UNIVERSITÀ
DEL SALENTO

Department of Innovation Engineering
Master's Degree in Management Engineering

ENERGY MANAGEMENT

ENERGY AUDIT REPORT

Evaluation and proposal for the energy efficiency of my home

ANGELO FOGGETTI – 20082267

Academic Year: 2024/2025

SUMMARY

1. GENERAL INFORMATION

General characteristics of the building under analysis

Municipality:	Lequile
Province:	LE
ZIP Code:	73010
Address:	via Magenta 48
Latitude:	40°18’14.246” N
Longitude:	18°8’23.021” E
Altitude:	38 meters above sea level
Year of construction:	Before 1930
Number of residents:	2
Usable area:	124,74 m^2
External surface delimiting the volume:	385,90 m^2
Interior volume:	436,26 m^3
Electrical Power Supply:	3 kW
Other energy sources:	Natural Gas, Firewood

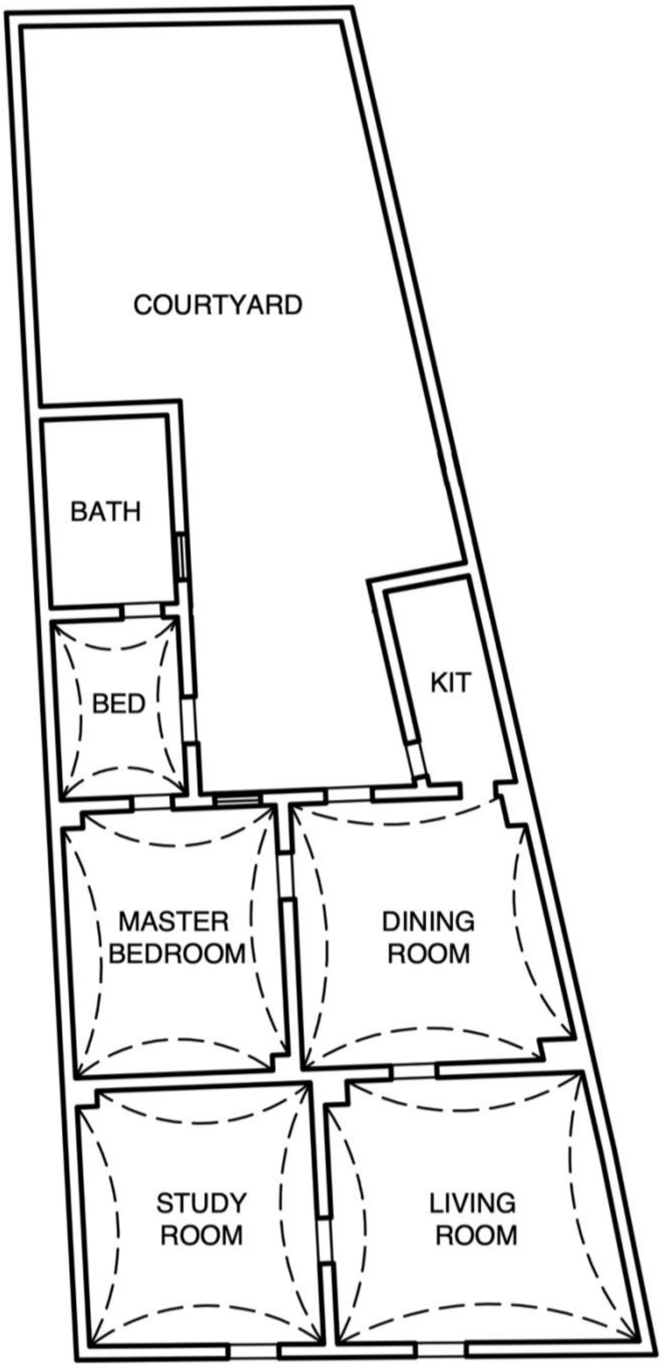
Brief description of the building

The building, located in the historic center of Lequile (LE), is a single-story residential construction dating back to a period before 1930. Featuring traditional architecture, it consists of 7 rooms, 5 of which have star vaults, and includes a large courtyard at the rear. The property is entirely independent, with no structures above or below it.

1.1 Building Layout

This section of the report presents the floor plan of the analyzed building and includes a detailed analysis of the relevant geometric parameters. Among these, the usable floor area of the property, the ceiling surface, the internal volumes, and the surface area bordering unheated external environments have been calculated. Figure 1 shows the building's floor plan, indicating the layout of the rooms.

Figure 1. **Planimetry of the building**



The building's floor plan reveals that the ceilings of the rooms labeled as *Living Room*, *Study Room*, *Dining Room*, *Master Bedroom*, and *Bedroom* are characterized by star vaults. To simplify the calculations necessary for the building's energy analysis, these vaulted ceilings have been approximated as flat ceilings. An indicative average height has been assigned to each, calculated using the following formula, with the parameters depicted in Figure 2:

$$h = (h' + h'') / 2 \text{ [m]} \tag{1}$$

where:

h: average height of the room with star vaults [m];
h': distance from the floor to the lowest point of the vault [m];
h'': distance from the floor to the highest point of the star vault [m].

Figure 2. **Representation of star vaulted ceiling and definition of parameters**

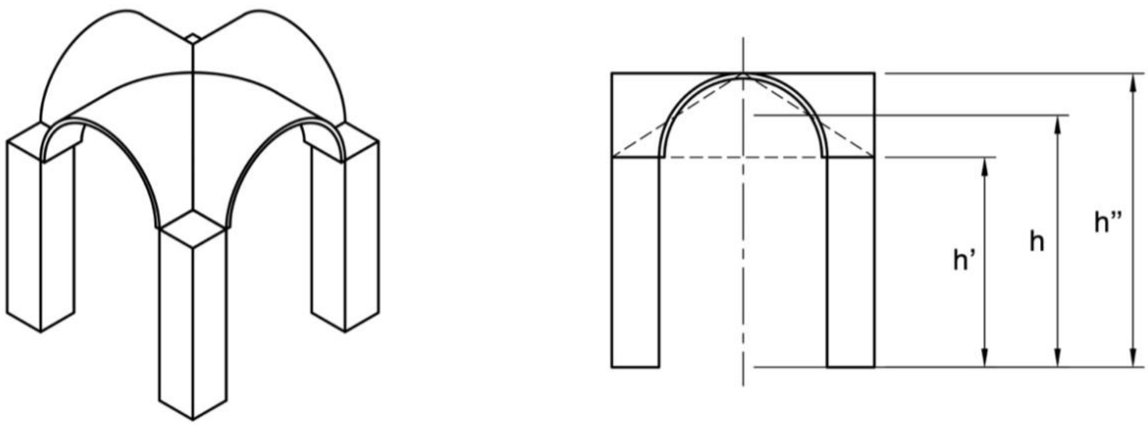


Table 1 provides the geometric parameters of the rooms, distinguishing between those with star-vaulted ceilings and those with flat ceilings for the height calculation. The surface area and volume values for each room are indicated.

Table 1. **Geometric parameters of the rooms**

Room description	Star Vaults	Floor Area m^2	h' m	h'' m	h m	Volume m^3
Living Room	Yes	28,65	2,65	4,75	3,70	106,00
Study Room	Yes	23,19	2,65	4,75	3,70	85,78
Dining Room	Yes	25,37	2,65	4,75	3,70	93,86
Master Bedroom	Yes	21,63	2,65	4,75	3,70	80,03
Kitchen	No	6,73	/	/	3,20	21,52
Bedroom	Yes	8,66	1,90	3,30	2,60	22,51
Bathroom	No	9,15	/	/	2,90	26,55
	Total Floor Area (m^2) =	**123,37**				
					Total Volume (m^3) =	**436,26**

Figure 3 displays the house floor plan again, highlighting the walls bordering external environments and indicating their orientation relative to the cardinal points. Additionally, Table 2 shows the surface area of the external walls, excluding the area occupied by openings. Table 3 provides details on the openings in these walls, with the total surface areas calculated as the product of height and width, based on the parameters shown in the Figure 4.

Table 2. **External wall area and orientation**

or.	Description of external wall orientation	Area m^2
SW	South-West	44,61
NW	North-West	8,66
NE	North-East	9,08
SE	Souht-East	21,98
NE	North-East	18,80
W	West	13,02

N	North	7,01
	Total wall external area (m^2) =	**123,17**

Figure 3. **Floor plan and orientation of the building with identification of walls bordering external environments**

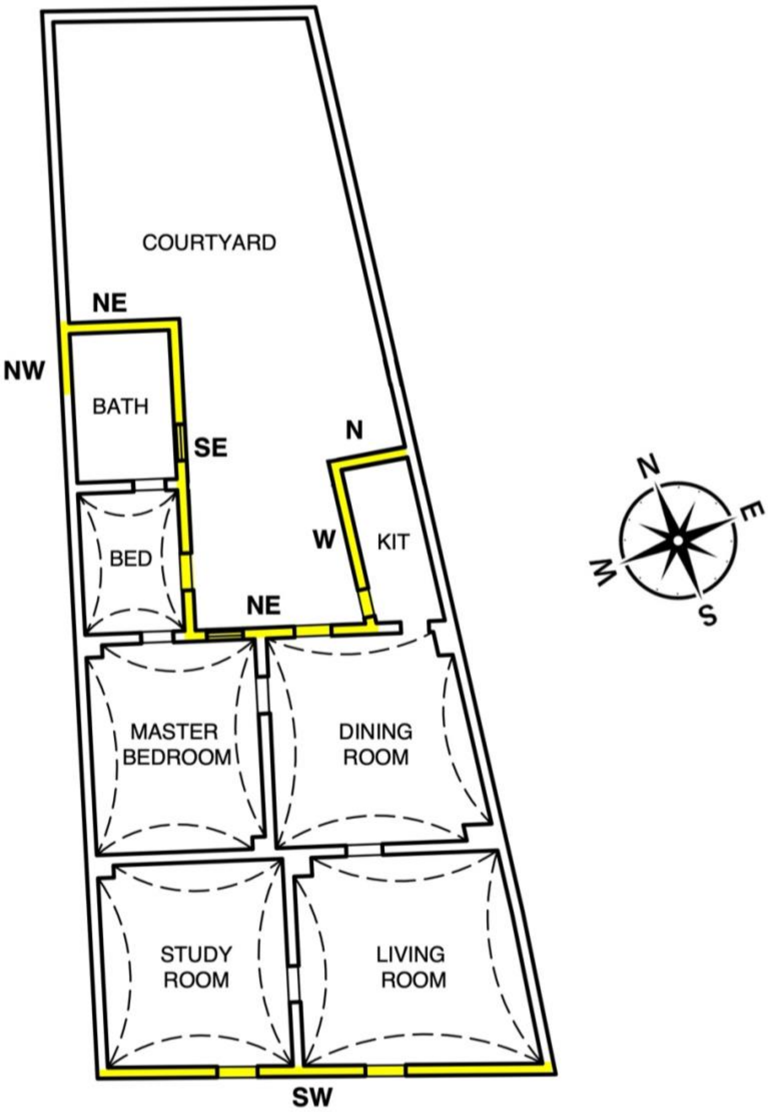
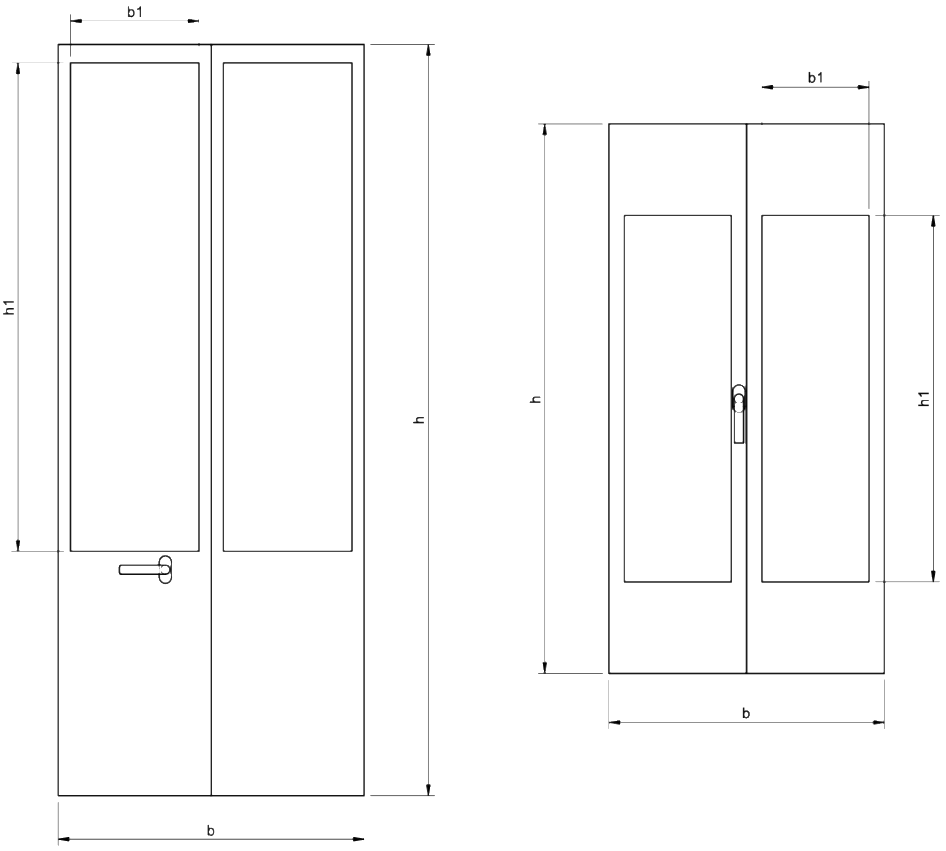


Table 3. **Geometry of openings**

Surface description	Room description	or.	b m	h m	A m^2
Partially glazed door	Living Room	SW	1,00	2,46	2,46
Partially glazed door	Study Room	SW	1,00	2,46	2,46
Window	Bathroom	SE	0,90	1,50	1,35
Partially glazed door	Bedroom	SE	0,92	2,20	2,02
Window	Master Bedroom	NE	0,90	1,50	1,35
Partially glazed door	Dining Room	NE	0,92	2,20	2,02
Fixed Window	Dining Room	NE	0,72	0,72	0,52
Partially glazed door	Kitchen	W	0,70	2,20	1,54
Fixed Window	Kitchen	W	0,48	0,72	0,35
Shutter box	Bathroom	SE	0,90	0,3	0,27
Shutter box	Master Bedroom	NE	0,90	0,30	0,27
				Total openings area (m^2) =	**14,61**

Figure 4. **Dimensional parameters of doors and windows**



1.2 Climate data

This section presents the climatic conditions of the area where the building is located. Such information provides an overview of the environmental context, useful for understanding the characteristics of the territory and its potential impact on the building.

General climate information

Climatic zone:	C (D.P.R. n. 412/1993)
Winter period:	from November 15 to March 31 (D.P.R. n. 412/1993)
Degree days:	1059 °C day (D.P.R. n. 412/1993)
Heating hours:	10 h / day (D.P.R. n. 412/1993)
Minimum external design temperature:	0 °C
Winter internal design temperature:	20 °C (UNI/TS 11300-1:2014)
Summer internal design temperature:	26 °C (UNI/TS 11300-1:2014)

Table 4 and Table 5 respectively present the monthly average values of the daily mean air temperature and the monthly average daily solar irradiation, as defined by the UNI 10349 standard. Since the municipality of Lequile is not directly included in the standard, the data for the city of Lecce, the nearest location for which such values are available, have been used.

Table 4. **Monthly average values of the daily mean air temperature in Lecce [°C] (UNI 10349)**

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
9,0	9,3	11,4	14,7	18,9	23,4	26,1	25,9	23,0	18,5	14,3	10,7

Table 5. **Monthly mean daily solar irradiation in Lecce [MJ/m^2] (UNI 10349)**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
OR	6,8	9,8	13,6	18,9	23,6	26,1	27,2	24,0	17,9	12,3	7,4	5,9
N	2,2	3,0	4,1	5,7	8,3	10,0	9,5	6,7	4,5	3,4	2,4	2,0
NE	2,5	3,9	6,0	9,1	12,2	14,0	14,2	11,6	7,8	4,8	2,8	2,2
E	5,3	7,3	9,6	12,6	15,3	16,5	17,5	16,0	12,6	9,2	5,7	4,6
SE	8,8	10,5	11,6	13,0	13,6	13,7	14,8	15,5	14,5	12,8	9,0	7,7
S	11,1	12,4	12,0	11,2	10,2	9,6	10,3	12,2	13,9	14,6	11,2	9,8
SW	8,8	10,5	11,6	13,0	13,6	13,7	14,8	15,5	14,5	12,8	9,0	7,7
W	5,3	7,3	9,6	12,6	15,3	16,5	17,5	16,0	12,6	9,2	5,7	4,6
NW	2,5	3,9	6,0	9,1	12,2	14,0	14,2	11,6	7,8	4,8	2,8	2,2

2. HISTORICAL DATA

This chapter conducts a historical analysis of the household's energy consumption, including electricity, gas, and firewood, with the aim of calculating the building's overall energy performance index. The final subsection will present the results of the experimental acquisition of electricity consumption data for the devices in the building, verifying the consistency between the field-measured data and those reported on utility bills.

2.1 Analysis of domestic energy consumption

2.1.1 Electricity consumption

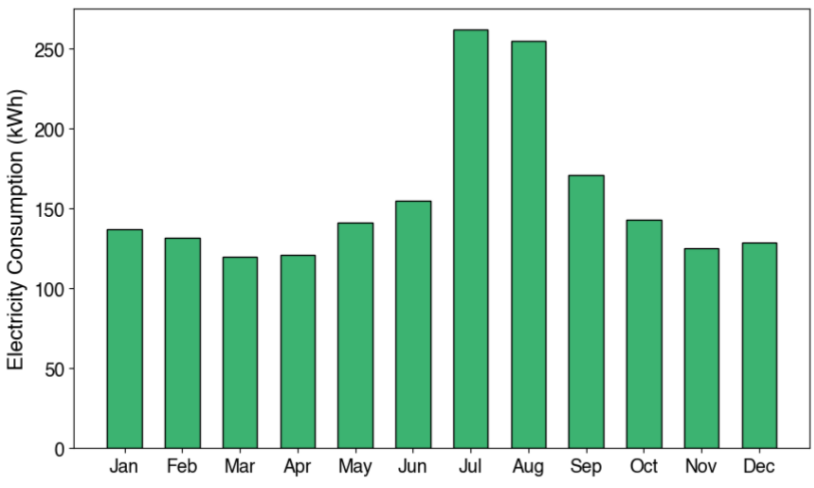
This subsection analyzes historical data on electricity consumption, derived from utility bills for the period between October 2022 and September 2024. The Table 6 shows the electricity consumption expressed in kWh and the corresponding costs, while the Figure 5 displays a histogram representing the average monthly electricity consumption. It is important to note that the cost includes all components of the bill, such as transportation charges, meter management fees, system charges, taxes, and VAT, but excludes the subscription fee for private television use.

Table 6. **Average electricity consumption [kWh] and cost [€]**

Electricty consumption (kWh)				
	2022	2023	2024	Avg.
Jan		156	118	137
Feb		148	116	132
Mar		119	121	120
Apr		118	124	121
May		142	139	141
Jun		149	160	155
Jul		251	272	262
Aug		215	295	255
Sep		158	184	171
Oct	150	135		143
Nov	130	119		125
Dec	139	119		129
			Total (kWh) =	**1889**

Electricity cost (€)				
	2022	2023	2024	Avg.
Jan		52,04	55,68	53,86
Feb		49,37	53,60	51,49
Mar		45,33	55,92	50,62
Apr		44,94	55,65	50,30
May		52,67	62,38	57,53
Jun		52,98	65,84	59,41
Jul		89,24	110,90	100,07
Aug		88,02	102,32	95,17
Sep		64,69	63,82	64,25
Oct	46,96	65,62		56,29
Nov	44,37	57,84		51,11
Dec	47,45	56,15		51,80
			Total (€) =	**741,89**

Figure 5. **Barplot of average monthly electricity consumption [kWh]**



Based on the values provided in the Table 6, the unit cost of electricity can be calculated by dividing the average annual cost by the average annual electricity consumption.

