D 2.2 Contribution from Case Study2
Palazzo d’Accursio /Municipal Palace Palace
Bologna (Italy)

EUROPEAN COMMISSION
DG ENVIRONMENT

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
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1 Formal commitments between the Owner, the local Authority, the Preservation Authority

The case studies in Bologna, Palazzo d'Accursio, is considered Monuments of high historical architectural value. He is located within an historically and totally urbanised urban context. In particular, Palazzo d'Accursio is located in the oldest city nucleus on the foundations of the ancient Roman city. The case studies can be considered as relevant examples of monuments placed in the city centre, whose projects aimed at the improvement of environmental comfort and energy efficiency can become a guide to improve and implement current municipal regulations.

Project proposals, derived from the historic and architectural-structural analysis of the buildings and from the collection of data regarding consumption and energy waste, do not imply changes in the overall functional structure, or changes regarding the public property. The buildings is in fact public property (Palazzo d'Accursio is owned by the municipal administration) and in particular, this aspect is important as regards permitting procedures, which in some passages imply the adoption of internal approval acts.

1.1 The Italian legislations for the preservations on cultural heritage

The concept of cultural value derives from the fact that the building is a monument of exceptional value, bound under the National Law of Conservation of historical art and ethno-anthropological goods (Legislative Decree 42/2004).

For the building listed with this low, all work referring restoration, extraordinary maintenance and normal maintenance must be done with the approval of the local Heritage Preservation Authority that is an offshoot of the Italian Ministry of Cultural Heritage.

The approval of project is the basis for the second approval of local authority (Building Commission of Municipality of Bologna).

The preservation of the building is guaranteed by the Director of Heritage Preservation Authority of Cultural Heritage based on:

- Guidelines for the evaluation and reduction of seismic risk of the Cultural heritage (Directive 26/2010)
- Charter of the restoration of Athens (1931) and Venice (1964) and subsequent to that of Krakow in 2000;
- UNI 11182:2006 former NorMal 1/88 that allows the classification of the deterioration of stone materials.

1.2 The case study of Palazzo d'Accursio and its specific issues

The building, being considered of high historical and artistic value, must be subject to national standards of conservation and restoration and local urban regulation, and to the local sanitary regulations. Regarding the energy legislation, please refer to the Municipal Energy Plan (PEC), even if the buildings of such value do not have defined obligations.

The promoter of the Palazzo d'Accursio case study is the local government - the Municipality of Bologna - who is also the owner of the building. In addition to the City of Bologna the case study involved the following stakeholders: University of Bologna (project partner), Artemis (project partner), ICIE (supplying specialist guidance in the environmental energy improvement), IBC Institute of Cultural Heritage (architectural and environmental heritage field that carries out support to local authorities for the understanding, conservation and enhancement of the architectural and natural heritage), the Heritage Preservation Authority for the architectural and landscape goods for the provinces of Bologna, Modena and Reggio Emilia (Organisation approving the interventions to be implemented in the project).

In the case study of Palazzo d'Accursio consultation with the local government coincides, while it is maintained consultation with the Superintendent. This consultation takes place directly between the representatives of the two entities, with a view to analysing the applicability of measures to improve energy on buildings of cultural value.

Case Study 2 - Palazzo d'Accursio – Bologna (Italy)
On the other hand, it's necessary to point out that the Heritage Preservation Authority has been involved in the LCS team but, because of the role that it covers, it preferred to keep an independent position in relation to the project procedure, that entails the release of the formal authorisation to the making of the Palazzo d’Accursio extraordinary maintenance works.

1.3 The Local case Study Teams

The exact constitution of LCS-Teams is based on 3encult partner and Stakeholders listed below:

1. Municipality of Bologna composed by:
   - process responsible: ing. Fabio Andreon (executive Public Works Dept.);
   - scientific responsible: arch. Manuela Faustini Fustini (Cultural Heritage, Public Works Dept.);
   - arch. Arturo Todaro (Designer for extraordinary maintenance, Public Works Dept.)
   - p.i. Capuzzi Davide (Plant engineer expert, Public Works Dept.);
   - dott.ssa Pamela Lama (International relations and projects Office);
   - dott. Francesco Tutino (Environment and energy Dept.);
   - dott. Daniele Zappi (Environment and energy Dept);
   - arch. Federica Legnani (Old town planning).

