Energy saving in typical architecture: The flow energy in traditional solutions in a sustainable perspective

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Energy saving in typical architecture: the flow energy in traditional solutions in a sustainable perspective

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Abstract. Quick urbanization increment causes a few difficult problems, such as social assessment, more energy demands, and pollution increase. A positive factor for a city is the concentration of energy requests. On the other hand, urbanization trend is going to fragmentation of settlements, with a consequent expansion of the energy distribution networks but also an increase of the energy wasted. Each building needs some of the total energy distributed in the city. Energy needs can be grouped into four essential parameters: construction, heating, electricity, and water. How were these four parameters satisfied in the XIX century, before the industrial revolution? In those days' energy requirement wasn't so high and could be supplied with basic energy production technology. The knowledge of appropriate building technology (project), the use of (energy saving) materials, with a low and punctual heating system (fireplace, stove) or passive refreshment all intervened in this process. These requirements were achieved in each country using building plans studied to face different weather conditions with different architectural typology and with human effort and time (work-energy). This paper analyses an energy balance in a single typical building in the center of Italy, describing the energy flow that will show the logical and technical solution for "energy-saving". Old buildings (before the introduction of "building-plant") were always designed and built with an energy-saving concern. This article wants to propose the study of a typical building in which are used only low-energy systems to meet all the comfort requirements, to demonstrate that it is not necessary to use high-energy technology. This is how architecture urbanization studies and implementation can be used to reduce high-energy production needs.

INTRODUCTION

Current trends of building research aim at collecting data for cover all the flows in the built environment [1] for monitoring and acting towards the satisfaction of comfort conditions [2] neglecting the attention paid by historical architecture to meet these needs without HVAC systems or active measures [3]. As a consequence, new buildings must achieve a high demanding target requiring a huge amount of technological plants and pushing the research & development towards innovative energy supply and use solutions [4]. The introduction of the system elements (heating, air conditioning, and electricity) in short time led to the planning and construction of a building without taking account of the thermoregulation element of the energy flows that cross it together with the indirect effect on other aspects such as acoustics [5, 6]. The development of bio-architecture and the urgent need for a low-energy solution, have made today the research for building with "thermo-regulation" element an important issue calling for passive behavior of the components for energy saving [7]. As a matter of fact, a great part of the building stock is and will be composed by the existing buildings, many of them built before any dedicated regulations [8], making challenging their alignment with sustainability [9]. Among the existing buildings, the traditional architecture, grown in relation to constructive climatic and technical characteristics of a place, is worth investigating [10]. In this article,

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the analysis of the energetic flows is carried out for a vernacular building. The architectural typology is located in the center-north of Italy, coping with a mild winter condition. The architectural and building physics concept of the house try to answer the challenges of the unfavorable conditions before the electrification event [11].

A book by L. Gambi [12] summarizes the architectural typologies, technical constructive and the distribution of the activities of such a case study. The calculation of Winter Dispersions is written up with a simplified method according to the law in force (Law 10/91 derivative from the EN832) [13].

DESCRIPTION OF THE CASE STUDY

The choice of the shack as historical typology has been made for its architectonic connotation and location in a territory without exceptional climate conditions.

Romagna (44°33, longitude 12°34) is an area situated in the center Italy, facing the Adriatic Sea. The land is mostly planned or with hills. Towards the south-east, there is the Apennines chain and the area extend sub to the hill.

The shack is in an area free from urbanization, far from the coastal tourist zone. The climate is mild, with maximum temperatures during the summer of approximately 24-25°C and the minimum ones in winter between -2° and -5°C with wind from North-West. The climatic parameters are defined by the Italian national standards Law 10/91 and UNI 10349 as follows.

TABLE 1. Climate conditions.

Climate Zone	E
Temperature	-2°C;-5°C
Period of Heating	183 Days
Wind velocity	2.3 m/s (North-West.)

This typology is depicted in Figure 1. The plans cover two levels. In the ground floor, the local legacies to the agricultural activity are found (stable for ovine, bovines and shelter tools). The southern façade is protected from a close arcade jutting out on 3 sides from which it is possible to approach the stairs leading to the first floor.

