POLITECNICO DI MILANO

School of Industrial and Information Engineering

Department of Management Engineering
Course of Energy and Environmental Management

HEATING AND POLLUTING CHARACTERISTICS OF SCHOOL BUILDINGS IN MILAN

AN ANALYSIS FOR IMPROVEMENT OF ENERGY CONSUMPTION IN THREE DIFFERENT MODELS ACCORDING TO AGE AND STRUCTURAL FEATURES

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ACADEMIC YEAR: 2019 - 2020

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ABSTRACT

Introduction and brief notes on extant knowledge

The mean age of school buildings in Italy is rather old and is estimated to be 52 years.
The majority of them was constructed after world war II with a peak incidence (30% of the entire sample) that is concentrated in the time frame 1961-1976, during the years of the economic and demographic expansion in Italy. Two earlier peaks of construction are related to the "*giolittian age"* at the beginning of the 20th century and to the *"fascist age"* between the two world wars.
A recent reports have estimated that 16% of school building have serious structural problems. Deficiencies related to environment and energy sustainability, are even more frequent and affects the majority of the sample. Heating and heat maintaining are, among these, one of the most relevant issue. This is responsible for elevated operating costs that could be significantly reduced by adopting simple technical measures.
Domestic heating is a major source of severe atmospheric pollution. The principle local pollutants are PM_{10} and $PM_{2,5}$ and NO_x . Any project for energy saving of a school building should take into account the new strict limitations to air pollution established by law and also indicated by the European Community .

Aim of the Study

The main objective of the study was to perform a technical evaluation and an economic analysis on costs, mainly derived from heating, on a sample of three school buildings in Milan and to propose accordingly three restorations projects. Although any single restoration project for any single building has its own peculiarities, the idea was to create then three different models that could in the future be applicable to other constructions with similar characteristics.
Secondary aims were to perform an analysis of the technical characteristics of the school buildings in Milan that have an influence on heating and an assessment of the pollutants concentrations in the Metropolitan Area of Milan in the last years including the recent COVID-19 shut down period.

Methods

Pollutants concentration assessment: Unpublished data requested and obtained from *ARPA Lombardia*, were personally analyzed. These were referred to the pollutants detection station of Brera, located in the city Centre. This choice was motivated by the need to reduce at minimum the influence of pollutants produced by traffic. As the matter of fact Brera is located in the Area C, a limited traffic zone.

Technical characteristics of the school buildings in Milan Data for this analysis were obtained from the Technical Area for heating and cooling of the Municipality of Milan . Missing information were retrieved from *Certificazione Energetica degli Edifici (CENED) Infrastrutture Lombarde*, from the *Geo Map,* the portal of the Municipality of Milan, and from the Italian Ministry of Education (MIUR). A comparison with the Italian situation was possible, when useful, consulting data recently reported by Fondazione Agnelli on an overview of the Italian educational system.

Different projects on heating production and dispersion on a sample of four school buildings. The following buildings were selected for sample analysis:

Villa Simonetta seat of the Musical School Claudio Abbado: an historical building belonging to the XV century. Any renovation or refurbishment or even maintenance work on it should meet the strict conditions imposed by strict protocols.

The comprehensive School Stoppani: built in the first years of the last century is the typical school building belonging to the Giolittian Age.

The Comprehensive School, *Einaudi Pascoli:* built in 1974 is a traditional example of low quality buildings constructed during and soon after the demographic post-war boom.

The Citylife, Nursery School: built in 2018 is a virtuous and rare example in Italy of a Nearly Zero Emission Building

The following characteristics were considered for the preliminary **technical analysis**: heated volume, material of construction, window characteristics, source of energy supply, source of energy diffusion, air exchange modality , thermal and electrical loads

For any proposed intervention thermal and electrical energy savings were calculated together with Capital Expenditure (CAPEX) and Operating Expense (OPEX)

The economic analysis was conducted according to different scenarios: voluntary vs reinforcement replacement, with or without incentives.

The financial indicators considered for analysis were the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Pay-Back Time (PBT).

Results

I) Pollutants concentration assessment: domestic heating is responsible for 25% and 30% and 14% respectively of PM_{10}, $PM_{2,5}$ and NO_x emission in the area of Milan.

While for PM_{10} and $PM_{2,5}$ the *mean concentration / year* resulted to be within the limits established by the DIRECTIVE 2008/50/EC. Nevertheless, the number of days exceeding the maximum allowed concentration of PM_{10} (threshold 50 µg/m^3) still remains always consistently above the requested limits in the last five years (35 days): 2015 (101 days), 2016 (73 days), 2017 (97 days), 2018 (79 days), 2019 (72 days).

The thermal year (October – April) and in particular the trimester December- February are the most critical period for concentration of particulate (PM_{10} and $PM_{2,5}$) due to the lower temperature and consequently the maximum emissions from heating system.

The *mean concentration / year* of NO_2 still consistently above the limit imposed by law in the Metropolitan Area of Milan. The maximum week concentration levels of NOx are typically registered in the Area of Milan in the second and third week of December (mean 2015-2020, 214 and 272 µg/m^3 respectively).

During the recent lock-down period (March-April 2020) imposed by the SARS-CoV-2 pandemia environmental concentration of PM_{10} and $PM_{2,5}$, did not significantly change as compared to mean values in the same months of the previous years. On the contrary, NO_x concentrations showed a consistent reduction with values significantly below the historic registrations of the last five years mainly due to the drastic limitation to traffic imposed.

II) Technical characteristics of the school buildings in Milan: The mean age of school buildings in Milan is 54 years. The majority of school buildings (63%) were constructed according the plugging technique. Load bearing constructions account for 14,4% of buildings. Aluminum is the most frequently used material for doors and windows, (73%). Wood accounts for only 23%. Gasoline thermal plants are still in function only in a minority of school buildings (3%). Nevertheless, methane still represents the heating source in 82% of the sample. Alternative sources of energy for heating represents a small portion of the sample: heating districts 12%, renewables energy 3%. Radiators still remain the main source of heating diffusion (86%). Other poorly represented ways of heat diffusion are fan coils (7%), aerothermal systems (5%) and radial panels (2%). Air exchange is mainly provided by natural ventilation (93%). Only 40% of school building in Milan have already undergone any kind of technical assistances aimed at energy savings.

III) Three projects on heating production and dispersion on a sample of four school buildings.

1 . Villa Simonetta seat of the Musical School Claudio Abbado. Intervention project:

A) Substitution of a classic methane condensing furnace with a an electric heat pump .

Electricity consumption + 56.181 €/year. Methane consumption – 62.287 €/year

Cost for energy consumption: - 6.106 €/yr

The high initial investment required for the installation of an electric heat pump system as compared to that required for a traditional methane supported plant (85.000 € versus 40.000 €) is economically not sustainable without incentives from the administration. In our specific case , considering a useful life of 15 years, the Net Preserve Value (NPV) in a Voluntary Replacement scenario of the intervention without incentives was – 28.492 € with a pay-back time (PBT) of 22 years .

B) Substitution of radiators with fan coils

Due to the cost of investment (34.340 €) and no energy saving , the economical scenario of an electric thermal plant associated to an air diffusing system is even worse than that above presented and should not be taken into account without incentives and without considering evident benefits on air pollution and ambiences comfort .

C) Installation of a building integrated photovoltaic (PV) system. This innovative but highly expensive solution of building integrated PV tiles (3500 €/kW installed) seemed to be the best solution due to the limitations imposed by the Fine Arts.

NPV (25 yrs) without incentives = -7.252 € - with incentive = 94.270€ - PBT without incentives 28 yrs - with incentive 11 yrs. Incentives are necessary for an economical viable results.

D) Substitution of fluorescent with led lamps.

This intervention allows a 60% reduction of electricity consumption (15.488 vs 62.264 kWh/yr) and is thus an easy to accomplish and economically viable solution for energy saving: without incentives. NPV (10 yrs) = 13.000 € - PBT = 19 months.

2 . Antonio Stoppani comprehensive school. Intervention project

A) Installation of a Building Energy Management (BEM) system

A BEM systems is aimed at monitoring and controlling services such as heating, ventilation and air-conditioning, ensuring the building operates at maximum levels of efficiency. The installation of a BEM system can guarantee high levels of thermal and electrical energy saving . In our case study, considering a thermal energy saving of 30% (37.500 m^3 /year of methane) the bill for methane consumption was reduced from 91.360 €/ yr to 63.960 €/ yr. Considering an electrical energy saving of 50% the costs for electricity were reduced from 57.326 €/yr to 28.633 €/yr.

NPV (10 years) = 418.250 € - PBT = 11 months.

BEM system are thus to be considered highly viable solution for energy saving.

B) Installation of traditional panel photovoltaic (PV) system.

Less expensive traditional PV panels (1325 €/kW installed) seemed to be the best solution for this building.

NPV (25 yrs) without incentives = 35.116 € - with incentive = 46.825 € - PBT without incentives 8 years - with incentive 5 yrs.

3 . Einaudi Pascoli Primary School. Intervention project

A) District heating

District heating systems are an alternative, safe and efficient solution for heating production. With district heating the production of heat is centralized and is assigned to a single high-efficiency plant. The Silla 2 central heating plant (*A2a Calore e Servizi*) is located in the north-west suburbs of Milan and its network could technically quite easily be connected in the future with the area of the school. One important economic advantage is represented by the absence of any initial and maintenance cost . This make possible an immediate 6,6% year cost reduction for thermal energy that account in our case study for a saving of 4.622 €/yr.

B) Rain screen cladding insulation on partitions and rooftops

The installation of a rain screen cladding is a solution aimed at improving the energy performances of buildings that are characterized by the poor features of materials of construction as in this case study.

The most significant technical result was the reduced heat dispersion of the building expressed by a decreased transmittance value 1,4 → 0,163 W/ m^2K and 1,63 → 0,162 W/m^2K for partitions and roof tops respectively. This resulted in a 15,3 % thermal energy saving (13'641,7 € / year).

Due to the high cost of the intervention (550.000 € in our case study) incentives are also necessary for rain screen cladding to sustain the economical feasibility of the project.

C) Installation of an air handling unit

An air handling unit (AHU) , is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning system.

In this study the installation of a AHU was considered particularly necessary for the Pascoli comprehensive institute that is characterized by low values of natural air exchange due to the poor architectural design.

The most relevant economic advantage derived from a AHU system is provided, in our case, by a 6,4% thermal energy saving obtained by the limitation of natural air exchange that is today possible only by opening windows and doors. This was calculated to be 5.700 €/yr.

Conclusion

The majority of school buildings in Italy and in the Metropolitan Area of Milan are characterized by problems related to environment and energy sustainability. Heating and heat maintaining are , among these, one of the most relevant issue.

Since the construction of new school building is no longer a priority, the future challenge for central and local school administrations is represented by the necessity of financing new and extensive programs for the implementation of the existing architectural heritage.

Among the different technical solutions that were considered in the present study, some resulted to be highly effective and economically viable. This was the case of BEM system installation and connection to heating districts. Others (electric heat pumps, PV plants, air handling units and rain screen cladding) require adequate incentives in order to results economically sustainable.

Nevertheless, regardless any economic issue, the restoration of the old Italian school building heritage according to the recent severe national and European regulations has become the new mandatory challenge of national and local administrations of the educational system.

Limitations

The main limitation of this study is represented by the lack of any economic analysis to calculate secondary but not less important benefits on atmospheric pollution, safety and environmental increased comfort of the school ambiences.

Moreover data regarding technical characteristics of school building were difficult to retrieve from the public administration and frequently incomplete and not up-to-date. The recent shut down period has deeply worsened this condition.

INTRODUCTION AND LITERATURE REVIEW

1. NUMBER AND DISTRIBUTION OF SCHOOL BUILDINGS AND STUDENTS IN ITALY, LOMBARDY AND IN THE MUNICIPLITY OF MILAN

1A. An overview of school buildings distribution in Italy.

As an introduction to this project, it seems reasonable to draw an overall picture of school buildings in our country according to different regional location.

Italy is divided in 20 regions. **Table 1** describes the distribution of school buildings in each of them.[1] We have taken into account kindergarten, primary schools, secondary schools of first and second degree. The hypothetical number of students and mean number of students for each institution have been calculated taking into account the percentage of inhabitants aged 3-19 yrs in each region according to ISTAT figures[2]

School Buildings and School Population in different Regions of Italy					
REGION	# schools	# inhabitants	(3-19 yrs) %	N° students (3-19 yrs)	#student/#school
Abruzzo	1919	1326513	14,5%	192344	100
Basilicata	1071	573694	14,7%	84333	79
Calabria	3992	1970521	15,4%	303460	76
Campania	8512	5850850	17,3%	1012197	119
Emilia Romagna	4288	4448146	14,9%	662774	155
Friuli	1476	1221218	14,1%	172192	117
Lazio	5742	5888472	15,6%	918602	160
Liguria	1732	1571053	12,9%	202666	117
Lombardy	9746	10008349	16,0%	1601336	164
Marche	1937	1543752	15,0%	231563	120
Molise	607	312027	14,1%	43996	72
Piemonte	4970	4404246	14,8%	651828	131
Puglia	4546	4077166	16,1%	656424	144
Sardegna	2522	1658138	13,7%	227165	90
Sicilia	7408	5074261	16,7%	847402	114
Tuscany	4090	3744398	14,8%	554171	135
Trentino	1094	1059114	17,5%	185345	169
Umbria	1226	891181	14,7%	131004	107
Valle d'Aosta	125	127329	15,7%	19991	1249
Veneto	5452	4915123	15,9%	781505	143
TOTAL	**72346**	**60665551**		**9480295**	**131**

***Table 1**: number of schools in Italy distributed according to each region. Number of students and mean number of students for each institution has been calculated taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figure*

1B. An overview of school buildings distribution in Lombardy

Lombardy with its over 10 million inhabitants is the most populated region in Italy and the third in Europe. Lombardy administration is divided in 11 provinces and 1 metropolitan area of Milan and includes 1523 municipalities. **Table 2** describes number of schools and their distribution in Lombardy[1]. The hypothetical number of students and mean number of students for each building have been figured taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figures.

School Buildings and School Population in different Provinces of Lombardy					
province	# school	# inhabitants	(3-19 yrs) %	N° students (3-19 yrs)	#student /#school
BG	1228	1108298	17,20%	190627	155
BS	1380	1264105	16,90%	213634	155
CO	682	599654	16,00%	95945	141
CR	417	360444	15,00%	54067	130
LC	423	339254	16,20%	54959	130
LO	258	229413	16,20%	37165	144
MN	464	412868	16,20%	66885	144
MI*	2383	3208509	15,80%	506944	213
MB	685	866076	16,30%	141170	206
PV	577	547926	14,60%	79997	139
SO	300	181712	15,60%	28347	94
VA	949	890090	16,00%	142414	150
TOTAL	**9746**	**10008349**	**16,00%**	**1601336**	**164**

Table 2 *number of schools in Lombardy distributed according to each Province. Number of students and mean number of students for each institution has been calculated taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figures. *metropolitan area*

1C. An overview of school buildings distribution in the Metropolitan Area of Milan

The Metropolitan Area of Milan is represented by the city of Milan and the urban agglomeration surrounding it. It accounts for roughly 3 250 000 inhabitants divided into 133 municipalities.

The city of Milan itself accounts for nearly 1’400’000 inhabitants

Table 3 describes number of schools in Milan compared to other most populated municipalities of its metropolitan area[3]. Number of students and mean number of students for each institution have been calculated taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figures.

School Buildings and School Population in different Municipalities of the Metropolitan Area of Milan					
Municipality	N° schools	N° inhabitants	(3-19 yrs) %	N° students (3-19 yrs)	#student/#school
Abbiategrasso	23	32610	16,80%	5478	238
Arese	18	19495	16,80%	3275	182
Bollate	27	36564	15,40%	5631	209
Cologno	38	47682	15,40%	7343	193
Corsico	24	34715	15,20%	5277	220
Magenta	30	24002	15,20%	3648	122
Milan	**938**	**1378689**	**14,70%**	**202667**	**216**
Pioltello	28	37002	18,00%	6660	238
Rho	49	50602	14,80%	7489	153
Segrate	29	35935	17,10%	6145	212
S. S. Giovanni	70	81393	15,30%	12453	178

***Table 3**: number of schools in Milan compared to others most populated municipalities of its metropolitan area. Number of students and mean number of students for each institution has been calculated taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figures.*

1D. An overview of school buildings distribution in different areas of Milan

This paragraph describes the distribution of school buildings according to their destination in the different areas of Milan.

The city of Milan was historically divided in 20 “administrative” zones until 1999. These were successively gathered in 9 larger zones that were named municipalities in 2016. Since then each municipality is administered by elected members.

Table 4 represents an overview of educational institutions and school buildings in the nine municipalities of the city of Milan[4]. Although the most peripheral zones (7, 8 and 9) accounts for a larger number of students, the percentage number of school buildings and institution in central municipalities are higher due to the central location of secondary schools of second degree and professional schools.

School Buildings and School Population in different Municipalities of the Metropolitan Area of Milan					
Zones	N° inhabitants	N° students (3-19 yrs)	N° schools	student/school	buildings
1	98531	14484	155	93	76
2	162090	23827	87	273	49
3	144110	21184	124	170	56
4	161551	23748	77	308	47
5	126089	18535	70	264	36
6	151291	22240	87	255	50
7	175465	25793	104	248	60
8	188367	27690	114	242	63
9	187773	27603	118	233	63

Table 4*: number of schools in different municipalities in the city of Milan. Number of students, and mean number of students for each school have been calculated taking into account the percentage of inhabitants aged 3-19 yrs according to ISTAT figures (14,7%).*

1E. An overview of schools and school buildings under the direct management of the Municipality of Milan

In this project we have focused our analysis mainly to public school buildings under the direct economic and technical management of the Municipality of Milan: nursery schools, kindergartens, primary schools, secondary schools of first degree and others (civic schools, night schools, etc).

Table 5 details the 499 schools gathered in the 364 buildings of which we have obtained detailed information, according to level of institution, from the technical school administration of the Municipality of Milan

Municipality of Milan- School destination	
civic school	3
school for disabilities	7
night school	5
polyfunctional school	1
primary school	127
secondary school	88
kindergarten	164
Arabic school	1
Jewish school	1
nursery school	101
film school	1

***Table 5** a description of schools under the direct management of the Municipality of Milan according to destination The sample and the number of utilities taken into account have been gathered from the Milan municipality database during the internship period.*

Some observations need to be done:

- Secondary schools of second degrees are not under the direct control of the municipality authority. The administration of Metropolitan Area of Milan (Province of Milan until 2014) is responsible for their management.
- The main school categories are nursery school (infants 1-3 years), kindergarten (toddlers 3-6 years), primary school (children from 6-11 years), secondary school of first degree (boys and girls from 11-14 years. However, other kinds of school building that are intended for other kind of users should to be considered.
- Number of school buildings and number of school utilities should not be considered the same. As a matter of fact, in some cases more than one utilities are concentrated in a single building.

Table 6 details three examples of different institutions according different utilities included in a single building.

BUILDING CODE	ADDRESS	UTILITY
S 434	via Moscati, 1/5	primary school
	via Moscati, 1/5	secondary school
S 426	via Porta Nuova, 4	primary school
	via Porta Nuova, 6	kindergarten
S 438	via Pisacane, 9	primary school
	via Pisacane,11-13	secondary school
	via Goldoni, 13	kindergarten
	via Goldoni, 13	nursery school

. ***Table 6****: depicted three examples of different institutions included in a single building*

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2. HEATING AND ENVIRONMENTAL REQUIREMENTS OF BUILDINGS AND SCHOOL BUILDINGS

2A. The Climatic Zone

The climatic zone concept has been introduced in Italy by the D.P.R. n.412 on August 26 1993, for energy savings purposes. It is an alphabetical index that summarize three main pieces of information: **heating degree day**, **heating period**, and **daily hours of operation**.

The definition for **Heating degree days (HDDs)** is "*number of degrees that a day's average temperature is below 20 C°, the target temperature, which is the temperature below which buildings need to be heated up.*"

In Italy, the thermal band are classified in six different groups from A (very hot weather) to F (very cold weather) depending on the area and municipality considered. Below **Table 7** summarizes the inherent characteristic of each climatic zone:

THE CLIMATIC ZONES			
Climatic Zone	HDDs (at To = 20 C°)	Heating period	# Hours per day
A (e.g. Lampedusa)	< 600	1st Dec - 15th Mar	6 hours per day
B (e.g. Trapani)	600-900	1st Dec - 31st Mar	8 hours per day
C (e.g. Naples)	901-1400	15th Nov - 31st Mar	10 hours per day
D (e.g. Rome)	1401-2100	1st Nov - 15th Apr	12 hours per day
E (e.g. **Milano**)	2101-3000	15th Oct - 15th Apr	14 hours per day
F (e.g. Belluno)	>3000	no limitation	no limitation

Table 7 the climatic zones in Italy HDDs = heating degree days, To = ambient temperature. Heating period and # hours per day: allowed by law

Although Italy is a relatively small country, due to its geographical characteristics, it is characterized by numerous climatic zones that go from the extreme south of the peninsula (zone A) to the alpine regions next to the northern national borders (zone F).

The HDDs depicted in column 2, are cumulative data related to the overall seasonal heating period.

The next paragraphs will go deeper into detail on HDDs with formula and numbers.

Milan, the object of our study, is located inside the climatic zone E that refers to a quite harsh climate during the winter with the thermal season included between 15th Oct and 15th Apr. Heat operating hours per day are 14, freely chosen from 5 am to 11 pm. In the residential sector of the city must be switched off from 11 pm to 5 am due to energy-saving issues.

2B. Indoor Ambient Temperature of School Buildings

Ambient temperature and number of hours of heating requested during the day in the heating season are parameters required according to an internal regulation of the municipality of Milan.

Since heating conditions of school building are contracted to private companies, lack of achievement is liable of penalties for non-compliance with legal obligations and may lead to contract interruption.

Table 8 describes target temperature required and duration through the day in different schools according to characteristic of institutions and to different rooms in them included.

TARGET TEMPERATURE REQUIRED IN DIFFERENT SCHOOL BUILDING OF THE MUNCIPALITY OF MILAN					
FOR DESTINATION	ROOM	WEEKDAY	FROM	TO	T (C°)
nursery school	classroom	from Monday to Friday	7.00	18.00	22
	office				20
	medical office				22
kindergarten, primary and secondary	classroom	from Monday to Friday	8.00	18.00	20
	medical office				22
school with night activities	classroom	from Monday to Friday	8.00	22.00	20
	office				20
	medical office				22
	gym				17
school for disabilities	classroom	from Monday to Friday	8.00	18.00	22
	office				20
	medical office				22
	gym				22
sportive centre	gym	during school activity	8.00	18.00	17
	locker room				22
	shower stall				22
school swimming pool	pool room	during school activity	8.00	18.00	28-32
	locker room				28-32
	shower stall				28-32
every school building	all the rooms	from Saturday to Sunday	0.00	23.59	7
	caretaker home	from Monday to Sunday	5.00 to 23.00 (max 14 h)		20

. ***Table 8**: target temperature required in different school buildings of the municipality of Milan*

Below some considerations concerning this matter:

- ✓ The target temperature required inside the classroom varies according to the kind of users considered. For instance, in nursery schools and schools for disabilities the ambient temperature should be 22C° in order to guarantee better conditions during study hours for infants and students with disabilities
- ✓ Target ambient temperature required should not be the same in a single school building. Different rooms require different target temperatures according to the activities. Medical offices need obviously a high level of standard temperature defined at 22 C°. Locker rooms also need this higher level of target temperature. Swimming pools and shower rooms annexed, as in Vespri Siciliani Primary School, require air temperatures in a range of 28 C° to 32C°. In gyms it is admitted and requested to keep temperature inside the room at the lower level of 17°C.
- ✓ Another consideration should be made on the operating hours of buildings during the heating season. In general, the activities run from Monday to Friday and from 8.00 am to 6.00 PM with few exceptions. For night schools, target temperature is due until 10.00 PM. In nursery school target temperature should be anticipated at 7.00 AM.
- ✓ During weekends or vacation periods, when activities are suspended, all the ambiances should anyway keep an indoor temperature above a 7 C° threshold, mainly for two reasons:
    1. Costs and environment pollution required to reach an adequate ambient temperature at restart of activities would be higher due to loss of efficiency of the systems.
    2. A second issue is related to the water pipes in the building. At a temperature of 0 C°, the ice point of water at ambient pressure, the volume inside pipelines would increase with the risk of damaging the heating and hydraulic systems causing a loss of water inside the walls meaning additional maintenance costs.
- ✓ Additional consideration should be made for the caretaker apartments inside the school. For these residential accommodations, the same rules as for household sector are applied: heating systems can be turned on up to 14 hours a day from Monday to Sunday

- ✓ It has finally to be considered that heating time schedule required sometime an extension due to extraordinary activities conducted outside the official time-table (e.g. parents' assemblies, cultural events, open days and others

3. A BRIEF ANALYSIS OF ENVIRONMENT POLLUTANTS CHARACTERISTICS

Environment pollutants can be schematically divided in two categories:

A: Global warming pollutants

B: Local environmental pollutants

3 A Global warming pollutants

Also named as **green house gases (GHG)** these are gases that trap heat in the atmosphere

This definition is mainly referred to **carbon dioxide (CO_2)** that accounts for 80% of emissions in the atmosphere (**Figure 1A**).