Average annual electricity consumption: 1889 kWh
Average annual electricity cost: 742 €
Unit cost of electricity: 0,393 €/kWh

2.1.2 Natural gas consumption

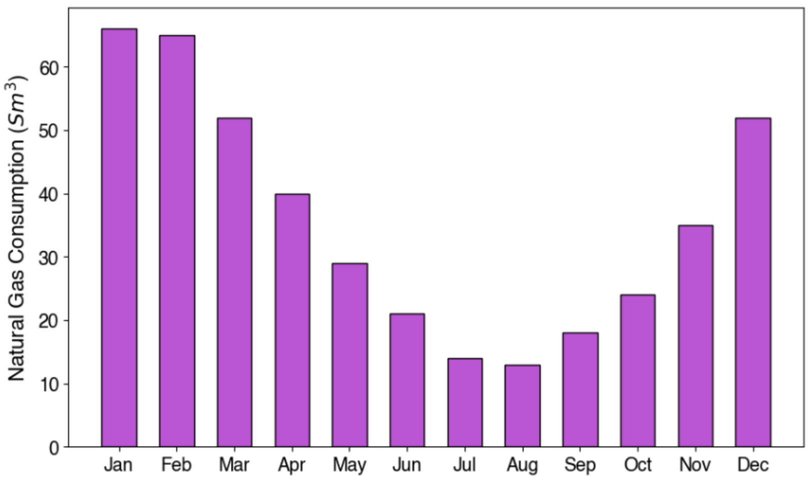
In a completely analogous way to what was done for electricity, this subsection focuses on the analysis of natural gas consumption. Table 7 provides data on the monthly natural gas consumption, expressed in standard cubic meters, and the related cost. As in the previous case, the total bill cost was considered, including transport fees, meter management charges, system charges, and VAT. The Figure 6 displays a histogram representing the average monthly natural gas consumption.

Table 7. **Average natural gas consumption [Sm^3] and cost [€]**

Natural gas consumption (Sm^3)				
	2022	2023	2024	Avg.
Jan		64	68	66
Feb		68	61	65
Mar		54	49	52
Apr		48	32	40
May		29	28	29
Jun		23	18	21
Jul		13	14	14
Aug		14	12	13
Sep		16	19	18
Oct	24	23		24
Nov	37	32		35
Dec	48	56		52
			Total (Sm^3) =	**425**

Natural gas cost (€)				
	2022	2023	2024	Avg.
Jan		37,05	96,77	66,91
Feb		39,36	89,63	64,49
Mar		51,65	71,99	61,82
Apr		45,92	61,87	53,89
May		37,29	54,13	45,71
Jun		-10,74	46,06	17,66
Jul		-6,07	35,82	14,88
Aug		31,76	27,25	29,51
Sep		36,30	43,15	39,72
Oct	25,03	44,92		34,97
Nov	32,16	62,50		47,33
Dec	41,71	79,70		60,71
			Total (€) =	**537,60**

Figure 6. **Barplot of average monthly natural gas consumption [Sm^3]**



Based on the data provided in the Table 7, the unit cost of natural gas can be calculated by dividing the average annual cost by the average annual consumption of natural gas.

Average annual natural gas consumption: 425 Sm^3
Average annual natural gas cost: 538 €
Unit cost of natural gas: 1,265 €/Sm^3

To calculate the energy generated from the average annual natural gas consumption, the following formula was used:

$$E = \rho \cdot Vol \cdot LHV \text{ [kWh]} \tag{2}$$

where:
E: average annual energy consumption, expressed in kWh
ρ: methane density under standard conditions, equal to 0,678 kg/Sm^3
Vol: average annual natural gas consumption, equal to 425 Sm^3
LHV: lower heating value of methane, equal to 13,89 kWh/kg

Result:
Average annual energy consumption: 4005 kWh
Unit cost of natural gas: 0,134 €/kWh

2.1.3 Firewood consumption

The building under audit is equipped with a wood-burning fireplace located in the dining room, which is used daily during the winter season. The fuel used is olive wood, for which the following data has been collected:

Average annual consumption of olive wood: 28 quintals
Unit cost of olive wood: 10 €/quintal
Total cost: 280 €

Based on this data, the average annual energy consumption from olive wood was calculated using the following formula:

$$E = m \cdot LHV \text{ [kWh]} \tag{3}$$

where:
E: average annual energy consumption from firewood, expressed in kWh
m: mass of firewood consumed in a year, equal to 2800 kg
LHV: lower heating value of olive wood, equal to 4,07 kWh/kg

Result:
Avg annual firewood energy consumption: 11394 kWh
Average unit cost of firewood: 0,025 €/kWh

2.1.4 Total consumption

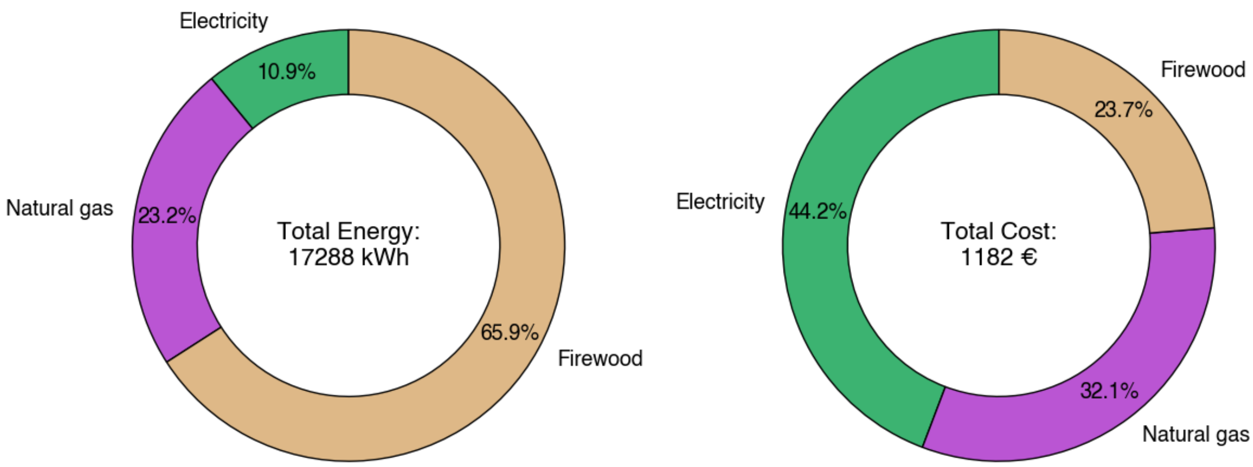
Based on the data regarding electricity, natural gas, and firewood consumption, the total average annual energy consumption of the building, along with the total average annual cost, has been calculated. The results are summarized in Table 8.

Table 8. **Overview of average annual energy consumption and costs by source**

	Avg. annual energy consumed kWh	Avg. annual cost €
Electricity	1889	523
Natural gas	4005	379
Firewood	11394	280
Total	**17287**	**1182**

Figure 7 illustrates a comparative analysis of energy consumption and associated costs for different energy sources. The donut chart on the left highlights the percentage distribution of energy consumption in kilowatt-hours, while the chart on the right shows the proportionate costs in euros. The central values in each chart summarize the total energy consumed and the overall cost, providing a clear overview of the energy usage profile.

Figure 7. **Comparison of energy consumption and costs by source**



2.2 Estimation of electricity consumption

This chapter provides an inventory of all electrical devices present in the building and reports their respective annual electricity consumption. Table 9 summarizes the findings of this analysis, while Figure 8 presents a pie chart illustrating the consumption data detailed in the table. The estimation process resulted in a total consumption value of 1891 kWh/year, closely matching the actual value recorded on the bill, which is 1889 kWh/year. The discrepancy of 0,14% confirms the alignment between the estimated and actual electricity consumption.

Table 9. **List of devices and electricity consumed per year**

Device description	No. of devices	Consumed energy kWh/year
Abat-jour	1	0,37
Air conditioner	1	132,73
AirPods 3	1	0,10
Apple Watch SE 2	1	0,11
Boiler	1	84,32
CD Stereo	1	0,21
Clothes iron	1	73,11
Fan	1	8,09
Fridge	1	480,71
iPad Air 4	1	5,62
iPhone 11	1	6,21
LED Tube 60 cm	3	18,46
LED TV 40"	1	307,65
Light bulb	20	75,13
Macbook Air M1	1	12,48
Magic Keyboard	1	0,02
Magic Mouse 2	1	0,10
Mirror lamp	2	1,46
Monitor + Smart LED Desk Lamp	1	50,88
Oven	1	67,28
Phon	1	63,02
Powerbank Redmi 20.000 mAh	1	0,91
Redmi 9C	1	2,29
Router + Landline	1	96,73
Shaving razor	1	0,07
Smart Lamp	1	21,48
Stove	1	9,75
Washing machine	1	371,80
Total:	**50**	**1891,05**

To evaluate these values, two methods were adopted depending on the type of device. If the device has a plug, an electricity consumption meter was used, designed to monitor and record the energy consumption in kWh of the connected appliances. For devices without a plug, the nominal power was identified and multiplied by the hours of annual use to determine the annual electricity consumption. To better understand how the data in Table 9 were derived, Table 10 and Table 11 respectively show the devices whose consumption was measured using an energy meter and those whose consumption was estimated based solely on the technical specifications.

Table 10. **Devices with energy consumption measured through the energy meter**

Device description	Qty	Detected consumption		Multiplicative factors				Energy cons. kWh
Router + Landline	1	0,011	kWh/hour	24	hour/day	365	day/year	96,73
CD Stereo	1	0,021	kWh/hour	0,5	hour/week	20	week/year	0,21
Monitor + Desk Lamp	1	0,212	kWh/day			240	day/year	50,88
Smart Lamp	1	0,086	kWh/day			250	day/year	21,48
LED TV 40"	1	0,879	kWh/day			350	day/year	307,65
Fridge	1	1,317	kWh/day			365	day/year	480,71
Abat-jour	1	0,001	kWh/day			365	day/year	0,37
Shaving razor	1	0,003	kWh/charge	2	charge/month	12	month/year	0,07
Clothes iron	1	1,406	kWh/hour	1	hour/week	52	week/year	73,11
Macbook Air M1	1	0,080	kWh/charge	3	charge/week	52	week/year	12,48

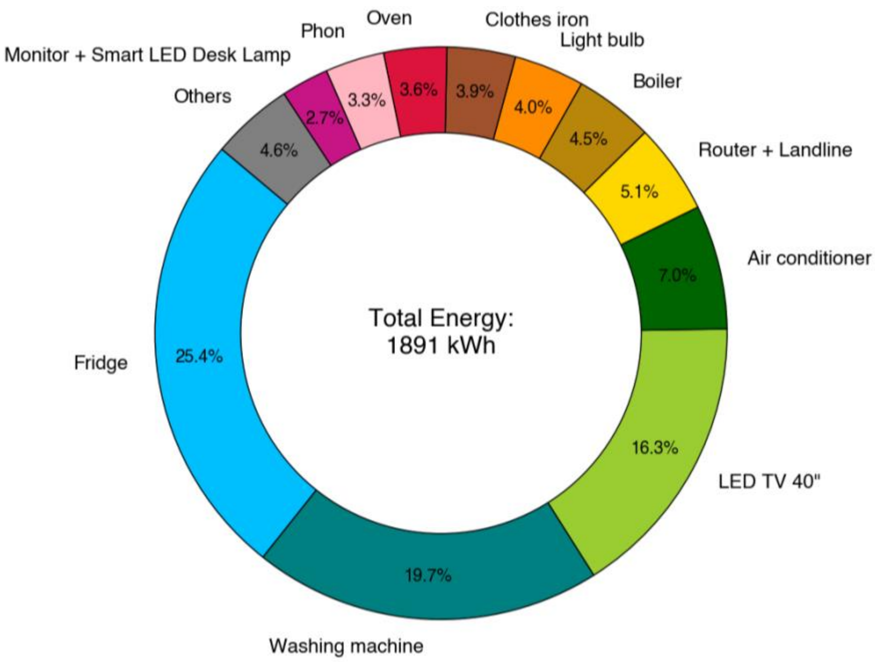
Magic Mouse 2	1	0,008	kWh/charge	1	charge/month	12	month/year	0,10
Magic Keyboard	1	0,003	kWh/charge	0,5	charge/month	12	month/year	0,02
iPhone 11	1	0,017	kWh/charge	1	charge/day	365	day/year	6,21
Redmi 9C	1	0,022	kWh/charge	2	charge/week	52	week/year	2,29
iPad Air 4	1	0,036	kWh/charge	3	charge/week	52	week/year	5,62
Apple Watch SE 2	1	0,003	kWh/charge	3	charge/month	12	month/year	0,11
AirPods 3	1	0,002	kWh/charge	1	charge/week	52	week/year	0,10
Powerbank	1	0,076	kWh/charge	1	charge/month	12	month/year	0,91
Fan	1	0,035	kWh/hour	3	hour/day	77	day/year	8,09
Stove	1	0,650	kWh/hour	0,5	hour/day	30	day/year	9,75
Phon	1	1,616	kWh/hour	0,75	hour/week	52	week/year	63,02
Total:	**21**							**1139,89**

Table 11. **Devices with energy consumption estimated through technical specifications**

Device description	Qty	Nominal Power W	Multiplicative factors				Energy cons. kWh
Light bulb	5	10	0,25	h/day	365	day/year	4,56
Light bulb	4	10	0,25	h/day	365	day/year	3,65
Light bulb	1	10	7,7	h/day	365	day/year	27,98
Air conditioner (*)	1	1021	5	h/day	40	day/year	132,73
Oven (*)	1	2300	3	h/week	15	week/year	67,28
Light bulb	1	10	3	h/day	365	day/year	10,95
Light bulb	5	10	0,5	h/day	365	day/year	9,13
Light bulb	1	10	0,5	h/day	365	day/year	1,83
Light bulb (Mirror)	2	8	0,25	h/day	365	day/year	1,46
Light bulb	2	10	1,5	h/day	365	day/year	10,95
Washing machine (*)	1	2200	5	h/week	52	week/year	371,80
Light bulb	1	10	1,7	h/day	365	day/year	6,08
LED Tube 60 cm	2	18	1,3	h/day	365	day/year	17,52
Boiler (*)	1	110	3	h/day	365	day/year	84,32
LED Tube 60 cm	1	18	1	hour/week	52	day/year	0,94
Total:	**29**						**751,17**

(*) The annual energy consumption was calculated by multiplying the nominal power by the annual usage hours and applying a correction factor of 0,7. This adjustment accounts for the fact that these energy-intensive devices do not operate continuously at full power but instead cycle on and off to reduce energy consumption.

Figure 8. **Annual energy consumption distribution by device**



3. DATA ACQUISITION

This chapter provides a detailed analysis of the main energy consumption of the building under audit. The first section focuses on calculating the ideal thermal energy demand for heating, evaluating both total heat transfer and overall heat contributions. The second part examines domestic hot water consumption, analyzing the required volumes and the energy needed to meet this demand. Finally, the chapter addresses the transport sector, evaluating the energy consumption associated with the vehicles owned by the building's residents.

3.1 Calculation of the ideal thermal energy demand for heating

This part of the chapter deals with the calculation of the ideal thermal energy demand for heating, in accordance with the UNI/TS 11300-1 standard. This demand, denoted as $Q_{H,nd}$, represents the energy required to maintain the design temperature (set at 20°C) in the heated spaces, calculated for each zone of the building and for each month, as:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \times Q_{gn} = (Q_{H,tr} + Q_{H,ve}) - \eta_{H,gn} \times (Q_{int} + Q_{sol}) \text{ [kWh]} \quad (4)$$

where:
$Q_{H,nd}$: ideal thermal energy demand of the building for heating [kWh];
$Q_{H,ht}$: total heat transfer in the case of heating [kWh];
Q_{gn}: total heat contributions [kWh];
$Q_{H,tr}$: heat transfer by transmission in the case of heating [kWh];
$Q_{H,ve}$: heat transfer by ventilation in the case of heating [kWh];
Q_{int}: internal heat contributions [kWh];
Q_{sol}: solar heat contributions [kWh];
$\eta_{H,gn}$: utilization factor of heat contributions.

3.1.1 Calculation of total heat transfer

In this section, the calculation of the total heat transfer in the case of heating $Q_{H,ht}$ is carried out, obtained by summing the heat transfer by transmission and by ventilation. The formula is provided below:

$$Q_{H,ht} = Q_{H,tr} + Q_{H,ve} \text{ [kWh]} \quad (5)$$

where:
$Q_{H,tr}$: heat transfer by transmission in the case of heating [kWh];
$Q_{H,ve}$: heat transfer by ventilation in the case of heating [kWh].

3.1.1.1 Calculation of the heat transfer by transmission

The heat exchange by transmission in the case of heating is calculated using the following formula:

$$Q_{H,tr} = H_{tr,adj} \times (\theta_{int,set,H} - \theta_e) \times t \text{ [kWh]} \quad (6)$$

where:
$H_{tr,adj}$: global heat transfer coefficient for transmission of the considered area, adjusted to account for the internal-external temperature difference [W/K];
$\theta_{int,set,H}$: internal setpoint temperature for heating of the considered area, set at 20°C according to the UNI/TS 11300-1 standard [°C];
θ_e: average monthly external temperature, obtained from the UNI 10349 standard [°C];
t: duration of the considered month [h].

Heat transfer from a thermal zone occurs toward the external environment, the ground, unconditioned zones, and other conditioned zones with different temperatures. Therefore, the global heat transfer coefficient for transmission is determined as:

$$H_{tr,adj} = H_D + H_g + H_U + H_A = (H_{D,o} + H_{D,f}) + H_g + H_U + H_A \text{ [W/K]} \quad (7)$$

where:

- H_D: direct heat transfer coefficient by transmission toward the external environment [W/K];
- $H_{D,o}$: direct heat transfer coefficient by transmission toward the external environment through opaque surfaces [W/K];
- $H_{D,f}$: direct heat transfer coefficient by transmission toward the external environment through transparent surfaces [W/K];
- H_g: steady-state heat transfer coefficient by transmission to the ground [W/K];
- H_U: heat transfer coefficient for transmission through unconditioned spaces [W/K];
- H_A: heat transfer coefficient for transmission toward other zones (either internal or external to the building) conditioned at a different temperature [W/K].

In the case of the building under audit, the terms H_U and H_A are zero.

Calculation of the heat transfer coefficient for transmission to the external environment: opaque surfaces

$$H_{D,o} = \Sigma_k A_{c,k} U_{c+pt,k} \text{ [W/K]} \quad (8)$$

where:

- $A_{c,k}$: area of the opaque component [m^2];
- $U_{c+pt,k}$: thermal transmittance of the opaque component, increased to account for potential thermal bridges [W/m²K].

Thermal transmittance, indicated by U and measured in W/m²K, represents the amount of heat that passes through 1 m² of a building component for a temperature difference of 1 K between its two sides. It is a key parameter for evaluating the energy performance of a building. Thermal transmittance is calculated as the reciprocal of the total thermal resistance of the building component R_{tot} [m^{2}K/W], using the following formula:

$$U = 1 / R_{tot} = 1 / \Sigma_i R_i \text{ [W/m}^2\text{K]} \quad (9)$$

where:

- R_i: thermal resistance of a single layer that constitutes the opaque building component [m^{2}K/W], calculated as $R_i = s_i / \lambda_i$

  where:
  - s_i: layer thickness [m];
  - λ_i: thermal conductivity of the layer material [W/(mK)]

The calculation of the total thermal resistances and thermal transmittance of the opaque components of the building under audit is provided below (Table 12, Table 13 and Table 14).

