition, the structure is supported by arches that can be supposed to be extended to the remaining basement structure. There is no historical information about the foundations, but the hypothesis of the presence of cellars and underground passages is governed by the evidence found on many of the historic buildings of the city. Following the destruction of the North East wing in World War II it was chosen to close the cellar spaces for further consolidation of the foundations.

Ground floor (name of floor/selected area)



Description	Ground floor

First floor (name of floor/selected area)	



Description	First floor
Description of room	
Name/ room number	1F9 Large hall
Construction phase	*List of construction phases:* no construction phases covered
Description	The large hall, the most representative room of the building, is placed in the centre of the 1st floor and yields a volume of about 670 m3. It is has an high historical value as it is characterized by completely frescoed walls, The large hall does not have direct opening to the exterior but natural light and air are entering from 6 wide French doors, 4 of connection to the front loggia (1F2) and 2 connecting with the S-W loggia.
Dimension	length:13.3 width:8.6 height:5.9 unit: [m]

Design Phase	
Description of design phase	
Description conditions	
Actual/planned use	To be used as seminar/meetings room.
Mobile equipment	
Present room conditions: temperature, air humidity (measured room climate as-is-state)	
Daylight potential	
Comments	

Description of room	
Name/ room number	1F2_S-E loggia (front)
Room group	
Construction phase	*List of construction phases:* no construction phases covered
image not found	
Description	The loggia on the front at the first floor has only one masonry wall and the other 3 walls made of glazing. It has a high cultural value, as it presents a painted timber ceiling and the masonry wall is frescoed.
Dimension	length:13.7 width:3.5 height:4 unit: [m]
Design Phase	
Description of design phase	
Description conditions	
Actual/planned use	Planned use: meeting room.
Mobile equipment	

Present room conditions: temperature, air humidity (measured room climate as-is-state)	The room greatly suffers from greenhouse effect, having only one masonry wall and the other 3 walls made of glazing, thus it is undergone to strong temperature excursions.
Daylight potential	The light amount tent to be always excessive, with high preservation risks for the decorations, and uncomfortable conditions - including glaring - to users.
Comments	

1.1.5 Internal partition

Vertical Opaque walls

All old walls are made of solid masonry, except for few partition walls inserted in the last period made of hollow bricks. The difference is also easy to view by observing the plan view below: there are big differences in thickness between old walls and new partitions. In some parts of building, walls are covered by frescos or f rescoes may be found below the painting layer. In figure 1.11 it is presented in red areas where already restored frescos are located and in blue the areas object of intervention in this restoration.

For information about thickness and technical data of material is possible to see some measures from plan view in the figures below.

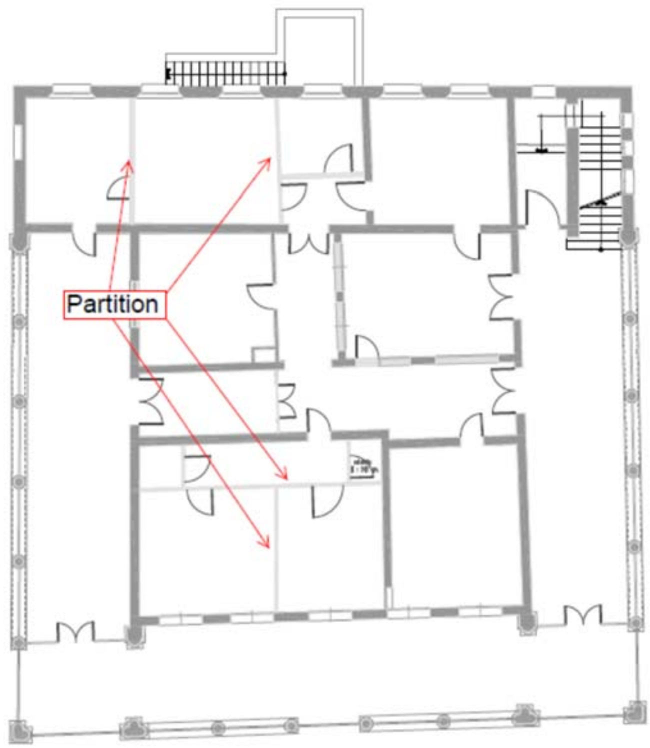


Fig. 1.10– Partitions at ground floor

Fig. 1.11– Plan of frescoed areas in building

Fig. 1.12– Vertical opaque walls in the ground floor (top) and 1st floor (bottom)

1.1.6 Ceilings

There are a number of different ceilings. This has happened because some interventions during the time have attempted to preserve some precious wooden ceiling and coffered ceiling, by putting modern ceilings with steel beams and brick infill on top of original timber ceilings. In figure are shown the main types.

