Giovanna Franco · Anna Magrini

Historical Buildings and Energy

Springer

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Preface

The book is the result of a research that started in 2010, when the Rector of the University of Genoa decided to involve the Post-graduate School of Architectural Heritage and Landscape at the same university (directed by Prof. Stefano F. Musso) in the preliminary studies aimed at comprehensive reuse and restoration of the historical complex of Albergo dei Poveri in Genoa. The building was already undergoing a partial restoration and reuse programme, but was incomplete. Since that time, the building's restoration has become an opportunity for various research investigations financed by university, ministerial, and regional funds.

In 2011, a research contract was concluded between the University's Building Development Area and the Post-graduate School of Architectural and Landscape Heritage (under the scientific responsibility of Prof. Stefano F. Musso, School Director, and Prof. Giovanna Franco), to embark upon a research programme on the solidity and state of conservation of the complex, which would serve as a preliminary check for a feasibility study on its full reuse. In January 2013, the same research group (coordinated by Prof. Stefano della Torre, Politecnico of Milano, and, as regards the Genoa unit, by Prof Stefano F. Musso) obtained ministerial funding, as the research was within the scope of Projects of Relevant National Interest PRIN 2010. The aim was to develop an ICT project for managing the restoration and maintenance of large monumental complexes, with the specific application of a Building Information Modelling (BIM) software for managing historical heritage sites (BHIMM - Built Heritage Information Modelling/Management). In February 2013, the Liguria Region funded a 2-year research project headed "Smart grid: smart management of the historical monumental heritage" jointly with Ansaldo Energia, to ascertain the applicability of solutions for "streamlining" the complex itself, the smart use of energy, and the potentially autonomous energy production inside or around it. The project, under the scientific responsibility of Prof. Giovanna Franco, has been driven forward by Architect Marco Guerrini under the supervision of Engineer Marco Cartesegna (heating consultant, author of technical calculations and their description in Chaps. 7 and 8). Lastly, in 2015 a grant was awarded to University Research Projects

(PRA) to fund research in 2015 on the topic “Heritage and energy” under the responsibility of Prof. Giovanna Franco.

The research opportunity has had an impact on the education of students of the Post-graduate School and the Master’s programme in Architecture, whose work is partially shown in the book.

Only a small part of the whole research is presented in this volume and, specifically, those relating to energy efficiency and the autonomous production of energy inside and outside the complex.

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Acknowledgments

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Scientific responsibility: Giovanna Franco, researcher: Marco Guerrini, supervisor: Marco Cartesegna.

Italian Ministry of University and Research funded the Relevant International Research Program (PRIN 2010–2011) titled "Built Heritage Information Modelling/Management—BHIMM", involving six national research units, Politecnico of Milano, Politecnico of Torino, National Research Council of Bari, University of Brescia, University of Rome La Sapienza and University of Genoa.

National coordinator: Stefano Della Torre, Politecnico of Milano.

Scientific responsibility for the University of Genoa: Stefano F. Musso.

Research group of the University of Genoa: Stefano F. Musso, Anna Boato, Giovanna Franco, Lucina Napoleone, Daniela Pittaluga, Rita Vecchiattini, Simonetta Acacia, Marta Casanova and Roberto Babbetto.

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1.1 The Main Principles

1.1.1 Heritage as an Active Resource

Cultural Heritage (especially architectural) is an important legacy of which we are merely temporary custodians; thus, we are aware of the need to preserve it for future generations, following the more general principles on which the concept of sustainable development is based. The customs and habits of life, work, and production of local communities have resisted for centuries, slowly adapting to changing conditions, to the external and internal forces (natural, economic, environmental…) which would modify them as their surroundings changed. The social and settlement plan of those communities therefore took shape; it basically "reified" itself in a specific and material way of being and occupying/using the territory that has then reached us today under the form of anthropized and urbanized landscape even during periods of particular architectural importance.

It is this awareness, together with that—typical of the culture of the new millennium—of the identificatory value linked to specific historical and territorial realities that gradually expanded the concept of "heritage" (the historical city, the "modern" city, the industrial city, the environment and landscape, real estate, and intangible property) and, consequently, put more focus on the active protection thereof.

Whatever the heritage in question, its preservation is guaranteed through a process of valorization and regeneration in present and future life, ensuring its

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endurance to future generations not as an expression of the past but as a fundamental part of contemporary and future societies.

Considering Cultural Heritage not only as a petrified memory of the past, but also as an active resource for the future, reusing and valorizing it, means changing how we think of preservation; no more merely the purely aesthetic perception of buildings and landscapes as they are, but considering it now as a process of revitalization for the benefit of all, with all the challenges this entails. In fact, heritage is a depot of precious resources that are at the same time both reusable but neither renewable nor replaceable. This means that all interventions to modify buildings are rather delicate as they must be undertaken without ruining the existing beauty.

1.1.2 Heritage and Sustainability: Aporias and Conflicts

Despite the fact that we cannot exactly talk of "sustainability" before contemporary times, the Cultural Heritage and debate regarding the protection thereof are increasingly compared to the concepts of growth and sustainable development though in a critical way. Sustainability and historical heritage, both material and immaterial, in fact seem to belong to increasingly tangent (and interactive) spheres, starting from the observation that heritage, as an expression of civilization, is the first and clearest cultural reference point for a specific place. Looking at the most material ambit, architecture is the complex, layered, and multi-significant result of a construction culture that for centuries was necessarily attentive to the environmental characters and conditions of the place in which it rose to natural materials (the only ones available at the time), the forms of construction that were in constant dialogue with the territory, and the safeguarding thereof (organizing of waters, defence of hillsides, protection against land erosion, government of woodland, and agricultural resources). Past construction resulted in a settlement structure that, even if located in arid lands and unfavourable climates, had the relevant knowhow to follow these aspects or protect itself from them, using natural resources as an opportunity and giving space to those which today we recognize as part of the identity or, better still, local specifics of the place to be preserved and valorized.

In this sense, the great importance that historical and cultural values represent in renovation and the renewed interest in sustainability and the environmental and ecological footprint have led those parts of the scientific community that have traditionally been distanced from these themes to rediscover some of the values of traditional building, bringing new inspiration to applied research and the very practices of its renovation. This is the case, for example, of the protocols of environmental certification specifically prepared for historical heritage such as the LEED and the GBC Historic Building (Lucchi et al. 2016), as a direct consequence thereof. These are important experiences which, even with the very limits of the methods of quantitative evaluation and the relative difficulty to compare quantity and quality, bear witness to the by now inescapable need to try and exceed the exasperated technicism that often characterizes contemporary society and which deals with complex problems by turning exclusively to the application of simplifying technical solutions.

Beyond these overtures, it is unfortunately true that the relationship between sustainability and heritage in many current realities is all too often reduced to an abstract process of the mere application of products and technologies to save primary energy, which does not necessarily represent true innovation and, above all, does not always trigger an effective, conscious, and virtuous cultural advance towards the real sustainability of future life in our territories (Staudenmaier 1985).

Of course, technological innovation is certainly a necessary tool to help and resolve the planet's environmental emergency, to obtain higher levels of energy efficiency, to reduce consumption and emissions of harmful pollutants into the atmosphere, to gradually improve environmental comfort, and to optimize the performance of the built heritage. Nevertheless, the contemporary age has often confused technological innovation with the social usefulness of technical solutions adopted to resolve the problems found within the society itself, contributing thus to the creation of a vision in which technology has taken on a total and absolute value, and is no longer a tool to help man but rather is an end in itself.

It is above all for these reasons that the sector of Cultural Heritage—even if a little late compared to others—should by now recognize the importance of the concept of "sustainable technologies" which is certainly not meant to be merely a slogan. This may also play a key role beyond the borders of the various disciplines involved, bringing the discussions and research back to a less reductive plan that is more aware of the many different implications that these matters have on the human environment, both now and in the future. The culture of preservation and renovation in fact leads to the attention of all, in a clear and urgent way, a group of values that help to bring back the technical sphere to its role as tool and not goal of our actions (Barthler-Bouchier 2013). A new and different approach, as well as brand new research horizons, may also be investigated and practised in the relationship between heritage and sustainability to contribute in overturning cultural references and objectives that are almost exclusively technological in character and which, until today, have influenced the debate and experiments in the matter, highlighting how much sectors of material and immaterial innovative research must be investigated in favour of an increasingly broader conservation of the built environment.

The research and experimentation offers us a number of occasions for reflection and technical and cultural advances, connecting differing scientific and research sectors and taking advantage of the potential of technological transfer (just think of the research into graphene, on synthetic organic photovoltaic modules, on new fabrics, high performance materials that may also influence a new way of using—and protecting—historical buildings).

1.2 The Context

1.2.1 Research and Technological Innovation

Within this complex and varied overview, energy efficiency of historical heritage in its widest meanings is a topic of international scientific debate as demonstrated in some recent conferences (Kilian et al. 2010; Norrström 2011; Broström and Nilsen 2011; AiCARR 2014; Lopez et al. 2014; De Bouw et al. 2016), and of methodological and applied research to fulfil community goals and the EeB PPP roadmap, Energy efficiency of Buildings—Public Private Partnership (Troy and Bastian 2014).

Listed heritage—especially publically owned—that is subject to reconversion and reuse, is considered by the European Union as a key sector for experimenting with new solutions, also for demonstrative and driving purposes for future private investments. There are still many barriers (technological and otherwise) to the actuation of the Directive on energy efficiency of historical constructions, especially in public buildings. A significant portion of this heritage is, in fact, still served by inefficient air conditioners run on fossil fuels, leading to high energy costs and emissions of pollutants into the atmosphere. This is often exacerbated by bad management which generates high consumption, to the detriment of any effective preservation of works or collections of art, in the case of museums, or comfort levels of users in the case of buildings used as homes, offices, or for services. And, even before dealing with management methods, the same models of evaluation of the thermal behaviour and energy production of buildings and systems sometimes do not completely resolve the real situations because the particular conditions of preservation themselves can significantly influence the effective behaviour (Lucchi and Pracchi 2013).

Energy improvement strategies on the one hand, and technical solutions that are compatible with the protection and valorization of cultural districts and buildings on the other, have been identified as priority activities in the “Horizon 2020” European research funding programme whose specific goals for the future energy efficiency of the historical heritage not by coincidence include:

- product and process innovation as leading elements for the creation of a specific market in the construction sector;
- the development, experimentation, and validation of technical tools to evaluate the performance of technologies, components, and quality standards through monitoring systems that close the gap between energy yield calculated predictively and that effectively produced;
- financial strategies to make large-scale interventions possible especially on publically owned heritage.

There are many research stimuli suggested by European and local institutions that for years have considered Cultural Heritage as an effective object of study, knowledge, improvement, and valorization. It is therefore all about finally sharing this knowledge, making it available to a much wider scientific community compared to the one that was traditionally interested in these studies. Firstly, we need to share, at least among the experts involved, a "holistic" approach to the problem, founded on the awareness of the complexity of the systems and values in play and the relationships between them caused by even the smallest change.

There is still much that can and must be done to fully activate the cognitive systems of organization of the information in play, as a preliminary and indispensable phase for any programming or design of auspiciously ameliorative interventions, integrating the knowledge of the "architectural" and "landscape" disciplines most directly involved with the methodologies of the expert systems, today even more necessary in governing complex systems (Dvornik-Perhavec et al. 2014). From the clash meeting between the physical and material reality of the system on which we intend to act (in the historical building: the matter, its physical–chemical characterization, the state of conservation, extension and gravity of phenomena of degradation or structural instability. . .) and the "a priori" modelling tools for its performance, occasions may arise to further refine the methods for the calculation and inspection of the energy behaviour in play, if necessary integrated with specific onsite instrumental monitoring campaigns so as to decrease, at least tendentially, the gap that is often found between the hypothesized behaviour and the real behaviour of the buildings on which we act (Colla and Gabrielli 2016; Rye et al. 2016).

1.2.2 Technical Regulations and Guidelines

Even the technical sector and consequent regulations feel the effect of a change in the cultural climate and broaden the horizon of the heritage to that protected by specific national constraints (Hartman et al. 2013; Pankhurst and Harris 2013). In this sense, the sector of architectural renovation and restoration is not the only one to open up to themes of sustainability (see the international charters), but the technical one linked to energy efficiency is working to include, with the due care and attention, the more or less important historical heritage (see Chap. 3). In this sense, we must also highlight the efforts made by the Italian government's Ministry for Cultural Activities and Property which are explicitly mentioned in the guidelines for the inclusion of air generators firstly—and energy improvement, recently published (Ministero per i Beni e le attività Culturali e del Turismo 2015, Carbonara 2014; De Santoli 2014a, b; Direzione Regionale per i Beni Culturali e paesaggistici del Veneto 2010).

Finally, to bridge the many, often deep, cultural gaps that still exist among categories of experts and between experts and citizens, the many European experiences developed on the theme until now show how important activities of sensitization, training, sharing, and active involvement of the users are in improving the energy behaviour of historical buildings and traditional settlements which make up a large part of the residential structure of our country as well as its Cultural Heritage (Andrews 2014; Heath 2014; Ronchini and Poletto 2014).

The numerous guides and manuals mainly published internationally represent an important study base, like a methodological and operative reference point aimed to supply a wide range of actors with indications of method and technical elements useful in formulating guidelines and operative methods (Advisory Council on Historic Preservation 2011; Bath Preservation Trust and the Centre for Sustainable Energy 2011; City of Westminster 2013; Grimmer et al. 2011; Heath and Baker 2013; Historic Scotland 2008, 2012, 2013, 2014; Islington 2014).

The sharing of knowledge and education, not only by technicians but also and above all by owners, are for example key actions that the English-speaking world has for a while now identified as proprieties to reach true levels of cultural advancement. There are many brochures, technical guides, manuals that deal pragmatically but nonetheless supported by clearly explained methodological principles with the problems that each user or owner may find himself dealing with regarding damp, insulation, improvement of plant engineering equipment, and consumption savings (Changeworks 2008, 2009; English Heritage 2008a, b, 2012; Edinburgh World Heritage; Cornwall Council Historic Environment Service).

Guidebooks describing works already undertaken and documented with photos of building sites and results shown through annual energy consumption, actual technical feasibility and relative savings, become a concrete source for sharing information.

Training and consultation activities in the United Kingdom, and in the English-speaking world in general, actively involve a variety of Institutions (Sustainable Buildings Alliance—STBA, Historic Scotland, English Heritage, Changeworks, and the Society for the Protection of Ancient Buildings—SPAB) working together leading not only to guidelines but also streamlined, online tools that are easily consulted and accessible to all.

With these experiences, we take into account the effects that climate change has on the active protection and safeguarding of historical heritage, moving the attention therefore from intervention on the individual building to the problems of overall management, also formulating urban-level risk maps.

1.3 The Questions

1.3.1 The Smart Grid System and Historical Heritage

The theme of intelligent networks will connote in the immediate future the production and distribution of electricity, integrating effectively and in a sustainable way the energy concentrated in large power stations with that distributed and supplied by renewable sources, to be used in a flexible and intelligent way. In programmes of urban redevelopment, however, the historical city has not yet been subject to significant experimentation: an intelligent use of energy could be aimed at ancient buildings and open spaces, energy savings for heating and cooling (especially of public heritage), the possibility of autonomous production within or around it (diffused microgeneration).

Passing from the scale of the individual building to a wider segment of the constructed heritage, be it a Cultural District, a part of the established urban fabric or an entire landscape, represents on the other hand a further and not insignificant challenge for contemporary research. This change in perspective opens us up to problems of a much more complex nature which may include some answers to the questions of energy supply as well as the correct management thereof, processes within which the Public Administration plays a fundamental role.

New strategies for public lighting, district heating systems, systems of distributed cogeneration, systems of intelligent energy management, systems of production with the integration of renewable sources are all themes which, for a while now, have represented specific applications of "smart city" programmes but, until now, have not had any concrete experimentation on the historical and Cultural Heritage.

From here, we find the first question on which the research presented in this volume is based: is it possible to find space within intelligent networks systems for ancient fabrics, until now excluded by any planning attempt that goes beyond experimentation on individual products? This sector also spurs the cultural debate on the protection and valorization of the architectural heritage opening up interesting new perspectives of research and operations which today perhaps are not giving the due attention, but which could significantly contribute—considering the dimensions and quantity of the heritage with which it deals—to the pursuit of the main goals of the smart city.

Consider, then, historical buildings not only as consumers but also as real producers of energy, implementing technology that is already available on the market and transferring them to the sector of construction recovery; this approach, moreover, has already been explored and undertaken in some recent experiments (for example, in the university campuses of Rome and Venice).

Considering then the specific economic limits of the real estate owners (potentially differing greatly from each other), as well as those implicit in the authorization regimes of the listed property, it also appears necessary, as suggested by the European Community, to push applied research to the construction of models and financial tools. This is to make it possible not only to carry out individual interventions, but also to include the historical Cultural Heritage in the more general planning activities of public administrations (even considering the NZEB—Nearly Zero Energy Buildings standard, a priority goal also in the existing public heritage).

1.3.2 Quality of the Renovation Process and Sustainable Management

Before defining the plans and architectural projects on individual products, we must first concentrate on the dynamic processes of the management of realities in constant evolution, effectively the recovery and reuse of the ancient heritage, which clashes with uncertain, transitory, and temporary realities. The accent moves thus from the specific and autonomous event (a single project, even regarding energy efficiency) to various processes that precede it, accompany it, and follow it, involving numerous players. It is therefore necessary to follow a sustainable management of change, focusing on the quality of the process, without which the quality of the results cannot be guaranteed.

The management of interventions on the built heritage, in fact, presents a number of noteworthy and clear difficulties, especially if compared with that of new construction. These are difficulties that challenge the cognitive phases, tender procedures, building site management, and the subsequent life cycle of the products and which often invalidate, under the profile of efficiency and effectiveness, the very result of the interventions. These difficulties are provoked by unpredicted, unpredictable and potentially rather risky situations which may slow the process and impose, in progress, even consistent modifications, thwarting the set quality objectives, dilating execution times, and increasing intervention costs. Even the extreme fragmentation of knowledge, which on the one hand enriches a recovery project with meaning, on the other may reveal itself to be a difficult operation to manage. The cognitive process is never closed, but implements itself with continual updatings that represent new informative levels that are independent from the previous ones and often not integrated with them. Another negative effect on the quality of the results is the multiplicity of the players involved, often moved by contrasting and conflicting interests, which makes it difficult to organize in linear and effective ways a decision-making process aimed at optimizing the entire system, rather than maximizing a single sub-system (or a specific group of values or needs) over the others.

This does not certainly put the skills of the technicians involved in the processes triggered under debate, but it does reflect some peculiarities that sometimes negatively influence their results, and introduces new questions on the effective possibility of improving the management of data and phases towards an objective of real sustainability (Musso and Franco 2014).

1.3.3 The Role of the Tools

Thus, a correct and complex management of a growing amount of information acquired during the cognitive phases (both analytical and diagnostic) becomes fundamental, as they are effectively used in the decision-making phase, be it planning or of specific and punctual intervention undertaken. We need to put into a correct reciprocal relation the various types of information (data) and refer them to the places that are linked to them or from which they come. It is therefore also essential to record the variations that the project and the building site imply on the products, in their constructive components and in their spaces, and for this we need to organize that information together with their variability in time, in the study, planning, building site phases and in the subsequent management thereof, avoiding excessive and unsustainable levels of discretionality of the choices, also in the authorization phase by the organizations working in safeguarding the heritage. Correct data management is, therefore, an indispensable step in supporting the complex decision-making process of each operation (restoration, preservation, renovation…) to recover the built heritage, to follow the future life of the products, once reused and, finally, to really qualify change in a more sustainable way than in the recent past (Musso and Franco 2014).

Within this overview, information technology (ICT) has held a priority role for a while now in the sector of Cultural Property; this technology is increasingly necessary for the construction of a variety of models, also of an anticipatory type. Such models, based on knowledge, offer undoubtable advantages for the organization of information in view of the correctness and effectiveness of the decisions, but also suffer evident limits, implicit in their very construction (Musso 2011).

With the work integrated by experts in different disciplines, guided by common goals and interests, innovative paths of research may emerge that exploit digital technologies adapting them to their own ends, to organize the connections between topological and diversified information (alphanumeric, graphic, textual…), no longer only on a two-dimensional level (as traditionally has occurred until now), but linked to the three-dimensionality of construction. Thanks to specific innovative tools, including the Building Information Modelling (BIM), we can broaden our horizons of experimentation and application. The BIM allows us, at least ideally, to follow an effective coordination between the operators of construction processes, a better consequentiality between the phases and, consequently, effective savings in terms of time and costs. If suitably built and used, BIMs could moreover positively influence the quality of the interventions, eliminating risky margins of discretionality or invasiveness for the protection of the buildings. “Green BIMs” then, introduce into the construction process management some parameters more directly linked to the sustainability of the entire life cycle of the products and their environmental certification, energy behaviour and actions linked to their possible improvement, themes still not completely perceived as crucial in the field of restoration, and even more so in that of the preservation and recovery of listed heritage (Godager 2011; Fai and Sydor 2013; Backes et al. 2014).

Working on the management of the renovation process, it may also be necessary to implement some diagnostic and computer tools to optimize the management of the life of the building, including the control of its energy consumption. This is, for example, the goal of the development of the “Smart Energy Management System” for the historical heritage, systems that can be applied to individual buildings or entire Cultural Districts, aimed—once the most appropriate technical interventions are defined—to reduce the operative costs of the installed (or installable) systems and their pollution emissions. These systems, based on specific monitoring activities, with the installation of peripheral sensors linked between them and remotely with a central system of surveying and control for the exchange and elaboration of the data found, are characterized by high levels of flexibility in order to guarantee the best acquisition, management, and elaboration of information (Magrini and Franco 2016; Magrini et al. 2015).

1.4 Energy Efficiency in Historical Heritage and Applied Research

The volume offers, in the second part, a panorama on the three-yearly research on an historical monumental complex which, given its dimensions and particular collocation in the urban context, may be assimilated into a real urban district (Franco et al. 2014, 2015). In fact, it is believed that a credible planning methodology must be able to provide the results of experiments on a real case (Fig. 1.1). This is a listed complex that is particularly interesting not only culturally but also for public life. The choice of this research object is consequent to the identification, in a consolidated urban fabric, of different systems and sub-systems, which may rotate around specific hubs (museum system, the system of public areas, university system…). Specifically, a sub-system was chosen that is linked to university activities and may be connected to peripheral buildings and, for this reason, can be inserted in all effects in a sort of small district. The object of the research was deeply studied, with the contribution of experts in various analytical and technical disciplines, aiming at the restoration, renovation, and reuse of it for university purposes. In parallel, a feasibility study was started up in order to inspect:

- the possibility of carrying out a “System Research” on the historical construction, trying to find a balance between charge and generation
- the definition of an integrated methodology of process and project that takes into account different demands (preservative and ameliorative) in a balanced way
- the real possibility of application of advanced technological tools for the sustainable management of the historical heritage

The research was structured according to three main phases, from which we got some specific results; the three phases have been transversally crossed by the use of computer tools (GIS and BIM).

1. The system of knowledge
2. The evaluations
3. The technical solutions and strategies

1.4.1 The System of Knowledge, Data Acquisition, Cataloguing and Management

- Analysis of the physical space, reading of the direct sources: geometries, dimensions, material and constructive data, plant engineering system (system networks and terminals), state of conservation (instability and degradation) (Figs. 1.2, 1.3, 1.4 and 1.5)

Fig. 1.1 Aerial view of the centre of Genoa. Highlighted the monumental historical complex of the *Albergo dei Poveri* and the *Valletta Carbonara*. Considering its dimension and location, close to other university buildings, the building was object of several investigations, as its possible inclusion in a smart grid system

Prospetto Sud-Est, scala 1:100

Fig. 1.2 Data acquisition and processing. Conservation status of the façades of the western wing (Biasio, M., Del Monte, M., Galesio, P., Kyuyeon, K., Migogna, T., Pedroni, M., Pescetto, M. Roccon, B. 2014. Post-graduate School in Architectural Heritage and Landscape, University of Genoa)

- Reading of the indirect sources (archive research, evolution of construction, modifications over time, constructive peculiarities) and comparison with the direct sources (Fig. 1.6a, b)
- Reading of the system of the spaces (exterior–interior accessibility, entrance hall systems and stairwells, layout by floor)

1.4.2 The Evaluations

- Compatible reuse, definition of new uses in comparison with historical evolutions and with the values of the context

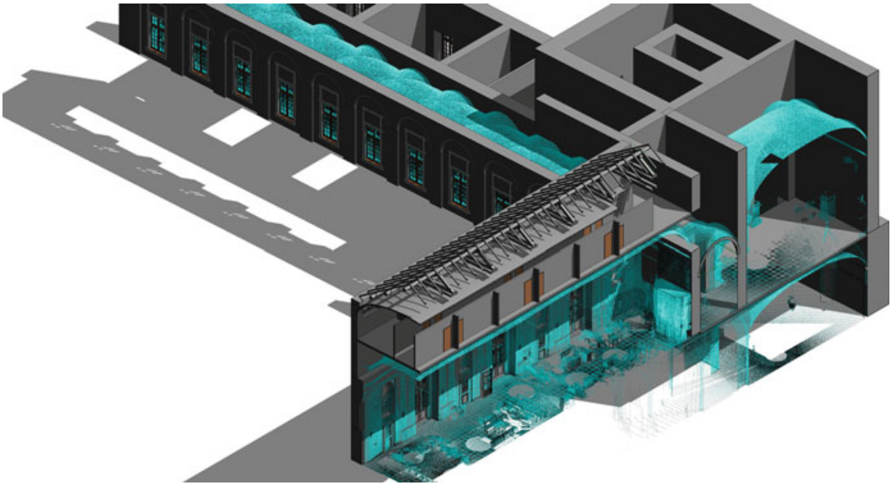

Fig. 1.3 Laser scanner survey and 3D modelling (BIM Autodesk Revit) of the south wing. (Babbetto, R., 2014. PhD course in Architectural Preservation, Politecnico of Milano)

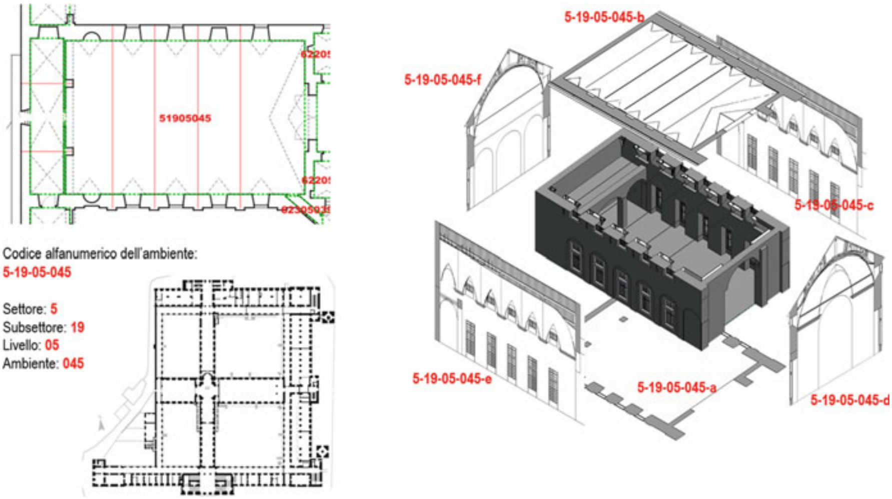

Fig. 1.4 Information management. Construction of 3D BIM model and GIS structure for the cataloguing of data and its subsequent processing. Identification of the rooms with alphanumeric code label in a hierarchic system (level respectively, sub-sector and sector). (Babbetto, R. 2014)

- The evaluation in terms of safety (fire, structural through specific monitoring and calculation systems) and usability
- The evaluation of the thermal behaviour of the existing physical structures through calculation methodologies and environmental monitoring systems

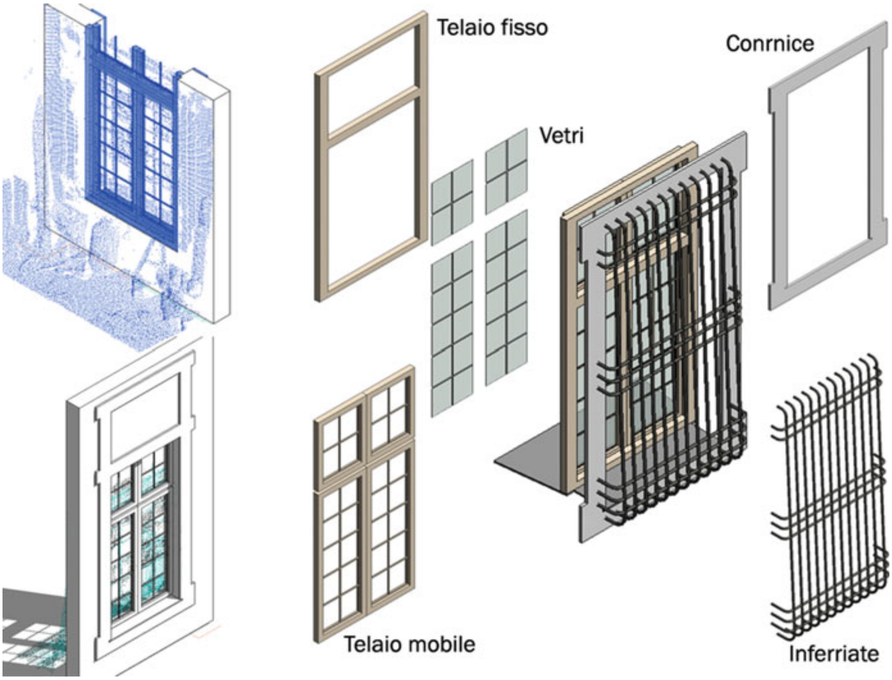

Fig. 1.5 3D modelling: external windows. The window, based on the single component elements, represents a parametric family. Each window could be modelled in its real size. (Babbetto, R., 2014)

- The evaluation of the behaviour of external environmental agents (damp, infiltration water, solar radiation) on the construction, also based on the real conditions of preservation and constructive characteristics
- The evaluation of comfort perceived by users
- The energy audit and definition of new demands regarding technical and normative specifications and the evaluation of their reliability through a comparison with real consumption
- The definition of technical solutions compatible with the preservation and effectively applicable, the identification of the impacts, and the evaluation of benefits implied in terms of savings

1.4.3 The Strategies

- Definition of the strategies of improvement of the thermal behaviour of the building through the combination of technical operations and the evaluation in terms of costs/benefits and of environmental sustainability

Fig. 1.6 (**a**, **b**) Processing of data acquired from indirect (archive) and direct sources. Representation of the constructive phases of the staircase leading to the *Albergo dei Poveri* (D'Andrea, M., Serpe, E. 2014. Post-graduate School in Architectural Heritage and Landscape, University of Genoa)

- Distributed generation strategies with the application of suitable plant engineering technologies, identification of possible "energy islands" that may be inserted into the overall system of intelligent networks
- Strategies of sustainable management of the energy system (regulation of methods of use, applications of Smart Management Energy System monitoring systems)

1.5 The Structure of the Book

The book is divided into two parts: the first part deals with theoretical and methodological issues and the second one describes the results of applied research on a historical monumental building which, because of its size and complexity of the problems involved, may be considered a paradigmatic example.

The theoretical and methodological approach is discussed from different points of view. In Chap. 2, Stefano F. Musso[1] enucleates, in a contemporary framework, the fundamental questions inherent the discipline of architectural restoration, opening to the most pressing problems related to the theme of environmental sustainability and enhancement. The authors of Chap. 3[2], which in most experiences have already been working in multidisciplinary teams, address the issue of the new European legislation, and explain the content and structure of the Guide elaborated within the AiCARR activities. Chapter 4[3] is focused on the thermal behaviour of historical buildings, the calculation methods, and their reliability and on the results for typical traditional building elements and their possible insulation.

The second part of the book discusses the methodology and research results applied to the case study, described in Chap. 5 in its general aspects and, in more detail in Chap. 6[4], as concerns materials and constructive characters. The Chaps. 7 and 8 constitute the core part of the feasibility study on energy efficiency, the results of which were included in the BIM parametric model. In particular in Chap. 7 are calculated the thermal behaviour of the building and energy needs for new uses, while in Chap. 8, the benefits induced by some insulating measures are calculated, and, moreover, the possible energy production through the installation microturbines (cogeneration) and of photovoltaic glasses on greenhouses in the valley behind the complex. These data are necessary to define the most suitable strategies to reach an energy balance or even to produce electricity to be placed on network systems. Finally, Chap. 9 deals with a topic of general, linked to the impacts on the historic heritage and landscape of solar technology and aimed at identifying factors that might qualify these delicate interventions.

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[3] Anna Magrini, full professor in Building Physics, teaches at the Post-graduate School in Architectural Heritage and Landscape of Genoa.

[4] Simonetta Acacia and Marta Casanova had a research grant to develop a GIS system for the complex itself. Both of them are Graduate in Architectural Heritage and Landscape.

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Chapter 2
Conserving–Restoring for the Future What We Inherited from the Past

Stefano Francesco Musso

2.1 The Reasons of Conservation–Restoration of Built Environment Today

For more than two centuries, Europe is discussing about the fate of what every generation inherited from the previous ones and tries to solve the related problems: ideal, doctrinal, theoretical, technical or pragmatic, and operational. A rich and wide literature, to which a large range of projects and interventions corresponds, attests this scientific, technical, aesthetical, historical, and "ideological" history that will never be declared concluded. The problem will in fact re-propose itself as life will go on, always enquiring which kind of relationships any new generation will establish with the relics and the material traces inherited from the past. It is also clear that the issues of conservation–restoration will remain meaningful in the future only if "a past" will continue to exist, producing remains, because, as Marc Augé suggests: *"future History will never produce again "ruins" but only rubble. It will not have enough time to do so"* (Augé 2003).

This also means that the central and crucial question in this perspective is: "Why do we conserve–restore?" or treat in different ways those material traces? And "why" can have at least two different and even mirrored meanings: it can evoke the reasons, or the causes, "because" we think or we do something, or it can refers to the aims "why" we do so, and to the aims we want to pursue of the objectives we want to reach by acting in that way.

As it happened during the past centuries, we will thus continue affirming that we want to preserve, maintain, conserve, or restore the fragments of previous ages and

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societies for different and sometimes mixed, contradictory, and conflicting reasons and aims, such as:

- to know, to discover, to understand, and to reveal—or to unveil—“what” is already clear and evident inside/within the material body of the ancient artefacts (embedded), or what is still hidden;
- to save, to take care of the existing artefacts by contrasting the effects of the injuries that they suffered along the past story and still suffer in the present;
- to consequently repair ancient or recent damages that have been caused by the unpredictable forces of nature or, more often, by men lack of care, distraction, ignorance, excessive needs, desires, and so on;
- to remember and therefore highlight, within the material fabric, anything we think could be important for our present but, even more, for our descendants and future generations;
- to celebrate, to remind, and to educate those who will look at those relics, thus improving our historical consciousness, our aesthetical and creative capabilities and sensibility and, finally, our “sense of beauty”;
- to use again the monument we are in front of, or to continue using it within a sort of historical continuity or with significant changes, so that it can be still part of our present and future life, urban scene, and landscapes.

The problem is that all these noble aims, sometimes deeply conflicting in between themselves, are often translated in really alternative actions and attitudes like, for example:

- to “complete” the ancient monuments, following the ideas and the suggestions by Eugène Emmanuel Viollet-le-Duc, thus discovering and rebuilding their lost unity in order to give them again a presumed or supposed original completeness, perfection, and splendour so that can still be able to speak, to teach, and to be really understood and comprehended by everyone;
- to “create and invent”, in this perspective, a new completeness, totally different from the original supposed one, basing our action upon the reasons and the rights of our present culture to leave its signs upon the ancient monuments, as any other previous age and generations made;
- to “correct or to erase”, in such a way, also the ancient or recent mistake, or what we consider bad and incorrect previous interventions of transformations and modifications carried on the buildings in the past;
- to even “ameliorate” those old artefacts, in order to raise their qualities and performances, or to preserve or to enhance their legibility, at least when they are conceived as a text, a palimpsest, a mine of knowledge and of information to be still discovered and metaphorically and concretely excavated.

These alternative but sometimes deeply mixed intentions and the correspondent actions are possible because conservation and restoration are not simply a matter of disciplinary discussion for some artists, scientists, technicians, architects, historians, scholars, or administrators, generically or directly involved in the responsibilities about the destiny of what we inherited from the past(s) and we call now

"Heritage", with all the contradictions that this word finally carries in itself. The pair conservation–restoration belongs in fact to the deepest roots of our societies and culture, affecting the life of the individuals and of the social communities, even if they are not always aware.

Of course, the answers we can provide too so many, various and conflicting questions and issues—in terms of ideas, values, concepts, tools, and intervention techniques—are theoretically and even pragmatically very different. On the other hand, we still work on them rightly to give answer to some fundamental needs that more than two centuries of debates and of real interventions on pre-existing architectures did not solved in a definitive way. This is the reason why they are continuously re-proposed in our present days and will be in the future as well.

2.2 A Brief Historical Profile of the Discipline

Since more than two centuries, as we already said, Europe is discussing about the fate of an impressive amount of ancient monuments, of poor but meaningful buildings, of urban fabrics, and of rural hamlets that fortunately survived from the past and still characterize our territories and built landscapes (Carbonara 1996; Conti 1980; Jokilehto 1999; Musso 1988, 2007; Torsello 1984). They are the fragments, remains, or relics of a material and spiritual legacy, irreplaceable traces of an ancient and sometimes unknown or forgotten history. They are not only something to be transmitted to future generations, for several reasons and also in view of a really "sustainable future" that can be achieved if we first of all do not waste for nothing the existing resources. Those traces and remains are also among the most important signs and expressions of our cultural and social identity (or better "specificity"). For these and other reasons, our monuments (ancient or recent, rich or poor) are not "mere buildings". They are more important than simple products of our ancestors' constructive capability. Churches, palaces, mills, warehouses, and farmhouses are first of all an incredible "mine" of knowledge, of "direct" and "indirect" information useful to understand the past but necessary also to imagine and design the future. Over the centuries and the decades, further on, the aims and the objects of architectural conservation and restoration have significantly enlarged, since their beginnings, moving their focus from limited individual and isolated buildings to towns, territories, built landscapes, or even widest systems of artefacts and to their relationships, thus coming to face new challenges.

Today, beside the conservation, the safeguard of the processes on the field, of the technological systems, of the traditional skills, and of the bodies of knowledge has become one of the main challenges for the scientific and cultural community. We are aware and conscious of the role that our "Heritage" (better to say our built environment) plays in improving the sense of identity or specificity and that of integrity of the individuals and of the societies, thus participating in the construction of the future though apparently only in indirect ways.

At the same time, some new and additional reasons to affirm and pursue the safeguard of our built environment have come to the fore. Among them we may highlight at least: the informative potential of ancient architecture, from which we can derive several interesting lessons about smart technological solutions to build in a more ecological and respectful way for the environment and the limited resources of our planet; the need for sparing resources (economic, energetic, territorial, human, social, environmental) because the energetic crisis and the fragile ecological situation of the Earth, also through the saving, recovery, recycle, and upgrading of existing buildings. After decades of interventions on existing architectures (not only "monuments"), moreover, it is now acknowledged that conservation or restoration interventions cannot be considered as arrival points for the life cycle of a building. They are delicate phases of its existence that may either positively or negatively affect its future and the need to be maintained on regular basis and with clear and documented methods and actions.

These new challenges do not mean that the old questions and issues have been definitely solved or that they have lost their relevance: the problems of "why?" and, consequently, of "how" to intervene on existing architectures maintain their actuality. The problem is that our theoretical reflections and technical tools do not always seem adequate to the present needs, also because most of the conservation discourse has been till now conceived to give the final prominence to the recalled opposite terms of "conservation", "preservation", and "care", on the one hand, or to "restoration", "renewal", "revitalization", or "upgrading", on the other hand. And, unfortunately, the conflict between these words has been frequently used to define and to decide the destiny of ancient buildings, monuments, towns, and cultural landscapes even if it seems very often exclusively an academic dispute.

We perfectly know, otherwise, that the contraposition between "conservation" and "restoration" is as ancient as the debate on the fate of architectural "Heritage" or "Patrimony". During the nineteenth century, the two recognized "fathers" of the modern "restoration theories" elaborated a propos two opposite ideas about the attitude and the behaviour to be adopted in relation with the traces of the past. Eugène Emmanuel Viollet-le-Duc clearly declared that restoration was a modern word for a modern thing and that: *restoring it is not preserving a building, but it could mean to bring it again to a state of wholeness that could have never been existed in a given moment...* (Viollet-le-Duc 1854–1868). With a completely different approach, but agreeing on the modern essence and origin of the problem, John Ruskin asserted that: *restoration is a lie; the worst lie which is accompanied by the destruction of the beloved artefact accompanied by the fake description of the destroyed thing…* (Ruskin 1849). The "restored" building, in fact, does not ensure in his mind the survival of the authentic ancient monuments for future generations. Ruskin thought in fact that restoration would change the monument in such a way that, at the end of the intervention, it would deal with the restorer's work, ideas, intentions, age, and culture and not with those of the men that created and transformed or modified it after the first construction.

We have to recognize, nowadays that the above-mentioned sentences by Eugene Emmanuel Viollet le Duc and John Ruskin clearly synthesize two antithetical ideas about what we would have to do of the ancient monuments, and those ideas still influence our debates, researches, and projects. Furthermore, all over Europe it is possible to identify more or less codified theoretical–doctrinal positions in accordance with (or in opposition to) Ruskin's or Viollet's thoughts, which left their traces on the materiality of our buildings and on their image, thus affecting the perception we have now of them. Some of the theories, or better reflections proposed after those first explicit assertions conditioned more than others some interpretations and treatment of our architectural "Heritage". We could thus try to synthesize what really happened afterwards by selecting some extreme and clear positions that of course do not exclude the existence and the importance of others intermediate positions.

We can therefore provisionally identify at least the following main theoretical–doctrinal proposals:

– the so-named stylistic restoration focused on the construction of a "history of styles", by using real-scale "exempla" and selecting those parts of a monument that are considered consistent with the prevalent architectural language recognized in the building as belonging to a same age and reconstructing what has been missing in order to complete its image, on the base of a comparative study and analysis[1];
– the presumed "philological restoration" (Giovannoni 1931, 1946) recognized the essence of the monument considered as a "document" and stated the necessity to valorize all the signs of succeeding phases of its history and status as are showed on its material body through a complex of formal, structural, and material stratifications that should be revealed and fixed in its image for didactic or pedagogical purposes;
– the so-called critical and creative restoration (Bonelli 1963), in its purest version, implied first of all the critical identification of the outstanding aesthetical values of a monument, its "true form" as the result of a genius's creation, and basing on this judgement stated the need of a "creative action" in order to free the "true form" of the monument that constitutes its image, by abolishing any incoherent and subsequent element that cancelled, modified, or transformed it;
– a parallel and more complex version of this approach brought afterwards to the fundamental definition of the treatment of the so-called lacunae, i.e. the voids existing within a figurative texture, in order to "re-establish" not the original and lost unity but only the "potential" one, still suggested by the survived and remaining parts of the masterpiece of art and thus deciding which instance should prevail between the "historical" and the "aesthetic" one[2] (Brandi 1963, 1977);

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[1] See, during the XIX C., in Italy, the works of some restorers as Alfredo D'Andrade, Carlo Maciacchini, and Alfonso Rubbiani whooften forced and misunderstood the ideas and the works by Viollet Le Duc giving life to the so-called stylistic restoration.

[2] See also the contributions by Walter Frodl and Paul Philipot who co-operated for several years with the School of Specialization in Restoration of Monuments in Rome, directed by Renato Bonelli, the Italian Central Institute for Restoration, founded and directed by Cesare Brandi, and then with ICCROM, contributing in diffusing the Italian positions about restoration.

- the usually identified as the modern "preservative approach" (or "Conservation School") gave then the greatest relevance to the permanence of the existing artefacts, recognized and "accepted" in their irreducible complexity and contradictory, with no aspiration in transforming the existing buildings to match a coherent idea of them but trying to safeguard all the past interpretations already embedded in the body of the monument and the possibility for future ones[3].

All these different positions in any case derive from different theoretical–doctrinal assumptions about History, Science, Technology, Arts, or human creativity and evidently lead to opposite ideas about "what to do" for the safeguard, protection, or enhancement of our built environment. The monuments that have been restored following those different ideas have afterwards influenced both experts and public and, today, we cannot ignore that our ideas about (and knowledge of) architectural "Heritage" have to take into careful consideration also their transformations occurred in the last two centuries.

In any case, what is now really important is to find a way to escape from the paralysing effects of these ancient conflicts. Different words, in fact, often hide different and even opposed intentions or actions. "What we declare" as our goals can thus bring to deeply different results that we cannot compare one to another, right because they cannot take place or exist simultaneously. While different words

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[3] At the end of the 80s of the past century, in Italy, the panorama saw the birth of a new disciplinary tendency within the field of restoration. Someone, belonging to the so-named Milanese School opposed to the overpowering presence of the so-named Roman School and proposed some new horizons and a new concept of what restoration could have been. The "Roman School", represented by scholars and professors like Giovanni Carbonara or Guglielmo De Angelis D'Osssat was the heir of the long and important tradition interpreted by Renato Bonelli and Cesare Brandi and, even before, by Gustavo Giovannoni. Within that intellectual tradition the influence of the neo-idealistic philosophical thought by Benedetto Croce was still predominant with all the consequences upon a vision of the monuments like masterpieces of art, aesthetically and figuratively examinable, valuable, and consequently treatable with a restoration aiming to free their "real form" (Bonelli), hidden by casual and insignificant transformations, or establishing again their "potential unity" (Brandi). In Milan, reacting to these positions, scholars, university teachers, and professionals like Marco Dezzi Bardeschi and Amedeo Bellini, immediately accompanied by Paolo Torsello and afterwards by many younger ones, gave life to a new tendency that, recalling Alois Riegl's, John Ruskin's, William Morris', or Max Dvorak's fundamental ideas and works, considered the ancient monuments as far as documents of their own history and, therefore, proposed to respect every traces of that complex history, without any preventive choice due to aesthetical, historical, or ideological assumptions. The debts towards the so-named New History (the "Nouvelle Histoire" funded by the French historians), the Culture History (or "materialist and archaeological culture", derived from the German term "Kulturgeschichte") and the most updated currents of the contemporary philosophical and epistemological thought were, in this case, very evident. Recently, that firstly very hard and almost irreducible contraposition has been almost completely exceeded, thanks to the efforts of many protagonists and we conquered, at least in Italy, the common consciousness of the irrepressible historical nature of any artefact derived from the past and, consequently, the idea that right this material consistency must be first of all respected and preserved. What to do beyond the primary needs for conservation, on the contrary, is still a hard and intriguing matter of discussion, above all regarding the possible construction of lacking parts or new necessary components of the monuments entrusted to our care.

or discourses can always coexist also provoking a productive dialogue, in fact, each single concrete action eliminates the possibility for any other to be realized or put in place. We can neither hope to definitely close the problem by looking for a general (or universal) agreement about the meanings of those different words. By elaborating about similar problems in the framework of the scientific research, Karl Popper (Popper and Notturno 1994) perfectly explained that this is just a myth, the "myth of the cornice". It is based on the fault idea that if a community firstly discusses to define the worlds they are going to use within its common researches, then it will be possible to really compare what each member of the community will say and elaborate. But, any attempt to define a "cornice" of such a kind will in any case use other words of uncertain or at least discussable meanings. The cornice will thus continuously enlarge along an endless process and no real common understanding and willing will be never acquired in such a way.

We have therefore to accept the irreducible opening of all the questions related to the conservation or to the fate of our built heritage and that this circumstance does not imply the impossibility to choose or to do anything, but it simply imposes the responsibility of a choice and not a chance to apply some superior rule, or behaviour code, because they simply do not exist. It is a good situation, perhaps, also because our landscapes, cities, and monuments are a complex whole of heterogeneous things, aspects, meanings, messages, and so on, the results of different or opposite actions, wills, intentions, needs, aspirations, and skills, and it is therefore a good practice not to reduce them to a stereotyped model. Monuments are also very often the random stratification of materials, forms, and traces of ancient uses that have been put together by the long river of an almost unknown history. We can only hope to be able to shed light on it and to reconstruct some fragments of this history, starting from its material remains and considering them as precious documents, direct witnesses of what has happened in the past ages and that nobody can entirely know.