2. University of Bologna composed by:
   - arch. Camilla Colla (non-destructive analysis and tests);
   - ing. Elena Gabrielli (non-destructive analysis and tests);
   - ing. Marco Giuliani (energy analysis and simulations);
   - ing. Francesco Ubertini (DICAM department responsible);
   - ing. Giacomo Paci (Wireless sensor networks).

3. Artemis srl composed by:
   - ing. Enrico Esposito (IR thermography tests and indoor monitoring);

4. Icie – Larcolcos Laboratory (supplying specialist guidance in the environmental energy improvement) composed by:
   - Arch. Valerio Nannini;
   - Ing. Sandra Dei Svaldi;
   - Arch. Mena Viscardi.

5. IBC- Regional Institute of Cultural Heritage (architectural and environmental heritage field that carries out support to local authorities for the understanding, conservation and enhancement of the architectural and natural heritage) composed by;
   - arch. Piero Orlandi
   - arch. Andrea Zanelli

6. Heritage Preservation Authority office for the provinces of Bologna, Modena and Reggio Emilia (Department for architectural treasures and landscape for the provinces of Bologna, Modena and Reggio Emilia. Organisation approving the interventions to be implemented in the project).composed by:
   - arch. Franca Iole Pietrafitta (project officer)
   - arch. Paola Griffoni (Heritage Preservation Authority Director)
2 The conservation aspects and energy saving actions for the “Sala Urbana” in Palazzo d’Accursio

2.1 The “Palazzo d’Accursio”

2.1.1 Local climate data

<table>
<thead>
<tr>
<th>Local climate data</th>
<th>BOLOGNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>(building plan showing the north)</td>
<td>Climate zone: E</td>
</tr>
<tr>
<td></td>
<td>Climate area: 3F</td>
</tr>
<tr>
<td></td>
<td>Degree days: 2.259</td>
</tr>
<tr>
<td></td>
<td>Altitude: 54 m</td>
</tr>
<tr>
<td></td>
<td>Coordinates: Lat N 44° 29’ - Long E 11° 20’</td>
</tr>
<tr>
<td></td>
<td>Average wind speed: 1.60 m/s (max 3.20)</td>
</tr>
<tr>
<td></td>
<td>Prevailing wind direction: South/West</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Winter climate data</th>
<th>Summer climate data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter design temperature: -5°C</td>
<td>Temperature: dry/wet bulb: 33/22 °C</td>
</tr>
<tr>
<td>HR max: 95% (Nov.- Dec.)</td>
<td>HR: 43%</td>
</tr>
<tr>
<td>Heating days per year: 183 (15 Oct.- 15 Apr.)</td>
<td>Daily temperature range: 12 °C</td>
</tr>
</tbody>
</table>

2.1.2 Report on history of the 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.

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 crenellated 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.

Some observations have to be done referring to the current constraints for the protection and preservation of the whole building, in particular for what is concerned with the transformability of space, and the possibility to change the structural solutions and plants network.

The building does not have any particular structural problem. 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...). On the other hand, there are some problems for the management of the plants network due to the antiquated status of these.
This is the proposal addiction of buildings that characterize Palazzo d’Accursio from the origin until now. This reconstruction is based on the thesis described from Hans W. Hubert in “DER PALAZZO COMUNALE VON BOLOGNA” 1993 Bohlau edition.
Palazzo della Biada in 1295 (Origin of Palazzo d'Accursio)

Palazzo della Biada in 1336 (First addition)

Taddeo Pepoli's Palazzo Grande in 1340,
Palatium Apostolicum des Andrion de la Roche at 1365

Palatium Apostolicum and your first extension in 1425
Palatium Apostolicum with Cortile degli Svizzeri in 1436

Palatium Apostolicum in 1513 defined also as Giulio II's Palace
Palatium Apostolicum in 1585

Project drawings by Pietro Fiorini made between 1606 and 1611 for the completion of the rooms that were supposed to host the Swiss soldiers.
### Historical summary table