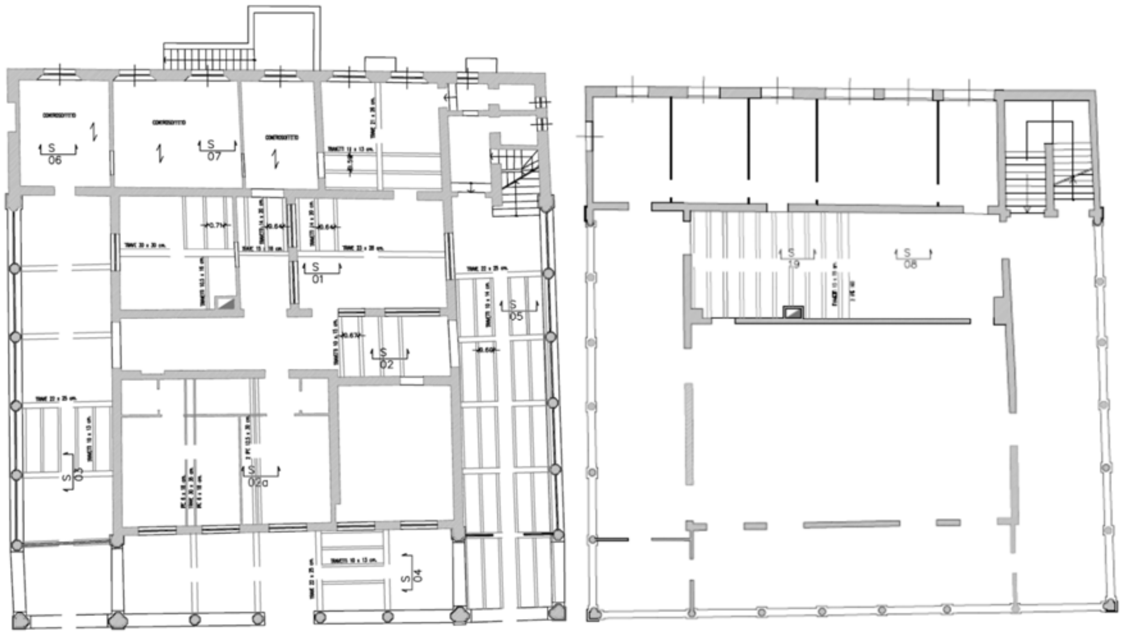
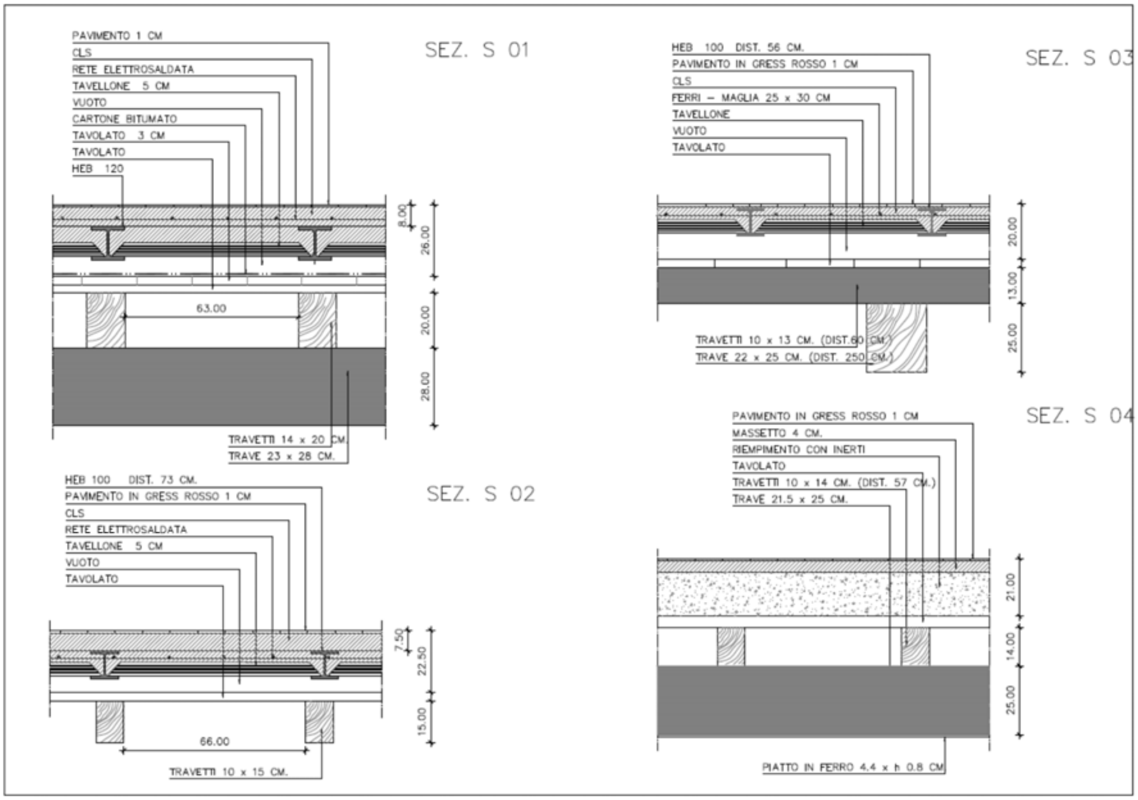
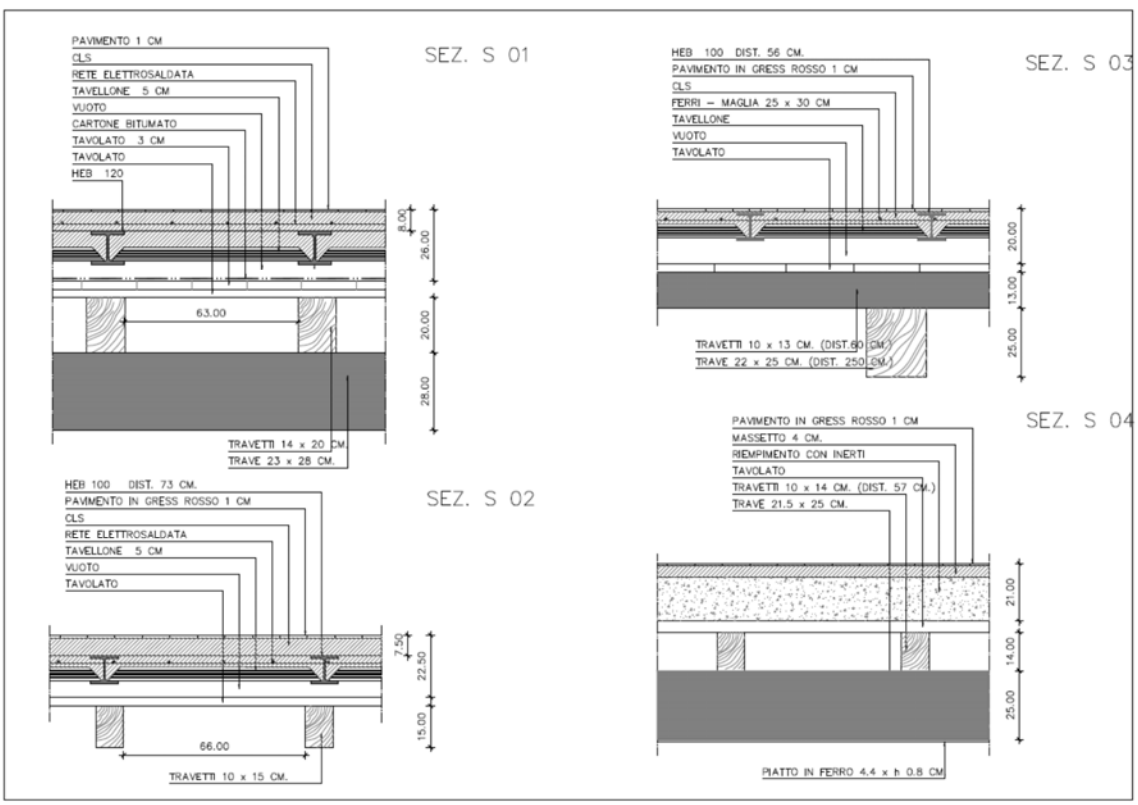
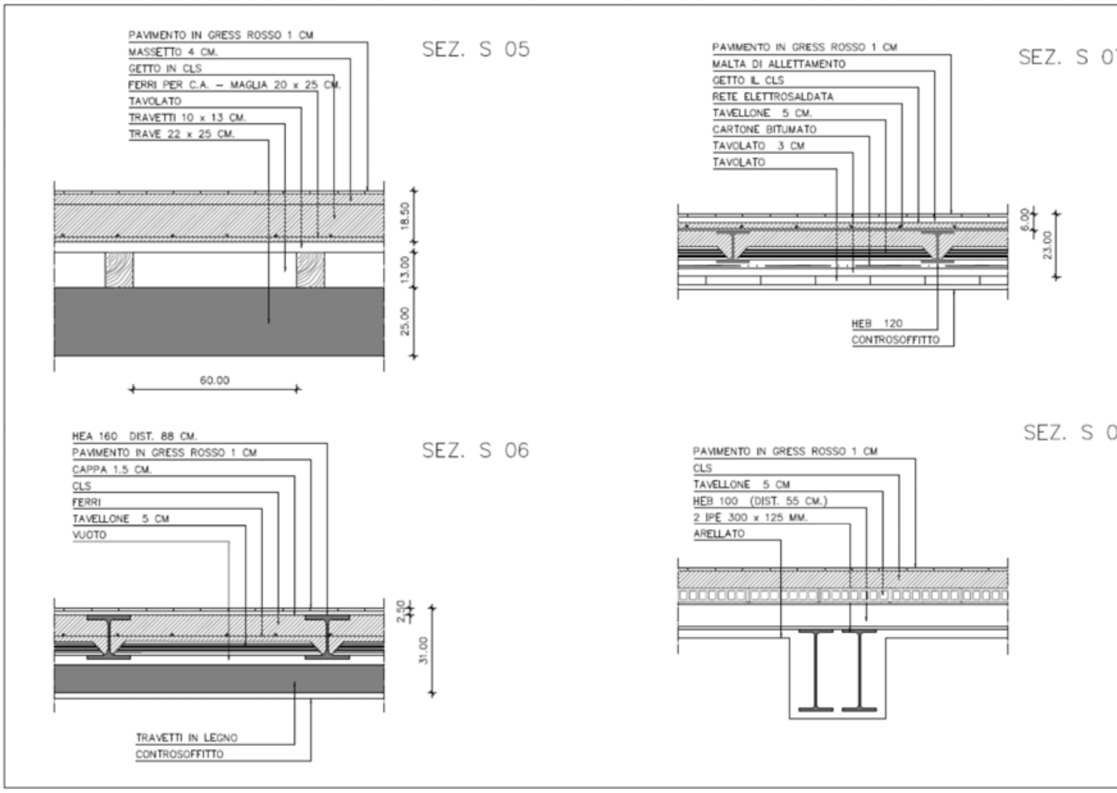
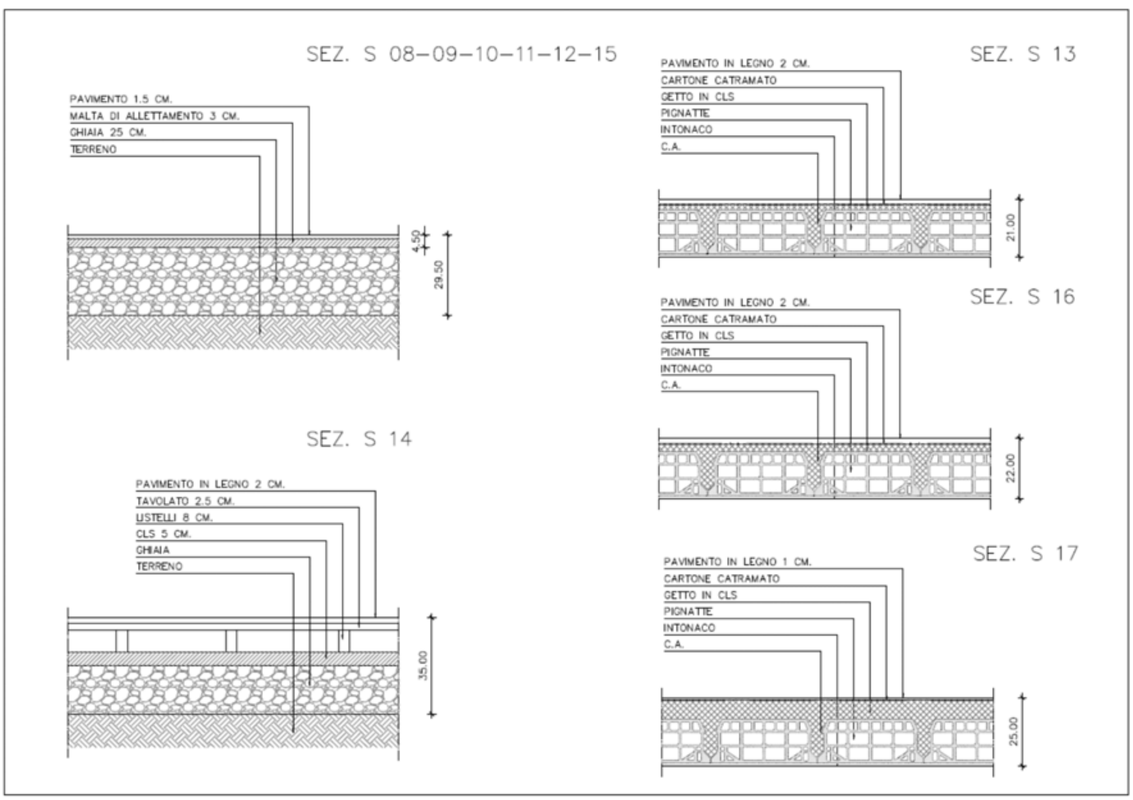


Fig. 1.13- Plan view of ground floor and first floor with openings' positions (used to examine the floors' structure).


SEZ. S 01
PAVIMENTO 1 CM
CLS
RETE ELETTROSALDATA
TAVELLONE 5 CM
VUOTO
CARTONE BITUMATO
TAVOLATO 3 CM
TAVOLATO
HEB 120
63.00
TRAVETTI 14 x 20 CM.
TRAVE 23 x 28 CM.
SEZ. S 02
HEB 100 DIST. 73 CM.
PAVIMENTO IN GRESS ROSSO 1 CM
CLS
RETE ELETTROSALDATA
TAVELLONE 5 CM
VUOTO
TAVOLATO
66.00
TRAVETTI 10 x 15 CM.
SEZ. S 03
HEB 100 DIST. 56 CM.
PAVIMENTO IN GRESS ROSSO 1 CM
CLS
FERRI – MAGLIA 25 x 30 CM
TAVELLONE
VUOTO
TAVOLATO
TRAVETTI 10 x 13 CM. (DIST.60 CM.)
TRAVE 22 x 25 CM. (DIST. 250 CM.)
SEZ. S 04
PAVIMENTO IN GRESS ROSSO 1 CM
MASSETTO 4 CM.
RIEMPIMENTO CON INERTI
TAVOLATO
TRAVETTI 10 x 14 CM. (DIST. 57 CM.)
TRAVE 21.5 x 25 CM.
PIATTO IN FERRO 4.4 x h 0.8 CM


SEZ. S 01
PAVIMENTO 1 CM
CLS
RETE ELETTROSALDATA
TAVELLONE 5 CM
VUOTO
CARTONE BITUMATO
TAVOLATO 3 CM
TAVOLATO
HEB 120
63.00
TRAVETTI 14 x 20 CM.
TRAVE 23 x 28 CM.
SEZ. S 02
HEB 100 DIST. 73 CM.
PAVIMENTO IN GRESS ROSSO 1 CM
CLS
RETE ELETTROSALDATA
TAVELLONE 5 CM
VUOTO
TAVOLATO
66.00
TRAVETTI 10 x 15 CM.
SEZ. S 03
HEB 100 DIST. 56 CM.
PAVIMENTO IN GRESS ROSSO 1 CM
CLS
FERRI – MAGLIA 25 x 30 CM
TAVELLONE
VUOTO
TAVOLATO
TRAVETTI 10 x 13 CM. (DIST.60 CM.)
TRAVE 22 x 25 CM. (DIST. 250 CM.)
SEZ. S 04
PAVIMENTO IN GRESS ROSSO 1 CM
MASSETTO 4 CM.
RIEMPIMENTO CON INERTI
TAVOLATO
TRAVETTI 10 x 14 CM. (DIST. 57 CM.)
TRAVE 21.5 x 25 CM.
PIATTO IN FERRO 4.4 x h 0.8 CM


