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

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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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G. Franco, A. Magrini, *Historical Buildings and Energy*,
DOI 10.1007/978-3-319-52615-7_8

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).

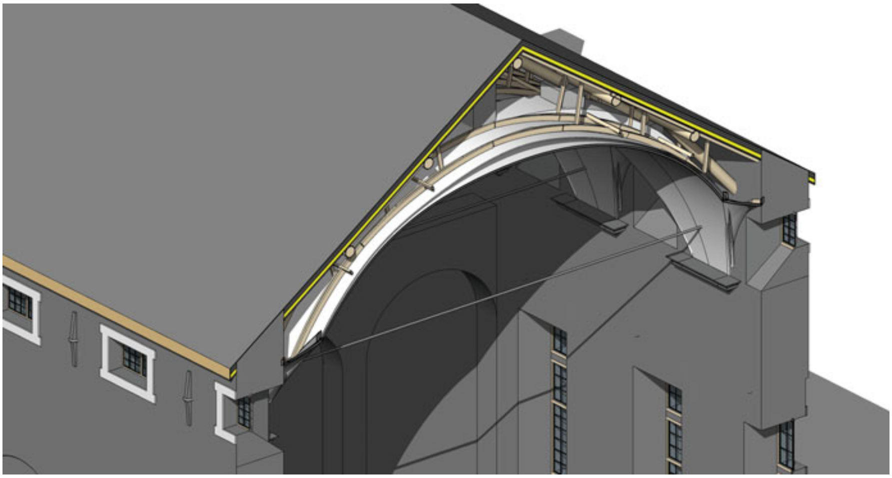

Fig. 8.1 Thermal improvement of the roof (BIM model, Babbetto, R. 2015)

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).