The porch and the stairs are two important thermoregulators elements of the rooms. The furnace for baking bread is found inside the porch. The wine cellar is found on the ground floor on the northern façade. The stairs link the living room and the kitchen where they use to prepare and have their meals. In these rooms is placed the fireplace. The flanking room had a warehouse function.

FIGURE 1. The shack

The two bedrooms are located in the southern part in order to take advantage during the nights of the thermal accumulation of the daily solar radiation. While, the hygienic services are located outside, in the courtyard.

From this description, it emerges that no HVAC systems were conceived and, subsequently, modern high-tech solutions for thermal management do not fit for it [14] while, detailed analysis and tailored derived design should be done for handling carefully this existing building and preserving its architectural features [15]. Furthermore, it is noteworthy that so simple design is often discussed in the literature as the one performing in operation conditions most closely to its design ones, properly connecting those two phases [16]. It entails that changes are required mainly when the new intended use is different from the designed one [17] rather than assuming it low performing as old.

The Materials and Thermophysical Structure Characteristics

The constructive techniques derive the availabilities of local material. Figure 2 shows the different plans. The ground is a cretaceous expansion; therefore, the soil is rich in clay. Tiles are the main element used for the construction of cottages. As the constructive system is known masonry and tiles with the natural stone were used. The bearing walls are built with tiles and malt and are realized with a scarf in an irregular way. The building structure behaves like a box, and therefore reduces the risks of seismic damages and thermal links of structural type.