Table 12. **Thermal Transmittance of the External Wall**

Code: M1 – External wall				
N.	Layer description	s m	λ W/mK	R m^{2}K/W
1	Lime plaster	0,010	0,90	0,011
2	Tuff block (mv. 1500)	0,250	0,63	0,397
3	Lime plaster	0,010	0,90	0,011
			Total Thermal Resistance (m^{2}K/W) =	**0,419**
			Thermal Transmittance (W/m^{2}K) =	**2,386**

Table 13. **Thermal Transmittance of the ceiling of rooms with star vaults**

Code: S1 – Ceiling of rooms with star vaults				
N.	Layer description	s m	λ W/mK	R m^2K/W
1	Lime plaster	0,015	0,900	0,017
2	Tuff block (mv. 1500)	0,230	0,630	0,365
3	Tuff powder	0,300	0,350	0,857
4	Lecce stone slab (mv. 1750)	0,050	0,850	0,059
			Total Thermal Resistance (m^2K/W) =	**1,298**
			Thermal Transmittance (W/m^2K) =	**0,771**

Table 14**. Thermal Transmittance of the ceiling of rooms with flat ceilings**

Code: S2 – Ceiling of rooms with flat ceilings				
N.	Layer description	s m	λ W/mK	R m^2K/W
1	Lime plaster	0,015	0,90	0,017
2	Slub - 24 cm			
3	Reinforced concrete - 4 cm	0,300	0,81	0,370
4	Cement mortar - 2 cm			
5	Tuff block (mv. 1500)	0,150	0,63	0,238
6	Lecce stone slab (mv. 1750)	0,050	0,85	0,059
			Total Thermal Resistance (m^2K/W) =	**0,684**
			Thermal Transmittance (W/m^2K) =	**1,462**

The calculation of direct heat transfer coefficient by transmission through opaque surfaces toward the external environment $H_{D,o}$ is now carried out, in Table 15. The contribution of window shutter boxes is also included, with a thermal transmittance assumed to be 6 W/m²K, as specified in Prospetto A.2 of the UNI/TS 11300-1 standard. The transmittance calculated for each opaque component has been increased by 5%, in accordance with Prospetto 4 of the UNI/TS 11300-1, which refers to a "homogeneous wall made of solid bricks or stone (without insulation)".

Table 15. **Direct heat transfer coefficient by transmission through opaque surfaces**

Code	Opaque surface description	or.	A m2	U_c W/m2K	$U_{c+pt,k}$ W/m2K	$H_{D,oi}$ W/K
M1	External wall	SW	44,61	2,39	2,51	111,78
M1	External wall	NW	8,66	2,39	2,51	21,70
M1	External wall	NE	27,89	2,39	2,51	69,88
M1	External wall	SE	21,98	2,39	2,51	55,06
M1	External wall	W	13,02	2,39	2,51	32,63
M1	External wall	N	7,01	2,39	2,51	17,57
S1	Ceiling of rooms with star vaults	/	107,49	0,77	0,81	86,97
S2	Ceiling of rooms with flat ceilings	/	15,88	1,46	1,54	24,38
B1	Shutter box	SE	0,27	6,00	6,30	1,70
B1	Shutter box	NE	0,27	6,00	6,30	1,70
					$H_{D,o}$ (W/K) =	**423,39**

Calculation of the heat transfer coefficient for transmission to the external environment: transparent surfaces

$H_{D,f} = \Sigma_k A_{w,p,k} U_{f,k.}$ [W/K] (10)

where:
$A_{w,p,k}$: area of the transparent component [m^2];
$U_{f,k}$: thermal transmittance of the transparent component [W/m²K].

To calculate the thermal transmittance of transparent components, such as windows or glazed doors, the following formula is used:

$U_{f,k} = (A_g U_g + A_f U_f + I_g \psi_g) / (A_g + A_f)$ [W/m^2K] (11)

where:

A_g: glass area [m²];
U_g: thermal transmittance of the glass [W/m²K];
A_f: frame area [m²];
U_f: thermal transmittance of the frame [W/m²K];
l_g: length of the perimeter of contact between frame and glass [m];
ψ_g: linear thermal transmittance coefficient of the thermal bridge between frame and glass [W/mK], assigned in accordance with Prospetto E.1 of the UNI EN ISO 10077-1.

The calculation of the total thermal resistance of the building's transparent components is presented below, distinguishing between the glass section and the frame of the fixtures (Table 16, Table 17 and Table 18).

Table 16. **Thermal Transmittance of the glass and frame of the partially glazed door**

Code: F1 – Partially glazed door				
N.	Glass - Layer description	s m	λ W/mK	R m^2K/W
1	Glass	0,004	1,00	0,004
2	Argon gas	0,012	0,02	0,714
3	Glass	0,004	1,00	0,004
			Total Thermal Resistance – Glass (m^2K/W) =	**0,722**
			Thermal Transmittance – Glass (W/m^2K) =	**1,384**
N.	Frame - Layer description	s m	λ W/mK	R m^2K/W
1	Aluminum	0,002	209,000	0,000
2	Air chamber	0,023	0,026	0,885
3	Polyimide	0,020	0,330	0,061
4	Air chamber	0,023	0,026	0,885
5	Aluminum	0,002	209,000	0,000
			Total Thermal Resistance – Frame (m^2K/W) =	**1,830**
			Thermal Transmittance – Frame (W/m^2K) =	**0,546**

Table 17. **Thermal Transmittance of the glass and frame of the window**

Code: F2 – Window				
N.	Glass - Layer description	s m	λ W/mK	R m^2K/W
1	Glass	0,003	1,000	0,003
			Total Thermal Resistance – Glass (m^2K/W) =	**0,003**
			Thermal Transmittance – Glass (W/m^2K) =	**333,333**
N.	Frame - Layer description	s m	λ W/mK	R m^2K/W
1	Wood	0,08	0,11	0,727
			Total Thermal Resistance – Frame (m^2K/W) =	**0,727**
			Thermal Transmittance – Frame (W/m^2K) =	**1,375**

Table 18. **Thermal Transmittance of the glass and frame of the fixed window**

Code: F3 – Fixed window				
N.	Glass - Layer description	s m	λ W/mK	R m^2K/W
1	Glass	0,004	1,000	0,004
2	Argon gas	0,016	0,017	0,952
3	Glass	0,004	1,000	0,004
			Total Thermal Resistance – Glass (m^2K/W) =	**0,960**
			Thermal Transmittance – Glass (W/m^2K) =	**1,041**
N.	Frame - Layer description	s m	λ W/mK	R m^2K/W
1	PVC	0,007	0,0145	0,48276
2	Aluminum reinforcement	0,002	209	0,00001
3	Air chamber	0,052	0,026	2,00000
4	Aluminum reinforcement	0,002	209	0,00001
5	PVC	0,007	0,0145	0,48276

Total Thermal Resistance – Frame (m^2K/W) =	**2,966**
Thermal Transmittance – Frame (W/m^2K) =	**0,337**

The calculation of the thermal transmittance of the transparent components is now presented in the Table 19, using the equation (12). In accordance with Prospetto E.1 of the UNI EN ISO 10077-1, the ψ_g value has been assigned as follows: 0,06 W/mK for fixtures identified by code F1 ("Metal frame with thermal break") and 0,04 W/mK for fixtures with codes F2 and F3 ("Wooden frame and plastic frame"). The geometric parameters of the fixtures h, b, h_1, and b_1 are consistent with Figure 4 presented in Chapter 1.

Table 19. **Thermal Transmittance of the fixtures**

Code	or.	b m	h m	b_1 m	h_1 m	A m^2	A_g m^2	A_f m^2	l_g m	U_g W/m^2K	U_f W/m^2K	ψ_g W/mK	$U_{f,k}$ W/m^2K
F1	SW	1,00	2,46	0,42	1,60	2,46	1,34	1,12	8,08	1,38	0,55	0,06	1,20
F1	SW	1,00	2,46	0,42	1,60	2,46	1,34	1,12	8,08	1,38	0,55	0,06	1,20
F2	SE	0,90	1,50	0,31	1,20	1,35	0,74	0,61	6,02	333,33	1,38	0,04	183,74
F1	SE	0,92	2,20	0,35	1,35	2,02	0,96	1,07	6,82	1,38	0,55	0,06	1,14
F2	NE	0,90	1,50	0,31	1,20	1,35	0,74	0,61	6,02	333,33	1,38	0,04	183,74
F1	NE	0,92	2,20	0,36	1,35	2,02	0,97	1,05	6,84	1,38	0,55	0,06	1,15
F3	NE	0,72	0,72	0,60	0,60	0,52	0,36	0,16	2,40	1,04	0,34	0,04	1,01
F1	W	0,70	2,20	0,55	1,00	1,54	0,55	0,99	3,10	1,38	0,55	0,06	0,97
F3	W	0,48	0,72	0,36	0,60	0,35	0,22	0,13	1,92	1,04	0,34	0,04	1,00

The calculation of direct heat transfer coefficient for transmission through transparent surfaces toward the external environment $H_{D,f}$ is now carried out, in Table 20.

Table 20. **Direct heat transfer coefficient by transmission through transparent surfaces**

Code	Transparent surface description	or.	A m^2	$U_{f,k}$ W/m^2K	$H_{D,fi}$ W/K
F1	Partially glazed door	SW	2,46	1,20	2,96
F1	Partially glazed door	SW	2,46	1,20	2,96
F2	Window	SE	1,35	183,74	248,04
F1	Partially glazed door	SE	2,02	1,14	2,32
F2	Window	NE	1,35	183,74	248,04
F1	Partially glazed door	NE	2,02	1,15	2,33
F3	Fixed Window	NE	0,52	1,01	0,52
F1	Partially glazed door	W	1,54	0,97	1,49
F3	Fixed Window	W	0,35	1,00	0,35
				$H_{D,f}$ (W/K) =	**509,01**

Calculation of the steady-state heat transfer coefficient by transmission to the ground

$$H_g = A \times U_f \times b_{tr,g} \text{ [W/K]} \quad (12)$$

where:

A: area of the element [m^2];

U_f: thermal transmittance of the suspended part of the floor (between the internal environment and the subfloor space) [W/m^2K];

$b_{tr,g}$: correction factor, provided by Prospetto 6 of the UNI/TS 11300-1 standard.

The calculation of the total thermal resistance of the building's floor is provided below.

Table 21. **Thermal Transmittance of the floor**

Code: P1 – Floor				
N.	Layer description	s m	λ W/mK	R m^2K/W
1	Glazed porcelain stoneware	0,015	1,470	0,010
2	Cement mortar	0,030	1,400	0,021
3	Lightweight concrete	0,100	0,330	0,303
4	Gravel	0,300	1,200	0,250
			Total Thermal Resistance (m^2K/W) =	**0,585**

Thermal Transmittance (W/m^2K) =	**1,710**

Recalling that the usable floor area of the building is 123,37 m² and that the correction factor $b_{tr,g}$ is equal to 0,45 according to Prospetto 6 of the UNI/TS 11300-1 standard ("Floor in contact with the ground"), the steady-state heat transfer coefficient by transmission through the ground is:

H_g = 94,95 W/K

Calculation of the heat transfer by transmission in the case of heating

Before presenting the calculation of the heat transfer by transmission in the case of heating, the global heat transfer coefficient by transmission is determined according to equation (7), which is the sum of the coefficients $H_{D,o}$, $H_{D,f}$, and H_g. It should be noted that in this case, the contributions related to H_U and H_A are zero.

$H_{tr,adj} = H_{D,o} + H_{D,f} + H_g$ = (423,39 + 509,01 + 94,95) W/K = 1027,35 W/K

Heat transfer by transmission in the case of heating is calculated using equation (6).

Table 22. **Heat transfer by transmission**

	$H_{tr,adj}$ W/K	$\theta_{int,set,H}$ °C	θ_e °C	t h	$Q_{H,tr}$ kWh
Jan	1027,3	20	9,00	744	8408
Feb	1027,3	20	9,3	672	7387
Mar	1027,3	20	11,4	744	6573
Nov	1027,3	20	14,3	360	2108
Dec	1027,3	20	10,7	744	7108
				Total $Q_{H,tr}$ (kWh) =	**31585**

3.1.1.2 Calculation of the heat transfer by ventilation

The UNI/TS 11300 standard specifies air changes depending on the occupancy of the rooms and their intended use to ensure adequate air quality. The heat transfer by ventilation in the case of heating is calculated using the following formula:

$$Q_{H,ve} = H_{ve,adj} \times (\theta_{int,set,H} - \theta_e) \times t \text{ [kWh]} \quad (13)$$

where:
$H_{tr,adj}$: global heat transfer coefficient for the ventilation of the considered zone, adjusted to account for the internal-external temperature difference [W/K];
$\theta_{int,set,H}$: internal setpoint temperature for heating of the considered area, set at 20°C according to the UNI/TS 11300-1 standard [°C];
θ_e: average monthly external temperature, obtained from the UNI 10349 standard [°C];
t: duration of the considered month [h].

Similar to the calculation of heat transfer by transmission, the global heat transfer coefficient for ventilation is presented as:

$$H_{ve,adj} = \rho_a c_a \times (\Sigma_k b_{ve,k} q_{ve,k,mn}) \text{ [W/K]} \quad (14)$$

where:
$\rho_a c_a$: volumetric heat capacity of air, equal to 1200 [J/m³·K];
$q_{ve,k,mn}$: time-averaged flow rate of the k-th air flow [m³/h];
$b_{ve,k}$: temperature correction factor for the k-th air flow, equal to 1. Is different from 1 if the supply air temperature differs from the external ambient temperature, as in the case of pre-heating, pre-cooling, or heat recovery from ventilation air.

The time-averaged flow rate of the k-th air flow, $q_{ve,k,mn}$, expressed in [m³/h], is calculated as:

$$q_{ve,k,mn} = f_{ve,t,k} \times q_{ve,k} \text{ [m}^3\text{/h]} \quad (15)$$

where:
$f_{ve,t,k}$: fraction of time during which the k-th air flow occurs. For a permanent situation is equal to 1;
$q_{ve,k}$: flow rate of the k-th air flow over time [m³/h].

In the case of natural aeration or ventilation, an air exchange rate of 0.3 vol/h is assumed for residential buildings. Therefore, recalling that the usable volume of the building is 436,26 m³, the flow rate of the k-th air flow over time is equal to:

$$q_{ve,k} = (0{,}3 \times 436{,}26) \text{ m}^3\text{/h} = 130{,}88 \text{ m}^3\text{/h}$$

Consequently, in accordance with equation (15), the time-averaged flow rate of the k-th air flow is equal to:

$$q_{ve,k,mn} = (1 \times 130{,}88) \text{ m}^3\text{/h} = 130{,}88 \text{ m}^3\text{/h}$$

Finally, according to equation (14), the global heat transfer coefficient by ventilation can be calculated as:

$H_{ve,adj}$ = 157053 J/Kh = 43,63 W/K

Heat transfer by ventilation in the case of heating is calculated using equation (13).

Table 23. **Heat transfer by ventilation**

	$H_{ve,adj}$ W/K	$\theta_{int,set,H}$ °C	θ_e °C	t h	$Q_{H,ve}$ kWh
Jan	43,63	20	9,00	744	357
Feb	43,63	20	9,3	672	314
Mar	43,63	20	11,4	744	279
Nov	43,63	20	14,3	360	90
Dec	43,63	20	10,7	744	302
				Total $Q_{H,ve}$ (kWh) =	**1341**

3.1.1.3 Calculation of $Q_{H,ht}$

Based on the data provided in Table 22 and Table 23, the total heat transfer for the heating case is calculated in Table 24. Equation (5) is restated for clarity:

$$Q_{H,ht} = Q_{H,tr} + Q_{H,ve} \text{ [kWh]} \quad (5)$$

where:
$Q_{H,tr}$: heat transfer by transmission in the case of heating [kWh];
$Q_{H,ve}$: heat transfer by ventilation in the case of heating [kWh];

Table 24. **Total heat transfer in the case of heating**

	$Q_{H,tr}$ kWh	$Q_{H,ve}$ kWh	$Q_{H,ht}$ kWh
Jan	8408	357	8765
Feb	7387	314	7701
Mar	6573	279	6853
Nov	2108	90	2198
Dec	7108	302	7410
		$Q_{H,ht}$ (kWh) =	**32926**

3.1.2 Calculation of total heat contributions

In this section, the calculation of the total heat contributions Q_{gn} is carried out. Heat contributions can be classified as internal (dependent on the occupants' metabolism, heat generated by electrical equipment, and lighting) and solar (resulting from the average solar radiation at the location, the orientation of the surface, shading, surface absorption properties, etc.). The total heat contributions are obtained by summing the internal heat contributions and the solar thermal contributions. The formula is provided below:

$$Q_{gn} = Q_{int} + Q_{sol} \text{ [kWh]} \quad (16)$$

where:
Q_{int}: internal heat contributions [kWh];
Q_{sol}: solar heat contributions [kWh].

3.1.2.1 Calculation of the internal heat contributions

The internal heat contributions are calculated using the following formula:

$$Q_{int} = \{\Sigma_k \Phi_{int,mn,k}\} \times t \text{ [kWh]} \quad (17)$$

where:
$\phi_{int,mn,k}$: thermal flux generated by the k-th internal heat source, averaged over time [W];
t: duration of the considered month [h].

According to UNI/TS 11300-1, for category E.1 (1) and E.1 (2) buildings (residential), with a usable floor area A_f less than or equal to 170 m^2, the global value of internal heat contributions, expressed in W, is determined as:

$$\phi_{int,mn,k} = 5{,}294 \times A_f - 0{,}01557 \times A_f^2 \text{ [W]} \quad (18)$$

Given that the conditioned usable floor area is 123,37 m^2, the thermal flux, according to equation (18), is equal to:

$\phi_{int,mn,k}$ = 416,14 W

The calculation of internal heat contributions according to the equation (17) is provided below, as shown in Table 25.

Table 25. **Internal heat contributions**

	$\phi_{int,mn,k}$ W	t h	Q_{int} kWh
Jan	416	744	310
Feb	416	672	280
Mar	416	744	310
Nov	416	360	150
Dec	416	744	310
		Q_{int} (kWh) =	**1358**

3.1.2.2 Calculation of the solar heat contributions

The solar heat contributions are calculated using the following formula:

$$Q_{sol} = \{\Sigma_k Q_{sol,mn,k}\} \times d \text{ [kWh]} \quad (19)$$

where:
$Q_{sol,mn,k}$: daily solar heat contribution [kWh/day];
d: duration of the considered month [days].

The daily solar heat contribution $Q_{sol,mn,k}$ is calculated using the following formula:

$$Q_{sol,mn,k} = F_{sh,ob,k} \times A_{sol,k} \times I_{sol,k} \text{ [kWh/day]} \quad (20)$$

where:
$F_{sh,ob,k}$: shanding reduction factor related to the external elements for the effective solar capture area of the k-th surface:

$$F_{sh,ob,k} = F_{hor} \times F_{ov} \times F_{fin} \quad (21)$$

where:
F_{hor}: shading factor related to external obstructions;
F_{ov}: shading factor related to horizontal overhangs;
F_{fin}: shading factor related to vertical overhangs

$A_{sol,k}$: effective solar capture area of the k-th surface, with specific orientation and tilt angle on the horizontal plane, in the considered zone or environment [m²];
$I_{sol,k}$: average monthly daily solar irradiation on the k-th surface, with specific orientation, obtained from UNI 10349 standard [MJ/m^2].

