The project of nZEB school buildings: comparison among building technologies

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key words: school building, sustainability, energy efficiency

Abstract

An important part of the school building heritage in Italy is old. In fact, 55% of buildings were built before 1976 and are seriously inadequate both in relation to energy efficiency and other aspects such as seismic vulnerability and/or plant adaptation. 70% of the building stock consisting of school buildings was built for school intended use while the remaining 30% initially did not have this goal.

The aforementioned data were made known by MIUR and give the idea of a complex and difficult management situation. The Law of 13 July 2015 n. 107 on the reform of the national education system establishes, inter alia, the construction of 60 innovative schools from an architectural, plant, technological, energy efficiency and structural and seismic safety point of view. Furthermore, with this Law, the Fund for the functioning of state schools is increased by €123,9 million in 2016 and by €126 million annually from 2017 to 2021. In this complex framework concerning the scholastic context, but attributable also to buildings with other intended use, the contribution of this work is inseted. This contribution does not want to deal with the relationship between educational innovation, design flexibility and technological innovation, even if in the proposal of the case study it inevitably refers to the guidelines for school buildings recently prepared by the ministry, but wants to contribute to deepen the exclusively technological aspect referring to the problem of the comparison and the most appropriate choice among construction technologies. In fact, this work, through the case study of the design of a school complex consisting of a nursery school, a kindergarten and an elementary school, located in the Municipality of Nove (VI), aims to compare three different technological systems with the same functional-spatial solution. The analysis takes into account and compares a plurality of aspects such as energy performance, in accordance with the requirements for nZeb buildings, costs and construction time. The study involves the comparison of dry and non-dry technologies.

The orientation towards the use of one or other of the technological choices by the operators of the sector, represents a fundamental break for the different implications that the choice involves in relation to the construction process.

In the first case the building system consists of a reinforced concrete frame and brick masonry, in the second case of a dry system with a steel structure and in the third of a dry system with a wooden structure in Cross Laminated Timber panels (CLT) and lamellar beams.

The study highlights the different potentials and perspectives of these technologies with respect to the following three aspects: energy performances and emissions of CO_2 in the atmosphere, costs and time of construction. Also due to the crisis that has hit the building sector in recent years, particular interest and attention are placed on the part of operators to develop and optimize the construction process; for this purpose costs and time of construction play a central role and both are decisive factors for the sustainable relaunch of the sector. The study aims to make a contribution to operators in that sector so that they can make more informed and profitable choices in relation to the use and application of the technologies taken into consideration, in accordance with the European and national guidelines for the sustainable renewal of the building heritage and in particular of school buildings one.

1. INTRODUCTION

The first difficulty encountered in defining the status of Italian school building heritage is the availability of updated and complete reference data. The register of the school building heritage was presented for the first time at the press conference of the Ministry of Education, University and Research (in italian M.I.U.R.) of 7 August 2015.

Actually already in art. 7 of the law n. 23 of 1996 it was foreseen the obligation of the MIUR, in the frame of its own information system and with the collaboration of the interested local authorities, to realize and to take care of the updating of the national school building registry aimed at verifying consistency, situation and functionality of the school building heritage.

This register must be organized in regions and constitute the fundamental fact-finding tool for the purposes of the different planning levels of the interventions in the sector.

Currently, from the data reported in the document "School building Register" ("Anagrafe dell'Edilizia Scolastica" - M.I.U.R. 2015)[1] 42,292 buildings for school use are registered in the Italian territory, of which 33,825 are still active.

From the analysis of the distribution of school buildings in relation to the age group of construction, as reported in Table 1, it results that 55% of the buildings were built before 1976 and of these it results that 70% was built for school use while the remaining 29% has been adapted.

Table 1 - *School building breakdown by year of construction (M.I.U.R., school building register)*

Year of Construction	% on overall heritage
Before 1800	1%
Between 1800 and il 1899	3%
Between 1900 and il 1920	4%
Between 1921 and il 1945	8%
Between 1946 and il 1960	12%
Between 1961 and il 1975	27%
From 1976 onwards	32%
n.a.	14%

In the chart of Fig. 1 is shown the distribution of the school building with regard to the year of construction and the regions where they belong.

Moreover, other data in the same document show that in 77% of the cases the buildings are owned by the Municipalities, while in 9% they belong to the provinces.

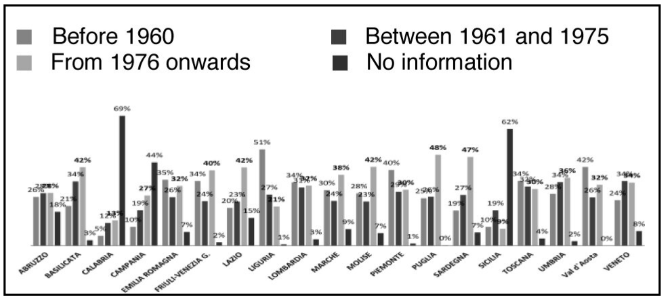

Figure 1 - *Regional distribution of buildings by year of construction age (M.I.U.R., school building register)*

Only 2% is attributable to other public bodies and equally to companies or private individuals.

The Registry also provides data on mobility, environmental sustainability and quality of the institute infrastructures (for example, in 63% of cases they have a school bus service and 40% of the transport service for disabled pupils). 71% of school buildings have taken steps to overcome architectural barriers (access by ramps, doors with a minimum width of 0.90 m or toilets for the disabled); while in 58% of the cases solutions were adopted to reduce energy consumption, for example with the zoning of the heating system (64%), double glazing (62%), solar panels (46%). As for security conditions, over 70% of schools have a risk assessment document (72%) and an emergency plan (73%). 39% are in possession of the certificate of conformity to standards.

In this regard, it should be remembered that 50% of the school buildings were built before 1971, the year of entry into force of the legislation that makes the static test certificate mandatory.

The conformity to standards therefore, must be compared with this datum and with the further obligations required by the current legislation.

If we take into account the quantitative data, related to the consistency of the school building heritage and we refer to the data present in the document drawn up by ENEA, with the in coordination with the Ministry of Economic Development, as part of the strategy for the energy requalification of the national building stock assets, STREPIN, related to the Italian building heritage park to non-residential destination, it emerges that 30% of these buildings is concentrated in 10 provinces (the first three are Rome, Milan and Naples) and over half (51%) is distributed in 24 provinces.

Approximately 29% are in municipalities of small demographic size (up to 5 thousand inhabitants), and as many in municipalities of medium-small size.

This document also shows that the area covered by school buildings represents 15% of the surface of non-residential buildings and is equal to 73,2 million m^2, corresponding to a volume of about 256,4 million m^3. Moreover, in the same survey, 27% of the school buildings are located in

[1] This document can be consulted at the following link: http://www.istruzione.it/edilizia_scolastica/anagrafe.shtml

the climatic zones A, B and C, 25% in the climatic zone D and the remaining 48% in the climatic zones E and F. To complete the framework of the state of the school building heritage we can refer to the document “School Ecosystem” (“Ecosistema Scuola”, Legambiente 2017), which deals with the theme of the quality and safety of buildings. The parameters of the research used concerned:

- master data and general information on buildings: year of construction; original intended use; buildings built according to green building criteria; buildings constructed with anti-seismic criteria;
- certifications, safety and maintenance: possession of safety certifications; diagnostic investigations; maintenance and investment needs in ordinary and extraordinary maintenance; access to national and regional funds for school buildings;
- energy efficiency and renewables: use of low energy consumption lighting sources; presence of renewable energy plants; energetic class;
- risk situations: indoor pollution (asbestos, radon) and related monitoring; electromagnetic risk and monitoring by high and low frequencies; exposure to sources of extended atmospheric, acoustic pollution, etc.).

The data of the dossier, made available by the educational institutions of the municipalities of the provincial Capitals, are related to 92 capital municipalities, to 6.029 school buildings and relate to the quality of school buildings, facilities and services. The survey then returns a photograph of kindergarten, primary and secondary schools, through indicators that intertwine the safety of school buildings with investment policies, the sustainability of buildings with the dissemination of good practices, risk factors environmental monitoring activities. Analyzing the parameters related to the safety referring to the years 2012-2016, it turns out that even if 41.6% of the buildings are located in areas with seismic risk, from the data shown in Table 2, it emerges that the buildings constructed with seismic criteria are only the 13,8%, and those according to the bio-construction criteria, the 0.8%. The seismic vulnerability assessment was carried out on 29,3% of the buildings. Significantly moderates the assessment performed on buildings placed in the municipalities in seismic area 1 and 2; the 36% against the 49,9% of the previous year. Finally, to complete the overall picture of the duties related to the regulatory adaptation, have to be taken into account the provisions of art. 4, paragraph 2 of the D.L. December 30th 2016, n. 244 coordinated with the Conversion Law 27/2/2017, n. 19 on “Extension and definition of terms” (so-called “Thousand-extension”).

In fact the deadline for adaptation to fire regulations for school buildings and premises used for schools, for which, on the date of entry into force of the decree, no the aforementioned adjustment has still been made, has been set to December 31, 2017 and not further extended. Finally, it is observed that the data referred to, coming from the

Table 2 - *Data related to buildings built according to safety criteria*

SAFETY	Year 2012*	Year 2013*	Year 2014*	Year 2015*	Year 2016*
Buidings built according to green building criteria	0,6%	0,6%	0,6%	0,7%	0,8%
Building built according to earthquake-proof criteria	8,8%	7,8%	8,7%	12,7%	13,8%
Buildings in which the seismic vulnerability assessment has been performed	27,3%	22,2%	25,1%	31,0%	29,3%
Buildings in which the seismic vulnerability assessment has been performed among municipalities at risk of earthquake (zone 1 and 2)	21,1%	14,3%	26,85%	49,9%	36,05%
** data reference year*					

various sources mentioned, are not all homogeneous and comparable, but they agree on some points, in particular on the age of the assets. From the analysis of the data of the various surveys, therefore, a complex and articulated picture emerges, photographing a situation as complex and complicated also by the overlapping of obligations to regulatory adjustments. This particular situation of the state of the school building heritage, suggests and indicates that before intervening on the existing, investing in safety and adaptation to regulations, as well as on energy requalification, technical-economic investigations should be carried out to assess the economic advantage of the intervention that also contemplate the possibility of implementing choices aimed at demolition and reconstruction in some cases.