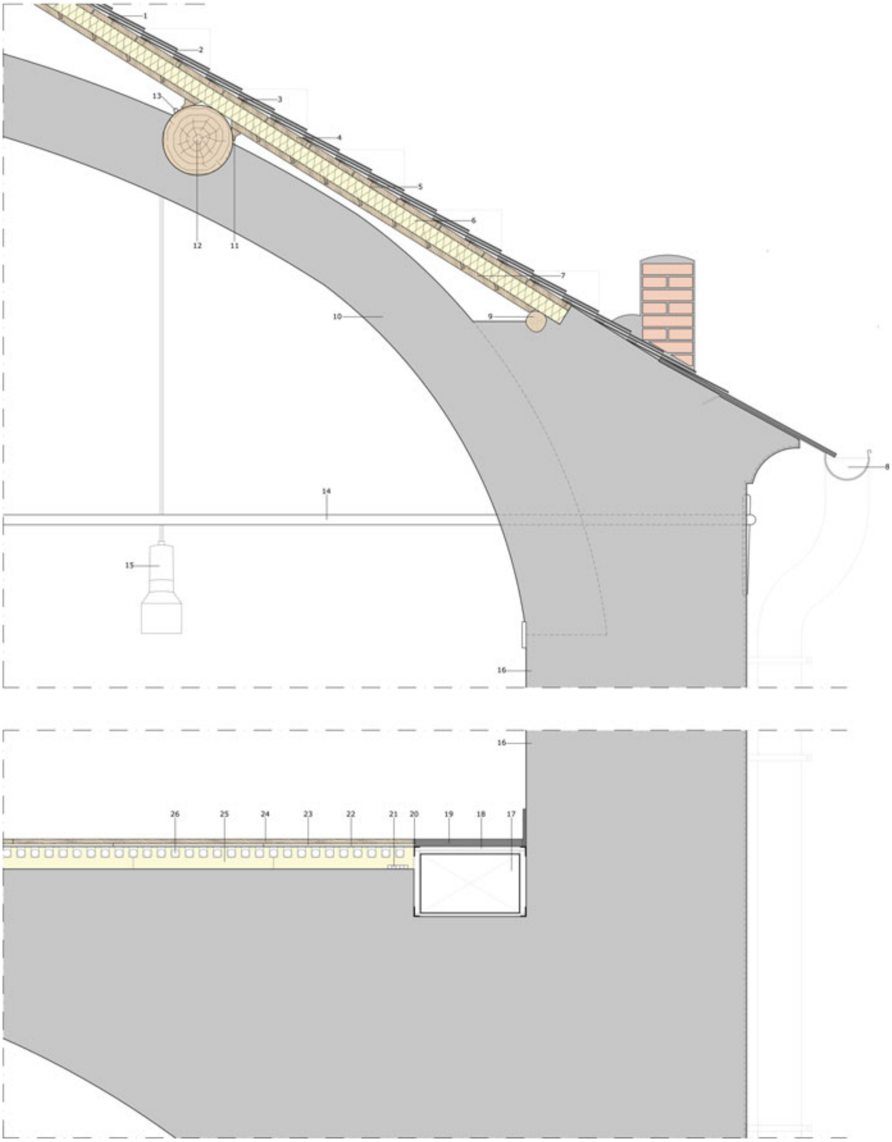

Fig. 8.2 Detailed design of the insulation of the roof, under the “ardesia” stone slate. (Battistini, J., Leonardi, M., Choquet, M. 2014 Master course in Architecture)

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).

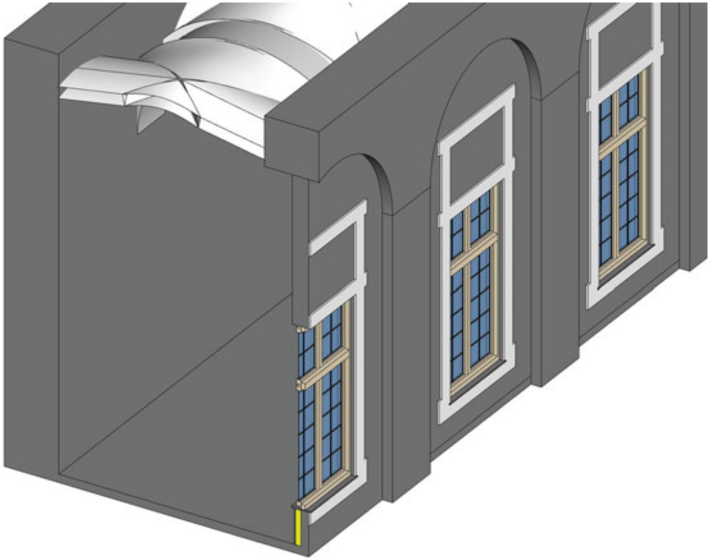

Fig. 8.3 (**a**) Thermal improvement of external walls, insulation of the portion under the window (BIM model, Babbetto, R. 2015) (**b**) Detailed design of the thermal improvement of the western wing of the *Albergo dei overi*. Insulation of the roof and of external walls and ground floor (Biasio, M., 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)