The value of the shading reduction factor related to external elements for the effective solar capture area of the k-th surface $F_{sh,ob,k}$ has been assigned arbitrarily and is equal to 0,75.

Calculation of the effective solar capture area: opaque surfaces

$$A_{sol,o} = a_{sol,c} R_{se} U_c A_c \text{ [m}^2\text{]} \quad (22)$$

where:
$a_{sol,c}$: solar absorption factor of the opaque component, equal to 0,6 for medium-colored surfaces according to the UNI/TS 11300-1 standard;
R_{se}: external surface thermal resistance of the opaque component, equal to 0,04 [m^{2}K/W], in accordance with Prospetto 1 of UNI EN ISO 6946;
U_c: thermal transmittance of the opaque component [W/m^{2}K];
A_c: area of the opaque component [m^2].

The calculation of the effective solar capture area for opaque surfaces, according to the equation (22) is provided below, as shown in Table 26.

Table 26. **Effective solar capture area for opaque surfaces**

Code	Opaque surface description	or.	$a_{sol,c}$	R_{se} m^{2}K/W	U_c W/m^{2}K	A_c m^2	$A_{sol,o}$ m^2
M1	External wall	SW	0,6	0,04	2,39	44,61	2,555
M1	External wall	NW	0,6	0,04	2,39	8,66	0,496
M1	External wall	NE	0,6	0,04	2,39	27,89	1,597
M1	External wall	SE	0,6	0,04	2,39	21,98	1,259
M1	External wall	W	0,6	0,04	2,39	13,02	0,746
M1	External wall	N	0,6	0,04	2,39	7,01	0,402
S1	Ceiling of rooms with star vaults	/	0,6	0,04	0,77	107,49	1,988
S2	Ceiling of rooms with flat ceilings	/	0,6	0,04	1,46	15,88	0,557
B1	Shutter box	SE	0,6	0,04	6,00	0,27	0,039
B1	Shutter box	NE	0,6	0,04	6,00	0,27	0,039

Calculation of the effective solar capture area: transparent surfaces

Solar contributions entering through a glazed surface depend not only on the type of glass but also on the structure of the component and the effectiveness of any shading devices (e.g., curtains, shutters). The standard requires the calculation of an equivalent surface called the effective solar capture area $A_{sol,f}$, calculated as:

$$A_{sol,f} = F_{sh,gl}\ g_{gl}\ (1 - F_F)\ A_{w,p}\ [m^2] \tag{23}$$

where:
$F_{sh,gl}$: reduction factor for solar contributions related to the use of movable shading devices (e.g., curtains). For simplicity, this factor is assumed to be equal to 1;
g_{gl}: total solar energy transmittance of the window when the solar shading device is not used, as defined by UNI/TS 11300-1:

$$g_{gl} = F_W \times g_{gl,n} \tag{24}$$

where:
F_W: exposure factor, equal to 0,9;
$g_{gl,n}$: total solar energy transmittance for normal incidence

F_F: frame area fraction, defined as the ratio between the projected frame area and the total projected area of the glazed component, according to UNI/TS 11300-1, with the value (1 - F_F) equal to 0,8;
$A_{w,p}$: total projected area of the glazed component (window opening area) [m^2].

The value of the total solar energy transmittance for normal incidence, $g_{gl,n}$, has been determined using Prospetto 13 of UNI/TS 11300-1. Specifically, a value of 0,75 has been assigned to transparent components with codes F1 and F3 ("Double standard glazing"), while a value of 0,85 has been assigned to frames with code F2 ("Single glazing").
The calculation of the effective solar capture area for glazed components is now carried out, according to equations (23) and (24), as shown in Table 27.

Table 27. **Effective solar capture area for glazed components**

Code	Transp. surface description	or.	$F_{sh,gl}$	F_W	$g_{gl,n}$	1 - F_F	$A_{w,p}$ m^2	$A_{sol,f}$ m^2
F1	Partially glazed door	SW	1,00	0,90	0,75	0,80	2,46	1,33
F1	Partially glazed door	SW	1,00	0,90	0,75	0,80	2,46	1,33
F2	Window	SE	1,00	0,90	0,85	0,80	1,35	0,83
F1	Partially glazed door	SE	1,00	0,90	0,75	0,80	2,02	1,09
F2	Window	NE	1,00	0,90	0,85	0,80	1,35	0,83
F1	Partially glazed door	NE	1,00	0,90	0,75	0,80	2,02	1,09
F3	Fixed Window	NE	1,00	0,90	0,75	0,80	0,52	0,28
F1	Partially glazed door	W	1,00	0,90	0,75	0,80	1,54	0,83
F3	Fixed Window	W	1,00	0,90	0,75	0,80	0,35	0,19

Calculation of the solar heat contributions

The calculation of the daily solar heat contribution is performed for each month of the winter period using equation (20) (Table 28, Table 29, Table 30, Table 31 and Table 32). The values of the effective solar capture areas are obtained from Table 26, for opaque surfaces, and from Table 27, for transparent surfaces.
The global solar irradiation on a vertical surface, $I_{sol,k}$, is determined in accordance with the UNI 10349 standard, based on the orientation of the vertical surface. Complete data are provided in Table 5.

Table 28. **Daily solar heat contribution for the month of January**

January						
Code	Surface description	or.	$F_{sh,ob,k}$	$A_{sol,k}$ m^2	$I_{sol,k}$ MJ/m^2	$Q_{sol,mn,k}$ MJ
M1	External wall	N	0,75	0,40	2,2	0,66
M1	External wall	NE	0,75	1,60	2,5	3,00
B1	Shutter box	NE	0,75	0,04	2,5	0,07
F2	Window	NE	0,75	0,83	2,5	1,55
F1	Partially glazed door	NE	0,75	1,09	2,5	2,05
F3	Fixed Window	NE	0,75	0,28	2,5	0,52

M1	External wall	NW	0,75	0,50	2,5	0,93
M1	External wall	SE	0,75	1,26	8,8	8,31
B1	Shutter box	SE	0,75	0,04	8,8	0,26
F2	Window	SE	0,75	0,83	8,8	5,45
F1	Partially glazed door	SE	0,75	1,09	8,8	7,21
M1	External wall	SW	0,75	2,55	8,8	16,86
F1	Partially glazed door	SW	0,75	1,33	8,8	8,77
F1	Partially glazed door	SW	0,75	1,33	8,8	8,77
M1	External wall	W	0,75	0,75	5,3	2,96
F1	Partially glazed door	W	0,75	0,83	5,3	3,31
F3	Fixed Window	W	0,75	0,19	5,3	0,74
S1	Ceiling of rooms with star vaults	OR	0,75	1,99	6,8	10,14
S2	Ceiling of rooms with flat ceilings	OR	0,75	0,56	6,8	2,84
					Total $Q_{sol,mn,k}$ (MJ/day) =	**84,40**

Table 29. **Daily solar heat contribution for the month of February**

February						
Code	Surface description	or.	$F_{sh,ob,k}$	$A_{sol,k}$ m^2	$I_{sol,k}$ MJ/m^2	$Q_{sol,mn,k}$ MJ
M1	External wall	N	0,75	0,40	3,0	0,90
M1	External wall	NE	0,75	1,60	3,9	4,67
B1	Shutter box	NE	0,75	0,04	3,9	0,11
F2	Window	NE	0,75	0,83	3,9	2,42
F1	Partially glazed door	NE	0,75	1,09	3,9	3,20
F3	Fixed Window	NE	0,75	0,28	3,9	0,82
M1	External wall	NW	0,75	0,50	3,9	1,45
M1	External wall	SE	0,75	1,26	10,5	9,91
B1	Shutter box	SE	0,75	0,04	10,5	0,31
F2	Window	SE	0,75	0,83	10,5	6,51
F1	Partially glazed door	SE	0,75	1,09	10,5	8,61
M1	External wall	SW	0,75	2,55	10,5	20,12
F1	Partially glazed door	SW	0,75	1,33	10,5	10,46
F1	Partially glazed door	SW	0,75	1,33	10,5	10,46
M1	External wall	W	0,75	0,75	7,3	4,08
F1	Partially glazed door	W	0,75	0,83	7,3	4,55
F3	Fixed Window	W	0,75	0,19	7,3	1,02
S1	Ceiling of rooms with star vaults	OR	0,75	1,99	9,8	14,61
S2	Ceiling of rooms with flat ceilings	OR	0,75	0,56	9,8	4,10
					Total $Q_{sol,mn,k}$ (MJ/day) =	**108,31**

Table 30. **Daily solar heat contribution for the month of March**

March						
Code	Surface description	or.	$F_{sh,ob,k}$	$A_{sol,k}$ m^2	$I_{sol,k}$ MJ/m^2	$Q_{sol,mn,k}$ MJ
M1	External wall	N	0,75	0,40	4,1	1,23
M1	External wall	NE	0,75	1,60	6,0	7,19
B1	Shutter box	NE	0,75	0,04	6,0	0,17
F2	Window	NE	0,75	0,83	6,0	3,72
F1	Partially glazed door	NE	0,75	1,09	6,0	4,92
F3	Fixed Window	NE	0,75	0,28	6,0	1,26
M1	External wall	NW	0,75	0,50	6,0	2,23
M1	External wall	SE	0,75	1,26	11,6	10,95
B1	Shutter box	SE	0,75	0,04	11,6	0,34
F2	Window	SE	0,75	0,83	11,6	7,19
F1	Partially glazed door	SE	0,75	1,09	11,6	9,51
M1	External wall	SW	0,75	2,55	11,6	22,23
F1	Partially glazed door	SW	0,75	1,33	11,6	11,56
F1	Partially glazed door	SW	0,75	1,33	11,6	11,56
M1	External wall	W	0,75	0,75	9,6	5,37
F1	Partially glazed door	W	0,75	0,83	9,6	5,99
F3	Fixed Window	W	0,75	0,19	9,6	1,34
S1	Ceiling of rooms with star vaults	OR	0,75	1,99	13,6	20,28
S2	Ceiling of rooms with flat ceilings	OR	0,75	0,56	13,6	5,68
					Total $Q_{sol,mn,k}$ (MJ/day) =	**132,72**

Table 31. **Daily solar heat contribution for the month of November**

November						
Code	Surface description	or.	$F_{sh,ob,k}$	$A_{sol,k}$ m^2	$I_{sol,k}$ MJ/m^2	$Q_{sol,mn,k}$ MJ
M1	External wall	N	0,75	0,40	2,4	0,72
M1	External wall	NE	0,75	1,60	2,8	3,35
B1	Shutter box	NE	0,75	0,04	2,8	0,08
F2	Window	NE	0,75	0,83	2,8	1,74
F1	Partially glazed door	NE	0,75	1,09	2,8	2,30
F3	Fixed Window	NE	0,75	0,28	2,8	0,59
M1	External wall	NW	0,75	0,50	2,8	1,04
M1	External wall	SE	0,75	1,26	9,0	8,50
B1	Shutter box	SE	0,75	0,04	9,0	0,26
F2	Window	SE	0,75	0,83	9,0	5,58
F1	Partially glazed door	SE	0,75	1,09	9,0	7,38
M1	External wall	SW	0,75	2,55	9,0	17,25
F1	Partially glazed door	SW	0,75	1,33	9,0	8,97
F1	Partially glazed door	SW	0,75	1,33	9,0	8,97
M1	External wall	W	0,75	0,75	5,7	3,19
F1	Partially glazed door	W	0,75	0,83	5,7	3,56
F3	Fixed Window	W	0,75	0,19	5,7	0,80
S1	Ceiling of rooms with star vaults	OR	0,75	1,99	7,4	11,03
S2	Ceiling of rooms with flat ceilings	OR	0,75	0,56	7,4	3,09
					Total $Q_{sol,mn,k}$ (MJ/day) =	**88,38**

Table 32. **Daily solar heat contribution for the month of December**

December						
Code	Surface description	or.	$F_{sh,ob,k}$	$A_{sol,k}$ m^2	$I_{sol,k}$ MJ/m^2	$Q_{sol,mn,k}$ MJ
M1	External wall	N	0,75	0,40	2,0	0,60
M1	External wall	NE	0,75	1,60	2,2	2,64
B1	Shutter box	NE	0,75	0,04	2,2	0,06
F2	Window	NE	0,75	0,83	2,2	1,36
F1	Partially glazed door	NE	0,75	1,09	2,2	1,80
F3	Fixed Window	NE	0,75	0,28	2,2	0,46
M1	External wall	NW	0,75	0,50	2,2	0,82
M1	External wall	SE	0,75	1,26	7,7	7,27
B1	Shutter box	SE	0,75	0,04	7,7	0,22
F2	Window	SE	0,75	0,83	7,7	4,77
F1	Partially glazed door	SE	0,75	1,09	7,7	6,31
M1	External wall	SW	0,75	2,55	7,7	14,76
F1	Partially glazed door	SW	0,75	1,33	7,7	7,67
F1	Partially glazed door	SW	0,75	1,33	7,7	7,67
M1	External wall	W	0,75	0,75	4,6	2,57
F1	Partially glazed door	W	0,75	0,83	4,6	2,87
F3	Fixed Window	W	0,75	0,19	4,6	0,64
S1	Ceiling of rooms with star vaults	OR	0,75	1,99	5,9	8,80
S2	Ceiling of rooms with flat ceilings	OR	0,75	0,56	5,9	2,47
					Total $Q_{sol,mn,k}$ (MJ/day) =	**73,77**

The solar heat contributions can now be calculated using equation (19), by multiplying the daily contribution values by the number of days in each month, as shown in Table 33.

Table 33. **Solar heat contributions**

	$Q_{sol,mn,k}$ MJ/day	$Q_{sol,mn,k}$ kWh/day	Days	Q_{sol} kWh/month
Jan	84,40	23,4	31	727
Feb	108,31	30,1	28	842
Mar	132,72	36,9	31	1143
Nov	88,38	24,5	15	368
Dec	73,77	20,5	31	635
			Q_{sol} (kWh) =	**3716**

3.1.2.3 Calculation of Q_{gn}

Based on the data provided in Table 25 and Table 33, the total heat contributions are calculated, as shown in Table 34. Equation (16) is restated for clarity:

$$Q_{gn} = Q_{int} + Q_{sol} \text{ [kWh]} \tag{16}$$

where:

Q_{int}: internal heat contributions [kWh];
Q_{sol}: solar heat contributions [kWh];

Table 34. **Total heat contributions**

	Q_{int} kWh	Q_{sol} kWh	Q_{gn} kWh
Jan	310	727	1036
Feb	280	842	1122
Mar	310	1143	1452
Nov	150	368	518
Dec	310	635	945
		Q_{gn} (kWh) =	**5074**

3.1.3 Calculation of $Q_{H,nd}$

The calculation of the ideal thermal energy demand for heating is finally carried out, referring once again to equation (4) presented at the beginning of the chapter:

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \times Q_{gn} \text{ [kWh]} \tag{4}$$

where:

$Q_{H,nd}$: ideal thermal energy demand of the building for heating [kWh];
$Q_{H,ht}$: total heat transfer in the case of heating [kWh];
Q_{gn}: total thermal contributions [kWh];
$Q_{H,tr}$: heat transfer by transmission in the case of heating [kWh];
$Q_{H,ve}$: heat transfer by ventilation in the case of heating [kWh];
Q_{int}: internal heat contributions [kWh];
Q_{sol}: solar heat contributions [kWh];
$\eta_{H,gn}$: utilization factor of heat contributions, which measures how much these contribute to the remaining energy demand.

The utilization factor of heat contributions for the calculation of heating demand is determined according to UNI/TS 11300-1 as:

$$\eta_{H,gn} = (1 - \gamma_H^{aH}) / (1 - \gamma_H^{aH+1}) \tag{25}$$

where:

$$\gamma_H = Q_{gn} / Q_{H,ht} \tag{26}$$
$$a_H = a_{H,0} + \tau / \tau_{H,0} \tag{27}$$

where:

τ: thermal time constant of the thermal zone, calculated as: $\tau = (C_m / 3600) / (H_{tr,adj} + H_{ve,adj})$ [h]
C_m: Internal thermal capacity, determined based on the construction characteristics of the building components, calculated as: $C\ m = 155$ [kJ/ (m^2 × K)] × A_f [J/K], with Af representing the conditioned floor area.

Recalling that the value of A_f is 123,37 m^2, C_m = 17888650 J/K. Consequently, given that $H_{tr,adj}$ = 1027,3 W/K and $H_{ve,adj}$ = 43,63 W/K, it follows that τ = 4,64 h.
According to UNI/TS 11300-1, $a_{H,0}$ = 0 and $\tau_{H,0}$ = 15 h, therefore, using equation (27), it results that a_H = 1,309. Table 35 presents the calculation of γ_H, month by month, using equation (26).

Table 35. **Calculation of γ_H**

	Q_{gn} kWh	$Q_{H,ht}$ kWh	γ_H
Jan	1036	8765	0,118
Feb	1122	7701	0,146
Mar	1452	6853	0,212
Nov	518	2198	0,236
Dec	945	7410	0,128

The calculation of the utilization factor of heat contributions is now provided using equation (25), as shown in Table 36.

Table 36. **Utilization factor of heat contributions**

	γ_H^{aH}	γ_H^{aH+1}	$\eta_{H,gn}$
Jan	0,061	0,007	0,946
Feb	0,080	0,012	0,931
Mar	0,131	0,028	0,894
Nov	0,151	0,036	0,881
Dec	0,067	0,009	0,941

To conclude this part of the chapter, the calculation of the ideal thermal energy demand for heating, evaluated for each month of the winter period, is presented using equation (4). The Table 37 shows the results.

Table 37. **Ideal thermal energy demand for heating**

	$Q_{H,ht}$ kWh	Q_{gn} kWh	$\eta_{H,gn}$	$Q_{H,nd}$ kWh
Jan	8765	1036	0,946	7785
Feb	7701	1122	0,931	6657
Mar	6853	1452	0,894	5555
Nov	2198	518	0,881	1741
Dec	7410	945	0,941	6521
Total (kWh) =	**32926**	**5074**		**28259**

It follows that the annual ideal thermal energy demand for heating is equal to 28259 kWh.

3.2 Analysis of energy consumption for domestic hot water

The calculation of the daily required water volume and the thermal energy demand to meet the domestic hot water needs of a building, based on this volume, is carried out in accordance with UNI/TS 11300-2.

Required water volume for residential buildings

For residential buildings, the required water volume V_w, expressed in liters per day, is calculated as:

$$V_w = a \times S_u + b \text{ [l/day]} \tag{28}$$

where:
a: parameter obtained from Prospetto 30 [liters / (m²·day)];
b: parameter obtained from Prospetto 30 [liters / day];
S_u: usable floor area of the dwelling [m^2].

Recalling that the usable floor area of the building under audit is 123,37 m², according to Prospetto 30 of UNI/TS 11300-2, a and b are equal to 1,067 [liters / (m²·day)] and 36,67 [liters / day], respectively ("$50 < S_u < 200$"). Therefore, based on equation (28), the required water volume is:

V_w = (1,067 × 123.37 + 36,67) l/day = 168 l/day = 0,168 m^3/day

Thermal energy demand for domestic hot water

The thermal energy demand Q_W to meet the domestic hot water needs of a building, based on the required water volume and the difference between the delivery temperature and the incoming cold water temperature, is given by:

$$Q_W = \rho_w \times c_w \times \Sigma_i [V_{w,i} \times (\theta_{er,i} - \theta_0)] \times G \text{ [kWh]} \tag{29}$$

where:
ρ_w: water density, assumed to be 1000 [kg/m3];
c_w: specific heat capacity of water, equal to $1,162 \times 10^{-3}$ [kWh/(kg × K)];
$V_{w,i}$: daily water volume for the i-th activity or required service [m^3 / day];
$\theta_{er,i}$: delivery temperature of water for the i-th activity or required service [°C];
θ_0: temperature of the incoming cold water [°C];
G: number of days in the considered calculation period [days].