Also for these reasons we cannot solve for ever the crucial problem of "what to do" for the future of our built Heritage, especially by reducing it to a mere struggle between the desire of a free territory for new unbound creativity and a strict respect for its existing situation. All our history, and certainly that of our cities and monuments, on the other hand, is deeply marked by constructive and destructive actions. Moreover, what we now consider as "Heritage" is only a small part of what other men built before us and an impressive number of subsequent generations co-operated to use and modify. "What to do" of this legacy or "inheritance" that our predecessors left us is a difficult and responsible choice for any generation, community, nation, and social group. Our choices will contribute in defining our identity or specificity, our place in the course of human history and civilization, and they should not be simply considered as a matter of technical discussion, but of a more profound cultural and ethical reflection and engagement. The destiny of our cultural, artistic, architectural, and environmental "Heritage" represents in fact a great responsibility for us that we cannot ignore or escape. Our descendants will ask us reason of our attitude and behaviour towards what they will rightly consider as their own proper Inheritance. For this reason, it is neither correct nor useful to continue asking why we cannot do what all other generations made before us, that is: using, consuming, changing, destroying, transforming, or modifying the buildings they received from the previous generations. We must in fact remember and acknowledge that, during the last two centuries, our world and culture knew such deep transformations that have never occurred before. Since the French Revolution, so many industrial, economic, social, and political changes have been so subverting the human world that we now live in a completely different environment, if compared with the one of our forefathers. Because of this, we are conscious that everything they built or made and left behind themselves is a sort of irreplaceable fragment of a lost world and a provisional legacy for ourselves that should be left to our descendants the more intact is possible. If we deplete or harm our landscapes, cities, and monuments, we cannot hope to re-create anymore of them in the future: they will be lost forever and nobody, after us, will ever have the chance to contemplate, to study, to use them any longer. In order to be effective in the safeguard of this legacy, we should overcome the simple struggle between the extreme terms of the traditional debate that continuously opposes those who always want to change, to modify, to destroy, and to substitute little fragments or large parts of our present landscapes, cities and monuments, and those who always hope to preserve everything. On the one hand, we cannot pretend to stop the course of natural and human events but, on the other hand, we have to choose, every time, “what to do” in front of the power of nature that tries to conquer again the products of human work and culture or in front of men willing to improve the environment and places where they live without any rule and constraints. In the difficult choice concerning the “if”, “why”, and “when” not to conserve a piece of our Heritage we must remember, in any case, that what we destroy will be lost forever and that according to Leon Battista Alberti: “*There is always available time to demolish, to level or to destroy any structure*” (1454). We do not know exactly nor completely what we deal with, we cannot say in a definitive way that a building, an urban area, or a landscape has no precious elements for the understanding of the past, for the use of its values and resources, but also for a better future. The destruction, but also a restoration that radically modifies the existing buildings and artefacts, in the unadvised attempt to re-create their lost configuration, could be a real and irreversible loss of chances and resources for the future, more than a simple loss as regards the past. That is the reason why we have to accept the destiny of death that belongs to every natural being and, consequently, to the men work products as well. This means that we cannot really “restore” a monument, at least if we intend for restoration the desire to go back into its history by modifying its materials, its spatial layout, its aspect or structural behaviour in the attempt to recover (or repropose) a lost condition. On the contrary, we must take care of that artefact, with a preventive surveillance, an effective and programmed conservation, and respecting all the signs that the passage of natural time and of human events have left upon its surfaces and inside its body, even if—or just because—we cannot completely know and understand them. Those signs–traces bear witnesses to the “true story” of the building (not necessarily a “monument”) and of the men that constructed, used, and modified it during the past ages, even if this “true story” is hidden and partly unknown. We have to "take care" of our monuments as precious sources of culture, knowledge, and technical skills, in order to contrast the threats and the actions that could damage or destroy them. We have to make all our possible efforts to ensure our built Heritage a longer life, always stopping ourselves in front of any temptation of transforming it in a sort of "fake" simulacrum or clone of itself. We cannot therefore simply or "a-priori" decide whether everything we inherited from the past must be "conserved" or "restored" (i.e. "preserved" or "modified, integrated, substituted"...), also because both perspectives cannot take place in the space and time of existence of the same generation. We must be conscious that where the care for conservation stops (because we decide it is impossible, not convenient nor viable to retain one particular building) the space of new design and of new Architecture begins. There is no space for any ambiguous mix between the needs of preservation and those of innovation. Where one stops the other begins, even if the boundaries between these two central activities are not always clear and easy to be defined and fixed. Afterwards, we have to decide if new and "never seen" forms must characterize the new architectures or if they could follow ancient rules or "reproduce already seen solutions and forms". This is, of course, a matter of discussion and every chance is the result of a free choice and not of an obliged behaviour. Therefore, if the choice of "how" to intervene on existing buildings is a matter of decision, we must assume all the responsibilities about it, renouncing to invoke metaphysical or legal reasons in order to diminish the role we play in determining the real impact of our ideas and proposals. We must moreover denounce in advance "what we gain" and "what we lose" when we adopt one or another solution. We also should select the options that minimize the losses and maximize the permanence of material sings, immaterial cultural meanings and values of the legacy we aim at safeguarding. This is neither a duty nor a metaphysical or a simply ethical law; it is a call for prudence and for a responsible and thoughtful action.

2.3 Methodological and Operational Issues and Tools

Though the above-mentioned problems could have as in the past various and different answers, any conservation/restoration enterprise usually respects some fundamental methodological steps, a sort of logic scheme, or a sort of flow chart that in any case asks frequent feedback procedures, in order to check its correctness and efficacy (or efficiency).

Concerning this topic, we could also recall a very ancient metaphoric or symbolic image of Architecture or of a building as a "body", a natural body. Leon Battista Alberti (1454) inaugurated the Renaissance adventure and the rediscovery of the ancient classical culture of Rome not to imitate it but to overpower right it by using this powerful "paradigm", as Françoise Choay qualified it (Choay 1980). One of the consequences of this theoretical concept is represented by the comparison we often propose between the activity of a physician and that of an architect, when this last intervenes on an existing monument that was built following forgotten rules and plans and that is now affected by unknown decay phenomena or structural diseases. It is not a modern metaphor. It was explicitly proposed and used by Leonardo da Vinci when he was asked to suggest a solution for the completion of the unfinished "*Duomo*" (Cathedral) of Milan and to propose the best form to be adopted for the flesh to be built completing the church. Leonardo (Bruschi et al. 1978)[4] proposed, right starting from Alberti's idea of the necessary "conformitas" (accomplishment) between the existing parts and the new ones of the building to adopt a light structure based on a square or octagonal plan in order to match the existing pillars of the dome and thus respecting the structural logic of the ancient gothic church. That was not the result of an academic, aesthetical, or simply architectural preference. As Leonardo clearly explained, in fact, it was firstly necessary to discover which were the rules of the good building practice, which the loads and the forces that ruled the existing construction and, consequently, which were the problems or the phenomena that put in danger the equilibrium or structural balance of the already-existing cathedral. Only thanks to this "naturalistic", scientific, and inductive method, it would have been possible to find the right solution: the medicine able to "recover" the "*malato* (sick) *Duomo*" respecting is constitution, its "sanity", its life and avoiding the risk to kill it, or to transform it in unacceptable (unnatural) way.

So, if we accept to use this ancient metaphor (conscious, of course, of its limits), we could individuate in our job at least the following schematic but fundamental phases, even if they do not always exist and follow each other in this specific unidirectional order: (a) analysis, (b) diagnosis, (c) anamnesis, (d) prognosis, (e) therapy, (f) prophylaxis. Other parts of the job follow the basic phases of inquiry, as we see, on the level of intervention, passing towards the crucial and not automatic moments of the interpretation of the analytical and diagnostic results. These new phases are represented by the design hypothesis (prognosis), their control, the definition of the project (the therapy: aims, tools, intervention techniques, technological, environmental, and economic requirements), and its realization in the construction site to end with the maintenance of the restored building.

The "anamnesis" is particularly interesting for us because it implies the attempt to reconstruct the history of the monument in order to understand "how" it was conceived and realized and afterwards changed, modified by men or by natural events, but also "how" and "why" it was used and consumed in the past. We are dealing with an "idea of history" that is quite distant from the traditional one and

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[4] Leonardo Da Vinci, *Lettera ai fabbriceri*. In the same volume, some other interesting texts are collected belonging, among the others, to Donato Bramante and Francesco di Giorgio Martini, always related to the problem of the completion of the flesh of the Milanese cathedral and, further on, the so-called Lettera addressed by Raffaello Sanzio (but probably witten by Baldassar Castiglione) to Pope Leone X about the state and the destiny of the ancient ruins in Rome. These writings are very interesting and explicit theoretical expressions about the problematic relationships existing between the protagonists of the birthing Renaissance culture and the medieval incomplete monuments or with the ancient classical ones they assumed as a reference legacy.

that expresses the evolution of the historical sciences and methods during the past century, particularly the birth and development of the so-named New History—Nouvelle Histoire (Braudel 1986, 1987; Bloch 1949; Le Goff and Nora 1974; Le Goff 1988, 1999; Fevre 1930) aside the traditional one. It was a new history defined as a "history as a problem", facing the ancient "history as a tale" and attentive to the "long duration" of some phenomena more than to the single outstanding "events" that signed the existences of the past generations and societies. It was a new concept of the historian's trade carefully intent in studying all the possible traces of the past, material and immaterial, tangible and intangible, descriptive and qualitative but also quantitative and apparently meaningless in themselves because their sense could exclusively emerge from the greatest series of single data considered under different and new perspectives. It was a method to reconstruct the unknown history of the past, ancient or recent, avoiding any preventive selections of data, any "a-priori" choice of a particular position within the rich offer elaborated on the level of the more general "Philosophy of History". Only this kind of historical research could allow reaching new cognitive borders thus contributing also to the development of the conservation/restoration issues. This intention to discover and recover the starting moment of the existence of the artefact and all its subsequent phases can and must use, in fact, different data and information sources: indirect, i.e. independent from the physical status of the monument (written documents, iconography or oral testimonies, and oral traditions), or direct, i.e. the monuments considered as the first and fundamental document of themselves. Right within this second perspective, our job inevitably interacts with all the analysis and the diagnostic tests that could be developed in order "to inquiry and to know" the building, in its present material state and consistency. Among these last methods we could briefly remember the: (1) architectural survey (executed with topographic, longimetric, photogrammetry techniques) intended to know and dominate, thanks to elaboration and restitution techniques, the "geometries" of the monuments (original and acquired, for construction mistakes or for structural assessments or changes, regular and irregular, intentional and casual—Torsello 1988; Musso 2016); (2) materials and decay phenomena identification (mineralogical and petrography characterization, physical and chemical analysis, biological, botanical, and zoological inquires...); (3) analysis and interpretation of the constructive techniques, throughout the instruments of the "history of culture" and of the archaeological methods applied to architectural standing structures (see apropos the experiences of the so-called medieval archaeology and Harris's stratigraphy); (4) structural analysis with specific interpretative numeric models or non-destructive tests. All these aspects, in fact, could be essentially used to understand the building as it is today but, above all, why it finds itself in its present status (i.e. the "anamnesis" phase of the inquiry, by the way). Any attempt to discover, reveal, unveil, and understand the monument, in this perspective, brings in any case our attention towards the reasons that determined its construction and subsequent existence, and this means that we have to look at the society that produced it, keeping again in consideration the crucial question about "why", we started from, even if in a different perspective but with not less important consequences on our job.

Another important aspect of our discipline (even if it is could not be exactly a discipline) is represented by the wide and urging theme of the protection and the valorization of our Heritage, that will bring us towards the impact it can have on the social, economic, and cultural context.

It is also necessary to remind that someone still doubts about the existence of possible general methods in this field, or at least he highlights the risks of misunderstanding about it (Torsello 2008). They usually argue, about the possible sense and the role that a method can have (provided that it exists) as regards research, teaching, and professional practice in conservation/restoration. By a bolted game of cross-references and comparisons with other domains of human knowledge and activity—not casually mainly regarding Medicine—they affirm that such a method does not actually exist and cannot really exist because one can teach how to analyse an artefact or how to choose and accomplish specific technical actions but nobody can really teach how to build a synthesis, while a project is eminently the result of a synthetic or "holistic" action and, by many aspects, a "creative" one. What we call methods, in the teaching of Architecture and—even more appropriately—in restoration seem thus to be frequently reduced to simple "ways of thinking or behaving" that each one of us adopts and would aim at taking in charge a wider and more universal role. Therefore, it is not a matter of a method universally recognized by a scientific community, but of an indistinct ensemble of ethical or ideological rules which call the risk to deepen the division existing between the different competences involved in conservation/restoration and to encourage a project to drift towards a misunderstood freedom, totally unbound from a rigorous knowledge of the artefacts of our Heritage in their real context.

2.4 Studies and Researches

Also for these reasons, the analytical and diagnostic apparatus have assumed a crucial role and importance for conservation and restoration. In this field, a common language developed during the last decades, with evident and appreciable repercussions at least as regards research and didactic. Some worries emerge, on the other hand, about the risk that a sort of consolidated "orthodoxy" can hide a sort of purely formalistic respect for some apparently inescapable rules, accompanied by a certain passiveness. In any restoration intervention, relevant technological devices often support the architectural surveys. The historical inquiries, grounded on strong critical apparatus, are very often rigorous and rich. The collections of diagnostic data concerning the physical state of the artefacts, as regards the constructive materials and techniques, or their state of deterioration/conservation, are meticulous, faithfully and punctually visualized and synthesized in "thematic maps" of sure communicative and perceptive impact. The use of "virtual simulations" of the interventions, on the built materials and on the structures and spaces of ancient architectures are diffused and refined. Also some complex structural studies and non-destructive testing and monitoring are frequently exploited, generally with the consultancy of experts belonging to different disciplines.

At least from this point of view, it thus seems that we have achieved some elevated common standard. Nevertheless, this achievement does not seem to solve all our problems, and it raises some doubts about the real efficacy of our actions, for the evident risk of a formal homogenisation to which an analogous strong presence in our activity does not seem to correspond, in a field that appears to be beset or endangered by other disciplines and professions. No scandal lays in this circumstance, of course, but far too often this condition does not prelude to an effective generalization of the attention to the conservation–restoration themes to the necessities and objectives by it postulated but, rather, it seems to announce a possible Heritage's misuse and depredation. Concerning this hazard, in fact, the apparent and soothing homogeneity of our technical apparatus can hide an uncomplaining or unconscious closure of our entourage as regards the transformation the world goes through, the world in which we operate.

2.5 Values, Impacts, and Consequences of the Conservation–Restoration Interventions

When we think of (or we deal with) the problems, the ideas and the aims of any conservation or restoration theoretical or ideal (ideological) positions and practical actions, we inevitably face the crucial theme of the values involved in the field.

It is not a novelty at all and already Alois Riegl (1903) deeply treated this conflicting and contradictory aspect of the matter at the beginning of the nineteenth century, asking to himself the reasons why his times were so deeply crossed by a new and powerful "modern cult for ancient monuments". While examining the phenomenon, he clearly outlined and analysed a wide and articulated range of values belonging to the dimensions of contemporaneity and of memory (of every time, of course). They were and still are values belonging to men and assigned by themselves to the ancient monuments, thus reflecting the changing in their cultural asset and atmosphere, along the times passing on. We could even now refer ourselves to those values, together with their complex games, in order to explain which the real contents of our discussions and actions are, within the field of the protection, conservation, restoration, and valorization of built Heritage. This last notion, in itself, is quite recent, and it represents the result of the long and rich history of the modern "theories" of restoration (if any theory really exists) from its right beginnings, between the eighteenth and nineteenth centuries, as many protagonists affirm: Eugène Emmanuel Viollet-le-Duc, John Ruskin, William Morris, Max Dvorak, Camillo Boito, or Gustavo Giovannoni, among the others. It is sufficient to recall, apropos, the important analysis by Francoise Choay (1992) developed about the birth and evolution of the idea of "Patrimony" from a concept of monument initially considered as a "masterpiece of art", an isolated and unique object mainly characterized by aesthetical or historical values and slowly arrived to the more complex concept of a monument as a cultural and not exclusively a material good that can also have outstanding social and economic values[5]. Any doubt should therefore exist about the crucial role that our ideas, concepts, and theories but also our analytical, diagnostic, and intervention techniques, in their whole, play in the contemporary world and society, even if with frequent contradictory and conflicting results.

Once again, the question "why do we conserve/restore?" emerges as the really crucial one, as regards any attempt to understand and correctly use our ideal and operational tools, above all if we look at the non-specialist world. Within this perspective, in fact, any attempt, desire, or compelling attitude towards the conservation/restoration of a material good derived from an almost unknown past, so that it could reach the future, should be explained, communicated, and hopefully accepted from the social communities we belong to, more than by the only cultural or scientific ones. Only in this way we could hope that this effort will be really culturally sustainable and will be felt as chance and not only as a load or a problem for our present situation looking to a better future.

2.6 The Specificity of Any Conservation–Restoration Project

The "project" always emerges when we deal with the topic and the issues of conservation/restoration of our built Heritage, raising profoundly different meanings and accents. On the other hand, we know "project" is a crucial crossroad for research, teaching, and above all professional practice, here and in other fields of human activity. Right for this reason, someone underlines the existence of deep differences between a "project" aimed at creating a new object/building and a "project" that has to do with an already-existing objects/buildings/sites. In fact, this last one can never just limit itself to be the mere sum of some functional modifications of the given reality but should primarily aim at "taking real care" of it, with its memories, material traces, explicit of hidden depots of knowledge and potentialities, in order to make it still useable for our present and future, in the most undamaged and undivided state—if ever enriched by new resources and not certainly impoverished of the already existing ones.

The project is doubtlessly a crucial point in the process of conservation/restoration. In this regard, we could certainly list endless reasons why project of conservation/restoration of an existing building/site is—and must be—different from that of a new one, therefore demanding different contents, tools, and forms. However,

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[5] See, a propos, all the international documents and the numerous International charters devoted to the problem of the destiny of ancient architectures, towns, and cultural landscapes but also to the huge legacy of immaterial goods of humankind in the contemporary world in the perspective of the future generations.

project will be just only one moment—even if fundamental—within the complex process of conservation/restoration and programmed management of our historic, architectonic, and environmental Heritage. Furthermore, the project will be for sure a moment that "only apparently" ratifies any provisional conclusion of the conservation/restoration process. Here an enormous risk really lies. At least two centuries of discussions, debates, and interventions, in fact, have not decided, neither the coming ones will do, which possible alternatives, concerning goals, objects, tools, and methods of the conservation/restoration project should or could be. Also for this reason, architecture and conservation/restoration often look like "poor neighbours", not communicating in between themselves, subjected to the perennial contraposition between the exaltation of free creativity and the research for the analytical rigour, among the tension for pure "knowledge" and the pressure of the professional pragmatism, in a time of deep and quick transformations of our world which would instead demand their profound and meditated integration. According to many scholars, in fact, the relationship between conservation–restoration and Architecture does not simply consist in their common affiliation to the same world of objects, methods, or instruments. Conservation and restoration are profoundly tied to Architecture firstly by their shared aim of inhabiting the world on an even keel, between memories of a past which can be still significant and productive and a future that must be free—but not oblivious—for us not to waste what the earth has given and still offers us.

The reference to the contemporary philosophical and epistemological thought, at this point, is the necessary background in order to correctly underline the need of a higher integration with the various disciplines involved in Architecture, even by facing the risk—that many dreaded—that this would end up in a loss of the centrality of the conservation/restoration matter and issues, wrongly considered as an autonomous, self-sufficient, and self-related world. We must on the contrary ask ourselves if our scientific, cultural, and didactic action can keep on being proposed as a sort of "pillbox defence" (or a "Ivory tower"), granted that it exists or should exist, or if it should rather necessary and useful opening up it for a confrontation in which our reasons would stand just because their own strength, instead of invoking weak protectionist or policies that are actually ignored or half tolerated by the society for the welfare of which some of us are invoking them (Musso 2008).

On the other hand, it also appears evident that the project, considered as a mere technical action tied to the artefacts and their fate, cannot be the only focal point of our research and teaching activity because a wide amount of new questions, themes, and objects are progressively emerging in this field. Moreover, this is true if we think of the difficult relationship that presently exists between Science and Technique where the second one is no more a tool to realize the previsions of the first one but it is going to begin more and more the goal of (and in) itself[6]. We must thus at

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[6] As regards the relationships and the respective roles of Science and Technique/Technology in the contemporary world see, in general, the most recent epistemological elaboration from Karl Popper to Hans Georg Gadamer, Francoise Lyotard, and Jürgen Habermas.

least consider with new attention the problems connected to the management phases or to the normative rules that closely concern conservation and restoration. Unless, we will reduce our activities to a mere search for more or less shareable technical solutions (accepted by many, or few, by a “school of thinking” or another) in the attempt of answering to some questions that have been already selected by “others”, elsewhere, before, and ignoring us (Stovel 2008). It is time to recognize that we cannot just restrict ourselves to the mere discussion or confrontation (sometimes hardly hostile) exclusively about “how” to technically intervene but completely ignoring “who”, “where”, and, first of all, “why” decides what must or can be conserved or restored (Della Torre 2008). By and large, we cannot simply ignore, forget, or avoid facing the many facets and implications which the issues of conservation/restoration imply at larger scales—urban, territorial, of entire built landscapes—exceeding each single artefact we take care of. Mainly at these levels, in fact, it seems clear that the themes related to conservation/restoration are now more than in the past profoundly entwined with the general processes that are conditioning or marking our communities and culture that are now immerged in a global and planetary dimension but that are still seeking for more or less certain identities (or, better, specificities) that, just as regards Heritage, should be deeply rooted and clearly expressed why they are demanding an active tutorship and defence (Morin 1999a).

2.7 Conservation–Restoration as an Open and Transversal Field

As already underlined, architecture in itself, from the very beginning of its history and considering Vitruvius’s treatise, is “interdisciplinary” and “multidisciplinary” (or even trans-disciplinary). It is not simply a matter of choice; it is just a compulsory status. Every building, even the simplest one, is the synthesis and complex result of different components, material and immaterial, physical and spiritual, local and universal. It is “a big thing” made of “little things”, till the borders of the atomic and subatomic universe (if we simply think of the decay phenomena that affect the ancient artefacts and involve us for their care). Architecture always stays on the difficult edge between the “World—and time—of Nature” and the “World—and time—of Culture” (J. Ruskin). It is a product of artifice (made with art), and thus it stays between the world of Sciences and Technique/Technology and the world Humanities and free expression or creativity (Garimberti 1999). As a discipline, looking at the knowledge’s organization proposed by the nineteenth century culture, Architecture is part of the “nomothetic” sciences, with their willing to predict and to explain the reality and its phenomena but, in the mean time, it belongs to the “ideographic” world of the disciplines that are mainly signed by the search for individual facts and the desire to inquiry, save, and improve all the human expressions and creations that could not easily be put under the dominion of the first ones (Cassirer 1973). Moreover, architecture is potentially overcrossing these borders right because it mainly deals with a different topic: "how do we like or want the things and the inhabited world would be", more than to simply explain why it will be so. For its own nature, architecture is thus an ideal field for a really "holistic" way of seeing, studying, and managing the world, taking advantage of any results of a good "reductionism"—that brings with itself also that extreme disciplinary specialization we are sometimes worrying about—but going beyond it in order to conquer a higher and synthetic level of comprehension and of acting capability, as any project and any building to be preserved or restored actually claims.

Moreover, according to Hans Georges Gadamer's thought (Gadamer 1960), architecture needs, and in some way instigates, a never-ending "hermeneutic circle" as for what regards its objects, their conception and ideation, their construction and following life cycle, because they register upon and inside the material body of any building all the human and natural events occurred during their existence and their consequences with regard to inhabitants' and direct or indirect users' lives.

For these and other reasons, if we consider our built Heritage (or better Inheritance), from the single monument to an old town or city centre, from a poor rural house to entire fragments of our cultural landscapes, we have to recognize that it is time to conquer a real "trans-disciplinary" approach in architecture and even more in Conservation–Restoration. We have to conceive and develop our future studies, researches, projects, and actions upon the results of the already-existing multidisciplinary and interdisciplinary attitude and capability in these fields (Morin 1999a, b). It is not easy, but we must elaborate new intellectual and practical tools, in order to face the challenges that the endlessly changing world will put in front of us within a global and sustainable dimension of any problem and of the future human existence. Finally, if this is true for architecture, it is even more meaningful and rich of potential consequences for what we identify as the Conservation–Restoration field. The recalled hermeneutic challenge and needs, on the other hand, are also a fantastic opportunity for our future, if we think of the immense richness of knowledge, capabilities, skills, secrets of the arts, and other information that are embedded and hidden in the physical and material bodies of the elements of our Heritage (or Inheritance).

Let us consider by the way how we are already used in speaking and dialoguing with experts of other disciplines, and how this also means that we have to be able to propose them our questions in correct ways (i.e. using the right language, terms, discourse structure, and so on). It is a quite common circumstance that an architect, while working in the conservation field, asks to an engineer about the structural stability or behaviour of some ancient buildings. In parallel, he would frequently demand to a chemist some information about the nature of a material that must be often analysed in its already transformed or modified status by the decay phenomena, thus obliging us to better understand also the causes and the possible evolution of the processes responsible for that condition. At this point, we could easily add more examples in this direction, but it is not necessary at all. Right for the condition or for the "essence" of a building, it is evident that the competences or the various disciplines potentially involved by our need of understanding what we are in front of and what we have to take care of, are very numerous. The problem is that this way of interrogating the experts is often reduced to a simple mechanism that does not ensure the quality of our studies. It is evident, on the one hand, that it is necessary to use specialist competences and that nobody in the world could even only imagine to possess every possibly required ones. On the other hand, perhaps, it is not sufficient to be prepared to propose the right questions to the specialist on a single problem or on a specific aspect of the Conservation/Restoration work. It is not just (or only) a matter of difficulty of communication on a linguistic level. More deeply, it is a problem of communication between different worlds that were born sometimes very far from each other, in terms of basic principles, tools, instruments and, moreover, aims and goals. A geologist will ever look at a stone sample, kept from an ancient wall, as to a simple fragment of the lithosphere of our geode. He will analyse it with the maximum possible care and attention, using the simplest or more sophisticated technical instruments but, at the end of his efforts, that sample will in any case remain a fragment of the marvellous and astonishing "Book of Nature", as Leonardo da Vinci suggested inviting man to open and carefully read it in order to discover and to interpret its secrets. Also a lichen is always a lichen, for a botanic expert, but we, as conservationists or restorers, have to understand "how" and "why" it does not represent any problem when it appears upon a masonry wall in the garden or when it affects a face of a marble statue, asking to be eliminated because it risks to damage it, or to be preserved because it protects it or even improves its picturesque aspect[7]. The architect, as the artist, the historian, and perhaps also a citizen, on the contrary, will consider that same material sample a trace of a past history, a fragment of the work and the fatigue, the capabilities, and the tastes of other men who built that wall or sculptured that statue, one time, or of other men that, after that first building act, probably modified that construction for various reasons and needs. This is exactly what anyone would like to discover and to understand in this perspective. This is also the real reason (even if not the only one) that urges all of us committed in this field to save, preserve, protect, and sometimes "restore" that wall, by operating upon its physical body, but also by asking ourselves which is our real goal and also "when" and at "what point" to stop our intervention not to waste more than what we could gain through our intervention.

The problem at this point is, once again, "how" we could or we should intervene on the elements of our cultural legacy (Torsello and Musso 2003). Before answering to this question, we nevertheless must remark that if what we said about the different attitude of a geologist and of a conservator–restorer is true, or at least reasonable (extending the observation to other parallel categories of scientists and experts, of course), then we have to make more and new efforts towards a real

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[7] This circumstance means, by the way, that also our ideas about the decay phenomena and their meanings as regards the needs of intervention are quite relative and absolutely not fixed or universally conceived.

"trans-disciplinary" attitude in our job (Morin 1999a, b). We need new tools simultaneously belonging to various existing disciplines, rather than to limit ourselves in using together those derived from the "pure" and "self-referential" world of a single sector of the present knowledge's organization. We have to share something between those disciplines, starting perhaps from the objects of interest and the goals of our common actions, more than use or compare our already existing and perfected (finished) ideas, methods, instruments, and goals. Only if we really begin working together, starting from new shared basis, we could hope to go further on beyond the enclosures that sometimes make our work difficult, weakening its results and limiting its interest to a closed group of people, thus vanishing its real and richest power for the common good. The same need emerges, beyond any analytical and diagnostic phases of our job, within the design phase, as already mentioned. It urges, actually, in any moment of the development of the intervention project and, after it, during the construction works and within the foreseeable life of the involved artefact through the conservation–maintenance programmes and management. In every phase, in other words, we need to confront ourselves with other experts or with the representatives of other disciplines. That's the reason why the analysis and the diagnostic inquires and tests are not mere preparatory steps for the design phase. They should in fact continue during the construction works, when new aspects of the building could be casually discovered or when new unexpected problems could suddenly and dangerously emerge. In this perspective, the need of cooperation is destined to continue and to reinforce. Also the maintenance and the management phases, even in the form of the possible valorization ("mise en valeur") of monuments and sites, ask this capability in using different competences. We have thus to teach and to show to our students, with our practice (didactic and professional), how to correctly use this kind of "trans-disciplinary" attitude or "mood". Once again, it is not simply a matter of choice: it is in some way a compulsory attempt for our future and for that of our built Heritage, for our historic towns and settlements, monuments, and cultural landscapes.

2.8 New Reasons and Challenges for Conservation–Restoration in the Future World

Conservation, after more than two centuries of history, debates, and interventions, is now in front of new and difficult challenges that cannot be faced by using the same arguments of the past, even if some of them are still true and useful. Our world is deeply and quickly changing, thus obliging us to renovate our instruments, tools, methods, and also the real reasons for our actions. In a globalized and "post-ideological" world, even if this last assertion is at least strongly arguable, we cannot continue using the traditional instruments that our fathers adopted in this field. We must also remember that two centuries of debate and experimentations were deeply and completely aroused in the Western World or—even better—merely

European (Glendenning 2013; Jokilehto 1999; Munoz-Vinas 2005). This long process, as it has been already highlighted, saw the appearing and the progressive consolidation of the opposite polarities of "Conservation" and "Restoration", up until the slow but consolidated process of expansion, "for kind, age of formation, for extension and quality", of the artefacts subjected to tutorship and safeguard. For this reason, we are now almost acquainted to think of a completely known and consolidated universe of subjects and objects although they seem to be progressively widening. New problems and artefacts, on the other hand, everyday emerge in front of us, asking for our attention and care, potentially making our world, that is rich of fragile certainties, explode or implode. Many journalists or scholars, politicians, or architects at this regard could remind, for example, the fatigue and disillusions while working in some troubled lands and parts of the world, where conserving can mean to have to deal not just and not as much with the technical or theoretical alternatives within which we often limit or constrain our work. This new situation would in fact imply to face wider horizons of sense for our behaviour and, in particular, it would call on the table the crucial problem of co-existence between people that are everyday fighting, each of them living and interpreting their living environment and its depots of signs and historic traces in very hostile ways. Not to speak about the dramatic situation of many human groups and communities with no State, no Land, no food or citizenship and for whom conservation, even before restoration, could assume very non-understandable meanings. We conserve, in fact, for a future world of civilization, cohabitation, and sharing of memories, values, and potentialities of life within a perspective of true freedom. Otherwise: why should we do it? For this and for other reasons, we cannot ignore similar questions and problems, pretending that they exclusively concern the political assets of our world, and that they are regarding our possibilities of acting. It seems that, instinctively, we think to ourselves as responsible only of some "jewels", which value we debate on but that for sure seek to belong to a world of consolidated peace, for which these problems seem to have no meaning at all, or that they have been already solved by others, throughout different fights during previous times. The situation is not exactly like it appears, even for us Europeans, and we have to acknowledge this simple fact. Being able to see through the curtains of approximation, we could thus discover that they could concern also the monuments or the artefacts belonging to our civilized countries and not only those in some world areas that seem to be perennially at risk of surviving because of the many conflicts and radical contrapositions affecting them and the entire humankind of nowadays. Not to forget or ignore the everyday more urgent demands derived from the need to protect our built environment and, within it, the more culturally significant artefacts, by the recurring risks of natural disasters, usually emphasized and worsened by human wrong actions and behaviours, like fires, floods, and earthquakes. Let us also think of the need of really making the "Heritage" something belonging to everyone. This also means to make it really universally accessible, in physical or in mediated ways, also thanks to contemporary ICT (Musso 2009a, b, 2011, 2014) for cultural goods and using all our true creative capability to look for innovative solutions, instead of stopping to the already experimented and consumed ones.

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Chapter 3
Energy Efficiency and HVAC Systems in Existing and Historical Buildings

Francesca R.d'Ambrosio Alfano and Livio de Santoli

3.1 Introduction

In many countries, and especially in Italy, where historic buildings are a consistent part of the building stock, the redevelopment of historic buildings is a priority and a cultural and technical challenge. It is cultural because it is operated on buildings that represent a historical document for their architectural and technological features, and it is technical because very often are required novel and advanced techniques compliant with the respect of the artefact and the constraints imposed by protection authorities.

One of the critical aspects of the energy improvement is just related to the constraints of protection, which often do not allow the intervention on the building and the system, where existing and running. Not to mention the installation a system from scratch, which could be considered an invasive and therefore not feasible procedure.

Another critical issue is the different responsibilities of designers and those involved in energy conservation and restoration, which often leads to misunderstandings related also to different linguistic codes. Finally, very often the techniques and technologies used for upgrading the energy efficiency negatively affect the cultural landscape.

In 2017, the European Standard EN 16883 "Conservation of cultural heritage—Guidelines for improving the energy performance of historic buildings" has been

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published, which prescribes the criteria to be used when you want to redevelop energetically a historic building (CEN 2017).

In Italy, in 2014 AiCARR published in his Series Guide “Energy Efficiency in historic building” (de Santoli et al. 2014), who wants to be a bridge between the designers and the conservatives and which aims to create a common language for the different disciplines involved. This Guide has been implemented by the Ministry of Culture which has included it in its Guidelines on Energy Efficiency in Cultural Heritage. This Guide is also the basis of the Federation of European Heating, Ventilation and Air Conditioning Associations, REHVA, Guide Book “Energy Efficiency in historic building”.

The European Standard EN 16883 contains Guidelines for energetic refurbishment of historic buildings. The document, written by experts in conservation and energy efficiency in historical buildings of all types and ages, defines an historic building as single manifestation of immovable tangible cultural heritage in the form of an existing building that does not necessarily have to be a heritage-designated building.

The scope of the Standard is to underline the peculiarities of historic buildings and the need of a careful and interdisciplinary analysis aiming to know how to optimize energy and conservation aspects. Each historic building has been considered as a particular case. To achieve this goal, the Standard presents a systematic approach or procedure which could not presuppose a need for energy improvements in all historic buildings. In Fig. 3.1, the iterative process for determining the best intervention is shown.

3.2 AiCARR’s Guide

The European Standard EN 16883 outlines the general approach to the historic buildings refurbishment and indicates the need to evaluate properly the energy aspects, the Italian contribute represented by the AiCARR’s Guide has been prepared by energy experts and contains more specific indications on the energy refurbishment.

AiCARR’s Guide consists of two parts. The first is addressed to the technicians of Authorities and contains general information about climatic issues, indoor air quality, building envelope and its plants, possible interventions, maintenance and, finally, the fundamentals on the economic analysis of energetic redevelopment. In the final sections of this part, AICARR tries to clarify energy saving issues by providing few, clear and unambiguous information to be easily adapted to the requirements and peculiarities of historic buildings, where also conservation has to be taken into account.

The second part is addressed to designers who are accompanied in the *path of knowledge* which is an unusual approach in the thermo-technical field. The path starts from the reading (also historic) of the context where the building is placed and its anamnesis, continues with the analysis of the degradation (assisted by aimed

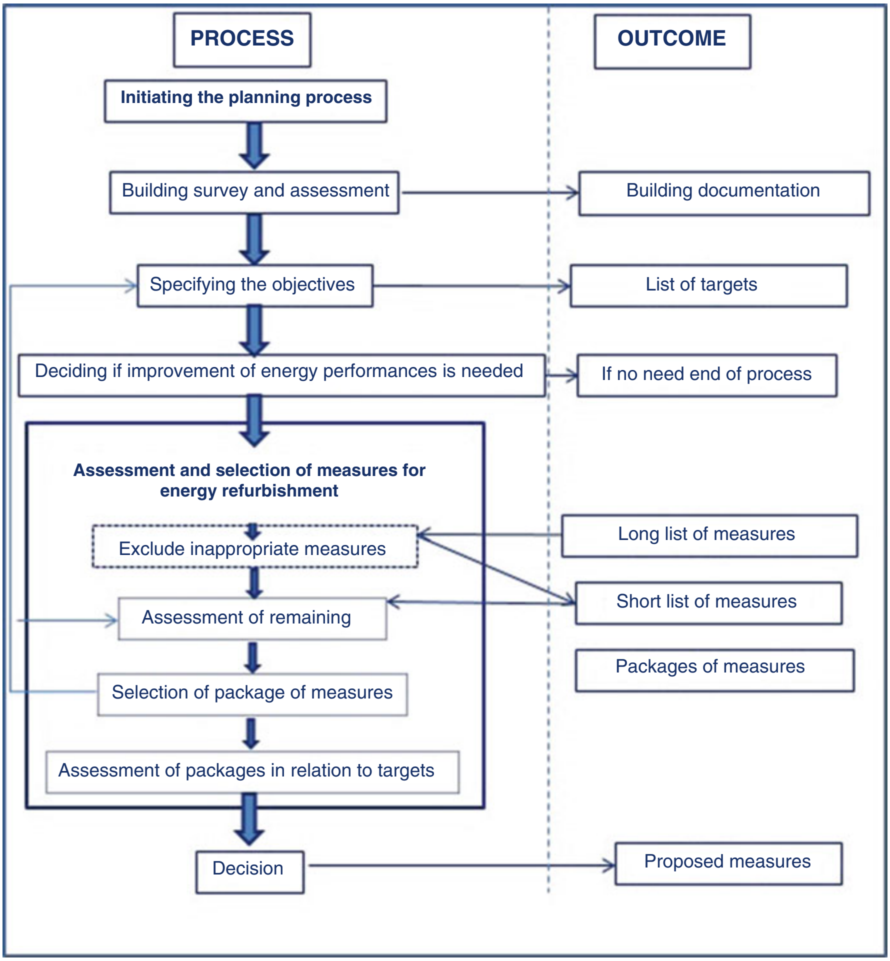

Fig. 3.1 The procedure for the evaluation of energy improvement in historic buildings

reliefs) and the study of the evolution of systems and proto-systems of the building, and finally arrives to the energetic diagnosis and the intervention to be implemented. This part also contains an in-depth analysis of technical issues on the type of possible interventions on the envelope and its plants.

In few words, the Guide gives to the institutions of preservation the knowledge on the technical criteria at the base of the energetic redevelopment and provides designers with all those information required for the energetic redevelopment of so special buildings as historic, where is not admitted the concept of repeatability (very used in the contemporary architecture).

Synthetically, the Guide sends two messages to designers interested on the energetic redevelopment of a historic building:

- The redevelopment is a part of the restoration, and the main goals are the conservation and the preservation of the artefact;
- The matter has to be handled with an interdisciplinary approach by following the above-described path of knowledge.

3.2.1 The Energy Efficiency As Preservation Tool

The energy redevelopment of historic buildings should be considered not only an answer to the need of energy efficiency in construction, but also a tool for the conservation and the preservation. In this sense, all design solutions should be agreed with conservation specialists, and designers should be taken into account the criteria fixed by the Venice's Charter for the Conservation and the Restoration of Monuments and Sites (ICOMOS 1964) which are very important and valuable tools for the attainment of the goal of conservation (compatibility, minimal intervention, reversibility, distinguishability, expressive authenticity, durability, and respect of the original tissue). Moreover, it is very important to stress the role played by the relationship between restoration and plants, which is often ignored at theoretical and practical levels in favour of the binomial restoration-structural reinforcement.

Over the past years, the debate in the structural field focused on historic-critical and technical-scientific processes for the structural reinforcement in restoration has produced a well-established standardization. This is the reason why the Guide aims to propose a unitary method also for the attainment of the energy efficiency of a cultural good. This is especially because the connection between restoration and plants is affected by a culprit delay in disciplines, laws, and regulations although the need to take into account the plants as an integral part of restoration and all above-discussed criteria (compatibility, minimum intervention, reversibility) is a well-established matter (Ministero della Pubblica Istruzione 1972).

From this point of view, the Guide introduces the concept of "improvement" in antithesis to "adaptation", formulated on the basis of an "integrated conservation" (AA.VV 1975).

3.2.2 HVAC Systems in Historical Buildings

HVAC systems in historic buildings are often obsolete unless in case of ordinary, extraordinary, or preventive maintenance interventions. The best solution is the replacement or, at least, the modification by adopting all technologies and systems aimed to improve the energy performances. In some cases, the plant is a cultural good to be protected being a witness of the past. In this case, it has to be valourized and recovered with high care and, if possible, it should be made functioning. This is the case of the not many known, but very interesting site of San Leucio (Italy) in Fig. 3.2, which has been inserted in the World Heritage List and where is placed the

Fig. 3.2 San Leucio's complex

"Bagno di Carolina" traceable to the ancient Roman baths. When a HVAC system with historic value and restrictions is restored, the thermo-technical designer has to consider the path of knowledge, and interact not only with conservators but with all Cultural Heritage experts. In fact, the analysis of historic artefacts is an integrated process where the designer plays a very important role but is not the leader.

This also occurs when a new system is installed, and the interaction between designers and Cultural Heritage experts is aimed to avoid damages. The case of replacement or modification of an existing plant is easier. Anyway, it is necessary to take into account all historic, architectural, and functional restrictions that make inadvisable or impossible some typologies of intervention. The maintenance has to be also considered. In fact, the Italian Code of the cultural heritage and the landscape. (Italian Government 2004) firstly introduced this concept in the Italian legislation for the conservation of the architectural heritage. In particular, as part of a broader concept of "conservation planning", it states that the Ministry should draw up guidelines, directives, and objectives also in this specific field.

The code requires that the maintenance of the plants is mandatorily required at design level; it has to be embedded within the general maintenance plan, and it has to be compatible with the proper maintenance over time of the entire building. To ensure the proper maintenance, meeting the constraints and needs of conservation is not enough. In fact, the designer has also to ensure regular access to parts of the plant that do not require routine maintenance (e.g. hydronic and aeraulic ducts, electric systems). In addition, a special care has to be devoted to the control the chemical physical characteristics and the behaviour of new materials during time to avoid the occurrence of phenomena not compatible with the proper life of the old building.

3.2.3 *Thermal Insulation of the Envelope of Historical Buildings*

Concerning the energy performances of the building envelope, most common interventions are those aimed to reduce the thermal transmittance (consequently, the heat transfer with the outdoor environment) of transparent (horizontal, vertical, and inclined) and opaque components by using special technologies or materials. Implementing this strategy in historic buildings is not easy mainly due to the strong interferences with the external and internal architecture of the artefact.

3.2.4 *AiCARR's Procedure to Improve the Energy Efficiency in Historical Buildings*

According to above-mentioned issues, a right energy diagnosis coupled with a technical-economic analysis are not enough to choose the proper intervention of qualification. On the contrary, conservation facets and possible historic and architectonic restrictions should be carefully considered. To this purpose, AICARR proposes the procedure schematized in Fig. 3.3. The procedure requires some preliminary actions for a correct energy audit. In a second phase, the energy performance of the building, Ep, and all possible actions for its improvement (with related Ep' value) should be assessed. Only those interventions effective for obtaining interesting and tangible results will be considered. These will be studied extensively to define the best one from the energy and conservation points of view. Obviously, in this final phase is necessary a strict cooperation with the conservator.

3.2.5 *Energy Efficiency and Cultural Landscape: A Tool to Assess Their Integration*

Sometimes, solutions judged as effective to improve the energy performance of an historic building can strongly affect also the cultural landscape: this is the case of historic centres. It is necessary to avoid this occurrence by operating those solutions consistent with the architectonic and landscape integration. In this case, the improvement proposition has to be carefully calibrated. This means that, in some situations, the architectonic integration will be incomplete to avoid interventions, which distort both the building and the landscape. Unfortunately, this occurs when the historic building is forced to be adapted to the energy efficiency legislation in the same manner of a new building.

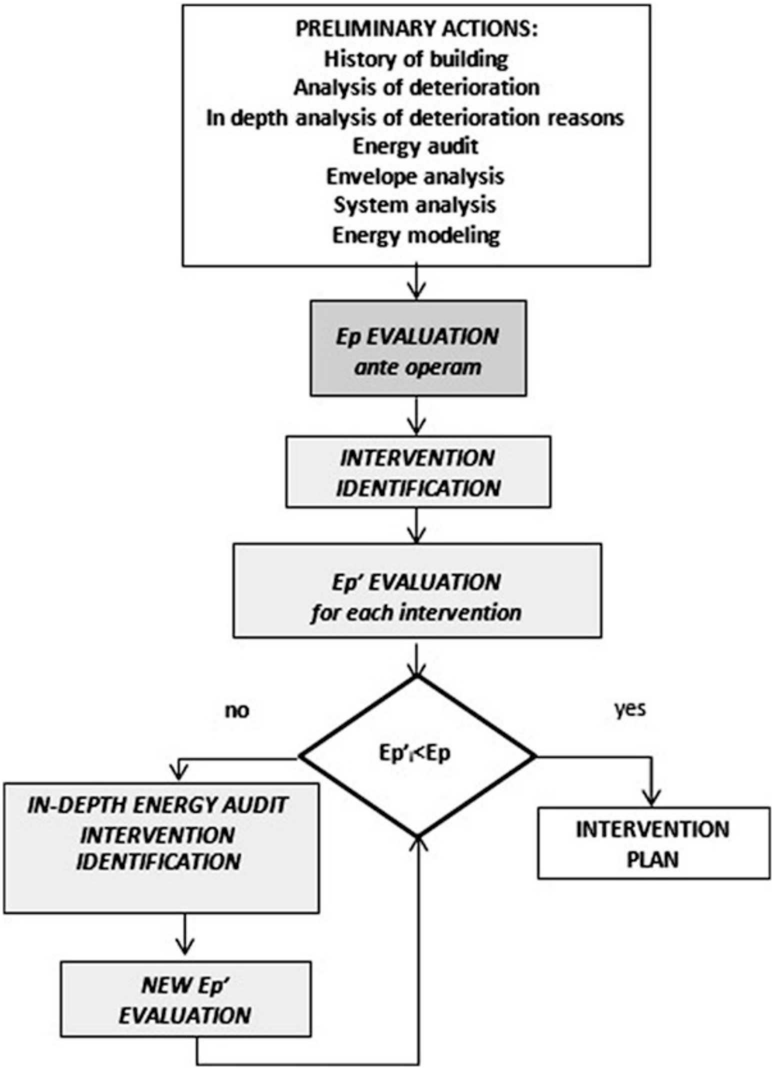

Fig. 3.3 Flow chart of the procedure proposed by AICARR for the improvement of the energy efficiency of historic buildings

In these cases, it would be necessary to provide each typological element of the building with a scale of intervention according to the following criteria:

- Technological level of replacement of the elements of the building and the plant;
- Landscape perception from the morphological, chromatic, and formal points of view.

Table 3.1 Datasheet for the preliminary assessment of the integration with the landscape

			Levels of integration			
				Landscape		
Scale	Typological element		Technological	Formal	Morphological	Chromatic
Architectural micro-scale building-place-construction	Roof	Opaque walls				
		Transparent walls				
	Facade	Opaque walls				
		Transparent walls				
	Plants					
Meso-scale square-blok-neighborhood	Roof					
	Facade					
	Plants					
Macro-scale territory	Roof					
	Facade					
	Plants					

Level of integration ○=partial; ●=full

To this purpose, AICARR's Guide propose the datasheet reported in Table 3.1, which has to be filled by the designer to obtain a first screening on the acceptability of the project. This means that can be presented only with those interventions characterized by a partial integration level, at least. The datasheet is useful also for the superintendents as it allows the assessment of the compatibility of the redevelopment proposition with the integration requirements of the landscape.

3.3 Conclusions

The energy redevelopment of a historic building is a delicate matter, which has to consider not only engineering facets, but also historic and architectural constraints and the conservation requirements of the artefact. From this perspective, neither traditional energy diagnosis nor solutions based on design criteria adopted for other buildings (according to regulations and standards under force) should be considered. Each building has to be dealt as a "unique case" requiring the strict cooperation with the authorities of conservation. This allows the identification of the intervention of improvement consistent with the energy saving, the conservation and integration with the cultural landscape requirements.

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Chapter 4
Thermal Behaviour of Historical Buildings, Materials and Components: Methodological Framework, Calculation, Results

Anna Magrini

4.1 Introduction

The energy-saving target, in the refurbishment of historical buildings, should be considered a fundamental element for their reuse, as the running costs may represent a significant economic problem especially for the public administrations that in Italy are widely located in these representative buildings (Magrini and Franco 2016, Franco et al. 2015, Magrini et al. 2015).

The absence of regulatory minimum requirements for the energy performance of historical buildings doesn't mean that they must not be considered as a target and that some actions cannot be evaluated in terms of technical feasibility in respect of the architectural and historical constraints. This kind of buildings is used also as home or it hosts representative institutions, trade-banks, and other private enterprises. Their high maintenance costs, especially for heating or cooling systems, may determine a progressive moving of the activities to less expensive buildings: the ancient buildings risk to be subdued to a progressive degradation without an active role in the social context. The reduction of the energy consumption can be designed by means of wall insulation.

However, actions on the building envelope are difficult to realize and, in any case, they must be evaluated with care: thermal insulation, when applicable, may cause worse hygrometrical behaviour of the walls. Moreover, it may be useful a good thermal insulation designed jointly with the evaluation of the thermal inertia influence on the heat transfer behaviour (Magrini 2016, Magrini et al. 2013).