SEZ. S 05
PAVIMENTO IN GRESS ROSSO 1 CM
MASSETTO 4 CM.
GETTO IN CLS
FERRI PER C.A. – MAGLIA 20 x 25 CM.
TAVOLATO
TRAVETTI 10 x 13 CM.
TRAVE 22 x 25 CM.
18.50
13.00
25.00
60.00
SEZ. S 07
PAVIMENTO IN GRESS ROSSO 1 CM
MALTA DI ALLETTAMENTO
GETTO IL CLS
RETE ELETTROSALDATA
TAVELLONE 5 CM.
CARTONE BITUMATO
TAVOLATO 3 CM
TAVOLATO
6.00
23.00
HEB 120
CONTROSOFFITTO
SEZ. S 06
HEA 160 DIST. 88 CM.
PAVIMENTO IN GRESS ROSSO 1 CM
CAPPA 1.5 CM.
CLS
FERRI
TAVELLONE 5 CM
VUOTO
2.50
31.00
TRAVETTI IN LEGNO
CONTROSOFFITTO
SEZ. S 02
PAVIMENTO IN GRESS ROSSO 1 CM
CLS
TAVELLONE 5 CM
HEB 100 (DIST. 55 CM.)
2 IPE 300 x 125 MM.
ARELLATO


SEZ. S 08-09-10-11-12-15
PAVIMENTO 1.5 CM.
MALTA DI ALLETTAMENTO 3 CM.
GHIAIA 25 CM.
TERRENO
4.50
29.50
SEZ. S 13
PAVIMENTO IN LEGNO 2 CM.
CARTONE CATRAMATO
GETTO IN CLS
PIGNATTE
INTONACO
C.A.
21.00
SEZ. S 16
PAVIMENTO IN LEGNO 2 CM.
CARTONE CATRAMATO
GETTO IN CLS
PIGNATTE
INTONACO
C.A.
22.00
SEZ. S 14
PAVIMENTO IN LEGNO 2 CM.
TAVOLATO 2.5 CM.
LISTELLI 8 CM.
CLS 5 CM.
GHIAIA
TERRENO
35.00
SEZ. S 17
PAVIMENTO IN LEGNO 1 CM.
CARTONE CATRAMATO
GETTO IN CLS
PIGNATTE
INTONACO
C.A.
25.00

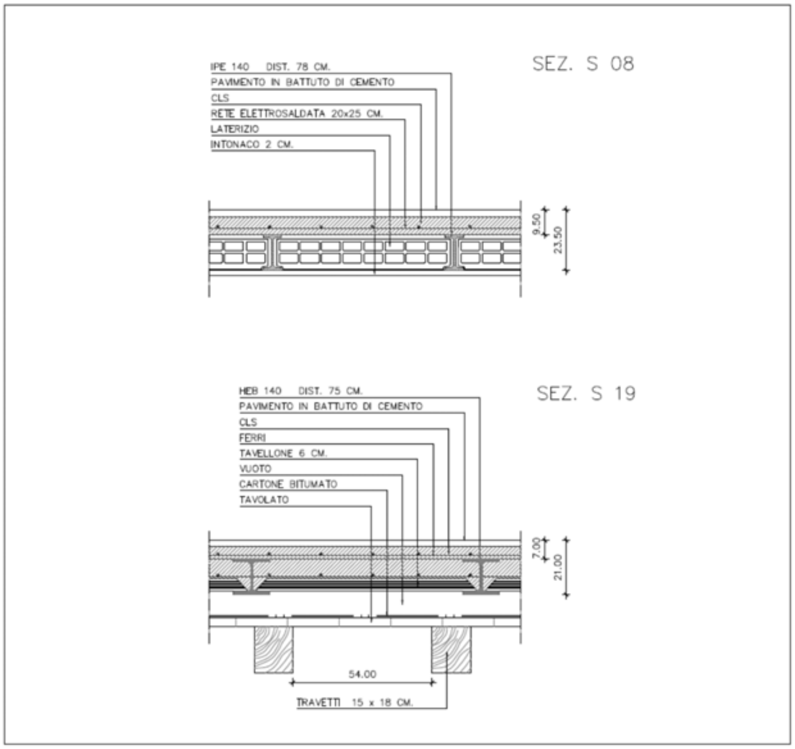


Fig. 1.14- Sections of floors

Fig. 1.16 - Internal views of the wooden roof structure

1.1.8 Basement

Almost all the building has no foundations and there is a layer of gravel about 50 cm below the floor (this can be determined by the destructive openings carried out on the floor of the building's ground level in several places). At the rear side of the building is instead present a basement that serves in part as a foundation. From this, an access to a vaulted opening can be gained, that shows the shape of the building underground structure. The presence of voids under the building partially filled with earth and gravel has to be noticed. In addition, the structure is supported by arches that can be supposed to be extended to the remaining basement structure. There is no historical information about the foundations, but the hypothesis of the presence of cellars and underground passages is governed by the evidence found on many of the historic buildings of the city. Following the destruction of the North East wing in World War II it was chosen to close the cellar spaces for further consolidation of the foundations.

Fig. 1.17- Plan view of the underground floor and a detail of the floor (red position in the plan view).

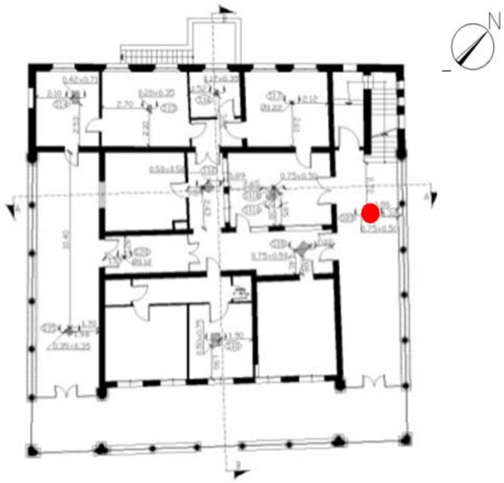


Fig. 1.18- Plan view of the ground floor

Fig. 1.19- Ground floor pavement, NE side, and detail of a floor opening (red spot Fig. 1.18)

Fig. 1.20– Structure of basement

The microclimate of underground floor is constant during the year with fresh and humid air, so theoretically considering only this aspect is possible to used temperature gradient between underground ambient and upper zone building. In reality is impossible because this option conflicts with the choice of designers that have defined the intended purpose of the basement for the toilets. However is possible to use the tunnel or use heat exchanging with the ground putting an exchanger in the land surrounding the building.

1.1.9 Shielding (internal and external)

The trees surrounding the building are shading its façades; another shielding element is represented by the roof structures and the porch in the main façade. In addition some few windows of the ground floor present internal shielding elements. Examples are reported in the following figures. The shading systems are mainly curtains, in all windows except in glazed porch at NE and SW sides. There are also cornices in all side, but not very large. In the South façade there is a porch that protects room of ground floor. On rear windows interior wooden shutters are mounted directly on the frames, such as are showed in figure 1.23.

Fig. 1.21- Shading in the main façade (left) and view of the trees from above (right)

Fig. 1.22- N-W façade: examples of shading due to trees and roof in two different climatic conditions (a sunny and a cloudy day)

Fig. 1.23 - Shading system on a window of the ground floor

1.2 Structural analysis and assessment of moisture

Structural analysis:

The structural analysis has started from a geometrical survey to check the dimensions reported in the available plans and views. For this reason the thicknesses of the walls at different levels were measured and the results are reported in the plan views below, with different colours. It is possible to see the presence of historical external and internal load-bearing walls with a thickness that vary from 30 to 50 cm and non-load bearing walls of more recent construction.

The building presents some structural problems as cracks in walls, ceilings and floor at different levels, especially in the South-West side (Fig. 1.24). In this case the survey and drawing of the crack pattern is very important and it has been conducted in order to better understand the state of damage of the structure and its vulnerable points. An example of a sketch of the crack pattern recorded on-site is given in

Fig. 1.25.

Moreover, some of the opening and movements of cracks are being monitored by using different systems as shown in Fig. 1.26.

Other structural problems are related to the wooden roof structures, made of ancient, original and new timber elements; the main problems are due to the water leakages as visible in Fig. 1.27.

Fig. 1.24 – Cracks on the exterior walls in the SW side (left and centre); measurement of the air-flow through cracks from the interior with an anemometer (right)

Fig. 1.25 - Crack pattern survey on a vertical section

Fig. 1.26 – Monitoring of cracks

Fig. 1.27 – Water leakages on the wooden beams of the roof.

NDT testing for moisture detection

NDT tests, like GPR Radar or IR-thermography have been conducted in different position, both on exterior and interior walls of the building in order to detect the presence of moisture. Examples of GPR radar test and thermography tests are given in Fig. 1.28 and Fig. 1.29.

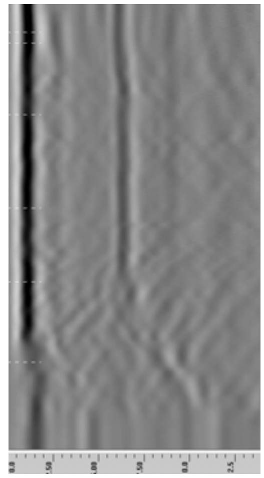


Fig. 1.28 – GPR radar for moisture detection: vertical survey line on a masonry wall (left) and the collected radargram (right)

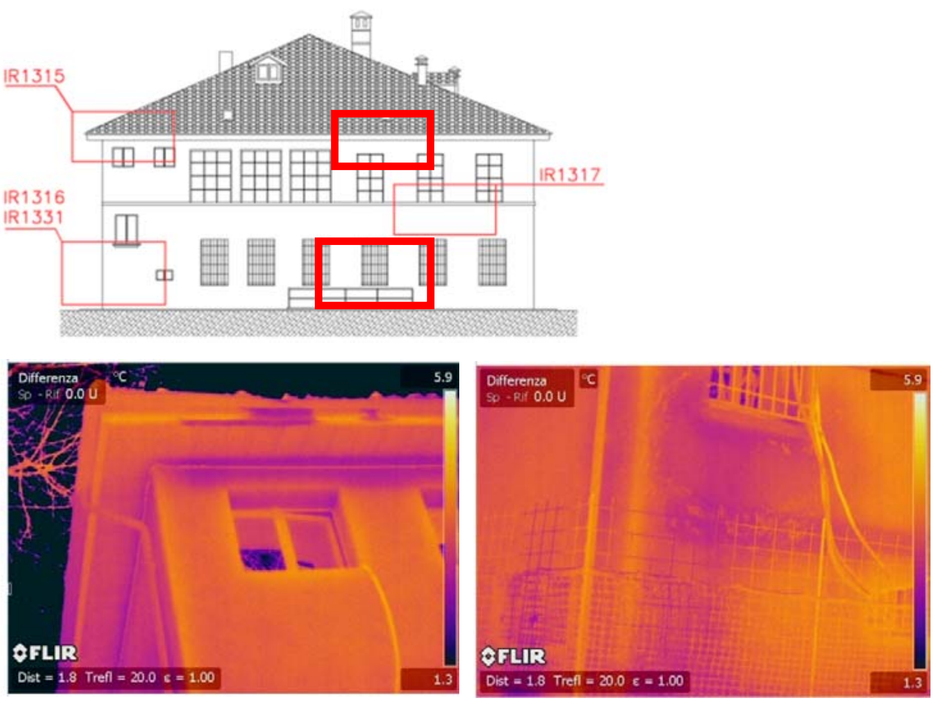


Fig. 1.29 – IR-thermography for moisture detection, exterior wall, rear side of the building

U-value determination in historical buildings

Different U-value measurements have been conducted in a direct way in accordance to the norm ISO 9869, 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. The U-value measurements positions are reported below, on the plan views of the building (Fig. 1.30).