2. THE SCHOOL BUILDING AS A MODEL OF SUSTAINABILITY

Answering to the appeal made by the teacher and pedagogue Franco Lorenzoni from the columns of the cultural supplement of the Sole 24Ore (2014) the arch. Renzo Piano has created a project for a sustainable and “shared" school that starts from the suburbs. The one conceived by Piano is a Montessori-inspired school, in which education takes place not only through words but also through the experiences that the child makes in the environment around him, which must therefore be rich and stimulating. The space is in fact understood by Piano[2] as "a constitutive part of the educational relationship" and the same Piano explains that its architectural model of ideal school is a sustainable school, which "is built lightly, in which resources are saved and the materials are chosen among those who have the property to regenerate in nature". A school built on three levels, earthquake-proof and made with wood material to ensure the sustainability of the project. The proposed school model is above all designed as a safe place that interacts with the surrounding territory.

From the constructive point of view the building is designed with wood material, low energy consumption and powered by renewable sources, where the geothermal energy is used for heating and cooling, while the electricity is produced by photovoltaic systems. In order to educate children and young people to respect nature and to save resources, the school itself must be an example of sustainability and a continuous opportunity for learning; then, in the interview that he gave, he said that it was necessary "to explain to them that the building that housed them did not cause deforestation but gave birth to a new forest, because for each cubic meter of wood used a new tree was planted". The choice made by Piano applies the criteria of sustainability in the design of a school building and identifies in the construction technology using wood the way to use renewable resources[3].

Is this choice an intuition or rather a fruit of experience? Is it possible to show that in comparison with other applicable technologies, does this choice fully realize a model of sustainable school construction?

The present work through the case study that is going to present seeks to give answers to this question.

3. THE CASE STUDY

The case study concerns the design of a school complex in the Municipality of Nove (VI), a town in the north-east of Italy (Fig. 2). The Municipality of Nove has a population of 5.038 inhabitants and is located in the flat area of the province of Vicenza.

The project proposal is an answer to a real need expressed by the City Council. In the presence of obsolete school buildings, in fact, assessed the high cost for upgrading existing buildings to the current requirements of seismic, energetic and spatial functional performance, the City Council decides the demolition of the same and the construction of a new school complex, providing that this uses the same grounds as the existing buildings and the adjacent undeveloped area. The area of intervention equal to 14.262,00 m^2, already allocated by the Municipal Master Plan to services for education, is located (Fig. 3 and 4) in a central position of the municipal area within a residential built area .

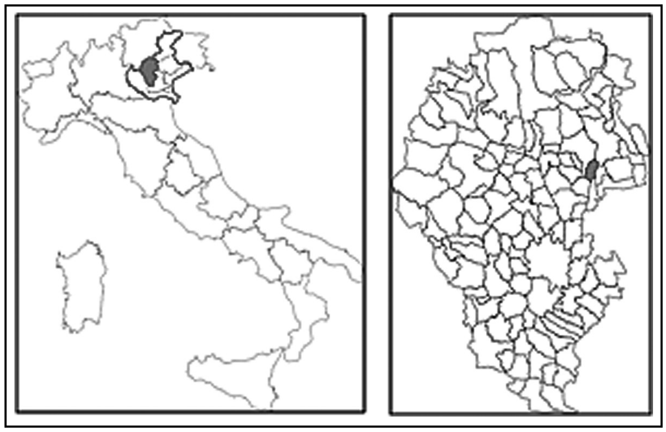

Figure 2 - *Identification of the Municipality of Nove in the province of Vicenza - Veneto region*

The feasibility study[4] prepared by the Municipal Technical Department on August 7, 2014, identifies the needs that the new school complex will have to meet and below described.

The school complex should consist of: nursery school, kindergarten school, primary school, canteen serving both schools, gym and auditorium both serving primary school and open to the local community. The nursery must contain 10 children (1 classroom), the relative toilets and ancillary rooms. It must be integrated into the kindergarten. That one must contain 150 children (6 classrooms), the relative toilets, a common room to be used as a play area, a canteen without kitchen and ancillary rooms. These spaces must be organized into a single floor. The primary school must contain 300 students (12 classrooms), 6 laboratories, relative toilets, canteen without kitchen, multipurpose room and ancillary rooms, small library and common rooms. The distribution of primary school spaces used as a classroom can be divided into two or three floors. The Gym must have

[2] Interview available at the following link:

http://www.ilsole24ore.com/art/notizie/2015-10-09/renzo-piano-ecco-mia-scuola-sostenibile-senza-corridoi-e-legno-antisismico--175841.shtml?uuid=ACIv7QDB

[3] V. Tarquini, Renzo Piano e "la scuola che farei": l'edilizia scolastica sarà sostenibile in: https://www.architetturaecosostenibile.it/argomenti/tag/renzo-piano/

[4] This study was drafted in accordance with the "technical-framework standards, containing the minimum and maximum indexes of urban planning, building, also with reference to the technologies in terms of efficiency and energy saving and production from renewable energy sources, and teaching essential to guarantee adequate and homogeneous reference design guidelines throughout Italy. "DM 11 April 2013: MIUR guidelines for designing school buildings.

Figure 3 - *Intervention zone (flight plane frame: "2010 Raven Asiago")*

Figure 4 - *Intervention zone cadastral extract*

an internal surface of not less than 400 square meters. It is also required that the design study meets the following requirements: a) allows a total space economy by optimizing the available resources, b) takes into account all the current legislation in school subjects, c) considers the ratio of new volumes to build with those of existing buildings so that the intervention can be configured as a total redevelopment of the area, d) that the technological systems are also optimized with the use of home automation systems in order to maximize the energy efficiency and management of the school complex, e) that the energy performance of the new complex falls into class A, f) that the canteen can be used by both nursery and primary schools while providing different shifts for use.

The design study foresees that the school complex consists of two distinct main blocks (Fig. 5), one for primary school and the other for nursery and kindergarten connected to each other through covered paths with the canteen placed in position such as to guarantee service to both school activities.

Figure 5 - *Roofing map*

The first block [1] includes the elementary school, the gym [1a], the canteen [1c] and the auditorium [1b] and a second block [2] includes the kindergarten school and the nursery school.

The parking (Fig. 6) used mainly by schools is provided in a central position between the two main blocks accessible only in one way direction from the east side of the parcel. A second parking lot is planned to the north of the parcel serving mainly the local community that uses the gym and the auditorium.

The pedestrian access to the complex can take place both on the east side and on the west side of the parcel, where there is already a cycle path that connects the area with the center of Nove.

The needs of the users and the environmental-climatic context have led to deepen the study, according to the principles of bioclimatic design, both on the optimal orientation of the volumes and the premises as well as on

Figure 6 - *Location of parkings and accesses*

Figure 7 - *Location of classrooms in red and laboratories in blue*

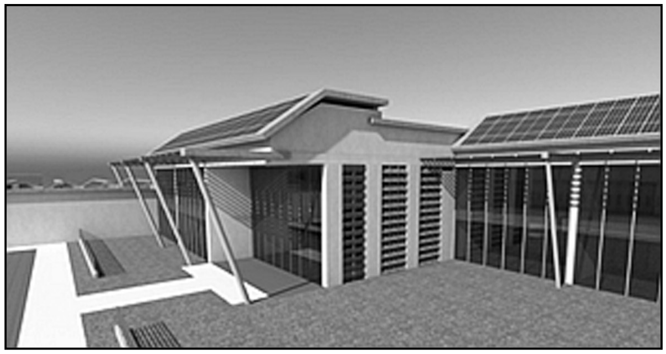

Figure 8 - *Lighting on 28th of february at 11:45*

Figure 9 - *Location of the gym*

Figure 10 - *Location of the canteen and the auditorium*

the best ratio of glazed surface on the opaque surface of the facades, so such as to be able to identify design choices that, exploiting the free solar energy supplies of the place, allow to achieve the goal of optimizing the energy efficiency of buildings, while ensuring the thermo-lighting and acoustic comfort.

The design strategy adopted is described as follows.

In order to maximize the free solar contributions thus reducing the winter air-conditioning requirements and at the same time benefiting from the contribution of the necessary natural lighting, the location of the classrooms, which are the most used rooms during the day, has been foreseen to the south side, the location of the laboratories, due to the heterogeneous activities that take place inside and their less use during the day, has been planned partly to the West (from that side in fact the direct light that it could provide excessive solar supplies, it is present only in the second half of the afternoon), and partly in the South (Fig. 7).

Furthermore, on the south side, buildings are equipped with shielding to guarantee optimal shading of the façade in the event of excessive radiation (Fig. 8).

The gym, having an internal project temperature for the winter equal to 18 °C and for the summer equal to 24 °C, lower than that of the other rooms, is located in the North/East. In this way, no excessive solar supply will occur which would decrease the efficiency of the air conditioning during the summer (Fig. 9).

The canteen, whose prevalent use is expected at midday and the auditorium whose prevailing use is expected in the evening, were arranged in the West (Fig. 10).

The auditorium, in fact, is mainly aimed at satisfying the need for habitual use of the local community.

This design choice allows the canteen to not receive excessive radiation during lunch; in fact during this period of use of the room, the position of the sun is high enough not to generate negative energy interference, and at the same time allows the auditorium to take advantage of the contributions of the solar radiation of the afternoon for the following evening use.

The distribution of the functional spaces envisaged in the project for the ground floor and the 1st floor is shown respectively in Fig. 11 and in Fig. 12.

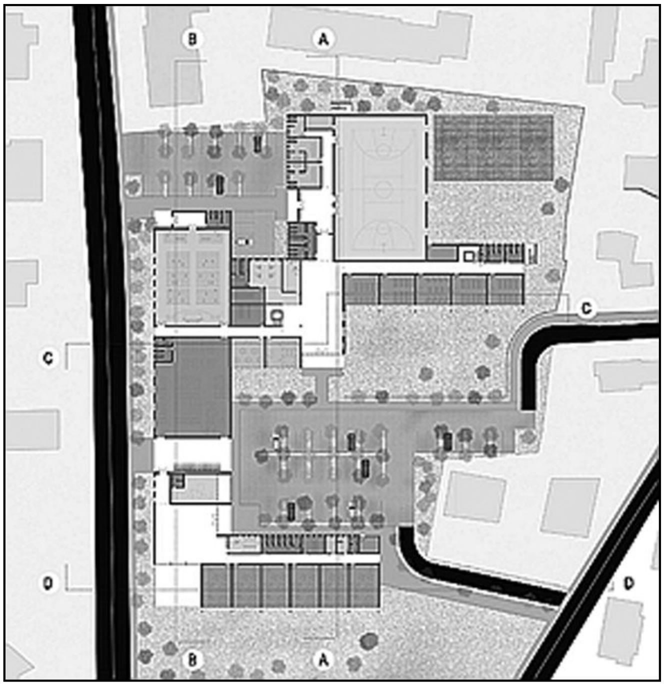

Figure 11 - *Map of the ground floor with functional spaces*

From the design point of view, the same typology of plants has been defined, whose characteristics remain a constant in the comparison among the three technological solutions considered, so that the study can focus more on the advantages and disadvantages of the technologies examined. The plants are governed by two distinct thermal power plants, one serving the primary school, the gym, the auditorium and the canteen and one serving the nursery school and kindergarten. The first thermal power plant is equipped with a reversible electric heat pump with external air energy source and the water-type heat transfer fluid for heating all areas as well as the cooling of the gym, the auditorium and the canteen. The fan coil units as terminal type have been provided. A domestic hot water system (A.C.S.) has also been installed with a heat pump, as a generator for all areas. A solar thermal system with storage has been added to increase its efficiency. Finally, a mechanical ventilation system is envisaged with the function of air intake and extraction, integrated with a centralized double fluid heat recovery.