Carbon Dioxide (CO_2) according to the definition of EPA (Environmental Protection Agency – United States) is: "*A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal human caused greenhouse gas that affects the Earth's radiative balance".*

Other global warming pollutants are:

Methane (CH_4) "*is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills."* (EPA definition)

Nitrous oxide (N_2O) "*is emitted during agricultural and industrial activities, combustion of fossil fuels and solid waste, as well as during treatment of wastewater."* (EPA definition)

Fluorinated gases "*Hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes."* (EPA definition)

Figure 1A is a schematic representation of GHG emissions in 2018.[5] **Figure 1B** is a schematic representation of the CO_2 emissions worldwide in the last six decays[6].

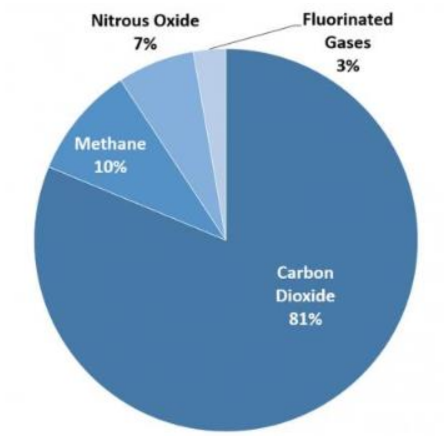

Figure 1A: *Total world emission of green-house gases in 2018 (obtained by EPA)*

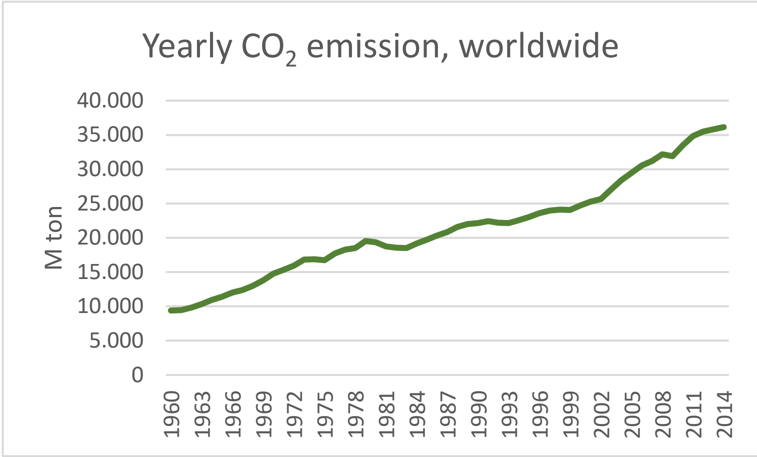

Figure 1B: *Total world emission of CO_2 in the last six decays. (personal representation from data obtained by World Bank Data)*

CO_2 emissions and in general environment degradation are typical expression of the industrial development of a country. These are mainly concentrated in the first industrial expansion period and should go to plateau and hopefully decrease in the post-industrial service era in direct proportion with Gross Domestic Product (GDP) of a country according to Kuznet theories that can be applied also to environmental pollutions[7].

Figure 2A is a schematic representation of environmental degradation according to CO_2 according to Kuznet theories

Figure 2B represents total CO_2 emissions in the last four decays in three countries with different industrial characteristics: Italy (post-industrial), Thailand (industrial), Madagascar (pre-industrial).

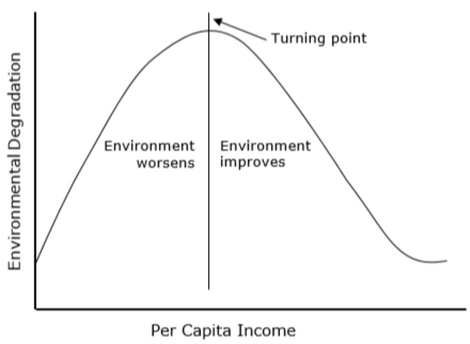

***Figure 2A**: The environmental Kuznets curve*

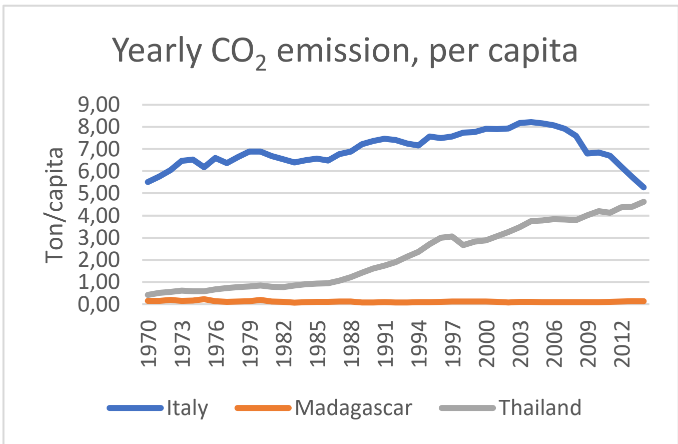

***Figure 2B**: CO_2 emissions per capita, in countries with different industrial levels*

As already mentioned, CO_2 is the most relevant cause of global warming in the world.

According to a report from Politecnico of Milan[8] on a sample of five Italian urban agglomerates, heating systems are responsible for CO_2 emissions up to six times larger than those produced by traffic and industrial processes. (**Table 9**)

City	Heating systems	Urban transports	Industrial processes
Milan	74%	10%	16%
Genoa	47%	6%	47%
Florence	75%	9%	16%
Parma	63%	11%	26%
Perugia	62%	15%	23%
Mean	64,2%	10,2%	25,6%

***Table 9**: Incidents of environment pollution by CO_2 in five Italian cities (Source Politecnico of Milano)*

In 2019, the Municipality of Milan has approved a plan for corrective actions also addressed on heating systems for reduction of 45% CO_2 emission in the next ten years and is expected to be a carbon free area by 2050.[9]

Nevertheless, since CO_2 emission represents a global issue, it will be not the main object of this thesis that will be particularly concentrated on local pollutants.

3B: Local environmental pollutants

These are dependent on morphological characteristics of the geographical area considered and on the industrial activities that is conducted in it..

The main local environmental pollutants and their definition according to EPA (Environmental Protection Agency – United States)[10]are:

Particular Matter 10 (PM10): indicating "*inhalable particles, with diameters that are generally 10 micro-meters and smaller*".

Particular Matter 2,5 (PM2,5): indicating "*fine inhalable particles, with diameters that are generally 2.5 micro-meters and smaller*".

Nitrogen Oxides (NO_x): *"a family of poisonous, highly reactive gases. These gases form when fuel is burned at high temperatures. NOx pollution is emitted by automobiles, trucks and various non-road vehicles (e.g., construction equipment, boats, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines.".*

Nitrogen Dioxide (NO_2): is the most harmful to human health and to the environment among the NO_X family pollutants.

Ozone (O_3): "*at ground level (troposphere) is a harmful air pollutant, because of its effects on people and the environment, and it is the main ingredient in "smog".*

Figure 4 is a schematic representation of sources and chemical interactions responsible for local pollutant emissions that will be briefly described below

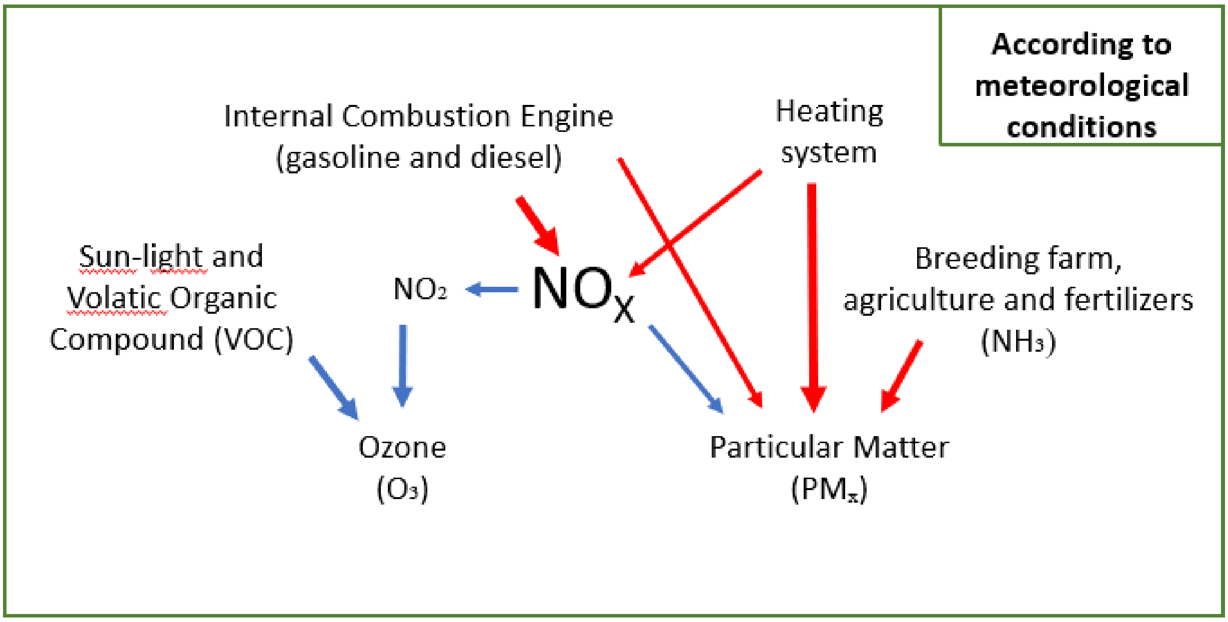

Figure 4*: a schematic representation of sources and chemical interactions responsible for local pollutant emissions*

-Winter and summer local pollutants-

Local pollutant emissions are significantly dependent on atmospheric conditions and temperatures.

PM_{10} and NO_2 (**winter local pollutants**) have their incident peak during the cold season for two main reasons:

- ✓ Heating systems are an additional source to their emissions
- ✓ Weather conditions (temperature and pressure) promote their concentration

On the contrary, peaks of O_3 (**summer local pollutant**) emission are typically reached during the hot season, being its production mediated by photo-dynamic reactions. As a matter of fact, Ozone is not emitted directly but is formed through chemical reactions in the atmosphere between NO_X, O_2 and Volatile Organic Compound (RO_X) with heat and summer sun light.

$NO_2 + hv\ (l < 420\ nm) \rightarrow O + NO$

$O + O_2 \rightarrow O_3$

$NO + O_3 \rightarrow NO_2 + O_2$

$NO + RO_x \longrightarrow NO_2$ + other products

Figure 5 is a graphic representation of seasonal peak emissions of different local environmental pollutants in 2019 in the Metropolitan Area of Milan according to ARPA (Azienda Regionale per la .Protezione Ambientale)[11]

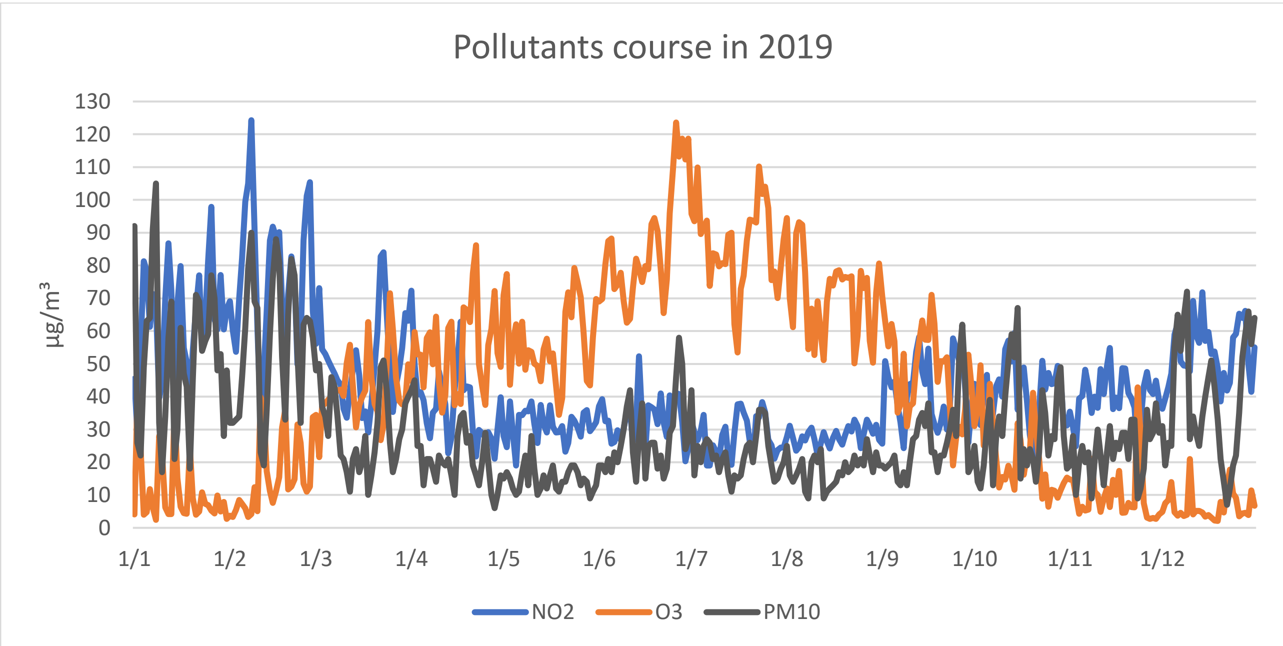

***Figure 5**: pollutant emissions in Metropolitan Area of Milan during 2019. Personal representation from data of by ARPA (Azienda Regionale per la .Protezione Ambientale)*

3 C: Primary and secondary sources of pollutant emissions-

Pollutant agents can also be classified according to their modality of generation.

Pollutants generated by **primary sources** are those emitted directly into the atmosphere by natural or human activities.

Typical primary generated pollutants are PM_X, NO_X (primary sources: traffic, heating and industrial systems etc) and NH_3 (primary sources: breeding farm, agriculture, fertilizers).

Pollutants generated by **secondary source** are those combined subsequently in the atmosphere by chemical reactions.

A typical secondary generated pollutant is O_3 according to the above mentioned process on NO_2.

PM_X and NO_2 are also secondary generated according to the following processes

Ammonia gas in the atmosphere reacts with sulfuric (H_2SO_4) and nitric acids (NO_3) to create the ammonium sulphate [$(NH_4)_2SO_4$] and nitrate (NH_4NO_3):

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

$$NH_3 + NO_3 \rightarrow NH_4NO_3$$

These products exist in the atmosphere as form of particular matter ($PM_{2,5}$).

NO together with a small percentage of NO_2 (5%) is generated from internal combustion of gasoline or diesel at high temperatures (1250 C°)

NO_2 is the oxidation product of NO in the atmosphere:

$N_2 + O_2 \rightarrow 2NO$ (generated by primary source)

$2NO + O_2 \rightarrow 2NO_2$ in presence of excess of oxygen (generated by secondary source)

4. LEGISLATIVE AND REGULATORY ACTS

4A: Legislative decree n° 28, March 3rd 2011

This decree accepts the ordinances of the European Community 2001/77/CE and 2003/30/CE and imposes the allocation of renewable sources for new buildings and for those with a plant surface > than 1000 m^2 undergoing significant restoration. "*Significant restoration"* means a complete restructure of the building coat or buildings subject to demolition and reconstruction. In particular, this legislative decree makes a must for these building categories to recover at least 50% of domestic hot water (dhw) and 50% of the sum of consumption for dhw, heating and cooling with thermal energy production plants from renewable sources. These percentages must be increased by 5% for public constructions as in the case of school buildings.

This same legislative decree considers renewable sources wind, solar, hydro, biomass, biogas, geothermic and tide energies.

In Lombardy, an energy diagnosis of the building must be conducted to compare the available alternatives during a restoration or for all new installations of a thermal power plant higher or equal to 100 kW.

Besides, the act 28/2011 gives instructions to install photovoltaic plants with a minimal electric power surface unit equal to 20 W/m^2. This constraint is reduced by 50% in historical centre areas.

4B: CAM (Criteri Ambientali Minimi) legislative decree n°259, October 11th 2017

In this ordinance, the Public Institution (Italian Ministry of the environment) enters in details in the field of energy and of sustainability designs. Before this, the energetic and environmental sustainability were certified only for private building sectors according to LEED and BREEAM protocols (see below).

According to legislative decree n°259, October 11th 2017, new construction projects must guarantee that the overall energy requirements inside the building are obtained by renewable sources or systems with high efficiency (as cogeneration and trigeneration) with an incremental value of 10% compared to the legislative decree 28/2011. The law also requires to ensure an internal environmental quality that respects a number of parameters such as natural lighting, air ventilation, sun protection and thermo-hygrometric comfort to protect life inside the building.

4C: F-Gas decree n° 517, 2014

Energy efficiency and environmental condition in heating, ventilation, air conditioning (HVAC) systems depends not only on the kind of components involved but also on the type of refrigeration fluid chosen. All fluids available in the market produce a greenhouse effect. The most common ones used are R134a and R410A with an index of global warming potential (GWP) respectively of 1300 and 2088. The F-Gas n°517 act imposes to reduce progressively the consumption of both these fluids from a percentage of 37% as reported in 2018 to a 79% expected in 2030. These fluids need to be replaced with other synthetic products such as R1233ze that is characterized by a significantly lower GWP value of 7.[12]

4E: Ministry of Education Decree, 18/12/1975: *Technical indications for scholastic buildings.* Paragraph 5.3*: heat, humidity and air purity requirements.*

Paragraph 5.3.12, **air purity requirements**: the following external air flow rate, should be guaranteed by means of adequate systems: i) rooms used for group teaching activities. For kindergartens and primary schools air exchange coefficient (AEC = number of complete air replacement in one hour) 2,5. For secondary school of first-degree AEC = 3,5. For secondary school of second-degree AEC = 5. ii) Other connecting ambientes or offices AEC = 1,5. iii) toilets, gyms, refectories AEC = 2,5.

Heat: see Table 6.

4F: DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe

This important directive of the European Commission among other issues on ambient air quality, defines limit values and alert thresholds for air pollutants, among which PM10 and NO_2. Below we report Article 13 on such issue and a schematic definition on limit values adopted.

Italy has transposed this European Directive with the **Legislative Decree August 13th, 2010.**

Article 13 Limit values and alert thresholds for the protection of human health

"Member States shall ensure that, throughout their zones and agglomerations, levels of sulphur dioxide, ***PM10,*** *lead, and carbon monoxide in ambient air do not exceed the limit values laid down in* ***Annex XI****. In respect of* ***nitrogen dioxide*** *and benzene, the limit values specified in Annex XI may not be exceeded from the dates specified therein."*

ANNEX XI: LIMIT VALUES FOR THE PROTECTION OF HUMAN HEALTH

Limit values

Averaging Period	Limit value	Margin of tolerance	Date by which limit value is to be met
Nitrogen dioxide			
One hour	200 μg/m^3, not to be exceeded more than 18 times a calendar year	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010	1 January 2010
Calendar year	40 μg/m^3	50 % on 19 July 1999, decreasing on 1 January 2001 and every 12 months thereafter by equal annual percentages to reach 0 % by 1 January 2010	1 January 2010

Limit values

Averaging Period	Limit value	Margin of tolerance	Date by which limit value is to be met
PM_{10}			
One day	50 μg/m^3, not to be exceeded more than 35 times a calendar year	50 %	— (1)
Calendar year	40 μg/m^3	20 %	— (1)

4G: BREEAM certificate

BREEAM (*Building Research Establishment Environmental Assessment Method*) is an international scheme dated 1988 and provided by BRE (British Research Establishment) that provides independent third-party certification of sustainability performance on individual buildings, community, and infrastructure projects. BREEAM measures sustainable value in a series of categories: energy, pollution, waste, water, health and well-being, innovation, land-use, materials and management. Each of one is given a credit. The category scored is calculating according to the number of credits achieved and its category weighting. The final performance is determined by the sum of weighted category scores that gives to the project one of the following certification: pass, good, very good, excellent, outstanding.

Special BREEAM certifications adopted for school buildings are available (BREEAM International New Construction, BREEAM International Refurbishment & Fit-Out, BREEAM In-Use International)[13]

4H: LEED certificate

LEED (Leadership in Energy and Environmental Design) certification established in 1993 by the United States Green Building Council and is now diffused in more than 140 countries. It provides and independent third-party verification that a building was designed and built according to strategy aimed at achieving high performance in key areas of human and environmental health. Categories evaluated are similar to those already detailed for BREEAM. A Green Building Council Italy has been active since 2008. Protocols and certifications dedicated to school buildings are also available among the LEED family (LEED V4 for Building Design and Construction: Schools)[14].

4I: ITACA PROTOCOL

In Italy, an assessment method called "ITACA Protocol" has been devised and used in several ways by institutions. ITACA Protocol is a multicriteria method to evaluate the environment and the energy performance of building. ITACA Protocol consists of 35 criteria, each one regarding an environmental or energy aspects of the system building-plant and the site. The criteria are divided in 5 category: 1. Quality of site 2. Resource consumption 3. Environmental load 4. Indoor environmental quality 5. Quality of the service For each criteria, a score is assigned from -1 to +5. Score 0 represent the benchmark (law limits if available or typical acceptable practice) and positive score correspond to better practice. Negative score means that the building in a particular aspect is poor of quality, less than the benchmark. The total score is calculated by multiplying the score of each criteria by its appropriate weight and then adding the scores of all criteria.

Protocols and certifications dedicated to school buildings are also available among the ITACA family (National ITACA Protocol for School buildings 2011).[15]

5.AIMS OF THE STUDY

This thesis was designed to reach the following targets:

A. An analysis of the mean external temperatures and a calculation of the degree days during the thermic period in Milan throughout the last five years.

B. An assessment of the pollutants and their concentrations in the Metropolitan Area of Milan in the last years including the last COVID-19 shut down period. Together with a brief comparison with other provinces in Lombardy. In particular, this study was targeted on local pollutants and their concentrations during the thermic period.

C. An overview of the technical characteristics of the school buildings in Italy and in Milan that have an influence on heating and energy required for maintenance of it together with a brief general analysis on technical interventions for energy savings.

D. A technical and economical analysis for energy saving by increasing the efficiency of heating source and thermal dispersion on a sample of four school buildings having different characteristics according to year of construction and architectural style.

6. METHODS

6A: Analysis of the mean external temperatures and a calculation of the degree days during the thermic period in Milan throughout the last five years.

Results reported in this section were extrapolated from unpublished data requested and obtained by *ARPA Lombardy*, the public regional agency for environment protection. They are referred to data detected by the meteorological station of Lambrate, one of the nine installed in Milan. Due to its characteristics, within the urban belt but outside the historic centre, the Lambrate zone represent, in my opinion, a reliable surrogate of the scenario of the entire area of Milan for the information considered.

The definition for Heating degree days (HDDs) is "*number of degrees that a day's average temperature is below 20 C°, the target temperature, which is the temperature below which buildings need to be heated up.*"

6B: Assessment of the pollutants and their concentrations in the Metropolitan Area of Milan in the last years including the last COVID-19 shut down period. Together with a brief comparison with other provinces in Lombardy.

Unpublished data were as well requested and obtained from *ARPA Lombardy* database and are referred to the pollutants detection station of Brera, located in the city centre. This choice was motivated by the need to reduce at minimum the influence of pollutants produced by traffic. As the matter of fact Brera is located in the Area C that limited to traffic.

In particular, this study was focused on local pollutants and their concentrations during the thermic period. The following indicators of pollution were taken:

- ✓ **Carbon Dioxide (CO_2):** *"A naturally occurring gas, and also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal human caused greenhouse gas that affects the Earth's radiative balance"* according to United States Environmental Agency (EPA)
- ✓ **Particular Matter 10 (PM10):** indicating *"inhalable particles, with diameters that are generally 10 micro-meters and smaller*" according to EPA
- ✓ **Particular Matter 2,5 (PM2,5):** indicating *"fine inhalable particles, with diameters that are generally 2.5 micro-meters and smaller*" according to EPA
- ✓ **Nitrogen Oxides (NO_x):** *"a family of poisonous, highly reactive gases. These gases form when fuel is burned at high temperatures. NOx pollution is emitted by automobiles, trucks and various non-road vehicles (e.g., construction equipment, boats, etc.) as well as industrial sources such as power plants, industrial boilers, cement kilns, and turbines."* according to EPA
- ✓ **Nitrogen Dioxide (NO_2):** is the most harmful to human health and to the environment among the NO_X family pollutants.
- ✓ **Ozone (O_3):** "*at ground level (troposphere) is a harmful air pollutant, because of its effects on people and the environment, and it is the main ingredient in "smog".*

6C: Overview of the technical characteristics of the school buildings in Italy and in Milan that have an influence on heating and energy required for maintenance of it together with a brief general analysis on technical interventions for energy savings.

Data for this analysis were obtained from the Technical Area for heating and cooling of the Municipality of Milan (unpublished data), from *Certificazione Energetica degli Edifici (CENED) Infrastrutture Lombarde*[16] and from the Italian Ministry of Education (MIUR)[17] A comparison with the Italian situation was possible, when useful, using data recently reported by Fondazione Agnelli on an overview of the Italian educational system.[18]

They are referred to a list of respectively 384, 57 and 285 school buildings in Milan. The reason for missing data in each data base was not clear to me and I was unable to obtain information regarding the few remaining buildings not included in the three lists.

Data obtained from the excel document requested and received from the Technical Area were sometimes missing useful pieces of information regarding some buildings. These were thus retrieved, when possible, by *Geo Map* the portal of the Municipality of Milan updated at 2011.[19]

The technical characteristics for every single building considered for the analysis were the followings:

- ✓ Heated volume (V).
- ✓ Material of construction.
- ✓ Window characteristics: frames and glasses.
- ✓ Source of energy supply.
- ✓ Source of energy diffusion.
- ✓ Air exchange modality.