In the following, the calculation method of the energy performance of buildings is outlined, and some relevant parameters of the opaque envelope are highlighted. Some definitions and fundamental concepts, on which the calculations to be carried

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out are based, are briefly summarized. The application of the calculation methods is supported by examples. Some common historical building walls are considered, and the calculation of their thermal features is performed. The application of an insulating layer on the existing structures is evaluated. The choice of three insulating materials is proposed, taking into account both their thermal and hygrometrical behaviour.

4.2 The Calculation Method of the Energy Performance of Buildings

The Directive 2010/31/EU (Directive 2010) of the European Parliament and of the Council on the energy performance of buildings indicates requirements regarding the common general framework for a methodology for calculating the integrated energy performance of buildings. It shall be determined on the basis of the calculated or actual annual energy that is consumed for the heating and cooling energy needs and domestic hot water needs.

Among the aspects taken into consideration by the methodology, there are: thermal capacity; insulation; passive heating; thermal bridges; the design, positioning and orientation of the building, outdoor climate; passive solar systems and solar protection; indoor climatic conditions; internal loads. Also the positive influence of the local solar exposure conditions should be taken into account.

The measures to ensure that minimum energy performance requirements for buildings may not be applied to “buildings officially protected as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance”.

The methodology for calculating energy performance takes into account the existing European Standards. In the EN ISO 13790 Standard (Energy performance of buildings—Calculation of energy use for spaces—heating and cooling), two approaches for the design and evaluation of thermal and energy performance of buildings are indicated.

The calculation methods can be:

- quasi-steady-state methods to obtain the heat balance over each month or a whole season, taking into account dynamic effects by the simplified determination of an utilization factor
- dynamic methods that perform the heat balance over short time steps and take into account the heat storage properties of the building

The methodology provides calculation procedures to obtain the energy need for space heating and cooling by means of a monthly quasi-steady-state calculation method, a simple hourly dynamic calculation method; and detailed (e.g. hourly) dynamic simulation methods.

Referring to the first method, for example, the building energy need for space heating, $Q_{\mathrm{H,nd}}$, in conditions of continuous heating, is calculated by:

$$Q_{\mathrm{H,nd}} = Q_{\mathrm{H,ht}} - \eta_{\mathrm{H,gn}} Q_{\mathrm{H,gn}} \tag{4.1}$$

where

$Q_{\mathrm{H,nd}}$ is the building energy need for continuous heating, assumed to be greater than or equal to 0 [MJ].
$Q_{\mathrm{H,ht}}$ is the total heat transfer for the heating mode [MJ].
$Q_{\mathrm{H,gn}}$ gives the total heat gains for the heating mode [MJ].
$\eta_{\mathrm{H,gn}}$ is the dimensionless utilization factor.
and the total heat transfer, $Q_{\mathrm{H,ht}}$, is given by:

$$Q_{\mathrm{H,ht}} = Q_{\mathrm{tr}} + Q_{\mathrm{ve}} \tag{4.2}$$

where Q_{tr} is the total heat transfer by transmission and Q_{ve} is the total heat transfer by ventilation.

Focusing the attention on Q_{tr}, it depends on the temperature difference between indoor and outdoor environment (t_{i}–t_{e}) on the heating or cooling time period τ and on H_{tr}, the overall heat transfer coefficient by transmission, determined by:

$$H_{\mathrm{tr}} = H_{\mathrm{D}} + H_{\mathrm{g}} + H_{\mathrm{U}} + H_{\mathrm{A}} \tag{4.3}$$

where each term represents a heat transfer coefficient by transmission:

H_{D}: direct heat transfer coefficient by transmission to the external environment [W/K]
H_{g}: steady-state heat transfer coefficient by transmission to the ground [W/K]
H_{U}: transmission heat transfer coefficient by transmission through unconditioned spaces [W/K]
H_{A}: heat transfer coefficient by transmission to adjacent buildings [W/K]

For the first two approaches (quasi-steady-state and simple hourly dynamic methods), the basic physical data must be the same while, for the detailed simulation methods, the compliance with steady-state properties needs to be demonstrated.

Some of the most important features of the building envelope are considered by means of the transmission heat transfer coefficients H_{D}, H_{g}, H_{U}, or H_{A}. Indicating each of them generally as H_{x}, they can be calculated through the following expression (EN ISO 13789):

$$H_{\mathrm{x}} = b_{\mathrm{tr,x}} \left[\sum\nolimits_{\mathrm{i}} A_{\mathrm{i}} \cdot U_{\mathrm{i}} + \sum\nolimits_{\mathrm{k}} l_{\mathrm{k}} \cdot \psi_{\mathrm{k}} + \sum\nolimits_{\mathrm{j}} \chi_{\mathrm{j}} \right] \tag{4.4}$$

where

A_i is area of the i-element of the building envelope [m^2].
U_i is thermal transmittance of the i-element of the building envelope [W/(m^2 K)].
l_k is length of the k-linear thermal bridge [m].
ψ_k is linear thermal transmittance of the k-thermal bridge [W/(m K)].
χ_j is point thermal transmittance of the j-point thermal bridge [W/(K)].
$b_{tr,x}$ is adjustment factor for the external temperature; it has to be applied when the envelope element borders on a space which has a different temperature than external environment

4.3 Main Parameters for the Thermal Characterization of Walls

For the assessment of the heat transfer coefficient H_x, the thermal transmittance of the building walls U and of the thermal bridges ψ must be defined. The EN ISO 6946 provides the method of calculation of the thermal transmittance of building components and building elements. It is determined by the calculation of the thermal resistance of each thermally homogeneous layer of the component that depends on its composition and thickness. Also surface heat transfer coefficients and air layer thermal resistances can be calculated according to the values defined by the EN ISO 6946 Standard.

4.3.1 Thermal Transmittance

The thermal parameters of the building envelope may be really hard to define in the case of historical buildings: the wall composition usually is not well known.

If it is possible to assume the thermal conductivity of the wall materials and their thickness, the thermal resistance of each layer can be calculated as:

$$R = d/\lambda \tag{4.5}$$

where

d is the thickness of the material layer in the component.
λ is the design thermal conductivity of the material (calculated or obtained from tabulated values).

The total thermal resistance, R_T, of a plane building component, characterized by thermally homogeneous layers perpendicular to the heat flow is calculated as the sum of the thermal resistances of the single layers as:

$$R_{\mathrm{T}} = R_{\mathrm{si}} + R_1 + R_2 + \ldots.R_{\mathrm{n}} + R_{\mathrm{se}} \tag{4.6}$$

where

R_{si} and R_{se} are the internal and external surface resistances, respectively.

R_1, $R_{2,}\ldots$ R_{n} are the design thermal resistances of each layer.

Finally, the thermal transmittance U [W/(m^2 K)] is obtained as:

$$U = 1/R_{\mathrm{T}} \tag{4.7}$$

A methodology to evaluate the heat transmittance of a building wall by means of in situ measurement is indicated in the international Standard 9869, based on the use of the heat flow meter (HFM) and thermometers.

The sensor measurements must be registered over a period of complete days. The minimum test duration is 72 h (3 days) if the temperature is stable around the HFM. Otherwise, it may last more than 7 days.

The U-value can be obtained by dividing the mean density of heat flow rate by the mean temperature difference.

Some difficulties may be encountered in the installation of the apparatus because the sensors must be mounted in an area representative of the whole element; they should not be under the direct influence of either a heating or a cooling device or under the draught of a fan. The outer surface of the element should be protected from rain, snow, and direct solar radiation.

4.3.1.1 Example: Thermal Transmittance Calculation

Given a wall structure with its layers' characteristics and thermal properties, it is possible to calculate the thermal transmittance U. In Table 4.1, the calculation details are reported, with reference to three common wall structures that can be found in historical buildings (brick and/or stone wall). Maintaining the same thickness, the U-value is significantly different in the four layouts, and therefore the knowledge of the wall composition is an important element for the thermal energy calculations.

The thermo-physical properties (ρ, material density in kg/m^3, λ, thermal conductivity in W/(m K)) of the materials are taken by the Italian national standard UNI 10351 "Building materials and products—Hygrothermal properties. Procedure for determining the design values", and it is assumed that the surface resistances are referred to horizontal flux through a vertical wall (Fig. 4.1).

4.3.2 Thermal Bridges

A thermal bridge is considered "part of the building envelope, where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of

Table 4.1 Example of thermal transmittance evaluation for historical building common walls

(a) Brick wall layer	d [cm]	ρ [kg/m^3]	λ [W/(m K)]	R [m^{2}K/W]
Internal surface resistance				0.13
1. Internal plaster	3	1400	0.70	0.04
2. Composite layer: Brick	80	1800	0.72	1.11
3. External plaster	3	1800	0.90	0.03
External surface resistance				0.04
Total resistance R_{T} [m^2 K/W]				1.36
Thermal transmittance $U = R_{\mathrm{T}}{}^{-1}$ [W/(m^2 K)]				0.74
(b1) Brick (60%) and stone wall layer	d [cm]	ρ [kg/m^3]	λ [W/(m K)]	R [m^2 K/W]
Internal surface resistance				0.13
1. Internal plaster	3	1400	0.70	0.04
2. Composite layer: Brick (60%) and stone	80	2080	1.40	0.57
3. External plaster	3	1800	0.90	0.03
External surface resistance				0.04
Total resistance R_{T} [m^2 K/W]				0.82
Thermal transmittance $U = R_{\mathrm{T}}{}^{-1}$ [W/(m^2 K)]				1.22
((b2) Brick (20%) and stone wall layer	d [cm]	ρ [kg/m^3]	λ [W/(m K)]	R [m^2 K/W]
Internal surface resistance				0.13
1. Internal plaster	3	1400	0.70	0.04
2. Composite layer: Brick (20%) and stone	80	2360	2.06	0.39
3. External plaster	3	1800	0.90	0.03
External surface resistance				0.04
Total resistance R_{T} [m^2 K/W]				0.63
Thermal transmittance $U = R_{\mathrm{T}}{}^{-1}$ [W/(m^2 K)]				1.58
(c) Stone wall layer	d [cm]	ρ [kg/m^3]	λ [W/(m K)]	R [m^2 K/W]
Internal surface resistance				0.13
1. Internal plaster	3	1400	0.70	0.04
2. Composite layer: stone	80	2500	2.40	0.33
3. External plaster	3	1800	0.90	0.03
External surface resistance				0.04
Total resistance R_{T} [m^2 K/W]				0.58
Thermal transmittance $U = R_{\mathrm{T}}{}^{-1}$ [W/(m^2 K)]				1.73

the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions" (EN ISO 10211).

In general, the hypothesis of mono-dimensional heat flow through this element is not correct since it causes two-dimensional or three-dimensional heat flows. In order to take into account the incidence of a thermal bridge in the transmission heat transfer coefficients calculation, the linear thermal transmittance ψ [W/(m K)] is

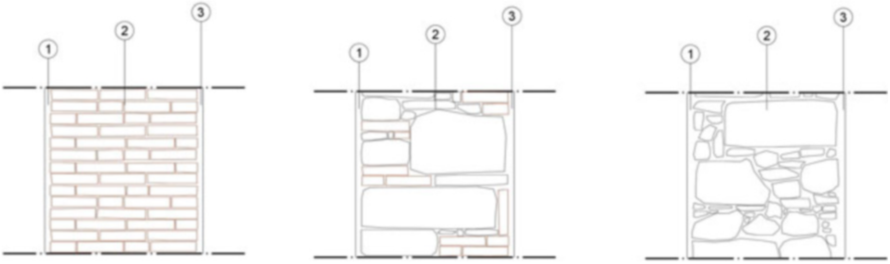

Fig. 4.1 Example of stone and/or brick wall

used. It can be defined as the heat flow rate in steady-state conditions, divided by the length of the junction and by the temperature difference between internal and external surfaces.

As shown in the Eq. (4.4), thermal bridges have a significant weight on the heat flow rate calculations and the internal surface temperature, and therefore their influence on the envelope energy performance assessment must be correctly evaluated.

In the past, a "thumb rule" usually applied to take into account the presence of thermal bridges was represented by 20% U-value increasing, even if their influence, in some cases, could be also around 30%. Actually, it is possible to determine its linear thermal transmittance through numerical methods, indicated in the EN ISO 10211 Standard.

The definition of a geometrical model of a thermal bridge for the numerical calculation of heat flows and surface temperatures is outlined, considering that:

- all physical properties are independent from temperature.
- there are no heat sources within the building element.

Reference values could be used for some standard structures referring to a catalogue of thermal bridges and values of ψ (EN ISO 14683) in relation to some different geometrical dimension, as follows:

ψ_e: linear thermal transmittance determined according to the external dimensions, measured between the finished external faces of the building external elements [W/(m K)]

ψ_{oi} linear thermal transmittance determined according to the overall internal dimensions, measured between the finished internal faces of the building external elements including the thickness of internal partitions [W/(m K)]

ψ_i: linear thermal transmittance determined according to the internal dimensions measured between the finished internal faces of each room in a building excluding the thickness of internal partitions [W/(m K)]

National regulations in some cases allow to assume the indications given by thermal bridges catalogues. Some information can be taken by the "Catalogue des ponts thermiques" (OFEN 2003) and in the "Abaco dei ponti termici" of Regione Lombardia (Regione Lombardia 2011).

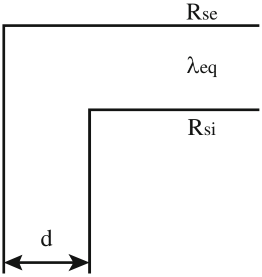

Fig. 4.2 Example of a thermal bridge (vertical corner without thermal insulation)

Table 4.2 Linear thermal transmittance ψ_i of a corner for three historical building common walls

Wall structure	d [m]	U [W/(m^2 K)]	λ_{eq} [W/(m K)]	ψ_i [W/(m K)]
Brick wall	0.86	0.74	0.72	0.29
Brick (60%) and stone wall	0.86	1.22	1.32[a]	0.48[b]
Brick (20%) and stone wall	0.86	1.58	1.85[a]	0.66[b]
Stone wall	0.86	1.73	2.10[a]	0.75[b]

[a] Value out of the range of applicability

[b] The probability that the estimate of ψ_i falls within the confidence interval may be lower than 95%

4.3.2.1 Example of Linear Thermal Transmittance Evaluation

From the last catalogue, an example of a common thermal bridge for a corner, that can be applied also in the case of historical buildings is shown in Fig. 4.2. Its linear thermal transmittance can be calculated as indicated in Table 4.2. The values reported in the catalogue are valid for typical wall thicknesses of existing buildings. They are not always suitable for the wall thicknesses of ancient buildings. Therefore in some cases, the probability that the estimated linear thermal transmittance falls within the confidence interval may be lower than 95%.

The linear thermal transmittance ψ_i [W/(m K)], determined according to the internal dimensions, can be calculated as:

$$\psi_i = 0.064 - 0.073\,U + 0.358\,\lambda_{eq} \tag{4.8}$$

where

$$U = \left[R_{si} + \left(d/\lambda_{eq}\right) + R_{se}\right]^{-1} \ \left[\mathrm{W}/\left(m^2 K\right)\right] \tag{4.9}$$

d = thickness of the whole wall [m]

λ_{eq} = conductivity of the whole plane wall structure as if it were constituted by a single layer [W/(m K)]

Range of applicability:

$U = 0.47 \div 2.09$ W/(m^2 K)

$\lambda_{eq} = 0.23 \div 0.81$ W/(m K)

Confidence interval IC: IC$_i$ (95%) = ± 0.02 W/(m K)

4.3.3 Dynamic Thermal Characteristics of the Envelope

The dynamic thermal characteristics of the envelope that can be considered in the energy performance evaluation are indicated in the EN ISO 13786 Standard. Among the parameters that can be used to outline the effects on the heat storage of the building envelope, there are:

- the periodic thermal transmittance Y_{ie} [W/(m^2 K)], defined as the amplitude of the heat flow rate through the component surface adjacent to a zone which is kept at constant temperature, divided by the amplitude of the temperature in the adjacent zone (which also could be the external environment).
- the decrement factor f, expressed by the ratio between the periodic thermal transmittance Y_{ie} [W/(m^2 K)] and the quasi-steady-state thermal transmittance U [W/(m^2 K)]. It represents the effect of the envelope on the inward heat flow rate,

$$f = \frac{|Y_{ie}|}{U} \tag{4.10}$$

- the time shift $\Delta\tau$, defined as the period of time between the maximum amplitude of a cause and the maximum amplitude of its effect, helps to evaluate the envelope influence on the thermal behaviour.

An example of the values obtained following the methodology reported in the EN ISO 13786 Standard are resumed in Table 4.3, showing the highest time shift Δt value for the stone wall that is characterized by the maximum value of surface mass m_{s}. In this case, the high thermal transmittance U means high heat flux through the wall, while its thermal inertia produce a relevant effect reducing the outdoor climate variations and maintaining the indoor thermal conditions scarcely influenced by the external ones. Regarding the periodic thermal transmittance, it should be maintained low in the regions with high solar radiation to make the best use of the wall inertia against the overheating during daytime.

As an example, in the existing building refurbishment (not mandatory for the historical ones), the Italian National legislation indicates upper limits of the U-value for vertical walls varying from 0.24 to 0.43 W/(m^2 K) depending on the climatic zone.

Table 4.3 Example of dynamic parameters evaluation for three historical building common walls

Wall structure	d [m]	U [W/(m^{2}K)]	m_{s} [kg/m^2]	Y_{ie} [W/(m^2 K)]	f	Δt [h]
Brick wall	0.86	0.74	1536	0.003	0.003	30
Brick (60%) and stone wall	0.86	1.22	1760	0.012	0.009	24
Brick (20%) and stone wall	0.86	1.58	1984	0.022	0.014	22
Stone wall	0.86	1.73	2096	0.027	0.016	21

Moreover, for locations where the average monthly value of the irradiance on the horizontal plane is greater than or equal to 290 W/m^2 at least one of the following conditions on all the opaque vertical walls must be verified:

- the surface mass, m_s, $>230\ \text{kg/m}^2$
- the modulus of the periodic thermal transmittance $Y_{ie} < 0.10\ \text{W/(m}^2\ \text{K)}$

The typical historical building walls usually are characterized by high U-values and therefore the mean heat losses are high, in the heating period. On the contrary, their inertia is very high (high thermal mass and low dynamic thermal transmittance) and then the climatic variations affect less the internal climatic conditions, in the cooling period.

The evaluation of the dynamic thermal behaviour of the envelope can be performed by means of transient building simulation models, which consider the heat storage in the structure and the time dependence of boundary conditions.

The quasi-steady-state methods are considered approximatively affordable to represent the thermal behaviour of buildings during the heating season, but not in other periods of the year. In this case, a transient model is suitable to have more detailed results.

As the cooling energy needs have been increased during the last years, the European Directive 2010/31/EU indicates to adopt strategies to enhance the thermal performances also during summer period. Higher attention must be put on the thermal properties, which influence the internal overheating, such as heat thermal capacity, specific mass, periodic thermal transmittance, time shift, and decrement factor. In particular, the minimum requirements according to the climatic conditions have to be fixed at national level: it represents a priority for the countries of the Mediterranean area, where the dynamic envelope features to reduce the cooling energy needs have to be evaluated with attention because it represents an interesting resource.

4.3.4 Vapour Transmission Through Walls

Several aspects related to the presence of water may affect building structures, such as capillary rise of water in the walls, condensation inside building components due to infiltration of indoor air (hot and humid), problems with tightness to rainwater, salts migration inside materials, and hygrometric surface problems (growth of mould and moisture condensation). A further problem is linked to the moisture transfer through the building envelope because it can meet such a low temperature as to cause its condensation. The phenomenon takes place generally in building materials because they are normally permeable to water vapour.

The moisture transfer through a wall depends not only on the thermo-physical features of the wall layers, but also on the internal and external thermo-hygrometric conditions.

Usually, the historical building walls have such thermal properties that do not allow interstitial condensation. However, the hygrometric assessment of historical building components presents considerable practical interest when the reuse and the possible change of the building use is planned. Therefore, for example, it is useful to determine if the operating conditions may lead to a progressive deterioration of the structures. Moreover, if measures for energy performance improvement are considered, as the thermal insulation is often allowed only on the internal face of the wall, the risk of moisture problems can be increased.

The condensation phenomena may be relevant as they generally occur easily in the case of internal insulation applications. In this case, in the interface between the internal face of the existing wall layer (brick or stone layer) and the insulating material, liquid water can damage the insulating material thermal properties, such as its thermal conductivity, making useless its application.

Degradation of the building structures and unhealthy environments can be the consequences of these phenomena, such as:

- growth of fungal colonies on the inner surface of the building envelope
- presence of condensed water on the surface and inside of the walls
- decay of wooden structures
- plaster degradation
- reduction of the thermal insulation
- dimensional changes and damage of artefacts
- salts migration, efflorescence

The International Standard EN ISO 13788 indicates a method for the assessment of moisture problems in the walls, simplifying the complex physical behaviour and neglecting the interaction between moisture and heat transfer.

The methodology considers the moisture transfer through a wall as a function of inside and outside temperature and humidity conditions, and of dimensional and thermo-physical characteristics of its layers. In the Standard also surface phenomena, due to high values of internal relative humidity and low surface temperature of the walls are considered and an evaluation method is described.

To evaluate the risk of interstitial condensation, the graphical method, known as Glaser method, is proposed, referring to the monthly mean values of the climatic data. Material thermal properties and layer thicknesses must be estimated; the temperature and the internal moisture production must be calculated or assumed by the building use.

The water vapour pressure and the saturation pressure trends are compared through the wall layers. The saturation pressure P_s [Pa] can be calculated as a function of the temperature distribution within the layers by means of the following expressions:

$$t \geq 0°\mathrm{C} P_s = 610,5\ \mathrm{e}^{\frac{17,269 \cdot t}{237,3+t}} \tag{4.11}$$

$$t \geq 0°\mathrm{C}\, P_\mathrm{s} = 610{,}5\ \mathrm{e}^{\frac{21{,}875 \cdot \mathrm{t}}{265{,}5+\mathrm{t}}} \tag{4.12}$$

The vapour pressure P_v [Pa] on the external and internal surface of the wall depends on temperature and humidity. It can be expressed as function of the saturation pressure $P_\mathrm{s} = f(t)$ and the relative humidity φ [−]:

$$P_\mathrm{v} = \varphi P_\mathrm{s} \tag{4.13}$$

In absence of condensation, the trend of P_v can be represented by means of the Fick's Law. The vapour flow rate per unit area g'_v through *a* is related with the difference ΔP_v between the vapour pressures of the air on its surfaces. Assuming steady-state conditions, g'_v [kg/(m^2 s)] can be expressed as:

$$g'_v = \delta_\mathrm{o} \Delta P_\mathrm{v} / s_\mathrm{d} \tag{4.14}$$

where

δ_o = reference vapour permeability of air = 200×10^{-12} kg/(m s Pa)
$s_\mathrm{d} = d\ \delta_\mathrm{o}/\delta$ [m]
d = layer thickness [m]
δ = vapour permeability [kg/(m s Pa)]

From a graphical comparison of the two trends, if the vapour pressure reaches the value of the saturation, there is condensation.

The standard indicates that the assessment is positive if both the following two criteria are met:

- the calculation (usually on a monthly basis) demonstrates that any condensation can be completely dry throughout the year.
- the condensation in a layer does not exceed the limit values of the materials involved.

4.3.4.1 Example: Interstitial Condensation Risk Evaluation

The calculation procedure indicated in the EN ISO 13788 Standard can be briefly summarized by means of a case study represented by a brick (20%) and stone wall. With a thickness of 40 cm, it can represent the wall below the windows in a historical building: the application of an insulating layer on the internal side may be considered a measure to reduce heat loss (Table 4.4).

The calculations are referred to the environmental conditions indicated in Table 4.5. The internal moisture production may be considered low, corresponding to offices, dwellings with normal occupancy and ventilation (as indicated in EN ISO 13788); therefore, the internal vapour pressure is defined as function of the external vapour pressure and temperature:

$$P_\mathrm{vi} = P_\mathrm{ve} + 100 + [(540 - 100)/20](20 - t_\mathrm{e}) \tag{4.15}$$

Table 4.4 Thermal properties of an insulated brick (20%) and stone wall

Layer	d [cm]	ρ [kg/m^3]	λ [W/(m K)]
1. Plasterboard and surface finishing	1.5	900	0.21
2. Insulating layer	2–12	40	0.036
3. Internal plaster	3	1400	0.70
4. Composite layer: brick (20%) and stone	40	2360	2.06
5. External plaster	3	1800	0.90

Table 4.5 Internal and external climatic conditions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
t_e [°C]	10.2	10.3	10.9	15.1	18.5	22.2	24.4	23.4	22	18	13.1	9.8
P_{ve} [Pa]	918	782	812	1109	1333	1804	2033	1806	1691	1276	1021	808
t_i [°C]	20	20	20	20	18.5	22.2	24.4	23.4	22	18	20	20
P_{vi} [Pa]	1234	1095	1112	1317	1466	1856	2036	1831	1747	1420	1273	1132

The calculations are executed for each month starting from the first month of the heating season and verifying that condensation doesn't occur. On the contrary, it would be necessary to proceed backwards with the search of the first month of condensation. Starting with the month of October, the surface temperatures t_{pi} and t_{pe} and each t_x [°C] at the x interface between layers are calculated by the following expressions:

$$t_{pi} = t_i - (t_i - t_e)R_{si}/R_T \tag{4.16}$$

$$t_{pe} = t_e + (t_i - t_e)R_{se}/R_T \tag{4.17}$$

$$t_x = t_{x-1} - (t_i - t_e)R_x/R_T \tag{4.18}$$

where each $R_x = d/\lambda$ value is indicated in Table 4.6, where the calculations are developed referring to the thermal properties of mineral wool ($\rho = 40$ kg/m^3).

Starting from the assumption that there is no condensation and therefore the vapour flow rate through the wall is constant, the two surface values can be connected by a straight-line segment in a plot P_v vs. s_d. Analytically, the vapour pressure of each interface is calculated according to Fick's law:

$$g'_v = \delta_o(P_{vi} - P_{ve})/s_{dtot} = \delta_o(P_{v,x-1} - P_{v,x})/s_{d,x} \tag{4.19}$$

In Table 4.7, the calculations for 1 month (January) are indicated, and in the plot of Fig. 4.3 the comparison between P_v and P_s is shown. The two lines do not cross; therefore, there is not the risk of interstitial condensation. However, in the interface

Table 4.6 Calculation details for the wall

Layer	d [cm]	λ [W/(mK)]	R [W/(m^2 K)]	δ (10^{-12}) [kg/(m s Pa)]	s_d [m]
0. Internal thermal resistance R_{si}			0.13		
1. Plasterboard and surface finishing	1.5	0.21	0.071	23	0.13
2. insulating layer	10	0.036	2.78	193	0.104
3. Internal plaster	3	0.70	0.043	18	0.33
4. Composite layer: brick (20%) and stone	40	2.06	0.194	11	7.27
5. External plaster	3	0.90	0.033	18	0.33
0. External thermal resistance R_{se}			0.04		
Total resistance R_T [m^2 K/W]			3.29		
Total equivalent thickness s_{dtot}					8.17
Thermal transmittance $U = R_T{}^{-1}$ [W/(m^2 K)]			0.30		

Table 4.7 Vapour and saturation pressure calculation

Interface	R [W/(m^2 K)]	s_d [m]	t [°C]	P_s [Pa]	P_v [Pa]
			20	2337	1234
0–1	0.13	0	19.6	2282	1234
1–2	0.071	0.13	19.4	2252	1229
2–3	2.78	0.104	18.6	2138	1228
3–4	0.043	0.33	11.0	1312	1212
4–5	0.194	7.27	16.5	1881	1525
5–0	0.033	0.33	10.4	1262	931
	0.04		10.3	1254	918

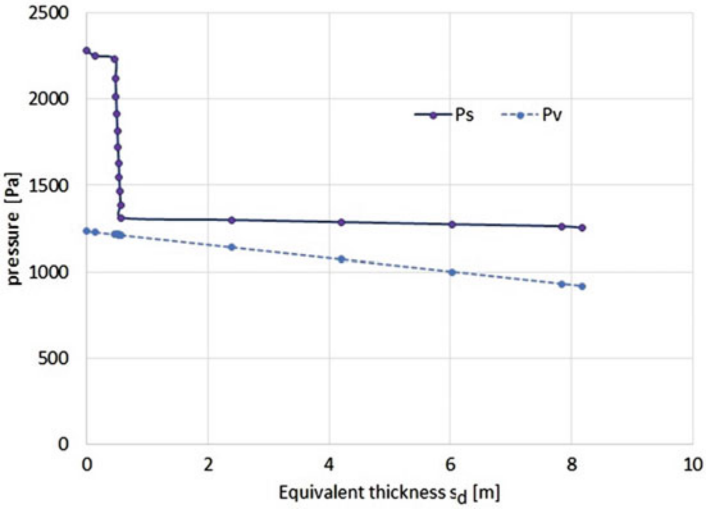

Fig. 4.3 Glaser method: comparison between the vapour pressure and the saturation pressure calculated with the climatic conditions of January

between the insulation layer and the existing wall, the difference between the vapour pressure and its upper limit, represented by the saturation pressure, is small. If higher moisture content would be taken into account for a different use of the building, the calculation will lead to condensation. In this case, the need of a vapour barrier on the internal face of the insulating layer should be considered.

4.4 Some Typologies of Walls and Their Characteristics

The thermal parameters of some typologies of historical building walls are presented, indicating thermal transmittance, thermal mass, periodic thermal transmittance, time shift, and decrement factor.

In Table 4.8, the wall typologies and their parameters are reported. For the calculations, surface thermal resistances indicated in EN ISO 6946 Standard are applied. The variables indicated have the following meaning:

d = thickness [cm]
ρ = density [kg/m^3]
λ = thermal conductivity [W/(m K)]
c = specific heat [kJ/(kg K)]
U = thermal transmittance [W/(m^2 K)]
m_s = specific mass [kg/m^2]
Y_{ie} = dynamic thermal transmittance [W/(m^2 K)]
$\Delta\tau$ = time shift [h]
f = decrement factor [−]

Note: the plaster thickness from 3 to 6 cm on the external side produce a U-value variation lower than 5%.

4.5 Thermo-Hygrometric Analysis in the Energy Refurbishment

The overall energy consumption of a building is influenced by factors such as the geometry, the orientation, the presence of opaque and transparent surfaces, their characteristics, the heating system, and the location in the urban area. Some of them cannot be changed under renovation, and therefore they represent constraints to the improvement of building energy performance. In addition to them, the limits due to the preservation of the characters of the building, its historical architectural and artistic value are elements that reduce the possibilities to obtain good energy performance. However, the effort to realize the maximum energy saving must be one of the targets of the restoration to allow a sustainable management of the building.

Table 4.8 Thermo-physical parameters of some historical building walls typologies

01 BM—brick masonry wall					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick	25–100	1800	0.720	1000	
3. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 25 – 3	1.686	546	0.407	10.3	0.242
3 – 38 – 3	1.292	780	0.118	15	0.091
3 – 51 – 3	1.048	1014	0.034	19.8	0.033
3 – 64 – 3	0.881	1248	0.010	24.5	0.011
3 – 77 – 3	0.760	1482	0.003	29.2	0.004
3 – 90 – 3	0.737	1716	0.001	34	0.001
3 – 103 – 3	0.650	1950	0.00	38.7	0.00
02 BM—brick masonry wall					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick	25–100	1800	0.720	1000	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 25	1.786	492	0.513	9.42	0.287
3 – 38	1.350	726	0.148	14.2	0.110
3 – 51	1.086	960	0.043	18.9	0.04
3 – 64	0.908	1194	0.012	23.6	0.014
3 – 77	0.780	1428	0.004	28.4	0.005
3 – 90	0.684	1662	0.001	33.1	0.002
3 – 103	0.609	1896	0.00	37.8	0.00
03 BSM—brick (60%) and stone masonry wall					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick (60%) and stones	30–100	2080	1.390	1000	
3. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 30 – 3	2.165	720	0.46	10	0.212
3 – 40 – 3	1.873	928	0.22	12.9	0.117
3 – 50 – 3	1.651	1136	0.105	15.7	0.064
3 – 60 – 3	1.476	1344	0.05	18.5	0.034
3 – 70 – 3	1.334	1552	0.024	21.3	0.018
3 – 80 – 3	1.217	1760	0.012	24.2	0.009
3 – 90 – 3	1.119	1968	0.006	27	0.005
3 – 100 – 3	1.036	2176	0.003	29.8	0.003
04 BSM—brick (20%) and stone masonry wall					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick (20%) and stones	30–100	2360	2.060	1000	

(continued)

Table 4.8 (continued)

04 BSM—brick (20%) and stone masonry wall					
3. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 30 – 3	2.552	804	0.561	9.3	0.22
3 – 40 – 3	2.271	1040	0.295	11.7	0.13
3 – 50 – 3	2.045	1276	0.155	14.2	0.076
3 – 60 – 3	1.861	1512	0.081	16.7	0.044
3 – 70 – 3	1.706	1748	0.043	19.1	0.025
3 – 80 – 3	1.576	1984	0.022	21.6	0.014
3 – 90 – 3	1.464	2220	0.012	24	0.008
3 – 100 – 3	1.367	2456	0.006	26.5	0.004
05 SBR—masonry wall in stone and brick rows					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick and stones	30–100	2000	0.900	1000	
3. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 30 – 3	1.72	696	0.295	12	0.171
3 – 40 – 3	1.45	896	0.12	15	0.083
3 – 50 – 3	1.247	1096	0.049	18.5	0.039
3 – 60 – 3	1.095	1296	0.020	22	0.018
3 – 70 – 3	0.977	1496	0.008	25	0.008
3 – 80 – 3	0.88	1696	0.003	29	0.004
3 – 90 – 3	0.80	1896	0.001	32	0.002
3 – 100 – 3	0.74	2096	0.001	36	0.001
06 SIC—stone masonry wall with inner concrete					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Brick	12	800	0.720	1000	
3. Concrete	5–20	1500	0.700	1000	
4. Brick	25	1800	0.720	1000	
5. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f
3 – 12 – 5 – 25 – 3	1.20	467	0.255	11.5	0.212
3 – 12 – 10 – 25 – 3	1.12	542	0.163	13.2	0.147
3 – 12 – 15 – 25 – 3	1.026	617	0.104	14.8	0.102
3 – 12 – 20 – 25 – 3	0.956	692	0.067	16.5	0.070
07 SM—stone masonry wall					
Layer	d	ρ	λ	c	
1. Internal plaster	3	1400	0.700	840	
2. Stone blocks	40–100	2500	2.400	1000	
3. External plaster	3–6	1800	0.900	840	
Layers thicknesses	U	m_s	Y_{ie}	Δt	f

(continued)

Table 4.8 (continued)

07 SM—stone masonry wall					
3 – 40 – 3	2.42	1096	0.32	11.4	0.132
3 – 50 – 3	2.2	1346	0.173	13.7	0.079
3 – 60 – 3	2.01	1596	0.093	16	0.046
3 – 70 – 3	1.86	1846	0.051	18.4	0.027
3 – 80 – 3	1.73	2096	0.027	20.8	0.016
3 – 90 – 3	1.61	2346	0.015	23.1	0.009
3 – 100 – 3	1.51	2596	0.008	24.5	0.005
08 SM—stone masonry wall without finishing					
Layer	*d*	ρ	λ	*c*	
1. Internal plaster	3	1400	0.700	840	
2. Stone blocks	40–100	2500	2.400	1000	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
3 – .40 – 3	2.63	1042	0.456	10.55	0.173
3 – 50 – 3	2.37	1292	0.247	13	0.104
3 – 60 – 3	2.16	1542	0.133	15.2	0.062
3 – 70 – 3	1.98	1792	0.072	17.6	0.036
3 – 80 – 3	1.83	2042	0.039	20	0.021
3 – 90 – 3	1.70	2292	0.021	22.3	0.012
3 – 100 – 3	1.59	2542	0.011	0.65	0.007
09 FR—flat roof					
Layer	*d*	ρ	λ	*c*	
1. Internal plaster	3	1400	0.700	840	
2. Reinforced concrete slab and brick	16–24	900	0.24	1000	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
3 – 16	1.14	186	0.641	6.6	0.564
3 – 24	0.824	258	0.252	10.2	0.306
10 FR—flat roof					
Layer	*d*	ρ	λ	*c*	*R*
1. Internal floor layer	2	1700	1470	1000	
2. Lime mortar	3	2000	1.40	1000	
3. Wooden plank	3	710	0.180	1000	
4/5. Secondary wooden beams + air gap	25–40				0.180
6. Plasterboard + finishing layer	1.5	900	0.21	840	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
2 – 3 – 3 – 30 – 1.5	1.60	129	1.21	3.4	0.754
11 FR—flat roof					
Layer	*d*	ρ	λ	*c*	*R*
1. Internal floor layer	2	1700	1470	1000	
2. Lime mortar	3	2000	1.40	1000	
3. Wooden plank	3	710	0.180	1000	
4/5. Secondary wooden beams	25–40	–	–	–	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
2 –3 – 3	2.69	115	2.28	2.52	0.847

(continued)

Table 4.8 (continued)

12 FR—flat roof					
Layer	*d*	*ρ*	*λ*	*c*	*R*
1. Internal floor layer	2	1700	1470	1000	
2. Lime mortar	3	2000	1400	1000	
3. Concrete	15	2000	1160	1000	
4. Rock—stone	20–40	1700	1200	1000	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
2 – 3 – 15 – 20	2.0	734	0.37	11.2	0.186

13 FR—flat roof					
Layer	*d*	*ρ*	*λ*	*c*	*R*
1. Internal plaster	2	1400	0.700		
2. Slab (brick blocks + reinforced concrete beams)	16	900	–		0.330–0.370
	24				
3. Reinforced concrete	4	2400			
4. Mortar	2	2000	1.40		
5. Concrete substrate	2–12	2000	1.060		
6. Bituminous waterproofing membrane	1	1200	0.170		
7. Cement mortar substrate (under the pavement)	3	2000	1.4		
8. External floor	3	1500	0.700		
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
2 – 22 – 10 – 1 – 3 – 3	1.34	785	0.12	14.8	0.09
2 – 30 – 10 – 1 – 3 – 3	1.27	945	0.069	17	0.054

14 FR—flat roof					
Layer	*d*	*ρ*	*λ*	*c*	*R*
1. Internal plaster	2	1400	0.700	–	
2. Slab (brick blocks + reinforced concrete beams)	16	900	–		0.330–0.370
	24				
3. Reinforced concrete	4	2400			
4. Cement mortar	2	2000	1.40		
5. Concrete substrate	2–12	2000	1060	–	
6. Bituminous waterproofing membrane	1	1200	0.170	–	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
2 – 22 – 10 – 1	1.467	680	0.186	13	0.127
2 – 30 – 10 – 1	1.38	840	0.107	15.2	0.077

15 R—roof					
Layer	*d*	*ρ*	*λ*	*c*	*R*
1. Wooden plank	3	550	0.150	1600	
2. Roof slate in "ardesia" stone	1.5	1500	0.3	1000	
Layers thicknesses	*U*	m_s	Y_{ie}	Δt	*f*
3 – 1.5	2.38	39	2.34	1	0.983

Note: the 3–40–3 cm wall corresponds to the wall under the windows of the case study described in another chapter

Therefore, even if sometime the substitution of the heating generator is the most evident action to reduce energy consumption, the possibilities offered by synergistic actions on elements of the building envelope and plant components should be examined. The aim should be the best agreement between the need of preservation and the opportunity of maintain also the ancient buildings live and with an active role in the urban context.

The first step for an integrated analysis on the energy consumption reduction can be represented by the evaluation of the impact of the external walls insulation, when possible. Reducing the U-value of the building envelope can lead to calculate a reduction of the heat losses and consequently often the need of an energy generation system of smaller size besides the lower energy consumption.

In this way, also the indoor comfort can be improved: the wall surface temperature of an insulated wall can be higher, the heat exchange by radiation between the human body and the different surfaces is reduced, and it becomes more similar to the heat exchange by convection with air, with a feeling of thermal field homogeneity.

The possibilities for the thermal insulation in historical buildings exclude in the majority of the cases external insulation and air layer insulation (appropriate for cavity walls). The most common solution remains the internal insulation: it is effective mostly if the insulating layer thickness is higher than 4–6 cm, especially in the continental climatic conditions. However, this thickness could reduce the internal surface of the living spaces, and it has to be correctly designed and planned.

Regarding the dynamic thermal performance of the walls, the position of the insulation greatly influences the thermal inertia of the structure. The heat storage is determined by the properties of materials, which are involved in the heating transmission of the envelope.

In addition, the moisture transfer is influenced by the insulating material: higher thermal insulation allows maintaining higher surface temperature of the wall internal side and reduces the risk of surface moisture problems. Nevertheless, the situation should be carefully assessed in terms of risk of interstitial condensation, when the insulating layer is applied on the internal side of the wall.

4.5.1 Effects of the Insulation on Historical Building Walls

The reduction of the thermal transmittance U offers the chance to reduce heat loss through the building envelope. Even if the insulation of historical building walls often is not easy to plan, verifying this possibility is useful for a more complete analysis of the measures to adopt for the reduction of the energy consumption and of the management costs of a building.

Table 4.9 Hygrothermal properties of insulation materials

Type	λ [W/(m K)]	δ [kg/(m s Pa)]	ρ [kg/m^3]
Plasterboard with finishing (PL)	0.21	23×10^{-12}	600
Mineral wall (MW)	0.036	193×10^{-12}	40
Wooden fibreboard (WF)	0.040	97×10^{-12}	110
Polystyrene (PY)	0.033	1.3×10^{-12}	35

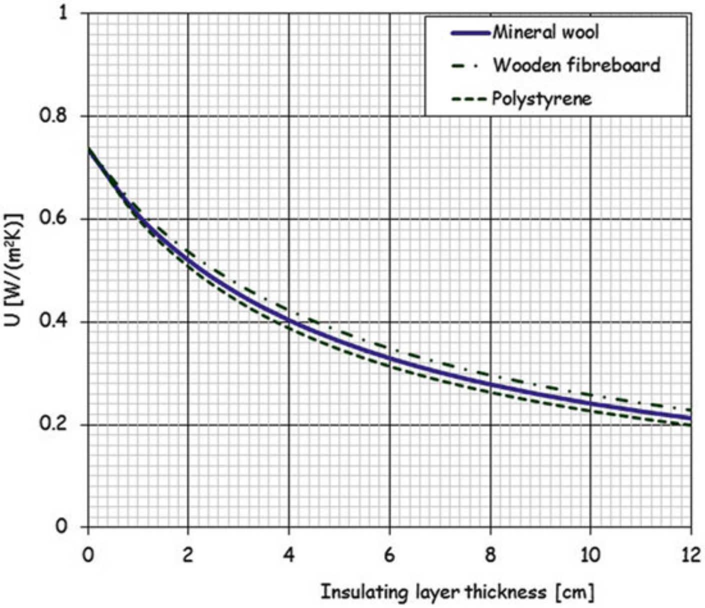

Fig. 4.4 Brick wall. U-value by varying the insulation thickness

The effects of the thermal insulation of some of the structures of the database (Table 4.8) are calculated, considering the application of an insulating layer on the internal side of a wall. Reference to a wall thickness of 86 cm is considered as the base case.

For each structure, three different kinds of insulated materials widely used in building refurbishment are considered (Table 4.9). Their properties are gathered from the technical files of commercial products. The insulating layer is covered by means of a plasterboard panel and a surface finishing layer.

The following graphs (Figs. 4.4, 4.5, 4.6 and 4.7) allow to check the insulation thickness needed to improve the thermal transmittance U. As the periodic thermal transmittance Y_{ie} has usually very low values and the thermal mass is high, their variations are not calculated as already satisfactory.

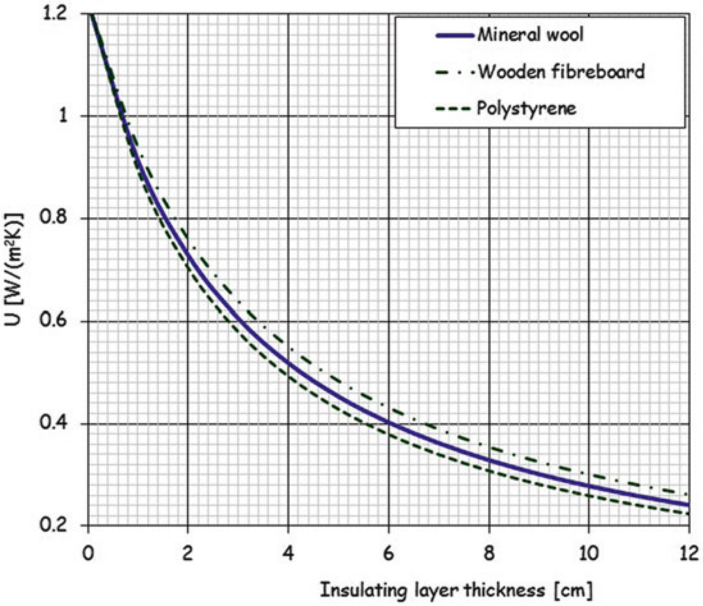

Fig. 4.5 Brick 60% and stone wall. *U*-value by varying the insulation thickness

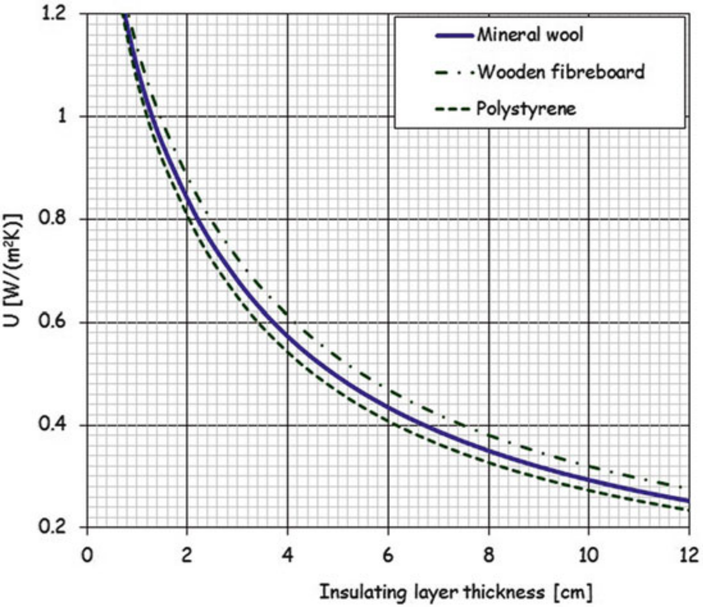

Fig. 4.6 Brick 20% and stone wall. *U*-value by varying the insulation thickness

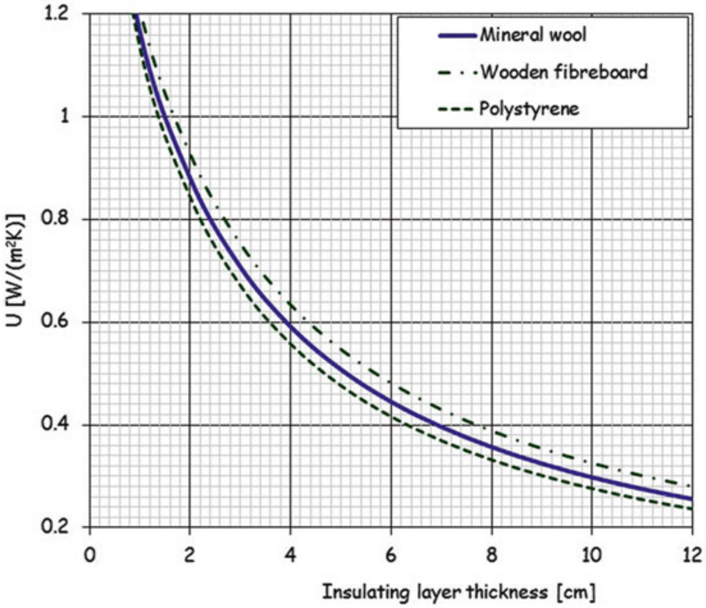

Fig. 4.7 Stone wall. *U*-value by varying the insulation thickness

It is important to verify that an insulation improvement of the wall satisfy also the hygrometric assessment. Sometimes, for continental climatic conditions, mostly in the case of internal insulation, a good opportunity in terms of energy saving may increase the risk of interstitial condensation.

Applying the procedure for the interstitial condensation evaluation, with a low internal moisture production (corresponding to offices, dwellings with normal occupancy and ventilation, as indicated in EN ISO 13788), an indication on the maximum insulating layer thicknesses, suitable for a positive assessment, is shown in Table 4.10.

The climatic data of six different regions in Europe are resumed in Table 4.11 (t_e in °C, P_{ve} in Pa).

The hygrometric assessment shows that in the considered climatic conditions the existing walls are not subdued to the risk of vapour condensation. The thermal insulation applied on the internal side of the wall, however, can produce condensation also for a small thickness of mineral wool panel or wooden fibreboard. Polystyrene represents often a better choice, but its hygrometrical performances must be evaluated accurately.