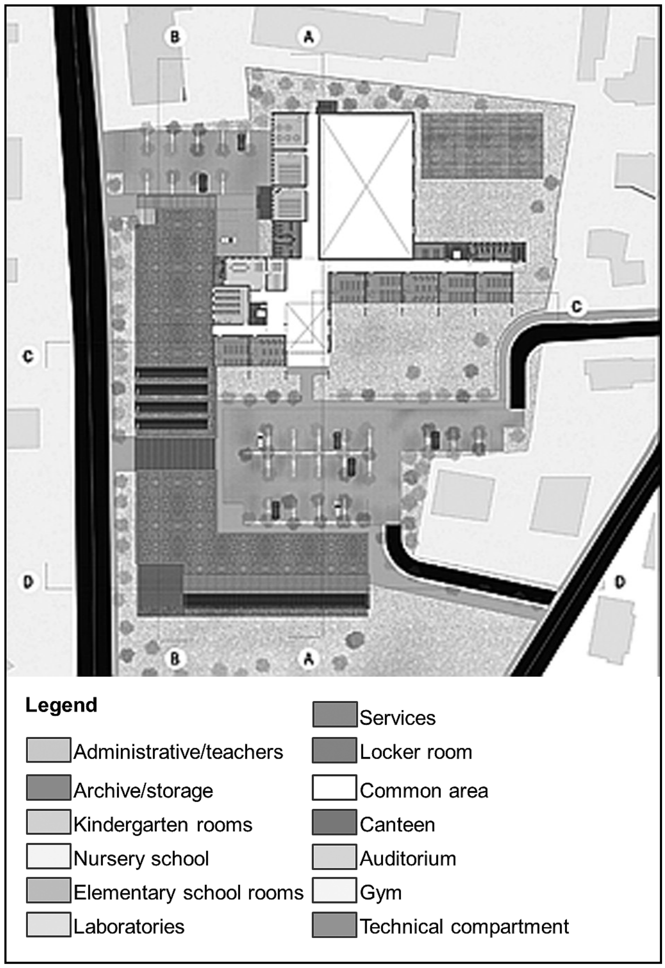

Figure 12 - *Map of the 1st floor with functional spaces*

The second thermal power plant is equipped with a reversible electric heat pump, with an external air energy source and a water-type heat transfer fluid, both for heating all areas and for heating the A.C.S.. The heating terminal is a fan coil type.

A solar thermal system with accumulation has also been planned in this case to increase the efficiency of A.C.S. production. A mechanical ventilation system with the function of air intake and extraction, integrated with a double fluid centralized heat recovery, is also envisaged. The solar thermal systems for the production of domestic hot water are of the vacuum tube type with flat absorber, integrated architecturally to the roof with an inclination equal to 35° and oriented to the south. The buildings are equipped with a photovoltaic system (Fig. 13) for the production of electricity, which are also integrated into the roof with the same inclination and orientation of the solar thermal system. The photovoltaic system installed in the roof of the elementary school has a surface equal to 620 m^2 corresponding to a Power equal to 93.00 kWp The photovoltaic system installed in the roof of the kindergarten has a surface equal to 150 m^2 corresponding to a Power equal to 22.50 kWp.

Figure 13 - *Elementary and kindergarten render*

4. TECHNOLOGIES TAKEN INTO ACCOUNT IN THE CASE STUDY

The study took into account and compared three technologies that can be used in the project execution phase. They are respectively: the reinforced concrete frame and brick masonry, the dry system with steel structure, and finally the dry system with a wooden structure consisting of panels of Cross Laminated Timber (CLT) and lamellar beams. The most relevant features of the three technologies used are described below.

4.1 The technological system in reinforced concrete and brick masonry

The construction system in reinforced concrete and bricks is considered the most traditional construction system. It was designed by providing a structural mesh consisting of pillars and beams in reinforced concrete, on which rest predalles floors for a maximum lights of 9.5 meters, while for higher lights the use of prefabricated precast double T concrete slabs is foreseen.The vertical perimeter walls were made of bricks. The thermal insulation of the vertical perimeter walls was entrusted to the brick and to the external thermal insulation composite system (ETICS). The internal partitions that delimit the premises that require particular acoustic comfort are made of double masonry with a crawlspace consisting of a layer of rock wool. Of this technological solution, the stratigraphy of the envelope is shown below, and namely:

a) the vertical perimeter wall consisting as illustrated in Fig. 14, starting from the inside, respectively, of: 1) thermo-plaster cm. 2, 2) brick blocks cm. 25, 3-4) ETICS consisting of rock wool cm. 16, skim coat and finishing plaster.

Table 3 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 14, whose symbols have the following meaning: s = thickness of the layer; λ = Thermal conductivity of the material; C = Unitary conductance; M.S. = Superficial Mass; P $<50*10^{12}$= Vapour permeability with relative humidity up to 50%; C.S. = Specific Heat; R = Thermal resistance of the individual layers; with real Resistance and Transmittance values; with Value of the Surface Mass calculated as set out in Annex A of Legislative Decree n. 92/05 and subsequent amendments.

b) the roof having maximum light less than mt. 9.5, made as shown in Fig. 15 respectively, starting from the outside, from: 1) gravel cm. 5, 2) non-woven fabric and waterproofing membrane, 3) layer slope in lightened concrete cm 10, 4) thermal insulation made of extruded polystyrene foam cm. 20, 5) vapour barrier, 6) slab floor predalles, 7) layer of air, 8) layer of rock wool cm. 5, 9-10) layer of plasterboard and paint.

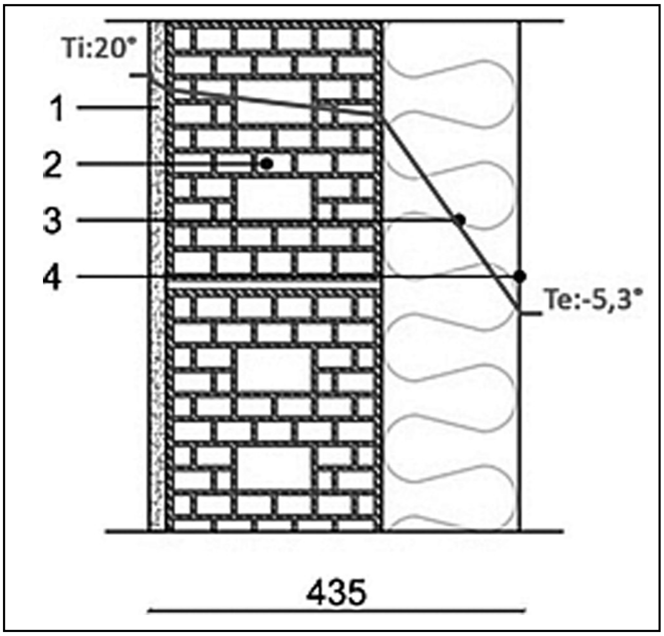

Figure 14 - *Stratigraphy of the vertical perimeter wall of the technological solution with a structural mesh in reinforced concrete and brick masonry*

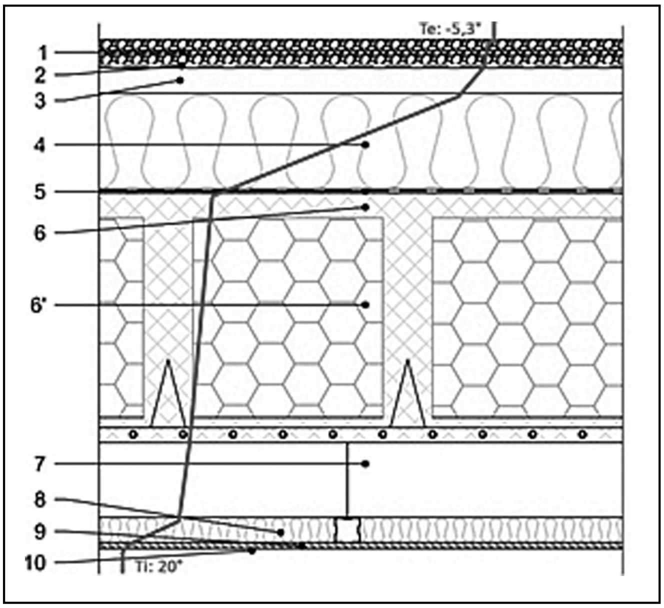

Figure 15 - *Stratigraphy of the roof with lights less than mt. 9,5 of the technological solution with a structural mesh in reinforced concrete and brick masonry*

Table 3 - *Vertical perimeter wall*

N.	DESCRIPTION OF THE LAYER (from int. to ext.)	s [mm]	Λ [W/mK]	C [W/m²K]	M.S. [kg/m²]	P<50*10¹² [kg/msPa]	C.S. [J/kgK]	R [m²K/W]
–	Int. heat transfer coefficient	0		7.700			0	0.130
1	Thermo plaster	20	0.090	4.500	10.00	4.000	840	0.222
2	BBricks: solid(pot/light/- high mechanical strenght humidity 1, 5%- mv.1000.	250	0.470	1.882	250.00	30.860	840	0.531
3	Rock wool	160	0.037	0.231	14.40	193.000	1030	4.324
4	Finishing	5	0.750	150.000	2.50	4.000	840	0.007
–	Ext heat transfer coefficient	0		25.000			0	0.040
RESISTANCE = 5.255 m²K/W						**TRASMITTANCE = 0.190 W/m²K**		
THICKNESS = 435 mm		**PER UNIT AREA THERMAL CAPACITY (lower) = 29.406 kJ/m²K**				**SURFACE MASS = 264 kg/m²**		
PERIODIC THERMAL TRANSMITTANCE = 0.02 W/m²K		**MITIGATION FACTOR = 0.10**				**DISCREPANCY = 12.88 h**		

Table 4 below shows the thermotechnical characteristics of the layers described and illustrated in Fig. 15.