In accordance with UNI/TS 11300-2, the value of $\theta_{er,i}$ has been assumed to be 40 °C. For θ_0, the monthly mean daily outdoor air temperature values for the considered location, Lecce, as reported in Table 4, have been used. Based on these data and applying equation (29), the thermal energy demand to meet the domestic hot water needs of the building has been calculated and is presented in Table 38.

Table 38. **Thermal energy demand for domestic hot water production**

	G days	$\theta_{er,i}$ ° C	θ_0 ° C	$Q_{W,i}$ kWh
January	31	40	9,0	187,9
February	28	40	9,3	168,1
March	31	40	11,4	173,4
April	30	40	14,7	148,4
May	31	40	18,9	127,9
June	30	40	23,4	97,4
July	31	40	26,1	84,3
August	31	40	25,9	85,5
September	30	40	23,0	99,7
October	31	40	18,5	130,3
November	30	40	14,3	150,8
December	31	40	10,7	177,6
			Q_w (kWh) =	**1631,5**

In calculating the thermal energy demand for domestic hot water, the efficiency of the installed boiler η must also be considered. Consequently, the required energy is determined by the following relation:

$Q_W' = QW / \eta$ [kWh] (30)

Since the efficiency of the installed boiler at home is 90% (Roca RS-20/20F), equation (30) becomes:

Q_W' = (1631,5 / 0,90) kWh = 1812,8 kWh.

3.3 Transport sector energy consumption analysis

This section aims to analyze the energy consumption associated with the use of family vehicles. The Table 39 provides the technical specifications of the vehicles in use, while Table 40 highlights their operational data.

Table 39. **Technical specifications of the vehicles**

	Year	Displacement cm^3	Fuel	Tank capacity l	Power kW	Mass kg	Fuel consumption l/100km
Renault Clio II	2002	1460	Diesel	50	60	1535	8,8
Opel Astra H	2006	1686	Diesel	52	74	1855	6,3

Based on the reported data, the full-tank range, that is, the number of kilometers traveled with a full tank, can be calculated using the following formula:

Full-tank range = tank capacity / (fuel consumption / 100) [km / full-tank] (31)

where:
tank capacity: usable volume of fuel available in the vehicle's tank [l];
fuel consumption: vehicle's fuel consumption in liters per 100 km [l / 100 km].

Result:
Renault Clio II Full-tank range: 50 / (8,8 / 100) km / full-tank = 568 km / full-tank
Opel Astra H Full-tank range: 52 / (6,3 / 100) km / full-tank = 825 km / full-tank

Table 40. **Operational data of the vehicles**

	Total mileage km	Average annual mileage km/year
Renault Clio II	173775	1864
Opel Astra H	235741	4223

Energy available in a full fuel-tank and energy consumption

The energy available in a vehicle's fuel tank represents the amount of chemical energy stored in the fuel that can be converted into mechanical energy to power the vehicle, considering the engine's efficiency. The formula to calculate it is:

$E_{fft} = Vol \times \rho \times LHV \times \eta$ [kWh / full tank] (32)

where:
Vol: tank capacity [m^3];
ρ: fuel density [kg/m^3];
LHV: lower heating value of the fuel [kWh/kg];
η: engine efficiency.

Recalling that both vehicles are diesel-powered, the results are presented in the Table 41, using equation (32).

Table 41. **Energy available in the full fuel-tank**

	Vol m^3	ρ (Diesel) kg/m^3	LHV (Diesel) kWh/kg	η (Diesel engine)	E_{fft} kWh / full tank
Renault Clio II	0,050	835	11,8	0,25	123
Opel Astra H	0,052	835	11,8	0,25	128

The annual energy consumption of the vehicles can now be calculated as:

$E_{cons} = (E_{fft}$ / Full-tank range) × Avg. annual mileage [kWh / year] (33)

where:
E_{fft}: available energy in the full fuel tank [kWh / full tank];

full-tank range: number of kilometers traveled with a full tank [km / full tank];
avg. annual mileage: average annual distance traveled by the vehicle [km / year].

Result:
Renault Clio II annual energy consumption: (123 / 568) × 1864 [kWh / year] = 404 kWh / year
Opel Astra II annual energy consumption: (128 / 825) × 4223 [kWh / year] = 656 kWh / year

Annual expenses

Before proceeding with the calculation of the total annual expenses, shown in the Table 42, the annual fuel cost must be determined. This is done using the following formula:

Annual fuel cost = avg. fuel price × avg. annual mileage × (fuel consumption / 100) [€ / year] (34)

where:
avg. fuel price: average cost of fuel per liter, estimated at 1,638 €/l;
avg. annual mileage: average annual distance traveled by the vehicle [km / year];
fuel consumption: vehicle's fuel consumption in liters per 100 km [l / 100 km].

Result:
Renault Clio II annual fuel cost: (1,638 × 1864 × 8,8 / 100) [€ / year] = 268,68 € / year
Opel Astra II Annual fuel cost: (1,638 × 4223 × 6,3 / 100) [€ / year] = 435,79 € / year

Table 42. **Total annual expenses of the vehicles**

	Fuel money €/year	Insurance €/year	Car tax €/year	Testing €/2 years	Maintenance €/year	Annual total expenses €/year
Renault Clio II	268,68	350	165	80	150	974
Opel Astra H	435,79	360	195	80	250	1281

The unitary cost per kilometer is equal to:

c_u = Annual total expenses / Avg. annual mileage [€ / km] (35)

Result:
Renault Clio II c_u: (974 / 1864) € / km = 0,52 € / km
Opel Astra H c_u: (1281 / 4223) € / km = 0,30 € / km

4. PROPOSALS FOR IMPROVING THE ENERGY EFFICIENCY

This section presents and analyzes technical proposals to improve the energy efficiency of the building under audit. The evaluated solutions include interventions on the building envelope, such as the installation of external thermal insulation and the replacement of windows, aimed at reducing thermal losses. Additionally, renewable energy integration solutions are considered, such as the installation of photovoltaic panels and solar thermal panels, to reduce primary energy consumption and increase energy self-sufficiency. Finally, the adoption of a heat pump is evaluated, a technology capable of improving the efficiency of the heating system and domestic hot water production. These proposals will be analyzed in terms of technical feasibility, energy benefits, and, in the next chapter, potential economic savings.

4.1 Building envelope interventions

This section focuses on interventions aimed at reducing thermal losses through the building envelope. These improvements enhance the thermal insulation of the structure, thereby increasing overall energy efficiency and reducing heating demand. The proposed measures include the installation of external wall insulation and the replacement of inefficient windows, both of which are critical in minimizing heat transfer and improving indoor comfort.

4.1.1 External wall insulation

The installation of an External Wall Insulation (EWI) system on the external vertical walls exposed to the outdoor environment is a strategic solution to reduce heat losses. This approach is supported by the calculation of the direct heat transfer coefficient for transmission through opaque surfaces, as shown in Table 15, where the contribution of the external walls, identified by code M1, accounts for 73% of the total.
Table 43 presents the stratigraphy of the new external wall, identified by code M1', along with the calculation of the total thermal resistance and thermal transmittance.

Table 43. **Thermal Transmittance of the external wall after improvement**

Code: M1' – External wall (after improvement)				
N.	Layer description	s m	λ W/mK	R m²K/W
1	Lime plaster	0,010	0,90	0,011
2	Tuff block (mv. 1500)	0,250	0,63	0,397
3	Lime plaster	0,010	0,90	0,011
4	Extruded polystyrene insulation panel	0,120	0,035	3,429
5	Acrylic plaster	0,010	1,000	0,010
			Total Thermal Resistance (m²K/W) =	**3,858**
			Thermal Transmittance (W/m²K) =	**0,259**

The new thermal transmittance value, equal to 0,259 W/m²K, complies with the *Decreto 6 agosto 2020 - Requisiti tecnici per l'accesso alle detrazioni fiscali per la riqualificazione energetica degli edifici,* published in the Official Gazette of the Italian Republic. In fact, Allegato E of the decree specifies that, for vertical opaque surfaces in climate zone C, the maximum allowable thermal transmittance value to qualify for the deductions is 0,30 W/m²K after the intervention.
With the installation of external thermal insulation, the direct heat transfer coefficient to the external environment through opaque surfaces $H_{D,o}$ is significantly reduced, decreasing from 423,39 W/K (Table 15) to 148,28 W/K, with a percentage reduction of 65%. Consequently, the global heat transfer coefficient for transmission $H_{tr,adj}$ also decreases, from 1027,35 W/K to 752,24 W/K. Furthermore, the change in the wall composition affects solar heat contributions, as the new transmittance value directly impacts the effective solar capture area for opaque surfaces.

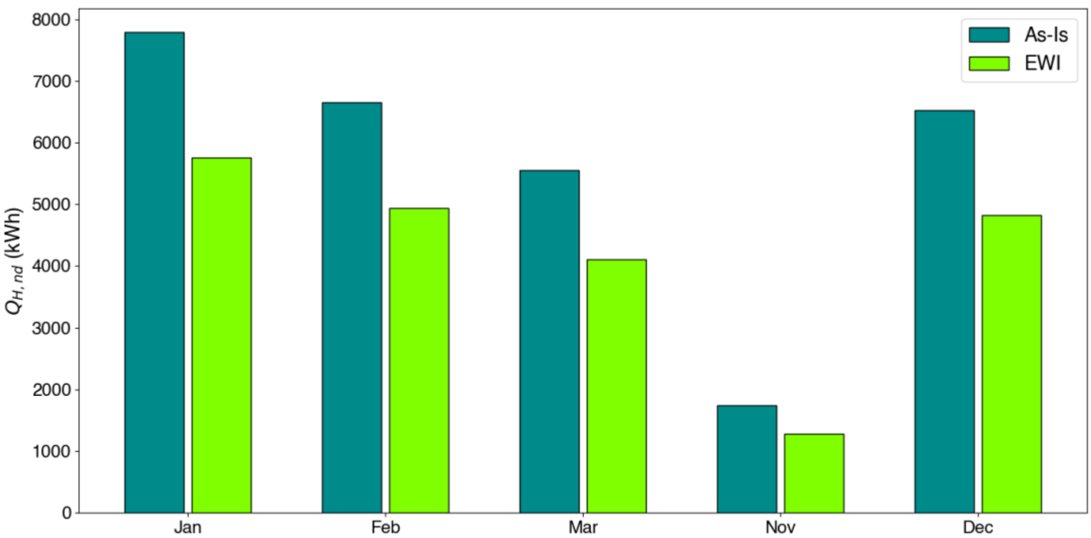
To highlight the overall impact of the external thermal insulation on the building's energy efficiency, Table 44 presents the data on the ideal thermal energy demand for heating, considering both heat losses and heat contributions.

Table 44. **Ideal thermal energy demand for heating: impact of external wall insulation**

	$Q_{H,ht}$ kWh	Q_{gn} kWh	$\eta_{H,gn}$	$Q_{H,nd}$ kWh
Jan	6513	785	0,956	5763
Feb	5723	837	0,943	4933
Mar	5092	1075	0,911	4113
Nov	1633	392	0,896	1282
Dec	5507	725	0,950	4818
Total (kWh) =	**24468**	**3813**		**20909**

Based on the data from Table 37 and Table 44, the Figure 9 illustrates the comparison of the ideal thermal energy demand between the current state and the state after the installation of the thermal insulation.
In aggregate terms, the energy demand decreased from $Q_{H,nd}$ = 28259 kWh to $Q_{H,nd}$ = 20909 kWh, corresponding to a 26% reduction.

Figure 9. **Comparison of ideal thermal energy demand: current state vs. post-insulation**



4.1.2 Windows replacement intervention

Similar to the intervention on the external thermal insulation, another proposal for the building envelope focuses on replacing the F2-type windows. Due to their old installation, these windows have excessively high thermal transmittance values, reaching 183 W/m²K, as shown in Table 19. Analyzing the data in Table 20, related to the calculation of the direct heat transfer coefficient for transmission through transparent surfaces $H_{D,f}$, it appears that 97% of the total 509,01 W/K is attributable to the two F2-type windows, which is a remarkably high value.
Therefore, Table 45 presents the proposed new stratigraphy for the F2 windows, identical to that of the F3 windows already installed in the building, which offer significantly better thermal performance compared to the F2 windows.

Table 45. **Thermal Transmittance of the glass and frame of the window after improvement**

Code: F2' – Window (after improvement)				
N.	Glass - Layer description	s m	λ W/mK	R m²K/W
1	Glass	0,004	1,000	0,004

2	Argon gas	0,016	0,017	0,952
3	Glass	0,004	1,000	0,004
			Total Thermal Resistance – Glass (m^2K/W) =	**0,960**
			Thermal Transmittance – Glass (W/m^2K) =	**1,041**

N.	Frame - Layer description	s m	λ W/mK	R m^2K/W
1	PVC	0,007	0,0145	0,48276
2	Aluminum reinforcement	0,002	209	0,00001
3	Air chamber	0,052	0,026	2,00000
4	Aluminum reinforcement	0,002	209	0,00001
5	PVC	0,007	0,0145	0,48276
			Total Thermal Resistance – Frame (m^2K/W) =	**2,966**
			Thermal Transmittance – Frame (W/m^2K) =	**0,337**

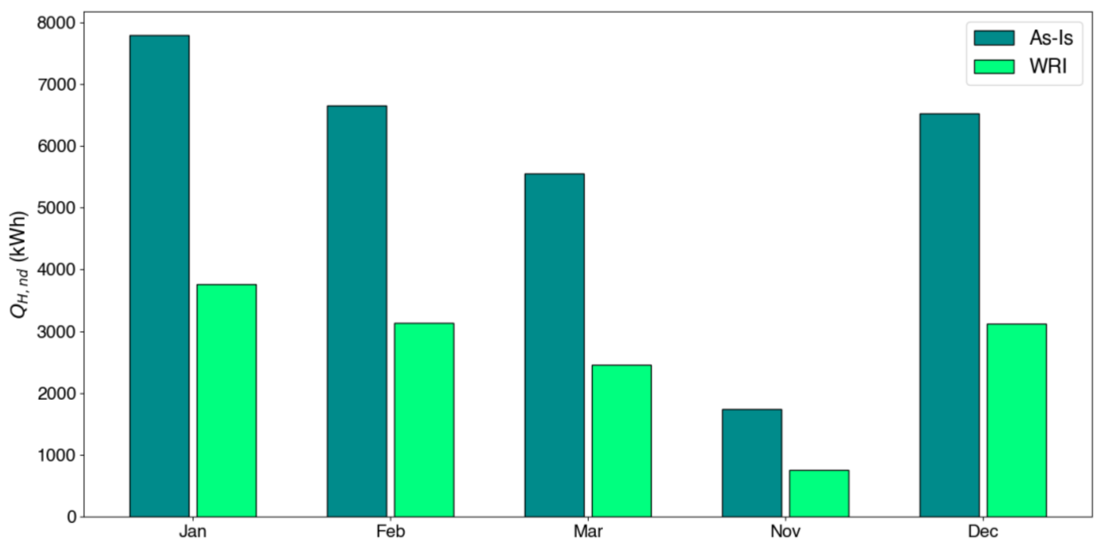
With this intervention, the thermal transmittance of the F2-type windows is reduced to 0,90 W/m^2K, according to equation (11). This value is fully compliant with Allegato E of the previously mentioned decree regarding external wall insulation, ensuring eligibility for tax deductions.
As a result, the direct heat transfer coefficient for transmission through transparent surfaces $H_{D,f}$ is significantly reduced, from 509,01 W/K to just 15,35 W/K, representing a 97% reduction. Similar to the external wall insulation, Table 46 presents the updated values of the ideal thermal energy demand for heating, highlighting how the replacement of this type of windows affects heat transfers, heat contributions, and consequently, the overall thermal energy demand of the building.

Table 46. **Ideal thermal energy demand for heating: impact of windows replacement intervention**

	$Q_{H,ht}$ kWh	Q_{gn} kWh	$\eta_{H,gn}$	$Q_{H,nd}$ kWh
Jan	4725	1036	0,927	3764
Feb	4151	1122	0,904	3137
Mar	3694	1452	0,846	2464
Nov	1185	518	0,826	757
Dec	3995	945	0,919	3126
Total (kWh) =	**17749**	**5074**		**13249**

Based on the data from Table 37 and Table 46, Figure 10 illustrates the comparison of the ideal thermal energy demand between the current state and the state after the installation of the thermal insulation.
In aggregate terms, the energy demand decreased from $Q_{H,nd}$ = 28259 kWh to $Q_{H,nd}$ = 13249 kWh, corresponding to a 53% reduction.

Figure 10. **Comparison of ideal thermal energy demand: current state vs. post windows replacement**



4.2 System upgrades for energy efficiency

This section addresses the optimization of building systems to improve energy efficiency through the integration of renewable energy sources and the enhancement of heating and hot water systems. The proposed upgrades include the installation of photovoltaic panels for electricity production, solar thermal panels to support domestic hot water needs, and a heat pump to increase the efficiency of heating. These measures aim to reduce primary energy consumption and reliance on non-renewable energy sources, contributing to a more sustainable and cost-effective energy system.

4.2.1 Photovoltaic panels

The installation of photovoltaic panels represents a key intervention for improving the building's energy efficiency by harnessing solar energy to generate electricity. This system allows for significant reductions in grid electricity consumption, promoting energy self-sufficiency.
The proposed improvement involves installing photovoltaic panels on the building’s terrace, which is spacious and free from significant obstacles. The modules will be positioned at a 30-degree tilt and oriented south to maximize energy efficiency. For the system sizing, Suntech STP540S-C72 photovoltaic panels were selected. These modules, made with monocrystalline technology and 144 cells, provide a high conversion efficiency of up to 20,9%. Each panel has a maximum nominal power of 540 W and a robust design, certified to withstand wind loads of up to 2400 Pascal and snow loads of up to 5400 Pascal. Additionally, the modules offer excellent performance under low light conditions, such as on cloudy days or at sunset, thereby enhancing overall energy production. Appendix A includes the complete technical datasheet of the selected panel, while Table 47 provides a summary of the key data extracted from the datasheet, useful for system sizing.

Table 47. **Key technical data of the photovoltaic panel**

Photovoltaic Panel: Suntech STP540S-C72					
b	h	Max. Power (STC)	Opt. Oper. Voltage	Opt. Oper. Current	η
mm	mm	W	V	A	
1134	2279	540	41,75	12,94	0,209

To calculate the electricity produced by a photovoltaic panel in a given period, the following formula is used:

$$E_{prod} = \eta \times H \times A \times d \text{ [kWh]} \quad (36)$$

where:
η: overall efficiency of the photovoltaic system, given by the product of the individual efficiencies of the panel and the inverter;
H: average value of the average daily solar irradiation on the panel’s surface for the reference period (month, year, quarter, etc.). It depends on climatic conditions and the tilt angle of the panel [kWh/m^2 /day];
A: area of the photovoltaic panel [m^2];
d: number of days in the reference period indicated for H (e.g., 30 for a month, 365 for a year).

Based on the inverse formula of the above equation (36), it is possible to determine the required capture area to meet the building's annual electricity demand. Specifically, by setting the panel's produced energy equal to the building's annual electricity consumption, equal to 1889 kWh as shown in Table 6, assuming an average annual value of the average daily solar irradiation equal to 4,48 kWh/m² (obtained from the average of the OR row data in Table 5), and initially considering only the efficiency of the photovoltaic panel, as indicated in Table 47, the required capture area is calculated to be:

A_{need} = 1889 / (0,209 × 4,48 × 365) m^2 = 5,53 m^2.

The number of panels can be calculated as:

$$\text{No. of panels} = \mathit{ceil}\,(A_{need} / A_{panel}) \quad (37)$$

where:
A_{need}: capture area needed to meet the energy demand [m²];
A_{panel}: area of a single photovoltaic panel [m²].