The measurement positions have been chosen considering different aspects regarding the building structure, the presence of inaccessible points, the presence of frescoes and last but not least, the possibility related to the creation of a thermal gradient in the measurement areas, as the Palazzina was already under refurbishment and the heating system have already been removed.

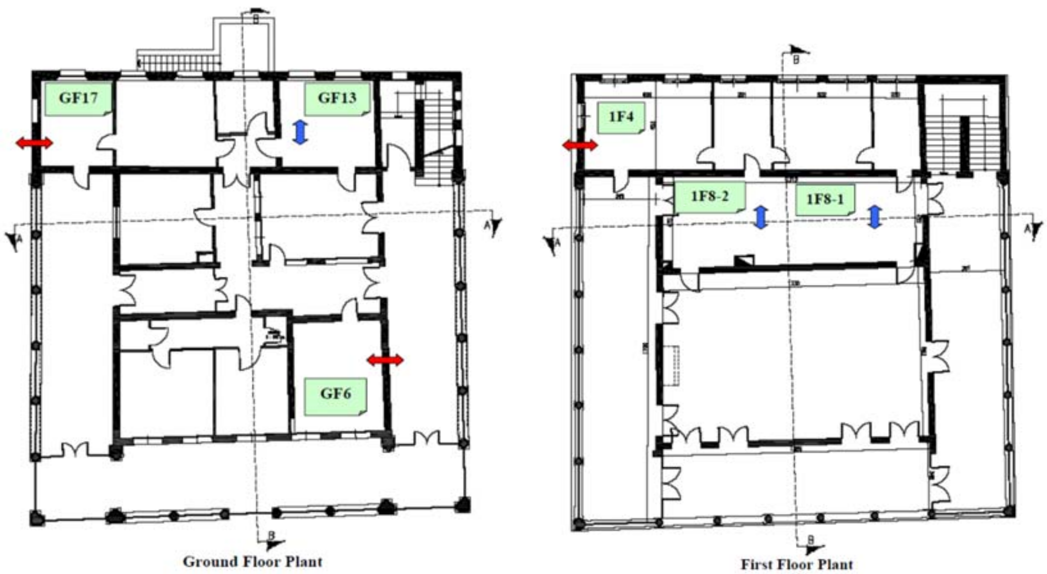


Fig. 1.30 – Plan view of the ground and first floor, with the position of U-value measurements

<u>Legend:</u>

Transmittance measure on ceiling between underground-ground floor and second floor-attic 

Transmittance measure on walls 

Room's code: 

Tab. 1.1: Measured U-value on each position

Room	Type	Thickness	Conductance	Standard Deviation
		mm	W/m^2K	W/m^2K
GF6	Wall on enclosed porch	330	1,84	0,16
GF13	Slab floor	250	2,94	0,467
GF17	Wall	52	3,12	0,494
1P4	Wall External	32	0.43	0,23
1P8-1	Slab floor	240	2,21	0,06
1P8-2	Slab floor	330	0,78	0,12

Tab. 1.2: Floor stratigraphy

Room GF13	
Opening S17 **Total estimated thickness 25 cm**	
Between ground and underground floor	
Wooden floor	1 cm
Impermeable layer (bitumen)	2 cm
Concrete	5 cm
Lightening elements (bricks)	16 cm
Plaster	Undetectable

The heat losses via the ground have been determined through the numerical calculation of the transmittance value and not following the norm ISO 6946. It has been considered the floor stratigraphy reported in Tab. 1.2.

The measured values, listed in Tab. 1.1 are greater than the supposed ones resulting from the scheduled data. This aspect will be analysed further.

The data acquisition on each measurement position has not been continued for more than 26 hours and the data have been post-processed using the most appropriate model for this particular building in its particular conditions: the Black-box model. In fact, the absence of a heating system in the building and the thickness of the walls have been contributed in increasing the thermal inertia. Moreover the measurements have been realized with a local heating system. For this reason, an adequate condition of thermal equilibrium has not been reached and the method of progressive averages could not be used, although the quantity of generated heating was higher than using the conventional heating systems. The moisture influence on heat transfer has also to be considered.

Airtightness in old buildings

Old buildings are often characterized by a great amount of thermal losses and a low airtight level. In our case study, Palazzina della Viola, the old original doors and windows presents bad airtight conditions as reported in the following interesting images.

Fig. 1.31 – Window frame around a masonry column (left) and detail of the opening (right), 1st floor, front side of the building.

Fig. 1.32 – Main entrance door in low airtight conditions, as visible from the passing light at the bottom

Fig. 1.33 – Detail of a window of the ground floor with a “bad closing”

Blower door test in old buildings

The blower door test has been carried out on March 23rd and April 4th 2011.

Due to the large volumes and the presence of air losses from windows and ceilings, it was not possible to perform one test for the whole building but it was necessary to divide the Palazzina into small areas.

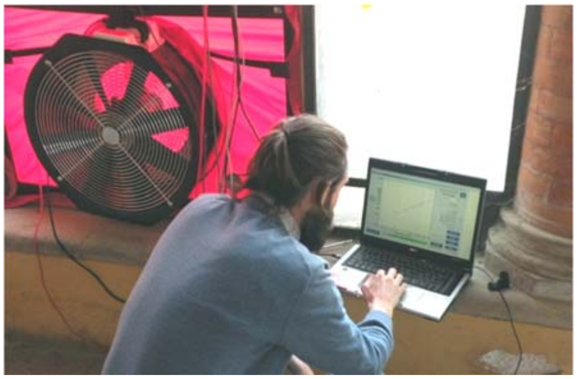


Fig. 1.34 – Phases of the blower door test

1.3 Hygrothermal and environmental monitoring

Repeated measurements of the environmental parameters (air temperature and relative humidity) have been carried out with portable instruments in different ways:

- climatic parameters have been collected through instantaneous reading at the centre of each room,
- a continuous monitoring for 24/48 hours period in the centre of rooms
- after closed/open doors and curtains
- at the discrete nodes of grids marked on floors, in each room in order to create psychrometric maps (an example of results is reported in Fig. 1.35, Fig. 1.36)

Moreover the surface T of walls has been measured.

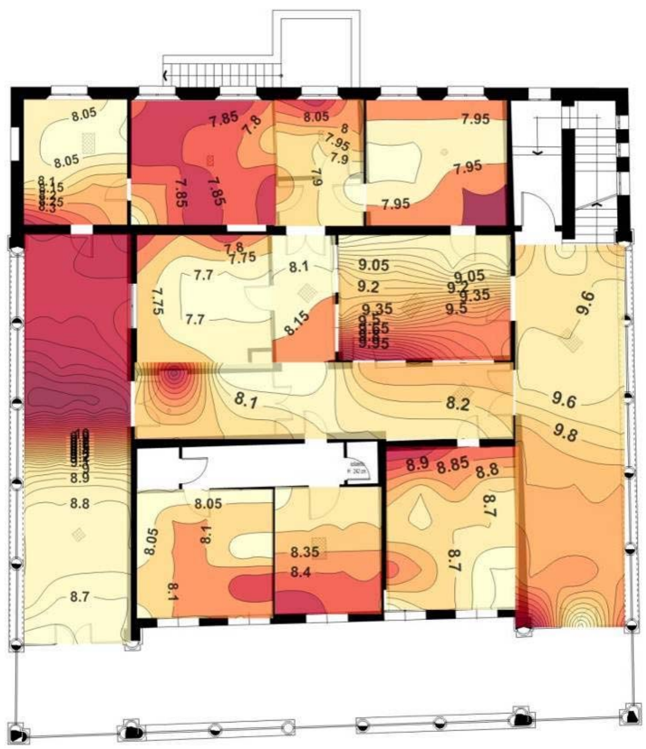


Fig. 1.35 – Psychrometric map of the temperature, ground floor (with all doors closed)

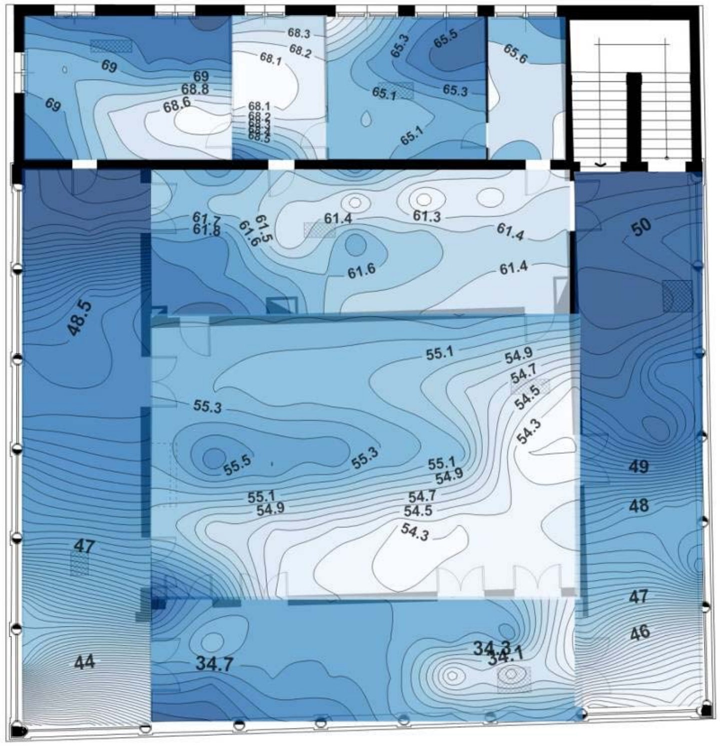


Fig. 1.36 – Psychrometric map of the air relative humidity, first floor (with all doors closed)

WSN Monitoring system:

The monitoring system is based to a state of the art Wireless Sensor Network, which has the following characteristics:

- Dimensions: 100 X 56 X 29 mm
- 32bit 32Mhz fully programmable Microcontroller
- 2.4Ghz IEEE802.15.4 radio transceiver
- Temperature and relative humidity sensor
  - Resolution of 0.01°C – 0.04 %RH
  - Accuracy of ±0.3°C – ±2% RH
- Ambient light sensor
  - Resolution of 0.23lx
  - Range (0 – 100000 lx)
- 3-axis ±2g/±6g linear accelerometer
  - Resolution 1mg
- Multi brand full controlled MOX gas sensor interface
  - Gas measurable VOC, CO, CO2, NOx, O3, NH4
- Micro SD card reader
- Expansion connector for extra analogue input channels, extra digital sensors and interface with several system by RS422, RS232, USB, RS428, UART, I2C, SPI. The connector provide 1.5W power supply
- Battery charge circuit for supply the device with energy harvesting system (i.e. Solar panel, wind turbine, vibration, heat flow) or USB port
- Multi-chemistry battery support (Standardized for AA battery format)
- Sleep power consumption 8uA
- Selectable acquisition rate (continues to 1.5day)

The network has been installed in February 2011. The network firmware will be updated constantly to improve the network deployment easiness, the availability of new feature and improve the battery life.