Table 4 - *Roof of the elementary school*

N.	DESCRIPTION OF THE LAYER (from upper to above)	s [mm]	Λ [W/mK]	C [W/m²K]	M.S. kg/m²]	P<50*10¹² [kg/msPa]	C.S. [J/kgK]	R [m²K/W]
–	Higher heat transfer coefficient	0		7.700			0	0.130
1	Gravel layer	50	1.400	28.000	85.00	0.019	1000	0.036
2	Non-woven fabric (TNT) and waterproofing membrane	10	0.170	17.000	12.00	0.000	920	0.059
3	Lightened concrete	100	0.090	1.800	17.50	24.125	1000	0.556
4	Extruded polystyrene foam	200	0.030	0.150	8.00	2.413	1450	6.667
5	Vapour barrier							
6	Reinforced concrete-cast	50	1.910	38.200	120.00	1.300	1000	0.026
6′	Slab floor predalles (thickness = 400 - downflow)	400		2.222	577.00	18.000	900	0.450
7	Verticalair layer of 15 cm	150	0.833	5.555	0.20	193.000	1008	0.180
8	Rock wool	50	0.05	0.700	2.00	193.000	1030	1.429
9	Plasterboard in sheets	12	0.20	17.500	10.80	23.000	1000	0.057
10	Paint	3	0.750	250.000	1.50	4.000	840	0.004
12	Lower heat transfer coefficient	0		25.000			0	0.040
RESISTANCE = 9.633 m²K/W		**PER UNIT AREA THERMAL CAPACITY (upper) = 66.947 kJ/m²K**				**TRASMITTANCE = 0.104 W/m²K**		
THICKNESS = 975 mm		**PER UNIT AREA THERMAL CAPACITY (lower) = 14.770 kJ/m²K**				**SURFACE MASS = 832 kg/m²**		
PERIODIC THERMAL TRANSMITTANCE = 0.00 W/m²K		**MITIGATION FACTOR = 0.00**				**DISCREPANCY = 0.54 h**		

c) the roof having maximum light greater than 9.5 meters, which is constituted as shown in Fig. 16 respectively, starting from the outside, from: 1) gravel cm. 5, 2) non-woven fabric and waterproofing membrane, 3) layer slope in lightened concrete cm 10, 4) thermal insulation made of extruded polystyrene foam 20 cm, 5) vapour barrier, 6) floor in reinforced prestressing concrete.

The following Table 5 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 16.

d) the lower horizontal closure, which is constituted as illustrated in Fig. 16 respectively: 1) screed cm 5, 2) thermal insulation made of extruded polystyrene foam cm 8, 3) lightened concrete layer cm 5, 4) reinforced concrete, 5) crawl space, 6) waterproofing membrane 0.1 cm, 7) lean concrete, 8) soil.

The following Table 6 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 17.

Table 5 - *Roofing floor of the gym*

N.	DESCRIPTION OF THE LAYER (from upper to above)	s [mm]	Λ [W/mK]	C [W/m^2K]	M.S. [kg/m^2]	$P<50*10^{12}$ [kg/msPa]	C.S. [J/kgK]	R [m^2K/W]
–	Higher heat transfer coefficient	0		7.700			0	0.130
1	Gravel layer	50	1.400	28.000	85.00	0.019	1000	0.036
2	Non-woven fabric (TNT) and waterproofing membrane	10	0.170	17.000	12.00	0.000	920	0.059
3	Lightened concrete	100	0.090	1.800	17.50	24.125	1000	0.556
4	Extruded polystyrene foam	200	0.030	0.150	8.00	2.413	1450	6.667
5	Vapour bariier							
6	Reinforced prestressing concrete 85cm TT beam+ 10cm concrete hood	1.910	19.100	240.00	1.300	1000	0.052	
7	A Lower heat transfer coefficient	0		25.000			0	0.040
RESISTANCE = 7.539 m^2K/W		PER UNIT AREA THERMAL CAPACITY (upper) = 67.420 kJ/m^2K				TRASMITTANCE = 0.133 W/m^2K		
THICKNESS = 410 mm+Trave TT 850mm		PER UNIT AREA THERMAL CAPACITY (lower) = 169.985 kJ/m^2K				SURFACE MASS = 363 kg/m^2		
PERIODIC THERMAL TRANSMITTANCE = 0.05 W/m^2K		MITIGATION FACTOR = 0.34				DISCREPANCY = –11.99 h		

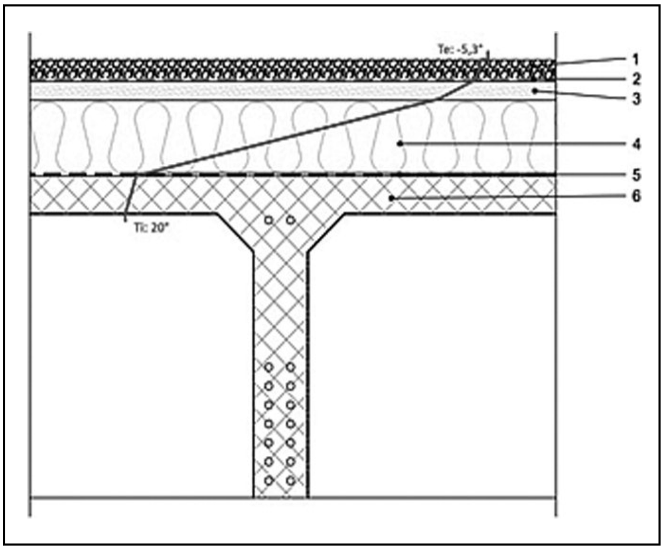

Figure 16 - *Stratigraphy of the roof with lights less than mt. 9,5 of the technological solution with a structural mesh in reinforced concrete and brick masonry*

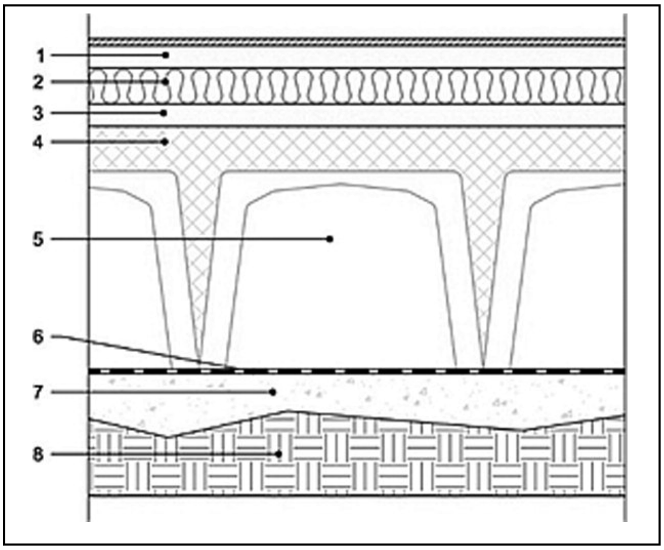

Figure 17 - *Stratigraphy of the lower horizontal closure of the technological solution with a structural mesh in reinforced concrete and brick masonry*

Table 6 - *Slab floor on the ground*

N.	DESCRIPTION OF THE LAYER (from upper to above)	s [mm]	Λ [W/mK]	C [W/m²K]	M.S. [kg/m²]	P<50*10¹² [kg/msPa]	C.S. [J/kgK]	R m²K/W]
–	Floor in pvc							
1	Screed	50 0.350	7.000	17.50	24.125	1000	0.143	
2	Extruded polystyrene foam	80	0.037	0.468	2.40	1.930	1450	2.139
3	Lightened	50	0.090	1.800	17.50	24.125	1000	0.556
4	Reinforced concrete-cast	100	1.910	19.100	240.00	1.300	1000	0.052
5	Vertical air layer in the crawl space	450	1.667	3.704	0.59	193.000	1008	0.270
6	Waterproofing membrane	10	0.170	17.000	12.00	0.000	920	0.059
7	Lean concrete	100	1.400	17.500	160.00	2.600	1000	0.057
8	Soil		1.5					

4.2 The dry technological system with steel structure

The dry technological system with steel supporting structure consists of a vertical mesh structure of steel pillars of class S275 and S345, of two types of horizontal structures, one for lights minor or equal to 9.5 meters, the other for superior lights. In the first case a double warping was foreseen, that means a main warping and a secondary one of steel beams on which rests a floor slab consisting of corrugated sheet and reinforced concrete slab.

In the second case it was foreseen the use of trusses of different sizes depending on the light they cover, on which purlins rest on a constant inter-axis on which in turn rests the floor slab that consists of a corrugated sheet and reinforced concrete slab. To buffer the structure it is foreseen the use of fibre cement plates for the parts in contact with the outside and of plasterboard for the internal and false ceiling parts so that to satisfy the requirements of thermal and acoustic insulation and fire resistance. This last aspect is relevant being the structure entirely entrusted to steel. Of this technological solution, the stratigraphy of the envelope is shown below and namely:

a) vertical perimeter wall made up as shown in Fig. 18, respectively starting from the inside, of: 1) finishing 0,5 cm, 2) fiber cement sheets 2,5 cm, 3) layer of rock wool 10 cm, 4) air layer 16 cm, 5) double plasterboard sheet 2,5 cm, 6) rock wool layer 7,5 cm, 7) double plasterboard sheet 2,5 cm

The following Table 7 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 18.