Result:
No. of panels: 5,53 / (1,134 × 2,279) = 2,14 → 3.

The three panels can be connected in series on a single string, as the voltage generated, equal to the product of the number of panels and the nominal voltage of each panel (41,75 Volts), amounts to 125,25 Volts. This value is significantly lower than the limit of approximately 230 Volts allowed by the domestic grid, thus ensuring system compatibility. Table 48 summarizes the characteristics of the photovoltaic system required to meet the annual electricity demand.

Table 48. **Photovoltaic system specifications**

No. of Lines	No. of panels per Line	No. of Panels	Total Area m^2	Total Power W
1	3	3	7,75	1620

For this system, the Growatt MIC 2000TL-X inverter was selected. This model is designed for residential photovoltaic systems and features a high efficiency of 97%. The inverter supports a nominal output power of 2000 W, with a maximum DC voltage of 500 V and an MPP voltage range between 50 V and 500 V, making it perfectly compatible with the proposed system. The maximum input current of the inverter is also compatible with the photovoltaic panel system (12.94 < 13 A). Appendix B contains the technical datasheet of the inverter. Based on equation (36), the energy produced by the entire photovoltaic panel system has been calculated and is shown in Table 49. The overall system efficiency η_{tot} was determined as the product of the panel efficiency, listed in Table 47, and the inverter efficiency, equal to 97%, resulting in a total value of 0,2027.
Regarding the value of H (average monthly global daily solar irradiation on an inclined surface), due to the limited granularity of the climatic data provided by the UNI 10349 standard, the ENEA database was used. The parameters set for the calculation are as follows:

municipality: Lequile;
azimuth: 00°00'00";
tilt angle: 30°00'00";
ground reflectance coef.: 0,22 (valid for aged concrete).

Table 49 also includes the energy consumption required by the building, extracted from Table 6 in Chapter 2. Based on these data, the difference between the energy produced by the photovoltaic panel system (E_{prod}) and the average monthly energy required by the building (E_{need}) can be calculated using the following equation:

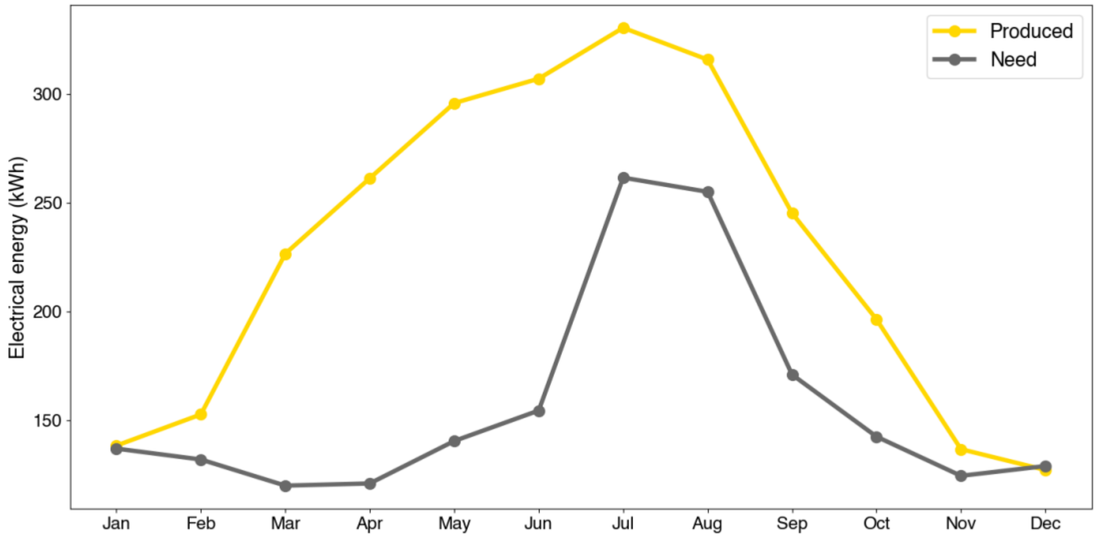
$$\Delta E = E_{prod} - E_{need} \text{ [kWh]} \quad (38)$$

Table 49. **Monthly energy balance between photovoltaic production and building demand**

	η_{tot}	H_{daily} kWh/m^2	d	$H_{monthly}$ kWh/m^2	Area m^2	$E_{produced}$ kWh	E_{needed} kWh	ΔE kWh
Jan	0,2027	2,84	31	88,04	7,75	138,38	137,00	1,38
Feb	0,2027	3,47	28	97,16	7,75	152,72	132,00	20,72
Mar	0,2027	4,65	31	144,15	7,75	226,57	120,00	106,57
Apr	0,2027	5,54	30	166,20	7,75	261,23	121,00	140,23
May	0,2027	6,07	31	188,17	7,75	295,77	140,50	155,27
Jun	0,2027	6,51	30	195,30	7,75	306,97	154,50	152,47
Jul	0,2027	6,78	31	210,18	7,75	330,36	261,50	68,86
Aug	0,2027	6,48	31	200,88	7,75	315,74	255,00	60,74
Sep	0,2027	5,20	30	156,00	7,75	245,20	171,00	74,20
Oct	0,2027	4,03	31	124,93	7,75	196,36	142,50	53,86
Nov	0,2027	2,90	30	87,00	7,75	136,75	124,50	12,25
Dec	0,2027	2,61	31	80,91	7,75	127,17	129,00	-1,83
Total (kWh):						**2733,23**	**1888,50**	**844,73**

Figure 11 graphically shows the data for electricity produced and electricity needed from Table 49.

Figure 11. **Comparison of monthly electricity production from photovoltaic panels and energy demand**



4.2.2 Solar thermal collector

The implementation of a solar thermal system represents a key intervention for improving the building's energy efficiency by harnessing solar energy to produce domestic hot water, thereby reducing reliance on traditional heating systems.
The project involves installing a natural circulation solar thermal system on the building's terrace, taking advantage of its ample space and favorable exposure. The selected system, the Riello CSNA 20 RS 200/1 model, combines a high-efficiency solar collector with an absorber treated with selective deposition to maximize heat capture, and an enameled storage tank with a 202-liter capacity, insulated with polyurethane to minimize heat losses. This system, free of pumps or electronic controls, relies on a natural convection mechanism, which allows the heat transfer fluid to circulate passively due to temperature gradients between the collector and the tank. The system will be installed at a 30-degree tilt and oriented south to optimize solar energy absorption. Additional details about the system's technical specifications are provided in Appendix C, while Table 50 summarizes the main data useful for sizing and performance analysis.

Table 50. **Key technical data of the solar thermal collector**

Solar thermal collector: Riello CSNA 20 RS 200/1				
Panel area m^2	η_0 (*)	a_1 (*) W/m^2K	a_2 (*) W/m^2K	η_{col} (**)
1,77	0,781	4,98	0,0005	0,579
(*) Based on a 33.3% water-glycol mixture, 160 l/h flow rate, and irradiance G = 800 W/m². (**) Calculated with a 40 K temperature difference between the collector and ambient air, under global irradiance of 1000 W/m².				

To calculate the thermal energy produced by a solar thermal collector over a given period, the same formula used for photovoltaic panels can be applied:

$$E_{prod} = \eta \times H \times A \times d \text{ [kWh]} \qquad (36)$$

where:
- η: efficiency of the solar thermal collector;
- H: average value of the average daily solar irradiation on the panel's surface for the reference period (month, year, quarter, etc.). This depends on climatic conditions, the collector's tilt angle, and orientation [kWh/m²/day];
- A: absorption area of the solar thermal collector [m²];
- d: number of days in the reference period indicated for H (e.g., 30 for a month, 365 for a year).

Following the same approach used for sizing photovoltaic panels, the required area for the solar thermal system can be calculated by applying the inverse formula of equation (36). In this case, the thermal energy to be produced is set equal to the energy consumed for domestic hot water over one year, which is 1631,5 kWh, as reported in Table 38. Additionally, an annual average daily solar irradiation value of 4,48 kWh/m²/day is considered, consistent with the methodology explained for photovoltaic panels. The calculation is expressed as follows:

A_{need} = 1632 / (0,579 × 4,48 × 365) m² = 1,72 m².

The number of solar thermal collectors can be calculated using equation (37):

No. of collectors: 1,72 / 1,77 = 0,97 → 1.

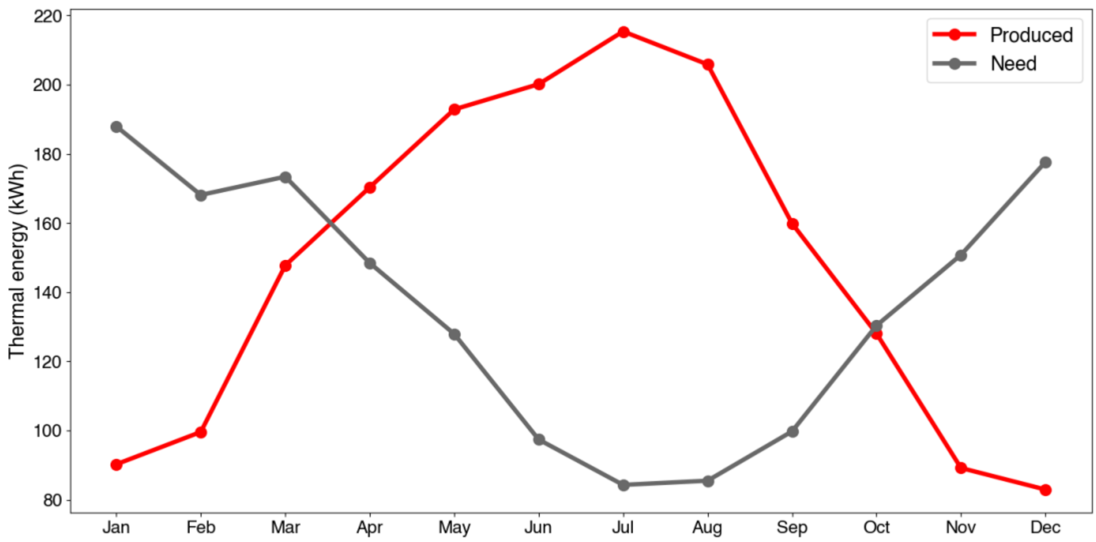
It is now possible to calculate the monthly energy produced by the solar thermal collector, once again using equation (36), in the same way as done for photovoltaic panels. For this calculation, the same monthly average solar irradiation values from the ENEA portal were used, as previously done for the photovoltaic system sizing. In this case, the term related to the energy need refers to the monthly energy required for domestic hot water production, calculated in Chapter 3 and presented in Table 38. Finally, the energy difference was calculated, representing the difference between the monthly thermal energy produced by the collector and the monthly energy demand to meet the hot water needs, as explained in equation (38). Table 51 presents the calculations performed, incorporating the monthly average solar irradiation values, the collector efficiency, and the monthly energy demand for domestic hot water.

Table 51. **Monthly energy balance between solar thermal production and domestic hot water demand**

	η	H_{daily} kWh/m²	d	$H_{monthly}$ kWh/m²	Area m²	$E_{produced}$ kWh	E_{needed} kWh	ΔE kWh
Jan	0,579	2,84	31	88,04	1,77	90,2	187,9	-97,7
Feb	0,579	3,47	28	97,16	1,77	99,6	168,1	-68,5
Mar	0,579	4,65	31	144,15	1,77	147,7	173,4	-25,7
Apr	0,579	5,54	30	166,20	1,77	170,3	148,4	21,9
May	0,579	6,07	31	188,17	1,77	192,8	127,9	64,9
Jun	0,579	6,51	30	195,30	1,77	200,1	97,4	102,8
Jul	0,579	6,78	31	210,18	1,77	215,4	84,3	131,1
Aug	0,579	6,48	31	200,88	1,77	205,9	85,5	120,4
Sep	0,579	5,20	30	156,00	1,77	159,9	99,7	60,1
Oct	0,579	4,03	31	124,93	1,77	128,0	130,3	-2,3
Nov	0,579	2,90	30	87,00	1,77	89,2	150,8	-61,6
Dec	0,579	2,61	31	80,91	1,77	82,9	177,6	-94,7
Total (kWh):						**1782,1**	**1631,5**	**150,6**

Figure 12 graphically shows the data for electricity produced and electricity needed from Table 51.

Figure 12. **Comparison of monthly thermal energy production from solar collector and energy demand**



4.2.3 Heat pump

The final proposed improvement involves the installation of a heat pump, a system that uses mechanical energy to transfer heat from a lower-temperature source to a higher-temperature destination, such as indoor spaces or a domestic hot water storage tank. The main advantage of heat pumps lies in their coefficient of performance (COP), which represents the ratio between the thermal energy supplied and the electrical energy consumed. A high COP allows for the generation of significantly more thermal energy compared to the electrical energy required, ensuring high energy efficiency. This technology therefore presents itself as an innovative and sustainable solution to optimize the building's energy balance.
To size the heat pump, that is, to determine its nominal power, the following formula is used:

$$P = E_{th,tot} \times (\theta_0 - \theta_{des}) / (DD \times HD) \text{ [kW]} \tag{39}$$

where:
$E_{th,tot}$: total thermal energy demand, calculated as:

$$E_{th,tot} = Q_{H,nd} + Q_W \text{ [kWh]} \tag{40}$$

where:
$Q_{H,nd}$: ideal thermal energy demand for heating [kWh];
Q_W: thermal energy demand for domestic hot water [kWh];

θ_0: indoor temperature, set at 20 °C;
θ_{des}: outdoor temperature, set at 0 °C
DD: degree days, relative to the building's climate zone [°C day];
HH: daily heating hours, relative to the building's climate zone [h day].

By calculating the total thermal energy demand based on the data previously presented in Table 37 and Table 38, respectively for the ideal thermal energy demand in the case of heating and for domestic hot water production, and noting that the values of DD and HD were already introduced in Chapter 1, it follows that, using equation (39):

$$P = [(28259 + 1631) \text{ kWh} \times (20 - 0) \text{ °C}] / (1059 \text{ °C day} \times 10 \text{ h/day}) = 56{,}45 \text{ kW}$$

This implies that, in the current state of the building, maintaining an indoor temperature of 20 °C throughout the winter season would require a heat pump with a nominal power of nearly 60 kW. However, considering that part of the thermal energy is recovered through the use of the fireplace, it is possible to recalculate the required nominal power by subtracting from the total thermal energy demand the share provided by firewood, which amounts to 11394 kWh per year, as detailed in Chapter 2.1.3. Therefore, equation (39) becomes:

$$P = [(28259 - 11394 + 1631) \text{ kWh} \times (20 - 0) \text{ °C}] / (1059 \text{ °C day} \times 10 \text{ h/day}) = 34{,}93 \text{ kW}$$

Even with this analysis, the required thermal power would exceed 30 kW, which poses a challenge regardless of the strategy adopted. Implementing the system with a single unit would be unfeasible, primarily because heat pumps of this capacity require a three-phase electrical network, which is not available in the building under audit. An alternative could be the installation of multiple heat pumps in a cascade configuration, selecting models whose combined thermal capacity meets the required demand. However, this solution also presents critical issues: the building's electrical system is limited to 3 kW, making it impossible to operate the heat pumps simultaneously. Even by selecting models with very high COP, the total electrical consumption would quickly approach this limit, thereby preventing the use of other appliances concurrently with the heat pumps. This scenario is therefore unacceptable.

5. ECONOMIC ANALYSIS

This chapter aims to evaluate the economic feasibility of the proposed improvements presented earlier, to assess their sustainability and economic impact over time. The economic analysis of the proposed improvements considers several factors to determine their feasibility and long-term convenience. These include the initial investment cost, potential periodic maintenance costs, tax deductions provided by government incentives, and the energy savings resulting from the intervention.
To assess the economic effectiveness of an intervention, several key performance indicators are used, including ROI, PBP, and NPV.

Regarding ROI (Return on Investment), it indicates the percentage of the initial investment that can be recovered each year through the savings generated and any incentives. It is calculated as:

$$ROI = (S + I - C_m) / C_0 \qquad (41)$$

where:
S: annual savings resulting from the intervention [€ / year];
I: annual incentives received [€ / year]:

$$I = (C_0 \times \%) / Years \qquad (42)$$

where:
%: percentage of the tax deduction offered;
Years: number of years over which the incentive is distributed;

C_m: annual maintenance costs required to maintain the effectiveness of the intervention [€ / year];
C_0: initial investment cost [€].

Regarding the PBP (Payback Period), it is calculated as the reciprocal of the ROI and indicates the number of years required to fully recover the initial investment through the savings generated and the incentives received. This indicator is useful for assessing how quickly a project becomes economically sustainable, providing an immediate reference for the time needed to recoup the invested capital.

$$PBP = 1 / ROI \qquad (43)$$

The NPV (Net Present Value) is an economic indicator that represents the sum of the expected cash flows from an investment, discounted to their present value using a discount rate. Unlike the PBP, which simply indicates the time required to recover the initial investment, the NPV takes into account the time value of money, providing a more accurate measure of a project's overall profitability. A positive NPV indicates that the project is economically advantageous, as the expected cash flows exceed the initial investment cost. A negative NPV, on the other hand, signals that the investment is not profitable, as it does not cover the total costs. The formula for calculating the NPV is:

$$NPV = \Sigma_k [CF_k / (1 + i)^k] [€] \qquad (44)$$

where:
CF_k: cash flow in year k [€];
i: discount rate, assumed to be 5% for all improvement proposals;
k: specific year in a project lasting n years.

Calculation of the unit cost for heating

To calculate the savings generated by the investment, it is essential to know the unit cost of both electricity and thermal energy. However, in the specific case of the audited building, firewood is also used as a source of thermal energy in addition to natural gas. In fact, heating is primarily provided by the wood-burning fireplace, with a secondary use of radiators powered by natural gas.
To determine the unit cost of thermal energy used exclusively for heating, expressed in €/kWh, a detailed analysis was conducted, taking both energy sources into account. This analysis allowed for the calculation of

a weighted average cost, based on the percentage of use of each source during the winter period. This provided a representative value for the unit cost of thermal energy used for heating.
Table 52 provides a detailed analysis of the radiators used for heating in the various rooms of the building, highlighting both the technical specifications, which are listed in Appendix D, and the daily operating parameters. Based on these data, the daily energy consumption of each radiator was calculated. The calculation is performed by multiplying the total power of the radiator (obtained as the product of the number of elements and the nominal power per element) by the daily hours of use. Table 53 presents the calculation of the annual energy required for heating through radiators, based on the daily data previously analyzed. The 136 days considered correspond to the period from November 15 to March 31, which marks the duration of the winter season for climate zone C.

Table 52. **Technical and operational data of radiators for daily energy calculation**

Radiator Model	No. of Elements	Nom. Power W/el	Hours of use h/day	Tot. Power W	Tot. Energy kWh
TEMA 4/871	14	137,5	2	1925	3,85
TEMA 5/871	5	165,8	2	829	1,66
TEMA 3/681	15	89,2	2	1338	2,68
				Total daily energy (kWh/day) =	**8,18**

Table 53. **Annual energy calculation for heating through radiators**

Daily Energy for Heating kWh/day	No. of Days (Winter Period) day/year	η	Annual Energy for Heating kWh/year
8,18	136	0,90	1237

Based on these data and those reported in Chapter 2.1.3 regarding firewood consumption, it is possible to estimate the unit cost of thermal energy used exclusively for heating, as shown in Table 54. The weighted cost of each energy source was calculated using the following formula:

Weighted cost = (energy used / total energy for heating) × unit cost [€] (45)

Table 54. **Heating unit cost**

Heating Source	Energy used kWh	Unit cost €/kWh	% of Use	Weighted cost €/kWh
Natural Gas	1237	0,134	0,10	0,013
Firewood	11394	0,025	0,90	0,022
Tot. Energy for Heating (kWh) =	**12631**			
			Heating Unit Cost (€/kWh) =	**0,035**

The unit costs used to calculate the savings are therefore presented again:

unit cost of electricity: 0,393 €/kWh;
unit cost of natural gas: 0,134 €/kWh;
heating unit cost: 0,035 €/kWh.