Table 4.10 Results of the hygrometrical assessment

		Genoa	Milan	Paris	Madrid	Brussels
01 BM	Existing	O	O	O	O	O
	MW	O	X(11)	X(8)	O	X(9)
	WF	O	O	X(9)	O	X(10)
	PY	O	O	O	O	O
03 BSM	Existing	O	O	O	O	O
	MW	O	X(5)	X(3)	X(6)	X(4)
	WF	O	X(5)	X(4)	X(7)	X(4)
	PY	O	O	O	O	O
04 BSM	Existing	O	O	O	O	O
	MW	O	X(4)	X(2)	X(4)	X(2)
	WF	O	X(4)	X(2)	X(4)	X(2)
	PY	O	O	X(4)	O	O
07 SM	Existing	O	O	O	O	O
	MW	O	X(2)	X(1)	X(3)	X(2)
	WF	O	X(2)	X(2)	X(3)	X(2)
	PY	O	X(3)	X(2)	X(6)	X(2)

O—no risk of interstitial condensation

X—the wall satisfies the two criteria (acceptable maximum condensate quantity and complete evaporation)

(*n*) maximum thickness of the insulating layer for a positive assessment (if not indicated, the assessment is positive up to 12 cm)

Table 4.11 Climatic conditions considered in the calculations

Climate		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Genoa	t_e	10.2	10.3	10.9	15.1	18.5	22.2	24.4	23.4	22	18	13.1	9.8
	P_{ve}	833.0	932.7	1042.1	1167.5	1523.9	1915.8	2354.7	2263.8	1962.0	1500.3	1153.5	953.3
Milan	t_e	4	7.1	10.6	13.4	19.4	22.8	24.5	24.3	19.8	14.1	7.5	3.5
	P_{ve}	556.8	479.4	698.1	885.2	1285.3	1857.4	1820.5	1817.2	1609.6	1300.7	803.6	523.3
Paris	t_e	3.9	4.2	7.0	10.0	14.3	16.8	19.4	19.7	15.7	11.3	6.4	4.5
	P_{ve}	735.4	558.7	754.7	891.2	1081.4	1486.4	1469.5	1555.8	1387.2	1090.8	859.3	754.3
Madrid	t_e	5.6	6.9	10.0	11.7	16.9	20.6	25.5	24.7	20.1	14.2	9.4	5.9
	P_{ve}	656.5	690.5	744.7	762.5	1151.7	1257.8	1293.8	1407.5	1339.6	1133.4	884.9	773.6
Brussels	t_e	3.1	3.2	6.4	8.9	12.9	15.6	18.4	17.4	14.5	10.9	6.6	4.9
	P_{ve}	644.6	663.8	804.8	868.6	1141.3	1320.4	1640.9	1492.9	1333.7	1047.6	817.6	754.7

Nomenclature

A	wall surface [m^2]
A_i	area of the i-element of the building envelope [m^2]
$b_\mathrm{tr,x}$	adjustment factor for the external temperature
c	heat capacity [J/(kg K)]
d	thickness [cm]
f	decrement factor [−]
H_A	heat transfer coefficient by transmission to adjacent buildings [W/K]
H_D	direct heat transfer coefficient by transmission to the external environment [W/K]
H_g	steady-state heat transfer coefficient by transmission to the ground [W/K]
H_tr	heat transfer coefficient by transmission
H_U	transmission heat transfer coefficient by transmission through unconditioned spaces [W/K]
l_k	length of the k-linear thermal bridge [m]
m_s	surface mass [kg/m^2]
P_s	saturation vapour pressure [Pa]
P_v	vapour pressure [Pa]
$Q_\mathrm{H,gn}$	total heat gains for the heating mode [MJ]
$Q_\mathrm{H,ht.}$	total heat transfer for the heating mode [MJ]
$Q_\mathrm{H,nd}$	building energy need for continuous heating [MJ]
Q_tr	total heat transfer by transmission [MJ]
Q_ve	total heat transfer by ventilation [MJ]
R	thermal resistance [m^2 K/W]
s_d	equivalent thickness [m]
t	temperature [°C]
t_i	internal temperature [°C]
t_e	external temperature [°C]
U	thermal transmittance [W/(m^2 K)]
U_i	thermal transmittance of the i-element of the building envelope [W/(m^2 K)]
Y_ie	dynamic thermal transmittance [W/(m^2K)]
$\Delta\tau$	time shift [h]
δ	vapour permeability [kg/(m s Pa)]
δ_o	reference vapour permeability of air $= 200\times10^{-12}$ kg/(m s Pa)
$\eta_\mathrm{H,gn}$	gain utilization factor [−]
λ	thermal conductivity [W/(m K)]
ρ	density [kg/m^3]
φ	relative humidity [−]
χ_j	point thermal transmittance of the j-point thermal bridge [W/(K)]
ψ_k	linear thermal transmittance of the k-thermal bridge [W/(m K)]

Appendix

CEN: Energy performance of buildings—Calculation of energy use for space heating and cooling, EN ISO 13790:2008, European Committee for Standardization.

CEN: Hygrothermal performance of building components and building elements—Internal surface temperature to avoid critical surface humidity and interstitial condensation—Calculation methods, EN ISO 13788:2013, European Committee for Standardization.

CEN: Building materials and products—Hygrothermal properties, Tabulated design values and procedures for determining declared and design thermal values, EN ISO 10456: 2008, European Committee for Standardization.

CEN: Building components and building elements—Thermal resistance and thermal transmittance, EN ISO 6946: 2008, European Committee for Standardization.

CEN: Thermal bridges in building construction—Heat flows and surface temperatures—Detailed calculations. EN ISO 10211: 2008, European Committee for Standardization.

CEN: Thermal performance of building components—Dynamic thermal characteristics—Calculation methods, EN ISO 13786:2008, European Committee for Standardization.

ISO 9869–1:2014 Thermal insulation—Building elements—In situ measurement of thermal resistance and thermal transmittance—Part 1: Heat flow meter method.

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Part II

Enhancing Energy Efficiency in a Monumental Complex: A Feasibility Study

Chapter 5
Energy and Heritage. Development on a Case Study

Giovanna Franco

5.1 The Complex of the *Albergo dei Poveri* in Genoa

The smart grids will mark in future the growth of electricity production and distribution, integrating in an effective and sustainable manner the generation of concentrated energy, distributed energy (fuelled by renewable sources), and the development, across the territory, of methods of consumption of flexible and smart energy. Within such a context, it is important to assess the potential for developing smart grids even in the historical urban hubs, hitherto excluded from any policy framework transcending the single experiment.

The idea to draw up a feasibility study for the complete recovery and reuse of a large monumental complex in the heart of Genoa's ancient city, and simultaneously examine in depth aspects associated with the improvement of its energy conduct, stems from the consideration that, within the scope of the smart grid system bound to characterize the city and the territory in the near future, the historical–architectural heritage—not just monumental—had until then been excluded from any specific reflection.

Such an absence seems clear since the translation of the European Directive on energy saving, which has scrapped the said heritage from the fulfilment of regulatory obligations; due both to reasons of compatibility, respect, and historical–cultural interest and to a nearly inborn distance, the scientific community concerned with its preservation and enhancement voices vis-à-vis the issues of technological innovation.

The main source objective of the specific research, therefore, was to define a system of smart management of the historical–monumental built heritage, protected

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through direct or indirect obligations by the State bodies vested with that task. The intention was, in other words, to build and organize, synergistically, a system, programmatic and technical in nature, aimed at the possible inclusion, in the smart grids envisaged by the general programme, of the built heritage (not just monumental) sector. The expected actions would have referred, in particular, to the smart use of energy for the liveability and management of that heritage, to energy saving for its heating, cooling, and for the necessary energy supply of the other plant equipment existing therein anyway, and to a possible autonomous energy production inside them or around (widespread microgeneration), always in compliance with the existing protection obligations.

In order to arrive at a pilot programme capable of representing a best practice experience transferable to other contexts, it was necessary to synergistically study a number of aspects and systems: the historical legacy system and its energy potential, the range of appropriate technologies, and sustainability applied to entire processes of asset recovery and future management. There was accordingly a need for a research and applied field that, given its size and its public character dimension, could serve as trial object pursuant to different disciplinary approaches.

The choice has fallen on an important as well as a vast monumental complex lying in the heart of Genoa's city, the *Albergo dei Poveri* (Hospice for the Poor), built between the mid-seventeenth to the mid-nineteenth century, owned by a personal service institution (heir to the original bequest the Hospice originated from) allocated to the University of Genoa in the late 1990s. Owing to the size, the location, and the importance of the complex, and owing to the relevance it is vested with at an urban level, as well as the many research and experimentation topics offered by it, especially in trans-disciplinary relations, the study may become paradigmatic and serve as model for other experiences (Fig. 5.1a–c).

The work put forward is the result of mutually related researches, backed up by various types of funding, aimed at testing innovative methodologies for a more sustainable management of the process of restoration, recovery, and reuse of historical monumental complexes protected by virtue of the Italian Code on Cultural and Landscape Heritage (Musso and Franco 2014).

5.2 Brief History of the Settlement

The *Albergo dei Poveri* (Hospice for the Poor) was built between the mid-seventeenth century and the mid-nineteenth century pursuant to a grand project, not entirely finalized. It was willed into being by the nobleman Emanuele Brignole, representative of one of the richest and most important families within the exclusive circle of those who ruled the oligarchic republic since the days of his father Andrea Doria (Banchero 1846; Grendi 1975; Parma Armani 1977, 1978, 1988, 1992; Gavazza and Rotondi 1992; Guerra and Molteni 1995; Altavista 1999).

Pursuing his desire to create a place of universal charity capable of absorbing even the penitentiaries scattered across the city of Genoa, in the first decades of the

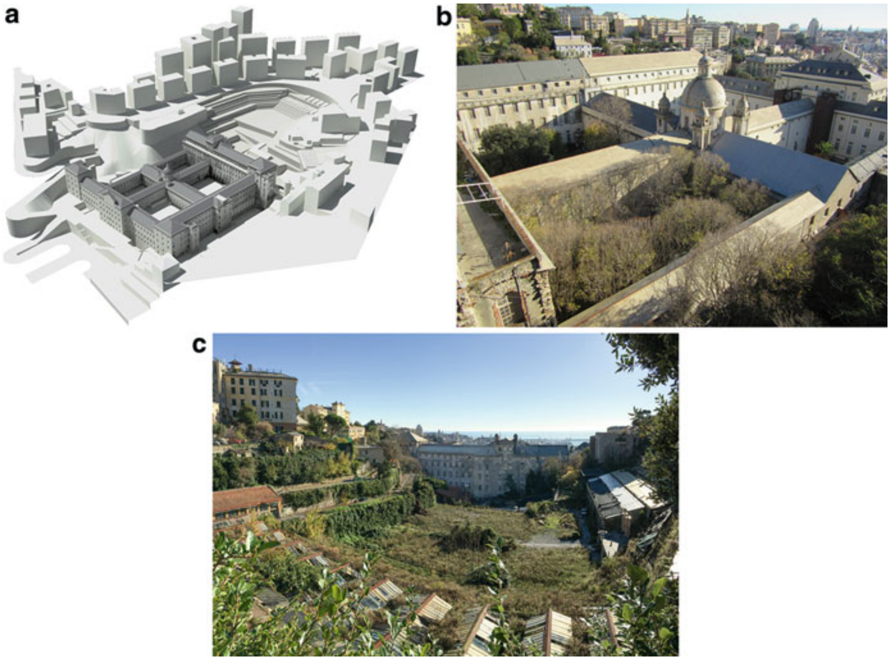

Fig. 5.1 (**a**–**c**) Model of the complex of the *Albergo dei Poveri* and of the *Valletta Carbonara* and views from west and nord sides (Macchioni, E. 2013)

seventeenth century it was decided to establish a new place of confinement, based on the segregation of inmates according to sex, age, social, and physical condition. In that place, also conceived in order to ensure tighter control and internal order, the compulsory work was deemed an instrument of spiritual rescue and, simultaneously, of self-sustentation as well. That was the genesis of the design and construction of the *Albergo dei Poveri*. The structure hosted, during periods of maximum expansion and activity, nearly 3000 persons, and shut its doors every night as if it was a place of detention.

The *Albergo dei Poveri* was thus the first building to be set up specifically to receive the poor and the needy of the city; its architectural aspect and its organizational structure reflected the ideas of the Genoese welfare service policy, chiefly those of Emanuele Brignole, who, since 27 August 1656, the day on which he concluded the contract for the new building, devoted his entire life and capital to the realization of the place of confinement.

The choice of site fell on the Carbonara valley, which proved to be the ideal site: it was situated between the old and the new walls (hence not in the city itself but quite close to it), morphologically it appeared very steep and thus hardly appealing to real estate speculation (whence low prices for the lands), equipped with water (due to the presence of Rio Carbonara, that flowed into the port) and healthy air; and not least, the plot consisted in rocky land from which building material could be drawn, thereby significantly reducing the building costs. The valley site, owned even at present by Azienda Servizi alla Persona Emanuele Brignole, represented therefore a source for procuring water and produce of the land, thereby contributing to the inmates' sustenance.

It follows that the builders were forced to create, prior to anything else, the artificial modelling of the valley, the reduction of the rocks on the inclined sides, the covering of Rio Carbonara, and the subsequent filling of the natural basis to obtain a regular surface on which to erect the complex. These characteristics render the whole not a mere building with a large green valley annexed to it, but an urban infrastructure properly so-called which, even today, might represent a huge potential for the city (Figs. 5.2, 5.3, 5.4, 5.5, 5.6 and 5.7).

Fig. 5.2 South façade, (digital photogrammetry, *Laboratorio MARSC*, University of Genoa)

Fig. 5.3 East façade

Fig. 5.4 North façade

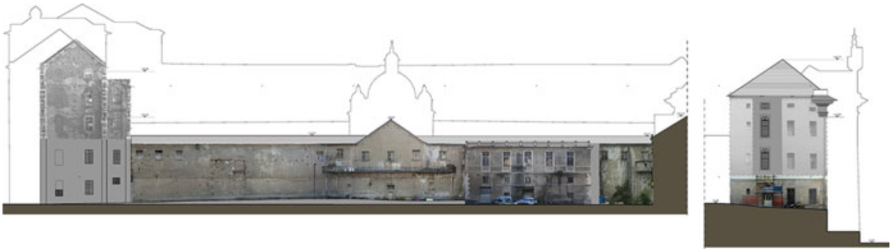

Fig. 5.5 West façade

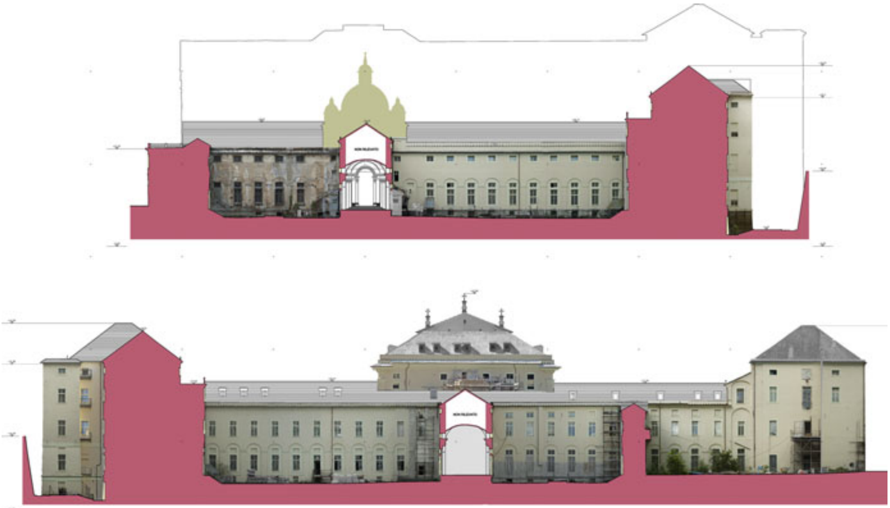

Fig. 5.6 Cross sections on the central wing (Church)

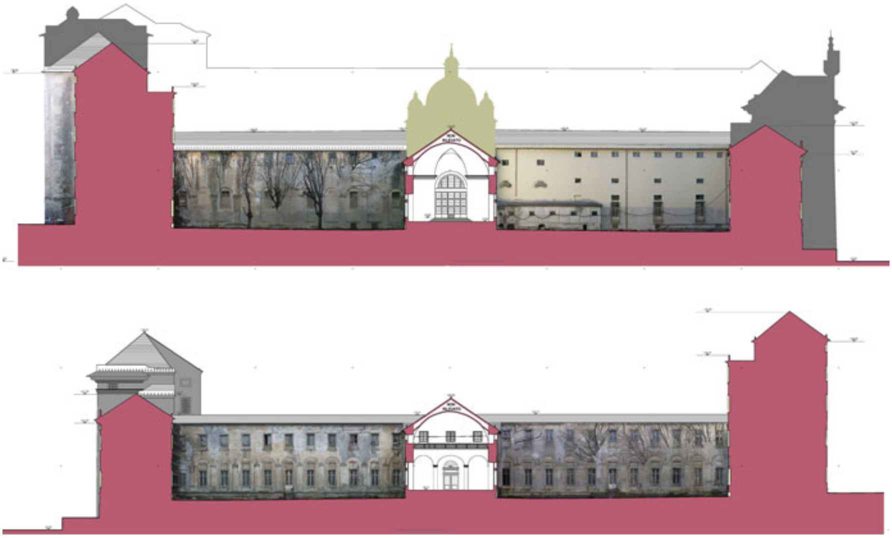

Fig. 5.7 Cross sections on the western wing

Fig. 5.8 The Church of Santa Maria Immacolata at the cross centre

The model envisaged for building the Hospice has been susceptible of a direct link to Filarete's theories (*Ospedale Maggiore di Milano*) and also recalls the Escorial big monastery and Royal Palace, Emperor Charles V's residence. The project perhaps strongly influenced the idea of the "Panopticon" which, in the nineteenth century, has transformed and revolutionized the architecture for prisoner control, granting the chance to see each part of the building from a single central perspective. In the Hospice, the visual and symbolical centre of the entire complex is the main altar of the *Santa Maria Immacolata* Church, where the statue of Maria by the French sculptor Pierre Puget stands, visible from all four wings tracing the geometry of the complex (Fig. 5.8).

The implementation of the Hospice project saw the participation of the most experienced and active master builders and architects based in Genoa, as per the traditional way of building between the sixteenth and seventeenth centuries. The most influential decisions from an aesthetic viewpoint were taken by the clients who, especially influenced by *Gian Galeazzo Alessi*'s models and by *Bartolomeo Bianco*'s proposals for realizing the Balbi family palaces, steered and controlled the designers' solutions. Because of this in Genoa, unlike other Italian cities, no strong personality in the architectural field ever emerged. The most influential figures who worked on the project were, according to the sources, architect *Stefano Scaniglia*, to whom the design of the first Greek cross-shaped square plan is attributed; *Gio Battista Ghiso*, author of subsequent changes to the plan (design of the latest version of the system) and supervisor of the initial works; and *Geronimo Gandolfo*, who was the factory architect until his death, which took place during the 1656–1657 pest. Other architects who worked at the factory included *Pietro Antonio Corradi*, foreman, and architect *Antonio Torriglia*.

The monumental complex, that occupies an overall surface of approximately 60,000 m^2, exhibits a plant and volume differing in part from the first project. There are, in fact, three different designs of the Hospice plan realized between 1661 and 1677. All the three versions, however, seemingly differ from the current shape of the building, incompletely finished in 1841 compared to the original plan due to a series of economic, managerial, and technical–operational problems, arising also from the difficulties linked to the necessary excavation of a rocky ridge on the western side.

Be it as it may, the first layout system, which guided in any event the execution of the work, envisaged the implementation of a quadrangular plant symmetrically divided into four quadrants, centred around the church area, located at the junction of the two basic square axes. The choice of the cross, as blueprint model of the Hospice, was influenced by the fourteenth–sixteenth century tradition of welfare services buildings. Practical and symbolical reasons gathered in fact in them: the cross, with the altar in the middle, facilitated visual control of all the wings while simultaneously enabling the inmates to attend religious ceremonies.

The most important Hospice construction phases are comprised between 1656, the year in which the purchase of the lands terminated, and 1838, when the building was finalized through the realization of the south-western tower, though reduced compared to the original plan. In lieu of the two square plan courtyards on the western side, two rectangular courts (smaller than the original plan on the North-South axis) were in fact realized, and the western wing shrank to a connecting corridor between the northern branch (only partly executed) and the main one to the south.

5.3 Morphological and Architectural Features

From a constructive viewpoint, the complex appears as a mighty load masonry structure in splitted stone mixed with bricks; its wings, of rectangular shape, are closed by heavy perimeter walls and divided internally into aisles by masonry pilasters on which cross-shaped vaults or barrel vaults with lunettes rest. The internal subdivision of the branches varies depending on their width: situated along the north-south axis, above Rio Carbonara, is a wing, broken by church and anti-church premises, with a single hall, covered by structural barrel vault, in one part, and wooden beams, in the other parts[1]. Along the east-west axis, we again find two single-hall branches and a uniform height on the *piano nobile* (main floor), larger than the former, that housed the Oratories set aside for men and women, respectively. The southern wing is morphologically characterized by a distribution corridor and side halls, whereas the opposite, northward branch, larger, is divided into three aisles, as is the case with the eastern one. The smallest-size wing in the whole complex is the western one, of reduced size compared to the imposing symmetrical project, due to the aforementioned technical and financial problems. The top floor vaults, lighter, are made of a wooden structure and plastered reed mats, as per the Genoese building tradition, and interpenetrate with the space below the roofing structures. Even the height of floors vary, depending on the branches, up to a height of five floors above ground in the northern branch (and even more in the northern small towers).

Of special significance has been the investigation into the material solidity of walls, especially vaults and roofing structures, to better define the thermal performances, to the specific chapter on which the reader should refer.

The *Albergo dei Poveri* complex has moreover suffered heavy damages during the last war, which has destroyed significant portions of roofs and attics on the top floors. In those instances, the new structures have been reconstructed with the then available techniques: roofs made of reinforced-concrete structures, storey terraces in slabs of reinforced brick of the prefab *SAP* type, intermediate attics with single or double structures in reinforced concrete and clay-brick lightening.

The roof structures not damaged by the bombings consist instead in wooden rafters supported by brick pillars, in turn supported by brick arches (that mark the aisles). Between one structural arch and the other, the ceiling consists in light wooden structure vaults and reed mats, plastered on the soffit, as per the typical construction tradition of historical Genoese buildings.

5.4 Current Use of the Building

The complex, still the property of the *Azienda Servizi alla Persona Emanuele Brignole* (Personal Services Company), has discharged its welfare role (health care clinics and post-hospital stay) until the end of the twentieth century, when a contract of loan for use was concluded with the University of Genoa, which has taken charge of the recovery and reuse operations, with a view to establishing the teaching and departmental headquarters of the faculties of Humanities, until now hosted in some monumental palaces of *Strada Balbi*, not far from the Hospice.

With this purpose in mind, some recovery and reuse interventions were launched (in the eastern and southern halls, with adaptation of the internal spaces to host

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[1] For a complete analysis of the roof structures in the *Albergo dei Poveri,* see Chap. 6 by Acacia and Casanova.

Table 5.1 Total surfaces of the complex of the *Albergo dei Poveri* and the valley *Carbonara*

	Surface (gross) [m^2]
Renovated area	18,750
Area to be renovated	48,000
Total area of the complex	66,750
Area of Valletta Carbonara	25,000

lecturing halls, the "*E. Vidal*" political sciences library, the main lecture classroom (*Aula Magna*) and offices, interventions to reinforce the vaulted structures, reconstructions of roofs and interventions on the facades, including the full replacement of windows and doors).

Currently, only a small part of the available spaces has been recovered (see Table 5.1), with the establishment of the activities of the Political Sciences and Law Departments (works undertaken on the first two floors of the eastern branch and partially in the southern branch); the remaining part, especially in the northern wing, is exposed to the degradation actions caused by the infiltrations of rainwater through the roofs, the openings (the windows are in many instances damaged or missing) (Fig. 5.9).

Due to a number of reasons, in fact, the reuse plan has been developed very slowly and punctuated by many pauses, on account of economic and technical problems which, at least partly, result from a lack of knowledge of the architectural complex, of its real solidity, and its state of conservation. The implemented interventions have concerned around 30% of the total surface; hence, the main part is still abandoned and subject to natural degradation. The situation of neglect and degradation impacts especially on the roofing system, on the windows, on the plasters, on the installations, as well as on the external spaces. Unchecked infiltrations of rainwater, actions by animals, homeless people and vandals, unruly growth of weeds, already manifest when the University took charge of the complex, are currently even more dangerous and demand urgent interventions as part of an organic plan, which had previously been missing and now is under development.

Apart from the physical deterioration problems (which, in the event of wooden structures subject to rainwater might result in structural instabilities), other problems to be tackled by the University stem from the application of technical rules (e.g. against the risk of fire, to adapt to the seismic risk, for the sake of worker safety, accessibility to handicapped persons and, last but not least, for energy saving purposes) often hardly applicable to complexes like this, without distorting their morphological and architectural features.

Even *Valletta Carbonara*, formerly the seat of the municipal nursery and currently neglected, will provide an interesting scenario for its reuse, that will necessarily involve the entire city, given the strategic position and the substantial size.

It is not only, therefore, a question of imagining the design of new spaces inside the old ones, but also of governing the life of the complex within the period of time separating it from its future full use, thereby minimizing the risks of deterioration and maximizing the inspection—maintenance and management practices.

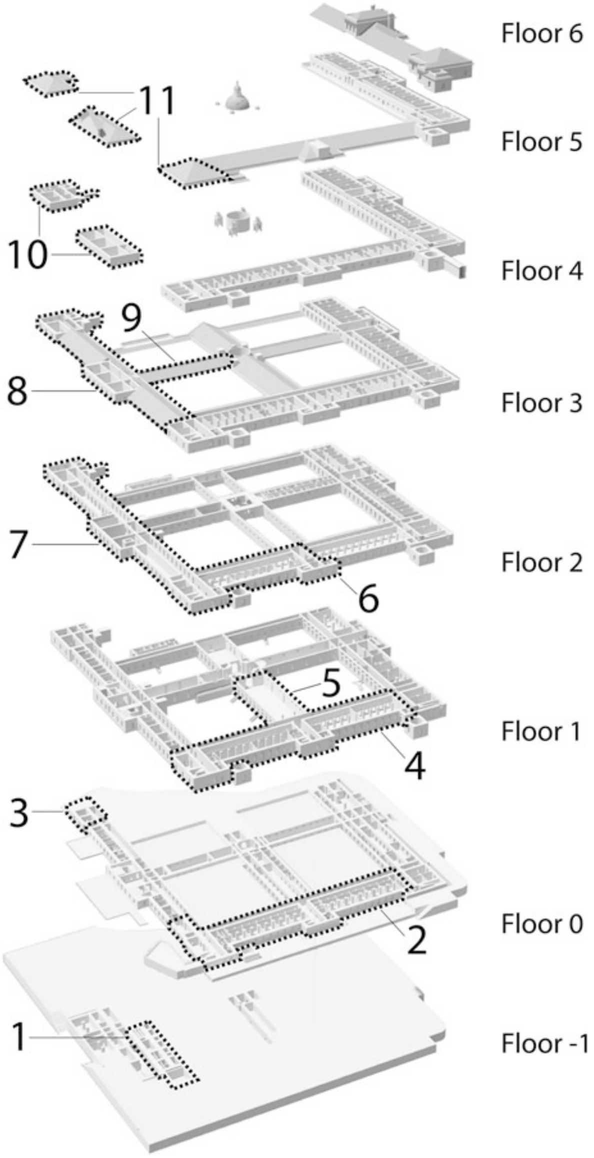

Fig. 5.9 Identification of the spaces already in use as University. (*1*). Technical plants. (*2*, *4*, *7*). Classrooms. (*3*, *8*, *10*). Department of Political Sciences. (*5*). Aula Magna. (*6*). Library E. Vidal. (*9*). University Language Laboratory. (*11*). Services (Macchioni, E. 2016. Graduate in Architectural Heritage and Landscape, University of Genoa)

Moreover, as researches go on, new information emerge, linked in particular to its story and its conditions, thereby enriching knowledge and at times debunking some theses about the construction phases; at the same time, with the passage of time, the University's requests undergo a change compared to the forecasts on reuse of the environments.

It was necessary to draw up a management plan, extending also to the huge and diversified amount of data resulting from the product knowledge process, that is open and dynamic, capable of recording diverse information and data (textual, such as archive documents, graphical, such as the deterioration maps and the identification of twentieth century plant networks, iconographic and alphanumeric, such as the data drawn from the energy audit and from other calculation procedures).

5.5 For a Sustainable Cognitive Approach: Acquisition, Cataloguing, and Management of Information

In order to fully implement the programme of recovering spaces and reusing them for university purposes, the University's Building Development has signed a framework agreement with its own Post-graduate School of Architectural Heritage and Landscape, to embark on a study campaign and develop a feasibility study on a complete reconversion to university campus. This was an opportunity to launch further the research activity on the complex, also by requesting and obtaining ministerial funds within the scope of the National Relevance Projects for developing an ICT programme to manage the huge amount of data and information gradually collected, of very diverse type and nature, and changing over time as well. Managing the data is in fact an essential step towards supporting the complex decision-making process of the recovery operations, and following the future life of the building, once restored and reused, towards qualifying its overall management in a more sustainable manner than in the recent past. The said project intended adapting to the historical heritage needs (morphological, architectural, construction features) a BIM (Building Information Modelling) meta-model, already widespread when it comes to newly built works (Babbetto 2014).

The data acquisition campaign has been organized across the following phases:

- Reconstruction of the history of the complex based on (indirect) archival and documentary sources and on physical observation of the building itself.
- Identification of technical, legal, and administrative constraints.
- Description of the building (layout, morphologies and dimensions of spaces, construction features).
- Survey campaign through different instruments, with a view to ascertaining effectiveness in terms of costs and restitution times (topographical survey, survey by thorough, simplified analytical and digital photogrammetry, survey through 3D laser and Z-scan, photographic survey by photo-scan).
- Analysis and diagnosis of materials, construction techniques and structural behaviour, technological and health deficits.
- Analysis and monitoring of environmental conditions.
- Identification of the old grid systems, including inspections on the recent archive of building and plant maintenance.

All the data have been organized in a relational GIS system; this mass of data, easily transferable to other software packages like ACCESS or REVIT, has served as the basis on which the BIM meta-model was built, beginning with the construction of the three-dimensional parametric model of the complex onto which the different alphanumeric and graphical data are anchored, tested on one part of the complex that will be targeted by recovery in the near future.

The construction of the BIM model on the *Albergo dei Poveri* (Figs. 5.10a, b, 5.11a, b, and 5.12), which entailed a careful reflection on the methods of application

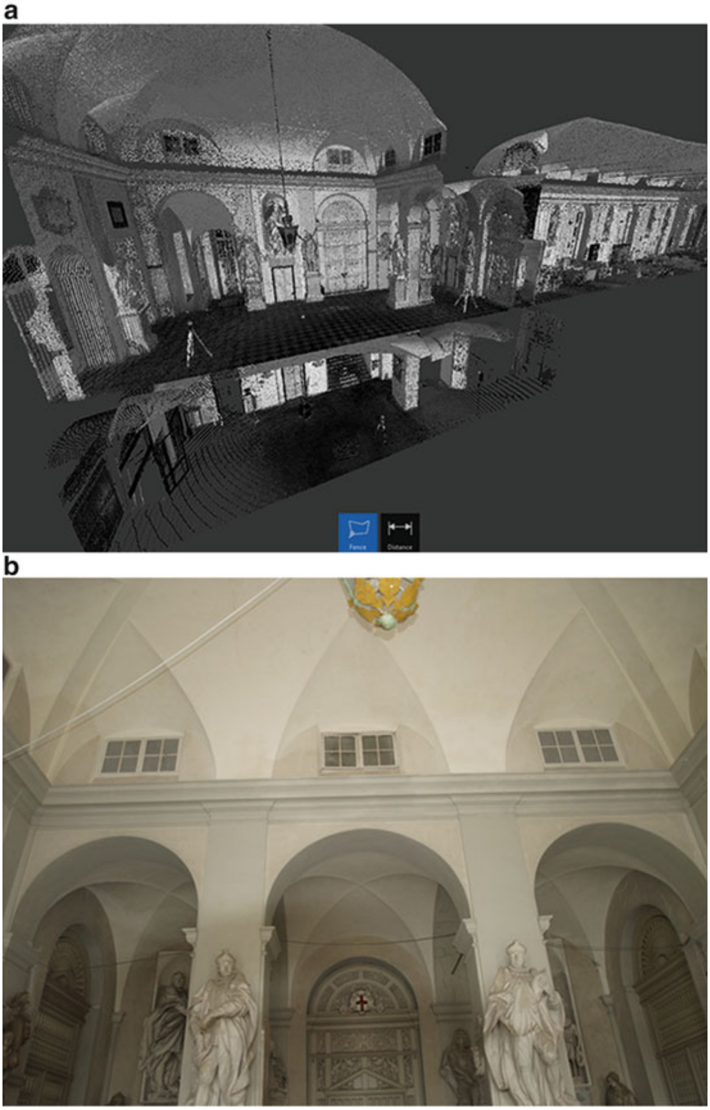

Fig. 5.10 (**a**, **b**) Laser scanner survey of the main entrance and monumental stairwell and picture of the entrance at the *piano nobile*

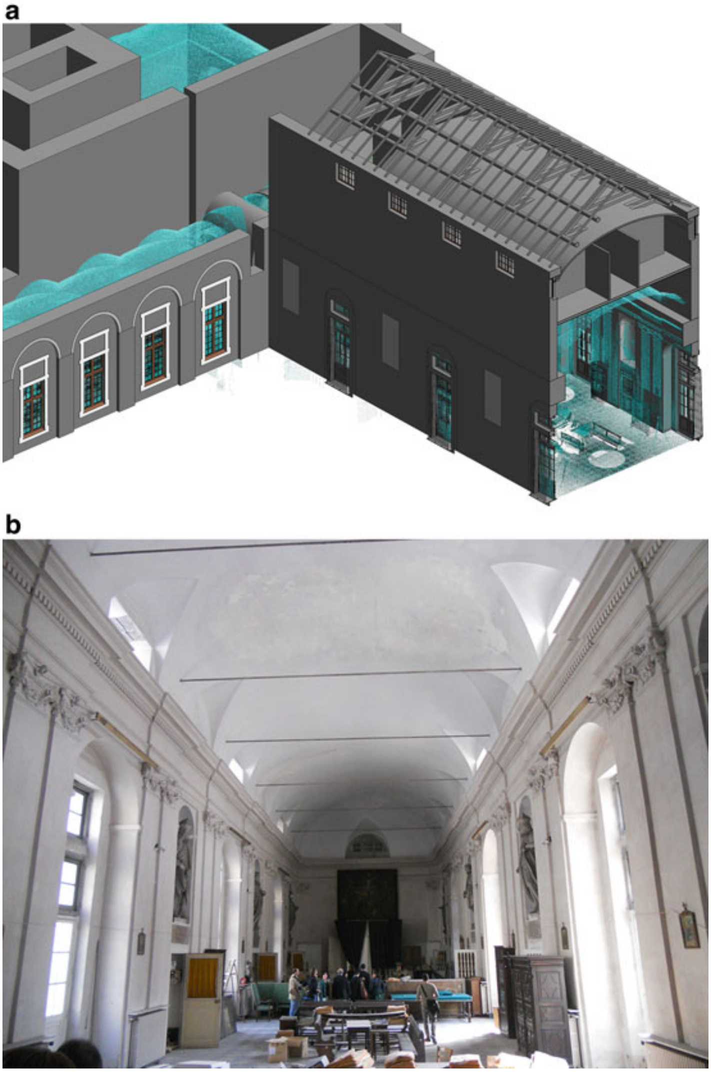

Fig. 5.11 (**a**, **b**) Modelling the space in front of the Church and picture

and its well thought out adaptation/enforced redefinition based on the characteristics of the complex (just to cite an example, the model does not envisage—by default—the presence of vaults or other typical building elements of traditional, and more specifically Genoese constructions), accordingly proved useful to:

– Organize within a logical, hierarchical, and non-redundant system the various information associated with the building and its parts (even the frames of external doors and windows, just to give another example) and their reciprocal relations (dimensional, spatial, and functional).

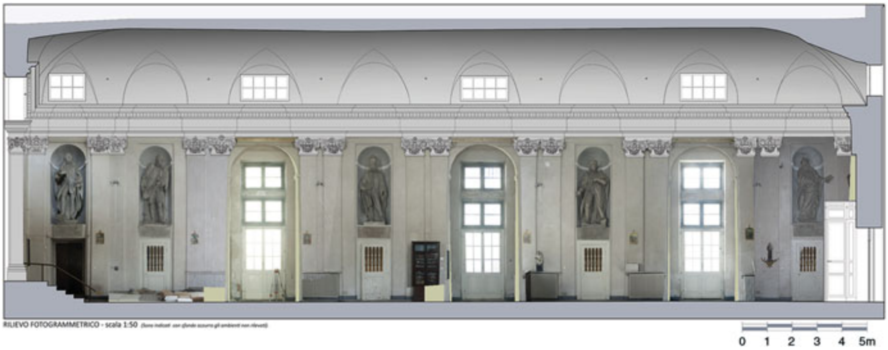

Fig. 5.12 Internal façade of the space in front of the Church (Musetti, V., Orefice, A., Panzani, L., Salvini, S., Trihim Duc Quang, Tu Vu Ngong. (2013). Post-graduate School in Architectural Heritage and Landscape, University of Genoa)

- Enable the easy questioning and coordinated updating of the model and the associated documentation, thereby facilitating the ongoing review of the state of the art.
- Record the variations that the project and the construction yard will produce on the complex, thereby ensuring a reliable basis for the activities bound to characterize its subsequent management.

5.6 Improving the Energy Performance of the Complex: A Feasibility Study

One of the first results of the work was to lay down a strategic plan for the full use of the complex, to be realized in successive phases, including also the interventions to be implemented with maximum urgency, setting out the main information on distribution layout and new uses, system of entries, vehicular and pedestrian, escape routes, and main interventions to put the spaces in safe conditions and then store and retrieve them and maximize their effectiveness.

Simultaneously, within the scope of research activities devoted to the possibility of including the historical heritage in a grid system, a work was launched on the study of thermal and energy aspects, in terms of both audit and investigation about possible interventions for improvement and inclusion in cogeneration systems (Franco et al. 2014, 2015). The said work has been synthetically organized in the following phases, subsequent to those centred on restoring the morphologies and geometries of the environments and the mapping of materials and building materials, as dealt with in detail in the following chapters of the book (see Table 5.2):

1. Calculation of the energy requirement for the building envelope (with a steady-state method) on the portion of the complex still to be recovered (around

Table 5.2 Research phases on energy efficiency improvement on the monumental complex

	Phases	Area
1	Calculation of energy requirement (thermal energy for heating)	To be renovated
2	Comparison of results (phase 1) with energy consumption	Already renovated
3	Calculation of the hot water and electricity requirements	To be renovated
4	Energy improvement interventions (passive) and energy gains	To be renovated
5	Recording of existing nets and inclusion in the BIM model	To be renovated
6	Calculation of cogeneration (micro-turbine and PV cells)	Total

135.000 m^3), along with a distinction in the proposed new uses and on the basis of the calculation of the transmission through all the various construction types of opaque and windowed parts. Excluded from the said study are the monumental staircases and the paths that might assume an urban value, such as the ground road that runs along the North-South axis and which, supported by vertical lift systems, might become an urban stretch between the low-level city and the hilly one. The said investigation made it possible to infer the calculation of thermal power requirements, on the current construction conditions, based on the uses defined in the feasibility plan.

2. Verification of the calculation assumptions through a comparison with the current consumption levels of the already recovered part of the complex, which exhibits the same morphological and construction characteristics as the parts still to be recovered (the interventions, accomplished a few years ago, did not however take into account consumption-related problems).
3. Calculation of the hot water and electricity requirements (based on the new intended uses set out in the strategic plan, account being taken of low consumption technologies).
4. Identification of the energy improvement interventions on the dispersing parts deemed compatible with protection of the morphological and architectural construction features of the complex (insulation of the floor against the ground, insulation of roofs, interventions on windows not susceptible of full replacement, as it already happened for the recovered part) and assessment of the resultant benefits in terms of energy saving.
5. Identification of the possible types of plant, including the air handling one. A preliminary step consisted in the identification of the existing situation, on the base of the archive of recent maintenance (twentieth century). The analysis of the existing and non-digitized plant network has been pursued on two fronts: archival analysis and direct survey. The cataloguing and digitization of the paper documents belonging to the archive of the *Emanuele Brignole* Personal Services company was undertaken. This work made it possible to find the project data on the old thermal station (existing, but by now unused), the ones relating to the pipes serving the water supply and the thermal one. Simultaneously, a census was conducted on the heating bodies throughout the complex, in such a manner as to identify the paths of the existing plant network (both in the used areas and

those still to be recovered). The totality of these data, inserted into the BIM model, enables us to know the paths of the existing plant networks and assess their reuse on behalf of the new thermal plants, including for purposes of safeguarding, as much as possible, the ancient wall structures from useless demolitions.

6. Calculation and assessment of the benefits arising from the cogeneration by adopting a micro-turbine gas model produced by *Ansaldo Energia*, the technical partner involved in the research project, and assessment of the possibility to insert photovoltaic glasses in the nurseries to be recovered as included in the rear valley, to try and view the complex of the *Albergo dei Poveri* as a possible energy-producing hub and not only as a voracious consumer, thereby incorporating, for the first time, the historical–monumental heritage into a broader smart grid system serving the *Strada Balbi* University campus.

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Chapter 6
Constructive Techniques in Historical Buildings

Simonetta Acacia and Marta Casanova

6.1 Introduction

The construction of the *Albergo dei Poveri* complex, begun in 1656, ground to a halt in 1740, leaving the original project incomplete; at the beginning of the nineteenth century, it was decided to close the courtyards to the west through a hallway across two floors and, between 1834 and 1838, the main façade was completed through the erection of the western tower.

Since the mid-twentieth century, the complex, in its material substance, was affected by three important alteration phases: the first one is associated with the post-war reconstruction, the second one with the unavoidable need to modernize the welfare structure (1960–1970s), while the third one (currently underway) entails the conversion of the building into university campus.

The *Albergo dei Poveri* complex offers a wide range of building techniques used in Genoa between the seventeenth and nineteenth centuries; within this context, we will focus in particular on the closing elements, such as perimeter walls, floors, roofs, and windows.

The information set out hereunder is drawn first and foremost from a direct observation of the building (building techniques, morphology, materials) and from perusal of the archive documents (both textual and iconographic), which enable us

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to also understand what is no longer there or what cannot be seen as it is concealed by finishes and coatings[1].

6.2 The Elevation Structures: The Walls

The Genoese building has been characterized, already since the Middle Ages, by continuous elevation structures[2], marked by a very thick walled section which, starting from the foundations, recedes the more the building rises.

Most of the walls of the *Albergo dei Poveri* complex are made with the technique termed in literature (and in the archive documents) *a scapoli e tocchetti*, i.e. large-size rough, angular and irregular stone cut into squares. This technique establishes itself in Genoese buildings in the course of the fifteenth century; it is characterized by a homogeneous wall in all its thickness, robust and compact, in which large-sized splitted stone elements (*scapoli*) are compacted through the forced insertion of flakes (*tocchetti*) of the same material, all of that tied with little mortar (Galliani and Mor 2006)[3] (Fig. 6.1).

The thickness of the walls is directly proportional to the number of floors (and thus of loads) of the building, variable, in the instance of the *Albergo dei Poveri* complex in Genoa, from a minimum of two (western hallway) to a maximum of seven (in the northern tower). We might get an idea of the substantial extent of the wall thickness by reading, for instance, the technical document on the construction of the western tower of the southern façade, which reaches a height of five floors; we learn therein that up to the first floor they must have an average width of 2 m, which decreases the more we climb up to a 0.9 m thickness[4].

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[1] Within the scope of the research on the Albergo dei Poveri complex, the following archives have been consulted: *Archivio dell'Istituto Brignole*, Genoa (AIB); *Archivio storico Soprintendenza Belle Arti e Paesaggio della Liguria*, Genoa (SBAP); *Archivio storico della cartografia ligure*, Genoa (ASCLi); *Archivio storico Regione Liguria*, Genoa—*Fondo dell'Ufficio del Genio Civile di Genova. Classe: Opere dipendenti da danni bellici. Serie: Riparazioni edifici di opere pie e istituti di beneficenza e assistenza* (ASRLi); *Archivio storico del Comune di Genova* (ASCG); *Archivio Fotografico del Comune di Genova* (AFCG); *Archivio di Stato di Genova* (ASG). The archival research has been conducted, apart from the authors of this chapter, even by the students of the Postgraduate School of Architectural and Landscape Heritage, University of Genoa, during the years from 2010 to 2015, as well as by Dr. Francesca Ferrando, under the guidance of Dr. Alfonso Assini.

[2] Except for the ground floor loggias.

[3] In a contract dating from 3 June 1659, relating to the construction of the southern and eastern branches, the building technique to be used in the main walls is thus described: *farle di petre dure grosse da carricho con quelle scaglie che saranno necessarie acciò il lavoro resti saldo e sicuro con quella dovuta calcina che fa bisogno* (ASG—*Fondo Notai Antichi*, 7348 Bartolomeo Castiglione).

[4] AIB, *Libro del Torrione 1834–1839*, document no. 21, art. 21–22.

Fig. 6.1 Example of wall *a scapoli e tocchetti*. Note the insertion of brick fragments in lieu of stone flakes

The walls might be locally reinforced through the implementation of “strong points consisting in masonry pillars in large blocks of carved stone, suitably laid in the most delicate areas of the building (wheel bases of the openings, meeting points of the wall)” and clamped “to the adjacent mixed masonry thanks to the building technique itself, that envisaged a laying of the alternatively protruding blocks on one side and of the pillar itself the other side” (Galliani and Mor 2006). In the case of the *Albergo dei Poveri* complex, we have testimonies of the adoption of such a technique in a 1660 contract for the supply of building stones (Boato 1991) and in the technical document mentioned shortly above[5].

This type of masonry, characterized by a disorderly texture, is as of rule coated, both internally and externally, by plaster, applied in two or three layers made up of the same materials (non-hydraulic lime and sand), but in different proportions and granulometry as the layer varies.

The building complex, during the eighteenth century[6], was fitted along the eastern façade with two isolated towers for the lavatories, where we may detect, thanks to a large spill of plaster, the presence of square blocks, in correspondence of the edges, and an orderly masonry texture, in the intermediate portion; such a difference may possibly be traced back to the leanness of the building that finds in the stone elements employed here a greater reliability than the one offered by markedly irregular *scapoli* (Fig. 6.2).

In the *Albergo dei Poveri* complex, even the use of solid bricks for the construction of walls with reduced thickness (less than 25–30 cm) was discerned, for

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[5] AIB, *Libro del Torrione 1834–1839*, document no. 21, art. 21.

[6] ASCG—*Fondo Albergo dei Poveri*, unit 871.

Fig. 6.2 In the lavatory towers, square blocks have been used

instance, in the buffering of the aisle between the isolated pillars punctuating the southern wing front facing the courtyard, on the first floor, and in some sub-window parapets[7] (Figs. 6.3, 6.4 and 6.5).

It is further worth noting that in the interventions carried out by the Provincial Infrastructure Department (*Genio Civile*) on the parts damaged by the bombardments, in the reconstruction of large portions of masonry the technique, widespread in the nineteenth to twentieth centuries, of inserting rows of bricks, in order to regularize the laying of the stone quoins, was adopted (Galliani and Mor 2006) (Fig. 6.6).

The historical Genoese buildings exhibit a consolidated use of wrought iron chains, inserted in the masonry, as static reserve, for the purpose of closing the masonry shell: the presence of such devices is revealed in the façade by the widespread presence of end-plate stakes (*stanghette*) in correspondence of the

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[7] In general, even the jambs and the discharging arches of the windows are made of bricks (Boato 1991). The presence of solid brick walls has likewise been detected even on the top northern tower floor.