6D: Technical analysis for energy saving by increasing the efficiency of heating source and thermal dispersion on a sample of four school buildings having different characteristics according to year of construction and architectural style.

The following section represents the core issue of my project and was made possible of course only through an on analysis directly made on the field and data

The object of this study was to give indications for alternative solutions on heating generation and maintenance within all school buildings of the Milan area.

Being impossible to do a detailed analysis on every school building, my choice was to focus on a sample analysis on four single constructions having different characteristics according to the following criteria and defining a model transferable to other buildings having similar properties.

The main criteria for selection were the following:

YEAR OF CONSTRUCTION:

- ✓ historical ages,
- ✓ early twentieth century,
- ✓ second after-ward period and
- ✓ present years

MATERIALS OF CONSTRUCTION:

- ✓ Masonry
- ✓ Metallic structure + wall panels
- ✓ Wood

INTENDED USE:

- ✓ night school
- ✓ nursery school
- ✓ kindergarten
- ✓ primary school

HEATED VOLUME:

- ✓ low: < 5000 m^3
- ✓ medium: < 20'000 m^3
- ✓ medium-high: < 35'000 m^3
- ✓ high: > 35'000 m^3

HEATING SOURCE:

- ✓ natural gas
- ✓ district heating
- ✓ diesel fuel*
- ✓ heat pump

*excluded from the project analysis since a European directive will not allow the use for heating proposal starting from the 2023

The selection of buildings was arranged in accordance with my relator and tutor going through the lists of all schools under the supervision of the Municipality of Milan.

Having identified the buildings worthy of analysis I have gathered, when available, more detailed information concerning their characteristics and heating status from the official "*energy diagnosis"* made in 2012 by *DM Energie Rinnovabili* and *A2a Calore e Servizi* on behalf the Municipality of Milan[20]. Other pieces of information, when missing, were obtained from unpublished data following a formal request from the municipal archives (*Cittadella degli Archive del Comune di Milano* https://www.comune.milano.it/comune/cittadella-degli-archivi).

Following this preliminary analysis, an *in-the-field inspection* of each of the four selected buildings was conducted. During the inspections, particular attention was given to the thermal power station.

The following buildings were selected for sample analysis:

Building n°1: Music Civic School, *Claudio Abbado*

Name:	Civic School, *Claudio Abbado*
Location:	Via Stillicone 36, Municipality 8, Milan
Year of construction:	end of XV century
Intended use:	night school
Heated volume:	15'200 m^3
Number of floors:	3
Heating source:	natural gas
Contracting company:	Montalba Ita

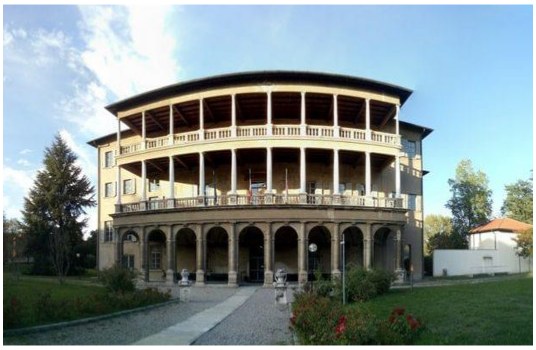

Figure 6A*:* an overview of Stilicone 36 by street view

Figure 6B*:* an overview of Stilicone 36 by Google

Description (Figures 6 A-B):

This historical building was erected at the end of XV century by Gualtiero da Bascapé, loyal collaborator of Ludovico il Moro. The luxury loggia was built up later on by the famous architecture Domenico Giunti (1505-1560). Then the contracture was purchased by the Simonetta family in 1555, so the name still used "Villa Simonetta". From 1836, after a period of decay, it performed different activities as lazaret hospital, mechanical workshop, tavern, carpentry and barracks. During the II

Ward World, it was bombed and destroyed because of its proximity to the Garibaldi railway yard. The building reduced to a ruin was restored and today it hosts a civic musical school.

Table 10 summarizes heating requirements of the school building throughout the week

Civic Music School Claudio Abbado					
DESTINATION	ROOM	WEEKDAY	FROM	TO	T (C°)
Civic Music School (day and night school)	classrooms	from Mon to Fri	8.00	22.00	20
		from Sat to Sun	8.00	18.00	20
	offices	from Mon to Fri	8.00	22.00	20
		from Sat to Sun	8.00	18.00	20
	medical office	from Mon to Fri	8.00	22.00	22
		from Sat to Sun	8.00	18.00	22
	all the rooms	from Sat to Sun	-	-	7

***Table 10**: Civic School, C. Abbado: hours of activity and temperature required in rooms according to destinations*

Building n°2: A. Stoppani Comprehensive School

Name: Comprehensive School, *Antonio Stoppani*
Location: Via Antonio Stoppani 1-3, Municipality 2 - Milan
Year of construction: 1901-1903
Intended use: nursery school, kindergarten, primary school
Heated volume: 50’687 m^3
Number of floors: 3
Heating source: natural gas

***Figure 7A**:* an overview of A. Stoppani 1-3 by street

***Figure 7B**:* an overview of A. Stoppani 1-3 by Google

Description:

The building was erected in 1901-1903. As many school buildings of the early XX century in Italy, it is characterized by large volumes disposed in a horseshoe shape (Figure 7 A-B). This characteristic turned to be necessary in Italy due to the increased age at 12 years for compulsory school in Italy as defined by the Orlando decree n°407 on July 8th 1904. The goal of school architecture in Italy in the first decades of the XX century was in fact to guarantee the larger number of classes for an increased number of students. This was made possible by the construction of school buildings having characteristics of the Stoppani school.

Table 11 summarizes heating requirements of the school building throughout the week according to different destinations

A. STOPPANI, 1-3					
DESTINATION	ROOM	WEEKDAY	FROM	TO	T (C°)
nursery school	all the rooms	from Mon to Fri	7	18	22
kindegarten	classrooms	from Mon to Fri	8	18	20
	office				
	medical office				22
primary school	classrooms	from Mon to Fri	8	18	20
	office				
	medical office				22
	gym				18
building	caretaker home	from Mon to Sun	5.00 to 23.00 (max 14 h)		20
	all the rooms	from Sat to Sun	00.00	24.00	7

Table 11 *comprehensive school, A. Stoppani: hours of activity and temperature required in rooms according to destinations*

Building n°3: Comprehensive School, *Einaudi Pascoli*

Name: comprehensive school, *Einaudi Pascoli*
Location: Via Val d'intelvi 11, Municipality 7- Milan
Year of construction: 1974
Intended use: Primary School Secondary School of first level
Heated volume: 24'027 m^3
Number of floors: 3
Heating source: natural gas
Contracting company:

Description:

The Einaudi Pascoli represents a typical school building of the 70s in Italy **(Figure A-B).** In those years it was essential to provide a proper number of school buildings for the increase scholar population as a consequence of the Italian economic boom of the previous decade. The great industrial cities such as Milan expanded their suburbs inhabited by the large number of industry workers and their families.

The easier, faster and less expensive way to front the increased demand of school buildings was to resort to prefabricated metallic structure.

Figure 8A*: an overview of Val d'intelvi 11, by street*

Figure 8B*: an overview of Val d'intelvi 11, by Google*

Table 12 summarizes heating requirements of the school building throughout the week

Val d'Intelvi, 11					
DESTINATION	ROOM	WEEKDAY	FROM	TO	T (C°)
Primary School	classrooms	from Mon to Fri	8.00	18.00	20
	offices				
	medical office				22
	gym				17
	all the ambientes	from Sat to Sun	00.00	23.59	7

Table 12 *Primary School, E. Pascoli: hours of activity and temperature required in rooms according to destinations*

Building n°4: *Citylife, Nursery School*

Name:	*CityLife Nursery School*
Location:	Via Demetrio Stratos 8, Municipality 8 - Milan
Year of construction:	2018
Intended use:	nursery school
Heated and cooled volume:	3359,92 m^3
Number of floors:	1
Heating source:	heat pump and district heating
Contracting company:	

Description

The nursery school is included in a broader project area called *CityLife, from which its name.*

It was built in 2018 and is the prototype of a net-zero emission building as requested by the mot recent European directive: on energy parameters for new constructions (**Figure 9 A-B**).

For this reason it will be described as an example for energy and environment sustainability but, of course, an analysis and a proposal for energy saving was not conducted -

Figure 9A: *an overview of D. Stratos 8, by street*

Figure 9B: *an overview of D. Stratos 8, by Google*

Table 13 summarizes heating requirements of the school building throughout the week

Stratos, 8					
DESTINATION	ROOM	WEEKDAY	FROM	TO	T (C°)
Nursery School	classrooms	from Mon to Fri	7.00	18.00	22
	offices	from Mon to Fri	7.00	18.00	20
	all the ambientes	from Sat to Sun	00.00	23.59	7

Table 13: *nursery school, CityLife: hours of activity and temperature required in rooms according to destinations*

6E: Restoration projects analysis

Three different projects were proposed for energy savings in Villa Simonetta Claudio Abbado Musica School, Antonio Stoppani comprehensive and Pascoli Einaudi primary school.
A restoration project was not considered for City life Nursery School already a Nearly Zero Emission building

The following characteristics were considered for the preliminary technical analysis

- heated volume
- material of construction
- window characteristics
- source of energy supply
- source of energy diffusion
- air exchange modality
- thermal and electrical loads

For any proposed intervention **thermal and electrical energy savings** were calculated together with **Capital Expenditure (CAPEX)** and **Operating Expense (OPEX)**

The economic analysis was conducted according to **different scenarios**:

- voluntary vs reinforcement replacement
- with or without incentives.

The **financial indicators** considered for analysis were the Net Present Value (NPV), the Internal Rate of Return (IRR) and the pay-back time (PBT).

7. RESULTS

7A Analysis of the mean external temperatures and a calculation of the degree days during the thermic period in Milan throughout the last five years.

External temperature.

Figures 10-16 A reported below on the left, are a graphic representation of mean temperatures detected in Milan throughout every single month of the thermic period during the last five years. On the right, **Figures 10-16 B,** are a are graphical representations of mean temperatures during the day in the same time frames.

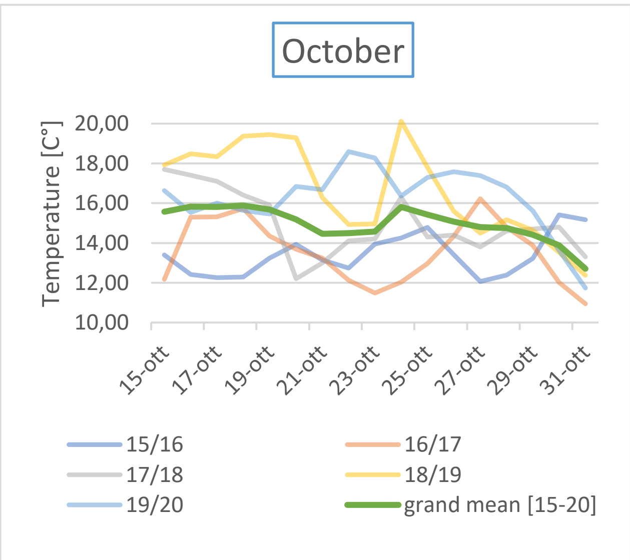

__Figure 10A:__ mean temperature detected in Milan in October during the last five years.

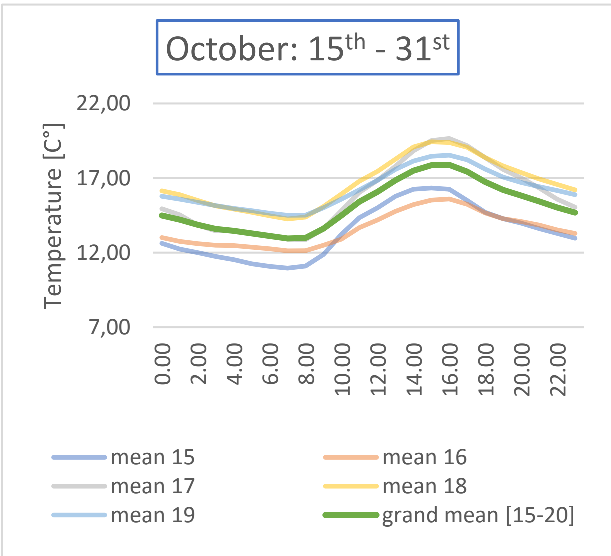

__Figure 10B:__ mean hour temperatures in Milan in October during the last five years

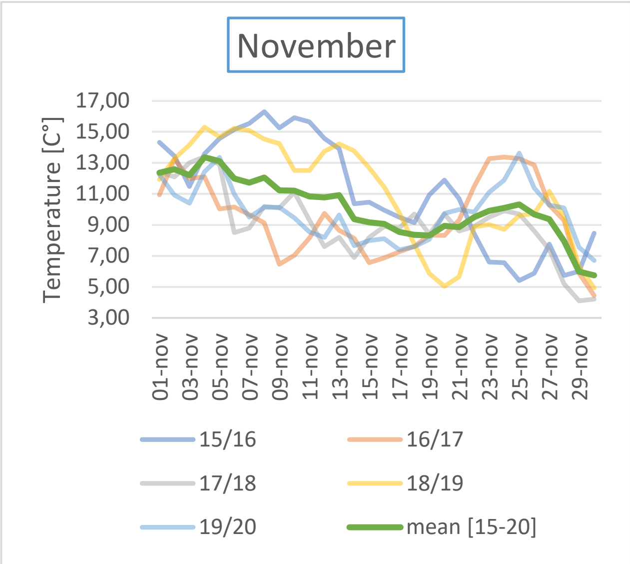

Figure 11A: *mean temperature detected in Milan in November during the last five years.*

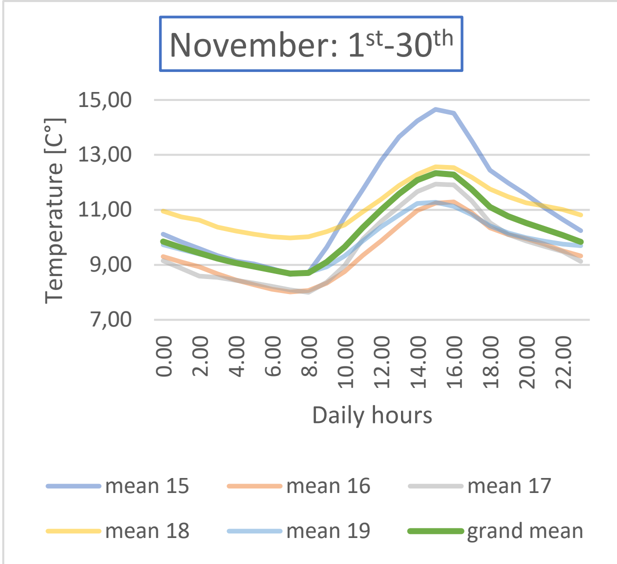

Figure 11B: *mean hour temperatures in Milan in November during the last five years*

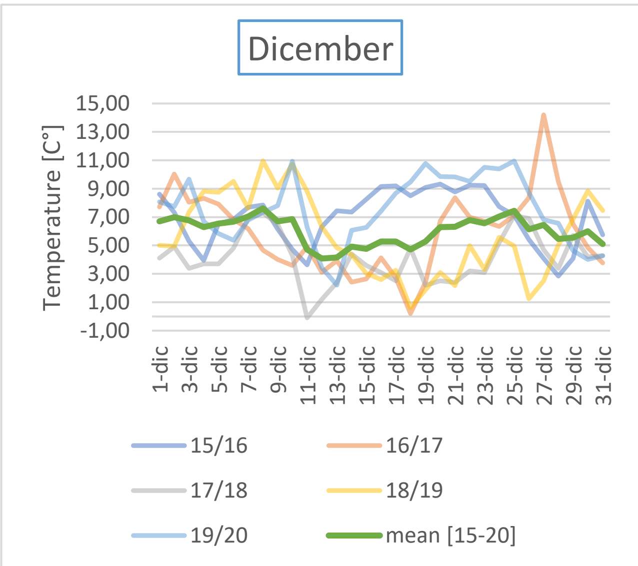

Figure 12A: *mean temperature detected in Milan in December during the last five years.*

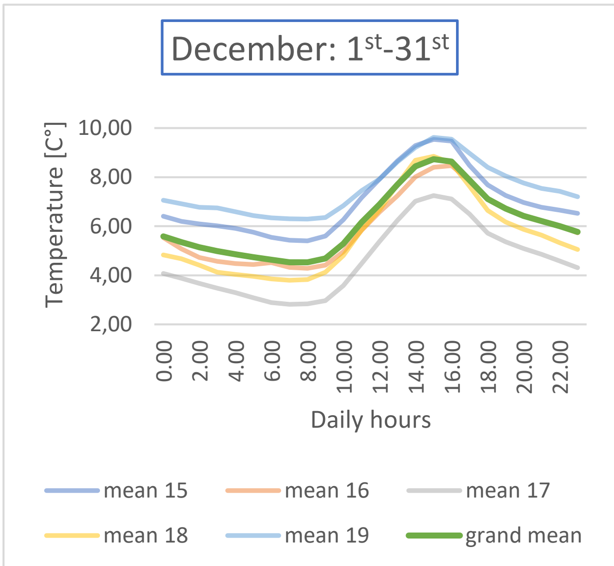

Figure 12B: *mean hour temperatures in Milan in December during the last five years*

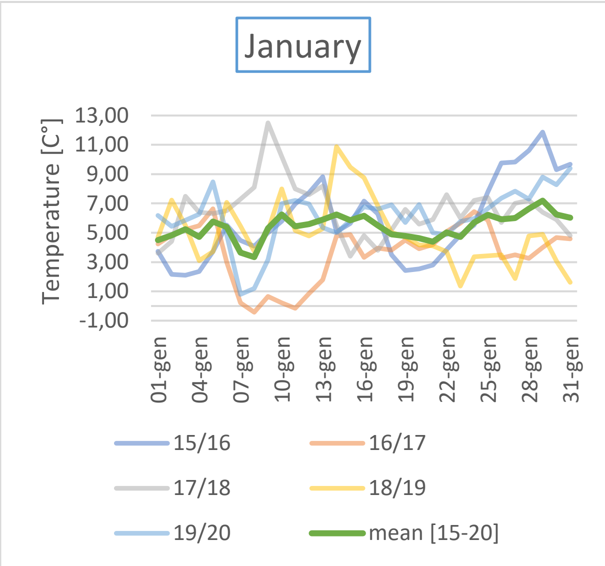

__Figure 13A:__ mean temperature detected in Milan in January during the last five years.

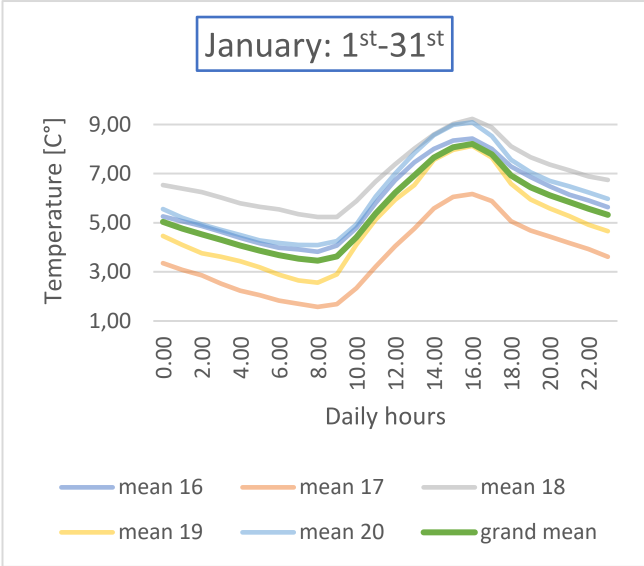

__Figure 13B:__ mean hour temperatures in Milan in January during the last five years

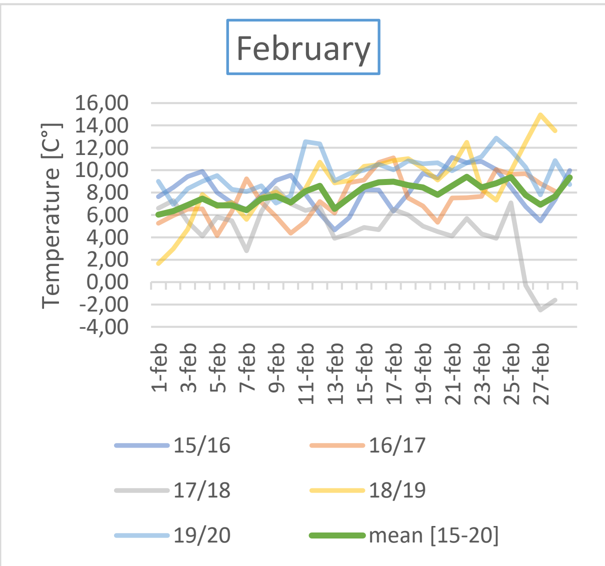

__Figure 14A:__ mean temperature detected in Milan in February during the last five years.

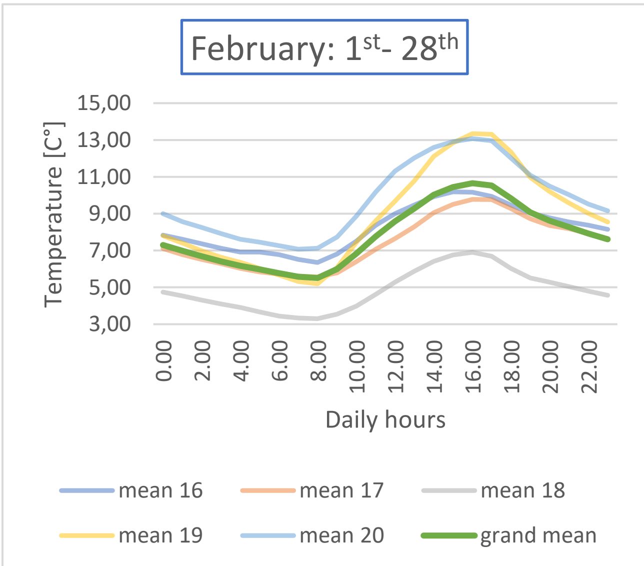

__Figure 14B:__ mean hour temperatures in Milan in February during the last five years

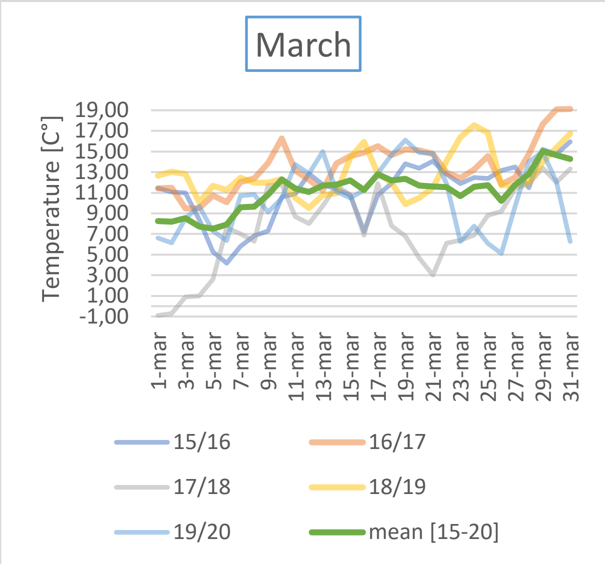

Figure 15A: *mean temperature detected in Milan in March during the last five years.*

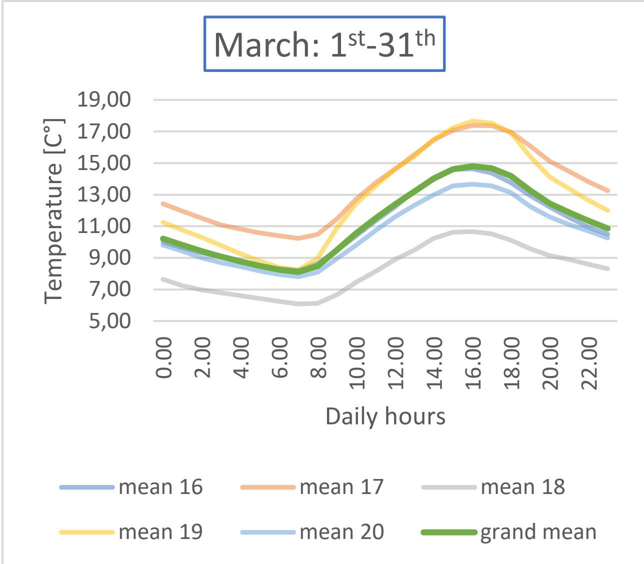

Figure 15B: *mean temperature detected in Milan in March during the last five years.*

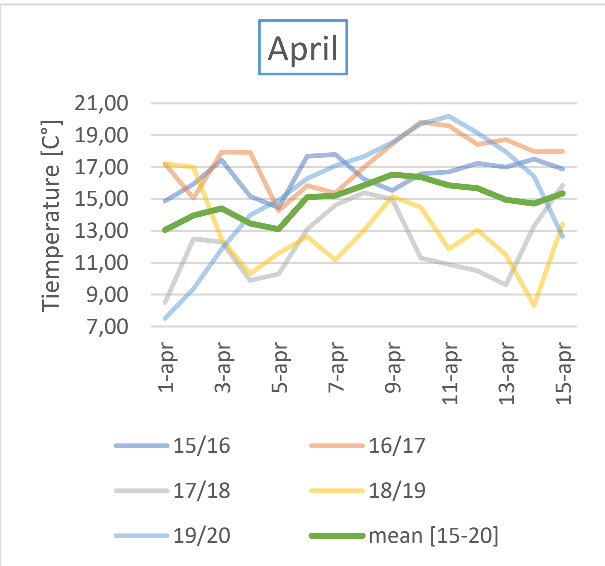

Figure 16A: *mean temperature detected in Milan in April during the last five years.*

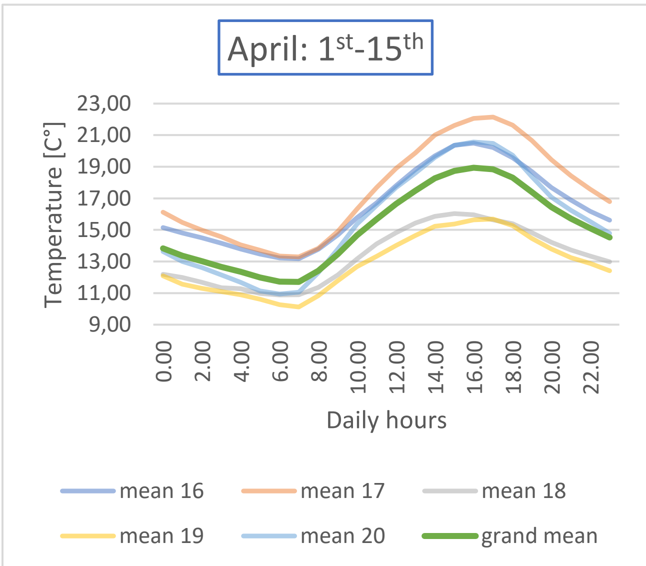

Figure 16B: *mean temperature detected in Milan in April during the last five years.*

Heating degree days. (HHDs)

Figures 17-23 reported below are a graphical representation of the mean degree days (evidenced in the grey area) calculated taking into account the external temperature in the last five years. Data are expressed for every single month of the thermic period.