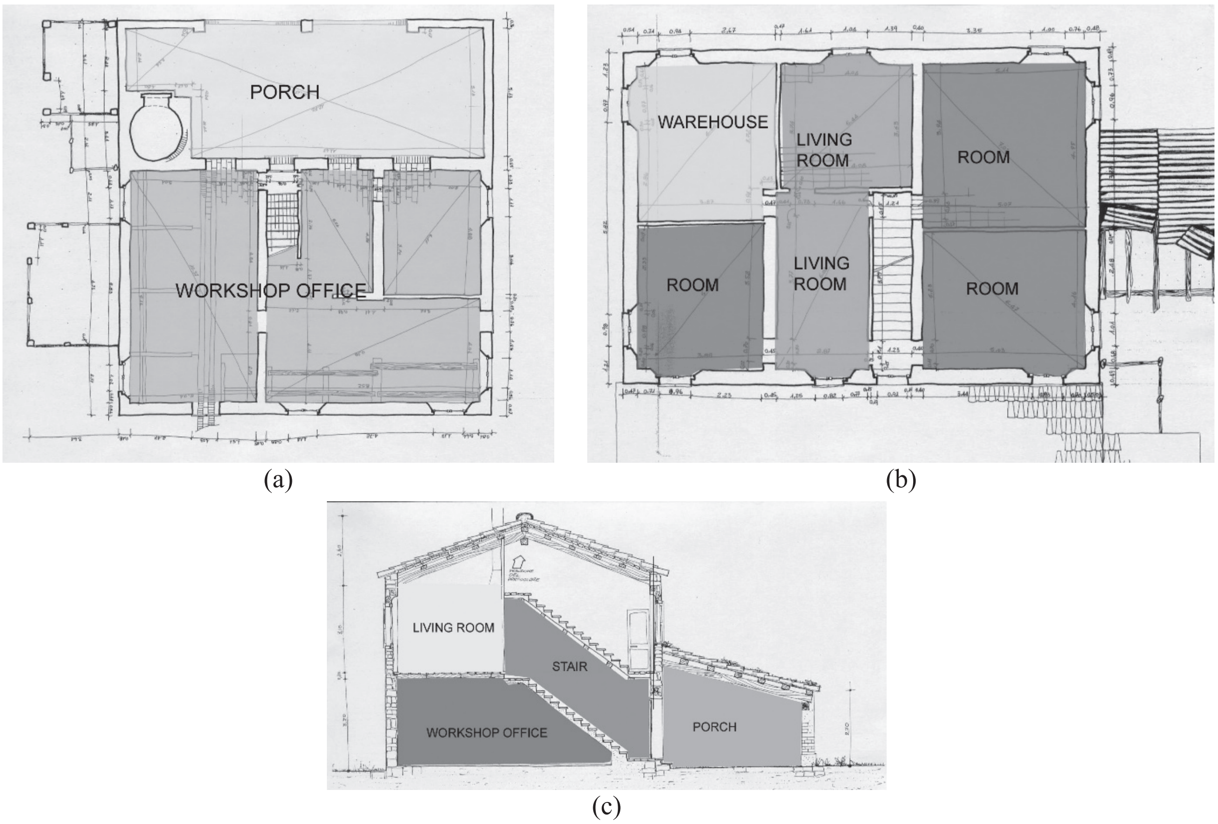

FIGURE 2. Plans (a, b) and sections (c) of the shack

The ground pavement is layered directly in contact with the ground. Attic between the first floor and the ground floor is realized with wooden bearing beams, rafters of connection and brick made of tiles, on which are the foundation and the pavement. The cover repeats the same structure of the attic, covered of a layer roof tile. The dimensions of windows and doors are small in order to reduce the cost of the glass. The openings in the mass building are obtained thanks to a wooden architrave.

CALCULATION OF THE HEAT LOSSES

The assumed temperature related to the different rooms accounting for their intended use is 16-18°C for laboratories, warehouse and stables, and 20°C for private houses during the winter with a relative humidity of 50-70%.

Calculation of the Thermal Dispersions in Winter time

In the winter period, the heating system is on for 183 days, in this climatic zone, where external Temperature of reference is -2°C. The same period of operation is assumed for the fireplace in the modeling [18].

From the technical literature and standard indications U=2.27 W/m^{2}C, but specifically, the U-value of the building façade was calculated following the UNI 10351/94, as reported in Table 2 and Equation 1.

TABLE 2. Transmittance and thickness: masonry.

Layer	Λ	Thickness
Plaster	0.70	0.03
Bricks	0.90	0.50 (density 2000Kg/m3)
Plaster	0.70	0.03

$$\frac{1}{\alpha_i + \sum_1^n \frac{S}{\lambda} + \alpha_e} = \frac{1}{\frac{1}{7.69} + \frac{0.03}{0.70} + \frac{0.5}{0.90} + \frac{0.03}{0.70} + \frac{1}{23}} = 1.2273 \left[{}^{W}/_{m^2K}\right] \quad (1)$$

where α_i= 1/7.69 [W/m^{2}K] and α_e=1/23 [W/m^{2}K].

FIGURE 3. bearing structure

Figure 3 shows the bearing structure. The attic is composed by the beam in wood + small beams in wood + tiles in brick + background + pave, excluding the wood like an insulating member. Table 3 reports the associated thermo-physical parameters. It is noteworthy that this wall structure has good performance in terms of indoor acoustics [19].

TABLE 3. Transmittance and thickness: wooden beam.

Layer	λ	Thickness
bricks- tiles in tile	0.90	0.08
Foundation pavement malt and sand (material lose to high density)	0.60	0.10
paves- tiles in tile-pavement	0.90	0.03

$$\frac{1}{\alpha_i + \sum_1^n \frac{S}{\lambda} + \alpha_e} = \frac{1}{\frac{1}{5.80} + \frac{0.08}{0.90} + \frac{0.10}{0.60} + \frac{0.03}{0.90} + \frac{1}{16}} = 1.9091 \left[{}^{W}/_{m^2k}\right] \quad (2)$$

With α_i= 1/5.80 [W/m^{2}K] and α_e=1/16 [W/m^{2}K] descendent flow.

TABLE 4. Transmittance and thickness: windows.

Layer	λ	Thickness	U	m^2
Glass	1.00	0.004	5.79	0.98 (Av)
Locking in fir	0.12	0.08	1.19	0.22 (As)

$$\frac{A_v \cdot U_v + A_s \cdot U_s}{A_v + A_s} = \frac{(0.94 \cdot 5.79) + (0.22 \cdot 1.19)}{0.98 + 0.22} = 4.9466 \setminus \left[{}^{W}/_{m^2K} \right] \quad (3)$$

Equation 2 reports the calculation of the U-value for the elements summarized in Table 3 while Equation 3 does for Table 4. Below, Figure 4 shows the windows present in the building.

FIGURE 4. Windows view

Finally, a wooden roof covers the structure and wooden flooring with ventilation and tiles. False ceiling with the *cannucciato* (false ceiling with river canes tied together and plastered) is not directly in contact with outside. Table 5 describes the values for the mentioned roof and Equation 4 gives the calculation result.