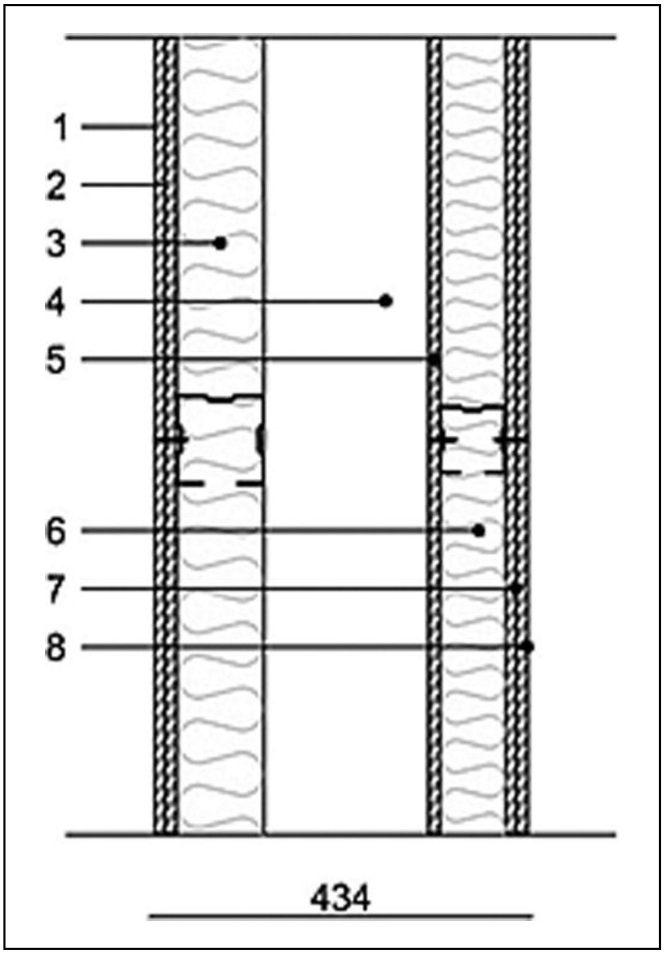

Figure 18 - *Stratigraphy of the vertical perimeter wall of the dry technological solution with steel structure*

Table 7 - *Vertical perimeter wall*

N.	DESCRIPTION OF THE LAYER (from int. to ext.)	s [mm]	l Λ W/mK	C [W/m^{2}K]	M.S. [kg/m^2]	P<50*10^{12} [kg/msPa]	C.S. [J/kgK]	R [m^{2}K/W]
–	Int. heat transfer coefficient	0	7.700	0	0.130			
1	Finishing	5	0.750	150.000	2.50	4.000	840 0.007	
2	Fiber cement sheets	25	0.210	8.400	22.50	23.000	1000	0.119
3	Rock wool	100	0.035	0.350	7.00	0.000	1030	2.857
4	16 cm air layer cm	187	0.889	4.753	0.24	193.000	1008	0.210
5	Plasterboard sheets	12	0.210	17.500	10.80	23.000	1000	0.057
6	Rock wool	75	0.035	0.467	5.25	0.000	1030	2.143
7	Plasterboard sheets	25	0.210	8.400	22.50	23.000	1000	0.119
8	Finishing	5	0.750	150.000	2.50	4.000	840	0.007
–	Ext. heat transfer coefficient	0		25.000			0	0.040
RESISTANCE = 5.689 m^{2}K/W						**TRASMITTANCE = 0.176 W/m^{2}K**		
THICKNESS = 434 mm		**PER UNIT AREA THERMAL CAPACITY (lower) = 26.381 kJ/m^{2}K**				**SURFACE MASS = 68 kg/m^2**		
PERIODIC THERMAL TRANSMITTANCE = 0.09 W/m^{2}K		**MITIGATION FACTOR = 0.50**				**DISCREPANCY = 7.37 h**		

b) roof formed as illustrated in Fig. 19, starting respectively from the outside: 1) gravel 5 cm, 2) non-woven fabric and waterproofing membrane, 3) layer slope in lightened concrete 10 cm, 4) thermal insulation made of polystyrene extruded foam 20 cm, 5) vapour barrier, 6) reinforced concrete screed, 7) air layer, 8) rock wool layer 5 cm, 9-10) plasterboard and paint layer.

The following Table 8 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 19

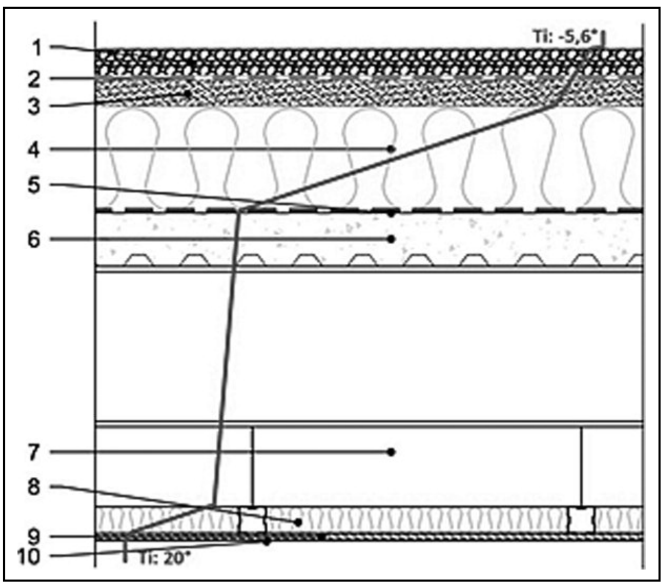

Figure 19 - *Stratigraphy of the roof of the technological solution whit steel structure*

c) Lower horizontal closure, consisting of the same stratigraphy illustrated in Fig. 16 respectively: 1) screed 5, cm., 2) thermal insulation consisting of extruded polystyrene foam 8, cm. 3) lightened concrete layer 5 cm., 4) reinforced concrete, 5) crawl space, 6) waterproofing membrane 0.1 cm, 7) lean concrete, 8) soil.

4.3 The dry technological system with wooden structure consisting of Cross Laminated Timber panels and lamellar beams

The school complex with the dry system with a wooden supporting structure has been designed with the use of CLT (cross laminated timber) panels for the vertical supporting structures, while for the horizontal supporting structures it is foreseen the use of beams lamellar with different section depending on the different project lights. The external vertical closures provide for the structural panels to be clad on the external side with an ETICS while inside, with plasterboard and rock wool counter-walls. Of this technological solution, the stratigraphy of the envelope is shown below and namely:

a) the vertical perimeter wall consisting as illustrated in Fig. 20 starting from the inside, respectively, of: 1) double plasterboard sheet cm. 2,5, 2) CLT panel cm. 25, 3-4) cladding consisting of rock wool cm. 16, skim coat and finishing plaster.

Table 9 below shows the thermotechnical characteristics of the layers described and illustrated in Fig. 20.

b) cover formed as shown in Fig. 21, starting from the outside respectively: 1) gravel 5 cm, 2) non-woven fabric and waterproofing membrane, 3) layer slope in lightened

Table 8 - *Roof with false ceiling*

N.	DESCRIPTION OF THE LAYER (from upper to above)	s [mm]	Λ [W/mK]	C [W/m²K]	M.S. [kg/m²]	P<50*10¹² [kg/msPa]	C.S. [J/kgK]	R [m²K/W]
–	Int. heat transfer coefficient	0	7.700	0	0.130			
1	Gravel layer	50	1.400	28.000	85.00	0.019	1000	0.036
2	Non-woven fabric (TNT) and waterproofing membrane	10	0.170	17.000	12.00	0.000	920	0.059
3	Layer slope in lightened concrete	100	0.090	1.800	17.50	24.125	1000	0.556
4	Extruded polystyrene foam	200	0.030	0.150	8.00	2.413	1450	6.667
5	Vapour barrier							
6	Reinforced concrete-cast	100	1.910	14.692	312.00	1.300	1000	0.068
7	air layer cm	480	0.833	1.736	0.62	193.000	1008	0.576
8	Rock wool	50	0.035	0.700	2.00	193.000	1030	1.429
9	Plasterboard in sheets	12	0.210	17.500	10.80	23.000	1000	0.057
10	Paint	3	0.750	250.000	1.50	4.000	840	0.004
–	Ext. heat transfer coefficient	0		25.000			0	0.040
RESISTANCE = 9.620 m²K/W		PER UNIT AREA THERMAL CAPACITY (upper) = 66.948 kJ/m²K				TRASMITTANCE = 0.104 W/m²K		
THICKNESS = 985 mm		CAPACITÀ TERMICA AREICA (lower) = 14.736 kJ/m²K				SURFACE MASS = 448 kg/m²		
PERIODIC THERMAL TRANSMITTANCE = 0.00 W/m²K		MITIGATION FACTOR = 0.02				DISCREPANCY = -8.36 h		

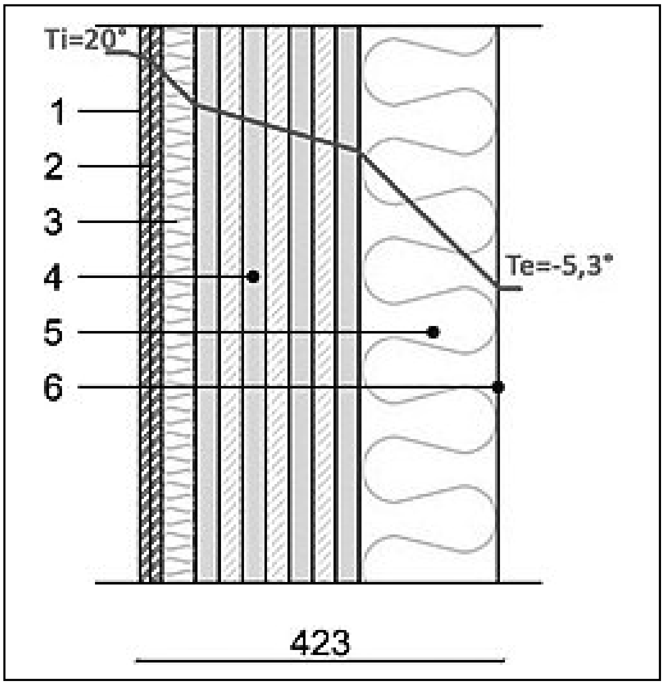

Figure 20 - *Stratigraphy of the vertical perimeter wall of the technological solution with dry structure with wooden structure*

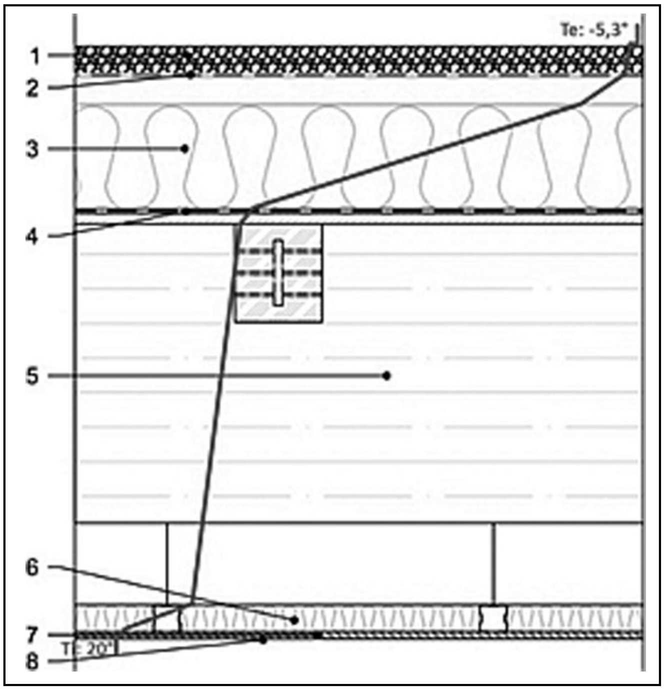

Figure 21 - *Stratigraphy of the roof of the technological solution with a wooden dry structure*