As already mentioned, the definition for **Heating degree days (HDDs)** is "*number of degrees that a day's average temperature is below 20 C°, the target temperature below which buildings need to be heated up.*"

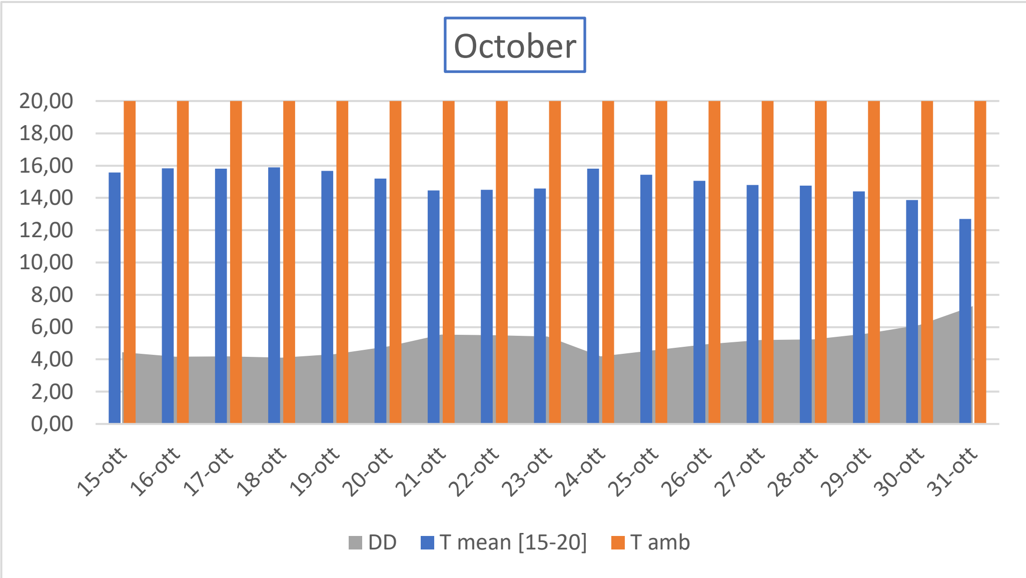

Figure 17: *mean heating degree days (HDDs) in the second part of October calculated in the last five years (2015-2019)*

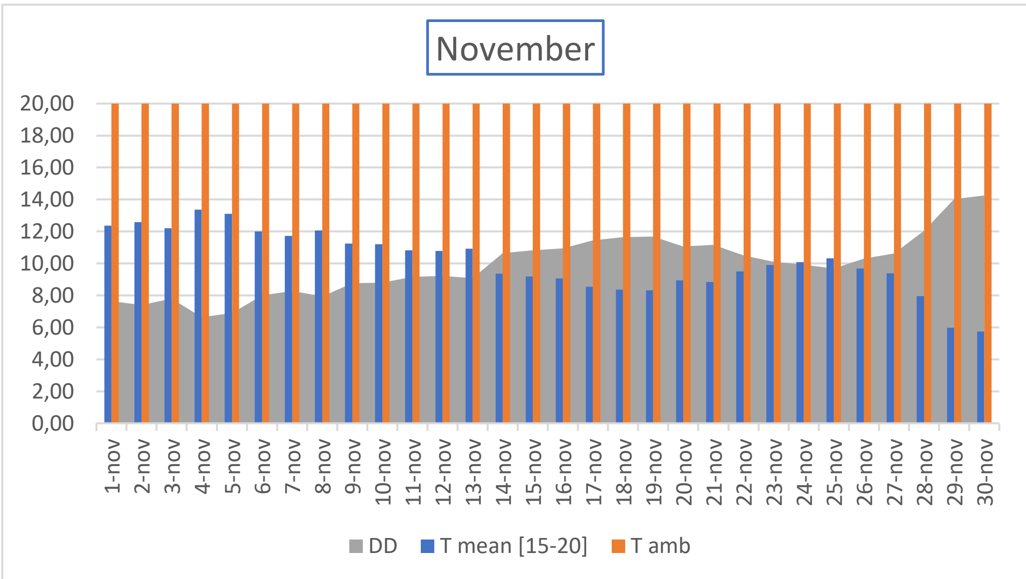

Figure 18 *mean heating degree days (HDDs) in November calculated in the last five years (2015-2019)*

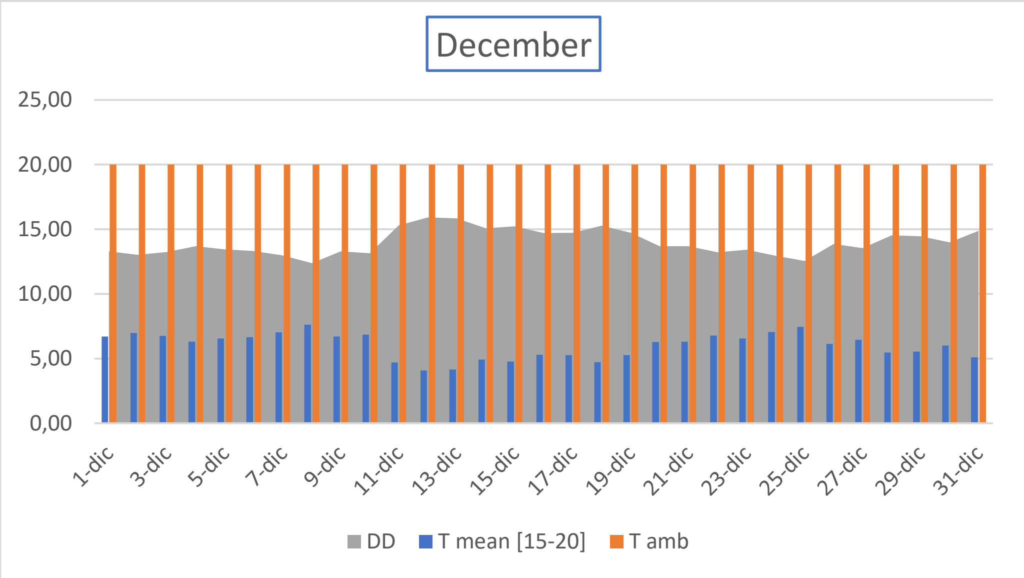

***Figure 19:** mean heating degree days (HDDs) in December calculated in the last five years (2015-2019)*

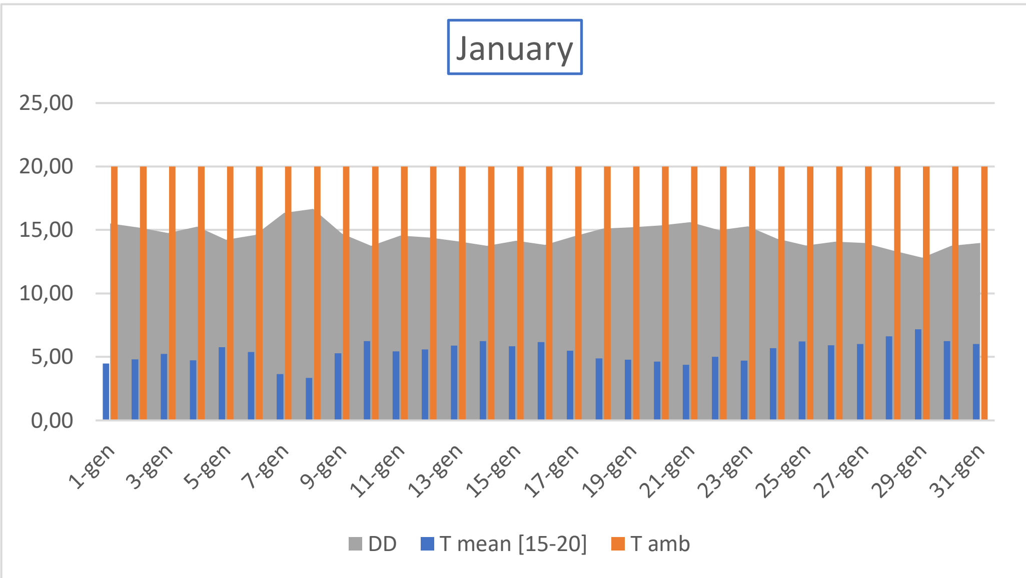

***Figure 20:** mean heating degree days (HDDs) in January calculated in January the last five years (2015-2019)*

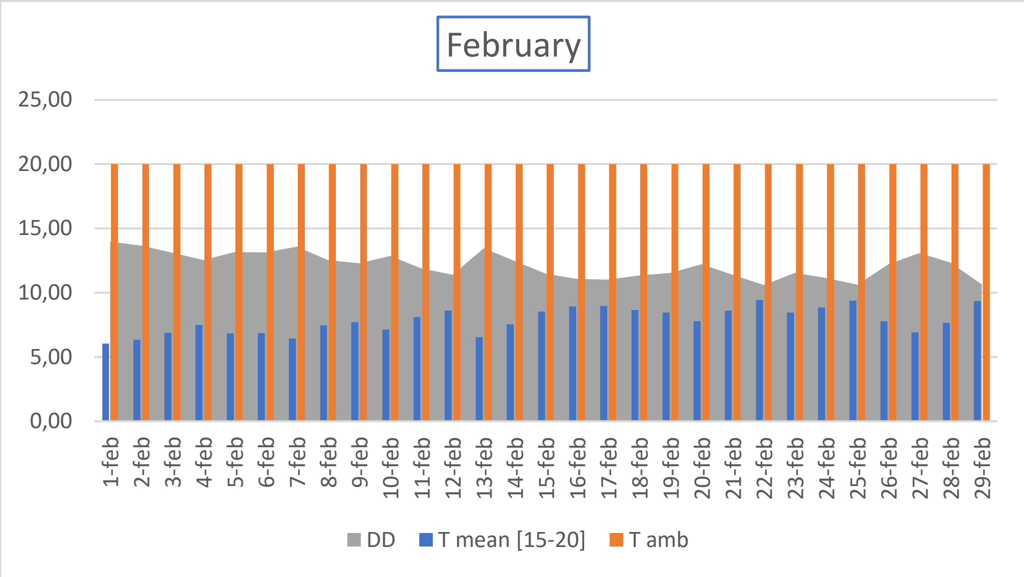

Figure 21: *mean heating degree days (HDDs) in February calculated in the last five years (2015-2019)*

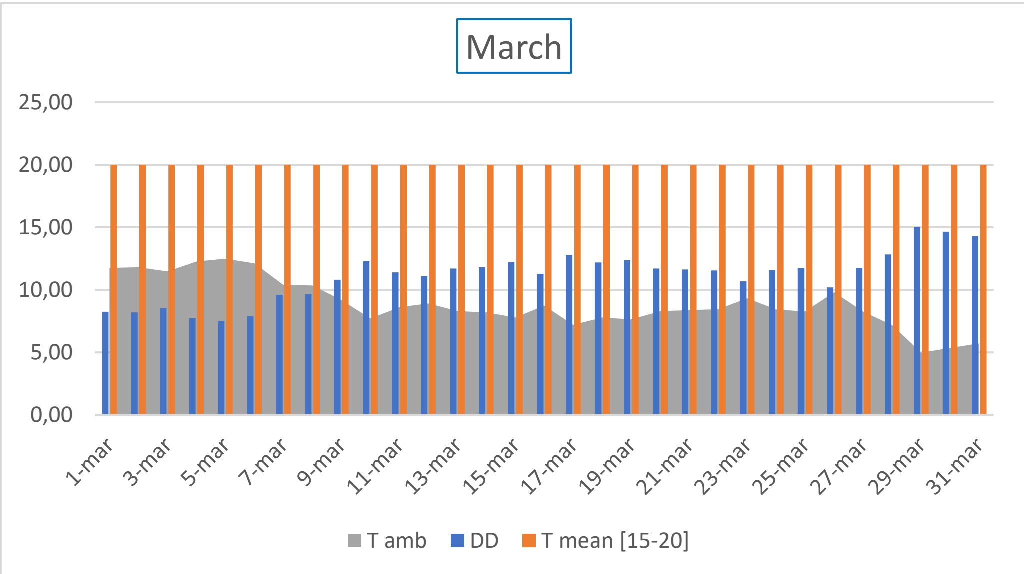

Figure 22 *mean heating degree days (HDDs) in March calculated in the last five years (2015-2019)*

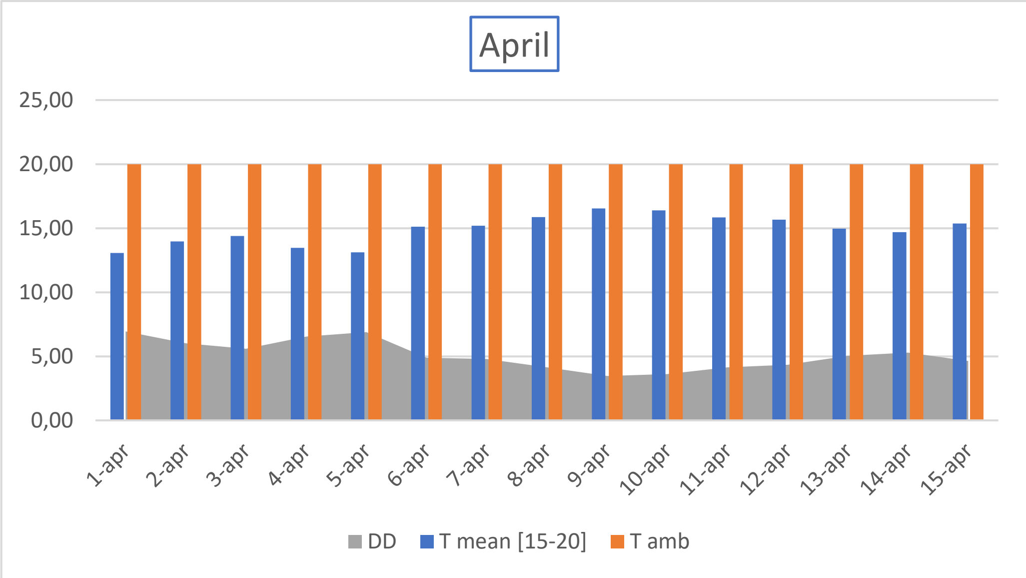

Figure 23 *mean heating degree days (HDDs) in the first part of April calculated in the last five years (2015-2019)*

7B: Assessment of the pollutants' concentrations during the thermic period in Lombardy and in the metropolitan Area of Milan in the last five years .

Pollutants concentrations in Lombardy

Figure 24 represents pollutants concentrations in the Metropolitan Area of Milan as compared to other Provinces of Lombardy in 2019.

While for PM_{10} and $PM_{2,5}$ the *mean concentration / year* resulted for all provinces within the limits established by the DIRECTIVE 2008/50/EC already reported in the *Methods* section, the *mean concentration / year* of NO_2 exceeded the defined limit in the Metropolitan Area of Milan (58 μg/m^3) and in the Provinces of Brescia (57 μg/m^3), Monza Brianza (45 μg/m^3), Como (44 μg/m^3) and Bergamo (41 μg/m^3).

It is also worth mentioning that the Metropolitan Area of Milan and the Province of Brescia have similar concentration for all pollutants.

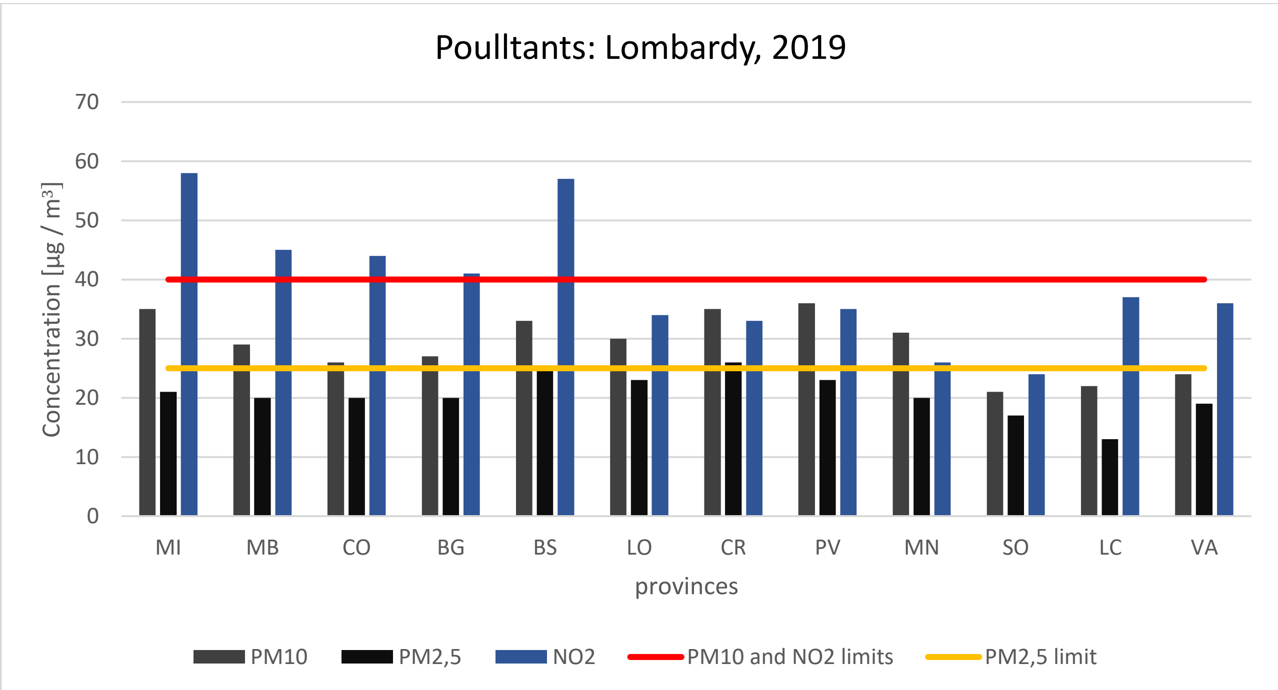

***Figure 14:** Historical* concentration / year *of PM_{10} $PM_{2,5}$ (data, available from 2002) and NO_2 (data, available from 2011) in Lombardy*

PM_{10} and $PM_{2,5}$ concentrations in the Metropolitan Area of Milan

The thermal year (October – April) and in particular the trimester December- February are the most critical period for concentration of particulate (PM_{10} and $PM_{2,5}$) due to the lower temperature and consequently the maximum emissions from heating system. As a matter of fact, heating sources contribute to about 25% and 30% of the total PM_{10} and $PM_{2,5}$ in Milan. PM_{10} and $PM_{2,5}$ produced by heating sources in 2017 accounted for 600 and 586 tons respectively.

Figures 25-26 represent emission sources of PM_{10} and $PM_{2,5}$ in Milan 2017.

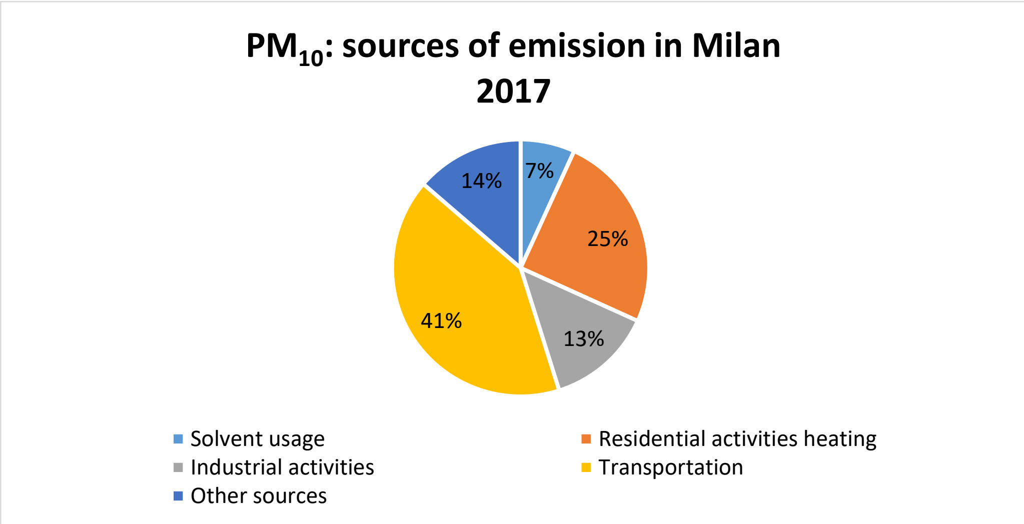

Figure 25 *Emission sources of PM_{10} in the Metropolitan Area of Milan in 2017.*

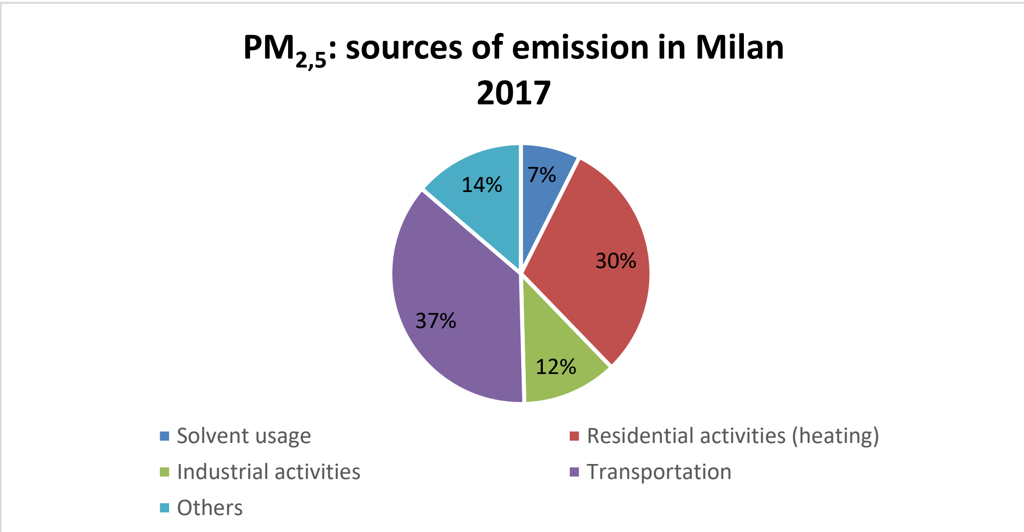

Figure 26 *Emission sources of $PM_{2,5}$ in the Metropolitan Milan in 2017.*

The ***concentration / year* of PM_{10}** in the metropolitan Area of Milan **(Figure 26)** has progressively decreased from 2002 and resulted to be maintained within the limit (threshold 40 μg/m^3), as defined by the DIRECTIVE 2008/50/EC, since 2013 with the only exception of year 2015. Nevertheless, although the number of days exceeding the maximum allowed concentration (threshold 50 μg/m^3) has shown a descending trend and is more than halved as compared to 2002 (163 days), it still remains always consistently above the requested limit (35 days) until now: 2015 (101 days), 2016 (73 days), 2017 (97 days), 2018 (79 days), 2019 (72 days).