#### History of the buildings

<table>
<thead>
<tr>
<th>Construction phases</th>
<th>First phase of construction: 1295</th>
<th>Original nucleolus of the Building (Palazzo della Biada)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Second phase of construction (first extension): 1340</td>
<td>Palazzo Grande di Taddeo Pepoli</td>
</tr>
<tr>
<td></td>
<td>Third phase of construction 1425</td>
<td>Palatium Apostolicum (1365-1425) Construction of the crenellated walls interspersed with towers</td>
</tr>
<tr>
<td></td>
<td>Fourth phase of construction 1436</td>
<td>Construction of the Cortile degli Svizzeri. Reinforcements of the walls</td>
</tr>
<tr>
<td></td>
<td>Fifth phase of construction 1513</td>
<td>Completion of the cardinal lagate apartments (firsts and second floor)</td>
</tr>
<tr>
<td></td>
<td>Sixth phase of construction 1585</td>
<td>Construction of the buildings around the Cortile degli Svizzeri</td>
</tr>
<tr>
<td></td>
<td>Seventh phase of construction 1886</td>
<td>Construction of the Stock room in the area of the botanical garden named Sala Borsa</td>
</tr>
<tr>
<td>Restoration phases</td>
<td>First restoration 1885</td>
<td>Palazzo della Biada front restauration</td>
</tr>
<tr>
<td></td>
<td>Second restoration 1933</td>
<td>Restoration front with the substitution of old windows</td>
</tr>
<tr>
<td></td>
<td>Third restoration 1936</td>
<td>Realization Municipal collections inside to Giulio’s palace</td>
</tr>
<tr>
<td></td>
<td>Fourth restoration 1939-1943</td>
<td>Restoration ovest front</td>
</tr>
</tbody>
</table>

On the next page will show the floor plans in advance by a plan color on the various phases of construction of the buildings.
2.2 Constraint and protection conditions

2.2.1 Principles of protection given 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 prescribes 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 pluvials; 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 terrazzo, 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.
2.2.2 Limits and prescriptions 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 be 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.

2.2.3 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.

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).

2.3 Selected area of intervention

If building as a whole is composed of different building blocks, you can break down the analysis for different functional area.

The diagnostic tests and the case study will be concentrated in certain significant "nodes" in the Municipal Palace, based on the following criteria:

- mixed construction features;
- presence of critical issues in the management of the thermal control according to the different "uses" inside the building;
- different construction age.

2.3.1 Functional Area 1 - Municipal Collections (2nd floor)

Selected area is dedicated to the art collections of the city with paintings and furniture related to different ages. This area has the problems related to the maintenance of movable goods kept inside, with critical issues related to the hygrometric control and mixed construction characteristics.

<table>
<thead>
<tr>
<th>Functional area consistency 1: Municipal Collections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional area 1: Municipal Collections</td>
</tr>
<tr>
<td>Height interpolated average net (m):</td>
</tr>
<tr>
<td>Surface area (Gross/Net) heated (mq):</td>
</tr>
<tr>
<td>Volume (gross/net) heated (mc):</td>
</tr>
<tr>
<td>Opening to the public (from/to; hours /day; temperature set-up):</td>
</tr>
<tr>
<td>Hours of working (from/to, hours/day; temperature set-up):</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
</tr>
<tr>
<td>Hours of air conditioning (from/to; hours/day; temperature set-up)</td>
</tr>
</tbody>
</table>

### Functional area consistency 1: Municipal Collections

<table>
<thead>
<tr>
<th>Years</th>
<th>Gradi Giorno (GG)</th>
<th>Consumption (l)</th>
<th>Consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-season 2007/2008</td>
<td>2.162,8</td>
<td>16.179</td>
<td>155.353</td>
</tr>
<tr>
<td>- season 2008/2009</td>
<td>2.238,1</td>
<td>13.133</td>
<td>126.107</td>
</tr>
<tr>
<td>- season 2009/2010</td>
<td>2.405,7</td>
<td>14.381</td>
<td>138.087</td>
</tr>
<tr>
<td>- season 2010/2011</td>
<td>2.130,1</td>
<td>14.629</td>
<td>140.466</td>
</tr>
</tbody>
</table>

#### 2.3.2 Analysis and monitoring results (status pre-intervention)

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
- Infrared Thermography (IRT)
- Blower door test
- U-value determination
- Monitoring through WSN
2.3.3 Design Builder applications results (current status of the building)

An Energetic Analysis of the most significant spaces with the aim of experimenting the use of the software Design Builder (an informatics tool for the energetic analysis in dynamic conditions developed with the ENERGY PLUS engine) that will be used in the Project.