Table 9 - *Vertical perimeter wall*

N.	DESCRIPTION OF THE LAYER (from int. to ext.)	s [mm]	Λ [W/mK]	C [W/m^2K]	M.S. [kg/m^2]	P<50*10^{12} [kg/msPa]ì	C.S. [J/kgK]	R [m^2K/W]
–	Int. heat transfer coefficient	0	7.700	0	0.130			
1	Paint	3	0.750	250.000	1.50	4.000	840	0.004
2	Plasterboard in sheets	25	0.210	8.400	22.50	23.000	1000	0.119
3	Rock wool	40	0.035	0.875	2.80	0.000	1030	1.143
4	CLT Panel	19	0.130	1.016	57.60	0.300	1000	0.985
5	ETICS	160	0.037	0.231	14.40	193.000	1030	4.324
6	Finishing	5	0.750	150.000	2.50	4.000	840	0.007
–	Ext. heat transfer coefficient	0		25.000			0	0.040

RESISTANCE = 6.751 m^2K/W		**TRASMITTANCE = 0.148 W/m^2K**
THICKNESS = 361 mm	**PER UNIT AREA THERMAL CAPACITY (lower) = 23.954 kJ/m^2K**	**SURFACE MASS = 97 kg/m^2**
PERIODIC THERMAL TRANSMITTANCE = 0.02 W/m^2K	**MITIGATION FACTOR = 0.14**	**DISCREPANCY = 12.11 h**

Table 10 - *Roof with false-ceiling*

N.	DESCRIPTION OF THE LAYER (from upper to above)	S [mm]	Λ[W/mK]	C [W/m^2K]	M.S. [kg/m^2]	P<50*10^{12} [kg/msPa]	C.S. [J/kgK]	R [m^2K/W]
–	Higher heat transfer coefficient	0		25.000			0	0.040
1	Gravel layer	50	1.400	28.000	85.00	0.019	1000	0.036
2	Non-woven fabric (TNT) and waterproofing membrane	10	0.170	17.000	12.00	0.000	920	0.059
3	Lightened	100	0.090	1.800	17.50	24.125	1000	0.556
3a	Extruded plystyrene foam	200	0.030	0.150	8.00	2.413	1450	6.667
4	Vapour barrier							
4a	Wood panel	20	0.130	6.500	9.00	0.300	1600	0.154
5	Air layer	730	0.833	1.142	0.95	193.000	1008	0.876
8	Rock wool	50	0.035	0.700	2.00	193.000	1030	1.429
9	Plasterboard in sheets	12	0.210	17.500	10.80	23.000	1000	0.057
10	Finishing	3	0.750	250.000	1.50	4.000	840	0.004
11	Lower heat transfer coefficient	0		10.000			0	0.100

RESISTANCE = 9.976 m^2K/W		**TRASMITTANCE = 0.100 W/m^2K**
THICKNESS = 1 125 mm	**PER UNIT AREA THERMAL CAPACITY = 15.469 kJ/m^2K**	**SURFACE MASS = 145 kg/m^2**
PERIODIC THERMAL TRANSMITTANCE = 0.02 W/m^2K	**MITIGATION FACTOR = 0.21**	**DISCREPANCY = 12.18 h**

concrete 10 cm, 4) thermal insulation made of polystyrene extruded foam 20 cm, 5) vapour barrier, 6) reinforced concrete screed, 7) air layer, 8) rock wool layer 5 cm, 9-10) plasterboard and paint layer.

Table 10 shows the thermotechnical characteristics of the layers described and illustrated in Fig. 21.

c) lower horizontal closure, which consists of the same stratigraphy illustrated in Fig. 15 respectively: 1) screed cm 5 cm, 2) thermal insulation made of extruded polystyrene foam 8 cm, 3) lightened concrete layer 5 cm, 4) reinforced concrete , 5) crawl space, 6) waterproofing membrane 0.1 cm, 7) lean concrete, 8) soil.

5. COMPARAISON BETWEEN TECHNOLOGIES

5.1 The methodology used

To compare the technologies described above, on the basis of the executive design, for each technology the metric estimate was made. The metric estimate (C.M.E.) is the tool used by the client and the designer for the evaluation of the construction cost of a building work. Starting from this data, the client is able to deepen the analysis on the appropriateness or not of the realization of a building intervention, both public and private. The metric estimate is the sum of the amounts resulting from the product of the quantities of each processing (Q_i) for the respective unit price (N_i).

$$CME = \sum_{i=1}^{n}, (Qi \times Ni).$$

The general methodological criterion adopted in this work, in order to better focus the comparison between the technologies, has provided that the CME should be realized through an analytical procedure to estimate the construction cost of all the involved building works, as the technologies under consideration change. It is nessary to exclude however from the CME both the fixed costs of the building site and the processings that would have remained unchanged from the use of the same, such as the fixtures and technical systems which, defined the design standard, can be used indifferently whether or not you decide to use a technological system rather than another one among those in question. The amounts resulting from the product of the quantities of each processing and the respective unit price were then added. The study was carried out in phases. The first phase was that of the "classification of works". It consisted in identifying the homogeneous categories of work to which the identification code, the qualitative description of the work, the unit of measurement to which the relative unit price is associated, were unequivocally associated. The second phase was that of "measurement of processings". It consisted in calculating the quantity necessary for the execution of the project for each item.

The third phase was that of identifying the "unit prices" on the basis of an estimate. This estimate was made in a synthetic-operative way, that is, considering the unit price of supply and laying of the specific processing, referring to the official unit prices drawn up by provinces and regions. In particular, reference was made firstly to the online price list of public works in the Veneto Region. In the case of lack of descriptions, reference was made to the price list prepared by C.C.I.A.A. (Chamber of Commerce, Industry, Handicraft, Agriculture) of Vicenza which is the province where the construction of the school complex is planned. In the case of works not present in official price lists, the unit prices were estimated analytically-constructively through a market analysis carried out through estimates requested to construction companies or by comparison of similar works.

The fourth phase consisted in the analysis of the construction cost, summarized in the CME, according to the construction time. The importance of this further analysis lies in the fact that the lesser duration of the construction site constitutes an undoubted economic advantage for both the client and the construction company. For example, from the early availability of the property, in the case of public clients, savings could be made for rents of buildings of similar use, and/or savings of all those costs related to any additional services (transport, etc.). In the case of private clients, a non-marginal saving could derive from the lower cost of money for the financing of the work. For the Construction Company, the advantage could consist in the lower cost of money for financing purchases of materials and products, payment of labor and management of the building site. To do this it was considered appropriate to calculate the estimate of construction times for each technology, starting from the CME and not to do it on the basis of planning considerations of the processings untied from the respective prices. This, is to avoid the inconsistency that certainly would have been determined by proceeding with this second way. To this end, the "Men per Day" index was used. This entity has been determined for the three technologies adopted. The formula adopted for the calculation of the men per day[5] is as follows:

$$\text{Men per day} = \frac{\text{Manpower total cost}}{\text{Worker dayly cost}}$$

The total cost of the manpower required to complete the work was calculated for each individual technology. It is a percentage value of the CME.

Therefore, the percentage of manpower impact has been calculated for each individual item. At this point, assuming for all three technologies examined the following hypothesis:

[5] D.lgs. 9 April 2008, n. 81. Article 89 paragraph 1 letter g: men per day: presumed entity of the buiding site represented by the sum of the working days provided by the workers, also autonomous, provided for the construction of the work.

– simultaneous presence on site of 18 workers;
– 250 working days per year;
using the following formula:

$$\frac{Men\ per\ days}{(250\ Working\ Days) * (18\ workers)} = Years$$

it has been possible to derive the duration of the construction site expressed in years. After determining the duration of the construction site for each technology, the fifth step consisted in determining the fixed cost of the construction site according to its duration. The estimate of the fixed costs of the construction site was calculated with reference to the rental prices of the equipment supplied by the main company operating in the area where the site is located. At the same time, the energy performances and the useful surfaces determined by the use of the three technologies were compared. It is in fact believed that this is also a factor to be considered.

5.2 The metric estimate for the quantification of construction costs

In Tables 11-12-13 there are some excerpts from the calculation of the metric estimate carried out for the three construction systems.

The estimated metrics made from the aforementioned hypotheses gave the results shown in the following Table 14.

From this first result the construction system in reinforced concrete and brick masonry is the most convenient. In order to develop the comparison among technologies, however, it is considered necessary to analyze the construction cost, summarized in the CME and highlighted in Table 14, taking into account the respective construction times.

5.3 Estimate of construction times

Determination of Men per Day for the three technologies adopted. For greater clarity, the formula is shown as expressed in the method:

$$Men\ per\ day = \frac{Manpower\ total\ cost}{Worker\ dayly\ cost}$$

The daily cost of the manpower was calculated as follows. Assumed the hourly rate of a skilled worker equal to € 21.17[6] and being the working day equal to 8 hours, the daily cost of a worker is equal to:

$$Dayly\ cost = € \ 21{,}17 * 8 = € \ 169{,}36$$

[6] Veneto Region Public Works 2013 cod A.01.03.b

Table 11 - *system with reinforced concrete frame and brick masonry*

Order number Item part number	Description	Quantity	Unit amount	Total amount
Structural				
17 E.08.19.a	REINFORCED CONCRETE C 25/30 FOR BEAMS, PILLARS, KERBS AND SLABS Supply and installation of concrete workability class S3 (semifluid), exposure class XF2, C 25/30, max ratio e/c = 0.5, minimum air content 3%, machine-packed for processings in reinforced concrete such as beams, pillars, kerbs, slabs, ramps stairs, etc. of any shape, thickness and dimension, including the FeB44K reinforcing rod iron with improved adhesion, controlled at the factory and shaped in the quantities foreseen by the static calculations, prepared, costs included by the Contracting Authority, for a maximum quantity up to 110 kg / m^3. The price is understood to include and offset the charges for the formation and removal of the internal worktops, the formation and removal of the rectilinear formwork of casts, the mechanical vibration, the formation of bevels, rabbets, holes, pilasters and string courses and other necessary to give good finished work.			
	OVERALL h	301,24 m^3	442,98 €/m^3	€ 133´443,30