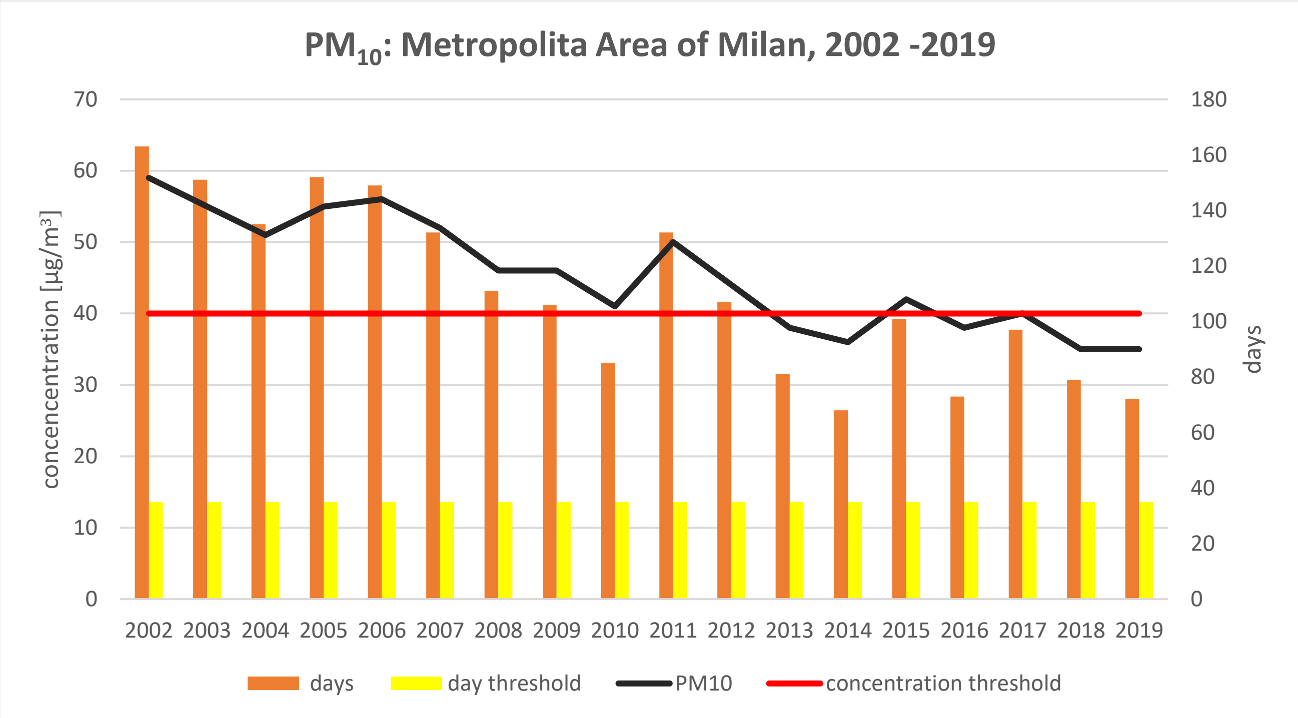

***Figure 26**: PM_{10} mean concentration / years since 2002 and number of days exceeding the limits in the Metropolitan Area of Milan.*

Below **Figures 27-28** describe the mean week concentrations of PM_{10} and $PM_{2,5}$ throughout the thermal year in Milan during the last five years.

The higher concentration of PM_{10} were always reached during the 3rd and 4th week of January (mean 76 μg/m^3 and 69 μg/m^3) with peak levels recorded in 2017 (81 μg/m^3 and 128 μg/m^3 respectively).

The same observations can be applied to $PM_{2,5}$: mean 60 μg/m^3 and 53 μg/m^3 and peak levels recorded in 2017 (57 μg/m^3 and 97 μg/m^3).

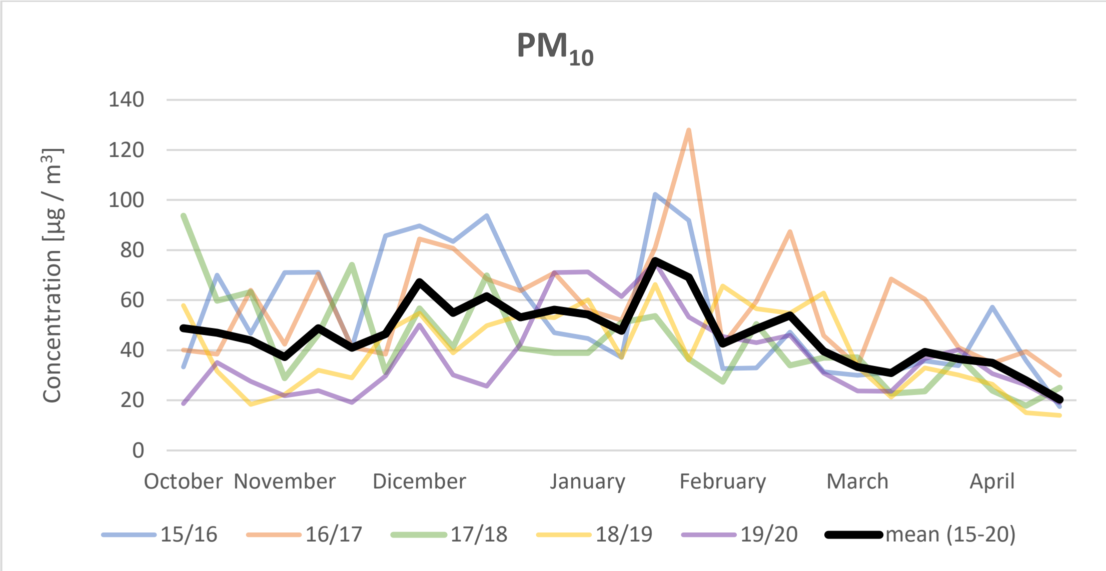

Figure 27: *PM_{10} (mean concentration/week) during thermal year in Metropolitan Area of Milan (2015-2020)*

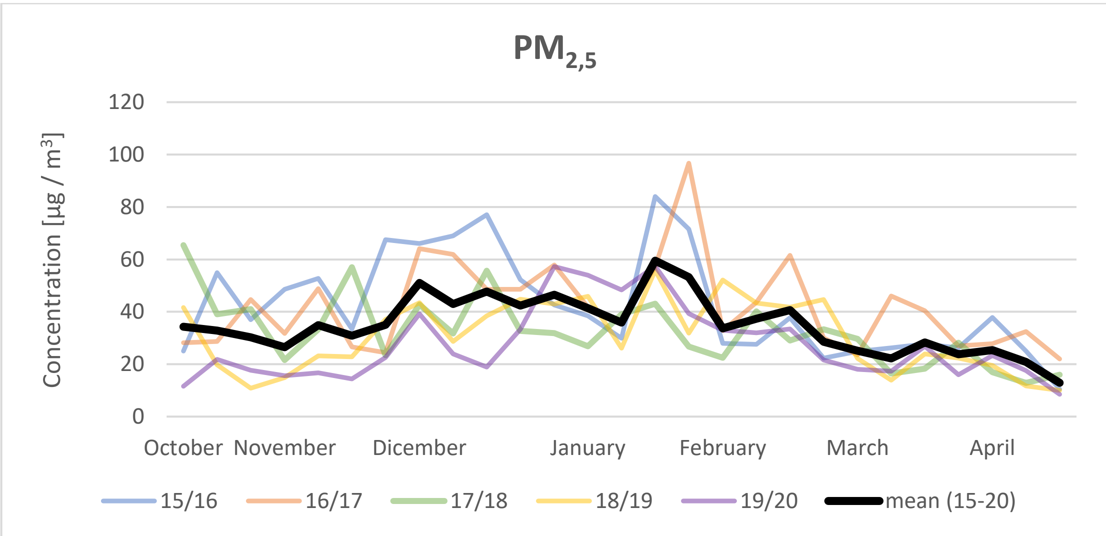

Figure 28: *$PM_{2,5}$ (mean concentration/week) during thermal year in Metropolitan Area of Milan (2015-2020)*

Figure 29 is a comprehensive representation of PM_{10} and $PM_{2,5}$ mean concentration in the last five years during the thermal period. The percentage of $PM_{2,5}$ as compared to PM_{10} resulted to be consistently stable at a value of roughly 75% during the entire observation time.

Since PM_{10} but not $PM_{2,5}$ environmental pollution can be a consequence of atmospheric phenomena (e.g. desertic powders carried in particular conditions) according to these data such events do not interfere in a medium-term observation. They might be relevant only considering specific days observation.

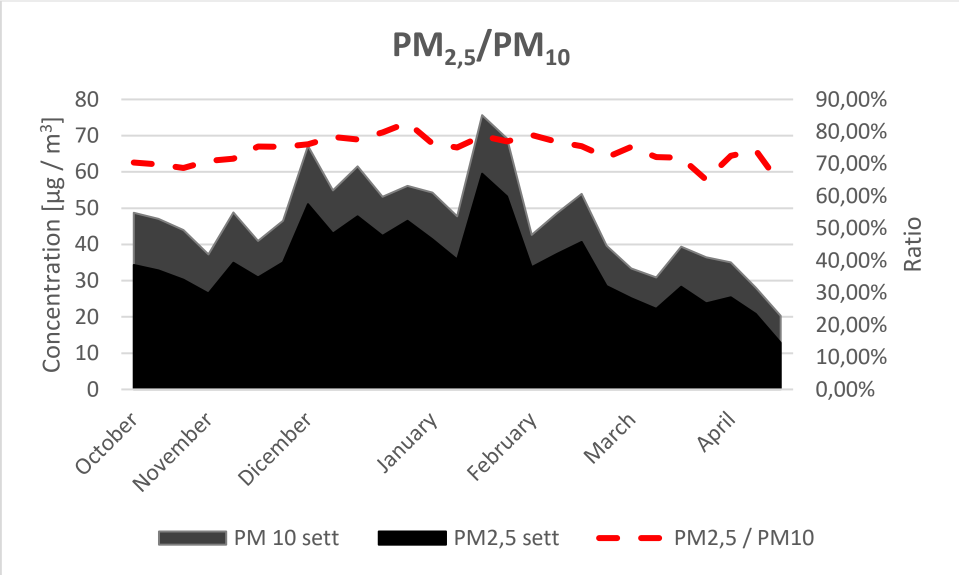

Figure 29 *PM2,5/PM10 ratio during the thermal period in the Metropolitan Area of Milan*

NOx and NO_2 in the Metropolitan Area of Milan

Traffic represents the most relevant source of emission of NO_x , proportionally higher (65%) as compared to PM_{10} and $PM_{2,5}$.

Heating accounts for nearly 14% of NO_x air pollution in the Metropolitan Area of Milan. Nevertheless it is estimated that 3034 tonnes of NO_x were produced by heating systems in Milan in 2017.

As for PM_{10} – $PM_{2,5}$, the thermal year and in particular the trimester December- February are also the most critical periods for environmental pollution by NO_x and NO_2 due to the lower temperature and consequently the increase of traffic and heating.

Figure 30 is a representation of emission sources of NO_x in Milan in 2017.

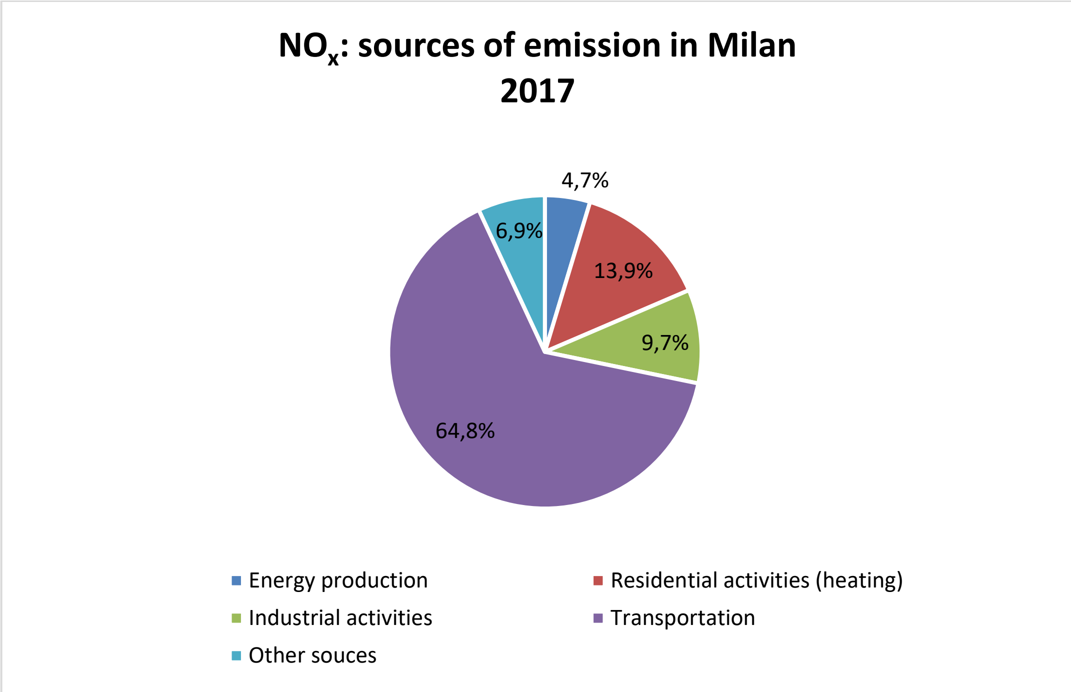

***Figure 30**: emission sources of NOx in the Metropolitan area of Milan in 2017.*

The *concentration / year* of NO_2 in the Metropolitan Area of Milan, according to data available since 2011, unfortunately has not shown the significant decrease reported in the previous two decades (**Figure 31**, unpublished data obtained from ARPA Lombardia with permission of *Dott. Guido Lanzani)*

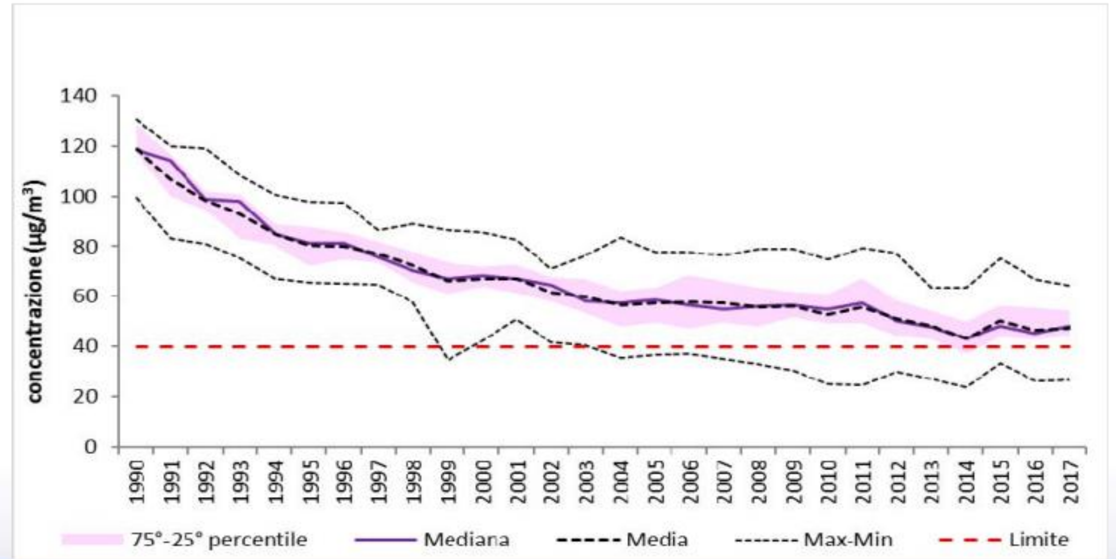

Figure 31: *Time evolution of NO_2 concentration in the Metropolitan Area of Milan mean / year in the last two decades.*

Figure 32 represents NO_2 concentration / year since 2011 in the Metropolitan Area of Milan. It is evident the rather stable levels registered in the last ten years.

It also represents number of hours / year of NO_2 concentration > 200 μg/m^3 (threshold 18 day according to the DIRECTIVE 2008/50/EC) detected in one central pollutant station in Milan. As already mentioned , data were obtained from *ARPA Lombardy* database and are referred to the pollutants detection station of Brera, located in the city centre. This choice was motivated by the need to reduce at minimum the influence of pollutants produced by traffic. As the matter of fact is located in the Area C that limited to traffic.

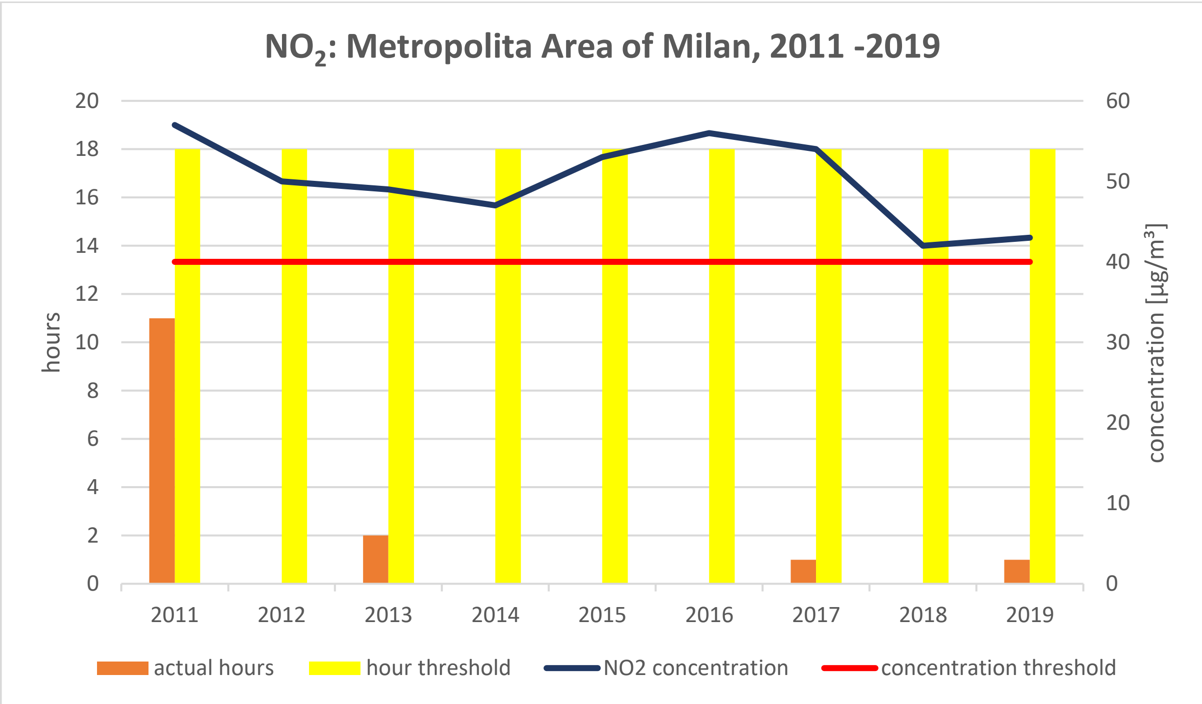

Figure 32: *An overview of NO2 concentration in the Metropolitan Area of Milan during the thermal year.*

The maximum week concentration levels of NOx are typically registered in the Area of Milan in the second and third week of December (mean 2015-2020, 214 and 272 μg/m^3 respectively) mainly due to increased traffic pollution during the Christmas period. The highest level was register in 2015 (331 and 453 μg/m^3 respectively).

Similarly, to PM_{10} and $PM_{2,5}$, the 3rd and 4th week of January represent a second peak of high atmospheric concentration of NO_x. (mean 2015-2020, 175 and 226 μg/m^3 respectively).

Figure 33 is a graphic representation of NO_x concentration during the thermal year in 2015-2020.

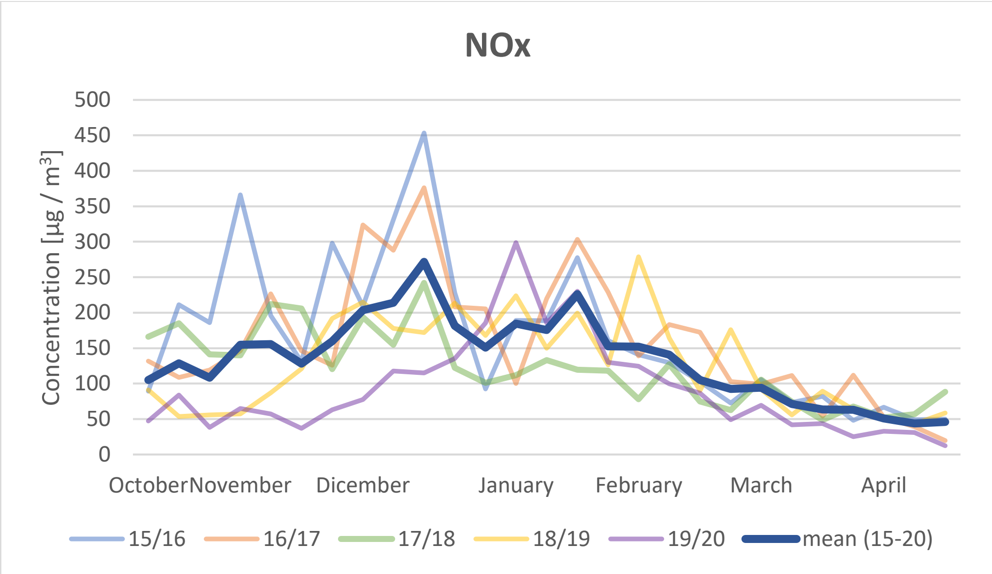

***Figure 33:** NO_x (mean concentration/week) during thermal year in Metropolitan Area of Milan (2015-2020)*

As we have already exposed previously in the introductive section, NO_2 are a secondary source environmental pollutants and are generated by NO oxidation. Maximum level concentrations of NO_2 are similarly reached as described for NO_x during the 2nd and 3rd week of December and the 3rd and 4th week of January.

Figure 34 is a description of NO_2 mean week concentration level during the thermal year in Milan during the last five years.

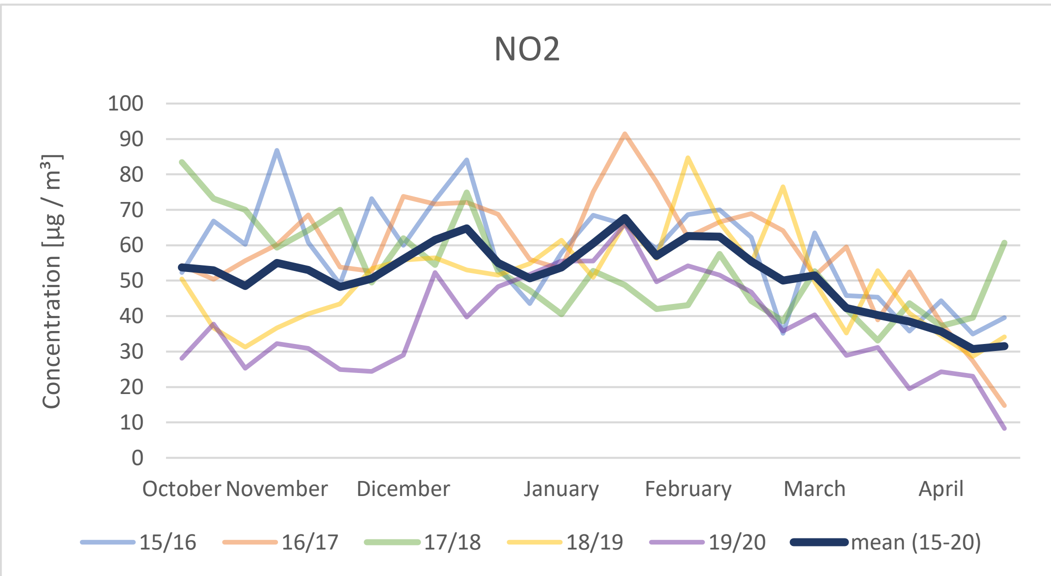

***Figure 34:** NO_2 (mean concentration/week) during thermal year in Metropolitan Area of Milan (2015-2020)*

Nevertheless, NO_2 oxidation processes are highly dependent on atmospheric and environmental conditions. In particular, atmospheric concentration of O_3, a typical summer pollutant (see introduction) promotes:

$NO + O_3 \rightarrow NO_2 + O_2$

For this reason, NO_2/NO_X atmospheric ratio is not stable throughout the year, ranging from a 30% in December to 70% in April.

Figure 35 represents mean NO_2 and NO_X concentration and mean NO_2/NO_X register in the last five year in Milan.

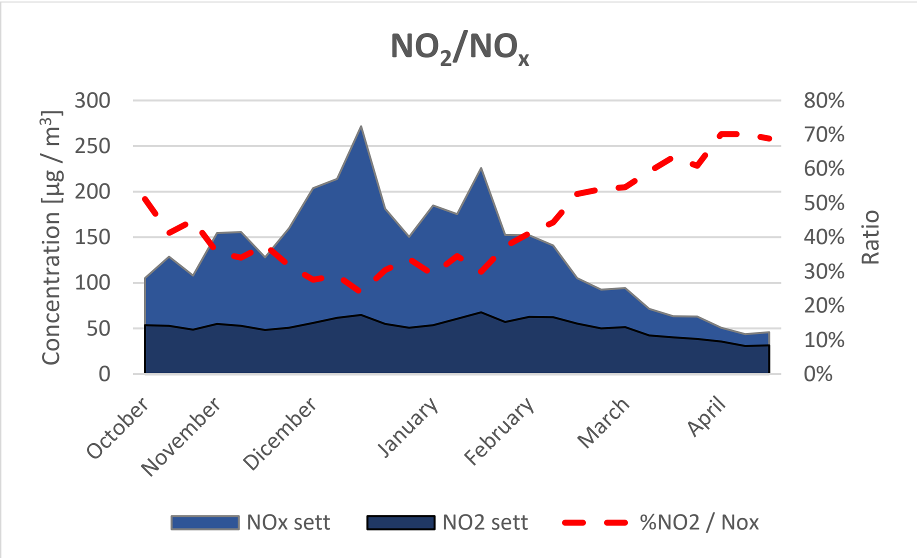

Figure 35: *mean NO_2/NO_X ratio during the thermal period in the Metropolitan Area of Milan (2015-2020)*

7C A brief overview of pollutants concentrations in Milan during the Covid-19 crisis-

On 31 December 2019, Chinese authorities notified the WHO regarding a novel Coronavirus, now designated SARS-CoV-2, that was first reported in Wuhan, China.