Moreover the WSN node will be extended with external sensors for surface climate detection.

The data collected will be shared with the 3ENCULT partners by remote server strategy.

For details see Annex.

1.4 Results derived from the application of PHPP

The results of the application of PHPP analysis for the pre-intervention scenario are presented in the figure 1.35. In according with the features of the building, the main energy lost is related to the windows. The losses through exterior wall, the attic and due to infiltration are consistent. The lost through the attic is contained into Non-heated area, the infiltration effect is estimated in the ventilation component based on the blower door test measurement realized on the building. The mean air change rate at 50 Pa is 10.

Also transmittance measurements were done to characterize some wall construction.

The building was not used for several year and information related to the utilization are not provided. We considered just 20 persons without taking in account equipment consumption. Therefore primary energy is related to the heating system.

Since the air changes were very high the building was totally climate driven, especially during summer as cooling balance shows.

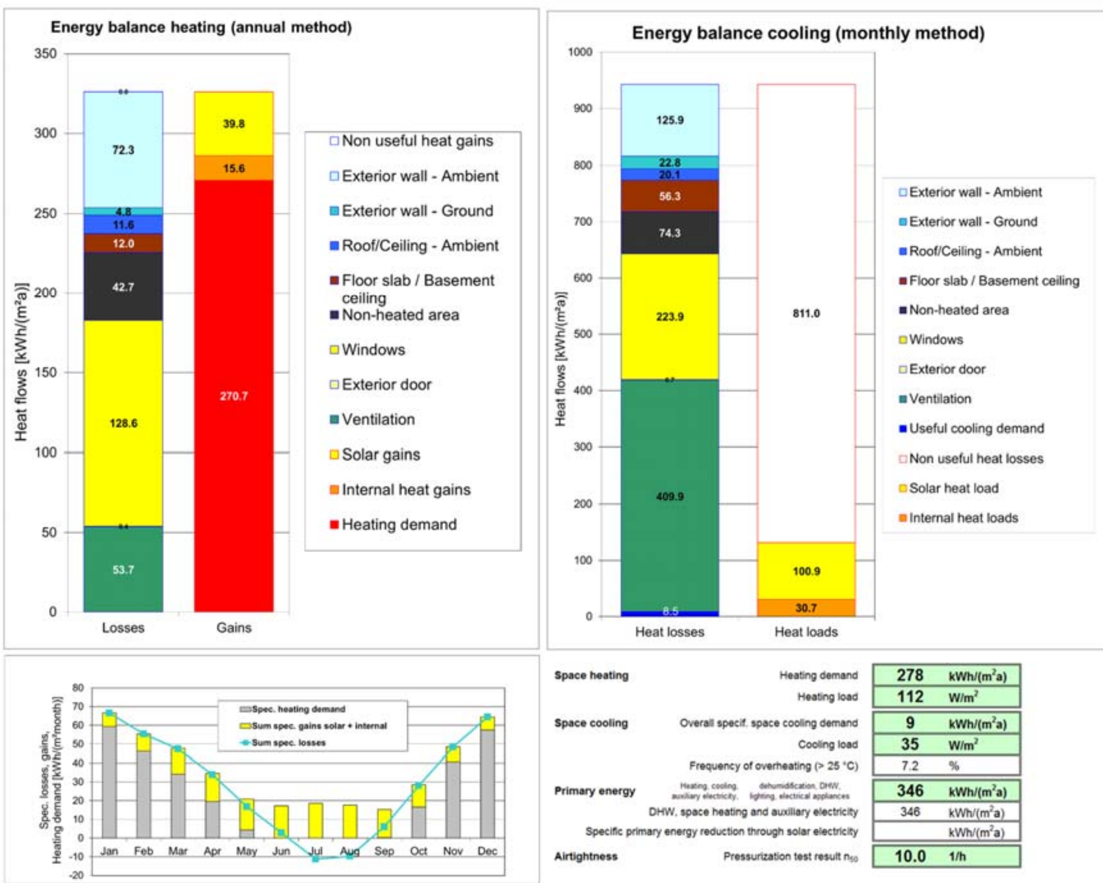


Fig. 1.37 – Energy balance before intervention

The PHPP was repeated also after the retrofit in order to evaluate which was the improvement of the chosen intervention from the energy point of view. The focus of the project manager was concentrated more of the conservation of the building but some aspect of the energy efficiency were taken in account.

Also in this scenario, an energy certification is useful to do some consideration on the strategy implemented, for future improvement of the same building and for other refurbishment project in general. The results of the application of PHPP analysis for the post-intervention scenario are presented in the figure 1.38. The losses through the windows, exterior wall and attic remain considerable; the values are very close to the pre-intervention scenario. The Ventilation component drops down due to the reduction of the infiltration. The air change rate per hour drops down from 10 to 5. According to the intervention, the airtightness level is improved with the restoration of the windows.

Considering the overall assessment, the heating and the cooling load are reduced of 12 and 30% respectively, the heating and cooling demand of 6 and 31 %. The overheating during summer is removed. In this second scenario the real occupancy and equipment load are considered. Primary energy is the sum of consumption of the entire building.

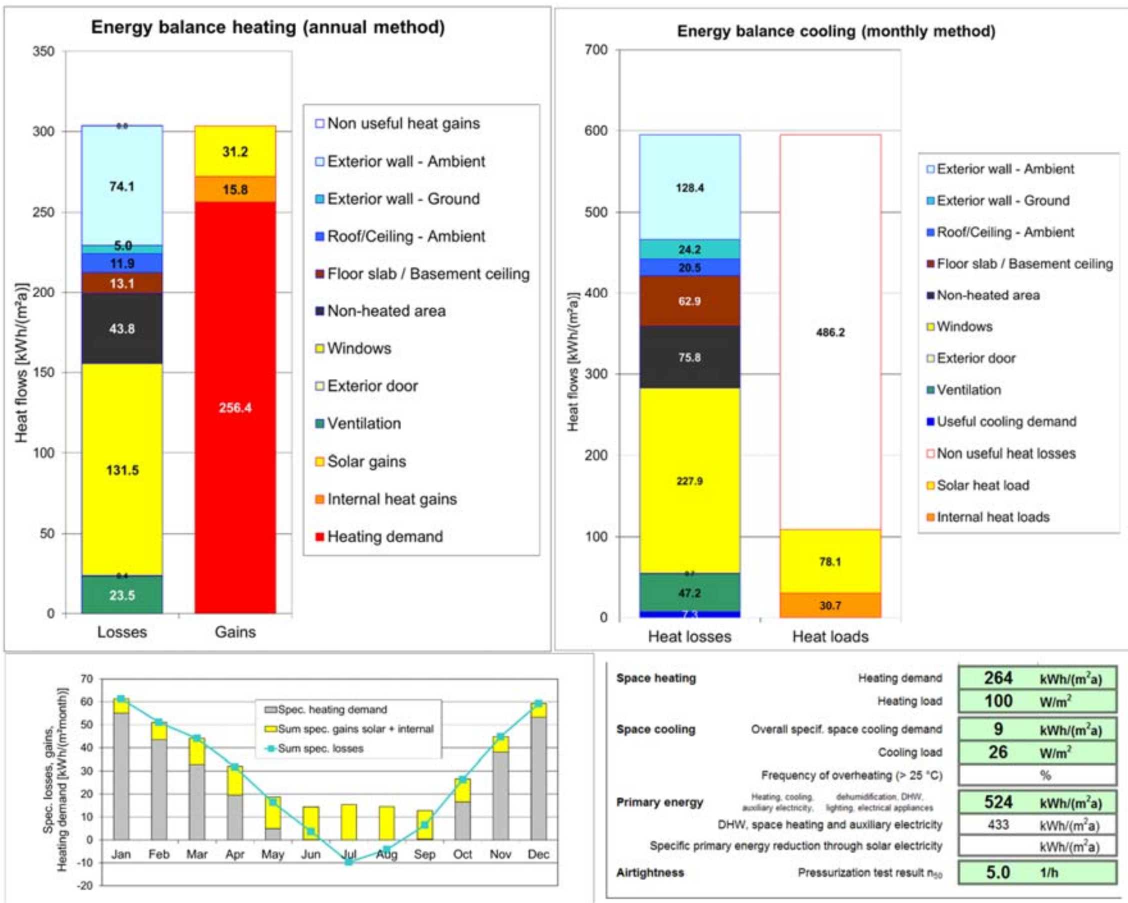


Fig. 1.38 - Energy balance for Post-Intervention scenario

2 Design

The design phase was carried out before the beginning of 3ENCULT taking into account the constraints reported below.

Principles of protection and constraints conditions imposed by the Authority for Cultural Heritage

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 elements of it.

For the preservation of original characters of the building, the limitations, given by the requisite ARE 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 pluvial 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.

In some part of building, walls are covered by frescos or there are possibilities to find them below the painting layer. In figure 1.39 are presented in red areas where there is already restored frescos and in blue areas that are abject of intervention in this restoration. For information about thickness and technical data of material is possible to see some measure from plan on the following figure.

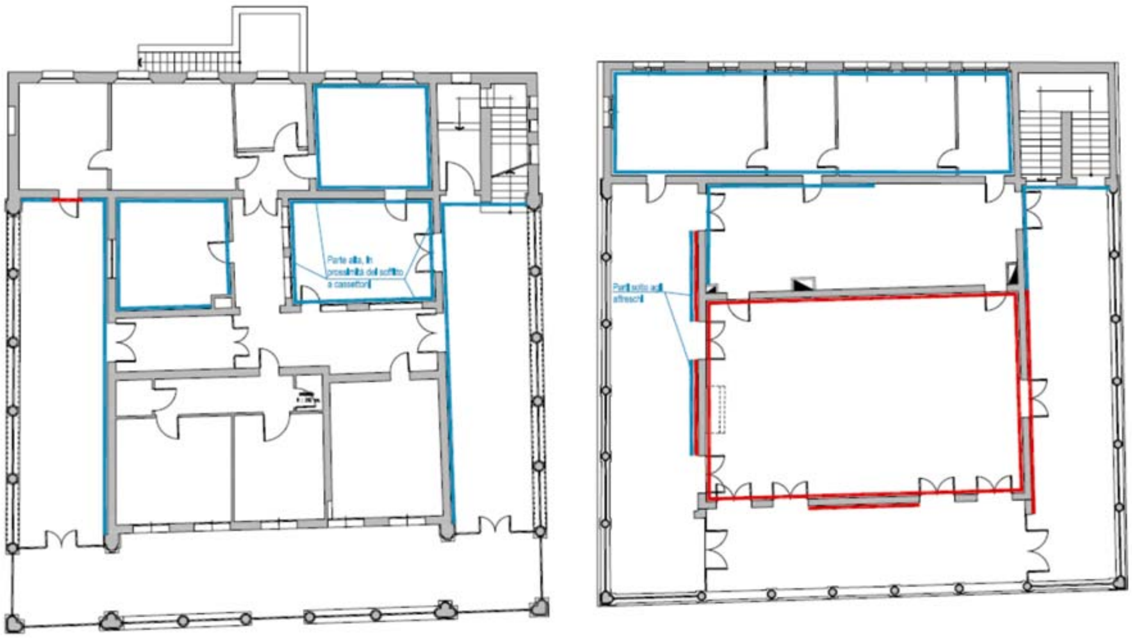


Figure 1.39 – Plan of frescos in Building

Some internal partition will be removed respecting the constrain condition imposed by the Authority of Cultural Heritage. The plan in figure 1.40 shows these partition in yellow.