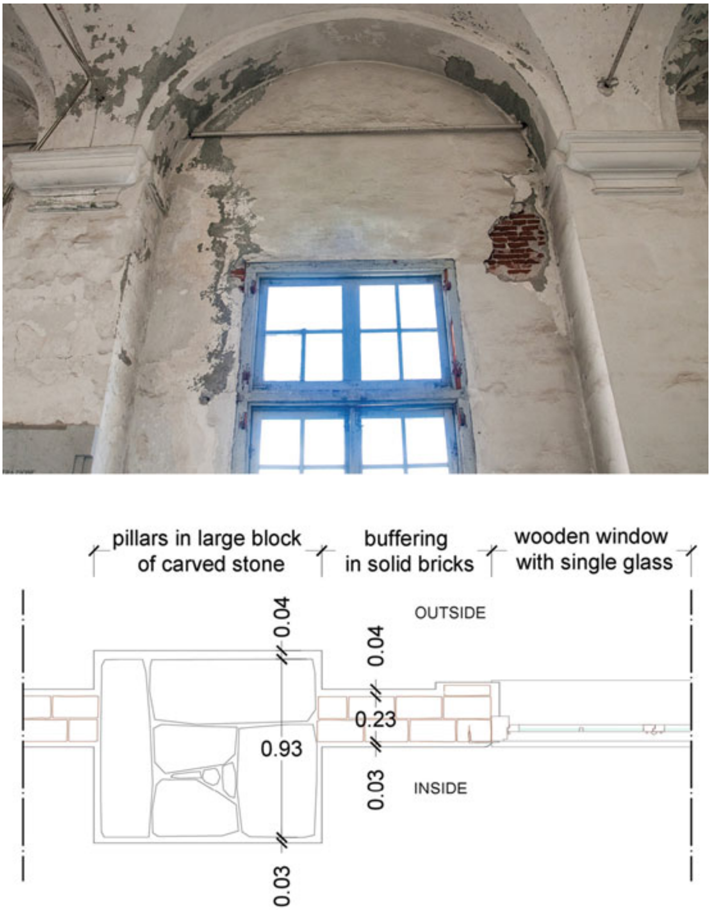

Fig. 6.3 Solid brick buffering in the southern wing hallway (photo and horizontal section)

corners and the spine walls, inserted in an eyelet obtained at the end of the tie rod[8] (Fig. 6.7).

The masonry works of the *Albergo dei Poveri* complex are mainly made of local stone, i.e. marly limestone (*calcare marnoso*) of Monte Antola, an excellent building material. The area on which the historical core of Genoa is built is in fact characterized by widespread surfacing of such limestone: it determined the prevalent type of foundations (direct and continuous) in the historical Genoese buildings and gave rise to the custom of opening new quarries near somewhat important construction yards, in order to ensure the procurement of stones and limit

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[8] AIB, *Libro del Torrione 1834–1839*, document no. 21, art. 23, 43–44.

Fig. 6.4 Sub-window parapet made of bricks (internal and external)

the transport costs (Boato 1991). The written sources relating to the case under examination confirm such a practice[9].

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[9] We might for instance mention the 12 May 1659 contract whereby the *San Barnaba* quarry, probably located near the Franciscan monastery of the same name, was rented, on the western ridge of the *Rio Carbonara* valley (ASG—*Fondo Notai Antichi*, 7348 Bartolomeo Castiglione).

Fig. 6.5 Solid brick masonry on the top northern tower floor

Fig. 6.6 Post-war reconstruction of masonry works in the advanced central body. We may observe the insertion of horizontal brick courses in the masonry characterized by irregularly shaped stone elements

6.3 Vaults and Wooden Floors

The changes the *Albergo dei Poveri* complex has undergone over time has resulted in the loss of many of its original horizontal structures, but it is reasonable to believe that most of the rooms were covered by vaults.

Fig. 6.7 End-plate stakes in correspondence of a spine wall (at the *top*). Metal chains removed at the time of the recent interventions for the redevelopment of the complex; quite visible are the eyelets built at the ends where the end-plate stake would be inserted (at the *bottom*)

From a morphological viewpoint, although we predominantly come across groin vaults (in the hallways, in the dormitories, and in the connecting areas), we also detect, in the large single-aisle rooms, barrel vaults with pavilion hands and lunettes, cloister vaults with lunettes in the representation atria, as well flying buttress vaults in the stairs. The constant formal presence of the vault element at the soffit conceals in actual fact two different structural solutions, both widely used within a Genoese context: masonry vaults and wooden floors.

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The masonry vaults, made of hewn stone and/or bricks, have been preserved better than the wooden structures; masonry vaults are always present on the bottom floors, due to their superior behaviour in the face of humidity (Fig. 6.8).

Clay-brick is given preference over stone where large span needs be covered, inasmuch as it enables thinner, hence lighter, structures to be obtained

Fig. 6.8 Examples of vaults on the bottom floors: barrel vaults in bricks and groin vaults in stone

Fig. 6.9 Groin vault in hewn stone (at the *top*). Brick vaults have in the wrench a minimum thickness of one head (at the *bottom*)

(approximately one half thinner); that is made possible thanks to the realization of reinforcement ribs *(ghiane),* again in bricks, visible at the extrados (Figs. 6.9 and 6.10); moreover, the modularity of the brick ensures that this building material exhibits good malleability and ease of implementation[10] (Galliani and Mor 2006).

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[10] The technical document of the western tower (AIB, *Libro del Torrione 1834–1839*, document n. 21, art. 32–33) stipulates that the vaults on the first two floors must be built for two-thirds with levelled *scapoli* and the remaining third with well-burnt bricks, termed *ferrioli* (Decri 2009), with a thickness that from the shutter (0.37 m) decreases down to the wrench (0.29 m). The vaults on the next floors must instead be built exclusively in *ferrioli*, with a variable thickness ranging from 0.29 m at the shutter to a 0.13 m at the wrench.

Fig. 6.10 Reinforcement ribs in a brick vault

Fig. 6.11 Lightened brick walls placed at the extrados of a vault; note that the wheel base is such as to enable a thin slab of stone (usually slate) to rest

Again at the extrados, to enable the realization of the floor of the above environment, preference over a massive filling is generally lent to recourse to a series of small brick walls, the distribution of which depends on the morphology of the vault and the arrangement of its elements (Fig. 6.11).

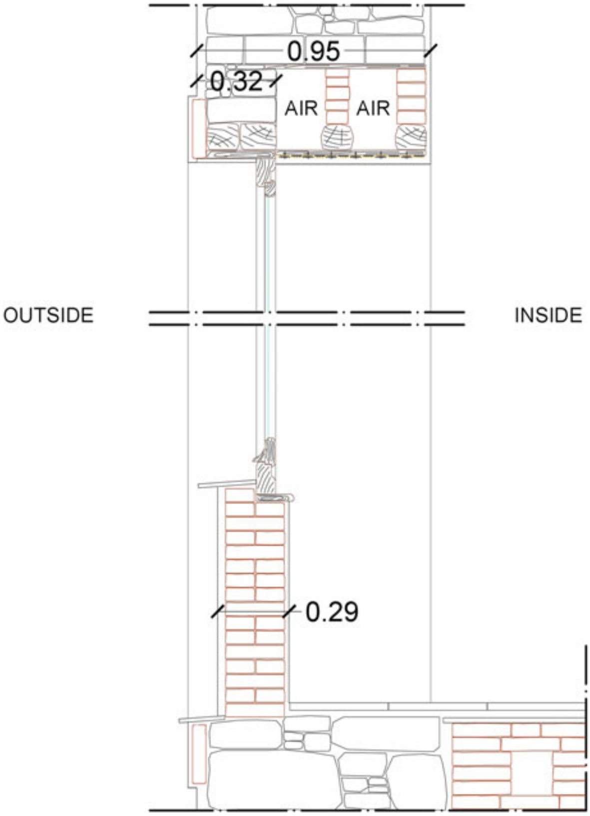
In the *Albergo dei Poveri* complex in Genoa, large use is likewise made of arches, round or three-centered, generally in stone or mixed, wherever inserted in the walls; in bricks, with a thickness of three to four heads, wherever free, to form the structural skeleton between isolated pillars or parallel walls (Figs. 6.12 and 6.13).

Fig. 6.12 Stone-and-brick arch in a wall to derive the gate of the window

Fig. 6.13 Brick arches between pillars and outer wall; the horizontal thrust is contrasted by the insertion of iron chains (AIB, folder 18)

Both the vaults and the masonry arches, besides being thicker by the shutter, usually exhibit at the extrados, in the area between the impost and the ribs, some abutments in loose material, with a stabilizing function. In order to contrast the horizontal thrust, moreover, use is made of metal chains, fastened, as in the case of the walls, through the aid of end-plate stakes. The chains may be placed both at the extrados and at the intrados, in correspondence with the ribs or the impost of the thrusting element (Galliani and Mor 2006).

Fig. 6.14 Main warpage of a wooden flooring system brought to light during the restructuring works on the northern wing, in 1968 (AIB, folder 58)



It is likely that all the wooden flooring systems of the *Albergo dei Poveri* complex have been lost: their presence is documented in correspondence of the top floors, where they were preferably adopted on account of their lightness and their static behaviour[11], but we also have a testimony thereof in some archive photos, showing the vestiges of a double warpage flooring system, with the main beams grafted onto the perimeter wall, on the one hand, and resting on the extrados of a large arch in bricks, on the other. Here the beams, with circular section and huge diameter, cover a span of approximately 6 m and are placed at a centre-to-centre distance of about 2.25 m; we can read on them the traces of the common rafters, placed at a reduced wheel base (around 25–30 cm) (Fig. 6.14). Above the common rafters, the joists were laid in planks next to one another, generally to support the screed and the overlying pavement.

The head of the main beams is usually lodged in the wall on a brick or a sleeper beam, with the function of distributing the loads transmitted by the attic; to prevent

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[11] Unlike the vaults, the flat slabs do not occasion lateral thrusts on the support structures.

Fig. 6.15 The wooden beam is anchored to the wall thanks to a pair of metal brackets (*vele*) (Boato and Decri 2009), fastened through nailing at the ceiling and at the extrados of the terminal part of the beam; they are fitted with an eyelet in which the end-plate stake is inserted

the slippage of the beams and ensure anchoring onto the masonry, metal chains, fastened onto the head through large nails, and, outside the wall, through end-plate stakes, were arranged (Galliani and Mor 2006) (Fig. 6.15).

Within the Genoese context, the essences used to realize the warpage of the flooring systems were chiefly the larch (*Larix decidua*), the oak, the fir (*Picea abies*), the pine of Corsica, and the chestnut (*Castanea sativa*); poplar (*Populus alba*) and elm (*Ulmus campestris*) for the planks, oak (*Quercus petraea*) for the wooden chains (Boato and Decri 2009; Galliani and Mor 2006; Montagni 1993).

The use of false ceilings, often in reed mats plastered on the spot, was widespread in the seventeenth century, as a finish of purely rough-hewed wooden floors. The mats could be bolted directly onto the superstructure or equipped with their own supporting structure hanged onto the warpage of the floor by means of wooden elements termed *candele* or *pendini*; between one floor and the next, therefore, an air chamber of variable consistency would be created[12] (Fig. 6.16).

The wattle false ceilings could be flat or shaped as vaults; in the latter instance, the supporting structure was rather complex and realized in such a manner as to be almost entirely self-supporting, relegating the *pendini* to a mere static reserve, once the realization was concluded[13] (Figs. 6.17 and 6.18). In correspondence of the

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[12] The mat was fastened onto the support structure by means of suitable large-headed nails, planted between one reed and the next (Galliani and Mor 2006).

[13] The structure of a wattle vault consists of wooden ribs made up of coupled elements and staggered joints nailed to each other, hardened by transversal wooden elements, forcibly inserted (Galliani and Mor 2006).

Fig. 6.16 False ceiling of a flight of stairs: the reed mat is bolted to a series of common rafters fastened at the soffit of the flooring system elements

Fig. 6.17 Interwoven reed mat

impost, on the perimeter wall, wooden beams were placed in order to preserve the vault from moisture.

In the historical Genoese buildings, we also detect slate plate false ceilings, especially suited to moist environments: the thin plates are pre-drilled and bolted to

Fig. 6.18 The system of wooden supporting structures of a wattle groin vault

Fig. 6.19 Soffit of an opening made with slate plates nailed to a supporting wooden structure

the overlying structure, and then plastered; in the *Albergo dei Poveri* complex, such as a type of finishing was detected at the soffit of the lintel of some openings, as well as in the lower part of a vault at the bottom (Figs. 6.19 and 6.20).

Fig. 6.20 Slate plate in the lower part of a wattle vault

6.4 The Roof Structures[14]

The originality of the technical solutions distinguishes the covering structures in Genoa from those of the neighbouring cultural and geographic areas, which consists of the tight connection of vertical and covering structures: in Genoa, it's unusual that the use of roof trusses as *capriata*.

Starting from the second half of the sixteenth century, the distinction between the covering of big spaces, such as churches and assembly rooms, and of residential buildings of greater importance emerges. In the former, the primary roof structure is supported by short pillars resting on arches or on the ribs of the vault below. In the palace or villa architecture, the coverings (normally hip roof) have load-bearing structures in accordance with flat frame schemes (*telai piani*), with purlins resting on braces and where the hip rafters have no bearing function in the same way as the common rafters, on which the planking is fixed (Galliani 1984)[15].

Above the planking, the roof covering in slate plates (*abbadini*) was placed directly, laid with triple overlapping and staggered joints in both directions; the plates were fastened through nails, along the upper strip, and through lime mortar, by the lower strip (Fig. 6.21).

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[14] This section is partly taken from the contribution presented by the authors of this chapter to the Shatis '15. 3rd International Conference on Structural Health Assessment of Timber Structures, Wroclaw— Poland, September 9–11, 2015 (Acacia and Casanova 2015).

[15] According to thesis upheld by some researchers, this technical solution reminds the naval building techniques (Galliani 2001).

Fig. 6.21 Slate roofing laid on a wooden plank

The choice of the wood species used in the roof structures depended mainly on two factors: their availability in the woods held by the Republic of Genoa and their workability using the tools available at that time. It is usually possible to find larch (*Larix decidua*) or oak (*Quercus petraea*) wood in the primary beams (principal rafters and purlins) and chestnut (*Castanea sativa*) in the secondary structures (common rafters and planking) (Galliani and Mor 2006).

The *Albergo dei Poveri* offers examples of both of the typically Genoese covering types, identified in specialist literature, because it shows extended bodies of the building (dormitories, churches, oratories, and corridors) and towers in the angles and in the central bodies. Moreover, there are also lattice truss scheme where the principal rafters are contrasted by two or more collar ties (Fig. 6.22).

Unfortunately, the historical events[16] and the passing of time brought to the loss of many original coverings, which are possible to identify, however, according to the typology they belonged to, only through an archive research and study of the building features of the bearing walls below.

The prevailing typology of the outer wings and of the central cross ones, that is to say the parts connecting the angular towers to the central ones, is one of the purlins (*arcarecci*) supported by short pillars which rest on masonry arches, provided with a tie rod. Above the main roof structure, there are common rafters (*travetti*) which follow the pitch slope and rest on the sleeper in proximity to the masonry. A self-supporting vault, both barrel (with lunettes) and groin type, is connected to the beams of the roof structure through hangers (*pendini*).

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[16] Above all incendiary bombs during the Second World War in October 1942.

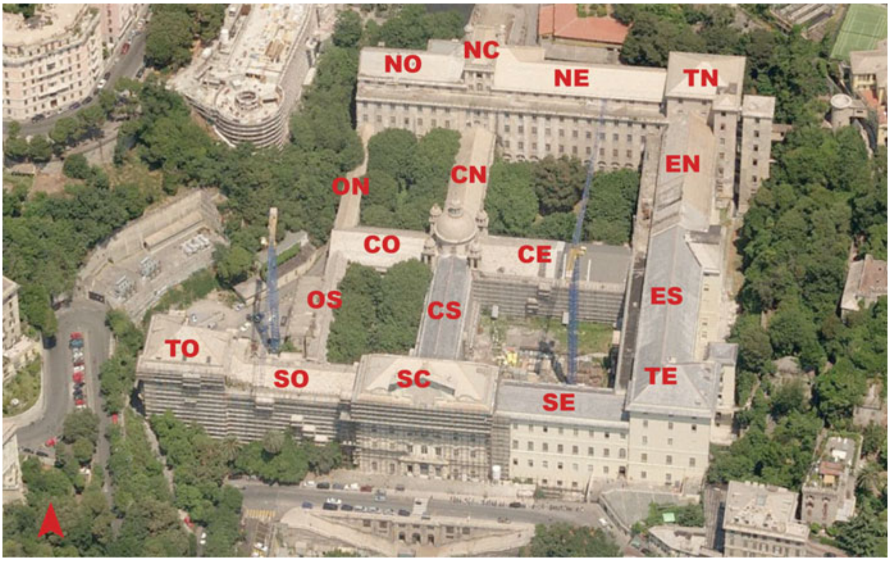


Fig. 6.22 Aerial view of the *Albergo dei Poveri* (taken from Google maps). The building has been subdivided in bodies, identified through a code

In the whole building, the spacing between two arches (or roof truss, in other cases), that is to say the effective length passing through the purlins, varies from 4.3 to 4.6 m.

There are some variations of the structural scheme in the *Albergo dei Poveri*, due to the position of load-bearing walls, both outer and inner, and of pillars, and their longitudinal and transverse spacing (Fig. 6.23).

The base scheme can be found in the wings of the central cross, with five or seven short pillars, according to the span of the arch below (respectively 9 and 16.5 m) (Fig. 6.24); in the case of the covering above the church nave (CS1), the covering structure rests on a masonry barrel vault instead of having a sequence of arches.

A first variation can be found in the eastern wing (EN-ES) which shows, on various floors, a central pillar supporting a couple of arches of about 6.75 m wideness; this allowed to build a pillar on it, higher than 4 m in order to support the ridge beam, making the attic practicable. Until the 1960s, there was only a dormitory in every building at the floor below.

Another example is the one adopted in the southern wing (SE-SO) organized on the various floors with a corridor (north, 4.4 m wide) useful to large single span rooms placed south (7.8 m wide); the intermediate bearing wall extends to the roof and supports without interruption a sleeper distinguished by a cross-section which is lower than the other horizontal beams. The asymmetry of the wall bearing structures is hidden by the roof pitches of equal depth; also in this case the attic is practicable.

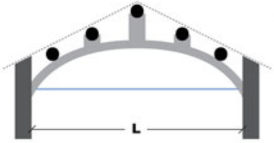
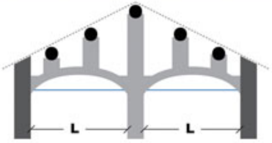
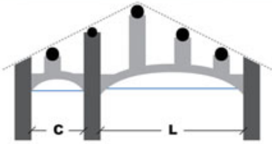
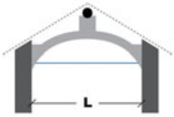
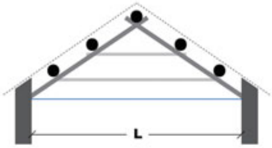
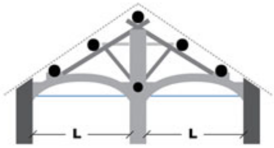
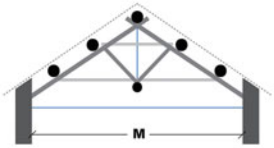
Structural scheme	Body	Dimensions	Span	Effective length	Period of construction	Conserved
	**CS^{1}**	11 x 13 m	L= 8,61 m	/	1656-1672	YES
	CO	19 x 30 m	L= 15,53m	4,45 m	1672-1740	YES
	CN	11 x 43 m	L= 9 m	4,3 m	1672-1740	YES
	CE	19 x 47,5 m	L= 16,55 m	4,4 m	1672-1740	NO
	**EN**	17 x 54 m	L= 6,75 m	4,3 m	1672-1740	NO
	ES	17 x 55,5 m	L= 6,75 m	4,3 m	1672-1740	NO
	**SE**	15 x 40 m	C= 4,4 m L= 7,8 m	4,6 m	1656-1672	NO
	SO	15 x 36 m	C= 4,4 m L= 7,8 m	4,5 m	1672-1740	NO
	**ON**	5,7 x 47 m	L= 3,8 m	4,35 m	1800-1838	YES
	OS	5,7 x 47 m	L= 3,8 m	4,35 m	1800-1838	YES
	**CS^{2}**	11 x 35 m	L= 8,9 m	4,3 m	1672-1740	NO
 	**NO**	15,5 x 34 m	L= 5,8 m M= 12,7 m	4,5 m	1672-1740	YES

Fig. 6.23 Abacus of the standard sections of coverings of the *Albergo dei Poveri* for the outer wings and of the central cross ones. *Dimensions* referred to the covered building; *effective length* to the purlins; *conserved* refers to the main roof structure (trusses and purlins). CS1 refers to the northern part of the covering identified by CS, corresponding to the church nave. CS2 is the southern part, above the room located in front of the church. Iron tie rod are indicated in *blue*

Fig. 6.24 Primary beams supported by short pillars on arches in the coverings of the northern wing of the central cross (CN)

The last version is in the western corridor: here the slight span (only 3.8 m) allowed to build only the central short pillar supporting the ridge beam.

The covering CS-south (CS2) follows a different scheme: the arch-short pillars system supporting the purlins is substituted by a wooden framework, made by a principal rafter couple (locally denominated *cavalletto* or *incavallatura*) with two series of horizontal collar tie; under the connection between rafter and wall, there is a tie rod.

The covering of the western body of the northern wing of the complex is one of the few which survived the wars, the post-war rebuilding and the interventions carried out by the University in the last decades; it shows unique features in the series of coverings present in the *Albergo dei Poveri*[17].

The surface interested by the covering is 600 square meters wide; it is partially delimited by a stone and brick masonry, spaced out by three couples of brick arches, placed at a distance of about 9 m and having a span of about 5.8 m (Fig. 6.25).

The principal rafters rest on the central pillar, which towers till the ridge, and on small pillars placed on the arches: they support the purlins which reach the maximum height of 20 m. The horizontal beams are placed on the ridge and divide each pitch in three equal parts; between two couples of big arches there is a wooden truss, which take up, as already said, the covering structural scheme CS2, with some variations (Fig. 6.26).

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[17] Nowadays, the covering NE isn't distinguishable anymore because of the heavy post-war violations; considering the spacing between the pillars below, a scheme similar to the one NO can be assumed.

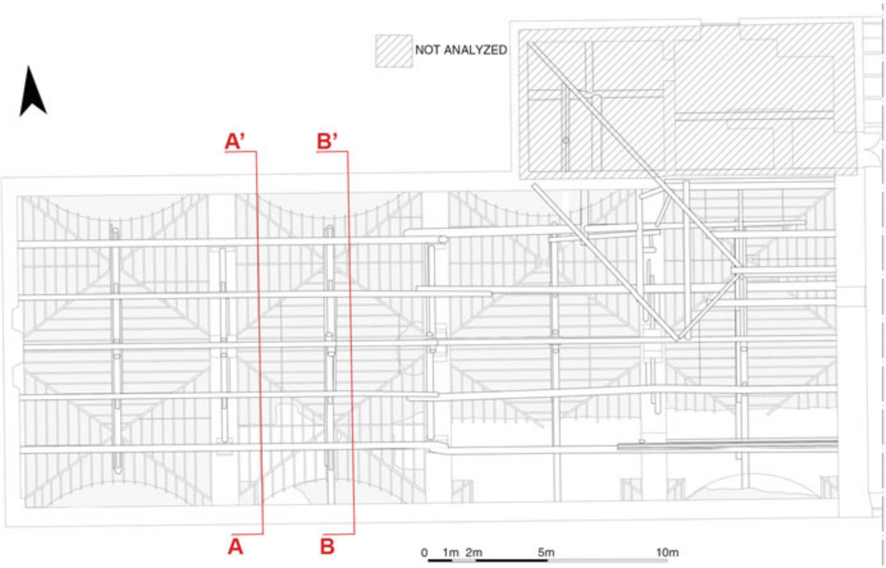

Fig. 6.25 Plant of the covering structure of the north-west wing

Fig. 6.26 Roofing structure of the north-west wing. The horizontal beams rest on wooden pillars, struts, and frames

Both in the arches–pillars system and in the frame, the effective length of the pitch rafters is reduced by the presence of a brace on each side, which in the first case insists on the base of the pillar, in the second on a longitudinal beam which serves as collar tie between a couple of arches and the other, fixed through iron

Fig. 6.27 On the small pillars rest the horizontal purlins and the struts sustaining the next order

Fig. 6.28 The braces of the frame rest on the beam-chain

elements (Figs. 6.27 and 6.28). The trusses show also an iron element acting as tie rod which from the higher cross of the rafters goes down to support the longitudinal collar tie. In proximity of the haunches of the arches and under the joint of the intermediate trusses, there is an iron tie rod (Fig. 6.29).

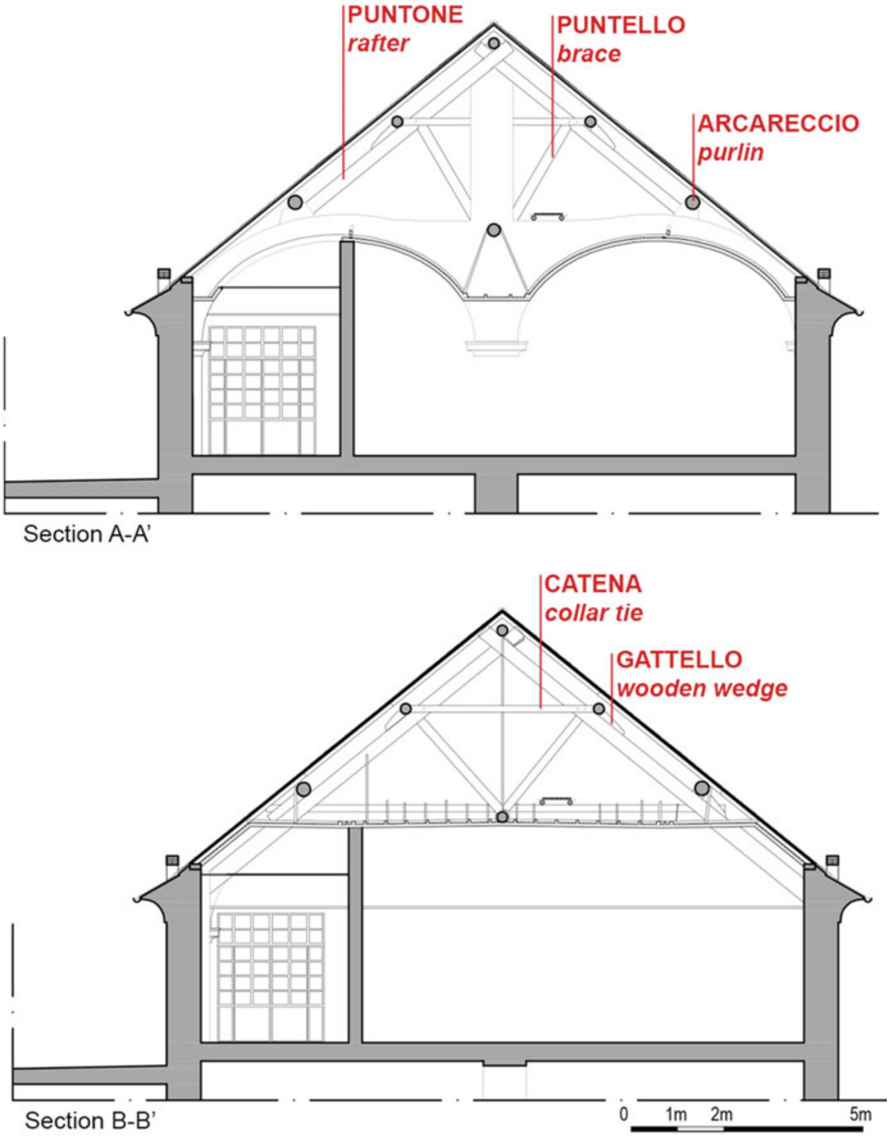

Fig. 6.29 Sections A-A′ and B-B′. Alternation of bearing structure on arches and pillars and roof trusses. The principal rafters have diameters which vary from 24 to 30 cm; the purlins from 23 to 34 cm; the braces from 22 to 26 cm; the collar ties are all almost with rectangular section with variable dimensions from 15 × 8 cm to 23 × 15 cm

The ridge joint between the principal rafters is obtained by half-lap joint (Fig. 6.30).

The purlin-rafter joint is resolved by *gattelli*, that is to say wooden wedges nailed to the extrados, which can be plain or elaborate to obtain a housing for the purlin (Fig. 6.31).

Fig. 6.30 Semi-mortise by the coupling ridge

Fig. 6.31 Wooden wedge nailed to the extrados of the rafter

In proximity of the eastern wall, the ridge is higher to meet a widening of the plant, following the same building logic described above (Fig. 6.32).

The roof structures of the angle and central towers of the *Albergo dei Poveri* were partially lost: only the ones of the western (TO) and northern (TN) towers survived. Both show the flat frame typology although with some differences.

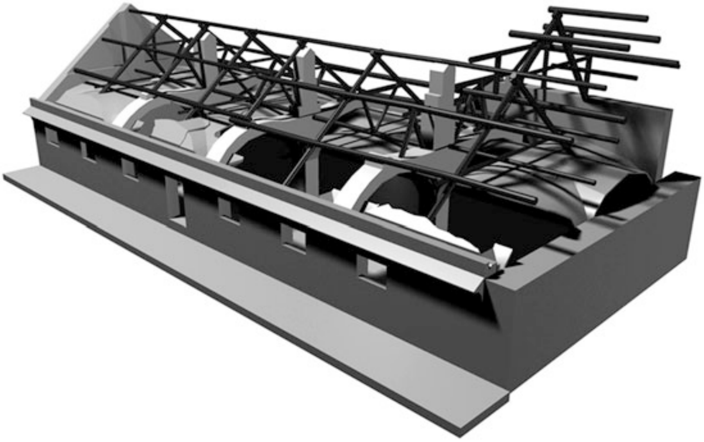

Fig. 6.32 In order to facilitate the comprehension of this complex structure, a three-dimensional tie rod model has been created which includes the main roof structure (principal rafters and purlins), the masonry parts (arches, pillars, and outside walls) and the false ceiling

The western tower has three subsequent orders of horizontal purlins (*costane*), supported by spine walls and braces which rest also on the outer walls where a sleeper is located (*trave radice*) (Galliani and Mor 2006; Montagni 1993). In the building specifications about the western tower, the wood species and the sections suitable for each element to adopt are accurately described, as well as the making procedures of the joints[18]; analyses conducted on the main elements of the structure, during the recent redevelopment works, have generally confirmed what is laid down in the technical document, having detected pine and spruce pine for the main elements and chestnut for the joists[19] (Fig. 6.33).

Concerning the northern tower, the purlins (five orders) and the braces rest on an inner wall and pillars on arches (Figs. 6.34 and 6.35).

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[18] The horizontal purlins are envisaged in pine, 90 cm in diameter, linked together through iron harpoons in the heads; of the same timber quality are the ridge beams, albeit with a smaller diameter (30 cm); the sleeper has instead a square section shape (13 × 32 cm), in chestnut, made of elements joined to each other through interlocking and nailing; the hip rafter/*puntone* is made of oak and links horizontal purlins, ridge beam, and sleeper; the common rafters, instead, are made of well-seasoned chestnut wood, with a square section (13 cm one side). The plank, too, is envisaged in chestnut (AIB, *Libro del Torrione 1834–1839*, document no. 21, art. 38-39-40).

[19] The study campaign of 1999–2001 carried out by the *Direzione Lavori* (Work Supervising Management) resulted in the preparation of some synthesis thematic maps, starting from the geometric mapping of the main and secondary roof structure of the coverings. These studies allowed to determine the wood species subdivided according to their strength to evaluate the reduction of the resistant section (range %), determining the density and the humidity rate (range %).

Fig. 6.33 Flat frame system in the western tower: on the right, the spine wall on which the braces rest

Fig. 6.34 Flat frame system in the northern tower: the horizontal purlins rest on a spine wall and on pillars built over large masonry arches; their span is reduced through the insertion of braces. Below the roof, we have an example of a hanging wattle vault

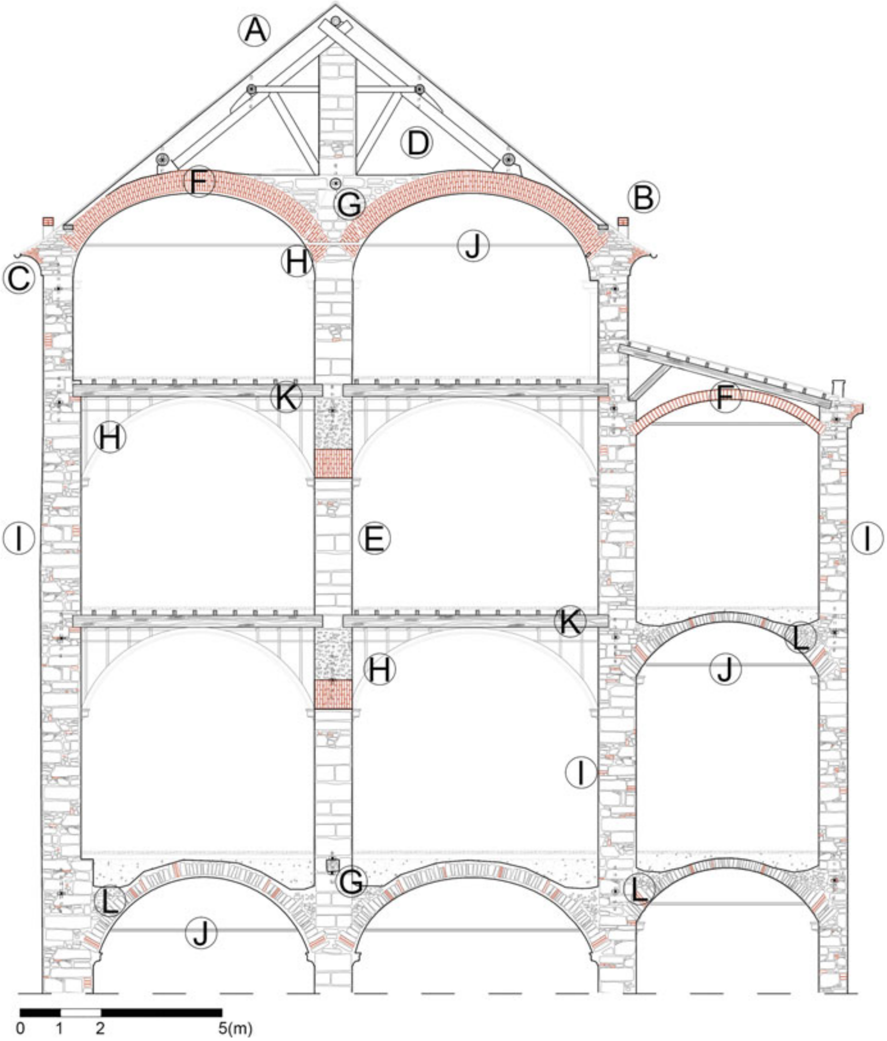

Fig. 6.35 Vertical section of the north-west wing, from the second level to the top. (**a**) roof covering in slate plates (*abbadini*); (**b**) *muretto d'attico* (a short wall located on the roof coating nearby the eaves); (**c**) eaves; (**d**) wooden roof structure; (**e**) pillar in blocks of carved stone; (**f**) arch in solid bricks; (**g**) wooden beam used as tie rod between two pillars; (**h**) wattle vaults and its structure; (**i**) bearing wall with large-sized splitted stone elements and flakes; (**j**) iron tie rod; (**k**) wooden floor; (**l**) vault in hewn stone

6.5 The Windows

Beginning with the fifteenth century, in the Genoese area doors and windows, one of the elements most exposed to atmospheric agents, and thus to deterioration, are built mainly in wood; the use of glass is introduced, instead, in the early seventeenth century (Galliani and Mor 2006).

Doors and windows are elements frequently subjected to maintenance, transformations, and replacements, due to the natural degradation of materials, changes in taste and in the performances demanded of them; as regards the *Albergo dei Poveri* complex, the most significant event in their history has certainly been World War II, with the allied bombardments against the city of Genoa, followed by several more or less consistent maintenance and repair interventions. Despite the copious losses in terms of material testimonies, it is still possible to trace their essential distinguishing features capable of establishing a continuity between them and the Genoese context.

The large variety, type- and design-wise, of windows found in the *Albergo dei Poveri* complex is in fact escorted by some elements, such as the fixed wooden frame, the movable frame with glass and the dark interiors. The use of external blinds in Genoa spreads in the course of the nineteenth century (Montagni 1993), but they are entirely absent from the building under examination.

We learn from the technical document of the western tower, where reference is repeatedly made to what has already been done in the eastern tower, that the fixed frame was supposed to be made of well-seasoned chestnut wood, 18 cm thick, finished with an inward cornice, and with mortises and nails to join the elements at the corners. The fixed frame is fitted with iron *parpaglioni* (Paganini 1857) for slantwise fixing and with hinges for placing the dark interiors (Fig. 6.36). The glass frame, normally thin in Genoese buildings, is in well-seasoned pine (*squera)*, with

Fig. 6.36 The fixed frame, devoid of sub-frame, is anchored onto the jamb through metal clamps

Fig. 6.37 The windows of the *Albergo dei Poveri* complex are divided into squares through slender glazing straight edges

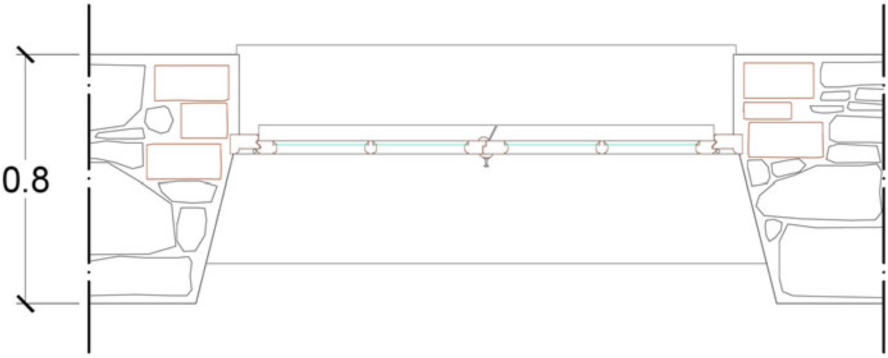

Fig. 6.38 Horizontal section of a window. Note the solid brick jambs

dripstone; the glass is probably described as "large" to indicate not particularly reduced thicknesses (Fig. 6.37). The dark interiors, consisting in adjacent plates, are likewise envisaged in pine[20].

The window, devoid of any sub-frame, is inserted in a peep-hole (opening) that generally shows, as hinted at earlier, solid brick jambs and, on top, a relieving arch with a brick or stone buffering, depending on the thickness of the wall. The lintel of the windows is often coated with slate plates or plastered wattle, fastened onto a wooden frame. The parapet may be of the same thickness as the walls (in stones) or less thick (often in bricks) (Figs. 6.38, 6.39 and 6.40).

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[20] AIB, *Libro del Torrione 1834–1839*, document no. 21, art. 48-49-50-52.

Fig. 6.39 Vertical section of a windows. Note the parapet in solid bricks and the inner lintel with plastered wattle

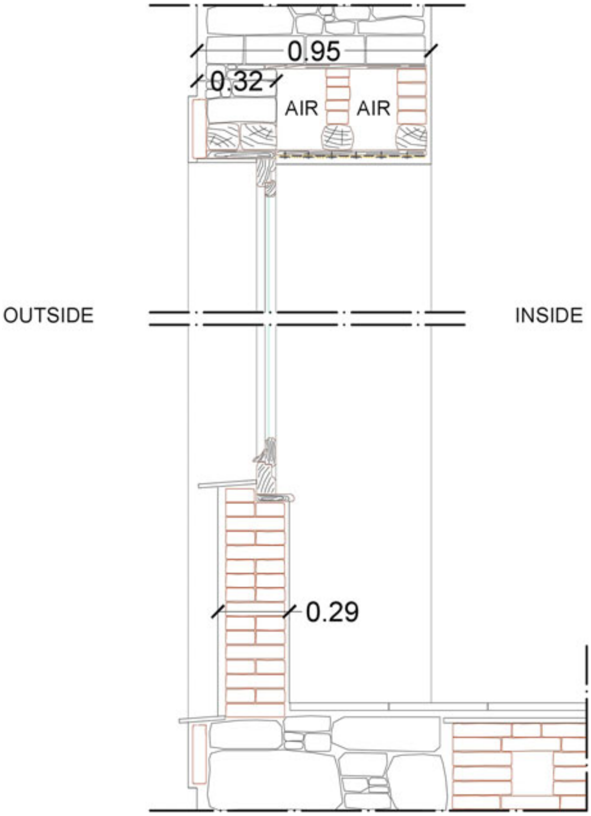

Fig. 6.40 Lintel of a window covered with plastered wattle

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Chapter 7
Thermal Behaviour and Energy Demand

Giovanna Franco and Marco Cartesegna

7.1 General Masterplan: Identification of New Compatible Uses

The phase to investigate morphological and constructive characteristics, as well as to elaborate the modifications the areas have been subject to over the centuries, initially resulted, in agreement with the University's Technical Departments, in the definition of a general masterplan identifying new uses necessary to fully establish the teaching of Humanities.

In summary, the definition of the new uses regarded:

- the distributive layout of the complex, identifying external access systems, distance covered, and use of the environments to be restored;
- the current emergency escape and exit systems, identification of the most obvious deficits, and the definition of new fire emergency exit systems (including a new staircase in the north wing);
- the identification of new routes through the complex on the urban public level (linked between the higher part of the nineteenth century settlement and the ancient part) also thanks to the creation of a large public park in the valley beyond and with the inclusion of new mechanical movement systems.

The new uses proposed have taken into account the activities already set up, the characteristics of the areas and paths, not only between the interior and the exterior

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but also within the same floor (in order to guarantee a ring-shape system of distribution).

The long corridor on the sea-front entrance level—which was once used to access the service area partially found in the basement (boiler and laundry, oven, kitchen. . .)—could become in the next future the main public distribution artery, linking the main entrance with the valley beyond and the city upland. Research led to the rediscovery of these service spaces—which are still well equipped—and put them to use again; complete restoration could further valorize this for public means. Similarly, the areas below the main symmetrical stairway that connects *Via Brignole Sale* with the main entry road (which could be closed to traffic to create a small square) may also be used for public catering purposes.

The *Albergo dei Poveri* could have, therefore, as well as access to the university areas already created within the east wing, a mixed entry which, from the main doorway to the centre of the south wing, would lead to the stairways and entrance hall on the *piano nobile* found immediately in front of the church. The project to reuse this level—where the renovated *Aula Magna* is also located (former women's Oratory)—includes the reopening of the still-consecrated Church of the Immaculate for worship again, and the former men's Oratory to be used as a teaching-museum laboratory, also using the area in front of the Church and that to the north which was once an infirmary. The south-west and west wings could be set up as a museum of the *Albergo dei Poveri*, archives and offices. The teaching areas will be extended to the north wing of the main floor—adjacent to that already renovated in the east—also using the main valley-side entrance.

The areas to be renovated on the second floor are mainly found in the north and west wings, with the idea of installing a new Jurisprudence Library to join that of Political Sciences which is already in use, a canteen in the area north of the church (which was once used as lodgings for the nuns) and common rooms and study areas in the west wing. The third and fourth floors are only found in the east wing, where the Jurisprudence library and department offices are planned, and in the north which is to be used as university accommodation. More accommodation and related services are located on the sixth and highest floor, which is found only in the north wing (Figs. 7.1 and 7.2).

The design of the areas must take into consideration the morphological characteristics of the surroundings, which in some cases reach 6 m in height causing problems both in terms of indoor comfort and also for the perceptive aspects (Figs. 7.3, 7.4, 7.5, 7.6, 7.7).

7.2 Quantifying Energy Needs: Power Demand for Heating

The calculation of the energy demand for the closure system (what is called envelope, although this term is not suitable for the historic building) was completed on the part of the complex that is yet to be renovated for a total of 135,063 m^3 of net volume (net of the entrance halls, staircases, and public throughways). All of the

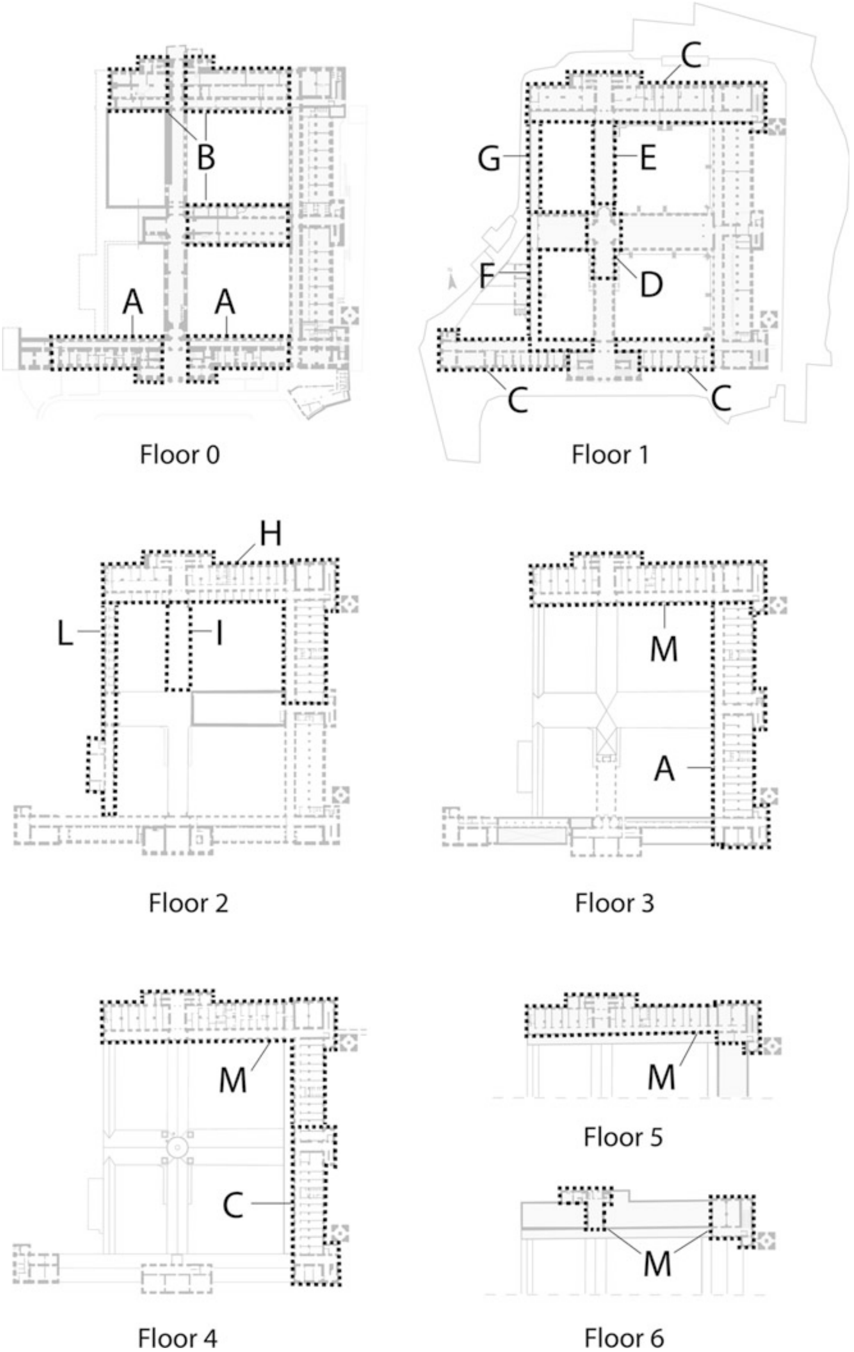

Fig. 7.1 Identification of new compatible uses for the complete renovation of the building as didactic pole for Humanities. *A* university offices, *B* library—archives, *C* classrooms and offices, *D* church, *E* laboratories, *F* museum, *G* bar, *H* Jurisprudence Library, *I* canteen, *L* study rooms, *M* university accomodation (Macchioni, E. 2016)

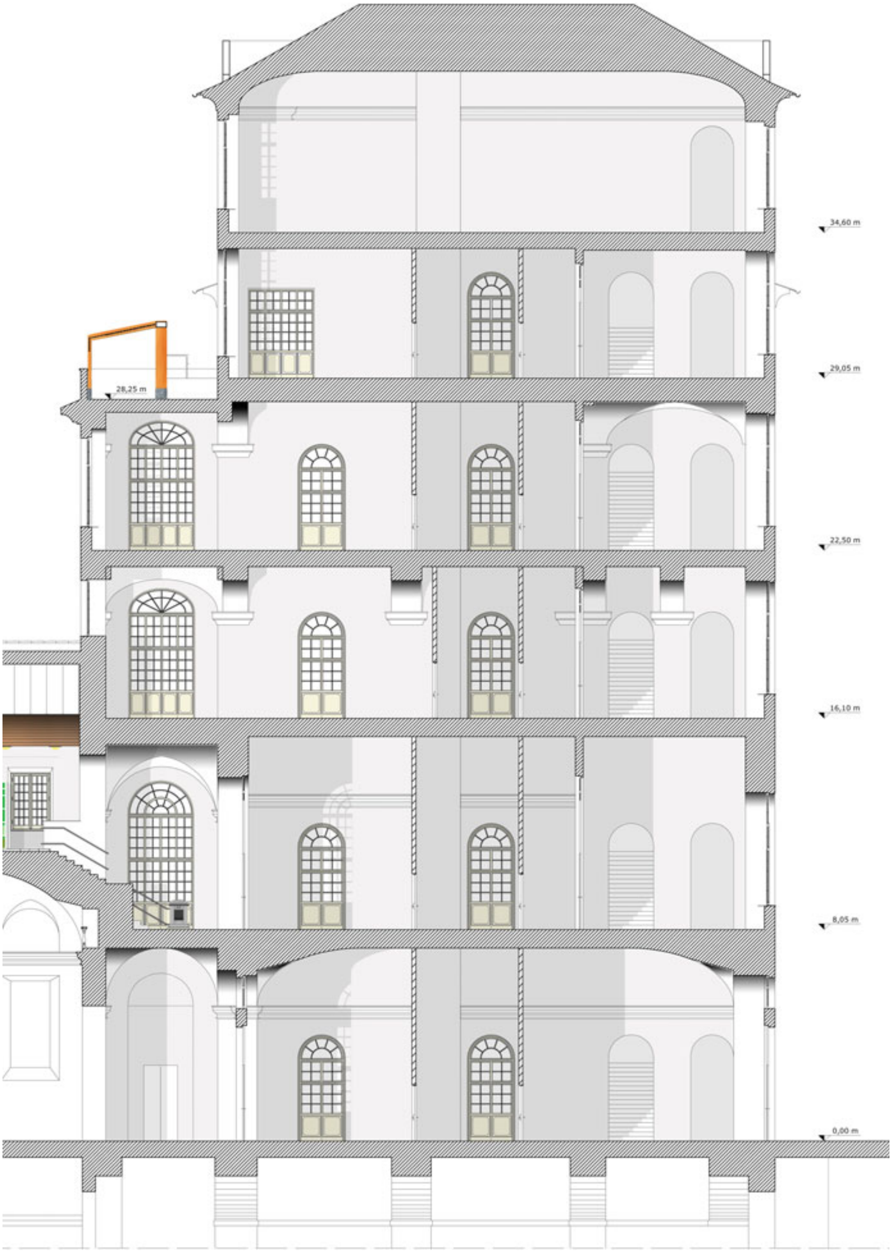

Fig. 7.2 Cross section of the northern wing (Bresolin, G., Stagnaro, I., Tomasetti, G. 2012, Master course in Architecture)

Fig. 7.3 Proposal for the university accomodation in the northern wing (Fanciotti, F., Occhipinti, C., Ferrando, C. 2012 Master course in Architecture)

Fig. 7.4 Proposal for the didactic laboratory in the north-south axis wing (Engrand, T. 2013 Master course in Architecture)

areas making up this volume will be heated, but not all areas will be equipped with a cooling or air handling system, as specified in the table below (Table 7.1).