Table 12 - *dry system with steel frame*

Order number Item part number	Description	Quantity	Unit amount	Total amount
Vertical closure				
8 Mur. Steel Partition	Supply and installation of the internal cladding consisting of: – Double truss U-shaped metal profile (Ref. Veneto Region Public Works 2013 code B.08.26.00) incidence: 1.4m/ml - Price2.57 €/m – Double row of metal profiles for plasterboard support (see Veneto Region Public Works in Veneto 2013 code B.08.25.00) incidence: 1.8m/ m2- Price: 0.61 €/m – 4 plasterboard slabs (Ref. Construction Works Vicenza 2012 code 09.02.00.33) Price single slab 3.90 € m2. – Filler for plasterboard (see Veneto Region Public Works 2013 code B.08.27.00) Incidence 0.7 kg/m2 - Price: 2.75 €/kg – Rock wool mattress: a 75mm layer and a 75mm layer (see Veneto Region Public Works 2013 code E.16.06.00). Price considering the increase of 25mm per side: 18.82 € /m2 Skilled worker (see Veneto Region Public Works 2013 code A.02.03.a) Incidence: 0.8h / m2 - Price: 27.18 €/h			
	OVERALL m^3	2´334,42 m^2	62.29 €/m^2	145´411,02 €

segue

Structural				
11 Estimate steel	Trusses and simple columns in hot-rolled steel in profiles of type S235, S275, S355, for load-bearing structures of complete buildings, with primer coat of anticorrosion paint; supplied and installed for heights up to 12 m. Design compliant execution. These include Gusset plates reinforcing plates, backing plates, scraps, as well as any other necessary ancillary performance, joining with bolts, including bolts, nuts and base plates.			
	OVERALL kg	295´903,89 kg	2,50 €/kg	739´759,73 €

Table 13 - *dry system with frame in CLT*

Order number Item part number	Description	Quantity	Unit amount	Total amount
Walls				
7 Estimate.01	Supply of 5 layers CLT panels. Supply on site of structural panels made of multilayer wood in fir-wood planks glued in crossed layers, with CE marking for the construction products provided for in Directive 89/106/EEC and subsequent amendments, implemented by the Presidential Decree 21.04.93 n. 246 and subsequent amendments or qualified as required by the chapter 11 of the D.M. 14.01.2008, from sustainable forest management (GFS) with chain of custody certification according to the PEFC or FSC scheme. The product must be accompanied by the construction drawings of the building site and the assembly instructions to be approved by the D.L. in addition to the maintenance plan. Cuts, scraps, holes for doors and windows are included in the price. Tolerance around 3% on the total thickness and on the individual 5 layers. The price includes the charges for lifting rings, screws, angles and brackets for the assembly of the structure, wooden caps for the masking of the fixing points that must be perfectly aligned.			
	OVERALL m^3	688,16 m^3	490,00 €/m^3	337´198,40 €
8 Estimate.02	Installation of 5 layers CLT panels. Installation of construction elements referred to in the item of the supply only, including any processing of interlocking and joining. the. The price includes the costs for transport and handling within the building site, the assembly by specialized personnel, and any other services including the control and acceptance of construction drawings provided by the manufacturer or the designer. The internal work plans, the final cleaning, the transport to landfill of differentiated material, the landfill charges according to the regulations in force and anything else to give good finished work according to the protocols of assembly established in the C.S.A. or by the D.L.			
	OVERALL m^3	688,16 m^3	30.00 €/m^3	€ 20´644,80

Table 14 - *Costs comparaison among the different systems*

System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
€ 2.537.222	**€ 2.753.565**	**€ 2.660.689**

Table 15 shows the case of the reinforced concrete system and brick masonry.

For the dry system in steel, Men per day, index of the lenght of the building site, is equal to: *8.187 M.D. (Men per Day)*

$$\frac{1.386.534,80\text{ € (manpower)}}{169,36\text{ (Average daily cost of a worker)}} =$$

Table 15 - *system with framenin reinforced concrete and brick masonry*

Fee code	Description of works	Total amount	% manpower	Manpower cost
A.02.03.a	Skilled worker	5´736,10 €	100%	5´736,10 €
B.02.03.d	Gravel	3´561,60	€ 0%	–
B.06.38.b	Rock wool	16´254,04 €	56%	9´102,26 €
E 08.002c	Crawl space	88´021,00 €	59%	51´932,39 €
E.02.02.00	Open section dig	16´826,40 €	50%	8´413,20 €
E.08.11.00	Concrete foundations	102´988,94 €	41%	42´225,46 €
E.10.03.c	Predalles slab floor	310´281,84 €	72%	223´402,92 €
E.10.03.c1	Concrete hood surcharge	7´662,60 €	0%	–
E.10.03.c2	Slab floor 1 oversizing	43´395,00 €	0%	–
E.10.03.c3	Slab floor 2 oversizing	13´543,00	0%	–
E.11.03.c	TT beam with h=65 cm	41´780,73 €	48%	20´054,75 €
E.11.03.d	TT beam with h=80 cm	34´768,40 €	39%	13´559,68 €
E.12.09.a	Partition walls	29´324,59 €	70%	20´527,21 €
E.12.16.00	Masonry	255´523,34 €	70%	178´866,34 €
E.13.03.00	Concrete above crawl space	131´801,88 €	31%	40´858,58€
E.13.12.00	Lightened	169´348,52 €	36%	60´965,47 €
E.13.13.00	Lightened (recuction)	–27´877,08 €	36%	–10´035,75 €
E.13.20.a	Self-levelling screed	161´099,18 €	44%	70´883,64 €

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E.13.21.00	Screed (increase)	40´677,78 €	44%	17´898,22 €
E.16.01.00	Reinforced sheath	58´130,40 €	67%	38´947,37 €
E.16.06.00	Rock wool	34´418,70 €	36%	21´683,78 €
E.16.06.00.a	Rock wool 1 surcharge	17´478,00 €	0%	–
E.16.06.00.b	Rock wool 2 surcharge	1´047,22 €	0%	–
E.16.10.a	EPS insulation (surcharge)	47´125,54 €	65%	30´631,60 €
E.16.10.d	Horizontal insulation in EPS	257´377,40 €	65%	167´295,31 €
E.16.12.b	Vapour barrier	7´748,60 €	19%	1´472,23 €
E.18.17.b	Thermo-plaster	234´561,60 €	71%	166´538,74 €
E.17.04.b	Thermal cut with glass wool	3´408,28 €	33%	1´124,73 €
E.18.22.00	Finishing	36´676,80 €	64%	23´473,15 €
E.19.09.00	Plasterboard false ceiling	125´574,80 €	34%	42´695,43 €
E.28.01.a	Latex paint	105´944,96 €	73%	77´339,82 €
F.05.09.00	Supply and installation of the lean concrete	30´498,85 €	13%	3´964,85 €
	TOTAL MANPOWER			**1'386´534,80** €

Table 16 shows the case of the dry system in steel.

For the dry system in steel the Men per day, index of the duration of the building site, is equal to: *6.487 M.D.*

$$\frac{1.098.644,59\text{ € (manpower)}}{169,36\text{ (Average daily cost of a worker)}} =$$

Table 17 shows the case of the dry system in clt and laminated timber:

For the dry system in clt the Men per day, index of the duration of the building site, is equal to: *5.555 M.D.*

$$\frac{940.802,01\text{ € (manpower)}}{169,36\text{ (Average daily cost of a worker)}} =$$

At this point, assuming for all three technologies examined the following hypothesis:

– simultaneous presence on site of 18 workers;
– 250 working days per year;

Table 16 - *Dry system in steel*

Fee code	Description of works	Total amount	% manpower	Manpower cost
B.02.03.d	Gravel	3´561,60 €	0%	–
B.06.38.b	Rock wool	14´567,30 €	56%	8´157,69 €
E 08.002c	Crawl space	85´100,00 €	59%	50´209,00 €
E.02.02.00	Open section dig	16´826,40 €	50%	8´413,20 €
E.08.11.00	Concrete foundations	81´998,28 €	41%	33´619,29 €
E.08.19.a	Concrete works	10´418,89 €	49%	5´105,26 €
E.10.07.a	Cruugated sheet floor slab	271´544,21€	20%	54´308,84 €
E.10.03.c1	Concrete hood surcharge	7´662,60 €	0%	–
E.10.09.00	Concrete hood increase	46´809,00€	0%	–
E.10.03.c3	Slab floor 2 oversizing	13´543,00 €	0%	–
E.10.11.00	Slab floor increase	5´722,60 €	100%	5´722,60 €
E.13.03.00	Concrete above crawl space	127´428,00 €	31%	39´502,68€
E.13.12.00	Lightened	169´348,52 €	36%	60´965,47 €
E.13.13.00	Lightened (deduction)	–27´877,08 €	36%	–10´035,75 €
E.13.20.a	Self-levelling screed	161´099,18 €	44%	70´883,64 €
E.13.21.00	Screed (Increase)	40´677,78 €	44%	17´898,22 €
E.16.01.00	Reinforced sheath	58´130,40 €	67%	38´947,37 €
E.16.10.a	EPS insulation (surcharge)	47´125,54 €	65%	30´631,60 €
E.16.10.d	Horizontal insulation in EPS	257´377,40 €	65%	167´295,31 €
E.16.12.b	Vapour barrier	7´834,60 €	19%	1´488,57 €
E.19.09.00	Plastboard false ceilin	125´574,80 €	34%	42´695,43 €
E.28.01.a	Latex paint	105´944,96 €	73%	77´339,82 €
F.05.09.00	Supply and installation of the lean concrete	30´498,85 €	13%	3´964,85 €
Mur. steel 105mm	Thermo acoustic cladding total width 125 mm	11´507,30 €	21%	2´416,53
Mur. steel 125mm	Thermo acoustic cladding total width 125 mm	22´439,59 €	29%	6´507,48 €

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Mur. steel Esterno	External cladding	186´629,99 €	36,6%	68´306,57 €
Mur. steel Internal	Thermo acoustic internal cladding	145´411,02 €	35%	50´893,86 €
Works Steel	Opere in acciaio	739´759,73 €	29%	214´530,32 €
	TOTAL MANPOWER			**1’098´644,59 €**