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;

Figure 1.40 – Plan of demolition at ground and underground floor of partition wall

Window

It is necessary to respect colours, size and shapes of the windows; 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.

Keeping the original window's infixes and shading elements in every external perimeter wall is necessary. 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.

Windows will be restructured so it is possible to think to change something as glass or shielding that could respect the limitation.

Roof

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.

Systems

All the systems were removed so there is space for good intervention. It is possible to reuse distribution scheme of old system and open some new hole preserving as much as possible the walls.

It is possible to use space around building as technical space to place some technical system like generator.

3 Implementation

The refurbishment of Palazzina della Viola consider structural consolidation, preservation of frescos and artworks and the modernization of the facilities and it started at the beginning of the 3ENCULT project.

Main constrain for energy efficiency improvement is the interdiction on changing the windows along the galleries. The only action that took place on them was the installation of solar protection film. The other windows have been restored and double glass pane has been installed.

Most of the floors have been rebuilt after the consolidation of the foundation and one impermeable layer has been added.

All the systems have been substituted with VRF direct expansion heat pump assisted from ventilation system for the control of the air quality. This technology provided heating and cooling with a reduced impact of the distribution network on the building.

The pipes were installed behind a plasterboard panel along the walls in the galleries and in the floor structure where it has been rebuild. The ventilation system has been installed in the attic, no heated area dedicated to the VAV system with the heat recovery. Extensive use of led technology has been used for the reduction of electric energy consumption.

4 Post evaluation

Status of the building at the end of the refurbishment works.

Figure 1.41- Main façade after refurbishment work

Ground floor:

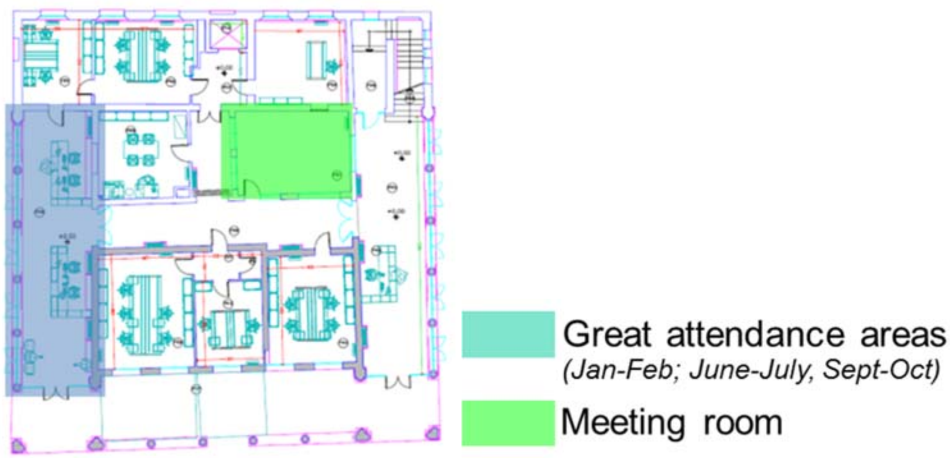


Figure 1.42 – Images of the ground floor after refurbishment

First floor

Figure 1.43 – First floor after refurbishment

4.1 Evaluation of the energy consumption

4.1.1 PHPP Calculated energy consumption

No data are available for the comparison of PHPP calculation with the real energy consumption.

For the pre-intervention scenario data are not available because the building was closed for several years before the intervention.

For the after intervention scenario a comparison will be done when enough data will be provided for building manager, at least one years of consumption data.

4.2 Evaluation of the construction´s situation

The procedure employed to perform a comprehensive diagnosis of this historical building has been repeated after the refurbishment works. In addition to the information recovered by the climatic WSN monitoring described in the previous chapter, several non-destructive techniques such as IR-thermography have been applied (Figure 1.44) in order to evaluate the current health-state of the Palazzina. Moreover, some “movable” WSN node have been used for innovative dynamic environmental focused monitoring. Results of distribution maps of light, air temperature, relative humidity, at various levels from ground, are useful for evaluating risk to CH and level of protection needed for delicate artefacts, as well as discomfort of working conditions.

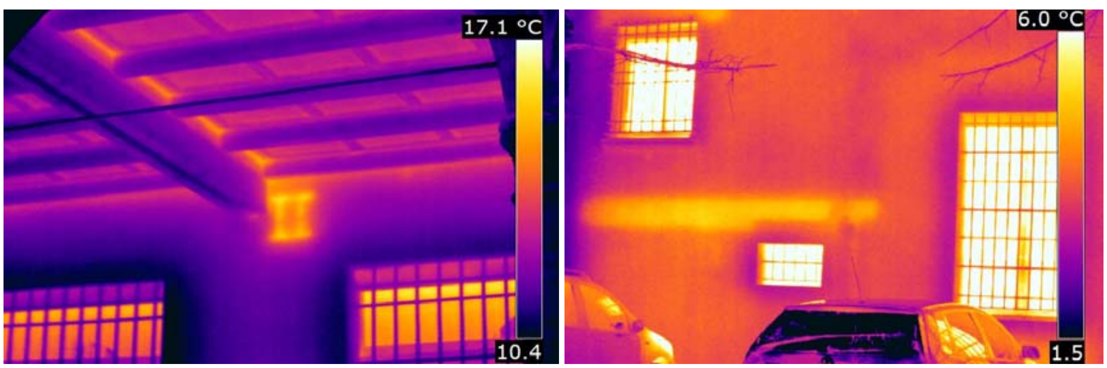


Figure 1.44 - Post-refurbishment NDT of thermal bridges by IR thermography: steel beam-ends (left); concrete stairs landing (right)

5 Summary and conclusion

This chapter should go briefly through all activities of the case study: pre-intervention analysis, description of intervention needed and general and close assessment of the renovation project.

The case study of Palazzina della Viola in Bologna, Italy, is a 15^{th} C. building of quadrangular plan, with 3 facades lightened by a double open gallery, enriched by frescoes and painted wooden ceilings (15^{th} - 16^{th} C.). It was defined a "*jewel of the Renaissance art*". After few years of abandon, the building, property of the University of Bologna, has undergone to rehabilitation and restoration interventions which started almost at the same time as the 3ENCULT project's start, although the intervention project had been designed a few years earlier.

In the framework of 3ENCULT project, an extensive and integrated diagnostic and monitoring approach was on-purpose implemented to obtain information about the structural and energetic behaviour of the building at different time periods: before, during and after the refurbishment works. The comprehensive diagnosis carried out, has foreseen the application, also in innovative and non-conventional way, of several non-destructive techniques and wireless sensor network monitoring.

The first diagnostic phase was based on visual inspections and searching for historic and archives information (photos, drawings, …), followed by geometric and materials surveys as well as decay and crack pattern surveys in order to obtain an overall picture on the health-state conditions of the building just before the beginning of the refurbishment work. Information about the existing heating/cooling systems and lightening were also collected although it was not possible to recover data about previous energetic consumptions. The three glazed façades represented a peculiarity and historical value of the building; hence, a detailed survey of the existing windows was carried out also to accomplish the requirements of PHPP calculations. This survey pointed out the presence of very many types of windows' frames (diverse for materials – steel, wooden –, age and dimensions) and glasses (single, double, printed, ….). Later, the pre-refurbishment conditions of the Palazzina were evaluated by means of NDT techniques such as IR thermography and GPR radar, used with a double aim, structural and energetic, in order to obtain reliable information about the building structure and health-state conditions (presence of moisture, thermal bridges, structural details of ceilings and walls, …) without provoke any damage neither to the structure nor to the delicate objects belonging to it (like frescoes, paintings, painted ceilings...). In-situ measurements of transmittance values were carried out to characterize the walls and estimate the current heat losses of the structure. The airtightness level of the building was also measured via blower door test, following a testing procedure specifically designed for this historic building (specific subdivision of the volume, closure of intentional openings in the ceilings, …), necessary because of its characteristics: large volumes (i.e. see the main hall at the 1^{st} floor) and consistent air losses, i.e. through wooden ceilings and historical window frames. This information was used as input for the PHPP evaluation of as-is state conditions.

Moreover, these results were combined with the climatic conditions of the building (which was not heated since several years), repeatedly measured with portable instruments in different ways, i.e. at the discrete nodes of grids marked on floors, in each room in order to create psychrometric maps of air temperature and relative humidity. At the same time, a first wireless sensor network, on-purpose developed and realized, was installed. It was composed by 17 nodes which were distributed on the four floors of the building and equipped with sensors for the continuous monitoring of air temperature, relative humidity, light and accelerations (3-axis).

Similar evaluations were carried out during the refurbishment works to monitor also the effects of these interventions on both the building structure (i.e. by monitoring the vibrations and openings of cracks) and the delicate objects (i.e. by monitoring the environmental parameters and evaluating if the conditions for the right conservation of frescoes were respected).

The research team was not involved in the decisional stages of the design of the interventions, completely defined a few years before the beginning of the 3ENCULT project. Briefly, the rehabilitation and refurbishments works carried out at Palazzina della Viola considered structural consolidation of foundations, ceilings and walls, preservation of frescos, restoration of painted ceilings as well as the modernization of the building facilities (i.e. substitutions of all the systems). Due to the high historical and cultural value of the building, several constrains had to be taken into account during the works. By way of example, one of the main constraint for the energy efficiency improvement was represented by the interdiction on changing the windows along the galleries (on which, after restoration, were installed only solar protection film); instead, double-glasses were installed on the windows of the rear façade.

After the refurbishment works, a definitive version of WSN with 36 nodes equipped with 144 sensors (air temperature, relative humidity, light intensity, acceleration) was installed. The network is collecting data since March 2012 and it is still working. These nodes have been used not only to collect data in "static" positions but some of them, being "movable" have been used for innovative dynamic environmental focused monitoring. Results of the long-term monitoring in terms of distribution maps of light, air temperature, relative humidity, at various levels from ground, are useful for evaluating risk to CH and level of protection needed for delicate artefacts, as well as discomfort of working conditions. Non-destructive evaluations, also following innovative procedures, were repeated at this time period to study the post-refurbishment health-state condition of Palazzina as well as to study specific aspects i.e. related to air exchange and movements between rooms of large volume.