To calculate the energy demand, considering the complexity and size of the subject, we have chosen the steady-state method (or nearly steady-state method)

Fig. 7.5 Proposal for the canteen above the didactic laboratory (Battistini, J., Leonardi, M., Choquet, M. 2014 Master course in Architecture)

which is based on rather broad evaluation times—generally monthly—which take into account the effects of the thermal capacity of the building using corrective factors. If on the one hand this method provides more approximate results compared to dynamic simulation methods, on the other it requires less data to determine the calculation parameters. From all the steady-state method software available, TerMus was chosen, ACCA software with subject input, in compliance with:

- Legislative Decree 192/2005 and President of the Italian Republic Decree 59/2009
- National guidelines for energy certification
- The most recent National Standards UNI in energy savings (UNI/TS 11300-1, UNI/TS 11300-2 and UNI/TS 11300-4)
- The regulations of the Liguria Region

In constructing the simulation model, some approximations were made to transfer and translate the real data to the calculation programme which is either geometric or constructive in type. From the geometric viewpoint, the monumental environments have curved geometrical forms that are rather difficult to correctly transfer to the three-dimensional model and, thus, the morphology of the environments was approximated to a parallelepiped form of the same size as the existing one. In the meantime, a BIM model was under construction and hopefully, in the future, it will be also used for energy calculations.

From the constructive point of view, the characteristics of the perimeter walls have been approximated considering the value of the thickness of the plaster covering the external and internal walls as being uniform throughout. Even the

Fig. 7.6 Proposal for the Jurisprudence Library in the north and east wings (Battistini, J., Leonardi, M., Choquet, M. 2014 Master course in Architecture)

characteristics of the flooring have been hypothesized where direct sampling or surveys have not been possible, similarly to examples of the same constructive periods or based on subsequent historical modifications documented and found in the various archives consulted. No consideration was made of solar generation and protection in accordance with the calculation method and regulations, which are not relevant during the winter period.

To calculate the thermal energy demand, it was therefore necessary to define the parts of the covering that confine with the exterior, those in contact with unheated rooms and the thermo-physical characteristics of dispersing elements. For further

Fig. 7.7 Proposal for the Jurisprudence Library in the east wing (Bruzzese, S., Famoso, J., Fogale, G., Lupi, C., Stanchi, F. 2013 Master course in Architecture)

information on the constructive characteristics and their thermal behaviour, please see the specific relevant chapters.

Once the geometric and constructive data was gathered, the thermo-physical properties were determined in reference to Standard UNI 10351 Building materials—thermal conductivities and vapour permeabilities.

Table 7.1 Identification of the types of system based on the various uses thereof

	Heating	Cooling	Air handling
Classrooms	x		
Laboratories	☐		
Bar	☐		
Library e archives	☐		
Jurisprudence Library	☐	☐	☐
Church of S.M. Immacolata	☐		
Canteen	☐	☐	☐
Museum of the hospice for the poor	☐	☐	☐
University accommodation	☐		☐ (Bedrooms only)
Staff room	☐		
Common rooms	☐		
Offices	☐	☐	

In conclusion, the dispersing cover has been divided into various portions, each of which has the same properties and characteristics in terms of: thickness, thermal conductivity, surface mass, and thermal aeric capacities as listed below.

7.2.1 Thermal Characteristic of Dispersive Elements: External Walls

The transmittance value of the walls was determined hypothesizing the same stratigraphy for all the walls of the complex (internal plaster with an average thickness of 3 cm, walls in irregular stonework with variable thicknesses, external plaster with an average thickness of 3 cm) and defining the conductivity of the materials according to the values proposed by regulation UNI 10351 (03/94) (Table 7.2).

7.2.2 Roofs

No deep study was made of the characteristics of the stratigraphy during the calculation as none of the rooms of the complex confine directly to the exterior, but have large attic areas. Therefore, the "room confining with attic area with un-insulated roof" option was defined considering rooms adjacent to other unheated rooms, and the various stratigraphy of the attic areas (both of old build and recent construction) was calculated (Table 7.3).

Table 7.2 Transmittance values of the external load masonry walls in relation to their thickness

Stratigraphy of the walls		Thickness [cm]	U [W/(m^2 K)]
1	Lime mortar plaster (external)	45	2.26
		60	1.9
		75	1.61
2	Stone walls	80	1.57
		90	1.44
		95	1.39
3	Lime mortar plaster (internal)	100	1.34
		110	1.24
		120	1.16
		125	1.13
		135	1.06
		140	1.03
		150	0.98
		160	0.93
		170	0.88
		180	0.84
		190	0.80
		200	0.77
		285	0.56

Table 7.3 Transmittance values of the roof

Stratigraphy of the roof		U [W/(m^2 K)]
1	Slates of “ardesia” stone	
2	Wooden plank	2.38

7.2.3 *Attic Floors*

This paragraph contains the calculations of the thermal behaviour of different types of attic floor and ceilings of the *Albergo dei Poveri* as shown in picture (Fig. 7.8) (Table 7.4):

- masonry brick vaults
- wooden structure vaults
- brick arches and wooden structure vaults
- reinforced concrete floors
- plasterboard false ceiling

The upper roof covering the top floor, wherever left undamaged by the bombings of the Second World War, is made up of a wooden structure with a wattle mat covering nailed to it and then plastered over. The calculations did not take into account the contribution of the wooden elements that support the lathes due to the small proportion represented by this part of the covering of the overall value and the desire to consider the worst case scenario (Table 7.5).

Fig. 7.8 Representation of the different types of attic floors (Macchioni, E. 2016)

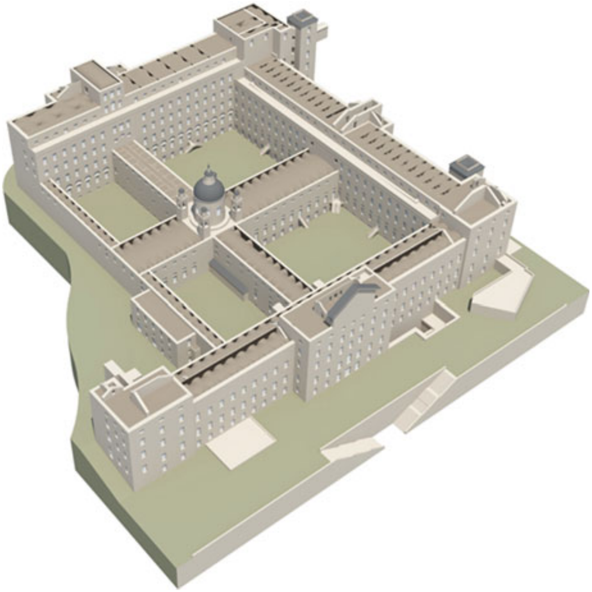

Table 7.4 Transmittance values of the masonry brick vaults

Stratigraphy of the masonry brick vaults		U [W/(m^2 K)]
1	Scratch-coat plaster in lime mortar	
2	Brick masonry and mortar	1.65
3	Lime mortar plaster	

Table 7.5 Transmittance values of the wooden structure vaults

Stratigraphy of the wooden structure vaults		U [W/(m^2 K)]
1	Scratch-coat plaster and wattle mat	
2	Lime mortar plaster	3.10

Table 7.6 Transmittance values of the brick arches and plastered wattle vaults

Stratigraphy of the brick arches and wooden structure vaults		U [W/(m^2 K)]
1	Scratch-coat plaster and wattle mat	
2a	Brick masonry and mortar	2.81
2b	Scratch-coat plaster and wattle mat	
3	Lime mortar plaster (soffit)	

Traditional structures not bombed area also made by brickwork arches and plastered wattle vaults as the type of roofing used to cover rooms on the top floor of the monumental complex. The brickwork arches support the smaller brickwork pilasters which, in turn, support the wooden beams of the roof structure. Between the arches—also defining the bays—are wooden structured lathed vaults as described above (Table 7.6).

Table 7.7 Transmittance values of the concrete and masonry flooring systems

Stratigraphy of the concrete and masonry flooring systems		U [W/(m^2 K)]
1	Pavement	
2	Mortar and waterproofing layer	
3	Reinforced concrete slab and clay-brick lightening	1.49–1.8
4	Plaster	

Table 7.8 Transmittance values of the plasterboard false ceiling

	U [W/(m^2 K)]
Plasterboard or mineral fibre panels	2.97

The floors reconstructed after bombings of the Second World War are made with reinforced concrete and brickwork relief (the large terraces of the south and east wings) and plasterboard false ceiling (Tables 7.7 and 7.8).

7.2.4 Windows

Traditional windows are made of a wooden frame, somewhere very thin, and single glazing. They have not been calculated in detail (type per type), as this is just a feasibility study, referring to a general U-value of 5.8 W/m^2 K (Fig. 7.9).

7.2.5 Prerequisites for New Uses and Calculation

The new uses of the complex (classrooms, laboratories, bar, library, church, canteen, student accommodation, museum, staff room, common rooms, offices) have specific characteristics defined by the limits of the particular directives governing requisites of indoor environments. This classification controls a series of connected parameters, such as air circulation, required internal temperature, and average consumption of hot water. In calculating the demand for heating, it was decided to not consider air circulation as prescribed by the Standards as not all rooms will be subject to air handling and, where this will be included in the final project, the air will be put into neutral conditions. The energy demand to put air in neutral conditions was calculated separately in the part regarding air handling units (AHU). Therefore, only the contribution of natural ventilation was considered for which the law prescribes a value of 0.3 m^3/h. As, however, we are dealing with historical construction and energy analysis that does not consider the replacement of existing windows, but only the restoration and possible improvement of them, the value taken into consideration was 0.5 m^3/h.

Fig. 7.9 Abacus of the northern wing windows (Borea, S., Brustio, M., Cafferata, D., Geromino, V., Moggia, C., Segantin, F., Szentirmai, B. 2012. Post-graduate School in Architectural Heritage and Landscape, University of Genoa)

While concerning the temperature inside the rooms, a planned 20 °C has been considered for all types of use, except in the church where the temperature goes down to 15 °C (Table 7.9).

The survey of existing heating system, from direct observation and archival analysis, will be helpful in the future planning operations, as for the reuse of existing passages (Fig. 7.10, 7.11a, b).

7.3 Energy Demand for Hot Water

The demand for hot water was calculated based on different reference points in relation to purposes of use and maximum crowding. To calculate the demand for hot water expressed in m^3 and in thermal power, we thought of the possible inclusion within the complex of accumulation tanks. Considering the characteristics of the uses assigned to the rooms, water consumption will be at a maximum during the day. During the night, therefore, we could imagine that the system will

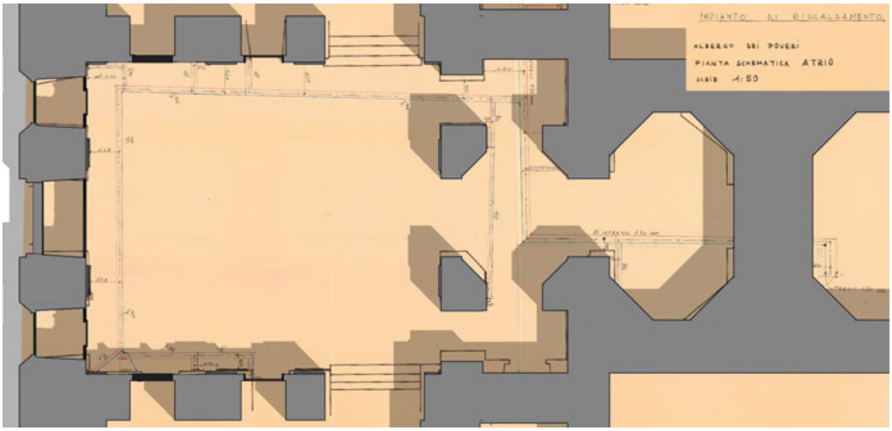

Fig. 7.10 Plant System. Representation of the existing sewer from archival research

reintegrate the quantities of water necessary for consumption in special tanks. This means, while sizing the systems, that there will be no need to consider the overall amount of the power necessary to produce instant hot water. The calculation of demand does not include the museum areas, areas set aside for archives and the conservation library and public throughways.

On the detail level, a variety of different criteria was used to calculate the water consumption for each use. In calculating the maximum crowding capacity of the university halls, Memorandum 3625/65 of the Italian Ministry of Public Works was taken into consideration indicating a maximum value per hall of between 60 and 90 people, at 1.5 m^2 per person. The pro-capita consumption calculation, on the other hand, used the “National Programme for the Promotion of Solar Energy: the sun in public organisations” published by the Italian Ministry of the Environment and Protection of the Territory and the Sea as a reference point. This pro-capita consumption calculation reference (evaluated at 5 L/person) was also used for the library areas and for those of the common rooms for students. The maximum capacity quota for the new library was obtained by comparing the maximum capacity of the areas used for the library currently in use. This hypothesis is valid if we consider the logic that dictates the new library plans, similar to the existing one: a percentage of mezzanine surfaces and a consultation area for most texts on open shelves.

The calculation estimation of the hot water demand for the canteen is based on Prospectus 13 of the UNI/TS 11300 part 2 for restaurants. According to this Standard, we should consider a daily demand quantified in 10 L per meal served each day. The canteen is available to the students and people staying in university accommodation. The canteen will be open and meals served only during lunchtimes and will be considered at an average of 80 seats. Calculating approximately half an hour per consumption of each individual meal and opening times of 11:30 am to

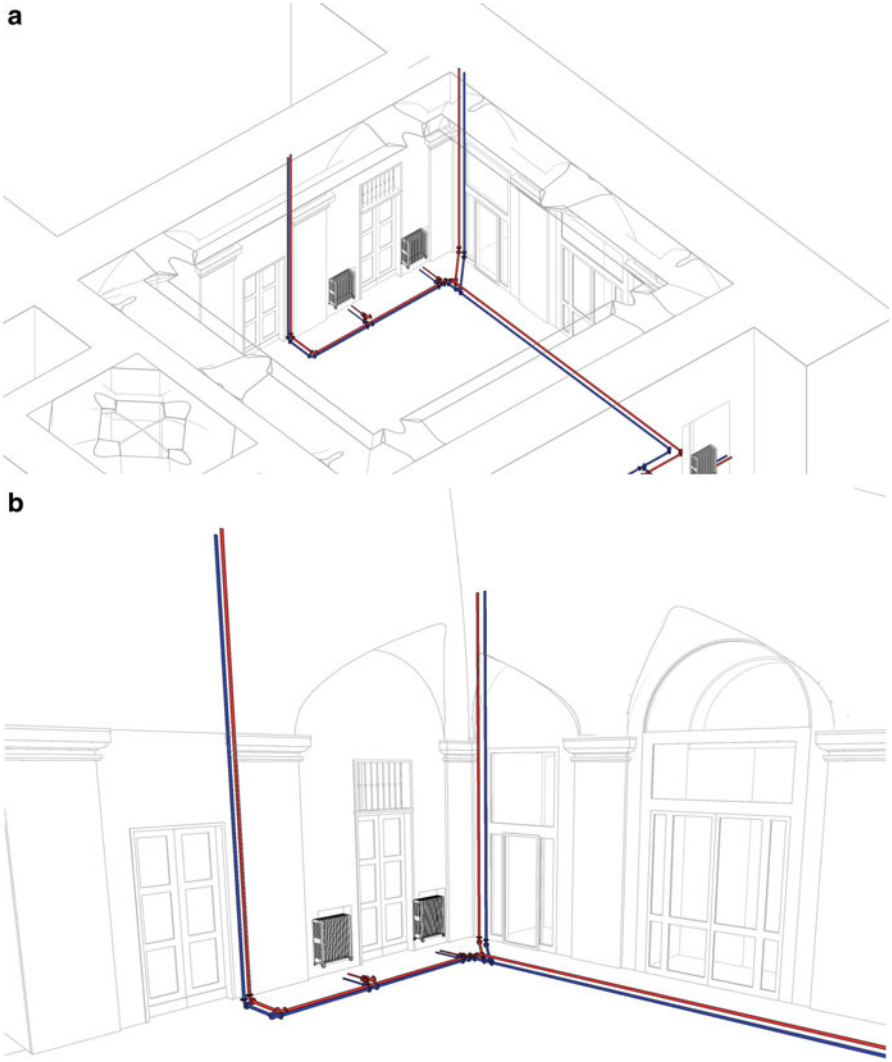

Fig. 7.11 (**a**, **b**) Existing heating plant in BIM model (Babbetto, R. 2015)

1:30 pm, we can consider around 300 meals per day. Returning to the results obtained for the canteen, or rather a number of 300 meals served daily, an average number of 300 clients a day has been maintained, also for the bar. Each client has been assigned a consumption demand of 2 L (source www.engicos.it).

The hot water demand calculation estimation for university accommodation is based on Prospectus 13 of Standard UNI/TS 11300 part 2. It was necessary to establish an average surface of each "apartment" which was obtained by dividing

Table 7.9 Calculation of thermal power for winter demand divided by floor and use

Floor	Wing	Use	Net surface area [m^2]	Net volume [m^3]	Thermal power [W]
Ground	South	University offices	725.50	4,727.48	49,002
	Centre	Library—archives	721.45	4,509.06	31,883
	North	Library archives	1,401.34	6,416.92	51,723
Total			2,848.29	15,653.46	132,608
First	South	Classrooms	487.76	3,157.82	39,640
		Offices	770.00	5,148.14	59,139
	Centre	Church	585.07	9,361.12	40,036
		Laboratory 1	372.31	3,611.41	46,024
		Laboratory 2	294.00	2,851.80	34,425
	West	Museum	686.84	7,650.65	101,575
		Bar	206.34	1,353.59	32,329
	North	Classrooms, study rooms	1,977.43	12,819.02	105,913
Total			5,386.75	45,953.53	459,081
Second	East	Library	1,027.80	6,136.12	48,912
	North	Library	1,976.68	11,923.22	93,114
	Centre	Canteen	427.06	1,554.50	44,781
	West	Common rooms	630.32	3,691.50	102,547
Total			4,061.86	23,305.34	289,454
Third	East	Faculty offices	1,262.94	6,314.70	55,635
		Library	1,129.28	5,646.40	51,741
	North	University accommodation	1,920.58	10,179.72	84,156
Total			4,312.80	22,140.82	191,532
Quarto	East	Faculty offices	988.63	4,943.15	75,992
		University accommodation	759.90	3,799.50	58,775
	North	University accommodation	1,935.13	10,380.78	106,148
Total			3,683.66	19,123.43	240,915
Fifth	North	University accommodation	1,558.95	6,778.12	131,734
Sixth	North	University accommodation	407.76	2,108.32	49,922

the total surface area used for bedrooms (6,552.63 m^2) by the number of bedrooms available to accommodate the students.

There are 13 bedrooms—single or twin—accommodating 26 people on the third floor, 22 accommodating 43 people on the fourth floor, 13 to accommodate 25 people on the fifth floor, and 3 to accommodate 6 people on the sixth floor. By adding this data, we are given 51 bedrooms which can accommodate up to 100 students.

Each apartment has an average surface area of approximately 128 m^2 (the feasibility study takes into consideration the available space among the masonry pillars; specific design could even reduce surface of each apartment looking for a specific interior design). In compliance with the law, we should consider a daily demand of 1.461 L/day per square metre for accommodation of around 120 m^2, while for those apartments of around 130 m^2 the demand is estimated at around 1.434 L/day. To be on the safe side, we chose to adopt the value corresponding to apartments of around 120 m^2.

Finally, to calculate the hot water demand in administrative offices and faculty study rooms, we referred to Prospectus 13 of Standard UNI/TS 11300 part 2, which leads us to consider a daily demand of 0.2 L/day per square metre. The overall net surface area considered in the calculation is 3,730 m^2.

Having noted the quantity of hot water used, the temperature of use and the temperature of the water as it enters the aqueduct, we can calculate the relative overall energy waste. As part of the project, we calculated the theoretical energy demand for the production of 1 m^3 (1000 L) of hot water considering a temperature of 12 °C upon entering the aqueduct, and an exit temperature around 40 °C. The data regarding the temperature upon entering the aqueduct refers to a worst case scenario compared to that in Standard UNI/TS 11300 (15 °C).

Results

Daily water consumption for hot water: 25,590 L—25.59 m^3

Annual water consumption for hot water: 7,713,160 L—7,713.16 m^3

Daily energy consumption for the production of hot water: 833.20 kWh

Annual energy consumption for the production of hot water: 251,123.20 kWh

The calculated consumption rates have been compared with those actually supplied by the University (regarding those parts that have already been renovated) to validate the model (Table 7.10).

Table 7.10 Calculation of the thermal demand for heating and hot water for the following uses

Uses	S [m^2]	V [m^3]	P_{THERM} [W]	E_{THERM} [kWh]	ACS [m^3/year]	E_{ACS} [kWh]
Classrooms	2,325.20	15,371.37	138,485	154,991		
Laboratories	666.31	6,463.21	80,449	118,694	1,976.25	64,342.30
Bar	206.32	1,353.59	32,329	39,418	219.00	7,130.20
Library e archives	2,122.79	10,925.99	83,606	64,254		
Jurisprudence library	4,133.76	23,705.74	193,767	168,289	841.50	27,397.40
Church	585.07	9,361.12	40,036	27,588		
Canteen	427.06	1,554.50	44,781	57,082	765.00	24,906.70
Museum	686.84	7,650.65	101,575	144,351		
University accommodation	6,582.32	33,246.44	430,735	675,928	3,476.70	113,844.80
Staff room	139.99	605.47	7,068	8,900		
Common rooms	630.32	3,691.50	102,647	154,462	224.48	7,308.40
University offices	3,754.07	21,133.47	239,768	278,783	190.23	6,193.50
Total	22,260	136,063	1,495,246	1,892,481	7713.16	251,123.20

S net surface, *V* net volume, P_{THERM} thermal power for heating, E_{THERM} thermal energy required for heating, *ACS* annual hot water demand, E_{ACS} annual thermal energy demand for heating water

7.4 The Electricity Demand

7.4.1 Electricity Demand for Lighting

The data necessary to calculate the demand for lighting interiors and stairways was obtained based on Standard UNI EN 12464-1 “Lighting workspaces. Part 1: interior workspaces” and the ENEA Table (National Organisation for Energy and the Environment)—Information on energy savings with lighting.

The Standard gave us indications on the number of lights necessary for each use, while the ENEA Table gave us an interval of values (for the calculation, for safety reasons, we considered the maximum values indicated in the interval). The value expressed in lux was multiplied by the surface area of the rooms to obtain the lumen; at this point in order to obtain the wattage absorbed, we needed to introduce the concept of lighting efficiency in proportion to the type of illumination. This is one of the most important parameters; it is expressed in lumen/watt and is the definitive parameter of the ration between light flow emitted (in lumen) and the electrical power absorbed (in watts). This parameter defines yield and therefore energy consumption.

The plan hypothesizes the use of LED lights and the light efficiency data was obtained from manufacturers’ catalogues. Individual products with varying shapes, sizes, power, and light flow have contributed to defining an average light efficiency value of 76 L/W.

The calculation hypothesis has taken into account the different uses: teaching areas, libraries, museums, religious worship buildings, accommodation, and the relative use of each over a 24-h period. As well as the individual uses, we also took into consideration the position of the rooms in regard to the helio-thermal axis and any obstacles that may decrease solar contribution in terms of natural lighting. For non-residential or museum or public uses (such as the new urban road), the total hours of average daily use was multiplied by annual working days (255 days). The daily value of average light use does not differ by season, but represents an average yearly data (Table 7.11).

7.4.1.1 Entrance Halls and Stairwells

The ground floor would require continual illumination of the entrance hall and the corridor all day every day, in order to guarantee the correct illumination of the urban road linking the valley *Carbonara* and the Porta Principe railway station. Routes of access to the student accommodation in the north wing are illuminated all year long throughout the day. The route starts on the main entrance on the first floor, in the central tower of the north wing.

7.4.1.2 Classrooms

The average daily illumination of the classrooms ranges from 8 h for those in the north wing to four for those in the south wing. For the corridors linking the classrooms, we considered an average value between those in the south wing (as they are north-facing) and those in the north wing (which are south facing): 6 h average illumination. Nine hours of average illumination has been considered for the bathrooms. The calculation of the demand has been considered over 255 days over the year, thereby excluding holidays.

7.4.1.3 Laboratories

For the teaching laboratories in the central wing, we have hypothesized 6 h average daily illumination multiplied by 255 working days over the year.

7.4.1.4 Bar

The hypothesized illumination of the bar area is 6 h per day on average throughout the year, in proportion to its exposition along the north-south axis with the windowed wall to the east. It is expected to open 365 days a year.

7.4.1.5 Church of S. Maria Immacolata

The church is not only used for worship but could also be included as part of the museum and therefore we hypothesize 9 h of illumination per day every day throughout the year (lux value taken from the old Standard UNI 10380 which has since been replaced by UNI 12454).

7.4.1.6 Library—Archives

The library will be used as university archives and partly as a warehouse for the library as planned. The hypothesized daily illumination is limited to 2 h for 255 working days a year. This average considers sectorial and non-continual use.

7.4.1.7 Jurisprudence Library

Following the example of the library currently in use, this area may be given a mezzanine and the project has thus taken into account the increased surface area to be lit; moreover, the use of this area requires different illumination requirements within the same space for study or consultation areas (60% of the overall surface area) or for shelving (the remaining 40%). The library is expected to be open from 9 am to 6 pm meaning that the bathrooms, entrance halls, and shelving areas will be illuminated for 9 h a day, 255 days a year. The reading areas are equipped with table lamps with variable illumination timetables; the general illumination will vary depending on position (8 h average for north-facing areas and six for east-facing areas).

7.4.1.8 Canteen

The canteen kitchen will be open from 8 am to 5 pm though lunch will be served from 11:30 am to 1:30 pm. The structure will be open only for lunch, 255 days a year.

7.4.1.9 Museum of the Albergo dei Poveri

The museum is not subject to any particular indications of the lux value and illumination is expected to change depending on the objects conserved by the museum itself. As a point of reference, we have used the Standard for pavilions and exhibitions. Illumination will cover opening hours (9 am to 6 pm) 365 days a year.

7.4.1.10 University Accommodation

Concerning the accommodation, we expect an average illumination of 5 h a day. We also took into account the corridors that lead to the various areas (with limited natural light) and hypothesize constant 24 h lighting every day of the year. The calculation considers the fact that lighting here will be supplied 365 days a year.

7.4.1.11 Staff Room

The staff rooms are lit 9 h a day, 255 days a year: all the time the rooms are open and in use (average daily open times 8:30 am–5:30 pm).

7.4.1.12 Common Rooms

The bathroom and catering areas have limited or no natural light so we have considered an average daily illumination of 9 h a day, 255 days a year. The students' common rooms have table lamps that can be turned on and off by the

Table 7.11 Electrical power and consumption for lighting only, divided by activity

Activity	S [m^2]	P_{EL} [kW]	C_{EL} [kWh/anno]
Classrooms	2,325.20	6.67	12,286.33
Laboratories	666.31	4.39	6,715.59
Bar	206.32	0.41	903.77
Library e archives	2,122.79	5.59	2,849.02
Jurisprudence Library	4,133.76	27.21	54,346.01
Church	585.07	0.77	2,528.89
Canteen	427.06	1.24	1,557.34
Museum of the *Albergo dei Poveri*	686.84	2.57	8,434.58
University accommodation	6,582.32	18.61	40,515.09
Staff room	139.99	0.57	1,319.38
Common rooms	630.32	1.51	2,501.50
University offices	3,754.07	18.05	24,500.91
Stairwells	3,084.60	5.71	35,495.23
Total	25,344	93.30	193,953.64

S net surface area, P_{EL} electrical power, C_{EL} yearly electricity consumption

user, while general lighting is expected to be on for just 6 h a day, considering the east-facing windows.

7.4.1.13 Offices

The offices have differing lighting times depending on position. Annual consumption is calculated over 255 days a year.

7.4.2 *Electricity Demand for Other Electrical Appliances*

As well as the demand for lighting, we have also calculated in detail and per area the electrical requirements for other electrical appliances estimated in detail and based on use, surface area, number of possible users, and annual hours of use. For the offices, we considered: computers, photocopiers, battery chargers; for the classrooms and laboratories: audio-visual systems, computers, battery chargers; for the libraries: computers, photocopiers; for catering areas: vending machines; for the bar and canteen: all appliances necessary for the conservation and preparation of drinks and food; for the university accommodation: devices for daily use, based on technical specifications of each. The university accommodation area will also include communal areas (floor by floor in compliance with the law) for laundry, the preparation and consumption of meals, common rooms, with the relative electricity consumption calculations (Table 7.12).

Table 7.12 Electricity power and consumption for other appliances

Activities	P_{EL}[kW]	C_{EL} [kWh/year]
Classrooms	4.06	4,141
Laboratories	0.58	592
Bar	9.44	18,570
Libraries	12	11,697
Canteen	35.37	17,823
University accommodation	438.42	155,182
Common rooms	3.74	6,307
University offices	22.39	19,028
Total	526	233,340

S net surface area, P_{EL} electrical power, C_{EL} yearly electricity consumption

7.4.3 Measuring the Air Conditioning Systems

Many of the rooms of the *Albergo dei Poveri* that are subject to new use require air handling systems to aid the natural mechanical ventilation. This guarantees the necessary air circulation required by the current law in force and also fulfils the adequate hygiene prescriptions. The places that require this type of system are: library/archives, Jurisprudence Library, Museum of the *Albergo dei Poveri*, bathrooms and university accommodation.

The air handling units may work, depending on the characteristics of the locations in which they are installed, completely with outside air or with mixed air. For example, in university accommodation air will be extracted from the bathrooms, and mixed with the primary air, linking the fan coil units of the rooms to the channels that emit primary air within the chamber (in neutral conditions: 20 °C, 50% humidity) in quantities (vol/h) equal to that extracted from the bathroom.

The aeraulic network necessary for the distribution of the handled air may be installed, where possible, within false ceilings so they remain hidden from sight.

The project, developed in detail, includes the definition of system terminals (for all areas, and not only those affected by air handling), the selected type of AHU, the measuring of the components (recuperators, humidifying section and thermal exchange batteries, ventilator, and filters) and the accommodation in special technical rooms and, finally, the measuring of the extractors which, together with the AHUs, are necessary to extract the air from the rooms and expel it.

Finally, the AHUs are linked to an aeraulic network that can distribute the flow of handled air in the best way possible. The canalizations of extraction and emission located within the building were measured schematically following the position of pre-existing technical cavity walls. The air is distributed through emission openings and intake grills which, specially measured and positioned within the rooms, create a uniform temperature throughout all the areas provided.

University accommodation and guest quarters are located on the third, fourth, fifth, and sixth floors in the north wing and the fourth floor of the east wing. In all, there are 57 bedrooms with private bathrooms which will be equipped with a heating system for the winter (heating + primary air) and an extraction system.

Bedrooms: the winter thermal charge will be lowered, thanks to fan coil units located in the false ceiling while a handling unit will circulate the air and maintain the bedrooms in slight overpressure.

Bathrooms: the winter thermal charge will be lowered, thanks to bathroom heating rails while an extractor fan will keep the rooms in slight depression.

The project includes the use of three independent systems (AHU + extractor), each of which is dedicated to a certain number of bedrooms.

In order to keep energy consumption down, all the "*AHU + extractor*" systems will be equipped with air/water recovery batteries.

Calculation method for the air capacity for A/B/C blocks—note the surface area A_i [m^2] of the i-th bathroom at a height of $h = 2.7$ m (false ceiling), the net volume can be seen from the following relation:

$$V_{\mathrm{n},i} = A_i \cdot h = 2.7 \cdot A_i$$

Considering a capacity of extracted air $Q_\mathrm{e} = 8$ vol/h (UNI 10339), we get the following:

$$Q_{\mathrm{e},i} = 8\ \mathrm{vol/h} = 21.6 \cdot A_i \left[\mathrm{m}^3/\mathrm{h}\right]$$

In order to guarantee pressure balance, the capacity of primary air $Q_{\mathrm{p},i}$ [m^3/h] is equal to that of the extracted air. Consequently resulting in the following:

$$Q_{\mathrm{p},i} = Q_{\mathrm{e},i} = 21.6 \cdot A_i \left[\mathrm{m}^3/\mathrm{h}\right]$$

Estimation of the drop in pressure in the aeraulic lines of blocks A/B/C—we consider the contribution of the distributed and concentrated charge losses.

The air handling units and extractors serving blocks A/B/C will be made up of the following main sections:

Extractors

1. Air/water recovery battery
2. Recovery ventilator

Air handling units

1. Pre-filters
2. Pocket filters
3. Air/water recovery battery
4. Hot water heating battery
5. Isotherm humidification
6. Delivery ventilator

As project conditions, we have considered the following:

External air : $T_e = 0°C \quad \Phi_e = 80\%$
Emitted air : $T_i = 20°C \quad \Phi_i = 50\%$ (neutral conditions)

In all "UHA + extractor" systems, we consider the equality between the delivery of renewed and extracted air. For university accommodation, considering the use of the bedrooms as equal to that of "buildings used for accommodation and similar", it is possible to reduce the air capacity by 50% ($Q_e = 4$ vol/h—UNI 10339). In this case, we may proceed to measure the "AHU + extractor" systems of blocks A/B/C again, or we may use the excess capacity for communal areas (located near the bedrooms) destined to be used by the students.

In the case of summer air conditioning (offices, library, museum, canteen, bar), the primary air handling units will also be equipped with cooling and post-heating batteries.

With the same calculation methodology, the following systems have been measured: libraries, canteen, offices, museum, bar area, and the bathroom air extraction systems.

Finally, the summer thermal charge was calculated approximately taking into account the following contributions:

1. Net volume of the rooms: it was observed that in rooms with medium dispersion and a net height $h_n = 3$ m and with reduced crowding, as refrigerating power as capacity units we can assume the following value: $P^* = 30$ W/m^3.

Taking into account the improving interventions on building closure system and the fact that in the majority of cases the result is $h_n \geq 5$ m, we can assume:

$P_1 = 12\ \text{W/m}^3$ in the presence of surfaces with dispersing covering
$P_1 = 9\ \text{W/m}^3$ in the absence of surfaces with dispersing covers
$P_1 = 6\ \text{W/m}^3$ with net heights of $h_n \geq 10\,\text{m}$

2. Number of people present: the contribution due to the presence of people takes into account the thermal capacity emitted in the absence of particular motor activities. With the following results:

$$P_2 = 120\ \text{W/pers}$$

The total summer thermal charge is calculated with the following relation:

$$P_{\text{Frig}} = V_n \cdot P_1 + N_p \cdot P_2$$

where:
V_n [m^3] is the net volume of the room.
N_p is the number of people present.

There are two expected configurations:

(a) Hot/cold fan coil units: when in winter these units are supplied with the hot water produced in a thermal power station (cogenerators + boilers)
(b) Hot/cold fan coil units: when in winter these units are supplied with the hot water produced by a heat pump

7.5 Overall Calculation of Energy Consumption

The calculation of the portion of the complex to be renovated takes into account of the following contributions (Table 7.13):

- Consumption of electricity and thermal energy for summer cooling
- Consumption of electricity and thermal energy for winter heating
- Consumption of electricity for extraction in communal bathrooms
- Consumption of electricity and thermal energy for hot water
- Consumption of electricity for lighting and supplying other appliances

7.5.1 Consumption of Electricity and Thermal Energy for Summer Cooling

As a first approximation, we consider a full capacity functioning for a period of time $T = 500$ h/year. With reference to the summer (90 days), if daily activation $T' = 12$ h/day, we get the following capacity factor:

$$E = P_{\max} \cdot T = 90 \cdot P_{\mathrm{eq}} \cdot T'$$
$$(\mathrm{FC})_{\mathrm{eq}} = 0.0111 \cdot T/T' = 0.463 = 46.3\%$$

E*lectrical power for summer cooling* includes the power absorbed by refrigerator groups, circulation pumps, ventilators, and fan coil units.

Refrigerator groups

The total refrigerating capacity is the following:

$$P_{\text{TOT-REFR}} = P_{\text{AHU-REFR}} + P_{\text{FC-REFR}} = 1236\ \text{kW}$$

Table 7.13 Quantification of the overall demand of the portion of the complex to be renovated

Electricity E_{EL}	Thermal energy E_{THERM}	Primary energy E_{PRIM}
$\mathrm{kWh_{el}}$	$\mathrm{kWh_{therm}}$	Tep
956,000	2,496,000	428

Quantifying the thermal loss of the subsystems of the installation through global yield $\eta' = 0.87$ we get the following result:

$$P'_{\mathrm{REFR}} = 1420\,\mathrm{kW}$$

A refrigerating group with EER = 3.1 will absorb the following electrical power:

$$P_{\mathrm{GF\_EL}} = 458.32\,\mathrm{kW}$$

Refrigerated water circulation pumps

We have calculated the total capacity elaborated:

$$Q_{\mathrm{TOT\_REFR}} = 59\,\mathrm{kg/s} = 212\,\mathrm{m}^3/\mathrm{h}$$

For the air handling units, we expect five pumps of 17 m^3/h while for the fan-coils we can consider seven pumps of 18 m^3/h. Prevalence is estimated based on a standard line length (delivery + return) $L_{\mathrm{st}} = 200$ m.

Distributed charge loss: $\Delta p_{\mathrm{d}} = 0.2$ kPa/m

Loss of charge concentrated along the line: $\Delta p_{\mathrm{c}} = 0.25 \cdot \Delta p_{\mathrm{d}}$

Loss of battery charge: $\Delta p_{\mathrm{b}} = 50$ kPa

Safety factor: $\sigma = 1.2$

For each refrigerated water pump, we get the following result:

$$\begin{aligned} Q' &= 17 \sim 18\,\mathrm{m}^3/\mathrm{h} \\ \Delta p_{\mathrm{TOT}} &= 1.2 \cdot (1.25 \cdot \Delta p_{\mathrm{d}} \cdot L_{\mathrm{st}} + 50) = 120\,\mathrm{kPa} \\ P_{\mathrm{PUMP}} &= 1.5\,\mathrm{kW} \end{aligned}$$

All in all, for the 12 circulation pumps we have:

$$P_{\mathrm{N^\circ 12\ PUMPS}} = 18\,\mathrm{kW}$$

Post-heating water circulation pumps

The total capacity elaborated is calculated:

$$Q_{\mathrm{TOT\_POST}} = 3.65\,\mathrm{kg/s} = 13\,\mathrm{m}^3/\mathrm{h}$$

We expect five pumps of 2.6 m^3/h. Similarly to that undertaken previously, we get the following result:

$$\begin{aligned} Q' &= 2.6\,\mathrm{m}^3/\mathrm{h} \\ \Delta p_{\mathrm{TOT}} &= 120\,\mathrm{kPa} \\ P_{\mathrm{PUMP}} &= 0.55\,\mathrm{kW} \end{aligned}$$

For the five post-heating circulation pumps we have:

$$P_{\text{N}^\circ 5\ \text{PUMPS}} = 2.75\ \text{kW}$$

We leave aside the contribution of the circulators supplying the recovery batteries present in the AHU + extractor systems.

Calculation of electricity consumption during the summer

$$E_{\text{EL-EST}} = T \cdot (P_{\text{AHU\_VENT}} + P_{\text{EXT\_VENT}} + P_{\text{FC\_EL}} + P_{\text{GF\_EL\_}} + P_{\text{N}^\circ 12} + P_{\text{N}^\circ 5})$$
$$E_{\text{EL-EST}} = 500 \cdot (22.13 + 12.64 + 13.09 + 458.32 + 18.0 + 2.75)$$
$$E_{\text{EL-EST}} = 526.93 \cdot 500 = 263,465\ \text{kWh}_{\text{el}}$$

Taking into account the factor of electricity conversion into primary energy, we have:

$$E'_{\text{PRIM-EST}} = f_{p,\text{el}} \cdot E_{\text{EL-EST}} = 2.6 \cdot 26,3465 = 685\ \text{MWh}_{\text{term}} = 58.9\ \text{tep}$$

where $f_{\text{p,el}} = 2.6$ is the above conversion factor and 1 tep = 11,630 kWh

Calculation of the demand for thermal energy during the summer

The thermal capacity needed for the post-heating batteries is the following:

$$P_{\text{AHU-POST}} = 153\ \text{kW}$$

Quantifying thermal loss of the subsystems of the installation with the global yield $\eta' = 0.87$, we obtain the thermal power entering the generation system:

$$P_{\text{IN-GEN}} = 175.86\ \text{kW}$$

Thermal energy consumption is equal to:

$$E_{\text{THERM-EST}} = T \cdot P_{\text{IN-GEN}}$$
$$E_{\text{THERM-EST}} = 500 \cdot 175.8 = 87,930\ \text{kWh}_{\text{term}}$$
$$E''_{\text{PRIM-EST}} = E_{\text{TERM-EST}} = 7.56\ \text{tep}$$

The total consumption of primary energy for summer cooling, expressed in *tep*, is therefore the following:

$$E_{\text{PRIM-EST}} = E'_{\text{PRIM-EST}} + E''_{\text{PRIM-EST}} = 66.46\ \text{tep}$$

7.5.2 Consumption of Electricity and Thermal Energy for Winter Heating

This was calculated in the following conditions:

In university accommodation (bedrooms + bathrooms), the ventilators of the AHU + extractor systems work continually throughout the year. The winter function is activated for 12 h/day during heating periods (166 days).

In other areas: the AHU + extractor systems are activated for 12 h/day during heating periods (166 days).

All fan coil units/radiators are activated for 12 h/day during the heating period.

- The average seasonal charge factor assumed is FC = 0.75

Electricity consumption of ventilators in university accommodation

$$P_{\text{AHU\_VENT}} = 3.69\ \text{kW}$$
$$P_{\text{EXT\_VENT}} = 1.99\ \text{kW}$$

Electricity consumption is the following:

$$E'_{\text{EL-VENT}} = T \cdot (P_{\text{UTA\_VENT}} + P_{\text{EXT\_VENT}})$$
$$E'_{\text{EL-VENT}} = 365 \cdot 24 \cdot (3.69 + 1.99) = 49{,}757\ \text{kWh}_{\text{el}}$$

Electricity consumption of ventilators for other uses

$$P_{\text{AHU\_VENT}} = 22.13\ \text{kW}$$
$$P_{\text{EXT\_VENT}} = 12.64\ \text{kW}$$

Electricity consumption is the following:

$$E''_{\text{EL-VENT}} = T \cdot (P_{\text{AHU\_VENT}} + P_{\text{EXT\_VENT}})$$
$$E''_{\text{EL-VENT}} = 166 \cdot 12 \cdot (22.13 + 12.64) = 69{,}262\ \text{kWh}_{\text{el}}$$

Electricity consumption of humidifiers

$$P_{\text{AHU\_HUMID}} = 43.4\ \text{kW}$$

Electricity consumption is the following:

$$E_{\text{EL-HUMID}} = T \cdot \text{FC} \cdot P_{\text{AHU\_HUMID}}$$
$$E_{\text{EL-HUMID}} = 166 \cdot 12 \cdot 0.75 \cdot 43.4 = 64{,}840\ \text{kWh}_{\text{el}}$$

Electricity consumption of the hot water circulation pumps

Taking into account the fan coil units and radiators and the pre-heating batteries of the air handling units, we have calculated the total capacity elaborated.

$$Q_{\mathrm{TOT\_HOT}} = Q_{\mathrm{AHU\_PRE}} + Q_{\mathrm{FC\_RISC}} + Q_{\mathrm{RAD}} = 4.34 + 22.09 + 1.25 = 27.68\ \mathrm{kg/s}$$
$$= 99.65\ \mathrm{m^3/h}$$

As a first approximation, we expect three pumps of 5.2 $\mathrm{m^3/h}$ for the AHUs, eight pumps of 10.0 $\mathrm{m^3/h}$ for the fan-coils, and one pump of 4.5 $\mathrm{m^3/h}$ for the radiators. The prevalence is estimated based on a standard line length (delivery + return) $L_{\mathrm{st}} = 300$ m.