TABLE 5. Transmittance and thickness: wooden roof

Layer	λ	Thickness
inner cannucciato-flooring	0.15	0.02
Air	0.26	0.05
Flooring external wood (fir density 450 Kg/mc)	0.15	0.03
Tile	0.43	0.08

$$\frac{1}{\alpha_i + \sum_1^n \frac{s}{\lambda} + \alpha_e} = \frac{1}{\frac{1}{9.30} + \frac{0.02}{0.15} + \frac{0.05}{0.26} + \frac{0.03}{0.15} + \frac{0.08}{0.43} + \frac{1}{23}} = 1.1591 \left[{}^{W}/_{m^2K} \right] \quad (4)$$

With α_i= 1/9.30 W/m^{2}K] and α_e=1/23 [W/m^{2}K] ascendant flow.

Calculation of the Dispersions

In the calculation of the heat dispersions, the air exchange rate equal to 0.5 was considered, as from standard in force for dwellings but usually, in the shack, this value is probably not respected. The dispersions due to the thermal bridges (about 15%) are considered totally due to the bad connection between the walls. The external temperature is considered equal -5°C, as indicated by Italian law 10/91. Table 6 gives the values.

TABLE 6. Dispersions

Ventilation Heating volume m^3	**V/hour**	**cv (Wh/m^{3}K)**	**°t inside**	**°t outside**	**(Qv) (W)**
520.80	0.5	0.35	20	-5	**2278.50**
Opaque Surface	**A - Surface (m^2)**	**U (W/m^{2}K)**	**°t inside**	**°t outside**	**(Qo) (W)**
North wall	46.50	1.2273	20	-5	1,426.74
East wall	34.72	1.2273	20	-5	1,065.30
South wall	46.50	1.2273	20	-5	1,426.74
West wall	34.72	1.2273	20	-5	1,065.30
Attic-Pavement	168	1.9091	20	15	1,603.66
Roof	180	1.1591	20	-5	5,215.95
				total	**11,803.69**

TABLE 6. Dispersions continued

Windows	n.°	m²	°t inside	°t outside	(Qt) (W)
North wall	3	4.9466	20	-5	371.00
East wall	2	4.9466	20	-5	247.33
South wall	4	4.9466	20	-5	494.66
West wall	2	4.9466	20	-5	247.33
				total	**1,360.32**
Thermal links	15%				**2,325.43**
				Total dispersion	**17,767.94**

For the shack, the dispersions are equal to 17.77 kW. The dispersions are reduced thanks to the thickness of the mass building and to the small dimensions of the windows. It is a key passive measure to save energy costs [20].

SOLAR GAINS

The contribution to the thermal radiation of the walls is calculated by means of the "solar gain", crucial in the modeling phase [21]. The absence of solar radiation that hits one vertical wall (east, west, and south), as well as the number of hours of sun, the number of days in the month, are considered during the winter period. From the diagram of the solar distance, in relation to the hours of complete sunny days in the winter months of the facades, the value of the solar radiation towards the wall is obtained.

Heat Transmission

For the calculation of the solar gain method, the equivalent DTE temperature is required.

$$t_{em(equiv)} = \left(t_a + \frac{aI}{\alpha_e}\right) \tag{5}$$

where t_a and t_e are inside and outside temperatures in a winter day, respectively. I is the solar radiation (for one tilted flat wall of 90° equal to approximately 600 W/m^2 and to 1200 W/m^2 for one flat wall (cover); a is the absorption coefficient equal to 0.50 (clear color); α_e is the external unit adducting coefficient (43 W/m^{2}K) for the vertical wall. The temperatures t_a and t_e range between 10-12°C and 15-17°C, respectively. Therefore, an average value of 12°C has been considered.

$$DTE = (t_{int} - t_{em}) + \gamma(t_{em} - t_e) \tag{6}$$

$$Q_{guadsolare} = U \cdot A \cdot (DTE) \cdot hour \cdot sun\ irradiation \tag{7}$$

In the summer period, the method used in order to estimate the thermal dispersions and the specific gain does not involve the use of software but simplified methodologies are easily applicable. This methodology enables to use the same model of applications to various typologies and buildings. The winter period is available in Table 7.