Table 17 - *Dry system in clt and laminated timber*

Fee code	Description of works	Total amount	% manpower	Manpower cost
09.02.00.33	Plasterboard slab	10´637,05 €	0%	–
09.03.04.09	Plasterboard counterwall	21´790,21 €	36%	7´844,47 €
A.02.03.a	Skilled worker	9´585,84 €	100%	9´585,84 €
B.02.03.d	Gravel	3´561,60 €	0%	–
B.06.38.b	Rock wool	14´567,30 €	56%	8´157,69 €
B.06.38c	Rock wool surcharge	7´790,00 €	0%	—
B.08.25.00	U-profiles for plasterboard	877,69 €	0%	–
B.08.26.00	U-rails for plasterboard	1´438,04 €	0%	–
B.08.27.00	Filler	1´706,32 €	0%	–
E 08.002c	Crawlspace	89´286,00 €	59%	52´678,74 €
E.02.02.00	Open section dig	16´623,45 €	50%	8´311,72 €
E.08.11.00	Concrete foundations	81´998,28 €	41%	33´619,29 €
E.08.19.a	Concrete works	10´418,89 €	49%	5´105,26 €
E.13.03.00	Concrete above crawl space	133´696,08 €	31%	41´445,78 €
E.13.12.00	Lightened	169´348,52 €	36%	60´965,47 €
E.13.13.00	Lightened (deduction)	–27´877,08 €	36%	–10´035,75 €
E.13.20.a	Self-levelling screed	161´099,18 €	44%	70´883,64 €
E.13.21.00	Screed (increase)	40´677,78 €	44%	17´898,22 €
E.16.01.00	Reinforced sheath	58´130,40 €	67%	38´947,37 €
E.16.06.00	Rock wool	29´311,55 €	63	18´466,28€
E.16.06.00.a	Rock wool 1 surcharge	17´478,00 €	0%	–
E.16.06.00.b	Rock wool 2 surcharge	1´015,88 €	0%	–
E.16.10.a	EPS insulation (surcharge)	47´125,54 €	65%	30´631,60 €
E.16.10.d	Horizontal insulation in EPS	257´377,40 €	65%	167´295,31 €
E.16.12.b	Vapour barrier	7´748,60 €	19%	1´472,23 €
E.17.04.b	Thermal cut with glass woll	3´408,28 €	33%	1´124,73 €
E.18.22.00	Finishing	70´804,80 €	64%	45´315,07 €
E.19.09.00	Plasterboard false ceiling	125´574,80 €	34%	42´695,43 €
E.20.06.00	Wooden roofs and floor slabs	573´094,91 €	21%	120´349,93 €
E.20.07.00	Coverage board	55´470,84 €	4%	2´218,83 €
E.28.01.a	Latex paint	105´944,96 €	73%	77´339,82 €
F.05.09.00	Supply and installation of the lean concrete	30´498,85 €	13%	3´964,85 €
Sima.01	5 layer Xlam panels suplly	337´198,40 €	0%	–
Stima.02	5 layer Xlam panels installation	20´644,80 €	100%	20´644,80 €
Stima.03	Counterwall on Xlam	172´636,19 €	37%	63´875,39 €
		TOTAL MANPOWER		940´802,01 €

segue

using the following formula:

$$\frac{Man\ per\ days}{(250\ Working\ Days) * (18\ workers)} = Years$$

it has been possible to derive the duration of the construction site expressed in years. In Table 18 is shown the duration of the building site for the three cases examined:

Table 18 - *Duration of the building site for all three technologies examined*

Duration of the building site		
System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
1,81 anni	1,44 anni	1,23 anni

5.4 The estimate of the building site fixed costs

The result of the calculation of the fixed costs of the building site according to its duration calculated with reference to the rental prices of the equipment supplied by the main company operating in the area where the site is located is summarized in Table 19.

Table 19 - *Fixed costs of the construction site*

Description	Annual cost
Monthly rental service of a crane with a 50 mt reach: € 1,400/month	€ 16.800
Monthly rental service of a crane with a 50mt reach: € 1,400/month	€ 16.800
Scaffolding service, assembly/dismantling service and maintenance for the first month per m2 2,852: 9.0 €/m2/month	€ 25.668
Monthly rental scaffolding service, maintenance in the following months per m2 2.852: € 1/m2/month	€ 28.520
Rental site fencing for 446 m2 of: € 1/ ml/month	€ 5.352
Rental of 2 chemical toilets with weekly cleaning service: € 290/month	€ 3.480
Rental of 2 steel containers for carriage use: € 150/month each one	€ 3.600
Installation and maintenance of the electrical system of the building site	€ 1.300
Rental of two lifting platforms for one year	€ 10.000
TOTAL ANNUAL FIXED COSTS OF THE BUILDING SITE	**€ 111.520**

The annual fixed cost for the building site is estimated at € 111.520,00. This data makes it possible to determine the total cost of the building site as the use of the technologies in question varies.

For the system in reinforced concrete and brick masonry:

[€ 2.537.222 + (€ 111.520 x 1,81)] = 2.739.073,20

For the dry system in steel:

[€2.753.565+ (€ 111.520 x 1,44)] = 2.914.153,80

For the dry system in CLT:

[€2.660.689+ (€ 111.520 x 1,23)] = 2.674.858,60

Table 20 - *Comparaison of costs, included fixed costs of the construction site, among different systems*

System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
€ 2.739.073,20	**€ 2.914.153,80**	**€ 2.674.858,60**

Therefore, from the more in-depth examination of construction costs, as shown in Table 20 analyzing in addition to the costs of supply and installation, also the fixed costs of the construction site and its duration, it emerges that the CLT dry construction system is the most convenient.

5.5 The comparison of energy performances

Considering the characteristics of the three technological solutions of the enclosure adopted in the project, described in chapter 4, the calculation of energy performance gave the results summarized in Table 21. In the same table are also reported the values obtained from the calculation of CO_2 emission in function of the technologies under consideration. The latter data is particularly relevant for the assessment of sustainability as defined by the most recent regulatory guidelines.

Table 21 - *comparaison of energy performances*

System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
Analysis of energy performances of the scholastic complex [EPgl, ren]		
17.281 KW/m²year Compared to steel	16.194 KW/m²year Compared to reinforced concrete	15.604 KW/m²year Compared to steel
CO_2 emissions of the scholastic complex		
4,43 Kg/m²year	6,98 Kg/m²year	3,99 Kg/m²year

The examination of the results shows that the dry technology in CLT gives significantly higher performances both in terms of energy efficiency and the containment of CO_2 emissions in the environment.

5.6 The comparaison of the useful surface in accordance with the technologies used

Considering the characteristics of the three technological solutions of the enclosure as defined in chapter 4, it has been deemed appropriate to compare the different useful surfaces of the rooms obtained from the use of the three technologies under examination. It is in fact believed that this parameter also contributes to making an economically more convenient technological choice. The result is shown in Table 22.

Table 22 - *comparaison of the useful surface*

Dimensional analysis [Useful surface]		
System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
5.065 m²	**5.010 m²**	**5.116 m²**

The examination shows that also in this case the comparison is favorable to the use of the dry system in CLT, which allows to have more useful surface available, precisely equal to 51 m2.

6. CONCLUSIONS

The work consisted in the design of a nearly zero-energy school complex (nZEB) in compliance with the requirements of the three interministerial decrees of 26 June 2015[7] that will be mandatory for all public buildings from 2019 and which will become mandatory for all the others new buildings starting from 2021.

The same spatial functional solutions of the definitive project have been developed in the executive project foreseeing the use of three different technological solutions, namely: a non-dry construction solution consisting of load-bearing structure in reinforced concrete and brick masonry, a dry solution with a steel supporting structure and finally a dry solution with a bearing structure in CLT.

From these design processes it was possible to make a comparison in relation to:

a. Costs and time of construction.

b. Energy performances.

c. Comparison on useful surfaces.

To determine the construction costs, on the basis of regional price lists, the CME was drafted to supply and install products and materials for each technology. Since the three technologies have different execution times, for the purposes of the comparison it was deemed necessary to draft the CME without taking into account the fixed costs of the builing site, which were calculated separately. From this CME it was then necessary to separate the cost of the manpower. With the cost of the manpower and the average daily cost, the size of the building site has been determined for each technological system in question. Assuming the hypothesis of an average daily presence equal to 18 workers and 250 working days per year, it was possible to calculate the duration of the building site thus obtaining the different durations of the building sites as the technological system expressed in years changes. With this data it was possible to draw up an analysis of the total costs of the building site which includes the costs of the works and the fixed management costs that vary with the duration of the construction site, which is equal to € 111.520 /year.

From this analysis, it emerges that the CLT and lamellar timber technology, with the same number of workers on building site, is the quickest to realize, with an estimate of construction of the building site equal to 1.23 years, while to follow, the steel with 1.44 years and the CA with 1.81 years. The total cost of the site is lower for the technology in CLT, equal to € 2.674.858,60, to follow the technology with construction system in reinforced concrete and brick masonry with a cost of € 2.739.073,20 and finally the technology with constructive system in steel with a cost equal to € 2.914.153,80. The total cost of steel technology is thus higher by about 8,95% compared to CLT technology, while the cost of concrete technology is about 2,35% higher than that of CLT, as shown in Table 23. The work also shows that also in relation to energy performance the system in CLT is at one time the most efficient and the most sustainable, being the one with the lowest CO_2 emission as shown in Table 21.

Finally, the greater value of the building with the wooden technology deriving from the larger surface area should be taken into consideration. In fact, from this comparison emerges the increase or decrease of the useful surface according to the technology used, due to the stratigraphies adopted necessary to achieve the design transmittance parameters. From the comparison we can see in Table 23 that the technology with a load-bearing structure in CLT is the one that has higher performances with reduced thickness and therefore allows to obtain a useful internal surface greater than the other two technologies considered.

The technology in CLT that in recent years has seen a significant technical construction refinement, has also the characteristic of being a system of dry construction that is well suited to the development of industrialization of the building process. It is believed that further investigations, aimed at further refining the development of all the phases of the process according to the use of this technology, could lead to further improvements in the efficiency of the building process and therefore a further decrease in both

Table 23 - *Comparison of construction times and costs*

System in reinforced concrete and brick masonry	Dry system with load-bearing structure in steel	Dry system with load-bearing structure in CLT
Metric estimate of building constructions		
€ 2.537.222	€ 2.753.565	€ 2.660.689
Estimate of construction times		
8.187 Men per day	6.487 Men per day	5.555 Men per day
1,81 Years*	**1,44 Years***	**1,23 Years***
* Assuming 18 workers working simultaneously and 250 working days a year		
Estimate of the total cost of the building site		
€ 2.739.073,20	**€ 2.914.153,80**	**€ 2.674.858,60**

[7] Specifically, these are the decrees published in the Italian Official Journal (Gazzetta Ufficiale) General Series n.162 of 15-07-2015 – Ordinary Supplement No. 39) concerning:

- Adjustment of national guidelines for the energy certification of buildings;
- Application of energy performance calculation methodologies and definition of provisions and of minimum building requirements;
- Schemes and methods of reference for the compilation of the technical project report for the application of the provisions and minimum energy performance requirements in buildings.

the direct construction costs and indirect financial costs. Taking into account the state of crisis in the sector, from the work carried out, it emerges that it is precisely in this direction that it is necessary to pursue and develop the research, having reason to consider this strategic for the revitalization of the construction sector.

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