- **The energetic model of the Municipal Collections Area**

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.
Energetic model of part of “D’Accursio” Palace

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 Urbanas
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.

4th 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).
The other information given in the weather data file are necessary for the dynamic energetic calculation, such as the solar radiation, in its direct and horizontally diffused component, temperature, relative humidity and wind speed.

When doing the dynamic modeling, it’s quite common refer to IWEC data (International Weather for Energy Calculations) taken from Energy Plus database, which was elaborated among 1960 and 1970. But in this case we used weather data taken from the weather forecast station of Bologna, in order to obtain a simulation that considers the last decades climate changes.

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].
For the elaboration of vertical solid components (walls), and of the transparent (window shutters and glass) components, re-built in the Tab “Glazing”, we used in particular the Data given at point 3.1.2.1 of the present study “Survey of the external walls - Municipal collections”.

In Tab “Construction” has been defined the infiltration index (ACH-Air Change per Hour) which considers eventual cracks in walls and in windows.

These values have been defined using the equation about the Infiltration Air Change Rate used in the “Ventilation” Tab of the PHPP, in respect of the norm EN 13790:

\[
\text{infiltration} = n_{50} \times e \text{ coefficient}
\]
where:
- $n_{50}$ is obtained from the results of the Blower Door Test analysis
- $e$ represents the wind control coefficient according to the norm EN832, considering in particular the value corresponding to the historic center zone (0.04) taken from the following table:

<table>
<thead>
<tr>
<th>Coefficient $e$ for Screening Class</th>
<th>Several Sides Exposed</th>
<th>One Side Exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Screening</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Moderate Screening</td>
<td>0.07</td>
<td>0.02</td>
</tr>
<tr>
<td>High Screening</td>
<td><strong>0.04</strong></td>
<td><strong>0.01</strong></td>
</tr>
</tbody>
</table>

Using the Blower Door Test results, the following “infiltration air change rates” are obtained:

<table>
<thead>
<tr>
<th>Tipo di zona</th>
<th>Risultato Blower Door Test ($n_{50}$)</th>
<th>Tasso d'infiltrazione [vol/ora]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sala 19-20</td>
<td>2,38</td>
<td>0,10</td>
</tr>
<tr>
<td>Sala 2-3-18</td>
<td>14,69</td>
<td>0,60</td>
</tr>
<tr>
<td>Sala 4-5-6</td>
<td>4,40</td>
<td>0,20</td>
</tr>
<tr>
<td>Sala Urbana(17)</td>
<td>2,52</td>
<td>0,10</td>
</tr>
</tbody>
</table>

But these values do not consider the infiltrations coming from the spaces connecting the room to the adjacent ones; in order to consider these contributions, each previously found out value has been increased of 0,2 vol/h.

The final results, therefore, are the following:

<table>
<thead>
<tr>
<th>Zone Type</th>
<th>Tasso d'infiltrazione [vol/ora]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 19-20</td>
<td>0,30</td>
</tr>
<tr>
<td>Room 2-3-18</td>
<td>0,80</td>
</tr>
<tr>
<td>Room 4-5-6</td>
<td>0,40</td>
</tr>
<tr>
<td>Sala Urbana (17)</td>
<td>0,30</td>
</tr>
</tbody>
</table>

**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. Then we put these information in the Tab “Activities”; the data requested by the software are the following ones:

A. the occupation, derived by the ratio between the number of users and the floor area (people/square meter)

B. the metabolic index of occupiers which expresses in quantity (measured W for persona) the intensity of the activity developed in the analyzed spaces, set on 140 W/persona (data derived from the Design Builder Data banking).