The absence of solar radiance considers the thermal inertia of the building structure. The heat radiation during the day irradiates with a delay of approximately 8 hours (mass building in tile) and replaces the heat dispersed during night hours. From the calculation, it could be observed that the heat to supply given from the difference between the heat earned for the solar radiation in the period October-March and the dispersed heat, is 505.73 kWh per day, shown in Table 8.

The heat power of the fireplace corresponds to 6.56 kW (i.e. 28,657.92 kWh). The comparison between the earned and the dispersed heat in the winter period helps us to verify if the fireplace as a source of the thermal energy was enough or not, as in Figure 5.

TABLE 7. Winter period.

	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	TOTAL.
East Walls							
U	1.2273						
A	34.72						
hour sunny	3.50	2.50	2.00	2.50	3.50	4.50	
I irrad. W/m^2	600.00						
°t_{equiv}	18.98	18.98	18.98	18.98	18.98	18.98	
DTE	22.95	22.95	22.95	22.95	22.95	22.95	
Q (Wh)	3,423.32	2,445.23	1,956.18	2,445.23	3,423.31	4,401.40	18,094.68
South Walls							
	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	TOTAL.
U	1.2273						
A	46.60						
hour sunny	6.50	7.50	7.00	7.50	6.50	6.50	
I irrad. W/m^2	600.00						
°tequiv	18.98	18.98	18.98	18.98	18.98	18.98	
DTE	22.95	22.95	22.95	22.95	22.95	22.95	
Q (Wh)	8,532.94	9,845.70	9,189.32	9,845.70	8,532.94	8,532.94	54,479.54
West Walls							
	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	TOTAL.
U	1.2273						
A	34.72						
hour sunny	1.50	0.00	0.00	0.00	1.50	2.00	
I irrad. W/m^2	700.00						
°tequiv	20.14	20.14	20.14	20.14	20.14	20.14	
DTE	25.28	25.28	25.28	25.28	25.28	25.28	
Q (Wh)	1,615.78	0.00	0.00	0.00	1,615.78	2,154.38	5,385.94
Roof							
	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	TOTAL.
U	1.1591						
A	160.00						
hour sunny	11.50	9.50	8.50	9.50	11.50	12.00	62.50
I irrad. W/m^2	1,200.00						
°tequiv	25.95	25.95	25.95	25.95	25.95	25.95	
DTE	36.91	36.91	36.91	36.91	36.91	36.91	
Q (Wh)	78,713.1	65,023.8	58,179.2	65,023.9	78,713.1	82,135.4	427,788

TABLE 8. Comparison between the earned amount of heat thanks to the radiation and the dispersed heat Lost Heating =Q x hour Q not sunned to the solar day.

Total Solar Gain	OCT.	NOV.	DEC.	JAN.	FEB	MAR.	TOTAL.
kWh day	92,29	77,31	69,32	77,31	92,28	97,22	**505,73**
hours not sunned (day)	12,50	14,50	15,50	14,50	12,50	12,00	
Q_{lost}/day (kWh)	222,10	257,64	275,40	257,64	222,10	213,22	
Difference (kWh)	129,81	180,33	206,08	180,33	129,82	116,00	
day/month	31,00	30,00	31,00	31,00	28,00	31,00	182,00
Q_{gain}/month (kWh)	2.860,99	2.319,30	2.148,92	2.396,61	2.583,84	3.013,82	**15.323,48**
Q_{lost}/month (kWh)	6.885,08	7.729,05	8.537,50	7.986,69	6.218,78	6.609,67	**43.966,77**
Difference month (kWh)	4.024,09	5.409,75	6.388,58	5.590,08	3.634,94	3.595,85	**28.643,29**