5.1 Economic analysis of improvements

5.1.1 Economic analysis of the external wall insulation installation

Before calculating the economic indicators used to evaluate the feasibility of the proposed improvement, it is necessary to determine the initial investment cost, denoted as C_0. The formula is:

$C_0 = C_m + C_l + C_s$ [€] (46)

where:
C_m: cost of materials [€ / m²];
C_l: labor cost [€ / m²];
C_s: scaffolding cost that covers the rental or installation of temporary structures required to enable work on the building's external surfaces [€ / m²].

To determine the material cost required for the installation of the external wall insulation, a website was consulted to retrieve the prices of the supplied products. The cost per square meter for each material was calculated using the following formula, while the results are shown in Table 55:

Cost per m^2 = Unit Cost × Qty per m^2 = (Cost / Qty sold) × Qty per m^2 [€ / m^2] (47)

where:
Cost: product price provided by the supplier [€];
Qty sold: unit in which the product is sold by the supplier (e.g., a 25 kg bag of adhesive) [-];
Qty per m^2: amount of material required to cover one square meter of external wall insulation, according to the technical specifications provided by the manufacturer [- / m^2].

Table 55. **Material costs for external wall insulation** [1]

Material	Cost €	Qty sold	-	Unit Cost €/-	Qty per m² -/m²	Cost per m² €/m²
Extruded Polystyrene Panels	49,82	2,25	m2	22,14	1	22,14
Adhesive / Smoothing Compound	16,78	25	kg	0,67	8	5,37
Pigmented Fixative	111,15	12,5	l	8,89	0,1	0,89
Fiberglass Mesh	4,03	25	m2	0,16	1,1	0,18
Dowels - 190 mm	0,61	1	pz	0,61	5	3,05
Plaster	70,27	24	kg	2,93	2	5,86
					Total material cost (€/m²) =	**37,48**

Table *56* shows the calculation of the initial investment costs, performed using equation (46) and considering, as stated in Table 2, that the external area to be insulated is 123,17 m².

Table 56. **Calculation of initial investment costs for external wall insulation**

Material cost €/m²	Labour cost [2] €/m²	Scaffolding cost [2] €/m²	Area m²	Initial Investment Cost €
37,48	25,00	8,00	123,17	**8682**

The formula to calculate the annual savings generated by the installation of the external wall insulation system is as follows:

$S = (Q_{H,nd\ AS\text{-}IS} - Q_{H,nd\ EWI}) \times$ Heating unit cost [€] (48)

where:
$Q_{H,nd\ AS\text{-}IS}$: thermal energy demand for heating in the current state, without insulation [kWh];
$Q_{H,nd\ EWI}$: thermal energy demand for heating after the installation of the external insulation system [kWh];

[1] www.puntoiso.it
[2] www.casa.top

Heat. unit cost: unit cost of thermal energy for heating [€/kWh].

Taking the data from Table 37 and Table 44, equation (48) becomes:

S = (28259 - 20909) × 0,035 €/year = 259,52 €/year

In 2025, for the installation of external wall insulation, the Italian government provides a tax incentive in the form of a 50% deduction on the initial investment cost, spread over a period of 10 years [3]. Thus, using equation (42), the annual incentives are equal to:

I = (8682 × 0,50) / 10 = 434,09 €/year.

Therefore, assuming routine maintenance every 5 years with a cost estimated at 2% of the initial investment cost (thus C_m = 173,64 €), the ROI and PBP can be calculated based on equations (41) and (43). In addition, Table 57 presents the NPV calculation, based on equation (44).

ROI = [259,52 + 434,09 – (173,64 / 5)] / 8682 = 0,0759 = 7,59 %
PBP = 1 / 0,0759 = 13,18

Table 57. **NPV calculation for external wall insulation**

t	C_0 €	C_m €	S €	I €	CF_t €	$(1+i)^t$	$CF_t/(1+i)^t$ €	NPV_t €
0	8681,84	0,00	0,00	0,00	-8681,84	1,00	-8681,84	-8681,84
1	0,00	0,00	259,52	434,09	693,61	1,05	660,58	-8021,26
2	0,00	0,00	259,52	434,09	693,61	1,10	629,13	-7392,13
3	0,00	0,00	259,52	434,09	693,61	1,16	599,17	-6792,96
4	0,00	0,00	259,52	434,09	693,61	1,22	570,64	-6222,33
5	0,00	173,64	259,52	434,09	519,97	1,28	407,41	-5814,91
6	0,00	0,00	259,52	434,09	693,61	1,34	517,58	-5297,33
7	0,00	0,00	259,52	434,09	693,61	1,41	492,94	-4804,39
8	0,00	0,00	259,52	434,09	693,61	1,48	469,46	-4334,93
9	0,00	0,00	259,52	434,09	693,61	1,55	447,11	-3887,82
10	0,00	173,64	259,52	434,09	519,97	1,63	319,22	-3568,60

5.1.2 Economic analysis of window replacement intervention

The economic analysis of the proposal to replace the two windows follows the same methodological approach used for the thermal insulation. In this case as well, both material costs and labor costs for installation have been considered to provide a comprehensive estimate of the required investment. Reference values for the analysis were obtained by consulting various online sources, allowing for an average market cost estimate for this type of intervention. The results of the analysis are summarized in Table 58. Information on the area of the windows can be found in Table 3.

Table 58. **Calculation of initial investment costs for windows replacement intervention**

Material cost [4] €/m^2	Installation cost [5] €/window	Area m^2	No. of windows	Initial Investment Cost €
505,48	450	2,70	2	2264,79

The annual savings can be calculated in the same way as was done for the thermal insulation, using equation (48). The data used for this calculation are taken from Table 37 and Table 46.

S = (28259 – 13249) × 0,035 €/year = 530,03 €/year

[3] www.studiomadera.it
[4] www.infissiepersiane.it, www.sceglierеinfissi.it and www.puntosicurezzacasa.it.
[5] www.ernesto.it.

For the replacement of windows, the Italian government has introduced an incentive known as the Ecobonus 2025 [6], similar to the one available for external wall insulation. The incentive consists of a 50% tax deduction on the initial investment cost, spread over a period of 10 years. Equation (42) is used to calculate them:

I = (2265 × 0,50) / 10 = 113,24 €/year.

Therefore, assuming routine maintenance every 2 years with a cost estimated at 2% of the initial investment cost (thus C_m = 45,30 €), the ROI and PBP can be calculated based on equations (41) and (43). In addition, presents the NPV calculation, based on equation (44).

ROI = [530,03 + 113,24 – (45,30 / 2)] / 2265 = 0,2740 = 27,40 %
PBP = 1 / 0,2740 = 3,65

Table 59. **NPV calculation for windows replacement intervention**

t	C_0 €	C_m €	S €	I €	CF_t €	$(1+i)^t$	$CF_t/(1+i)^t$ €	NPV_t €
0	2264,79	0,00	0,00	0,00	-2264,79	1,00	-2264,79	-2264,79
1	0,00	0,00	530,0	113,2	643,27	1,05	612,64	-1652,15
2	0,00	45,30	530,0	113,2	597,97	1,10	542,38	-1109,78
3	0,00	0,00	530,0	113,2	643,27	1,16	555,68	-554,10
4	0,00	45,30	530,0	113,2	597,97	1,22	491,95	-62,15
5	0,00	0,00	530,0	113,2	643,27	1,28	504,02	441,87
6	0,00	45,30	530,0	113,2	597,97	1,34	446,22	888,09
7	0,00	0,00	530,0	113,2	643,27	1,41	457,16	1345,24
8	0,00	45,30	530,0	113,2	597,97	1,48	404,73	1749,97
9	0,00	0,00	530,0	113,2	643,27	1,55	414,66	2164,63
10	0,00	45,30	530,0	113,2	597,97	1,63	367,10	2531,73

5.1.3 Economic analysis of the photovoltaic panel installation intervention

The economic analysis of the proposal to install photovoltaic panels aims to evaluate the financial feasibility of the intervention by calculating both the initial costs and the savings and incentives resulting from the investment. Table 62 presents the calculation of the initial investment cost, which includes the costs of photovoltaic panels (SUNTECH STP540S-C72/Vmh), the inverter (GROWATT MIC 2000TL-X), and installation, estimated based on the average market prices obtained from online sources, with the calculations previously reported in Table 60 and Table 61.

Table 60. **Calculation of photovoltaic system material cost**

Panel cost [7] € / panel	Inverter cost [8] €	No. of panels	Total materials cost €
255,74	415,53	3	1182,75

Table 61. **Calculation of photovoltaic system installation costs [9]**

Mounting system € / panel	Manpower €	Transport €	No. of panels	Total installation cost €
150	2000	350	3	2800

Table 62. **Calculation of initial investment costs of the photovoltaic system**

Total materials cost €	Total installation cost €	Initial Investment Cost €
1182,75	2800	**3982,75**

[6] www.diemmeinfissi.com
[7] www.solarenergypoint.it
[8] www.solarenergypoint.it
[9] www.instapro.it

To calculate the savings resulting from the installation of photovoltaic panels, a specific method is used, which is unique to this type of system. In particular, in addition to the energy produced and directly used to meet the building's demand, the surplus energy is sold to the national electricity grid. The savings are calculated as:

$$S = C_{el,AS\text{-}IS} - C_{el,PPS} \text{ [€]} \quad (49)$$

where:

$C_{el,AS\text{-}IS}$: current annual cost of electricity, without improvements [€];

$C_{el,PPS}$: projected annual cost of electricity after the installation of the photovoltaic panel system [€], calculated as:

$$C_{el,PPS} = (E_{bought} \times C_{el,u}) - (E_{sold} \times PUN) \text{ [€]} \quad (50)$$

where:

E_{bought}: annual amount of electricity that needs to be purchased [kWh/year];

E_{sold}: annual amount of electricity sold to the national grid [kWh/year];

$C_{el,u}$: unit cost of electricity [€/kWh];

PUN: Prezzo Unico Nazionale, which represents the average market price of electricity in the national wholesale electricity market [€/kWh].

Table 63 presents the calculation of the energy purchased and the energy sold to the national electricity grid, based on the data previously reported in Table 49.

Table 63. **Calculation of electricity bought and sold with photovoltaic system**

	$E_{produced}$ kWh	E_{needed} kWh	ΔE kWh	E_{sold} kWh	E_{bought} kWh
Jan	138,38	137,00	1,38	1,38	/
Feb	152,72	132,00	20,72	20,72	/
Mar	226,57	120,00	106,57	106,57	/
Apr	261,23	121,00	140,23	140,23	/
May	295,77	140,50	155,27	155,27	/
Jun	306,97	154,50	152,47	152,47	/
Jul	330,36	261,50	68,86	68,86	/
Aug	315,74	255,00	60,74	60,74	/
Sep	245,20	171,00	74,20	74,20	/
Oct	196,36	142,50	53,86	53,86	/
Nov	136,75	124,50	12,25	12,25	/
Dec	127,17	129,00	-1,83	/	1,83
Total (kWh/year) =	**2733,23**	**1888,50**	**844,73**	**846,56**	**1,83**

Furthermore, recalling that the current annual cost of electricity for the building is 741,89 €, as shown in Table 6, that the unit cost of electricity is equal to 0,393 €/kWh and that the average PUN for January 2025 is 0,142 € [10], according to the GME (Gestore Mercati Energetici), the annual savings can be calculated using equations (49) and (50):

$$S = 741{,}89 \text{ €} - [(1{,}83 \times 0{,}393) - (846{,}56 \times 0{,}142)] \text{ €} = 861{,}39 \text{ €}$$

A specific incentive, known as Bonus Fotovoltaico 2025 [11], is also available for the installation of photovoltaic panels, similar to the one provided for window replacement. The incentive consists of a 50% tax deduction on the initial investment cost, spread over 10 years. The calculation of the incentives is performed using equation (42).

$$I = (3982{,}75 \times 0{,}50) / 10 = 199{,}14 \text{ €/year.}$$

Assuming annual maintenance costs of 200 €/year [12], it is possible to calculate the economic performance indicators of the intervention, such as the Return on Investment (ROI), the Payback Period (PBP), and the Net Present Value, as shown in Table 64, using equations (41), (43), and (44).

[10] www.mercatoelettrico.org
[11] www.ambraconsulting.net.
[12] www.instapro.it

ROI = (861,39 + 199,14 – 200) / 3982,75 = 0,2160 = 21,60 %
PBP = 1 / 0,2160 = 4,63.

Table 64. **NPV calculation for photovoltaic system installation intervention**

t	C_0 €	C_m €	S €	I €	CF_t €	$(1+i)^t$	$CF_t/(1+i)^t$ €	NPV_t €
0	3982,75	0,00	0,00	0,00	-3982,75	1,00	-3982,75	-3982,75
1	0,00	200,00	861,39	199,14	860,52	1,05	819,55	-3163,20
2	0,00	200,00	861,39	199,14	860,52	1,10	780,52	-2382,68
3	0,00	200,00	861,39	199,14	860,52	1,16	743,35	-1639,33
4	0,00	200,00	861,39	199,14	860,52	1,22	707,95	-931,38
5	0,00	200,00	861,39	199,14	860,52	1,28	674,24	-257,13
6	0,00	200,00	861,39	199,14	860,52	1,34	642,14	385,00
7	0,00	200,00	861,39	199,14	860,52	1,41	611,56	996,56
8	0,00	200,00	861,39	199,14	860,52	1,48	582,44	1579,00
9	0,00	200,00	861,39	199,14	860,52	1,55	554,70	2133,70
10	0,00	200,00	861,39	199,14	860,52	1,63	528,29	2661,98

5.1.4 Economic analysis of the solar thermal panel installation intervention

The economic analysis of the proposal to install solar thermal panels follows the same methodological approach used for the other improvement solutions, considering the initial investment costs, annual energy savings, and available incentives. Table 65 shows the cost of materials (Riello CSNA 20 RS 200/1), Table 66 presents the installation costs, while Table 67 outlines the total investment costs.

Table 65. **Calculation of thermal solar panel system material cost**

Panel cost [13] € / panel	No. of panels	Total materials cost €
1000	1	1000

Table 66. **Calculation of thermal solar panel system installation costs**

Manpower cost [14] € / m^2	Panel area m^2	Total installation cost €
600	1,77	1062

Table 67. **Calculation of initial investment costs of the thermal solar panel system**

Total materials cost €	Total installation cost €	Initial Investment Cost €
1000	1062	**2062**

The savings in the case of solar thermal panel installation interventions are calculated as follows:

$$S = C_{dhw,AS\text{-}IS} - C_{dhw,STPS} \ [€] \quad (51)$$

where:

$C_{dhw,AS\text{-}IS}$: current annual cost of domestic hot water production, without improvements [€], calculated as:

$$C_{dhw,AS\text{-}IS} = Q_W' \times C_{ng,u} \ [€] \quad (52)$$

where:

Q_W': thermal energy to meet the annual domestic hot water needs of the building [kWh];

[13] www.climatuo.it
[14] www.nextville.it

$C_{ng,u}$: unit cost of natural gas [€/kWh];

$C_{dhw,STPS}$: projected annual cost of domestic hot water production after the installation of the solar thermal panel system [€], calculated as:

$$C_{dhw,STPS} = E_{bought} \times C_{ng,u} \ [€] \tag{53}$$

where:
E_{bought}: annual thermal energy required for domestic hot water production that is not supplied by the solar thermal panel [kWh];
$C_{ng,u}$: unit cost of natural gas [€/kWh].

Table 68 presents the calculation of the energy bought, based on the data previously reported in Table 51.

Table 68. **Calculation of energy bought with solar thermal panel**

	E_{needed} kWh	$E_{produced}$ kWh	ΔE kWh	E_{bought} kWh
Jan	187,94	90,23	-97,72	97,72
Feb	168,11	99,57	-68,54	68,54
Mar	173,39	147,73	-25,66	25,66
Apr	148,44	170,33	21,89	/
May	127,92	192,84	64,92	/
Jun	97,39	200,15	102,75	/
Jul	84,27	215,40	131,13	/
Aug	85,48	205,87	120,38	/
Sep	99,74	159,87	60,13	/
Oct	130,35	128,03	-2,32	2,32
Nov	150,79	89,16	-61,63	61,63
Dec	177,64	82,92	-94,72	94,72
Total (kWh) =	**1631,48**	**1782,10**	**150,62**	**350,58**

Recalling that the unit cost of natural gas is 0,134 €/kWh, the annual savings can be calculated using equation (51):

S = (1812,75 – 350,58) kWh × 0,134 € / kWh = 196,30 €.

The installation of solar thermal panels benefits from the Ecobonus 2025 [15] incentives, which include the same provisions as the other interventions. Specifically, these incentives provide a 50% tax deduction on the initial investment cost, distributed over a period of 10 years. The calculation of the incentives is performed using equation (42).

I = (2062 × 0,50) / 10 = 103,10 €/year.

Assuming a maintenance cost equal to 2,5% of the initial investment per year [16] (C_m = 51,55 €)., it is possible to calculate the economic performance indicators of the intervention, such as the Return on Investment, the Payback Period, and the Net Present Value, as shown in Table 69, using equations (41), (43), and (44).

ROI = (196,30 + 103,10 – 51,55) / 2062 = 0,1202 = 12,02 %
PBP = 1 / 0,1202 = 8,32.