The virus has spread worldwide and Italy, particularly Lombardy was the first western country to face against it.

On March 8th, 2020 due to pandemic diffusion of the virus, the Italian Government took drastic lock down measures limiting aimed at the essential contact between people and consequently industrial production and traffic. These measures were confirmed until May 4th.

The context gave the opportunity to gather and study preliminary data about pollutants concentrations PM_{10} and NO_x in a time frame characterized by an unusual and unique conditions of traffic limitation and heating condition relatively unchanged.

This paragraph will briefly analyse environmental pollution by PM_{10} and NO_x in Milan during the COVID lock down.

Figure 36 is a representation of temperature values in Milan in the time frame March 8th – May 4th, 2020 compared to the mean value of the previous ten years.

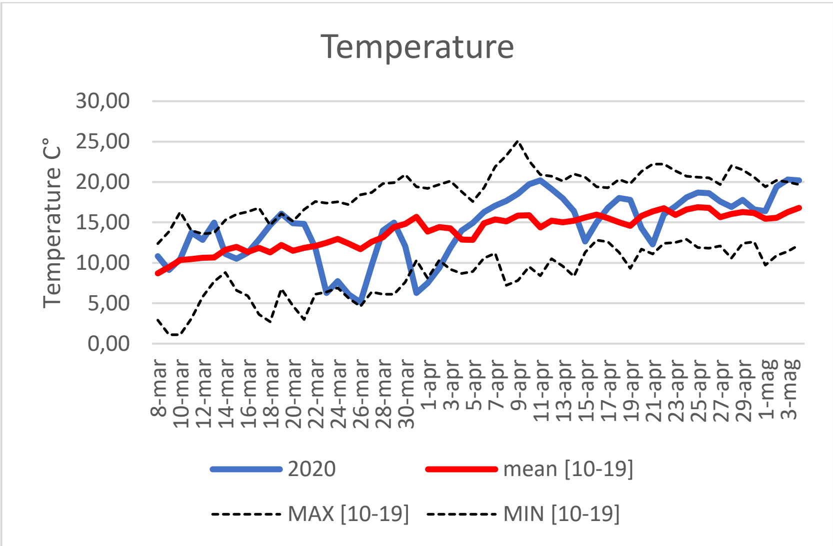

Figure 36: *Atmospheric temperature values [2010-2020] in Milan March 8th – May 4th*

Environmental concentration of PM_{10} and $PM_{2,5}$, did not significantly change as compare to mean values in the previous years. These figures can be perhaps explained by an increased pollution activity from residential heating system that has compensated lower emissions generated by traffic.

Figure 37 is a representation of PM_{10} concentration during the lock down period in Milan.

It is worth mentioning the peck registered March 28th and 29th, 2020 (85 µg/m^3 and 80 µg/m^3). In the same two days $PM_{2,5}$ concentrations were respectively 23 µg/m^3 and 19 µg/m^3 with an unusual $PM_{2,5}/PM_{10}$ ratio of 23% (standard 75%). This phenomenon represents one of those previously mentioned condition of environmental pollution due to natural atmospheric condition. In those days strong wind from East transported large amount of desert powders (natural PM_{10}) to Europe.

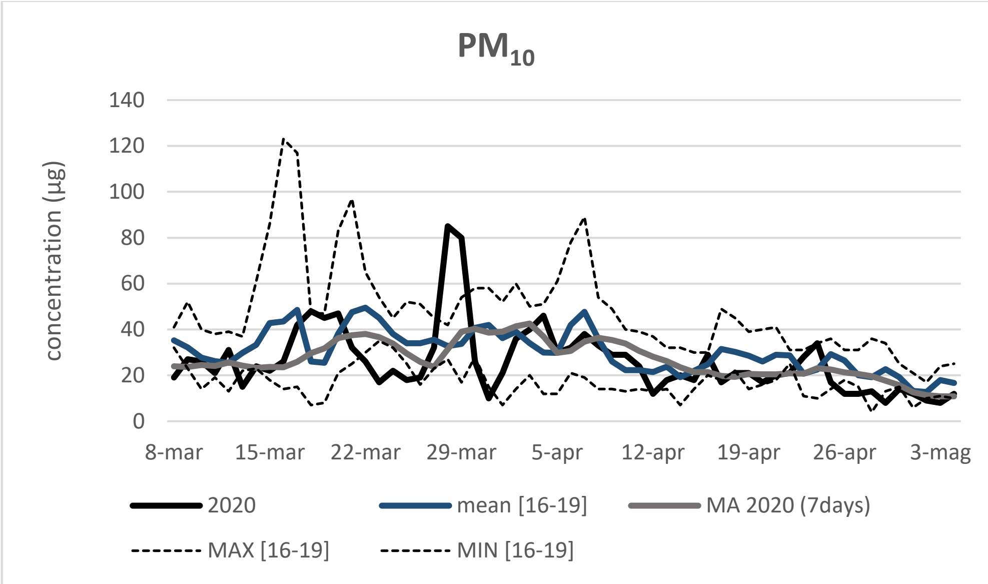

***Figure 37**: PM_{10} concentration during the lock down period in Milan (March 8th – May 4th, 2020)*

On the contrary, NO_x concentrations show a consistent reduction during the shut-down period in Milan with values significantly below the historic registrations of the last five years.

Registered values were almost always below the curve of mean minimum historical registration.

As already mention, traffic represents, by far, the main source of NO_x emission (64%). Drastic traffic limitation has thus logically led to significant NO_x pollution reduction.

Figure 38 is a graphic representation of NO_x concentration in Milan during the lock down period as compared to a mean representation of the previous four years.

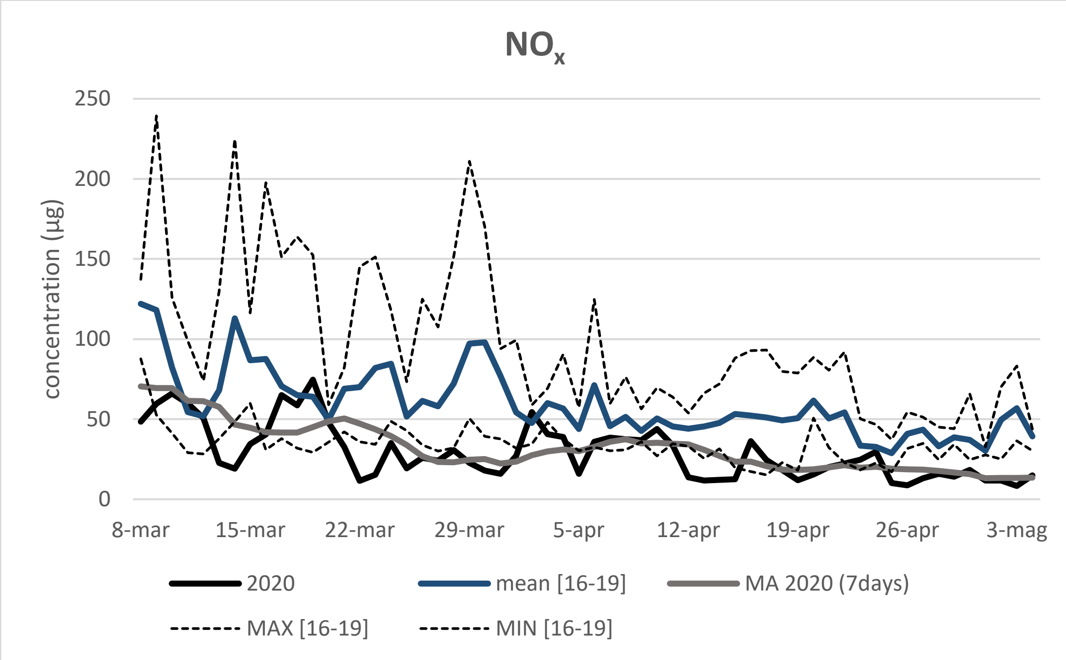

***Figure 38:** NO_x concentration during the lock down period in Milan (March 8th – May 4th, 2020).*

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7D An overview of the technical characteristics of the school buildings in Italy that have an influence on heating and energy required for maintenance of it

A brief description of school buildings according to the age of construction-

The history of school buildings in Italy is long and variegated.

Different ages of construction correspond to different architectural philosophies and consequently to different characteristics of buildings[19].

It is possible to describe at least four of them.

The Giolittian Age (1900-1920):

- With the Orlando law in 1904[21] compulsory school attendance was extended till the age of twelve. As a consequence, the student population in Italy from 1901 to 1907 significantly increased by 50% (from 2,5 to 3,7 million). In those time classrooms were composed by up to 70 students each.

The increase student population made thus necessary the construction of new school buildings. The majority of them were allocated in the North-West cities such as Milan and Turin.

- According to data from the Ministry of Education[18], 639 school buildings (3,3% of the entire sample) erected in *Giolittian Age* are still in use. Thirty-four of them (13,4% of the sample) are located in Milan.
- School buildings erected in this period are characterized by the centrality of large classrooms. Other common area like corridors are only intended as connection spaces. Relationships between school buildings and local community are almost non-existent following an architectural concept similarly adopted to military barracks.
- The typical shapes of school building are "L", "U" or "E" that allow to contain external areas, such as courtyards, reserved to recreation activity.
- The materials of construction are mainly: load-bearing brick masonry, concrete and mix structures. High quality of materials and research of external beauty are also characteristic by these kind of buildings.
- Due to the necessity of having overcrowded classroom, a particular attention was paid to the natural ventilation of building through height ceilings, large windows and wooden grills in the upper part of the doors.

Table 14 represents a synthesis of school building belonging to the *Giolittian Age*

School buildings of the *Giolittian Age* [1900-1920]					
n° of active building	3,3%	Load-bearing structures	brick and concrete masonry	Characteristics	large window
building shape	L, U or E	centrality space	classroom		H high quality of materials

Table 14: *A synthesis of the characteristics of school buildings erected in the Giolittian Age.*

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The fascist Age [1921-1944]

- In 1923 the total number of 32'000 classrooms in Italy was still far inadequate to the increasing demand.

The necessity of new classrooms was estimated in a 44% increase in Italy and 29% in Lombardy.

New building construction is the priority of any local administration according indication of the central authority.

In 1928 the adoption of the *"Testo Unico"* fixed 60 student per classroom as the maximum number allowed[22].

- In 1925 the guideline for new constructions announced: a range of classroom per building: 10-30; at least one gym and swimming pool per school; other possible room destinations are medical room, library, drawing room, refectory etc. The necessity of flexible space capable to host diversified activities was also a requirement.
- On the Italian territory, according to the data retrieved from the Italian Ministry of Education[18], 1322 school buildings (6,8% of the entire sample) erected in fascist Age are still active. Fifty-one buildings are located in Milan (20% of the sample)
- The key architectural element is to show the monumentality of the "Empire". This concept is translated by large volumes and the prestige of quality material such as floors and walls. Particularly emphasis is given to spaces dedicated to gym according to the will of the regime. With the purpose to give more fluidity to the building, the typical shapes used are: "the blocks" and the "E".
- An attention was given to the sizes of window that was design to allow natural lightning and ventilation. A maximum ratio of 1/5 between window and floor was established according to the Bottai "Carta della Scuola"[23].

Table 15 represents a synthesis of school building belonging to the *Fascist Age*

School buildings of the Fascist Age [1921-1944]					
n° of still active building	6,80%	Load-bearing structures	concrete masonry	characteristics	large window
building shape	blocks and E	centrality space	gym and swimming pool		High quality of material

Table 15: *A synthesis of the characteristics of school buildings erected in the fascist age.*

)

The post-war and economic expansion age [1945-1975]

- After War World II, a radical change in the design of school building is introduced in Italy.

The *DPR 1956, n°1688*[24] puts an emphasis on the new needs of school constructions and refers to the principle of considering the school building as a single entity and not anymore as the aggregation of multi-functional rooms.

The shift from the vision of the "*school as a barrack*" to the "*school as a home*"

- This new architectural trend nevertheless was conditioned by the urgency to provide a large number of new school buildings for the country. As a matter of fact, the first post-war decays were characterized by a demographic increase in the student population that reached the peak in the 60s.

  The decrees n°1859, 1962[25] regarding secondary school of first degree, that was in that year reformed, n°444, 1968[26] about the introduction of public kindergarten schools, n°820, 1971[27] about the introduction of the full-time in primary school, are clear examples of the attention given by the Government to the opportunity to build new school buildings in Italy. Construction of new buildings in a short time frame was made possible only with the adoption of "pre-fabrication" method that used a single project for many construction destinations.
- According to data of the Ministry of Education[17], 8591 school buildings (44% of the entire sample) erected between 1945-1975 are still active as schools. One-hundred and forty-six of them (58% of the sample) are located in Milan.
- Material of constructions, particularly in the early 70s and following the first economic crisis, often did not meet the requested standards. The pure quality of new material of constructions adopted such as aluminium doors and windows, synthetic membrane, and compost wood, brought to a rapid deterioration of these type of school

  building and of their structural, energetic and security performances

Table 16 represents a synthesis of school building belonging to the economic expansion age [1945-1975]

School building of the Post- War and Economic Expansion Age [1945-1975]					
n° of active building	44%	**Load bearing structures**	Reinforced concrete beams and pillars	**characteristics**	pre-fabrication (70s)
building shape	Compact unit	**centrality space**	A building as a unique entity		pour material quality

Table 16: *A synthesis of the characteristics of school buildings erected in the post war and economic expansion age.*

The contemporary Age [1975-2019]

- During the 70s, following the first economic crisis, Italy experimented a demographic contraction. Therefore, attention was not only given to the construction of new buildings but to preservation and refurbishment of what have already been built.
- Nevertheless, in this phase, the authorities become aware of the structural limits and energetic inefficiency of what had already been, and new construction projects were also necessary.

  The DM December the 18th 1975[28], approved the new technical norms about the materials and components of construction. The decree 1973 n° 373[29] exposed the norms for containing energy consumption inside the school building such as building and thermal plant insulation. These new law indications made necessary in the following years a compromise between economic limitations and the need of better quality materials and better safety standards.
- According to data retrieved from the Italian Ministry of Education[18], 8772 school buildings (45,4% of the entire sample) were constructed in contemporary Age are still active. Eighteen buildings are located in Milan (7,2% of the sample).
- The main concept in the design phase for new school buildings is flexibility with the introduction of movable furniture and sliding walls that help in re-modulating the spaces according to the teaching method used.
- As already mention particular attention in the last decays was given to the materials of construction in order to contain energy losses and environmental footprint emissions in buildings. The new paradigm of Nearly Zero Energy Building (NZEB) imposed by European Direction for new public constructions (EPBD, 2010/31/**EU**)[30] is the last standard for new public-school buildings.

The contemporary Age [1976-2018]					
n° of active buildings	45,4%	**material of construction**	Concrete masonry, wood	**characteristics**	Eco-design
building shape	Compact	**centrality space**	flexibility		Quality of materials, Safety, Energy savings

Table 17: *a synthesis of the school buildings erected in contemporary age.*

Age of construction-

Data regarding age of construction of school buildings in Italy are difficult to retrieve and incomplete. According to a study recently published by Fondazione Agnelli[18], information regarding this matter were available only in 59% of the entire number of school buildings examined.

According to a registry analysis on 19'665 public school buildings in Italy reported by the Italian Ministry of Education[17], 11'914 (60%) were erected between 1955 and 1985 with a peak incidence in the mid of 70s (**Figure 38**)

This time frame corresponds to the Italian economic reconstruction and demographic post war "boom".

The following decays (1985-2015) were characterized by a constant and drastic decrease of new school building construction. The decreased birth rate in Italy (7,2 per 1000 inhabitants in 2019) only partially give an explanation to this trend. Negative economic conjunctures (increased public debt and consequent spending review actions) did not allow an adequate turnover and maintenance of school buildings at least in the last two decays.

A second lower incidence peak of school constructions (corresponds to the Italian fascist era that was in general characterized by a great development of public and social architecture (**Figure 39**).

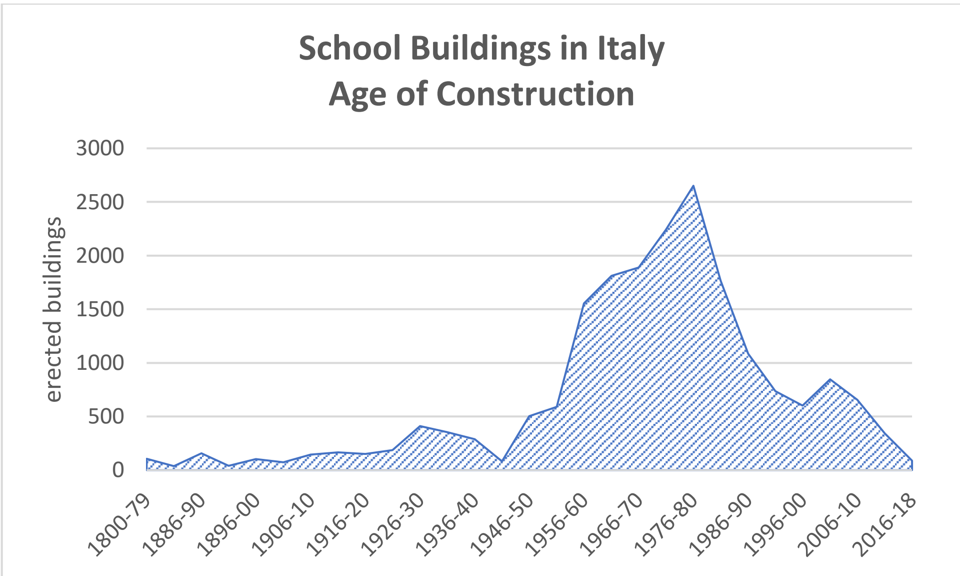

Figure 39: *age of construction of Italian school buildings. Personal analysis from data obtained by Italian Ministry of Education*[18]

The mean age of construction of school buildings in Italy is 52 years. The mean age of school buildings in Lombardy is 55 years.[17]

Table 18 represents mean age of construction of school buildings in Italy according to different Regions[18]

School Buildings	
Region	**mean age (yrs)**
Abruzzo	48
Basilicata	47
Calabria	42
Campania	48
Emilia Romagna	56
Friuli Venezia Giulia	53
Lazio	47
Liguria	75
Lombardia	55
Marche	54
Molise	42
Piemonte	64
Puglia	48
Sardegna	44
Sicilia	47
Toscana	56
Trentino Alto Adige	data not available
Umbria	49
Valle d'Aosta	data not available
Veneto	52

Table 18: *mean age of school buildings in different Italian regions, Fondazione Agnelli 2020.*

Volumes

Going through data from the Italian Ministry of Education[17] and the Municipality of Milan[16] I was able to retrieve information concerning age of construction and volumes in a sample of 256 school buildings in Metropolitan area of Milan.

Figure 40 is a representation of volumes of schools in Milan according to age of construction. The regression analysis confirms that more recent buildings are generally characterized by lower volumes.

This is due mainly to two reasons:

1. Better territorial distribution of school buildings (more buildings for the same number of students)
2. Architectural styles aimed at a different exploitation of spaces in the post-war era (e.g. low height of ceilings and narrow connection spaces)

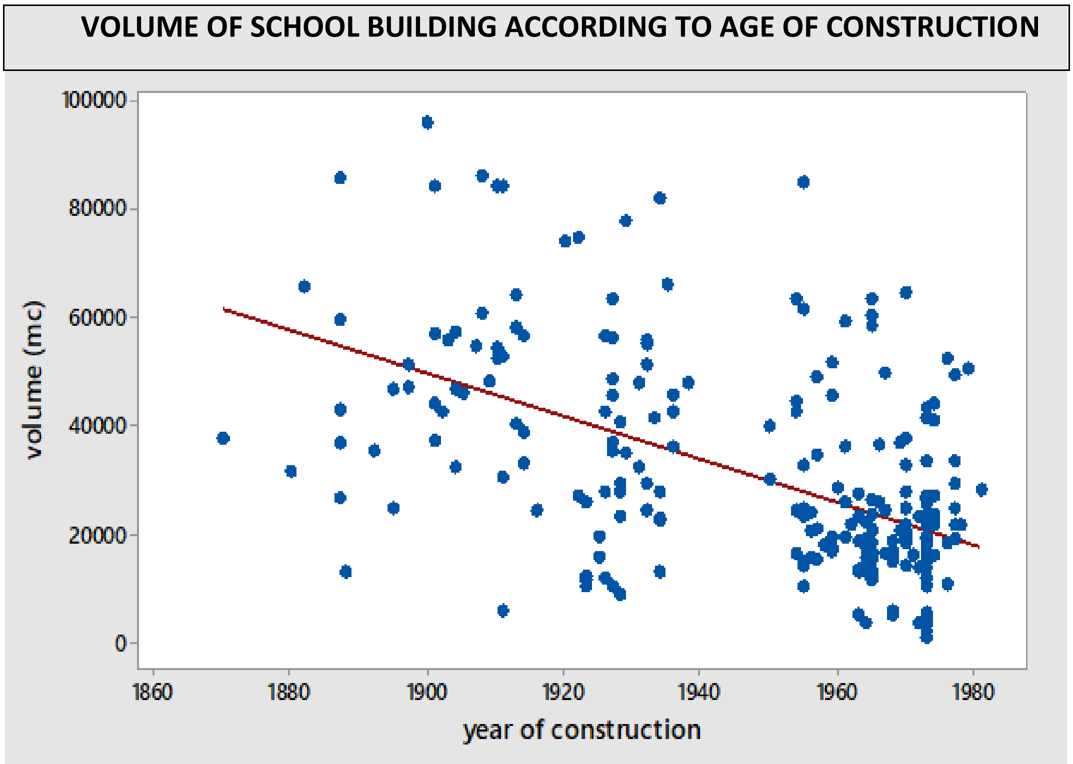

Figure 40: *Scatterplot regression analysis on volume according to age of school buildings in Milan.*

Volumes according to height

Higher volumes also correspond to a higher number of floors. Contemporary school buildings are characterized by a lower height. (**Figure 41**). The height of buildings was surrogated by number of floors.

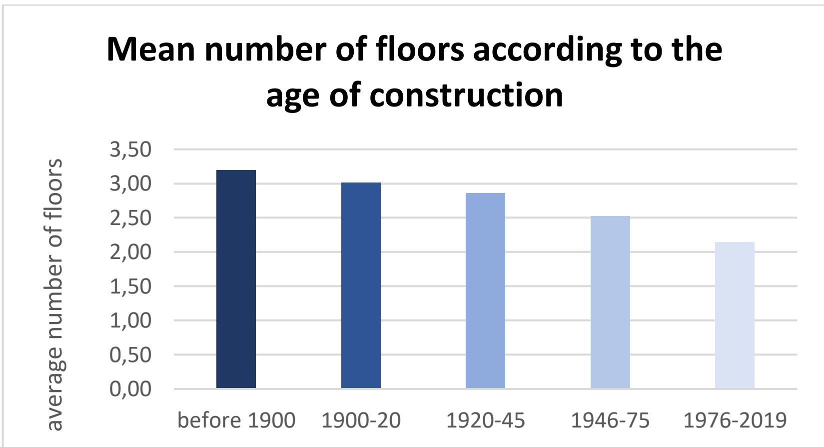

Figure 41: *mean number of floors in school building according to the age of construction*

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Volumes according to destination

Volumes of school buildings were also analysed according to their destination. Data are summarized in **Figure 42.** Larger mean volumes corresponds to primary (18'214 m^3), secondary schools of first degree (21'150 m^3) and comprehensive schools (48'065 m^3). Lower mean volumes are more typical for nurseries (3'455 m^3) and kindergartens (3'900 m^3).

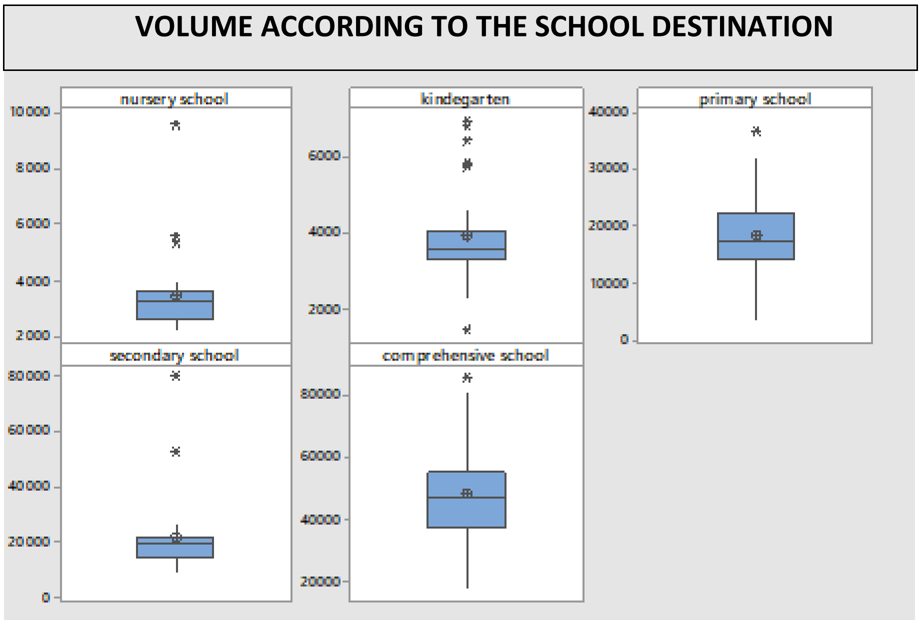


Figure 42: *Boxplot on volumes of school buildings in the area of Milan according to their destinations, personal representation of data obtained from the Municipality of Milan.*

Surface to volume ratio (S/V):

Surface area to volume ratio S/V " *is a measure of how compact a building is. It is often expressed as the 'heat loss form factor', which is the ratio for the external surface area of the building to the treated floor area."*

The higher the figure, the less compact the building, meaning there is more surface area from which heat can escape.