C. The clothing index, for which were considered standard values of 1,0 clo in winter and 0,5 clo in summer.

D. The consuming of sanitary warm water, absent in this Museum zone;

E. The control temperatures of the indoor environment for heating (20°C), as well as for cooling (26°C);

F. The internal contributions for air conditioning and electricity equipments and installations (in the Tab “Activity”, as well as the ones used for lighting (in Tab “Lighting”)}
• The results of the energetic analysis
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.

• Results of the dynamic simulation for winter season
The results are shown as a synthesis of winter and summer season, they refer to the whole period with a monthly frequency, and to the building as a whole unit.

Losses through the building external enclosure body (whole period)

Contribution

Solar gains through the windows
Contribution through the building external enclosure body (whole period)

The highest level of loss is due to external infiltrations caused by:
- the low thermal performances of the window shutters made in wood frames without seals;
- the thin interface between window and mobile frame and between fixed frames and the walls;
- the presence of installations going through the perimeter walls;
- the presence of cracks among the beams of the superior wood coffered ceiling

The rest of the gains has a minor role, especially the low contribution of the window walls due to the minor surface that they offer to the exchange with the outside. Among the free gains, those due to normal attendance and lighting assume a more significant role.

The total consumption of primary Energy for heating, resulting from the analysis done with this software can be estimated in 91.325 kWh, corresponding to 102 kWh/mq.

In the Tab below are reported the electricity consumptions due to equipments for air conditioning and for lighting.

<table>
<thead>
<tr>
<th>Electric Energy Consumptions</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>30.695</td>
</tr>
<tr>
<td>Air conditioning equipments (small stove)</td>
<td>6.635</td>
</tr>
<tr>
<td>Total</td>
<td>37.330</td>
</tr>
</tbody>
</table>

• Results of the dynamic simulation for summer season

In the following pages are shown the results referred to the whole year period in detail with a monthly frequency.

Whole year period
Below are reported the consumptions due to electric and air conditioning equipments

<table>
<thead>
<tr>
<th>Electric Energy consumptions</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>30.540</td>
</tr>
<tr>
<td>Air conditioning equipments (fan)</td>
<td>954</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31.494</strong></td>
</tr>
</tbody>
</table>

### 2.3.4 Energetic retrofit proposal for Sala Urbana

The energetic retrofit proposal of Palazzo D’Accursio’s “Sala Urbana” 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 energetic retrofit interventions that have been evaluated in order test their capacity to fulfil the given targets, considering the present constraint conditions, are the following:

1. Windows substitutions;
2. Insulation of the interior covering ceiling from the extrados of the roof;
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.
• **Windows glass and frames substitution**

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

The Room 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 and the external in aluminum varnished in dark brown color), with $U_f=1,372 \, \text{W/m}^2\text{K}$ associated to different “glass packets” was considered as option.

In particular, the choice was to analyze the effects obtained through the application of:

1) A triple glass $3 + 3 \text{be/12argon/3} + 3\text{be}$ (offered performances: $U_g=0,7\text{w/m}^2\text{K}$ and $g=33$);
2) A double insulating glass $5 + 5\text{be/16argon/4} + 4$ (offered performances: $U_g=1\text{w/m}^2\text{K}$ and $g=27$);
3) A double insulating glass $4 + 4\text{be/16argon/4} + 4$ (offered performances: $U_g=1\text{w/m}^2\text{K}$ and $g=26$);

In every option was 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 soleils 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.

• **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...
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 and 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.

- 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

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/m²K in the current status to 0,788 W/m²K 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).