Table 69. **NPV calculation for thermal solar panel installation intervention**

t	C_0 €	C_m €	S €	I €	CF_t €	$(1+i)^t$	$CF_t/(1+i)^t$ €	NPV_t €
0	2062,00	0,00	0,00	0,00	-2062,00	1,00	-2062,00	-2062,00
1	0,00	51,55	196,30	103,10	247,85	1,05	236,04	-1825,96
2	0,00	51,55	196,30	103,10	247,85	1,10	224,80	-1601,15
3	0,00	51,55	196,30	103,10	247,85	1,16	214,10	-1387,05
4	0,00	51,55	196,30	103,10	247,85	1,22	203,90	-1183,15
5	0,00	51,55	196,30	103,10	247,85	1,28	194,19	-988,96

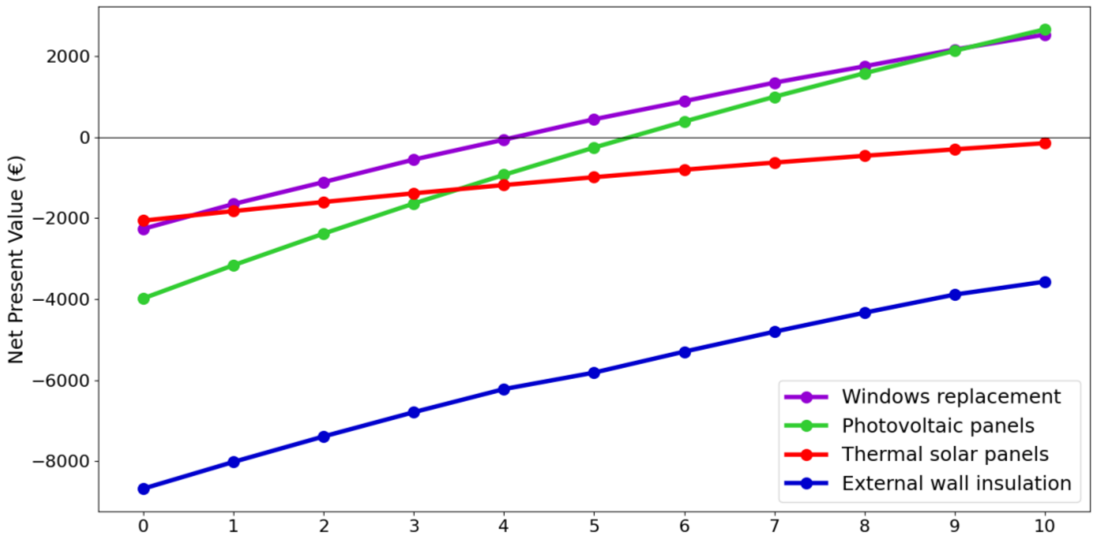
[15] www.studiomadera.it
[16] www.nextville.it

6	0,00	51,55	196,30	103,10	247,85	1,34	184,95	-804,01
7	0,00	51,55	196,30	103,10	247,85	1,41	176,14	-627,87
8	0,00	51,55	196,30	103,10	247,85	1,48	167,75	-460,12
9	0,00	51,55	196,30	103,10	247,85	1,55	159,76	-300,36
10	0,00	51,55	196,30	103,10	247,85	1,63	152,16	-148,20

5.2 Final comparison of improvement proposals

As part of this energy audit, several solutions to improve the energy efficiency of the building were evaluated, such as the installation of a thermal coat, replacement of windows, installation of photovoltaic panels and solar thermal panels. When comparing the different improvement proposals, only the net present value (NPV) was used. The reason for this is that ROI does not take into account the time-varying value of money, meaning that it does not consider the effect of the temporality of cash flows. In contrast, the NPV includes this variable, discounting future cash flows at the appropriate interest rate, and thus provides a more accurate assessment of the long-term profitability of an investment. A positive NPV indicates that the intervention will generate added value compared to the initial investment, while a negative NPV indicates a loss. Figure 13 shows the evolution of the Net Present Value (NPV) over time for each of the four energy improvement proposals considered. The data used to construct the graph are shown in Table 57 (external wall insulation), Table 59 (windows replacement intervention), Table 64 (photovoltaic panels system) and Table 69 (thermal solar panels system). The analysis was carried out over a 10-year time horizon, as after this period the expected state incentives expire, significantly affecting the profitability of the investments. From a graphical point of view, this would result in a change of slope of the curves that would further delay the achievement of the break-even point.

Figure 13. **NPV comparison of improvement proposals**



Based on the data shown in Figure 13, a ranking of the improvement proposals can be made, from most to least profitable:

1. windows replacement intervention;
2. photovoltaic panels system;
3. thermal solar panels system;
4. external wall insulation.

The window replacement intervention emerges as the most cost-effective among the analyzed solutions. This result is primarily due to the obsolescence of the existing windows, which are characterized by extremely high thermal transmittance values, leading to significant thermal energy losses. Such inefficiency significantly increases the ideal thermal energy demand, making this intervention particularly advantageous from both an energy and economic perspective. The installation of photovoltaic panels is another compelling proposal, offering the dual benefit of reducing the need to purchase electricity and selling excess energy back to the grid at the Prezzo Unico Nazionale (PUN). This mechanism allows for significant savings and enhances the investment's profitability. Regarding the installation of solar thermal panels, the economic analysis reveals that the initial investment cannot be fully recovered within the ten-year period, although the generated savings approach the initial cost. Finally, the installation of external wall insulation proves to be the least cost-effective intervention. While this measure reduces energy demand, the high initial investment cost is not offset by the achievable energy savings in the medium term, making this solution less economically viable.

APPENDIX A – Technical datasheet of the photovoltaic panel

SUNTECH

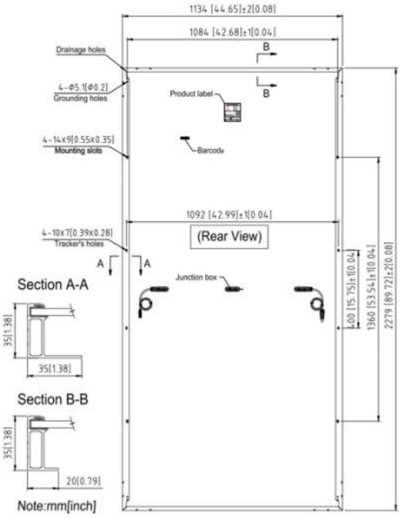
Electrical Characteristics

STC	STPXXXS-C72/Vmh				
Maximum Power at STC (Pmax)	550W	545W	540W	535W	530W
Optimum Operating Voltage (Vmp)	42.05V	41.87V	41.75V	41.57V	41.39V
Optimum Operating Current (Imp)	13.08A	13.02A	12.94A	12.87A	12.81A
Open Circuit Voltage (Voc)	49.88V	49.69V	49.54V	49.39V	49.24V
Short Circuit Current (Isc)	14.01A	13.96A	13.89A	13.83A	13.76A
Module Efficiency	21.3%	21.1%	20.9%	20.7%	20.5%
Operating Module Temperature	-40 °C to +85 °C				
Maximum System Voltage	1500 V DC (IEC)				
Maximum Series Fuse Rating	25 A				
Power Tolerance	0/+5 W				

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Tolerance of Pmax is within +/- 3% ;
For tracker installation, please turn to Suntech for mechanical load information.

NMOT	STPXXXS-C72/Vmh				
Maximum Power at NMOT (Pmax)	415.0W	411.5W	408.0W	404.3W	400.6W
Optimum Operating Voltage (Vmp)	38.9V	38.7V	38.6V	38.4V	38.2V
Optimum Operating Current (Imp)	10.67A	10.63A	10.58A	10.53A	10.47A
Open Circuit Voltage (Voc)	46.9V	46.7V	46.5V	46.4V	46.3V
Short Circuit Current (Isc)	11.22A	11.18A	11.13A	11.08A	11.02A

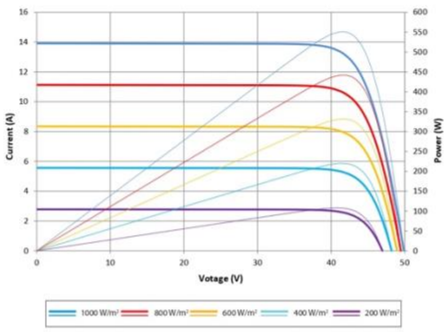
NMOT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s.



Temperature Characteristics

Nominal Module Operating Temperature (**NMOT**)	42 ± 2 °C
Temperature Coefficient of Pmax	-0.36%/°C
Temperature Coefficient of Voc	-0.304%/°C
Temperature Coefficient of Isc	0.050%/°C

Current-Voltage & Power-Voltage Curve (550S)



Mechanical Characteristics

Solar Cell	Monocrystalline silicon 182 mm
No. of Cells	144 (6 × 24)
Dimensions	2279 × 1134 × 35 mm (89.7 × 44.6 × 1.4 inches)
Weight	29.1 kgs (64.2 lbs.)
Front Glass	3.2 mm (0.126 inches)
Frame	Anodized aluminium alloy
Junction Box	IP68 rated (3 bypass diodes)
Output Cables	4.0 mm², Portrait: (-) 350 mm and (+) 160 mm in length Landscape : (-)1 400 mm and (+) 1400 mm in length or customized length
Connectors	MC4 EVO2, Cable 01S

Dealer information

Packing Configuration

Container	40' HC
Pieces per pallet	31
Pallets per container	20
Pieces per container	620
Packaging box dimensions	2310×1130×1245 mm
Packaging box weight	965 kg

Information on how to install and operate this product is available in the installation instruction. All values indicated in this data sheet are subject to change without prior announcement. The specifications may vary slightly. All specifications are in accordance with standard EN 50380. Color differences of the modules relative to the figures as well as discolorations of/in the modules which do not impair their proper functioning are possible and do not constitute a deviation from the specification.

 www.suntech-power.com IEC-STP-Ultra-V-NO1.01-Rev 2021

APPENDIX B – Technical datasheet of the inverter

GROWATT · PRODOTTI

Datasheet	MIC 750TL-X	MIC 1000TL-X	MIC 1500TL-X	MIC 2000TL-X	MIC 2500TL-X	MIC 3000TL-X	MIC 3300TL-X
Parametri d'ingresso (DC)							
Potenza FV massima raccomandata (per moduli STC)	1050W	1400W	2100W	2800W	3500W	4200W	4290W
Massima tensione DC	500V	500V	500V	500V	550V	550V	550V
Tensione di attivazione (V Start)	50V	50V	50V	50V	80V	80V	80V
Tensione nominale	120V	180V	250V	360V	360V	360V	360V
Intervallo di tensione MPP	50V-500V	50V-500V	50V-500V	50V-500V	65V-550V	65V-550V	65V-550V
No. di inseguitori MPP (MPPT)	1						
No. di Stringhe per MPPT	1						
Max. corrente di ingresso per MPPT	13A						
Max. corrente di cc per MPPT	16A						
Parametri d'uscita (AC)							
Potenza nominale AC	750W	1000W	1500W	2000W	2500W	3000W	3300W
Max. potenza apparente AC	750VA	1000VA	1500VA	2000VA	2500VA	3000VA	3300VA
Tensione nominale AC (range*)	230V (180-280V)						
Frequenza di rete AC (range*)	50/60 Hz (45-55Hz/55-65 Hz)						
Max. corrente di uscita	3.6A	4.8A	7.1A	9.5A	11.9A	14.3A	14.3A
Fattore di potenza configuurabile	0.8 in anticipo...0.8 in ritardo						
THDI	<3%						
Connessione di rete AC	Monofase						
Efficienza							
Efficiency massima	97.4%	97.4%	97.4%	97.4%	97.6%	97.6%	97.6%
Euro Efficienza	96.5%	96.5%	97.0%	97.0%	97.0%	97.1%	97.1%
Efficienza MPPT	99.9%						
Dispositivi di sicurezza							
Protezione inversione polarità DC	SI						
Sezionatore DC	SI						
Protezione sovratensione AC/DC	Tipo III / Tipo III						
Monitoraggio resistenza isolamento	SI						
Protezione cortocircuito AC	SI						
Rilevamento guasto di terra	SI						
Monitoraggio di rete	SI						
Protezione Anti-islanding	SI						
Monitoraggio corrente di fuga	SI						
Protezione archi elettrici (AFCI)	Opzionale						
Dati generali							
Dimensioni (L / A / P)	274/254/138mm						
Peso	6kg	6kg	6kg	6kg	6.2kg	6.2kg	6.2kg
Temperatura di esercizio	–25°C ... +60°C						
Consumo di potenza notturno	<0,5W						
Topologia	Senza trasformatore						
Sistema di raffreddamento	Convezione naturale						
Grado di protezione	IP65						
Umidità relativa	0-100%						
Altitudine	4000m						
Connettori DC	H4/MC4(Opzionale)						
Connessione AC	Connettore						
Display	OLED+LED/WIFI+APP						
Interfacce: RS485/USB/WIFI/GPRS/RF/LAN	Si/Si/Opzionale/Opzionale/Opzionale/Opzionale						
Garanzia:10 Anni	Si						

CE,AS4777, AS/NZS 3100, CEI 0-21, VDE-AR-N 4105, VDE 0126-1-1, UTE C 15-712-1, EN50549, IEC 60068, IEC 61683, IEC 62116, IEC 61727, INMETRO, G98, C10/C11, UNE217001, UNE206007, PO12.2

* L'intervallo di tensione e di frequenza AC può variare in funzione delle norme di Rete Elettrica locali.
Tutte le specifiche sono soggette a possibili modifiche senza preavviso.

APPENDIX C – Technical datasheet of the solar thermal panel

SOLARE TERMICO
Sistemi solari – Circolazione naturale

Sistemi CSNA 20 RS

DESCRIZIONE PRODOTTO

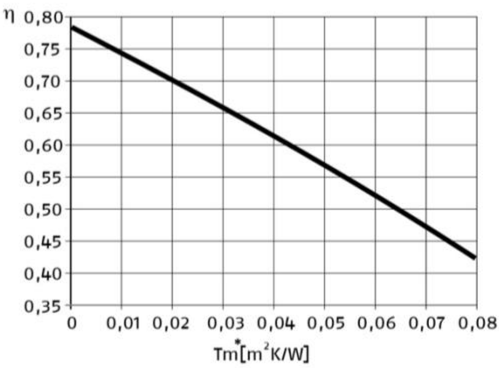
Soluzioni impiantistiche dedicate alla produzione di acqua calda sanitaria nelle utenze domestiche, anche in zone climatiche non particolarmente favorevoli (fino a 5 persone).
Si compongono di elementi preassemblati, non necessitano di pompa e controlli elettronici, garantendo così una semplice e rapida installazione.
La fornitura è composta da:
- collettore solare CSAL 20 RS, ad elevato rendimento, ben isolato, con assorbitore in alluminio trattato con deposizione selettiva
- bollitore smaltato, ad intercapedine con isolamento in poliuretano ed anodo in magnesio
- sistemi di fissaggio per installazione parallela al tetto o inclinata a 30° su superfici piane
- resistenza elettrica monofase integrativa (utilizzabile anche come antigelo) disponibile come accessorio
- liquido antigelo, atossico, biodegradabile e biocompatibile
- Sistema solare certificato secondo EN 12976

Garanzia di 5 anni sul sistema.

DATI TECNICI

SISTEMA SOLARE		CSNA 20 RS 150/1	CSNA 20 RS 200/1	CSNA 20 RS 220/2	CSNA 20 RS 300/2	CSNA 20 RS 300/3
Superficie collettore	m^2 x n° pannelli	1,91 x 1	1,91 x 1	1,91 x 2	1,91 x 2	1,91 x 3
Superficie di apertura	m^2 x n° pannelli	1,78 x 1	1,78 x 1	1,78 x 2	1,78 x 2	1,78 x 3
Superficie di assorbimento	m^2 x n° pannelli	1,77 x 1	1,77 x 1	1,77 x 2	1,77 x 2	1,77 x 3
Temperatura di stagnazione	°C	192	192	192	192	192
Capacità bollitore a intercapedine	l	153	202	223	278	278
Anodo in magnesio	Ø x mm	22 x 300	22 x 300	22 x 300	22 x 400	22 x 400
Contenuto liquido termovettore	l	8,5	13,6	16,3	20,3	22,2
Massimo carico vento e neve	Pa	1900	1900	1500	1900	1500
Pressione di intervento valvola circuito sanitario	bar	10	10	10	10	10
Pressione di intervento valvola circuito solare	bar	2,5	2,5	2,5	2,5	2,5

CURVA DI EFFICIENZA



La curva di potenza nominale è riferita a 800 W/m^2 mentre la potenza di picco viene calcolata da normativa con un irraggiamento di 1000 W/m^2

DESCRIZIONE	U/M	
Rendimento ottico all'assorbitore (ηo) (*)	%	0,781
Coefficiente di dispersione termica dell'assorbitore (a1) (*)	$W/(m^2K)$	4,98
Coefficiente di dispersione termica dell'assorbitore (a2) (*)	$W/(m^2K)$	0,0005
IAM (50°) (*)	-	0,87
Rendimento del collettore (hcol) (**)	%	0,579

(*) Valore riferito all'area di apertura. Test secondo EN 12975 riferito a miscela acqua-glicole al 33,3%, portata di 160 l/h e irraggiamento G = 800W/m^2.
Tm = (T_coll._ingresso+T_coll._uscita)/2
T*m = (Tm-T_ambiente)/G

(**) Calcolato ad una differenza di temperatura di 40K tra il collettore solare e l'aria ambiente circostante, con un irraggiamento solare globale, riferito all'area di apertura, di 1000 W/m^2.

APPENDIX D – Technical datasheet of the radiators

Serie:	**Bianco Tema**
Modelli:	**16**
Colore:	**Bianco "Ideal"**
Altezza:	**da 300 a 871 mm**
Larghezza:	**multipli di 60 mm**
Profondità:	**da 60 a 287mm**

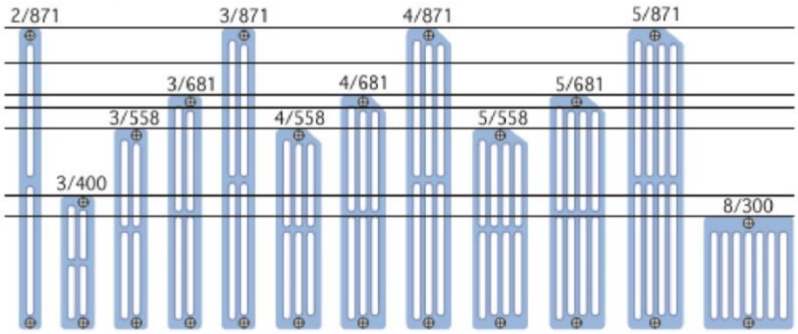
La rivoluzione del calore

TEMA nasce nel 1972 e con la sua forma innovativa a piastra frontale segna in modo definitivo l'evoluzione dei radiatori in ghisa.
Fin dal suo apparire sul mercato rivoluziona il modo di concepire il calorifero: la bellezza delle linee si fonde con le caratteristiche intrinseche della ghisa arrivando a un risultato davvero unico.
Il design razionalissimo che punta non solo all'estetica ma a massimizzare il rendimento del corpo scaldante segna il giusto equilibrio tra emissioni radianti e convettive.
TEMA è protagonista del riscaldamento, ma al tempo stesso sa anche mimetizzarsi con garbo, è di linea così attuale, sobria ed elegante, così senza tempo, che si adatta con naturalezza ad ogni soluzione di arredamento.
Più di trent'anni di ininterrotto successo fanno di TEMA il calorifero più venduto e più copiato al mondo.

Il calorifero su misura

È il radiatore TEMA fornito con preverniciatura di fondo bianco "Ideal" (due mani ad immersione), in batterie standard da 10 elementi.
Su richiesta è possibile avere batterie della larghezza desiderata.
Una comodità in più che consente di ridurre notevolmente il lavoro e i tempi di installazione.
TEMA è provato in stabilimento alla pressione di 10,5 bar, prima e dopo la lavorazione dei mozzi, ed è fornito per una pressione di esercizio di 7 bar. Approvato dai principali istituti europei, risponde alle norme EN 442-1/A1 e garantite dal marchio CE.
Batterie consegnabili in pallet su misura e con distinta per appartamento pronti per essere installati in cantiere.

Disegno quotato



Dati tecnici

MOD	ALTEZ mm	INTERASSE mm	PROF mm	LARGH mm	DIAM ATTAC pollici	CONT ACQUA litri/elem	MASSA kg/elem	UNI-EN 442 Δt 50° C W/elem	ESPON N°	N° COLONNE	SUP ELEM mq
TEMA 2-871	874	813	60	60	1"	0,71	5,00	81,7	1,300	2	0,25
TEMA 3-400	402	342	94	60	1"	0,52	3,78	55,8	1,327	3	0,15
TEMA 3-558	562	500	94	60	1"	0,73	4,80	76,2	1,313	3	0,21
TEMA 3-681	686	623	94	60	1"	0,80	5,70	89,2	1,304	3	0,26
TEMA 3-871	875	813	94	60	1"	1,00	6,80	109,2	1,289	3	0,33
TEMA 4-558	565	500	128	60	1"	0,82	5,80	93,4	1,299	4	0,27
TEMA 4-681	686	623	128	60	1"	0,97	7,00	112,1	1,336	4	0,33

TEMA 4-871	875	813	128	60	1"	1,21	8,62	137,5	1,331	4	0,42
TEMA 5-558	561	500	162	60	1"	1,03	7,35	113,7	1,311	5	0,34
TEMA 5-681	686	623	162	60	1"	1,18	9,00	136,1	1,321	5	0,40
TEMA 5-871	876	813	162	60	1"	1,43	11,00	165,8	1,323	5	0,50
TEMA 8-300	303	242	267	65	1"	1,14	6,70	103,0	1,326	8	0,29

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