In general S/V ratio is inversely related to volume. This was also the case for school buildings in Milan (**Figure 43**).

Consequently, S/V ratio was also inversely correlated to destinations of the school building (**Figure 44**)

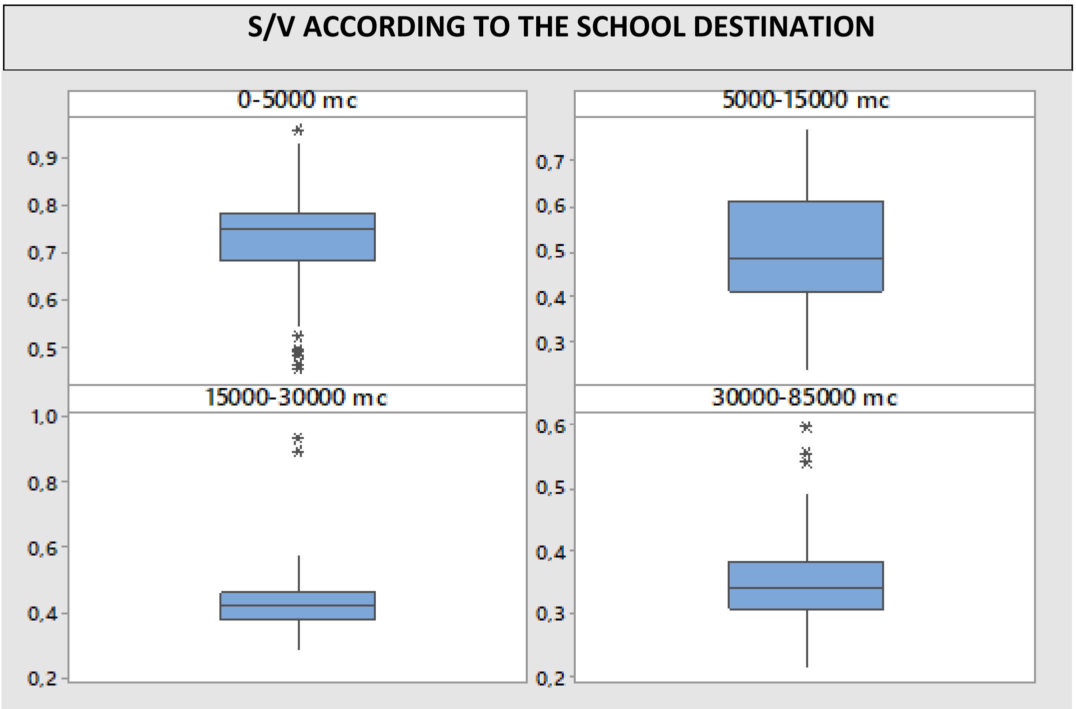


***Figure 43**: S/V ratio of school buildings according to volume in the metropolitan Area of Milan*

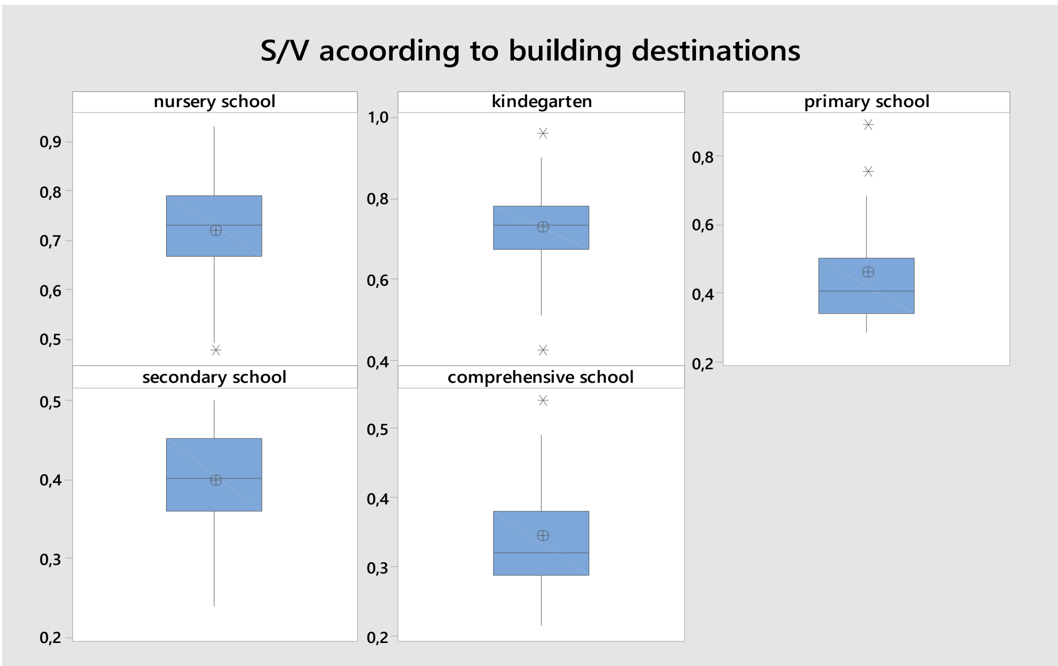


***Figure 44:** S/V ratio of school buildings according to the destination in the metropolitan Area of Milan*

This means that attention should be paid in the shape design and in the material of construction of new lower volume buildings (nursery school and kindergarten) in order to minimize their S/V ratio and heat dispersion. This matter will be the object of a more detail analysis in the final part of this thesis.

Material of construction

As already mentioned, material of constructions of school buildings differ according to their age:

In the giolittian and fascist ages materials of construction are mainly load-bearing brick masonry, concrete and mix structures. High quality of materials and research of external beauty are also characteristic of these buildings. An attention was given to the sizes of window that was design to allow natural lightning and ventilation. Material of constructions for doors and windows were mainly wood and less frequently iron

Due to the large number of school buildings requested in a short time frame, in the post-war period material of constructions often did not meet the requested standards. The easier, faster and less expensive way to front the increased demand of school buildings was to resort to prefabricated metallic structure or reinforced concrete beams and to the plugging technique of construction.
Poor quality of new material of constructions adopted al partitions such as aluminium, synthetic membrane, and compost wood for doors and windows brought to a rapid deterioration of these type of school building and of their structural, energetic and security performance.

An analysis of school building in Milan reflects the above-mentioned concepts.

Partitions

The majority of school buildings (155/247 = 63%) were constructed according the plugging technique.

Load bearing constructions account for 14,4% (43/247) of buildings (**Figure 45 A**).

These figures are obviously strongly correlated to those already presented for age of construction.

Doors and windows frame.

Aluminium is the most frequently used material for doors and windows, 204/281 =73%. Wood accounts for only 23% (**Figure 45 B**).

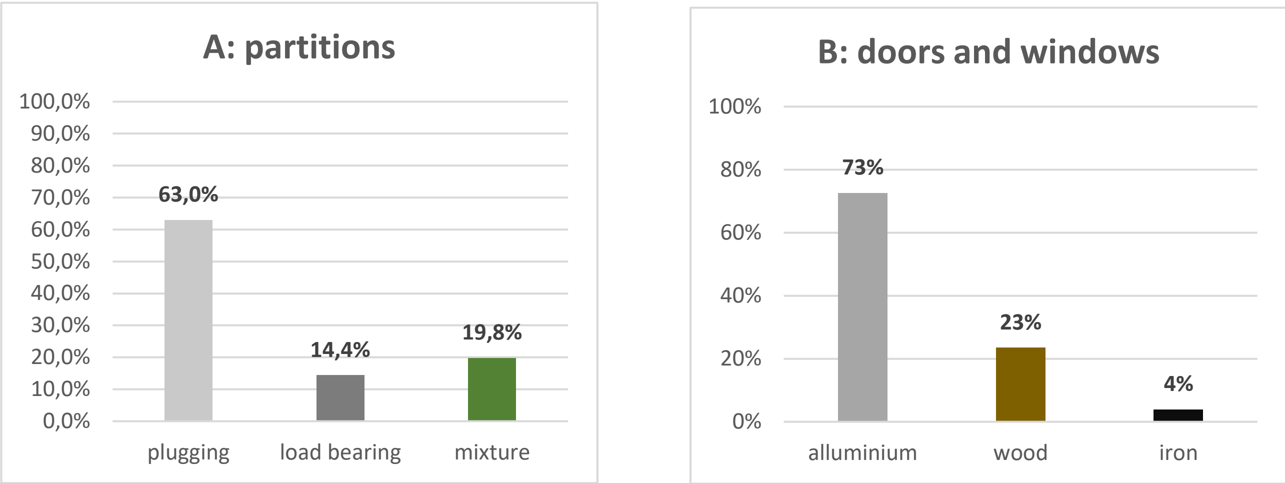


***Figure 45**: material of construction for partition **(A)** and doors and windows **(B)** in school buildings under the direct administration of the Municipality of Milan.*

Window glasses

Stratification safety glasses account for only 44% (118/268) of the sample (**Figure 46**). Unfortunately, no clear information about double glazing windows are available from the database of the Municipality of Milan. On the other hand, it is worth mentioning that half of the sample does not meet the standard criteria requested for safety and energy consumption.

***Figure 46:** window glasses in school buildings under the direct administration of the Municipality of Milan*

Sources of heating supply

Figure 47 reports below energy sources for heating according to data retrieved the Ministry Education[18] in Italy. Methane represents the main energetic supply (75%). Nevertheless and surprisingly enough gasoline is still used in 17% of the sample. According to the directives of the European and Italian authorities this scenario will be soon out of law. On the other hand, it is worth mentioning that the contributions of renewable energy sources is still limited.

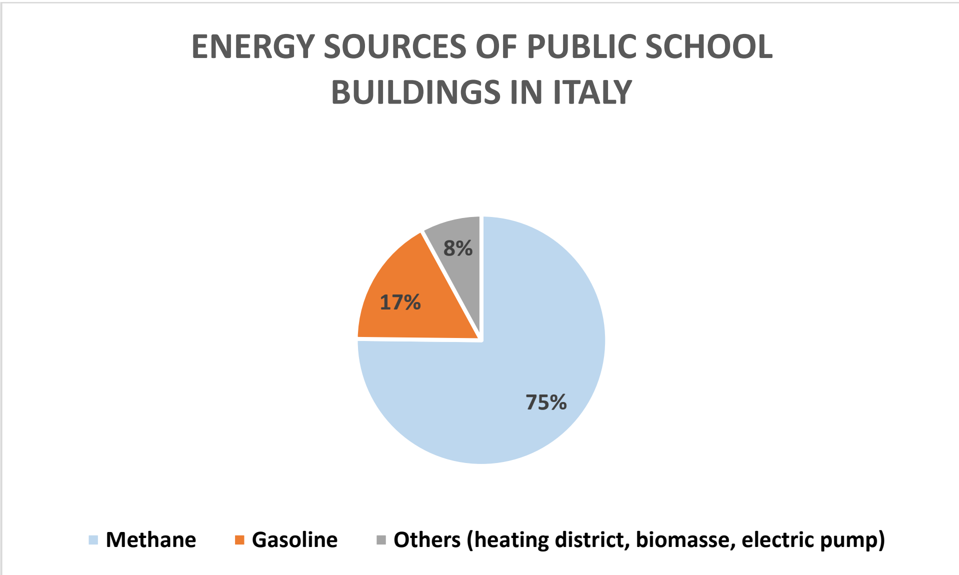


Figure 47*: energy sources for heating in schools building in Italy*

The scenario of heating sources in Milan has a different better trend: Low power gasoline plants still active (3%). Nevertheless, alternative source of energy for heating still represents a small portion of the sample. **(Figure 48)**

Among secondary energy sources district-heating accounts for 12% of heating modality for public school buildings in Milan. In contrast with the National scenario (3,2%). Nevertheless, alternative source of energy for heating still represents a small portion of the sample.

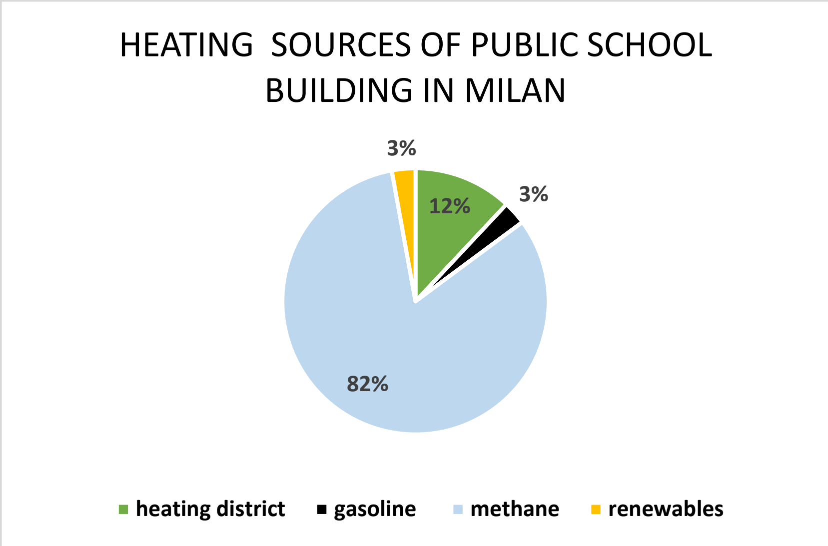


Figure 48*: energy sources for heating in schools building in Milan*

Heat diffusion and ventilation modality

Radiators remain the main source of heating diffusion in school buildings in Milan (86% - 268/312 school buildings).

Other poorly represented ways of diffusion: fan coils (7%), aerothermal systems (5%) and radial panels (2%). (**Figure 49**)

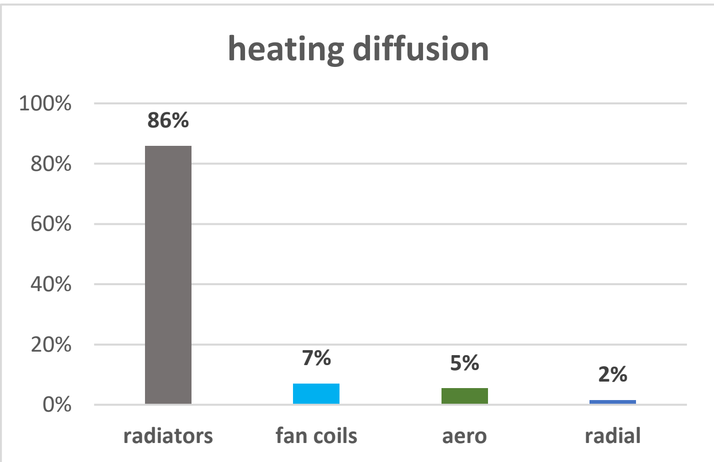


Figure 49: *heating diffusion systems in Milan*

Air ventilation and purity.

According to Ministry of Education Decree, 18/12/1975: *Technical indications for scholastic buildings.* Paragraph 5.3*: heat, humidity and air purity requirements.* Paragraph 5.3.12[29], the following external air flow rate, should be guaranteed by means of adequate systems:

Rooms used for group teaching activities.

- **Kindergartens and primary schools** air exchange coefficient (AEC = number of complete air replacement in one hour): AEC = 2,5
- **Secondary school of first-degree** AEC = 3,5
- **Secondary school of second-degree** AEC = 5,0

Other connecting ambientes or offices AEC = 1,5

Toilets, gyms, refectories AEC = 2,5

Air exchange of school buildings in Milan **(Figure 50)** is mainly provided by natural ventilation (93%). Old buildings have architectural characteristics (high classes, large windows, long corridors etc.) that guarantee an adequate air replacement. On the contrary the majority of more recent school have architectural structures that do not fulfil criteria of air exchange defined by law and the majority of them should be supported by assistant mechanical ventilation that is presently guaranteed only to new projects (7% of the sample).

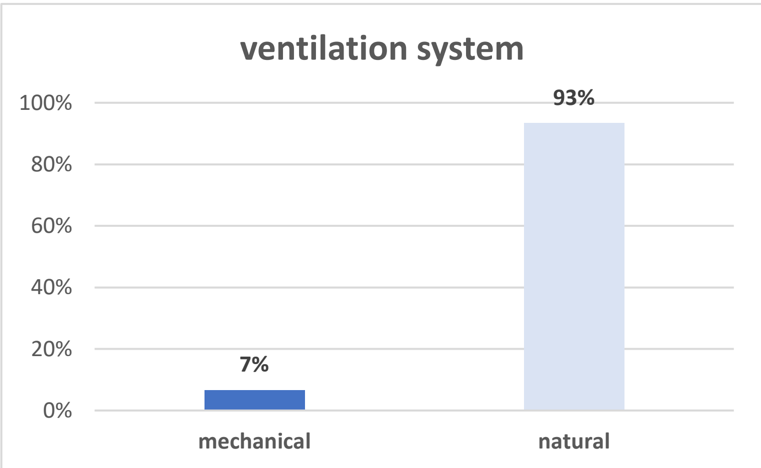


Figure 50*: ventilation system in school buildings of the metropolitan Area of Milan*

Technical interventions for energy savings improvement

According to the United Nation Environment Programme[32], buildings are responsible for 40% of the global energy consumption and 30% of pollutant atmospheric emissions. For this reason, construction of new buildings in the world requires elevated standards of energy savings

The above reported data (**Table 18**) clearly demonstrate that most of school buildings in Italy were constructed before energy saving and environmental preservation had become a critical issue for national authorities.

At the same time, due to the reduction of birth rate in Italy, construction of new school building has not been a priority in the last four decades.

For this reason, projects aimed at improving energetic efficiency of aged school buildings are now necessary in a large number of cases.

According to a recent report from Fondazione Agnelli, 16% of school buildings in Italy have serious **structural problems** regarding vertical or horizontal load bearing structures and roof tops. In 1,3% of cases more than 1 of the three above mentioned critical issues have been acknowledged by the competent authorities[18].

Problems related to energy **sustainability** are even more frequent and can be summarized as follows:

- ✓ Lack of double glazed windows or 61%
- ✓ Lack of heating zoning 64%
- ✓ Lack of photovoltaic and thermal panels 74%
- ✓ Lack of rooftops insulation 78%
- ✓ Lack of external wall insulation 88%

Below **Figures 51 A-B** present the rate of school buildings in Italy and in Milan respectively that have already undergone any kind of technical assistances aimed at energy savings. A large number in the sample is still lacking any kind of technical support since their construction.

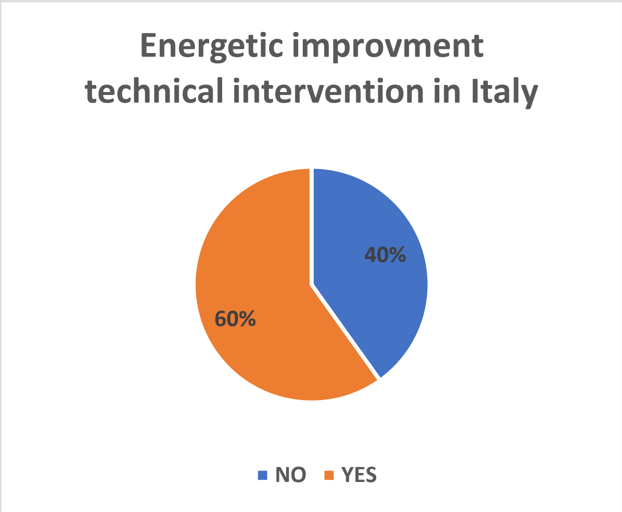


Figure 51 A: *rate of school building in Italy that have undergone technical assistance for energy improvement purposes, data obtained from MIUR data base*[17]

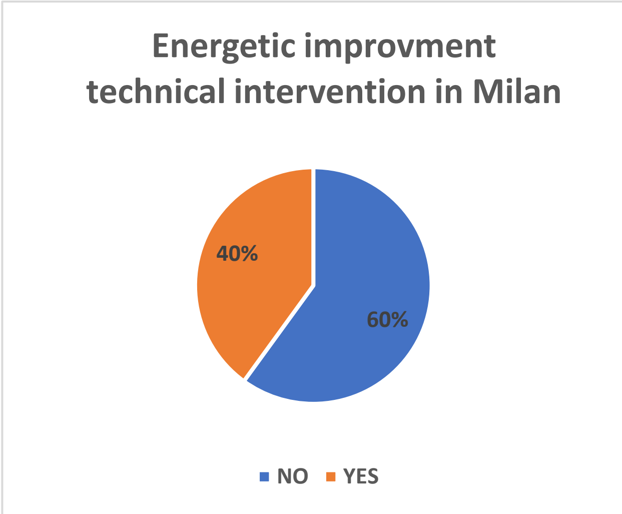


Figure 51 B: *rate of school building in Milan that have undergone technical assistance for energy improvement purposes, data obtained from MIUR data base.*[17]

Going into details **Figures 52 A-B** present the rate of technical assistance for energy saving of school building according to their characteristics in Italy and in Milan respectively

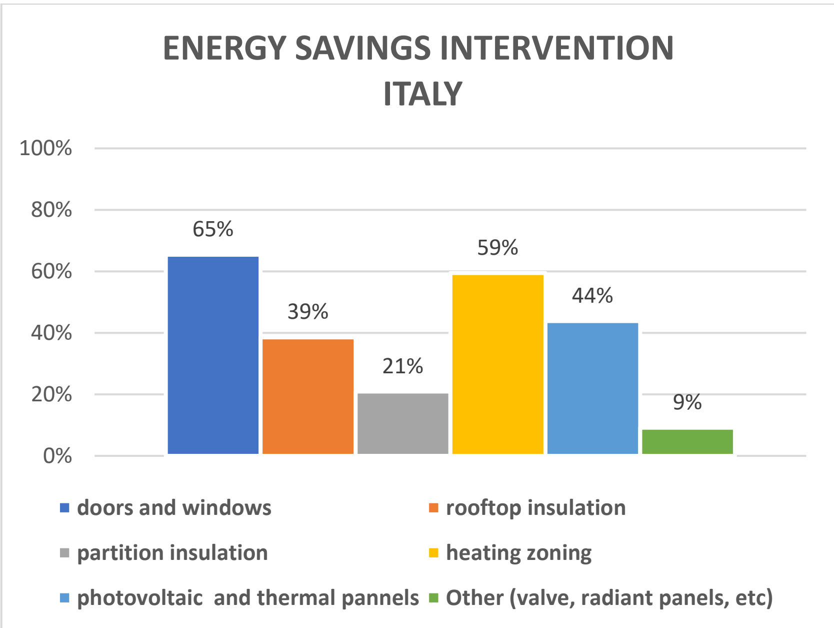


Figure 52A: *Technician assistance for energy saving of school buildings in Italy according to destination* [17]

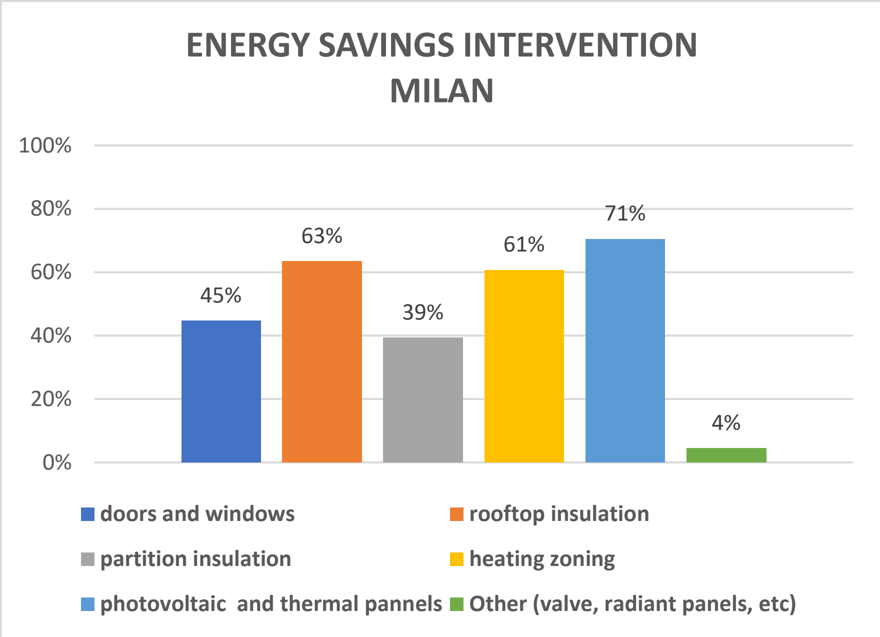


Figure 52B: *Technician assistance for energy saving of school buildings in Milan according to destination* [17]

7E: Technical analysis for energy saving by increasing the efficiency of heating source and thermal dispersion on a sample of four school buildings having different characteristics according to year of construction and architectural style.