Distributed charge loss: $\Delta p_{\mathrm{d}} = 0.2$ kPa/m

Loss of charge concentrated along the line: $\Delta p_{\mathrm{c}} = 0.25 \cdot \Delta p_{\mathrm{d}}$

Loss of battery charge: $\Delta p_{\mathrm{b}} = 50$ kPa

Safety factor: $\sigma = 1.2$

Each hot water pump gives the same result:

$$\begin{array}{llll} Q' = 5.2\ \mathrm{m^3/h} & \Delta p_{\mathrm{TOT}} = 150\ \mathrm{kPa} & P'_{\mathrm{PUMP}} = 1.1\ \mathrm{kW} & P'_{\mathrm{N^\circ 3\ PUMPS}} = 3.3\ \mathrm{kW} \\ Q'' = 10.0\ \mathrm{m^3/h} & \Delta p_{\mathrm{TOT}} = 150\ \mathrm{kPa} & P''_{\mathrm{PUMP}} = 2.2\ \mathrm{kW} & P''_{\mathrm{N^\circ 8\ PUMPS}} = 17.6\ \mathrm{kW} \\ Q''' = 4.5\ \mathrm{m^3/h} & \Delta p_{\mathrm{TOT}} = 150\ \mathrm{kPa} & P'''_{\mathrm{POMPA}} = 1.1\ \mathrm{kW} & P'''_{\mathrm{N^\circ 1\ PUMP}} = 1.1\ \mathrm{kW} \end{array}$$

The electricity consumption is the following:

$$E_{\mathrm{EL\text{-}PUMPS}} = T \cdot P_{\mathrm{PUMPS}}$$
$$E_{\mathrm{EL\text{-}PUMPS}} = 166 \cdot 12 \cdot 22.0 = 43{,}824\ \mathrm{kWh_{el}}$$

Electricity consumption of the fan coil units

Electricity consumption is the following:

$$E_{\mathrm{EL\text{-}FC}} = T \cdot P_{\mathrm{EL\text{-}FC}}$$
$$E_{\mathrm{EL\text{-}FC}} = 166 \cdot 12 \cdot 12.36 = 24{,}621\ \mathrm{kWh_{el}}$$

Calculation of electricity consumption during the winter

$$E_{\mathrm{EL\text{-}WIN}} = E'_{\mathrm{EL\text{-}VENT}} + E''_{\mathrm{EL\text{-}VENT}} + E_{\mathrm{EL\text{-}HUMID}} + E_{\mathrm{EL\text{-}PUMP}} + E_{\mathrm{EL\text{-}FC}}$$
$$E_{\mathrm{EL\text{-}WIN}} = 252{,}304\ \mathrm{kWh_{el}}$$

Taking account of the factor of conversion of electricity into primary energy, we have the following result:

$$E'_{\mathrm{PRIM\text{-}WIN}} = f_{\mathrm{p,el}} \cdot E_{\mathrm{EL\text{-}WIN}} = 2.6 \cdot 252{,}304 = 656\ \mathrm{MWh} = 56.40\ \mathrm{tep}$$

Calculation of demand of thermal energy during the winter

The thermal power necessary for the pre-heating batteries and installation terminals (fan coil units and radiators) is the following:

$$\begin{aligned} P_{\text{TOT-HOT}} &= P_{\text{AHU-PRE}} + P_{\text{FC-HEATING}} + P_{\text{RAD}} = 181.7 + 924.6 + 52.4 \\ &= 1158.7\ \text{kW} \end{aligned}$$

Quantifying the thermal loss of the subsystems of the installation with the following global yield $\eta' = 0.87$, we obtain the thermal power entering the generation system:

$$P_{\text{IN-GEN}} = 1331.84\ \text{kW}$$

Thermal energy consumption is therefore equal:

$$\begin{aligned} E_{\text{THERM-EST}} &= T \cdot \text{FC} \cdot P_{\text{IN-GEN}} \\ E_{\text{THERM-WIN}} &= 166 \cdot 12 \cdot 0.75 \cdot 1{,}331.84 = 1{,}989{,}769\ \text{kWh}_{\text{term}} \\ E''_{\text{PRIM-WIN}} &= E_{\text{THERM-WIN}} = 171.10\ \text{tep} \end{aligned}$$

The total consumption of primary energy for winter heating, expressed in *tep*, we have the following result:

$$E_{\text{PRIM-WIN}} = E'_{\text{PRIM-WIN}} + E''_{\text{PRIM-WIN}} = 227.49\ \text{tep}$$

7.5.3 Electricity Consumption for Extraction in Communal Bathrooms

This was calculated considering a constant functioning (24 h/day for 365 days/year). Total electrical power is obtained by adding up the various contributions, resulting thus:

$$\begin{aligned} P_{\text{EL\_TOT}} &= 0.96\ \text{kW} \\ E_{\text{EL\_B.C.}} &= T \cdot P_{\text{EL\_TOT}} \\ E_{\text{EL\_B.C.}} &= 365 \cdot 24 \cdot 0.96 = 8409.6\ \text{kWh}_{\text{el}} \\ \text{E}_{\text{PRIM-B.C.}} &= \text{f}_{\text{p,el}} \cdot \text{E}_{\text{EL-B.C.}} = 2.6 \cdot 8409.6 = 1.88\ \text{tep} \end{aligned}$$

7.5.4 Consumption of Electricity and Thermal Energy for Hot Water

The requirements of electricity and thermal energy for the production of hot sanitary water have been calculated by adding up the consumption of the various areas of the complex. The result is thus:

$$C'_{\mathrm{TOT\_HSW}} = 25.6\ \mathrm{m}^3/\mathrm{day}$$
$$C_{\mathrm{TOT\_HSW}} = 7716\ \mathrm{m}^3/\mathrm{year}$$

The daily demand of thermal energy used for heating hot water takes into account water storage in accumulation tanks. Considering the storage temperature $T_{\mathrm{acc}} = 60$ °C and that of supply $T_{\mathrm{er}} = 40$ °C (UNI/TS 11300-2), we expect three accumulation tanks with a capacity of $V = 5000$ L each. The result is thus:

$$E_{\mathrm{UT\_HSW}} = \rho_{\mathrm{H2O}} \cdot V_{\mathrm{TOT}} \cdot c_{\mathrm{H2O}} \cdot (T_{\mathrm{acc}} - T_{\mathrm{af}})$$
$$E_{\mathrm{UT\_HSW}} = 15{,}000 \cdot 4186 \cdot (60 - 12) = 837.2\ \mathrm{kWh/day} = 305{,}578\ \mathrm{kWh/year}$$

where

$$\rho_{\mathrm{H2O}} = 1\ \mathrm{kg/L}\ \text{and water density}$$
$$c_{\mathrm{H2O}} = 4.186\ \mathrm{kJ/kg^\circ C}\ \text{is the specific heat of the water}$$
$$T_{\mathrm{af}} = 12^\circ\mathrm{C}\ \text{is the temperature of the aqueduct}$$

Taking into account the energy loss of the accumulation estimated in $Q_{\mathrm{l,\ acc}} = 10{,}500$ kWh/year and that of the other subsystems of the installation quantified with yield $\eta' = 0.75$, thermal energy entering the generation system results thus:

$$E_{\mathrm{THERM\_HSW}} = (E_{\mathrm{UT\_ACS}}/\eta') + Q_{\mathrm{l,acc}} \approx 418{,}000\ \mathrm{kWh_{term}}$$

To calculate the electrical power absorbed by the circulation pumps, it is necessary to mention the system configuration adopted: we have considered the presence of a hot plate heat exchanger where the hot water produced from the heat generators evolves in the primary circuit while in the secondary one, linked to the accumulation tanks, the water that is to be heated circulates.

Expecting to take advantage of night time ($T^* = 8$ h/day) for the recovery of the accumulation, a first approximation of the thermal power necessary is thus:

$$P_{\mathrm{UT\_HSW}} = E_{\mathrm{UT\_HSW}}/(365 \cdot T^*) = 104.65\ \mathrm{kW}$$

The water capacity G_{PRIM} [kg/s] in the primary circuit is given in the following relation:

$$P_{\mathrm{UT\_HSW}} = G_{\mathrm{PRIM}} \cdot c_{\mathrm{H2O}} \cdot \Delta T$$
$$G_{\mathrm{C.P.}} = 104.65/(4{,}186 \cdot 10) = 2.5\ \mathrm{kg/s} = 9.0\ \mathrm{m}^3/\mathrm{h}$$

where

$$\Delta T = (70 - 60) = 10^\circ\mathrm{C}\ \text{and the thermal jump of the water}$$

The circulation pump must overcome the drop in pressure found in the hydraulic circuit. Considering $\Delta p_{\mathrm{TOT}} = 60$ kPa, we get:

$$P_{\mathrm{EL\_C.P.}} = 0.37\ \mathrm{kW}$$

For the secondary circuit, we consider four steps over 8 h with a drop in pressure $\Delta p_{\mathrm{TOT}} = 40$ kPa.

$$G_{\mathrm{C.S.}} = 104.65/(4.186 \cdot 12) = 2.08\ \mathrm{kg/s} = 7.5\ \mathrm{m^3/h}$$
$$P_{\mathrm{EL\_C.S.}} = 0.37\ \mathrm{kW}$$

The presence of users found at a certain distance from the power station of production obliges the use of a recirculating distribution network.

In a first approximation, we expect four recirculation pumps characterized by a prevalence of $H = 3.0$ m.c.a. and a capacity of $G_{\mathrm{P.R.}} = 1.5$ m^3/h.

Note: these circulators function for $T^{**} = 24$ h/day and for 365 days/year.

$P_{\mathrm{EL\_N^{\circ}4\ P.R.}} = 0.28$ kW

The overall consumption of electricity in the production of hot water is as follows:

$$E_{\mathrm{EL\_HSW}} = 365 \cdot [T^{*} \cdot (P_{\mathrm{EL\_C.P.}} + P_{\mathrm{EL\_C.S.}}) + T^{**} \cdot P_{\mathrm{EL\_N^{\circ}4\ P.R.}}]$$
$$E_{\mathrm{EL\_HSW}} = 365 \cdot (8 \cdot 0.74 + 24 \cdot 0.28) = 4614\ \mathrm{kWh_{el}}$$

Electricity consumption for the production of hot water

$$E_{\mathrm{EL\text{-}HSW}} = 4614\ \mathrm{kWh_{el}}$$

Bearing in mind the factor of converting electricity into primary energy, we have the following result:

$$E'_{\mathrm{PRIM\text{-}HSW}} = f_{\mathrm{p,el}} \cdot E_{\mathrm{EL\text{-}HSW}} = 2.6 \cdot 4614 = 11{,}996\ \mathrm{kWh} = 1.03\ \mathrm{tep}$$

Thermal energy demand for hot water

$$E_{\mathrm{TERM\text{-}HSW}} = 418{,}000\ \mathrm{kWh_{therm}}$$
$$E''_{\mathrm{PRIM\text{-}HSW}} = E_{\mathrm{THERM\text{-}HSW}} = 35.94\ \mathrm{tep}$$

The total consumption of primary energy for the production of hot water, expressed in *tep*, is therefore as follows:

$$E_{\mathrm{PRIM\text{-}WIN}} = E'_{\mathrm{PRIM\text{-}WIN}} + E''_{\mathrm{PRIM\text{-}WIN}} = 36.97\ \mathrm{tep}$$

7.5.5 Consumption of Electricity for Lighting and Supplying Other Apparatus

Electricity consumption considers the various uses of the areas to be renovated, as illustrated above in detail. The result is the following:

$$E_{\text{EL-LIG+APP}} = 427{,}294\ \text{kWh}_{\text{el}}$$

$$E_{\text{PRIM-LIG+APP}} = f_{\text{p,el}} \cdot E_{\text{EL-LIG+APP}} = 2.6 \cdot 427{,}294 = 95.52\ \text{tep}$$

Chapter 8
Energy Efficiency: Technical Feasibility, Compatibility, Energy Balance

Giovanna Franco and Marco Cartesegna

8.1 Improving the Thermal Performances of the Historical Buildings

Improving the thermal performances of the dispersing components of the building is one of the possible actions to pursue streamlining objectives. As already highlighted, however, most of the interventions currently deployed for the redevelopment of recent buildings devoid of architectural value prove unsuitable for the historical buildings, whether monumental or not. The range of technical solutions to refer to is drastically reduced to a few techniques and a few components (despite an opening towards research on new materials, the real compatibility of which still demands to be understood).

Once new plastering works, whichever their type (thermal plasters as well) are excluded, both on the external and the internal walls, and so is the replacement of windows and doors, regard may be paid to roof-insulation interventions (not altering the characters of the roof), interventions to replace glazed components of external doors and windows or possibly to add a new window or door, or interventions to insulate earth-retaining flooring systems. The insulation of walls, in those cases where plasters must be preserved, may be solved by resorting to new internal panels, in line with the design of environments to be reused.

In the specific instance of the *Albergo dei Poveri*, the greatest benefits in terms of energy saving may be achieved by improving the performances of the roof and the under-roof environments (the attic floor), insulation-free space, plus the windows and doors. With regard to external walls, account has only been taken of the

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insulation of the portion under the window, less thick than the rest of the wall and more exposed to infiltration-originated humidity.

In respect of each of the interventions considered, the thermal values as well as the gains in thermal terms over the current state were calculated. The data on thermal capabilities and the mass of elements making up the walls and flooring systems were presupposed by following the prescriptions of the UNI 10351 standard. The standard project assessments (UNI/TS 11300 standard) take into account an air exchange equal to 0.3 Volumes/h due to natural ventilation. This value has been increased and taken to 0.5 Volumes/h (thermal load), a data used by the standard replaced by UNI/TS 11300, when calculating both the energy and the power as regards all the improvement scenarios examined, except the case of adding a new certified window or door. That is so given that the external doors and windows, though restored, would nevertheless let a greater volume of air circulate.

The improvement solutions are listed hereunder (hypothesizing, in each instance, the inclusion of a rock wool insulating layer in a rigid panel or flexible mat)

a. Insulation of the roof (without modifying its shape)
b. Insulation of the attic floor underneath the roof structure. These attic floors, as previously underlined, have been implemented, over time, in different manners and with different materials:

- Masonry brick vaults
- Wooden structure and plastered wattle vaults
- Vaults with masonry brick arches and portions of wood and wattle vaults
- Reinforced concrete flooring systems
- False ceilings in gypsum plasterboard

c. Insulation of the outer perimeter wall in the portion under the window
d. Inclusion of a new window or door conserving and restoring the existing ones

Pursuant to the same method of calculation of the current state (see the previous chapter), the transmittance values of the insulated structures were calculated.

8.1.1 Insulation of the Roof (Type A)

The insertion of an insulating layer in the roof structures and, in particular, below the mantle involves a modification clearly visually detectable. Since the particularity of traditional roofs in the Genoese context is a very limited overhang through a single slab of slate posed on the cornice, it is preferable that the insulation solutions are carefully designed to not alter this characteristic (Figs. 8.1 and 8.2). The slabs or insulating panels can be positioned at the intrados of the structure or in the space between the wooden joists (Table 8.1).

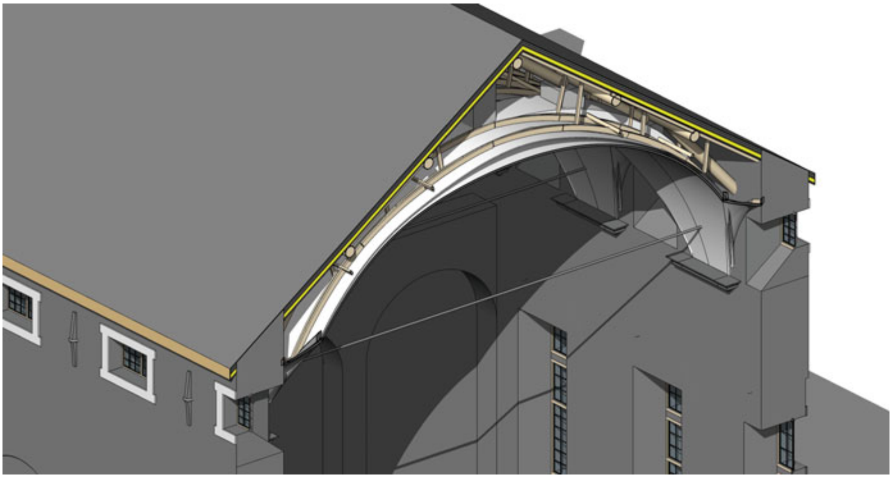

Fig. 8.1 Thermal improvement of the roof (BIM model, Babbetto, R. 2015)

8.1.2 Insulation of the Attic Floors (Type B)

In the specific case of the *Albergo dei Poveri*, which presents a large and not insulated space between the roof structure and the ceiling of the attic floor, it was preferable to preview an insulated layer on the extrados of the attic ceiling, not to waste heating. As described in Chap. 6, the attic floors of the complex vary in material since the building was bombed during World War II and then partly rebuilt. The different types considered are: brick masonry vaults (Table 8.2), wooden structure and plastered wattle vaults (Table 8.3), brick arches and plastered wattle vaults (Table 8.4), reinforced concrete floor, for example in the branches east and north terraces (Table 8.5), and plasterboard ceiling (Table 8.6). In all these cases, the calculation of thermal improvement considers a layer of insulating material at the extrados (8–10 cm thick). For specific calculations, see also Chap. 4. Choosing the most effective insulating material must reflect different instances: efficiency, adaptability to irregular surfaces and geometries, facility to be installed without damaging existing materials, resistance to humidity conditions, health of the environment (Krus et al. 2016; Vereecken and Roels 2016).

8.1.2.1 Masonry Brick Vaults

The insulating material suitable to this type of structure should be flexible, in accordance with the curve surface and even complex geometry of the vaults. In addition to the wool mats (rock, glass, or other fibres), other traditional materials could be suitable, as lime-based mortars (Larsen and Hansen 2016).

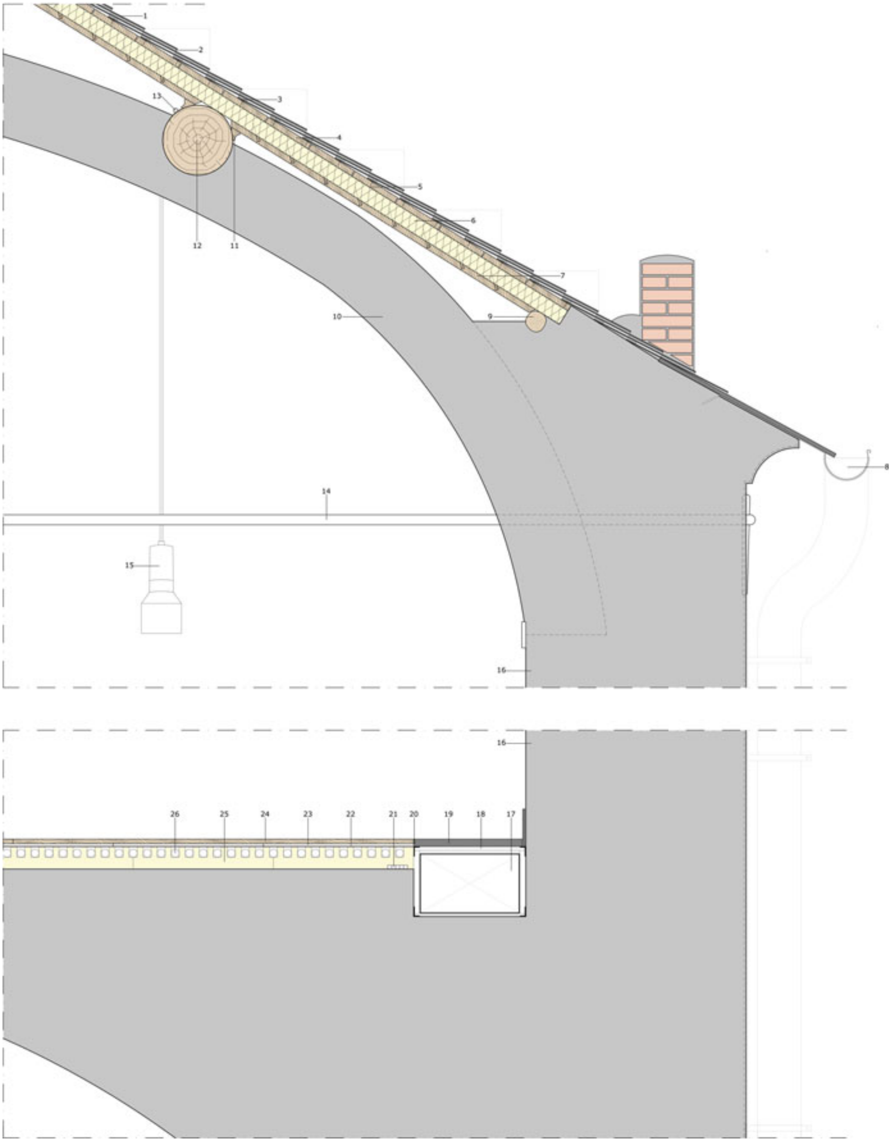

Fig. 8.2 Detailed design of the insulation of the roof, under the "ardesia" stone slate. (Battistini, J., Leonardi, M., Choquet, M. 2014 Master course in Architecture)

Table 8.1 Transmittance values of the insulated roof

Stratigraphy of the roof		U [W/(m^{2}K)]
1	Stone slate (ardesia)	
2	Wooden plank	0.3
3	Wooden joists	
4	Insulation	

Table 8.2 Transmittance values of the masonry brick vaults with extrados insulation

Stratigraphy of the masonry brick vaults		U [W/(m^{2}K)]
1	Rock wool insulation	
2	Scratch-coat plaster in lime mortar	
3	Brick masonry and mortar	0.35
4	Lime mortar plaster (soffit)	

8.1.2.2 Wooden Structure and Plastered Wattle Vaults

Table 8.3 Transmittance values of the wooden structure vaults with extrados insulation

Stratigraphy of the wooden structure vaults		U [W/(m^{2}K)]
1	Rock wool insulation	
2	Scratch-coat plaster and wattle mat	0.38
3	Lime mortar plaster	

8.1.2.3 Brick Arches and Plastered Wattle Vaults

Table 8.4 Transmittance values of the brick arches and undercover plastered wattle vaults with extrados insulation

Stratigraphy of the brick arches and wooden structure vaults		U [W/(m^{2}K)]
1	Rock wool insulation	
2a	Scratch-coat plaster and wattle mat	
	Brick masonry and mortar	0.33
2b	Scratch-coat plaster and wattle mat	
3	Lime mortar plaster (soffit)	

8.1.2.4 Reinforced Concrete Floors

Table 8.5 Transmittance values of the concrete and masonry flooring systems with insulation

Stratigraphy of the concrete and masonry flooring systems		U [W/(m^{2}K)]
1	Pavement	
2	Mortar and waterproofing layer	
3	Reinforced concrete slab and clay-brick lightening	0.35
4	Plaster	
5	Insulating panel	
6	Finishing	

8.1.2.5 Plasterboard Ceilings

Table 8.6 Transmittance values of the plasterboard false ceiling with extrados insulation

Stratigraphy of the plasterboard panels	U [W/(m^{2}K)]
Insulating panel	
Plasterboard or mineral fibre panels	0.34

8.1.3 Insulation of the External Walls (Type C)

Considering the thickness of the external walls of the complex (varying from 80 cm to even 200 cm), it was not previewed to extensively apply any insulation, be it external (for the presence of ancient plasters) or internal. At this preliminary stage (a feasibility study), the only hypothesis for wall insulation regarded the portion below the external windows (Fig. 8.3). However, specific solutions will have to be studied with design projects, on the occasion of which, for example it will be necessary to improve the acoustic behaviour of the environments recurring to internal panelling even thermally efficient (Figs. 8.3b, 8.4, and 8.5) (Table 8.7).

8.1.4 External Windows: Conservation, Restoration, and Addition (Type D)

The external windows and doors are the most fragile parts of the closure system, often subject of full replacement, also promoted by government economic incentives for achieving the targets of emission reduction and Energy Efficiency. In this specific feasibility study, we provided their conservation and restoration with addition of a new system of windows to improve their efficiency. Similar measures had already been implemented in few rooms, especially those north-facing (Figs. 8.6 and 8.7) (Table 8.8).

8.2 Energy Gains from the Insulation Techniques

The results of the calculations, summarized in tables, relate to the application of the different intervention techniques, examined separately or combining their application. As regards the B-type interventions, extrados insulations of ceilings have been calculated on the basis of the type of actually existing flooring system, masonry vault or wooden structure vault, and reed matting.

Given the complexity of the building and the design level, no attention was focused on investigating the formation of thermal bridges and interstitial condensation, to be remitted to the detailed design.

The results of the calculations are underlined, in the following tables, in relation to the floors (Tables 8.9 and 8.10) and the uses (Tables 8.11 and 8.12).

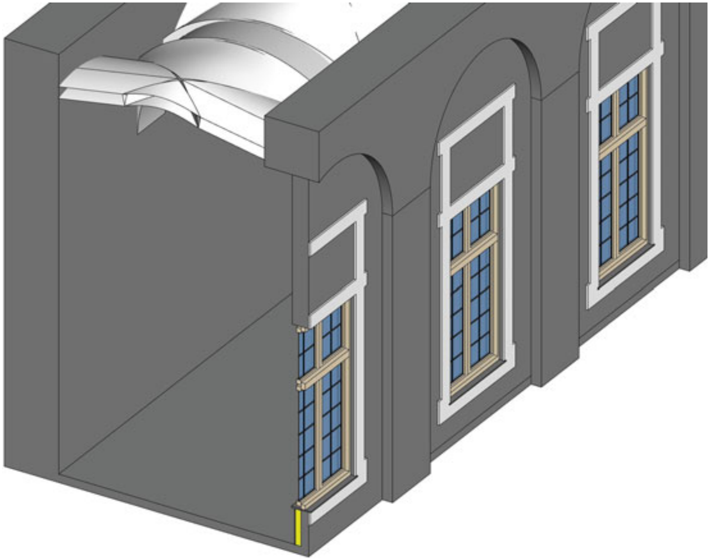

Fig. 8.3 (**a**) Thermal improvement of external walls, insulation of the portion under the window (BIM model, Babbetto, R. 2015) (**b**) Detailed design of the thermal improvement of the western wing of the *Albergo dei overi*. Insulation of the roof and of external walls and ground floor (Biasio, M., Del Monte, M., Galesio, P., Kyuyeon K., Migogna, T., Pedroni, M., Pescetto, M. Roccon, B. (2014). Post-graduate School in Architectural Heritage and Landscape, University of Genoa)

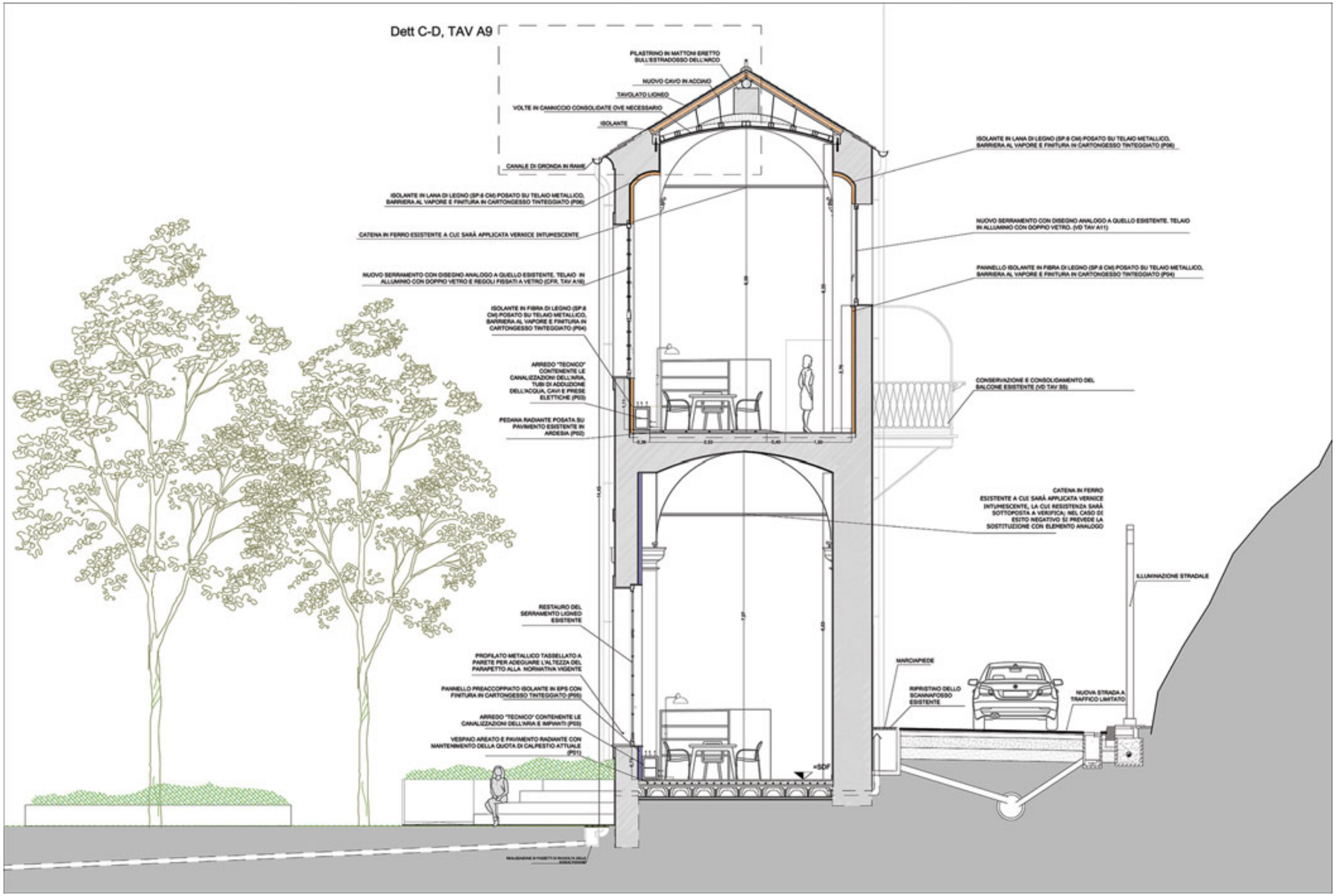

Fig. 8.3 (continued)

Fig. 8.4 Proposal for university accommodation in the northern wing of the complex recurring to small insulated boxes (Barbaresco, L., Mesmaeker, M., Secondini, L., Traversi, F. (2014). Master course in Architecture)

Fig. 8.5 Detail of new insulated internal layers for the university accommodations (Bresolin, G., Stagnaro, I., Tomasetti, G. (2012). Master course in Architecture)

Table 8.7 Transmittance values of the sub-window outer perimeter wall

Stratigraphies of the internally insulated masonry		U[W/(m^{2}K)]
1	Finishing	
2	Insulation	
3	Lime mortar plaster (internal)	0.3
4	Stone and brick masonry	
5	Lime mortar plaster (external)	

Fig. 8.6 View of the northern wing (facing north) and the solution of double window installed in the last century

8.3 The Cogeneration Systems: Installation of Micro-Turbines

A further phase of the research concerned a feasibility investigation on inserting cogeneration plants (specifically, micro gas turbines for the production of thermal and electrical energy).

The optimal use of cogeneration (combined heat and power) as an efficient energy production system presupposes a continuous full-load operating regime within the 24-h cycle (maximum performance) and an "onsite" consumption of the entire electricity and heat produced.

This circumstance, however, may only occur in respect of industrial users and some civil users (hospitals) where energy consumption levels are significant and always present, both in the winter and the summer periods. It is of course not essential that 100% of the heating/electricity requirement is constantly met by the cogeneration unit/s; it would however be important if the basic load was 100% covered. In most instances, users experience strong variations in energy demand, due not only to the intended use but also to the season of the year and the times of use of the structure. As regards thermal energy for heating purposes, we must of course envisage a higher consumption during the winter period, whereas the summer season will see the prevalence of electricity consumption (cooling systems).

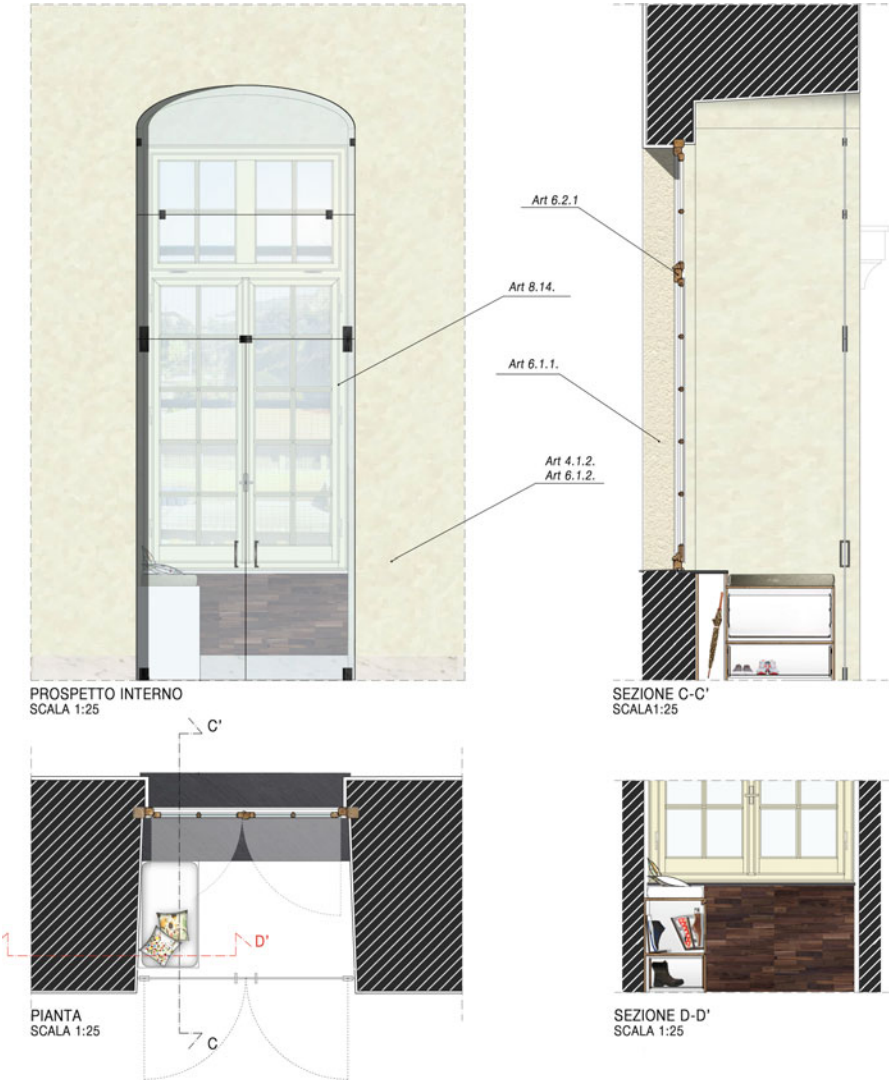

Fig. 8.7 Proposal for a new window system in the northern wing, doubling the existing one (Bresolin, G., Stagnaro, I., Tomasetti, G. 2012. Master course in Architecture)

Table 8.8 Performances of new windows/doors (additionally to the existing ones)

Characteristics of components	*U* [W/(m^2K)]
Softwood frame	1.8 Uf
Double glazing with low emissivity coating (normal solar transmission coefficient 0.75)	2.7 Ug

Table 8.9 Calculation of the thermal power for the winter requirement divided by floors and by uses in the different insulation scenarios

Floor	S [m^2]	V [m^3]	P_{THERM} [W]	$P_{\mathrm{THERM}}A$ [W]	$P_{\mathrm{THERM}}B$ [W]	$P_{\mathrm{THERM}}C$ [W]	$P_{\mathrm{THERM}}D$ [W]
Ground	2,848.29	15,653.46	132,608	–	–	126,656	93,731
First	5,386.75	45,953.53	459,081	451,842	432,734	447,913	350,715
Second	4,061.86	23,305.34	289,454	279,693	244,895	280,888	225,715
Third	4,312.80	22,140.82	191,532	–	–	184,665	135,415
Fourth	3,683.66	19,123.43	240,915	228,628	195,323	234,289	192,486
Fifth	1,558.95	6,778.12	131,734	119,825	82,093	128,868	113,038
Sixth	407.76	2,108.32	49,922	45,647	33,404	48,905	43,014

S net surface, *V* net volume, P_{THERM} thermal power, $P_{THERM}A, B, C, D$ thermal power for N-type interventions *A* (insulation of the roof soffit), *B* (insulation of the structures closing the top floor environments), *C* (insulation of the outer perimeter wall in the sub-window portion), *D* (insertion of a new internal window/door)

Table 8.10 Percentage variations of thermal power in the different insulation scenarios

Floor	S [m^2]	V [m^3]	P_{THERM} [W]	A [%]	B [%]	C [%]	D [%]
Ground	2,848.29	15,653.46	132,608	0	0	−4.49	−29.32
First	5,386.75	45,953.53	459,081	−1.58	−5.74	−2.43	−23.60
Second	4,061.86	23,305.34	289,454	−3.37	−15.39	−2.95	−22.02
Third	4,312.80	22,140.82	191,532	0	0	−3.59	−29.30
Fourth	3,683.66	19,123.43	240,915	−5.10	−18.92	−2.75	−20.10
Fifth	1,558.95	6,778.12	131,734	−9.04	−37.68	−2.18	−14.19
Sixth	407.76	2,108.32	49,922	−8.56	−33.09	−2.04	−13.84

S net surface, *V* net volume, P_{THERM} thermal power, *A* (Insulation of the roof soffit), *B* (Insulation of the structures closing the top floor environments), *C* (Insulation of the outer perimeter wall in the sub-window portion), *D* (Insertion of a new internal window/door)

Usually, in order to keep account of these variables and not to create disruptions, next to cogeneration one envisages the use of combustion heat generators (boilers) and connection to the electricity grid. The coupling of these plant types enable the use of cogenerators pursuant to two operational strategies:

- Electricity tracking (with power priority): the cogenerator regulates the electric power produced in such a manner as to follow an allocated profile; the thermal production accordingly varies, and the boiler intervenes where necessary.
- Thermal tracking: the cogenerator regulates the electric power produced in such a manner as to meet the thermal power needs.

Ultimately, in the energy production station servicing the areas to be recovered in the *Albergo dei Poveri* complex, we might envisage the use of heat generators fuelled by a certain number of cogeneration units.

Table 8.11 Calculation of the thermal requirement for heating purposes with possible insulation of the top floor and the sub-window wall, and with insertion of a new certified window/door

Uses	S [m^2]	V [m^3]	E_{THERM} [kWh]	$E_{\text{THERM}}B + C + D$ [kWh]	$B + C + D$ [%]
Classrooms	2,325.20	15,371.37	154,991	74,948	−51.64
Laboratories	666.31	6,463.21	118,694	88,422	−25.50
Bar	206.32	1,353.59	39,418	30,336	−23.04
Library and archives	2,122.79	10,925.99	64,254	20,514	−68.07
Jurisprudence library	4,133.76	23,705.74	168,289	64,017	−61.96
Church	585.07	9,361.12	27,588	9,480	−65.64
Canteen	427.06	1,554.50	57,082	1,763	−96.91
Museum	686.84	7,650.65	144,351	70,301	−51.30
University accommodation	6,582.32	33,246.44	675,928	304,374	−54.97
Staff room	139.99	605.47	8,900	5,700	−35.96
Common rooms	630.32	3,691.50	154,462	73,565	−52.29
University offices	3,754.07	21,133.47	278,783	104,161	−62.64
Total	22,260	136,063	1,892,481	847,582	−55

S net surface, *V* net volume, $E_{THERM}B + C + D$ thermal energy requirement for heating purposes in the *B*, *C*, and *D* insulation scenarios and percentage variations compared to the current state

Table 8.12 Comparison of thermal requirements between the current state and different *A*, *B*, *C*, and *D* interventions

E_{THERM} [kWh]	$E_{\text{THERM}}A$ [kWh]	$E_{\text{THERM}}B$ [kWh]	$E_{\text{THERM}}C$ [kWh]	$E_{\text{THERM}}D$ [kWh]	$E_{\text{THERM}}B + C + D$ [kWh]
1,892,481	1,806,255	1,497,828	1,821,261	1,313,454	847,581.69

To define the latter, it is necessary to embark on the following analyses:

1. Preliminary analysis of the cogenerative units in terms of size and performance characteristics
2. Analysis of the partial/total coverage of thermal and electrical loads based on the estimated consumption levels

8.3.1 Preliminary Analysis of the Cogeneration Units

The units chosen for illustration purposes are the Turbec T100 PH cogenerators produced by *Ansaldo Energia*.[1]

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[1] *Ansaldo Energia* took part in the research programme as a technical partner, giving assistance and information on micro-turbines and technical specifications.

They are units equipped with a gas turbine that might be fitted with a fumes/water heat exchanger capable of recovering the thermal energy from the exhaust gas. The unit may be installed in a suitable venue, provided due compliance, besides the necessary general prerequisites, with those linked to the characteristics of the machine.

Set out hereunder are some technical specifications and related remarks (surface and height of the venue, in loco installation, unit weight, fuel requirements, performances of the cogenerator, influence of the input CHP air temperature).

The surface and height of the venue must be enough for the installation and maintenance of one or more unit side by side (size characteristics of the Turbec T100 PH units: $W \times H \times L = 900 \times 1{,}810 \times 3{,}900$ mm). In case of an in loco installation, it is necessary to channel the outside air intake and obligatorily prescribe an input pre-filter. The piping must be thermally insulated with 50 mm of insulation to avoid possible condensation limits, and there are limits to the maximum pressure drops admissible between input section and T100-PH unit. **(c)** Taking into account the unit weight ($P = 2{,}770$ kg), wherever the installation is envisaged at the intermediate floors, we must assess any consequences on the structures. The units are essentially free from vibrations. The fuel requirements are set out as follows (during the executive phase, however, we must assess the gas supply characteristics at the distribution company):

Required pressure 20 mbar $\leq p_{CH4} \leq$ 500 mbar
Required temperature 0 °C $\leq T_{CH4} \leq$ 60 mbar
Lower calorific value 38 MJ/kg $\leq H_i \leq$ 50 MJ/kg

The unit is already fitted with a “gas train”, so it is sufficient to bring the line to the machine joints. In case methane gas is used, in normal conditions ($T = 0$ °C $= 273.15$ K$-p = 101{,}325$ Pa) the following materializes:

$$\rho = p/(R_1 \cdot T) = 101{,}325/(519.625 \cdot 273.15) = 0.7139\text{kg/Nm}^3$$

$R_1 = R/M = 8{,}134/16 = 519.625$ kJ/(kg K)
$R = 8{,}314$ J/kmol K
$M = 18$ kg/kmol

$$H_{\text{i-CH4}} = (50\,\text{MJ/kg}) \cdot \left(0.7139\,\text{kg/Nm}^3\right) = 35.695\,\text{MJ/Nm}^3$$

Set out hereunder are the performances of the cogenerator:

Electrical output: $P_{el} = 100 \pm 3\ \text{kW}_{el}$
Thermal output: $P_{th} = 167 \pm 5\ \text{kW}_{th}$ with $T_{\text{H2O-in/out}} = 50/70$ °C
Electrical performance of the cogenerator: $\eta_{\text{el-chp-el}} = 30\% \pm 1\%$
Total performance of the cogenerator: $\eta_{chp} = 80\% \pm 1\%$
Methane gas consumption: $G_{CH4} = 34\ \text{Nm}^3/\text{h}$
Input CHP thermal power: $P_{\text{th-in}} = (G_{CH4} \cdot H_{\text{i-CH4}})/3.6 = 337\ \text{kW}_{th}$

Gasoline fume rate: $G_{\text{fumes}} = 0.8$ kg/s
Temperature of the input fumes at the exhaust gas heat exchanger: $T_{\text{f-in}} = 270$ °C

Set out hereunder is the calculation of the output temperature of the fumes exiting the heat exchanger:

$$P_{\text{th}} = G_{\text{fumes}} \cdot c_{\text{p-fumes}} \cdot (T_{\text{f-in}} - T_{\text{f-out}})$$

$$T_{\text{f-out}} = T_{\text{f-in}} - P_{\text{th}}/\left(G_{\text{fumes}} \cdot c_{\text{p-fumes}}\right) = 270 - 167/(0.8 \cdot 1.1) \approx 80^{\circ}\text{C}$$

where: $c_{\text{p-fumes}} = 1.1$ kJ/kJ/(kg K) is the specific heat at constant pressure of the combustion gases

$T_{\text{f-out}}$ [°C] is the output temperature of the fumes exiting the regenerator.

Based on the calculations, the output temperature of the fumes exiting the exchanger is higher than the dew point temperature ($T_{\text{f-out}} > T_{\text{f-rug}}$), but we must assess whether condensation occurs down the flue. To ensure that the evacuation of fumes takes place properly, we must guarantee the (natural or forced) draught of the chimney, taking into account the pressure drops occurring in the regenerator and in the exchanger. It is likewise necessary to ascertain possible interferences in case more than one cogenerative unit discharging into a single exhaust manifold is used.

Set out hereunder is the calculation of the water flow at the exchanger ($c_{\text{p-H2O}} = 4.186$ kJ/(kg K)):

$$P_{\text{th}} = G_{\text{H}_2\text{O}} \cdot c_{\text{p-H}_2\text{O}} \cdot (T_{\text{H}_2\text{O-out}} - T_{\text{H}_2\text{O-in}})$$

$$G_{\text{H}_2\text{O}} = P_{\text{th}}/\left(c_{\text{p-}_{\text{H}_2\text{O}}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 20) \approx 2\ \text{kg/s} = 3600\ \text{L/h}$$
$$= 3.6\ \ \text{m}^3/\text{h}$$

The calculation evinces that, with $\Delta T_{\text{H2O}} = 20$ °C, in the primary heat exchanger a water flow of $G_{\text{H2O}} = 3.6$ m^3/h should circulate, whereas, in the secondary heat exchanger, the *G*' water flow depends on the temperature difference of the heating elements:

$$\Delta T_{\text{c.s.}} = 10^{\circ}\text{C} \ \ \rightarrow G'_{\text{H}_2\text{O}} = P_{\text{th}}/\left(c_{\text{p-H}_2\text{O}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 10) \approx 4\ \text{kg/s}$$
$$= 7200\ \text{L/h} = 7.2\ \ \text{m}^3/\text{h}$$
$$\Delta T_{\text{c.s.}} = 5^{\circ}\text{C} \rightarrow G'_{\text{H}_2\text{O}} = P_{\text{th}}/\left(c_{\text{p-H}_2\text{O}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 5) \approx 8\ \text{kg/s}$$
$$= 14{,}400\ \text{L/h} = 14.4\ \ \text{m}^3/\text{h}$$

Set out hereunder is the calculation of the thermal performance of the cogenerator:

$$\eta_{\text{chp}-\text{th}}[\%] = P_{\text{th}}/P_{\text{th}-\text{in}} = 3{,}600 \cdot P_{\text{th}}/(G_{\text{CH4}} \cdot H_{\text{i}-\text{CH4}}) = 3.6 \cdot 167/(34 \cdot 35.696)$$
$$\approx 49.5\%$$

As regards the performance of the cogeneration system, and with a view to maximizing efficiency, it seems indispensable to assess the electrical and thermal consumption on a monthly basis.

Concerning the influence of the input CHP air temperature, the graph highlights the performance variations of the cogenerator when the external air is $T_{\text{est}} = 15\ ^\circ\text{C}$, i.e. when $T_{\text{est}} = 0\ ^\circ\text{C}$.

We notice that, in project conditions ($T_{\text{est}} = 0\ ^\circ\text{C}$), the thermal power $P_{\text{th}} \approx 170\ \text{kW}_{\text{th}}$ whereas the total efficiency drops by 3%, i.e. $\eta_{\text{chp}} = 77\%$

8.3.2 Coverage of Thermal and Electrical Loads Through Cogeneration Units

Taking into account the annual consumption of heat and power, we may put forward a few preliminary considerations on the use of cogenerators (Table 8.13).

With regard to the micro-turbines examined, the electrical index E.I., i.e. ratio between the available thermal power and the electrical power produced is:

$$(\text{E.I.})_{\text{chp}} = P_{\text{el-chp}} / P_{\text{th-chp}} = 100/167 \approx 0.6$$

The production of thermal/electrical energy by the cogenerator varies depending on the number of operating hours and on the load. The following table shows the results potentially achievable in case of full operating regime for a Turbec T100 PH cogenerator (Table 8.14).

As regards the portion of the complex still to be recovered, the ratio between electricity and thermal energy is given as follows:

Table 8.13 Quantification of overall requirements in the portion of the complex to be recovered

Electric energy E_{EL}	Thermal energy E_{THERM}
kWh_{el}	$\text{kWh}_{\text{therm}}$
956,000	2,496,000

Table 8.14 Production of thermal and electrical energy

	$E_{\text{EL-CHP}}$	$E_{\text{TH-CHP}}$
Number of hours	kWh_{el}	kWh_{th}
2,920	292,000	487,640
4,380	438,000	731,460
5,840	584,000	975,280
7,300	730,000	1,219,100
8,760	876,000	1,462,920

$$(\text{I.E.}) = E_{\text{EL}}/E_{\text{TH}} = 0.38$$

If we envisage to supply electricity even to the part of structure already in operation for a total of approximately 346,000 kWh_{el} (the consumption levels are partly deduced from the real ones provided by the University and calculated in part, for the areas already recovered but not yet in use at the time of the feasibility study), we then have (Table 8.15):

$$\begin{aligned} E_{\text{EL}} &= 956,000 + 346,000 = 1,302,000 \\ (\text{I.E}) &\approx 0.52 \end{aligned}$$

Table 8.15 Quantification of overall requirements in the portion of the complex to be recovered (as regards the thermal energy requirement) and of the complex as a whole (as regards the electrical energy requirement)

Thermal energy E_{THERM}	Electrical energy E_{EL}
$\text{kWh}_{\text{therm}}$	kWh_{el}
2,496,000	1,302,000

In this case, the electrical index of the cogenerative system $(\text{E.I.})_{\text{chp}}$ is not too different from the one relating to consumption $(\text{E.I.})^{*}{}_{\text{AREA TO BE RECOVERED}}$, but we should keep in mind that the heat and electricity requirements are highly variable, both during the same day and on a monthly and seasonal basis, mostly due to the heating/cooling systems.

The intended use of the premises, moreover, is another significant aspect, given that, save for university accomodations and guest quarters, we expect the highest levels of energy consumption to be concentrated during daylight hours.

To keep account of the aforementioned aspects, we have decided, as a first approximation, to divide the year into two periods:

Period T': 181 days November/April (winter)
Period T'': 184 days May/October (summer)

The system operates in the "thermal tracking" mode. Any surplus of electricity produced is injected into the network and enhanced through the "net metering" mechanism.

8.3.3 Calculation During Winter and Summer Periods

During the winter period, part of the thermal energy consumption might be covered by a first unit operating for 4,344 h (24 h/day for 6 months) and by a second unit operating for 2,172 h only (12 h/day for 6 months from 8 h00 to 20 h00). This is what accordingly ensues:

Day (8:00/20:00).
$E_{\text{TERM-CHP N}^\circ 1+2} = 2\cdot(2{,}172\ \text{h})\cdot(167\ \text{kW}_{\text{th}}) = 725{,}448\ \text{kWh}_{\text{th}}$
$E_{\text{EL-CHP N}^\circ 1+2} = 2\cdot(2{,}172\ \text{h})\cdot(100\ \text{kW}_{\text{el}}) = 434{,}400\ \text{kWh}_{\text{el}}$
Units 1 and 2 provide thermal energy for heating and electricity

Night (20:00/8:00).
$E_{\text{TERM-CHP N}^\circ 1} = (2{,}172\ \text{h})\cdot(167\ \text{kW}_{\text{th}}) = 362{,}724\ \text{kWh}_{\text{th}}$
$E_{\text{EL-CHP N}^\circ 1} = (2{,}172\ \text{h})\cdot(100\ \text{kW}_{\text{el}}) = 217{,}200\ \text{kWh}_{\text{el}}$
Unit 1 provides thermal energy for the production of hot water and electricity.