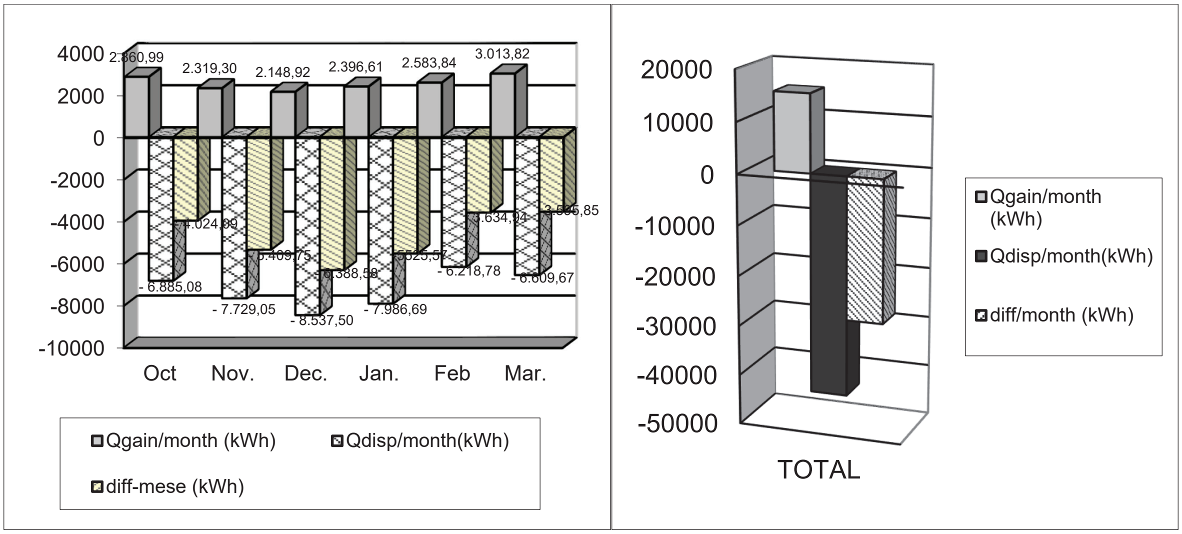

FIGURE 5. Gains and dispersions: Comparison

The Fireplace as Source of Traditional Energetic Production

The only source of active thermal energy in this building typology is the fireplace used also for cooking; therefore, it was also the only energetic source for the heating in the indoor environment. The heat of combustion of the firewood is ranging from 2,800 to 3,900 for the density of the firewood between 250 kg and 900 kg. Considering an average value of density of 550 kg/m^3 (pine or larch or oak) with a heat of combustion of 10,012 MJ/m^3, and the efficiency of the fireplace equal to 15% the firewood requirements become as in Equation 8 and 9:

$$\frac{energy - requirements\,\eta}{calorific - power\,\left({}^{MJ}/_{mc}\right)} = mc \cdot of \cdot wood \qquad (8)$$

for an equal energetic consumption to 28,657.92 kWh equal to 193,168.51 MJ, it is:

$$\frac{28{,}657.92 \cdot 0.15}{7{,}322} = 93.93\; mc\; wood \qquad (9)$$

which corresponds to 44,149.32 Kg_{wood}/year and 242.58 Kg_{wood}/day. This represents the consumption of compatible firewood with the agricultural activity of the time. Without considering the contribution of the sun we would have a consumption of 66,855.20 Kg_{wood}/year, corresponding to 367.34 Kg_{wood}/day, i.e. an energy saving of 66%. The efficiency of the fireplaces with modern technologies is greater and reaches up to 30-40% while, other technologies as wood stoves, have an even better result up to 80% of the wood burnt.

The fuel consumption with a more efficient system will have a further reduction.

$$\frac{28{,}657.92 \cdot 0.80}{7{,}322} = 17.61\; mc\; wood \qquad (10)$$

i.e. 8278 Kg_{wood}/year and 45.48 Kg_{wood}/day.

Other systems with different fuels (natural gases or LPG) have better efficiency in the reduction of consumption, but they have an emission of CO_2.

CONCLUSION

This study described the energetic behavior of a vernacular building in a mild climate. It can be said that not considering eventual dispersions due to infiltrations from the fixtures and the stairs, the dispersions of the structure are sufficiently compensated from the solar gain in the summer period. The fireplace typology as it was originally conceived succeeded alone to satisfy the parameters of comfort required even if this had low efficiency. Using various technological solutions other fuels (High-Energy) as methane or oils derives (LPG) the consumption is further reduced. The level of CO_2 emitted in the environment must be considered (beyond the system adaptation and of the infrastructural net in the gas methane option).

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