2.3.5 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):

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

<table>
<thead>
<tr>
<th>HP2</th>
<th>High efficiency window frames (selected in phase 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ventilated and insulated roof with wood fiber</td>
</tr>
<tr>
<td></td>
<td>Insulation of the roof from its extrados with glass wool</td>
</tr>
<tr>
<td></td>
<td>Remake of the external façade plaster using traditional lime plaster</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP3</th>
<th>High efficiency window frames (selected in phase 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ventilated and insulated roof with wood fiber</td>
</tr>
<tr>
<td></td>
<td>Remake of the external façade plaster using traditional lime plaster</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP4</th>
<th>High efficiency window frames (selected in phase 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ventilated and insulated roof with glass wool + double layer of panels with oriented fibers (OSB)</td>
</tr>
<tr>
<td></td>
<td>Remake of the external façade plaster using traditional lime plaster</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HP5</th>
<th>High efficiency window frames (selected in phase 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Remake of the external façade plaster using traditional lime plaster</td>
</tr>
<tr>
<td></td>
<td>Insulation of the roof from its extrados with glass wool</td>
</tr>
</tbody>
</table>
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/m² 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 (gran 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.
3 Project of the interventions and formal approval by the Heritage Preservation Authority

3.1 Guidelines for interventions (Municipal collections)

The actions to be taken within the Municipal Collections are orientated primarily to the execution of works relating to the room M 2F 17S called Sala Urbana or Sala degli Stemi. The interventions to be implemented are urgent because the state of deterioration is very advanced. Work will focus primarily on the replacement of the roof with waterproofing and replacement of existing windows. In the realization of these maintenance operations, we introduce the aspect of energy saving, which normally would not be introduced on historic buildings and protected by the Superintendent. Design objective involves the application of the legal limits that prevent energy loss to building components and building envelope.

3.1.1 Roof refurbishment

From the investigations conducted it was decided to schedule an urgent replacement of the roofs of the hall and to provide a conservative restoration of the frescoes on the ceiling through the consolidation to be carried out in extrados. The limit values of reference for the covers as by D. Decree 311/2006 for Zone E are equal to a 0, 30 W/m2 K. For these reasons it is assumed to isolate the cover through the use of insulating material made of wood fiber breathable, which must be applied on the extrados of the floor covering of the attic. In addition to the insulator, this material performs a protective function against the structure, especially when this is made of wood.

The roof must be completely replaced and it will be enough to realize a ventilated roof, because normally the insulation is introduced in the last opaque element facing the outside. To get the best benefits one could introduce an insulating layer (but taking into account the loads allowed by the structure). In this case it is necessary to use a transpirant insulating material suitable for summer periods, which has a low thermal diffusivity (thermal conductivity / density x specific heat, such as insulating materials based on wood fiber). With this arrangement is 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 are those in wood fiber, the maximum thermal conductivity should be around 0.043 to λ [W / (mK)]. For the isolation of the floor, the minimum thickness of the insulation will have to be of 8 cm, assisted by the panel of wood fiber, cloth transpirant waterproof, air chamber that allows for ventilation, and a wooden partition as a finish.

The base of the floor, with the introduction of insulating materials could achieve performance that is below the transmittance U = <K 30W/m2. Here below a schematic diagram of the materials that could be used for the last base of the attic.
Schematic stratigraphy of insulating

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. Barriera all'aria e freno al vapore a diffusione igrovariable s. 0.2 mm
7. Assito in Legno di pino flusso perpendicolare alle fibre s. 20 mm
3.1.2 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, it is proposed to replace them with a 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.

For windows facing east and west: it is proposed to replacing the windows while keeping the existing design, leading to a total transmittance of the window equal to $U_w = 2.2$ 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 must be 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 $U_w = 1.9$ 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 and built by artisans, but to address the maintenance issue, you could opt for a mixed window, which presents to the outside of an aluminium frame with thermal break, treated with brown colour and towards interior a wood frame.

Any option you choose, and be accepted by the superintendent, it is essential that the frame can be opened in order to create natural ventilation in summer months (although obscured by curtains specially arrears). May be developed further (with the manufacturers) the possibility of tilting windows (flap) with opening inwards and downwards, in such a way as to allow the flow of air in a direct way (chimney effect).
The window must be equipped with an automated system for its opening. Such a system must have a sophisticated automation that can be adjusted according to temperature and moisture present in the room, and will also provide for the automated closure in case of rain.

For windows facing south will be introduced an automated system that detects light output and regulating their opening and closing.