PHPP was repeated at the end of the rehabilitation interventions in order to evaluate the improvements of the chosen intervention from the energetic point of view, as, despite the constraints derived from the preservation of the historic/cultural value of the building, some strategies were employed to improve the energy efficiency (i.e. exploiting the use of curtains). The results show a reduction in the heating and cooling load and demand.

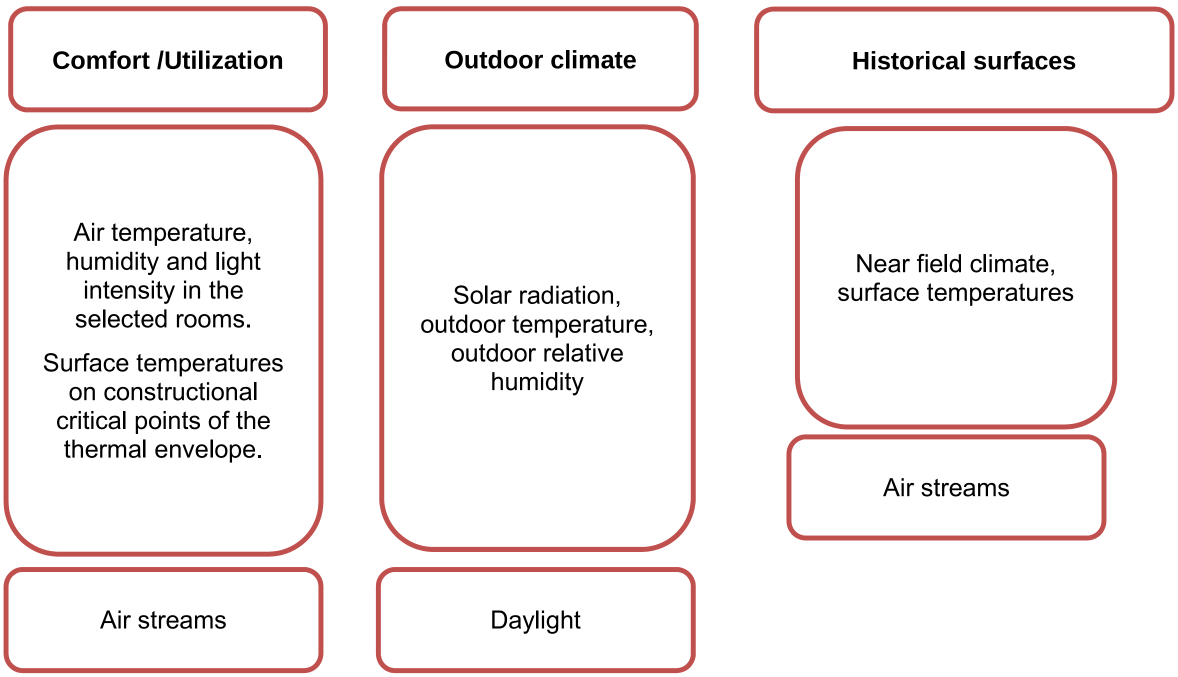
The novel procedure followed combining diagnostic and monitoring procedures allowed obtaining non-destructively a complete knowledge of the studied historic building both from energy and structural viewpoints at the three stages: pre-, during and post-interventions. Thus, the described integrated approach can lead to a new practice for a proper diagnosis of other historic buildings and it could represent a model to be followed, but with the recommendation to carefully translate in different and appropriate way according to the specific case study considered, the diverse possibilities and diagnostic methodologies shown.

6 Annex 1 - PHPP calculation for status pre-intervention

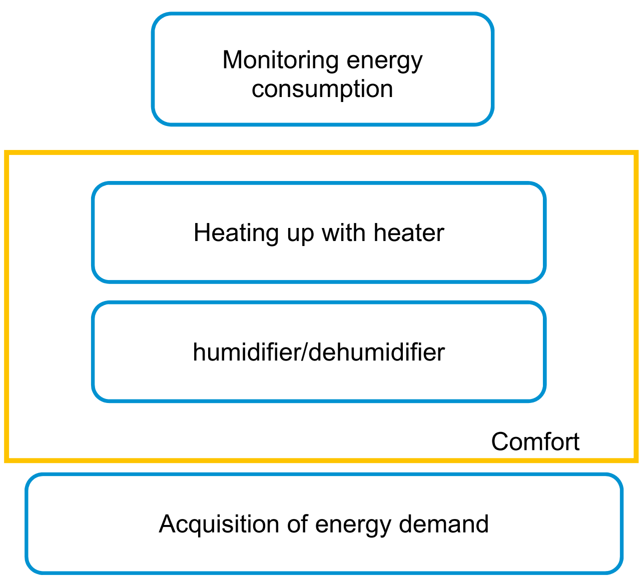
The PHPP calculation is presented in a separate file where pre and post intervention scenario are joint together with the analysis of the building necessary for the application of the protocol.

7 Annex 2 - Description of the monitoring system

7.1 Monitoring Concept



Monitoring concept energy demand



- **Monitoring concept before and after interventions**

Monitoring system 1: As-is-state:

Selected rooms will be monitored to detect light intensity, temperature and relative humidity

Acquisition of energy consumption -

↓

Interventions:

Selected rooms/surfaces: Interventions like Installation of windows prototype Installation of interior insulation (to discuss)

Selected rooms will be monitored to detect wall vibration intensity, light intensity, temperature and relative humidity.

↓

Monitoring system: after interventions

Selected rooms will be monitored to detect temperature, relative humidity and light intensity to interact with the building management system in order to increase the energy efficiency of the building.

-

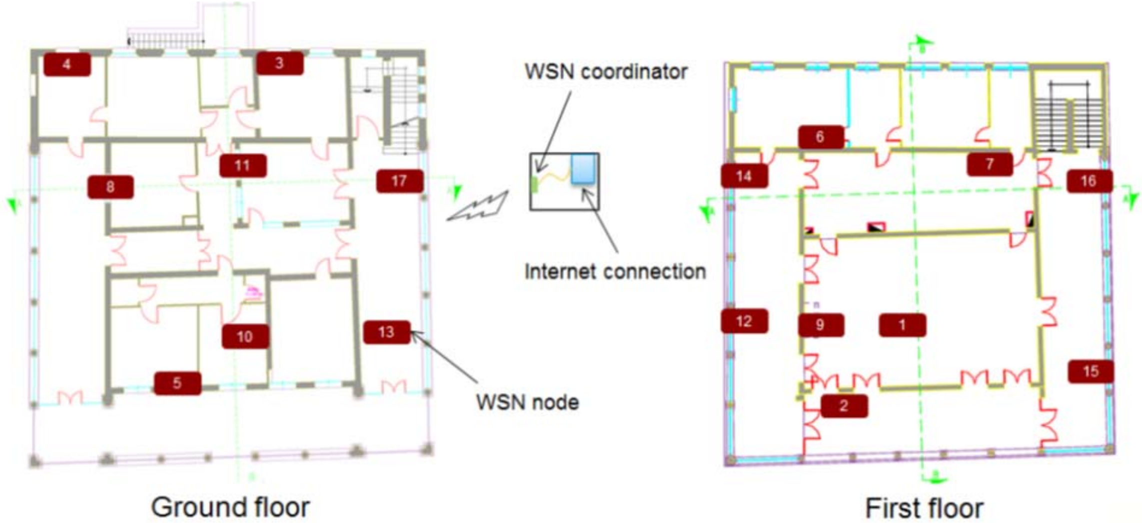
7.2 Monitoring system before intervention

- **Monitoring system 1 – basic sensors and description**

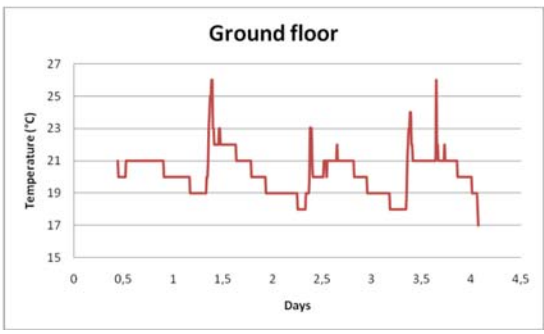
Sensor	Monitoring	Parameter [Unit]	Description	
1	Energy	Electricity consumption from energy bills [kWh]	Power consumption taken from energy	Whole build
2	Energy	Thermal Energy consumption from energy bills [kWh]	Thermal energy consumption taken from energy	Whole build
3	Energy Comfort/Utilization	Room climate [°C, %]	Temperature and relative humidity	Selected zones
4	Comfort/Utilization	Surface temperature [°C]	Temperature room sided	Selected zones
5	Energy Comfort/Utilization	Indoor lux level [lux]	Lighting condition inside	Selected zones
6	Energy Comfort/Utilization Building Historical surface	Outside climate [°C, %], Solar radiation [W/m²]	Temperature, relative humidity, radiation.	General
7	Building	Temperature [°C] Relative humidity [%] Surface Temperature [°C], Air streams	Climate and surface temperature at thermal bridges or other critical construction points of the thermal envelope (room sided). As: external corner, window, window reveal. Optionally temperature inside external wall, and surface temperature outside external wall	Selected external corners, windows, resp. to define
8	Historical surfaces	Temperature [°C] Relative humidity [%] Surface Temperature (inside and outside) [°C], Air streams	Near field climate and surface temperature at historical surfaces	Selected zones

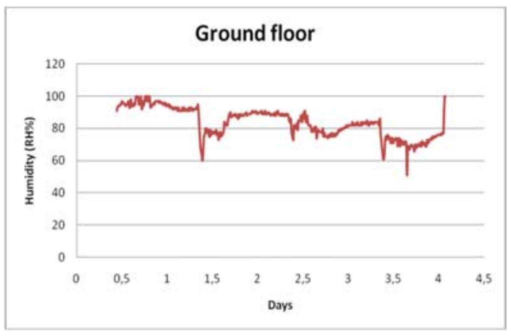
Monitoring layout

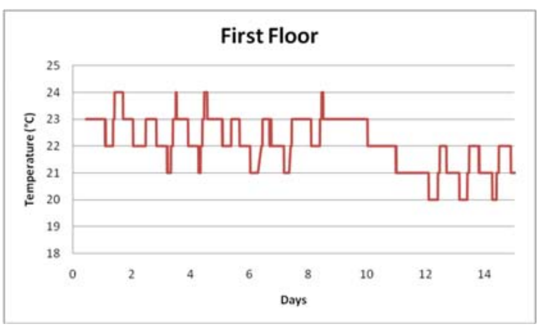
- 17 WSN node battery supplied
- 102 sensors
- 1 WSN coordinator USB powered
- 1 PC with internet connection for data forwarding and remoter WSN control

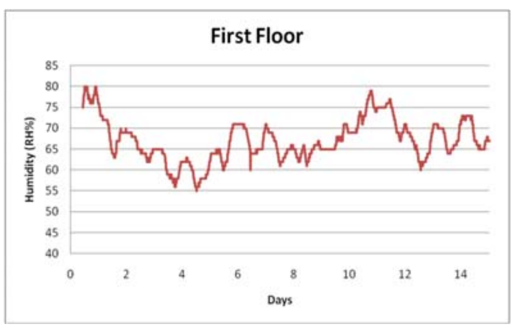


Examples of WSN data:









7.3 Monitoring system during/after intervention

7.3.1 General description

During the refurbishment works it has been installed a 3EncultWSN with 36 motes collecting data from 144 sensors, remaining active after the refurbishment work.