During the summer period, use of 1 micro-turbine operating for 2208 h (12 h/g for 6 months from 8 h00 to 20 h00) is envisaged. We thus have:

Day (8 h00/20 h00)
$E_{\text{TERM-CHP N}^\circ 2} = (2{,}208\ \text{h})\cdot(167\ \text{kW}_{\text{th}}) = 368{,}736\ \text{kWh}_{\text{th}}$
$E_{\text{EL-CHP N}^\circ 2} = (2{,}208\ \text{h})\cdot(100\ \text{kW}_{\text{el}}) = 220{,}800\ \text{kWh}_{\text{el}}$
Unit 2 provides thermal energy for the production of hot water and electricity.

We ultimately get:

COGENERATOR 1.
Production of heat: $E_{\text{TERM-CHP N}^\circ 1} = 725{,}448\ \text{kWh}_{\text{th}}/\text{year}$
Production of electricity: $E_{\text{EL-CHP N}^\circ 1} = 434{,}400\ \text{kWh}_{\text{el}}/\text{year}$
Number of operating hours: $N_{\text{h-CHP N}^\circ 1} = 4{,}344\ \text{h/year}$
Period of use:
24 h/day during the “winter season” (181 days)

COGENERATOR 2.
Production of heat: $E_{\text{TERM-CHP N}^\circ 2} = 731{,}460\ \text{kWh}_{\text{th}}/\text{year}$
Production of electricity: $E_{\text{EL-CHP N}^\circ 2} = 438{,}000\ \text{kWh}_{\text{el}}/\text{year}$
Number of operating hours: $N_{\text{h-CHP N}^\circ 2} = 4{,}380\ \text{h/year}$
Period of use:
12 h/day during the “winter season” (181 days−8 h00/20 h00)
12 h/day during the “summer season” (184 days−8 h00/20 h00) (Table 8.16)

Table 8.16 Overall data on energy production through the use of two cogenerators

$E_{\text{TERM-CHP N}^\circ 1+2}$	$E_{\text{EL-CHP N}^\circ 1+2}$	$N_{\text{h-CHP N}^\circ 1+2}$
$\text{kWh}_{\text{th}}/\text{year}$	$\text{kWh}_{\text{el}}/\text{year}$	$\text{kWh}_{\text{el}}/\text{year}$
1,456,908	872,400	8,724

$E_{\text{TERM-CHP N}^\circ 1+2}$ heat produced by the cogenerators 1 + 2, $E_{\text{EL-CHP N}^\circ 1+2}$ electricity produced by the cogenerators 1 + 2, $N_{\text{h-CHP N}^\circ 1+2}$ number of operating hours of the cogenerators 1 + 2

8.3.4 Operating Mode of "Thermal Tracking" Cogenerators

We envisage a plant scheme made up of cogenerators and boiler that keep in temperature the accumulation of thermal energy to power the fan-coils, radiators, and pre- and post-heating batteries of the air handling units as well as the production of hot air stored in insulated tanks at a 60 °C temperature. The electricity produced is used to power the units. The air-cooled chillers power the fan-coils of the conditioned premises and the cold air batteries of the air handling units. The buffer tank, properly dimensioned, ensure the smooth operation of the system by minimizing the on/off of the compressors and decoupling the chiller-accumulation circuit from those on the user side (secondary circuits).

The primary air flows have been determined by paying heed to the intended use of the premises, of the useful surface and the relevant crowding density. In general, it is assumed that the flow of extracted air is the same as the inserted one (pressure balance). The air handling units are fitted with a heat recuperator.

From an energy viewpoint, the system may be summarized through a block diagram, with four production subsystems:

- *Heat and electricity production subsystem*: the system, consisting of one or more cogenerators, operates in "thermal tracking" mode and keeps in temperature the thermal energy accumulation. The electricity produced is consumed onsite and, in case of surplus, it is introduced into the electricity grid.
- *Heat production subsystem*: it consists of one or more boilers that keep in temperature the thermal energy accumulation. If the cogenerative system is enough to maintain the conditions, the boilers are switched off.
- *Chilling energy production subsystem*: it consists of one or more electrically powered chillers. The chilled water services the fan-coils found in the conditioned premises and the cold batteries of the Air Treatment Units (ATUs).
- *Steam production subsystem*: the units are powered electrically and, if necessary, humidify the air handled by the specific units.

8.4 Microgeneration Through Solar Energy

The last phase of the feasibility study is devoted to exploring the applicability of other microgeneration systems, in an integrated manner with the cogeneration systems just described. More specifically, the following have been considered on a preliminary basis: the application of hydraulic micro-turbines following the changes in depth of *Rio Carbonara*, that runs in axis below the complex, and the possibility of recovering the *Valletta* greenhouses of *Rio Carbonara* itself, by inserting glass-glass photovoltaic panels.

The presence of a greenhouse system in the small valley behind the complex is motivated by the previous use of these open spaces, destined to the public nursery of the Municipality of Genoa, which has progressively freed them until total abandonment. In the terraced part, on the border with the town to the north, there are "historical" greenhouses, the preservation and retrieval of which is enjoined by the municipal town planning instrument.

Beside feasibility studies on the monumental complex of the *Albergo dei Poveri*, projects for the redevelopment of this large green space for public use have been elaborated by spontaneous committees made up of citizens from the neighbourhood, to which we may add a preliminary quantification of the possible production of electricity from solar technology.

The glazed surfaces of the greenhouses still found in the small valley extend for approximately 2,940 m^2 and exhibit different roofing morphologies, double- or single-pitched, and different orientations towards the cardinal points. As a first approximation, a calculation has been conducted on the energy productivity, taking into account photovoltaic panels with single-crystal glass extended across 50% of the roofing area of the greenhouses, excluding the frames and percentages of windows necessary to crops. The inclusion of photovoltaic panels, in fact, influences the level of brightness inside the nurseries, a factor we should take into account when calculating the influence of the brightness on the life cycle of the crops. When calculating the electricity production, regard was paid to a factor of 15% transparency of panels, with 3 mm distance between the cells and 178 W/m^2 power.

The energy contribution of the photovoltaic system has been calculated in accordance with the Liguria Region's guidelines set out in *Raccolta Normativa della Regione Liguria* (Liguria Region's Regulatory Collection) of 13 November 2012 (taken up by the UNI EN 15316-4-6 standard as subsequently amended and supplemented).

The energy contribution traceable to the photovoltaic $Q_{\text{el,exp.}}$ is expressed by:

$$Q_{\text{el,exp}} = \left(E_{\text{sol}} \times P_{\text{pk}} \times f_{\text{perf}}\right) / I_{\text{ref}}$$

E_{sol} (kWh/m^2)/year: total annual irradiation impacting on the plant surface. The value of such magnitude is obtained from the one impacting annually on a horizontal surface ($E_{\text{sol,or}}$) rectified through a factor of conversion by inclination (F_c).

P_{pk} (kW): peak power; it represents the electrical power supplied by the photovoltaic system at an irradiance $I_{\text{ref}} = 1$ kW/m^2 impacting on the surface with 25°C temperature. This magnitude may be assessed thus: $P_{\text{pk}} = K_{\text{pk}} \times S$

S (m^2): total surface of photovoltaic modules (net of the frame)

K_{pk} (kWh/m^2): coefficient of the peak power, depending on the type of photovoltaic modules incorporated into the building. In the absence of values provided by the building firm, the numerical values of K_{pk} can be found in the UNI EN 15316-4-6 standard.

f_{perf}: plant efficiency factor taking account of the conversion from direct current (DC) to alternating current (AC), of the actual temperature of the module, and of the incorporation of the modules into the building. The numerical values of such magnitude can again be found in the UNI EN 15316-4-6 standard.

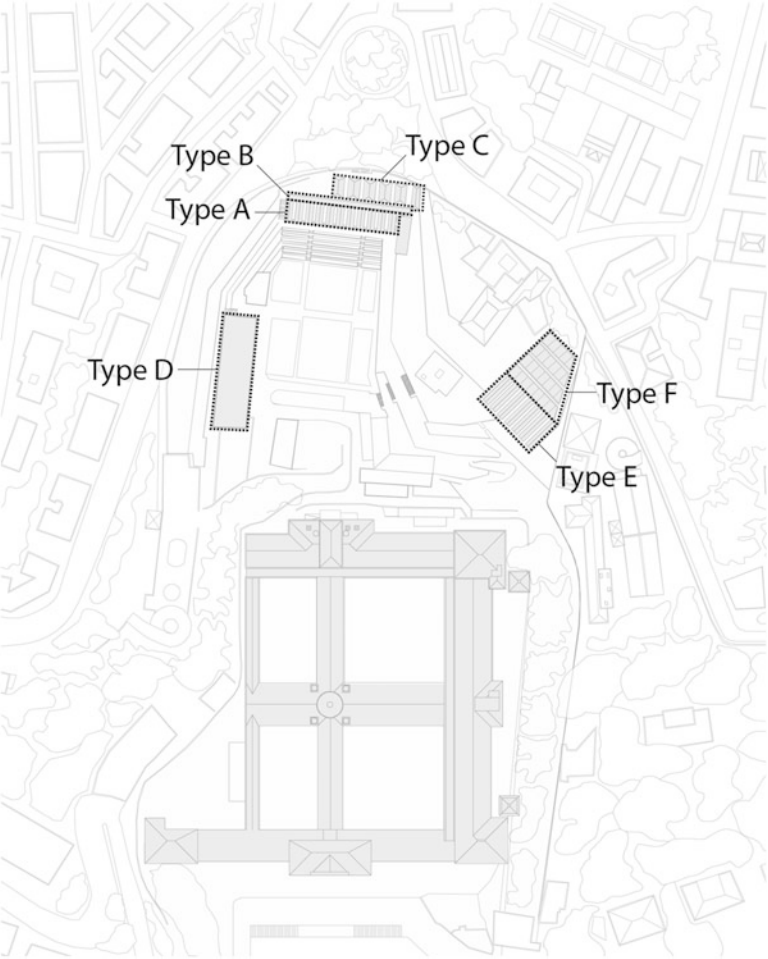

Fig. 8.8 *Valletta Carbonara*. Identification of different types of greenhouses (Macchioni, E. 2016)

The following tables set out the calculations relating to each type of greenhouses surface (Figs. 8.8, 8.9 and 8.10) (Table 8.17)

For the calculation of energy production:

$$Q_{\mathrm{el,exp}} = \left[E_{\mathrm{sol}} \times P_{\mathrm{pk}} \times f_{\mathrm{perf}}\right]/I_{\mathrm{ref}}$$
$$= [(1425 \times 1.07) \times (208 \times 0.178) \times 0.75]/1$$

Greenhouse A = 42,335 kWh/year
Greenhouse B = 15,485 kWh/year
Greenhouse C = 34,400 kWh/year

Fig. 8.9 View of the *Valletta Carbonara* from the west side

Fig. 8.10 Restoration of the greenhouses system with glass PV cells (photo-simulation) (Macchioni, E. (2016). Post-graduate in Architectural Heritage and Landscape, University of Genoa)

Table 8.17 Data relating to the different greenhouse types for calculating the microgeneration

Nursery	$E_{sol,or}$ [kWh/(m^{2}year)]	F_c	S [m^2]	K_{pk} [kWh/m^2]	f_{perf}	I_{ref} [kWh/m]
A	1,425	1.07	208	0.178	0.75	1
B	1,425	1.1	74	0.178	0.75	1
C	1,425	1.07	169	0.178	0.75	1
D	1,425	1.07	454	0.178	0.75	1
E	1,425	1.1	225	0.178	0.75	1
F	1,425	1.07	338	0.178	0.75	1

Table 8.18 Production of electrical energy through photovoltaic modules on the greenhouses

Greenhouse	S_{tot} [m^2]	S_p [m^2]	P [kW]	E_{el} [kWh/year]
A	417.67	208	37.024	42,335
B	147.5	74	13.172	15,485
C	339.3	169	30.082	34,400
D	908.22	454	80.812	92,413
E	451.5	225	40.050	47,083
F	676.3	338	60.164	68,801
Total	2,940.59	1,468.00	261.30	300,517

S_{tot} total roof surface, S_p total productive roof surface, P plant power, E_{el} electricity produced

Greenhouse D = 92,413 kWh/year
Greenhouse E = 47,083 kWh/year
Greenhouse F = 68,801 kWh/year (Table 8.18)

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Chapter 9
Impacts of Solar-Powered Panels on the Historical Environment

Giovanna Franco

9.1 Efficacy, Efficiency, and Life Cycle Assessment

“The mounting of solar or photovoltaic panels, generally on roof slopes, constitutes, due to the dimensions of the intervention, a clear *alteration* concerning the perception of the buildings and, in the case of properties of historical and artistic value, the monument’s unique characteristics. Since they are positioned on the roofs of the buildings, these elements cause a visual disturbance equivalent to aerials and skylights while being even more difficult to incorporate, as already mentioned, due to the size of the surface area covered, which is, of course, directly proportional to the cost-effectiveness of the intervention. (...) It is found that solar panels, in general, are a disturbance to the environment in which they are installed due to the intrinsically technical nature of their forms and colours, resulting from a design process focusing exclusively on optimum energy production criteria and completely overlooking the aesthetic aspect of the products and their integration into the architecture of the property or the morphology of the environment” (Direzione Regionale per i Beni Culturali e paesaggistici del Veneto 2010).

These sentences, from the Italian Ministry of Culture and Landscape, could be considered as a starting point for a reflection of the problematic item of incorporation of solar-powered panels into sensitive historic settings and landscapes (Franco 2015).

From a purely technical perspective, a correct approach to installation planning should take into consideration, in addition to economic factors, consideration of the effectiveness of such devices over time (guaranteed for only a few decades), problems associated with energy storage (with installation of accumulation

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The work presented in this chapter has been developed to set up a series of compatibility criteria in a UNESCO site.

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systems), their disposal (materials not fully recyclable), energy costs of production and, finally, their actual, as opposed to merely nominal, efficiency. In short, planners should, even where dealing with small-scale energy and architectural issues, adopt an attitude mindful of the environment and more in line with Life Cycle Assessment approaches[1] (English Heritage 2010; Tsoutsos et al. 2005).

It is also necessary to balance the purely technical data with that of a cultural nature. Indeed, also in the international arena, concerns regarding the delicacy and fragility of historical and architectural heritage are identified as a priority together with the need to conserve it according to the principles of reversibility, minimal intervention, and impact minimization, thus placing the safeguarding of historical and cultural values at the forefront. To give an example, the general guiding principles for the most appropriate installation of solar microgeneration technology drawn up by English Heritage may be summarized in the following points (English Heritage 2008, 2012):

1. Solar devices are considered as a last resort (and the impossibility of other options must be demonstrated).
2. The proposed intervention must be proven to offer environmental benefits.
3. The modifications and changes brought about by the new technologies must not result in the loss of particular features.
4. The building fabric must not be damaged during anchoring of the devices and, for this reason, reversible solutions are recommended.
5. The impacts must be minimized.
6. The image of the building and its context must not be compromised.
7. The devices must be removed at the end of their service life.

The incorporation of photovoltaic systems, even small-scale and less thermal ones, necessarily involves modifications to the character of the building and site, the impact of which must be carefully assessed in detail through analysis of the distinguishing features of the built landscape. This means, first of all, recognizing the identifying characteristics of the built environment or historical buildings to be protected, the presence of scenic paths and view points, and significant visual relationships between the possible intervention site and the context: one of the recommendations recurring in various guidelines is "non-visibility" of the new installations[2] (Changeworks, Edinburgh Word Heritage 2009; Haringey Council; Heath 2011; Hermannsdorfer 2005; National Renewable Energy Laboratory 2011; Parker 2009).

The most delicate problem, furthermore, lies in pre-emptive identification of the modifications resulting from possible interventions and in attributing value or,

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[1] The service life of photovoltaic panels is estimated at 25–30 years for monocrystalline technology, 20–25 years for polycrystalline technology, and 15–20 years for amorphous silicon (thin-film) technology. This must be considered in relation to the costs of installation and disposal.

[2] The non-visibility of systems and devices powered by renewable energy sources from the main access routes is one of the recurring principles in the international guidelines, at both landscape and construction level, particularly in the case of intervention on listed buildings.

conversely, loss of value, to these, thus defining them as positive or negative. This means that, in addition to technical and economic assessments and considerations relating to effectiveness and efficiency (also in terms of durability and disposal costs), installation of solar-powered devices contends with the broadest and most "slippery" aspect of conservation and protection of cultural and material values. Consequently, the pursuit of environmentally sound procedures, on the one hand, and definition of criteria for active protection, on the other, are operations which cannot forego the clear establishment of aims and objectives belonging to a domain which is, in any event, subjective, changeable over time and, in any case, not unanimously recognized by the scientific and wider communities.

9.2 Means and Aims: Integration, Mimes, Alteration

Indeed, not even the guiding principles upon which architectural and landscape compatibility are based are universally agreed, influenced by the varying importance—not easily commensurable—which the different operators attribute to the values in play.

The issues surrounding the possible *integration* of solar-powered technological devices are therefore complex and wide-ranging and in that grey area between *modification* and *alteration*; results deemed acceptable (the former) or unacceptable (the latter).

Indeed, the most evident problems associated with such technologies concern the various types of impacts on the historical, landscape, and environmental context and fall broadly into the following categories:

- visual intrusion due to the colours, shapes, and reflective surfaces of the collectors (generally at odds with the existing morphologies, materials, and colours)
- modification of the ground structure, fine soil textures, vegetation, etc.
- replacement of existing materials and loss of material characteristics of traditional buildings
- alteration of the social perception of the site

The following possible problems are therefore recognized as determining factors:

- impacts on the physical domain of the built heritage, landscape, environment, and ecosystem, with which the concepts of integrity, modification and, in a negative sense, alteration are associated, with increasing degrees of alteration
- impacts on the psychological and perceptive domain, in which the concepts of integration and mimesis (as the capacity of the observer to assimilate the application of a new technology to a traditional building based on certain culturally accepted values) prevail and, by contrast, alteration (as the perception of a transformation as incompatible or even unacceptable)

The term *integrity*, which recurs more than once in some of the international guidelines specifically addressing the problem of incorporating solar technologies, has to do with "authenticity", often featuring in international protection charters and relating to the value of material testimony, which must not be sacrificed in favour of new technology. The actual state of conservation of the asset therefore assumes importance, representing an important factor in the choice of the most appropriate intervention methods, and even resulting in recommendation against replacement of roof coverings in a good state of conservation. These reflections constitute an already solid international cultural background, in which some guidelines state that:

- the historical character of the building must be preserved, avoiding removal of historic materials
- new works must be differentiated from the context and compatible with the architectural and construction features
- removal of historic roofing materials in order to install solar systems is not permissible for any reason (Historic Scotland 2010; National Alliance for Preservation Commission 2011).

The term *integration*, as differentiated from *integrity*, has a more ambiguous meaning since, in the field of renewable energy sources, it is used with different connotations. Indeed, legislators and technicians use this term to refer to the methods of installation of the device in an existing context (a roof slope): total integration, in substitution of the roof covering, or partial integration, supported on top of the roof slope. Protection bodies, on the other hand, attribute a different meaning to the term, which has to do with the perceptive impact of the intervention, giving it the positive meaning of harmonious or proportionate completion or coordination (visual, morphological, chromatic, material, volumetric and spatial integration, etc.).

International guides also state that where small-scale systems are concerned, the objective of maximum integration of the technological products into the context into which they are being incorporated must be pursued, including through use of innovative technologies and always through organic planning. The most manageable solutions from a design perspective are those relating to the creation of new urban decoration or service products (such as shelters, coverings for outdoor vehicle parking areas, and coverings for refuse collection equipment) purpose-designed with the panels architecturally *integrated*. In pre-existing buildings, *integration* of photovoltaic technology may involve replacement of the materials present or adaptation through, for example, use of paints or films. Where there are large flat or angled glass surfaces, replacement of the transparent elements with semi-transparent photovoltaic modules may be envisaged. Replacement becomes an extremely delicate operation in historic contests where the removal of parts, generally of roofs, results in obvious discontinuity (Historic Scotland 2010).

Integration must therefore be understood—and pursued—not merely as a technique but also as the result of perception of the intervention, which inevitably concerns the domain of subjectivity, the act through which the psyche defines and determines the content of a vision by adding further data. In this sense, integration also means incorporation and assimilation, referring to another linguistic hybridization relating to the term *resilience*.

Are we or will we in the near future be culturally equipped to consider the incorporation of renewable sources into sensitive landscapes as a complement to achieve aesthetic unity?

It is difficult to find widely accepted answers to this question, even though, as previously highlighted, the need for guidelines issued by the protection bodies is becoming increasingly urgent, particularly in order to avoid the risk of discretional, case-by-case assessment.

Mimesis, as the objective of harmonious completion diagonally opposed to *alteration*, appears to be the preferred route, not only in the English-speaking world (Bath Preservation Trust and the Centre for Sustainable Energy 2011; Changeworks, Edinburgh Word Heritage 2009; Energy Heritage 2012), recommending or accepting interventions that replace already deteriorated stone roofing with products specifically designed to imitate the traditional material. Research associated with the world of manufacture, while appearing to have undergone a notable shutdown during the last year (perhaps due, at least within Italy, to the major reduction in government incentives), also reflects the demand for a lesser contrast, proposing elements in shapes and colours considered more in keeping with historic landscapes (predominantly interlocking tiles and pantiles but also imitation stone slabs). However, although the term *mimesis* literally refers to the concept of imitation and realistic reproduction of an environmental, social, or cultural reality, photovoltaic technology will never succeed in reproducing, even visually, the colour, grain, and texture of a traditional material, particularly in the case of stone slabs whose coloration changes perceivably under the effect of the sun.

At the opposite end of the spectrum is the perception of an *alteration*, in the sense of a substantial transformation in appearance or structure, therefore endowed with a decisively negative meaning[3].

If the pursuit of mimesis rests on more culturally consolidated ground, that of “harmonious contrast” still appears somewhat far-removed from common feeling, while undoubtedly making space for the role of creativity and research into material technology and design of components. “It is possible, today, to choose from a wide range of solutions which can be adapted to specific contexts requiring different cell types, shapes and colours, various designs and colours of the metal grid of the cell, and a variety of module sizes, materials, and shapes. For successful incorporation of a system, it is fundamental that the design of all its components is appropriate to the context into which it is being incorporated, particularly in the case of pre-existing buildings” (Regione Toscana, Comune di Greve in Chianti 2010).

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[3] International documents, in several points, recommend avoiding recourse to solutions that could alter the character of historic buildings.

Creativity may be used in the design of components more easily integrated with traditional architecture, keeping pace with the latest experiments in the field of new materials (for example, the manufacture of organic photovoltaic cells and thin films which can adhere to surfaces similarly to a photographic printing process, and photovoltaic elements on non-rigid membranes which are better suited to the creation of awnings and additional elements). Creativity is therefore understood not as the expression of the spectacular but rather as a process of information and knowledge organization which can yield unexpected results. The culture of safeguarding, indeed, calls for a poetry of hidden space and, at times, invisibility, revealing perhaps forgotten places and features through skilful placement of the necessary additions. (Fig. 9.1a, b and 9.2a, b)

Fig. 9.1 **(a, b)** The new covering system of *Banca Monte dei Paschi di Siena* in the historical centre of Mantova (picture **b**), Italy (arch. Franco Biondi), compared with the state before the intervention (picture **a**)

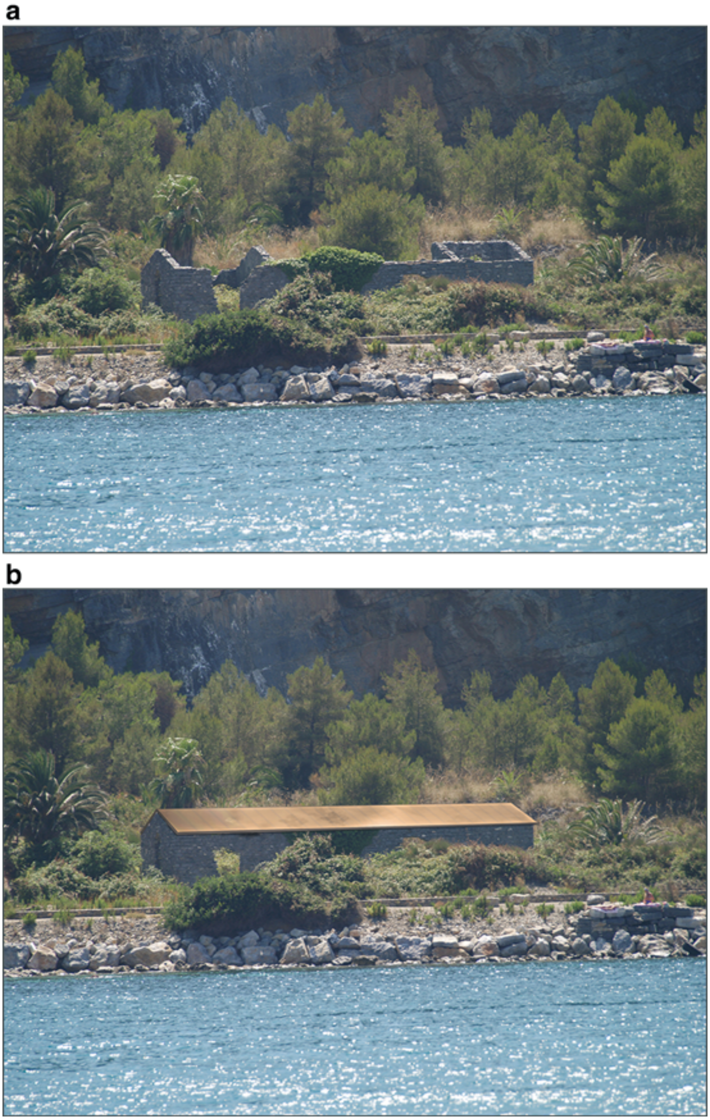

Fig. 9.2 (**a**, **b**) Isle of Palmaria, Italy, UNESCO site. Photosimulation of a new solar roof (copper tiles, not traditional, picture **b**) and the existing situation (picture **a**)

9.3 Identification of the Factors and Criteria for Compatibility

Following a desirable agreement on protection in the regulation of transformations, it will be possible to put forward more specific compatibility assessments, based on experience already gained in the national and international arena and on reciprocal interrelation of factors linked to the physical characteristics of the territory, buildings, and technical devices and the perceptive impacts consequent to new installations (Bonomo and De Bernardinis 2014; Chiabrando et al. 2009; Lucchi et al. 2014; Moschella et al. 2013; Munari Probst and Roecker 2012; Polo Lopez and Frontini 2014; Ran and Wittkopf 2014; Scudo 2013).

Indeed, the possible criteria for compatibility with architectural and landscape protection depend on the following factors:

- *location* (relating to the territorial vocations, the scenery and the construction and morphological characteristics of the building fabric, and also to the actual state of conservation of the buildings);
- *quantity* (depending on whether the systems are isolated or repeatable/aggregated);
- *quality* (relating to the morphology of the device, its colour tone, the potential for mitigating its visual impact, etc.).

All this is also influenced by another factor; that of *scale*, which affects the so-called cumulative factor, at both individual building and landscape level.

In order to provide further detail on certain general criteria, summarized in the aims and objectives discussed in the previous paragraph, it is necessary, first of all, to correctly identify the contextual situation, starting with the physical and construction characteristics of the building and its immediate surroundings. These criteria are then affected by the choice of technology, within the varying range of products on the market. Finally, the most delicate issue concerns the methods through which the intervention may be carried out, i.e. the criteria of planning, quantity, and quality.

Certain situations considered most significant and emblematic were therefore identified (Table 9.1). For each case, use of the most probable products and technologies was simulated, leaving out those which, for various reasons (excessive cost, technology not yet perfected, etc.) still require refinement and consolidation on the market (Table 9.2). In order to best express the range of possible solutions and their impacts on the existing context at perceptive level, several photo-montage in specific sites were selected. This technique has the specific objective of helping the reader to visualize the possible effect of the intervention, taking various alternatives into consideration (Table 9.3).

Some initial considerations may be formulated based on the current condition and historical, architectural, and landscape value attributed to the building or the site itself. Other considerations, however, are closely tied not only to the applicable technologies but also and above all to the installation procedures, depending on quantitative and qualitative factors.

Table 9.1 List of possible context situations

Isolated buildings	Pitched roof	One brick-tiled roof slope
		One stone roof slope
		Two brick-tiled roof slopes
		Two stone roof slopes
		Four roof slopes ore more
	Flat roof	
	Canopy or shelter	
Aggregated contexts	Pitched roof	One brick-tiled roof slope
		One stone roof slope
		Two brick-tiled roof slopes
		Two stone roof slopes
		Four roof slopes ore more
	Flat roof	
	Canopy or shelter	
Annexes service volumes		
Ground-based interventions		

Table 9.2 List of applicable products and technologies

Solar thermal	Panels	Flat solar panel
		Tube solar panel
	Roof covering products	Solar tile
		Solar pantile
Photovoltaic	Rigid panels	Monocrystalline modules
		Polycrystalline modules
		Amorphous thin-film modules
		Coloured modules
		Glass-glass modules
	Flexible modules	
	Roof covering products	Photovoltaic roof tile
		Photovoltaic pantile
		Photovoltaic slab

Table 9.3 List of factors influencing the quality of an intervention

Quantitative factors	Surface area and coverage ratio
	Height
	Width
Qualitative factors	Shape
	Colour
	Texture
	Tilt
	Attachment/anchoring method
	Arrangement: discrete or continuous
	Aggregation, proportion, and alignment

9.4 Compatibility Criteria: General Recommendations

9.4.1 Interventions on Historical Buildings, Either Isolated or Aggregated

When considering interventions to improve eco-efficiency and, above all, possible “integrated” or “semi-integrated” incorporation of solar-powered devices, it is preferable to intervene on traditional buildings in conditions requiring complete overhaul of one area (such as the roof covering and/or structure) as opposed to completely or partial replacing traditional materials that are still in good working order. Where it is necessary to intervene on buildings whose traditional construction features remain unaltered, it is, therefore, desirable to seek planning solutions involving elements other than the roof covering (shelters, pergolas or, if possible, non-traditional annexes or ground-based solutions preferably hidden or disguised from view).

For special cases (in terms of the number and morphology of roof slopes and the construction materials), quantitative and qualitative factors come into play, and the visibility of the new intervention from the access points assumes particular importance.

9.4.2 Interventions on Flat Roofs

In traditional buildings, flat roofs are often the result of changes to existing sections, or of extensions or even new constructions. For this reason, incorporation of solar panels, either solar or photovoltaic, into flat roofs is not generally considered a possible element of alteration to the perception of the landscape, provided that they meet certain size requirements, in some cases involving a height restriction : “panels must not exceed 1 m in height and must be positioned at a distance of at least 1 m from the edge” (Changeworks, Edinburgh Word Heritage 2009) or proportional relationship to the characteristics of the object of intervention. “In the case of installation on a flat roof, it must be ensured that the individual modules do not stand at more than half the height of the lowest part of the perimeter element”, according to the Guidelines of the Municipality of Greve in Chianti. “Restrict the maximum height of the system to the height of the first-floor parapet”, according to the Guidelines of the Veneto Regional Directorate (Badescu and Barion 2011).

9.4.3 Interventions on Annexes to the Building or Projecting Elements

When dealing with buildings whose material, construction, and morphological features remain unaltered, it is therefore preferable to intervene on annexes to the building, particularly if recently constructed, as opposed to on parts of the building itself. Where alteration of the building's features is undesired and where protective elements, including projecting ones, are already present or admissible, it is possible to replace materials used for shading (awnings, drapes, and plastic shelters) with photovoltaic modules, preferably made from glass-glass, thus emphasizing the difference between new materials and traditional ones, as opposed to attempting chromatic mimesis.

The Guidelines produced by the Veneto Regional Directorate offer some guidance on this subject: "Pergola structures, lifted off the ground and covered with strips of panels separated from one another in such a way as to allow rain water to fall naturally to the ground, have less visual impact. When arranging and incorporating panels, uniformly covered surfaces of large dimensions which make the ground impermeable and unusable for cultivation should be avoided" (Badescu and Barion 2011; Cornwall Council 2012, 2013).

9.4.4 Interventions on Recently Constructed Buildings

As the local and regional guidelines often point out, it is preferable to intervene on deteriorated areas, recently constructed buildings or buildings whose traditional characteristics have already been significantly altered through significant maintenance, restoration, or reconstruction interventions.

9.5 Recommendations Relating to Quantitative and Qualitative Factors

9.5.1 Surface Area and Coverage Ratio

The first and perhaps most significant quantitative factor to be considered with reference to the compatibility of installations concerns the maximum admissible size of the system in relation to the characteristics of the object or site and is generally assessed in terms of maximum ratio of covered area to surface area of the entire roof slope (in the case of buildings). With regard to the maximum area for a plot of land or a site, reference must be made to the urban planning or building regulations and, in the case of self-handling, to the qualitative criteria relating to aggregation and alignment methods. In this case, only the ratio to the surface area of the roof slope must be considered.

Pre-establishing a maximum surface area of panels, also in terms of percentage ratio to the area of the lot or roof slope affected by the incorporation (as found in many national and international guidelines), appears a somewhat complex operation to establish in advance, without any reference to the context, the visibility of the intervention or the surface area of the roof slope potentially affected by the intervention. Indeed, the necessary surface area depends on the characteristics of the individual building or aggregated nucleus and on the relative energy requirements. Some literary references exist: the Guidelines produced by the Veneto Regional Directorate for Cultural and Landscape Heritage, which refer to the installation of photovoltaic arrays, for example, identify the maximum ratio between the covered area of panels and the total surface area of the plot of land on which they are positioned as 40% (Badescu and Barion 2011). The recommendations found in the Regional Government of Tuscany's Guidelines, drafted in conjunction with the Italian Ministry for Cultural Heritage and Activities, are less quantitatively rigid: system solutions meeting the maximum yield requirements must be favoured in order to use the smallest possible number of elements (including solar tracking systems) (Ministero per i Beni e le Attività Culturali e Regione Toscana 2012). However, this criterion could clash with the compatibility criteria in terms of the colour of the panels (in the case of photovoltaic): the more harmonious with the existing context, the less efficient in terms of energy production.

Identification of a maximum ratio between the surface area of the roof slope and the surface area of the panels to be installed appears equally complex. In the Canton Ticino region of Switzerland, quantitative criteria are specified, also justified by the modest size of traditional alpine and rural buildings: The panels must be positioned on the roof in a way that respects the proportions of the slope. For successful incorporation, it is important that the covered area does not become the predominant element. At least 60% of the surface area of the individual roof slopes must maintain their original covering (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). The Veneto Regional Directorate recommends even more restricted proportions, perhaps in view of the larger size of the roofs in question: in general, for optimal perception of the roof, no more than 15% of the entire surface area of the slope should be covered. In the case of terracotta roofs, the ratio of panels to maximum surface area of the roof must be reduced, favouring arrangement in strips which emphasize the building's form (Badescu and Barion 2011).

However, in the case of isolated buildings dotted around the countryside, and considering the modest size of the roof slopes of traditional buildings, a similar size ratio would reduce the available surface area for installation of panels to an excessively restricted energy production. For this reason, too, various considerations could be put forward concerning the possible coverage of the entire roof of annexes and service buildings and potential coverage of open spaces. Due to the morphological and development characteristics in question, the requirement of the Regional Government of Lombardy—according to which, in the case of historic buildings, the system must only affect one of the building's roof slopes, to be assessed also in view of its visibility—may, in any case, be considered valid (Minosi and Zanzani 2013). In any case, it is not sufficient to consider quantitative factors alone; indeed, surface area being equal, it is also necessary to assess the compatibility of the intervention in terms of panel arrangement and their aggregation forms on the slope.

Fig. 9.3 Historical centre of Siena, Italy. Minimum percentage of coverage of solar panels

Furthermore, quantitative factors have implications for the "scale" factor and the cumulative effect associated with the repetitiveness of the intervention within the landscape, making any alterations more perceivable and unbalancing the proportions (Fig. 9.3).

9.5.2 Height

The minimum or maximum height of a small system powered by renewable energy concerns, predominantly, ground-based photovoltaic systems and micro-wind systems (whose height is also linked to their technical efficiency and can reach 4 m above ground depending on the environmental conditions). The guidelines analysed indicate minimum heights above the ground, to ensure that the soil can be treated as green, or maximum heights, to avoid excessive visual intrusions on the landscape. In ground-based systems, in order to ensure that the land beneath does not become "scorched earth" and is reached by the sun and rain, the Veneto Regional Directorate's Guidelines propose a minimum panel surface height of 1.5 m above the ground (Badescu and Barion 2011). Anglo-Saxon Guidelines, on the other hand, recommend a maximum height for ground-based panels (4 m) and a surface area not exceeding 9 m^2 (Changeworks, Edinburgh Word Heritage 2009; Cornwall

Council 2012). It should be noted, however, that pre-established minimum or maximum height recommendations are especially risky, particularly in sensitive contexts not suitable for housing large-scale plants. It is preferable to define relative compatibility criteria regarding the architectural, landscape, and environmental characteristics. Recommendations different to those of the Regional Government of Veneto are provided, for example, by the Regional Government of Tuscany: photovoltaic modules must have the minimum possible height from countryside ground level (2 m at the highest point). The support structures must be designed in such a way as to include loadbearing elements of minimum bulk (Ministero per i Beni e le Attività Culturali e Regione Toscana 2012). The choice between installation of a small ground-based system and an integrated or partially integrated one installed on the building remains, in any case, a problem to be dealt with on a case-by-case basis and must be assessed based on a specific plan and in relation to the site conditions.

9.5.3 Width

This factor refers to the maximum width of panels installed on the ground or on a roof covering. Maximum width is a factor referring predominantly to large-scale ground-based plants, in order to avoid cumulative effects and excessive soil occupation. The Guidelines of the Regional Government of Veneto, for example, consider strips of panels of reduced width (two panels) acceptable (Badescu and Barion 2011) although this recommendation is highly debatable since it is not applicable to various contexts. Width, a quantitative criterion, must therefore be linked to qualitative planning factors such as aggregation, proportion, and alignment procedures, to which reference should be made (Fig. 9.4).

9.5.4 Shape

This factor refers to the relationship between the geometric shape of one or more panels, installed as part of a group, and the shape of the roof slope affected by the intervention. One of the most delicate and difficult solutions is, for example, installation of panels on pyramid roofs which have triangular surfaces and are therefore ill-suited to housing rectangular devices or groups of devices. As a remedy to this problem, there are panels on the market which can be adapted to irregular geometries (laser cut). In any case, it is advisable to leave a strip at the edge clad in the traditional covering which must, however, be adaptable to the geometry of the roof slope. The “shape” factor must also, in any event, be considered in relation to the surface area and the method of arrangement.

Fig. 9.4 Punta Mesco, Italy, UNESCO site (FAI property). Maximun percentage of covera of red photovoltaic panels (photo-simulation)

9.5.5 Colour

This factor refers to the chromatic characteristics of the device (rigid or flexible panel or one to be integrated into discontinuous coverings) and constitutes one of the specific aspects to be considered in assessing the integration of the new device into the architectural or landscape context or, conversely, the alteration of the features. Panels' chromatic characteristics, as well as having the ability to reflect, or not, those of the covering on which they are to be incorporated and adapt, or not, to the environmental context (Ministero per i Beni e le Attività Culturali e Regione Toscana 2012), also affect one of the factors which is assessed in a negative sense, namely, the effect of reflection of the sun's rays. Therefore, when choosing the typology and characteristics of the cell (type, shape, colour, material, and dimensions), it is necessary to adopt solutions that reduce the visual impact caused by the glare from the reflective surfaces and the chromatic and material discontinuities, as, for example, with regard to the incorporation of photovoltaic panels arranged as fencing for farmland or for a building, or for panels added to a building as sun-blinds or balustrades. Amorphous modules have less impact through reflection of the sun's rays and the glare effect, but their lesser efficiency in terms of energy production, greater cost, and lesser durability, all factors which carry a certain weight in the selection of the device to adopt, should also be remembered.

Chromatic similarity may be achieved through selection of coloured photovoltaic panels or elements produced especially for integration into pantile, interlocking tile, or stone roof coverings. “Various types of panels exist and a variety of models are available in different module frame and surface colorations. Adoption of panels best suited to the context of incorporation is therefore required, and this depends, in particular, on the colour of the roof which is linked, in turn, to the materials (pantiles or stone or natural roof tiles)” (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). However, solar technology materials are not capable of imitating traditional roof covering ones, either stone or ceramic, due to the differences in the size, grain, and colour of the products. It is therefore advisable to simulate the various products on the market in turn, in order to assess their perception and visibility at close range. In isolated and small-sized buildings, moreover, it is possible to consider new incorporations not necessarily with the aim of mimesis with the characteristics of the traditional roof covering, in each case employing products that can be harmoniously incorporated into the context, albeit through contrast. In any case, it is necessary to combine qualitative factors with the condition of the asset undergoing intervention, always favouring conservation, where possible, of the traditional materials and creation of new interventions in service elements.

9.5.6 Texture

This factor is considered here with reference to interventions substituting entire ruined roof coverings with small-sized integrated solar or photovoltaic elements. Different textures may be proposed for arrangement of these small solar technology elements (for example, in alternate rows or in a haphazard and disorganized way, or, alternatively, in other geometric arrangements from the relative graphic table which proposes various possibilities for composition of the elements, in regular co-alignments or irregular textures). In any case, it is also necessary to assess the visual perception from a chromatic viewpoint. The texture factor can also be applied in the case of ground-based installations and, in this case, it affects other qualitative factors such as arrangement, composition, proportion, and alignments (Fig. 9.5a–d).

9.5.7 Tilt

Like shape, the tilt of the panel in relation to the surface on which the element lies and into which the solar panel is to be incorporated (whether on a roof or on the ground) is also a factor requiring careful consideration.< As a general rule, the majority of the guides examined agree on the necessity of aligning the panel with the gradient of the roof and, in cases where it is supported on the surface and not

Fig. 9.5 **(a**, **b**, **c**, **d)** Isle of Palmaria, Italy, UNESCO site. Example of different kind of texture with an integrated tile (photo-simulation)

integrated, some texts, particularly in the Anglo-Saxons ones, identify the maximum protrusion of the panel from the surface of the roof covering as 20 cm. From the Swiss Guidelines: "Incorporations at a gradient other than that of the roof slope are not admissible in terms of landscape protection". If the panels are supported on the roof slope, they must have the same tile, without visible support structures» (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). However, this factor must also be weighed against the relationship between the size of the panels and the support surface (Fig. 9.6).

Fig. 9.5 (continued)

9.5.8 Attachment/Anchoring Method

This factor refers both to cases of incorporation into the roof covering or integration into other parts of the building and to ground-based incorporation. The shared objective of guidance tools for protection and correct planning is that of minimizing the invasiveness of the supports, not only from the point of view of visual perception but also, and above all, of minimizing soil modifications (which, in the case of a terraced structure such as the one on the site under examination, could prove to be

Fig. 9.6 Historical centre of Siena, Italy. Small photovoltaic panels with different tilt in relation to the surface of the roof

fragile) or damage to buildings. “Externally, only the solar panels must be visible while all tubing and conductors must be positioned within the building. The support structures must not be visible” (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). In this sense, integrated solutions are preferable, in the case of complete overhaul of roof coverings, to solutions superimposed onto existing roof slopes. Attention to detail, moreover, particularly at the connection points between the panels and roof covering, constitutes one of the most delicate factors in terms of the perception of the intervention (Fig. 9.7).

9.5.9 Arrangement: Discrete or Continuous

This factor refers to the possibility of positioning several panels continuously or individually. As a general rule, it may be noted that, on roof coverings, it is often advisable to group the panels together, in rectangles or strips, obviously in proportion to the dimensions of the roof covering. “For particularly problematic areas, the best geometric shape is a regular parallelepiped arranged along the central axis of the roof slope, almost embedded in the tile covering. In order to permit perception of the shape of the roof covering, at the edges of the parallelepiped it is advisable to

Fig. 9.7 Alpine roof, Italy. Caothic attachement of solar and PV panels

maintain a strip of at least four rows of tiles for vertical edges and at least two rows of tiles between the ridge and the panels" (Direzione Regionale per i Beni Culturali e Paesaggistici della Regione Friuli Venezia Giulia, Soprintendenza per i Beni Architettonici e Paesaggisti del Friuli Venezia Giulia 2011, 2012). In other cases, it is specifically recommended to "incorporate the panels on the roof slope, in the edge strip, along the line of the eaves" (Badescu and Barion 2011). However, this recommendation appears relatively arbitrary and, in some cases, has more impact than incorporation in strips at the ridge. Indeed, with this second arrangement, a greater portion of traditional roof slope is perceivable, and the eave intersection remains unaltered (Fig. 9.8a–d). Panels incorporated into pitched roofs must not protrude above the highest element or more than 20 cm from the surface, a measurement comparable to the depth of a skylight (Changeworks, Edinburgh Word Heritage 2009; Cornwall Council 2012).

The criteria for interaction of panels with the roof coverings identified in Switzerland and taken up by the SuRHiB and EnBau European research projects are: panels lying coplanar with the roof slope, observance of alignments, regular shape, grouping, and precise integrated incorporation (Zanetti 2010; Zanetti et al. 2012; Polo Lopez and Frontini 2014).

Ground-based panels, on the other hand, particularly small-scale ones, are considered to have less impact when arranged individually, with panels not positioned side by side.

Fig. 9.8 (**a**, **b**, **c**, **d**) Schiara, Italy, UNESCO site. Different type of arrangement of solar panels have incidence of the visual perception of the roof

9.5.10 Aggregation, Proportion, and Alignment

This factor refers to the possible identification of symmetries, lines generating simple geometries and proportional relationships to be respected, and may refer to the morphological characteristics both of a building and of the land. This is, obviously, a qualitative factor and is difficult to set out in the form of a recommendation, although the guidelines examined do provide some examples, as shown in the following examples. “Panels must be incorporated into or supported on the roof with respect for the elements give the building its individual form and architectural

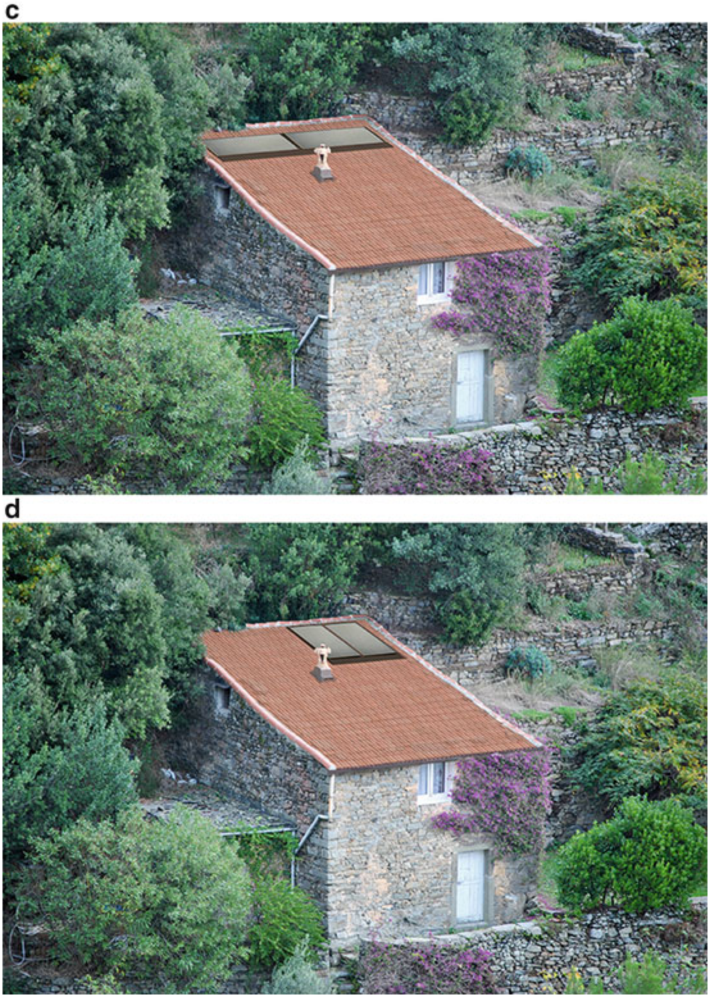

Fig. 9.8 (continued)

features, particularly the outlines of the construction—ridge, corners and eaves—as well as the chimney stacks and skylights" (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). Other recommendations advise incorporation in irregular patches and preference for incorporation of photovoltaic strips in such a way as not to oppose the building's architectural lines (Badescu and Barion 2011). "The entirety of the panels must form a regular surface, generally rectangular. It is not permissible to divide the panels into different groups on the same roof" (Canton Ticino, Ufficio della natura e del paesaggio, Commissione del paesaggio 2010). "It is advisable to plan configurations that maintain or improve the proportional relationships of the building" (Cornwall Council 2012).

In relation to this factor, it is possible to consider various possible solutions for ground-based photovoltaic panels: positioned individually as opposed to continuously, in colours in harmony with the context (green, for example) or in a strategic position in relation to the characteristic elements of the landscape (bordering paths, adjacent or parallel to retaining walls, etc.).

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