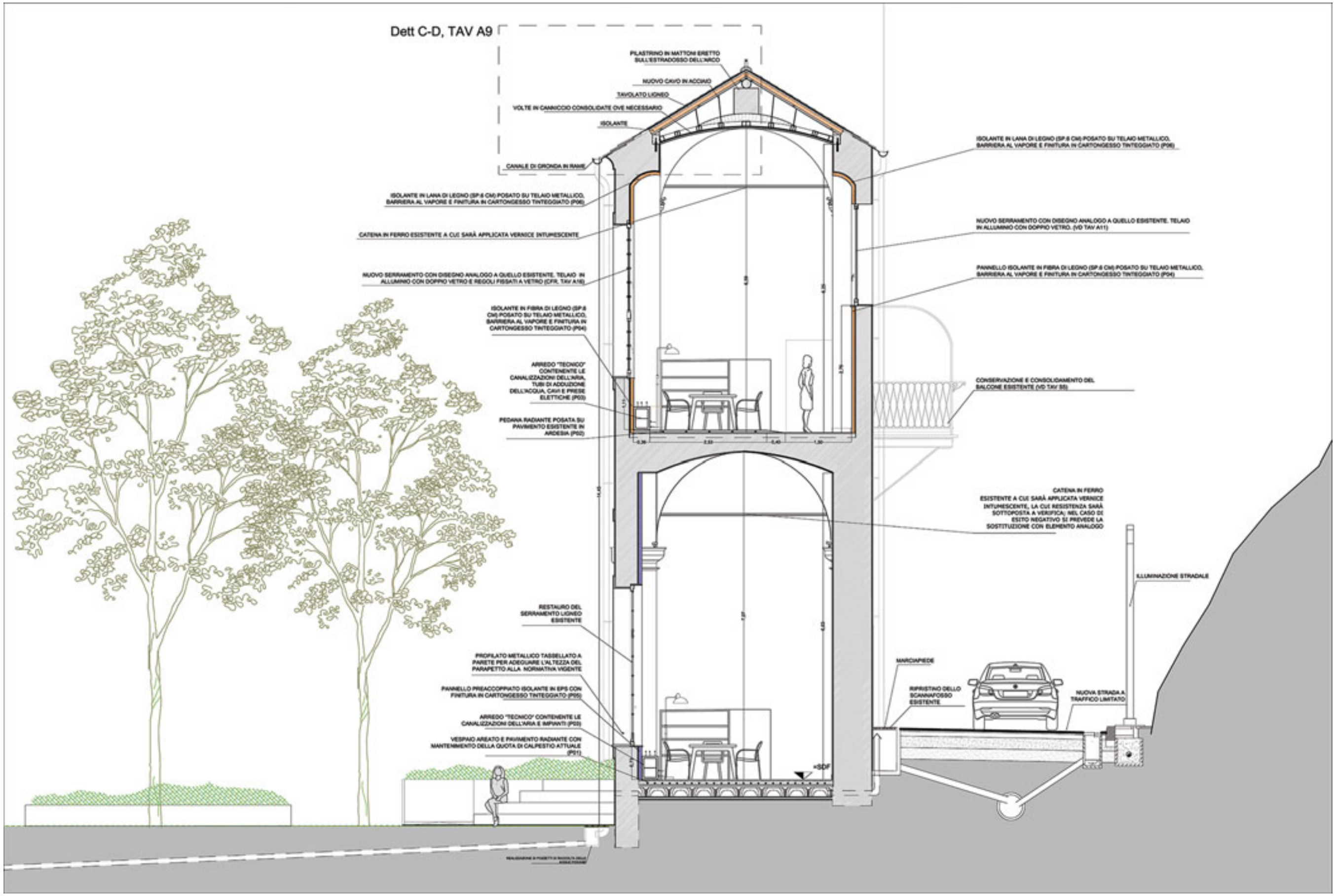

Fig. 8.3 (continued)

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).