The adjustment takes place through an external sensor and heated internally connected to the controller. The control unit, mounted in modular container, allows the adjustment of the delay times on the drive output, on disconnection of the output and the sensitivity adjustment of outside sensor.
3.1.3 Domotics equipment installation

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.

3.1.4 New led-lighting devices

The energetic diagnosis highlighted that a very high amount of electric energy, corresponding to the 25,33% of the entire energetic consume of the Museum area is consumed for light sources.

Inside the “Urban” room, project surveys of the natural illumination levels have been carried out together with project partners ARUP and Bartenbach, Lichtlabor and the possibility of providing the “Sala Urbana with led light sources and in a future perspective with solutions able to significantly reduce the electric consuming due to lighting, i.e. working with power regulation with respect to the effective visitors present in the room, have been studied.

The project has planned the integration of the new light led sources with the domotic equipment installed inside the room in order to program differenced use scenarios following different exposition solutions and different ignition/shut down situations with respect to the presence in the room of eventual visitors. In this case is quite evident the concept of exploiting all the meteorological and environmental lightness data for regulating the lighting devices emissions in order to obtain the highest energy saving while guaranteeing the best lighting conditions.
3.1.5 Authorization to proceed with the realization of works

ITALIAN MINISTRY OF CULTURAL HERITAGE
AND ACTIVITIES
Supervision for architectural treasures and landscape
for the provinces of Bologna, Modena and Reggio Emilia
Via IV Novembre 5, 40123 Bologna
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To the Municipality of Bologna
Department of Public Works
Operating Unit of public historic buildings
For the kind attention of Architect Manuela Faustini Fustini
Piazza Liber Paradisus 10
Torre B
40129 Bologna

Prot. No:11147
Class:34.19.07/164 Annexes: 6
Answer to the protocol 187 of 29/02/2012
(our protocol No. 3090 of 29/02/2012)
and to the protocol 553 of 21/06/ 2012
(our protocol no. 9838 of 21/06/ 2012)

SUBJECT: Municipality of Bologna- Building located in Piazza Maggiore and known as Palazzo d’Accursio. (Relevant with the Legislative Decree 42/2004 and subsequent modifications and additions- “Code of cultural and environmental heritage”, pursuant to the article 128, with the document of 31/12/1911 issued as ex lege 364/1909).

Owner and applicant: the Municipality of Bologna

Work of: extraordinary maintenance of the Sala Urbana (Urban Hall), (Roofing and replacement of windows)

Authorization pursuant to the article 21 prg.4 of the Legislative Decree 42/2004 and subsequent modifications and additions

With reference to the aforementioned, having analyzed all the technical documentation sent with the marginal notes and given the latest clarifications, considering the special historical and artistic characteristics of the present hall,

having acknowledged that the work is about the replacement of the damaged wooden window and the maintenance of the roofing and the false ceiling,

having assessed all the methods and solutions aimed at guaranteeing a perfect insulation from rain water seepage and a suitable microclimate inside the hall,

this Department authorizes, as far as it is concerned, the work which is deemed to be necessary to preserve and protect the building, and the following conditions must be followed:

- First, great attention to the scaffoldings and the temporary works of the hall must be paid and the best measures for the protection of the hall must be taken;

- In order to tailor all the suggested interventions, once the scaffoldings will be put up, the roofing will be inspected to control the preservation status of its components and verify any further work to improve the anti-seismic design of the building. For this purpose, an accurate geometrical survey with photos and with any detailed documentation will be done and then analyzed by this office;
- Regarding the new windows (made of wood/aluminum, and component brise soleil etc.), subject to prior analysis of suitable samples, we reserve the right to verify and agree upon the formal and chromatic characteristics together with any further detail during the construction;
- It is compulsory to send this Department a written document with the date of the beginning of the work at least 10 days in advance and to specify the name of the technician responsible for the work.

Waiting for the above mentioned documentation, which could be analyzed in greater detail once the work has started, we are giving back the copy of the received documentation with the approval stamp which is subject to the above mentioned provisions.

The Responsible for the procedure: Architect Franca Iole Pietrafitta

FIP/sta

THE SUPERVISOR

(Architect Paola Grifoni)