Sensors details

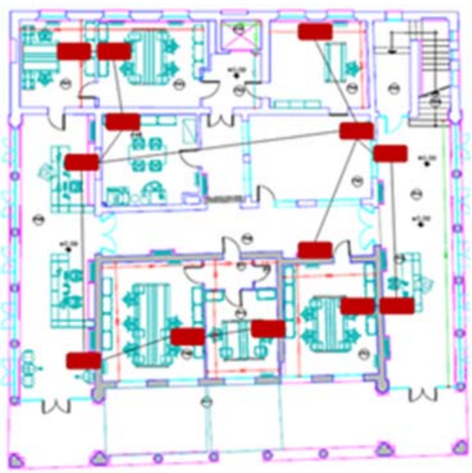
- 32Mhz 32bit microprocessor
- 2.4Ghz radio transceiver
- Zigbee Pro compliant
- Aggressive power management (sleep mode 8μA) for long battery life
- MicroSD card for local data logging
- On board sensors
  - Temperature (0.01°C resolution)
  - Humidity (0.04°C resolution)
  - Light sensor (0.23 lx resolution)
  - 3-axis accelerometer (1mg resolution)
  - Gas sensor interface (10% resolution)
    - VOC, CO, NHx, O3, NH4
- Analog input with 12bit resolution and 300khz sample rate
- 10 digital input/output
- 1 UART (convertible to RS232, RS422, USB)
- 1 I2C (used to communicate with IC sensors)
- 1 SPI (used to communicate with fast IC sensors and external Analog Digital converter)
- 3V 1.5W fully controlled DC output power supply for both external sensors and expansion board

7.3.1 Measuring system (planning shows the position of the sensor)

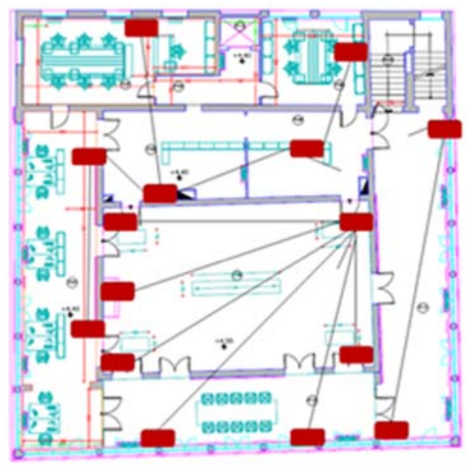
During the refurbishment works it has been installed a 3EncultWSN with 36 motes distributed on the 4 levels of the building, collecting data from 144 sensors, remaining active after the refurbishment work.

The data under collection are air temperature, humidity, light intensity and acceleration.

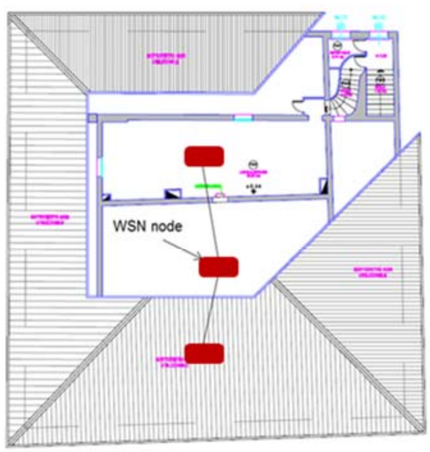
This network is collecting data since March 2012 and is still working. The datra acquired are send to a web service from which reader can view the data.



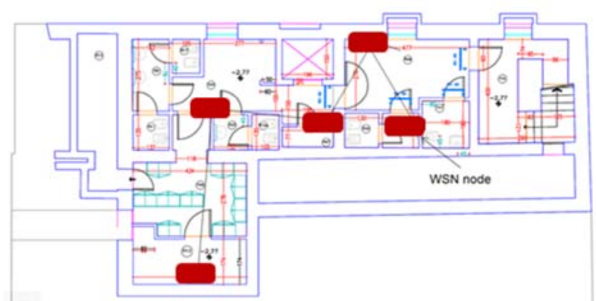
Ground floor



First floor



Attic floor

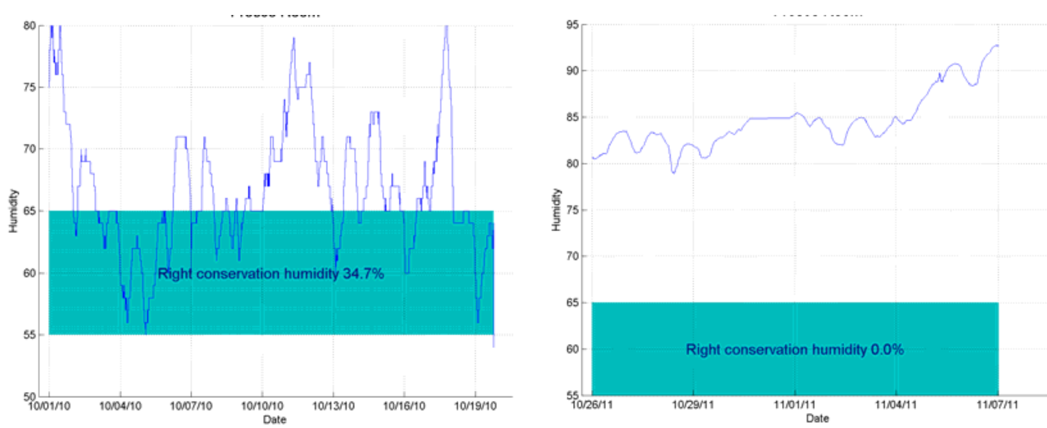


Underground floor

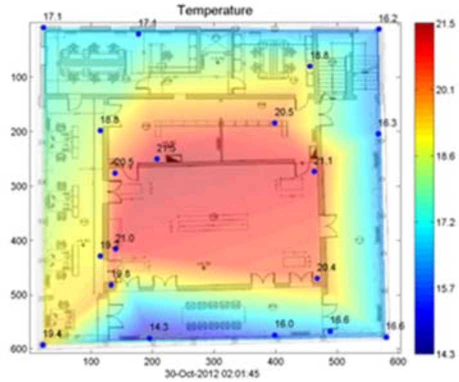
7.3.2 Measures

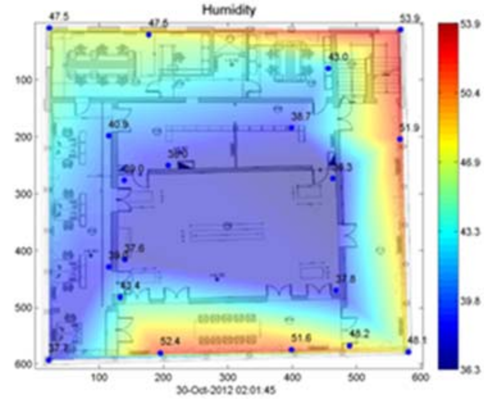
First of all, recorded climatic data are visualized as graphs of the single parameters.

Then, an automatic analysis procedure to generate temperature and humidity graphs and maps has been implemented.



Data of relative humidity collected in the main hall, before (left) and during refurbishment (right).





Examples of maps of temperature (left) and humidity (right) after interventions

8 Annex 3 - Case Study organisation

8.1 Local Case Study Teams (LCS teams) & meetings

Palazzina della Viola is owned by the University of Bologna and presently used as University department (International Relations Department). After a few years of abandon, the renovation works in the building started almost at the same time as the 3ENCULT project's start, although the intervention project had been designed a few years earlier by the technical office of the university (AUTC).

During project proposal preparation and negotiation and at the beginning of the project, contacts were taken with the Technical Office of the University and information exchanged.

During the approx. 18-month duration of the building site, a number of meetings were requested by the 3ENCULT UNIBO's team (DICAM + DEI Department) to the AUTC and in particular to the Architect acting as Director of Work, and to the Surveyor acting as second-in-place. During these meetings, repeated experiences showed that there was interest by AUTC in being informed about the planned project activities in the Case Study but little information was provided to UNIBO's Team by AUTC about the design, the time progression of works and the specific activities on-site with a little advance time. Also, repeated conversations showed that there was no possibility that the site works of intervention design could be modified according to the 3ENCULT suggestions, because of budget constraints. Good exchange of information and collaboration was achieved by UNIBO's team on site with the restorers carrying out cleaning, protection and restoration of the delicate artifacts present in the building, in particular of detached frescoes hanging on walls and painted timber-beam ceilings.

Several experimental diagnostic studies and investigations were conducted on site by UNIBO's Team and as well as a WSN monitoring system was installed in the CS during the building site works and afterward the refurbishment.

The Local Case Study Team of Palazzina della Viola was composed by

UNIBO's 3ENCULT partner team: Luca Benini, Camilla Colla, Elena Gabrielli, Marco Giuliani, Giacomo Paci, Francesco Ubertini

Restorers: Ada Foschini, Alessandra Freo

AUTC: Roberto Battistini, Andrea Braschi, Dina Uccelli, Anna Vecchi

Superintendent Authority for Cultural Heritage: Franca Iole Pietrafitta

9 Annex 4 – Associated documents

Description	Filename
CS3_Viola_SitePlan	CS3_SitePlan.pdf
CS3_Viola_Airtghtness	CS3_ReportPreIntervention_Airtightness.pdf
CS3_Viola_AnalysisArchitecturalElements_Basement	CS3_ReportPreIntervention_Basement.pdf
CS3_Viola_AnalysisArchitecturalElements_InternalPartition	CS3_ReportPreIntervention_InternalPartition.pdf
CS3_Viola_AnalysisArchitecturalElements_Windows	CS3_ReportPreIntervention_Windows.pdf
CS3_Viola_Monitoring_PsychrometricMaps	CS3_ReportPreIntervention_PsychrometricMaps.pdf
CS3_Viola_StructuralAnalysis_MoistureAssessment	CS3_ReportPreIntervention_StructuralAnalysis&MoistureAssessment.pdf
CS3_Viola_U-value	CS3_ReportPreIntervention_U-value.pdf
Annex I –PHPP calculation	CS3_Annex I_PHPP calculation