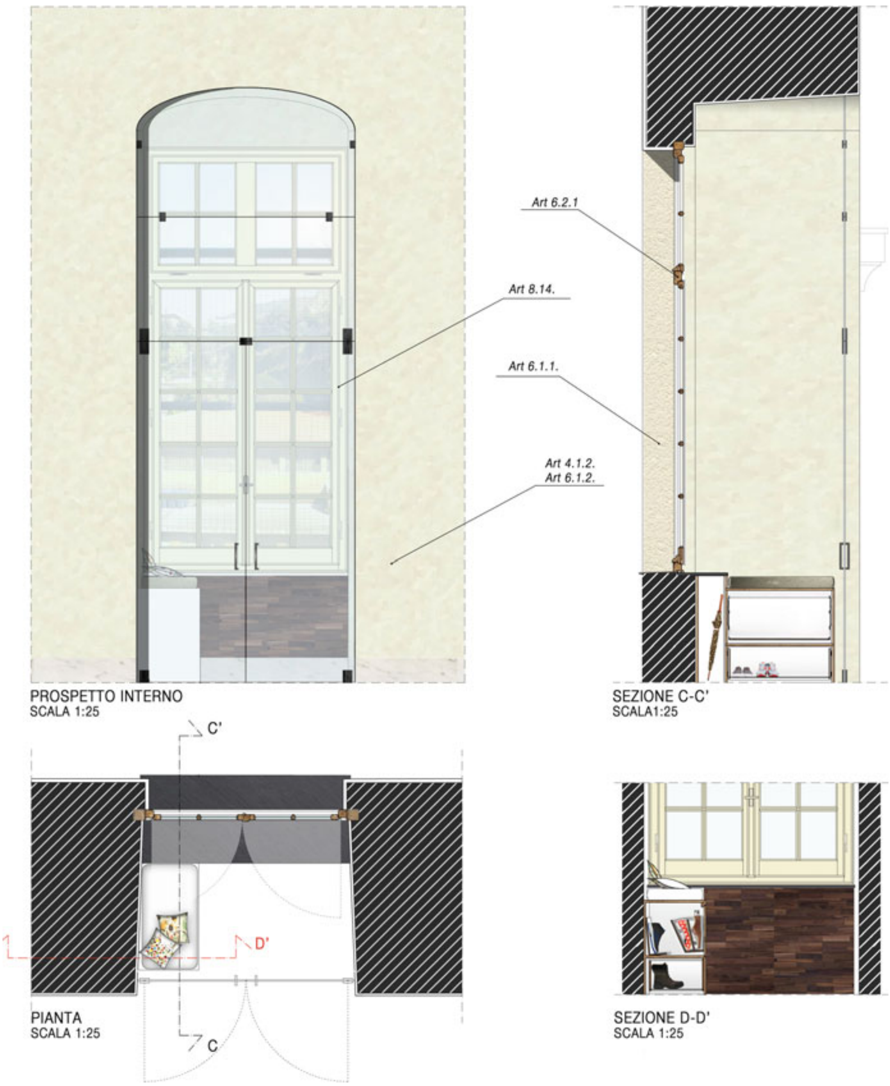

Fig. 8.7 Proposal for a new window system in the northern wing, doubling the existing one (Bresolin, G., Stagnaro, I., Tomasetti, G. 2012. Master course in Architecture)

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

Characteristics of components	U [W/(m^{2}K)]
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]	$P_{\text{THERM}}A$ [W]	$P_{\text{THERM}}B$ [W]	$P_{\text{THERM}}C$ [W]	$P_{\text{THERM}}D$ [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]	$E_{\mathrm{THERM}}B + C + D$ [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]	$E_{\mathrm{THERM}}A$ [kWh]	$E_{\mathrm{THERM}}B$ [kWh]	$E_{\mathrm{THERM}}C$ [kWh]	$E_{\mathrm{THERM}}D$ [kWh]	$E_{\mathrm{THERM}}B + C + D$ [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: $P_{el} = 100 \pm 3$ kW$_{el}$
Thermal output: $P_{th} = 167 \pm 5$ 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: $G_{CH4} = 34$ Nm^3/h
Input CHP thermal power: $P_{\text{th-in}} = (G_{CH4} \cdot H_{\text{i-CH4}})/3.6 = 337$ 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)):

$$P_{\text{th}} = G_{\text{H}_2\text{O}} \cdot c_{\text{p-H}_2\text{O}} \cdot (T_{\text{H}_2\text{O-out}} - T_{\text{H}_2\text{O-in}})$$

$$\begin{aligned} G_{\text{H}_2\text{O}} &= P_{\text{th}} / \left(c_{\text{p-}_{\text{H}_2\text{O}}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 20) \approx 2\ \text{kg/s} = 3600\ \text{L/h} \\ &= 3.6\ \ \text{m}^3/\text{h} \end{aligned}$$

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:

$$\begin{aligned} \Delta T_{\text{c.s.}} &= 10^{\circ}\text{C} \ \ \rightarrow G'_{\text{H}_2\text{O}} = P_{\text{th}} / \left(c_{\text{p-H}_2\text{O}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 10) \approx 4\ \text{kg/s} \\ &= 7200\ \text{L/h} = 7.2\ \ \text{m}^3/\text{h} \\ \Delta T_{\text{c.s.}} &= 5^{\circ}\text{C} \rightarrow G'_{\text{H}_2\text{O}} = P_{\text{th}} / \left(c_{\text{p-H}_2\text{O}} \cdot \Delta T_{\text{H}_2\text{O}}\right) = 167/(4.186 \cdot 5) \approx 8\ \text{kg/s} \\ &= 14{,}400\ \text{L/h} = 14.4\ \ \text{m}^3/\text{h} \end{aligned}$$

Set out hereunder is the calculation of the thermal performance of the cogenerator:

$$\begin{aligned} \eta_{\text{chp-th}}[\%] &= P_{\text{th}}/P_{\text{th-in}} = 3{,}600 \cdot P_{\text{th}}/(G_{\text{CH4}} \cdot H_{\text{i-CH4}}) = 3.6 \cdot 167/(34 \cdot 35.696) \\ &\approx 49.5\% \end{aligned}$$

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 $T_{\mathrm{est}} = 15\ ^{\circ}\mathrm{C}$, i.e. when $T_{\mathrm{est}} = 0\ ^{\circ}\mathrm{C}$.

We notice that, in project conditions ($T_{\mathrm{est}} = 0\ ^{\circ}\mathrm{C}$), the thermal power $P_{\mathrm{th}} \approx 170\ \mathrm{kW_{th}}$ whereas the total efficiency drops by 3%, i.e. $\eta_{\mathrm{chp}} = 77\%$

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:

$$(\mathrm{E.I.})_{\mathrm{chp}} = P_{\text{el-chp}}/P_{\text{th-chp}} = 100/167 \approx 0.6$$

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}
$\mathrm{kWh_{el}}$	$\mathrm{kWh_{therm}}$
956,000	2,496,000

Table 8.14 Production of thermal and electrical energy

Number of hours	$E_{\text{EL-CHP}}$ $\mathrm{kWh_{el}}$	$E_{\text{TH-CHP}}$ $\mathrm{kWh_{th}}$
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

$E_{\text{TERM-CHP N}^\circ 1+2}$	$E_{\text{EL-CHP N}^\circ 1+2}$	$N_{\text{h-CHP N}^\circ 1+2}$
kWh_{th}/year	kWh_{el}/year	kWh_{el}/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.

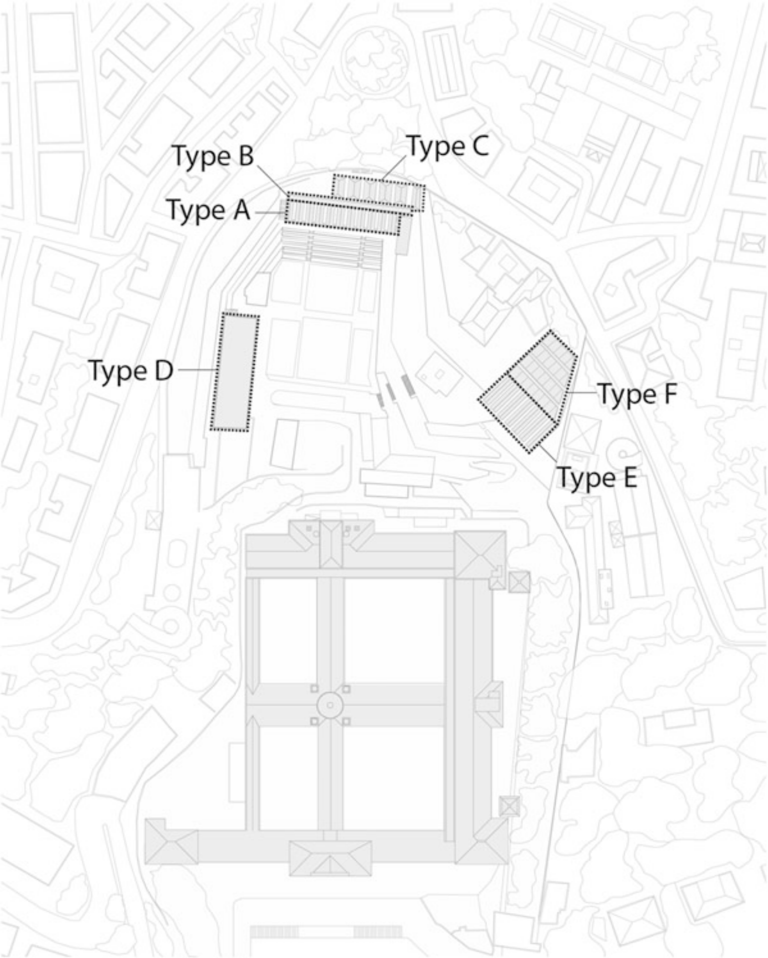

Fig. 8.8 *Valletta Carbonara*. Identification of different types of greenhouses (Macchioni, E. 2016)

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:

$$Q_{\mathrm{el,\,exp}} = \left[E_{\mathrm{sol}} \times P_{\mathrm{pk}} \times f_{\mathrm{perf}}\right] / I_{\mathrm{ref}}$$
$$= [(1425 \quad \times 1.07) \quad \times \quad (208 \quad \times \quad 0.178) \times 0.75]/1$$

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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