1. Building n°1: Music Civic School, *Claudio Abbado*

Name:	Civic School, *Claudio Abbado*
Location:	Via Stillicone 36, Municipality 8, Milan
Year of construction:	end of XV century
Intended use:	night school
Heated volume:	15’200 m^3
Number of floors:	3
Heating source:	natural gas
Contracting company:	Montalba Ita

Inspection

Two site inspections were conducted on February 2020 following permission and by appointment with a technician from “Municipality of Milan . Adjunctive inspections were unfortunately no longer possible later in the lock down period

On site inspections allowed to retrieve information concerning the structural condition of the building and of the thermal components of the HVAC system in place and critical issues concerning sustainability.

Structural building characteristics

As already mentioned above, this historical building was erected at the end of XV century. Its main and peculiar characteristic is thus to be found in the ancient and vulnerable elements of which is made of. Columns, frescos, and wooden ceilings characterize most of the spaces (**Figure 54 A-B**).

For this reason the building is under the supervision of the authority of Fine Arts. Any renovation or refurbishment or even maintenance work should meet the conditions imposed by strict protocols.

Figure 54 A-B*: an example of frescos and wooden ceiling that characterize the Music School Claudio Abbado*

The plant of the building has a typical U shape that delimits the wide and elegant inner garden **(Figure 55)**. A small and prestigious chapel in located aside the main building.

The building is composed by three very high floors (see below) that give to the visitor the feeling of airiness and magnitude. Ground, first and second floor connected by a main spiral staircase **(Figure 56)**.

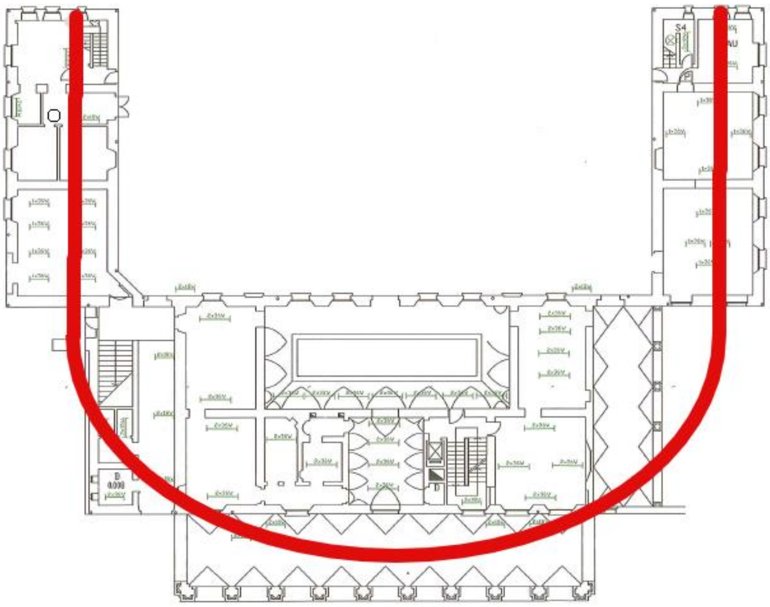


Figure 55*: the typical U shape of the Music School Claudio Abbado*

Figure 56: *the main stair connecting floors of the building.*

Technical characteristics

- **Load-bearing structure:**	Masonry
- **Useful and walkable surface** :	2’227,4 m^2
- **Volume**	15’216 m^3
- **Height of the ceilings**	10 m
- **Total Dispersing surface of the building**	5032,91 m^2
- **Transparent surface**	332,06 m^2 92 double glasses wood and aluminium window
- **Ground surface**	716,5 m^2
- **Rooftop surface**	805 m^2
- **Surface to volume ratio (S/V):**	0,33 m^{-1}

Different materials that characterize dispersing surfaces, account for different values of transmittance coefficients that are below reported.

- **Opaque surface**	(3179,35 m^2)	U =	0,93 $W/m^2 K$
- **Transparent surface**	(332,06 m^2)	U =	5,1 $W/m^2 K$
- **Ground surface**	(716,5 m^2)	U.=	0,34 $W/m^2 K$
- **Rooftop surface**	(805 m^2)	U.=	1,09 $W/m^2 K$.

Heat diffusion and ventilation modality

Heating diffusion is provided by 101 radiators:

No mechanic ventilation system is in place to exchange air with the outside ambient. Natural ventilation is the only way to guarantee air exchange. and is facilitated by height and in general large size of rooms.

.

Figure 57 *heating diffusion is provided by 101 radiators.*

Figure 58 *transparent surface is composed by 92 double glasses wood and aluminium window.*

Energy exchange: lost, gained, and requested

Energy loss (Ql)

The inside to outside loss of energy flows of the building and are related to two main factors: **natural ventilation** (Qv) and the **heat diffusion through walls and glasses** (Qh).

Total energy loss (Ql) is the sum of Qv and Qh *(Ql = Qh+Qv).*

Energy gain (Qg)

Energy gain instead is depends on flows from outside to inside the building and is related again to two main factors: **solar irradiation** during the day (Qs) and **internal energy contribution from people and things** (Qi). Surfaces exposed at south have better energy gains compared to surfaces at north.

Total energy gains (Qg) is the sum of Qs and Qi *(Qg = Qs+Qi)*

Energy requested (Qr)

The **energy requested** (Qr) by the building to maintain the target temperature in the rooms is: the energy losses (Ql) minus the energy gains (Qg) multiple by a corrective utilization factor (b):

$Qr = Qh + Qv – (Qs + Qi) * b$

Table 19 and **Figure 59** below report energy exchange and energy request during the thermal year in the Music School Claudio Abbado

Energy exchange [MJ] - Music School Claudio Abbado										
Month	**To**	**Text**	**Qv**	**Qh**	**Ql**	**Qs**	**Qi**	**Qg**	**b**	**QR**
October	20	12,4	12652	66028	78680	26943	11899	38842	0,879	44538
November	20	7,9	40285	200019	240304	35489	23798	59287	0,964	183151
December	20	3,1	56266	272513	328779	27844	23798	51642	0,985	277912
January	20	1,7	60928	293657	354585	31229	23798	55027	0,986	300328
February	20	4,2	52604	255900	308504	49604	23798	73402	0,967	237524
March	20	9,2	35957	180386	216343	73161	23798	96959	0,897	129371
April	20	13,2	11986	63009	74995	42528	11899	54427	0,788	32107
Total	-	-	**270678**	**1331512**	**1602190**	**286798**	**142788**	**429586**	-	**1204931**

Table 19 *Energy lost gained and requested during the thermal year in the Music School Claudio Abbado* ***Qv*** *= natural ventilation. -* ***Qh*** *heat diffusion through walls and glasses -* ***Ql*** *energy loss -* ***Qs*** *solar irradiation -* ***Qi*** *internal energy*

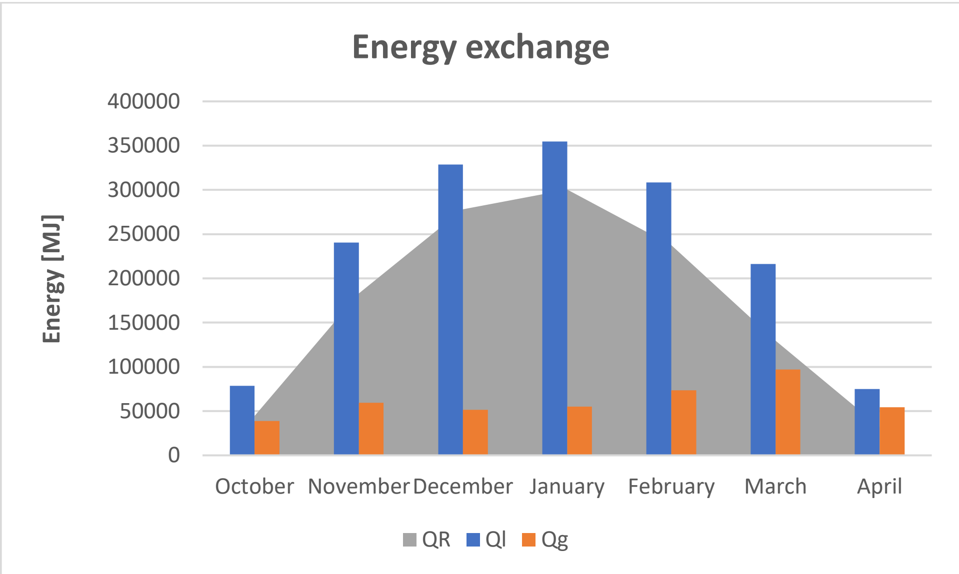


Figure 59 *Energy requested during the thermal year in the Music School Claudio Abbado*

The thermal plant

The thermal plant is located one level under the basement reachable by independent stairs that are at the right of the main building entrance.

This paragraph has the purpose to give the list of the main components adopted in it and how the heating generation is distributed by the different sub-circuits.

The **thermal plant** underwent a complete restoration in 2016 by *Montalba spa*. In that occasion the two old gasoline plants, *Ravasio* TRS D1 (320 KW × 2), were replaced with one **methane condensing plant** - Unical (639 KW)

The **heat distribution system** was also completely renovated in that occasion . A tube belt pathway was installed around the perimeter of the building. This made possible an easy connection to the diffusion radiators inside the school. This was the solution that better preserved the ancient and vulnerable partitions of the building ., according to the indications of the Fine Arts Authority.

Figure 60 gives a schematic representation of the thermal of the building

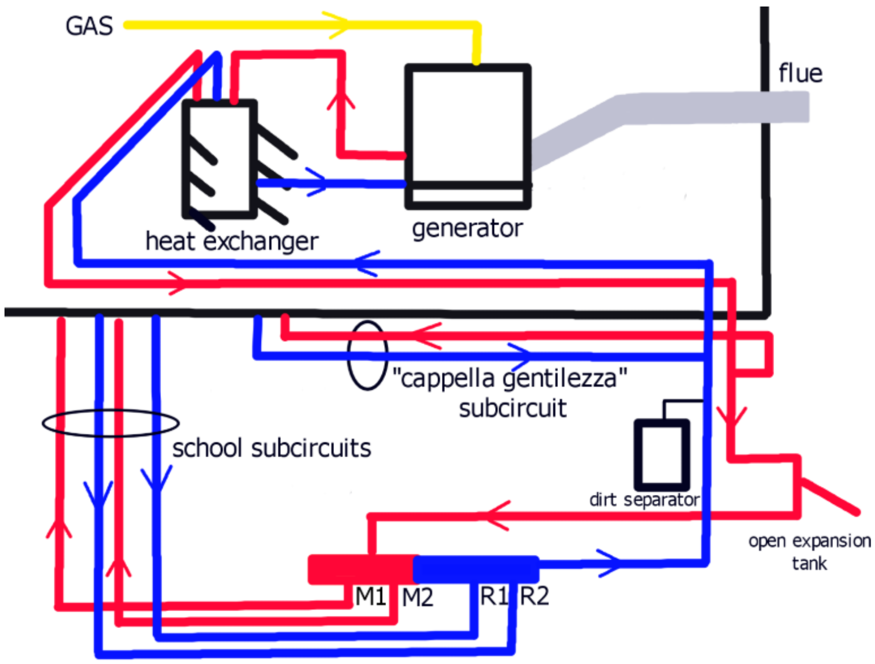


Figure 59 *a schematic representation of the thermal plant, heat generator and distribution system, of the school of the the Music School Claudio Abbado*

The scheme gives evidence to the two main with its two sub-circuits that characterize it..

The first subcircuit provide the heating supply demand of the North-West and the other of the South-East of the building. M (coloured in red) stands for the fluid that comes from the power plant and still has to release heat to the school radiators. R (coloured in blue) stands for the fluid that follows the reverse pathway from school radiators back to the power plant. Moreover, another independent circuit is in place that delivers both heating (water) and cooling (R410A) services to the separated *"Gentilezza*" chapel.

Beyond the Unical 639 kW methane condensing furnace already mentioned above, , the thermal room is composed by other main components

- One flue: to collect out the combustion fumes in a safety way.
- A plate heat exchanger: to regulate the delivering and returning temperature of water inside the circuit. (**Figure 60 C**)
- One close and open expansion vessel: to avoid excessive pressure in the collecting tubes that might injury the system. (**Figure 60 F**)
- One dirt separator (Caleffi) and softener (Nobel): to clean and perform the water inside the system. (**Figure 60 D**)
- Two twin pumps (Dab), five single pumps (Grundfons) and one three-way valve (Simens): to regulate the water flow inside the heating system. (**Figure 60 A-B**)
- One remote management panel, one electric panel and wireless antenna (**Figure 60 E**): to pick-up the outside-inside signals, manage them and run the system in a more suitable manner.

Figure 60 A-B: *a twin pump and a three way valve*

Figure 60 C*: a plate heat exchanger*

Figure 60 D*: a softener and dirty separator*

Figure 60 E*: a wireless antenna*

Figure 60 F*: a close and open vessel*

Figure 60 G*: a condensing methane furnace flue*

Thermal loads

Thermal loads were estimated according to the school operating hours during the thermal year 2018/19. (**Table 9)** . **Table 20** gives a figure of operating hours throughout the 2018/2019 thermal year No additional hours were required to run extracurricular activities in the year 2018/19.

Operating hours: and Thermal loads during the thermal year 2018/19	
MONTH	**OPERATION HOURS**
October (15th-31st)	160
November	348
December	234
January	338
February	324
March	359
April (1st-15th)	164
Extra-hours	0
Total	1927

Table 20 *operating hours throughout the 2018/2019 thermal year Civic Music School Claudio Abbado*

The thermal load during one week in December 2016 was analysed in details in (**Table 21)** and **Figure 61**. The thermal power plant activity hours do not correspond with school operating hours. The heating system is fully activated in the morning two hours before school opens in order to reach the target indoor ambient temperature. At the same time it is switched off before school activities end. According to the school timetable the heating system activity is reduced on Saturday and almost inactive on Sunday. The total energy heating consumption was estimated to be approximately 290,9 MWh in 2016.

DAY		HOUR	Furnace operation [kW]
Monday	12-dic	0.00	0,00
		7.00	476,16
		12.00	417,28
		18.00	448,00
Tuesday	13-dic	0.00	0,00
		7.00	501,76
		12.00	399,36
		18.00	463,36
Wednesday	14-dic	0.00	0,00
		7.00	517,12
		12.00	399,36
		18.00	473,60
Thursday	15-dic	0.00	0,00
		7.00	581,12
		12.00	427,52
		18.00	504,32
Friday	16-dic	0.00	0,00
		7.00	609,28
		12.00	506,88
		18.00	563,20
Saturday	17-dic	0.00	0,00
		7.00	590,00
		12.00	495,00
		18.00	0,00
Sunday	18-dic	0.00	0,00
		7.00	0,00
		12.00	0,00
		18.00	0,00

Table 21 *operating hours of the thermal power plant during one sample week in December 2016 - Civic Music School Claudio Abbado.*

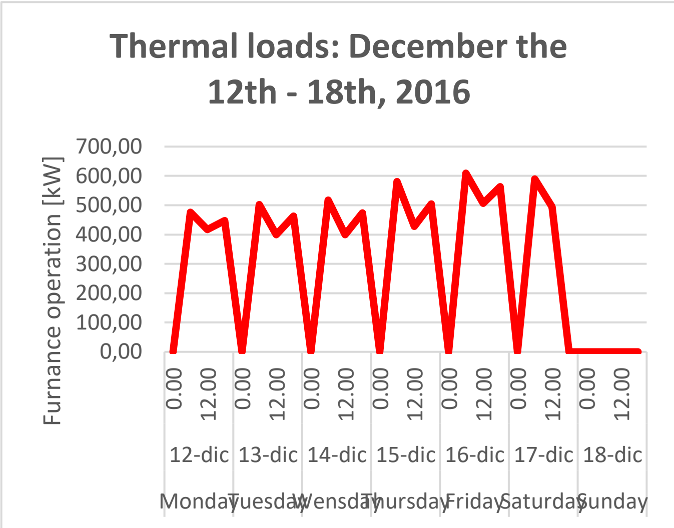


Figure 61 *a graphic presentation of operating hours of the thermal power plant during one sample week in December 2016 - Civic Music School Claudio Abbado.*

A few figures should be added to have a better picture of the building emissions and costs.

- **Methane consumption/year** not reported
- **Energy heating consumption** 291 MWh
- **Thermal + electrical energy** 25 TOE/year (TOE = Tonnes of Oil Equivalent)
- **CO_2 emissions** 60 tons/year
- **NOx emissions** not reported
- **Energetic class** E

Electrical loads

In this section we briefly report the electrical loads of the lightening spots and devices operating in the building.

The estimated **total yearly electricity demand** in 2018 was 36’370 kWh/year:

- **Fluorescent lamps** 5’488 kWh/year
- **Other electrical devices** 20’922 kWh/year

At full load, the electricity system requires 26,3 kW power to satisfy the entire demand.

Table (22 A and B) are a representation of the year electrical loads of the Civic School Claudio Abbado.

Lightening electrical loads						
Type	**N° spot**	**lamps/spot**	**Load per lamp [W]**	**Total load [kW]**	**Yearly operation hours**	**Estimated consumption [KWh/year]**
Fluor lamps	92	2	36	6,624	1080	7153,92
Fluor lamps	120	1	36	4,32	1080	4665,6
Fluor lamps	74	2	18	2,664	1080	2877,12
Fluor lamps	29	1	24	0,696	1080	751,68
Total	**315**			**14,304**		**15448,32**

Table 22-A *electrical loads lightening of the Civic School Claudio Abbado during the school year activity 2018/2019*

Other electrical loads					
Device	**N°**	**Power for unit [W]**	**Total power [kW]**	**Yearly operation hours**	**Estimated consumption [kWh/year]**
Computer	42	200	8,4	1760	14784
Monitor	42	75	3,15	1760	5544
Wi-fi	4	20	0,08	880	70,4
Television	1	100	0,1	660	66
Copy machine	2	100	0,2	1760	352
Printer	6	10	0,06	1760	105,6
TOTAL	**97**		**11,99**		**20922**

Table 22-B *loads for electrical devices of the Civic School Claudio Abbado during the school year activity 2018/2019*

The electrical load during one "sample" week in December 2016 were analysed in details **Figure 62**. Unlikely what happens for thermal loads, electrical loads almost completely match school activity schedule.

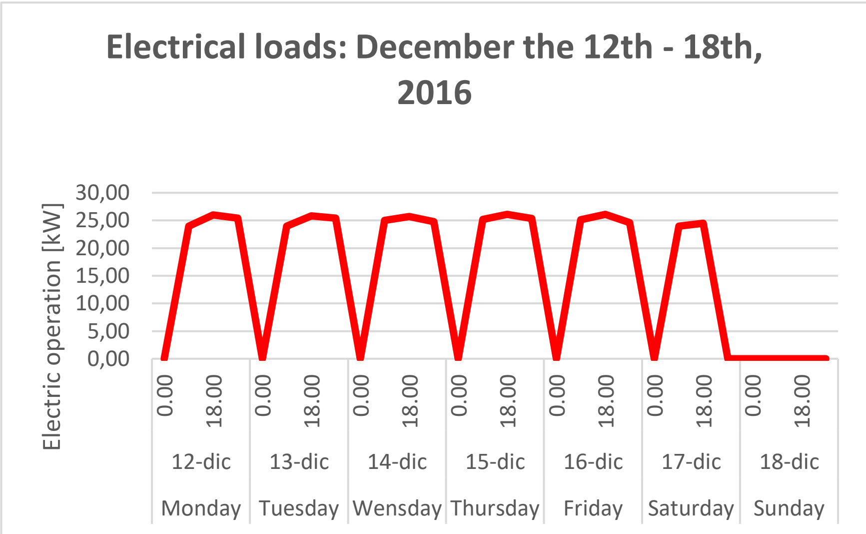


Figure 62 *a graphic presentation of electrical operating hours during one sample week in December 2016 - Civic Music School Claudio Abbado.*

-Improvement analysis and proposal-

Villa Simonetta is an antique, prestigious unique building and mainly for this reason is under the supervision of the authority of Fine Arts. As already mentioned, any renovation or even maintenance work should meet the conditions imposed by strict protocols.

It needs thus an outstanding proposal to satisfy the authority requirements and to improve the energy consumption profile at the same time.

I have focused my attention on the following renovation issues.

Replacement of the condensing methane furnace (Unical 639 kW) with a combination of an electric heat pump and a small methane plant, and replacement of the heating diffusion system from radiators to fan coils.

The installation of an **electric heat pump** is one of the most efficient solution to adopt. This is a complete and innovative system that allows to satisfy the requests for heating, cooling, and the same time for the production of hot sanitary water for the building.

The electric heat pumps generate more than one unit of thermal energy for each unit of electrical energy consumed. This is expressed by the coefficient of performance (COP) value that is always higher than one.

Different types of electric heating pump are available on the market. The main difference that characterise one from another is based on the fluid used during the heating exchange process.

Air and water heating vectors are the most frequently adopted solutions. These also reduce environmental load by re-using heat energy produced.

An electric heating pump can be located either outdoor (e.g. on the rooftop) or indoor (e.g. in the thermal room). It is a device that does not generate any acoustic pollution.

Among the numerous offers available on the market, I have chosen a solution (*Trane s.p.a.)* that meet the high capacity requirements of the school by installing two *Lyra* heat pumps (CXCN245 and CXCN270) in series.

The main characteristics of the heat pump are the following:

- Class A efficiency in heating mode
- Equipped with air-to-water heat pump technology to extract the outdoor air for energy.
- Reversible, enhanced cooling capacity.
- Outdoor air temperature range: -10 / 35 °C in heating and 5 / 45 °C in cooling mode
- Inverter fans management for enhancing part load efficiency.

Figure 63 is a picture of the Trane, Lyra: CXCN heat pump. **Table 23** presents the technical features of the system according to the two different heat pumps:

Figure 63 *The Trane, Lyra: CXCN heat pump*

Trane, Lyra: CXCN heat pump			
Capacity		**CXCN245**	**CXCN270**
Heating capacity	kW	243	268
Cooling capacity	kW	222	242
Minimum capacity [%]	%	20	20
Power input electricity [kW]	kW	78,7	89,8
Performance		**CXCN245**	**CXCN270**
COP	-	3,11	3,02
EER	-	2,36	2,25
Dimensions		**CXCN245**	**CXCN270**
Height	mm	2145	2145
Width	mm	1306	1306
Length	mm	6676	6676
		CXCN245	**CXCN270**
Price	€	40’000	45’000

Table 23 *technical characteristics and price of the Trane, Lyra: CXCN heat system according to the different heat pumps installed*

The electric pump transfers the heating fluids in the distributing system at a maximum temperature value of 55-60 °C. The presently in use condensing methane furnace enable a distribution temperature of 75-80 °C. For this reason, it is appropriate to make the heating diffusion system more efficient by replacing radiators presently with fan coils.

Looking again at the numerous offers available on the market, I have chosen for my analysis the Daikin **wall fan-coil FWL10C** that in my opinion best meets the requirements of the building.

Some characteristics about the fan coil are the following:

- Quick fixing system for wall/ceiling mounting.
- Valve packages contain balancing valves and sensor pocket.
- Quick removal of washable filter.
- Two overheat cut-out thermostats.

Figure 64 is a picture of the Daikin fan coil (2-pipe), FWL06C. **Table 24** presents the technical features of the system.

Figure 64 The Daikin fan coil (2-pipe), FWL06C

Daikin fan coil (2-pipe), FWL06C		
heating capacity	kW	6,36
current absorbed	W	0,43
sound power	dBA	56
air flow rate	m^3/h	706
water flow	l/h	820
Dimensions		
height	mm	564
width	mm	774
depth	mm	226
Unit price		
	€	340

***Table 24** The technical characteristics and price of Daikin fan coil (2-pipe), FWL06C fan coil*

In general the main limit of any heating pump is represented by their inadequate performance during extreme climatic conditions at temperatures below 0 °C. Since Milan is in climatic zone E, the designed temperature for heating power plants is -5°C. According to our above mentioned analysis, Milan has never reached an atmospheric temperature < 5°C in the last five years. Nevertheless it is necessary to support this technical limit with the installation of a smaller condensing methane furnace that might operate and support heating in extreme climatic conditions.

I have chosen for this purpose the *Riello* condensing methane furnace CONDENSAPRO 115 to be installed in the thermal room.

Figure 65 is a picture of the condensing methane furnace CONDENSAPRO 115 **Table 25** presents the technical features of the system

Figure 65 *The condensing methane furnace Riello CONDENSAPRO115*

Riello, CONDENSAPRO135		
HHV	kW	146
LHV	KW	131
Efficiency at max load	%	88,2
Max gas consumption	m^3/h	13,91
Sound power	db(A)	57
Max electric load	W	302
Dimensions		
Height	mm	1165
Width	mm	600
Depth	mm	435
Price		
	€	15’525,00

Table 25 *technical characteristics and price 65 he condensing methane furnace Riello CONDENSAPRO115*

Substitution of fluorescent with led lamps

Fluorescent lamps are still the lightening sources for the entire building with an estimated total consumption of 15’488,32 kWh/year.

Below is a presentation of the fluorescent lamps in us

- **304 fluorescent lamps power 36W** estimated consumption 11’819 kWh/year
- **148 fluorescent lamps power 18 W** estimated consumption 2’877 kWh/year
- **29 fluorescent lamps power 24 W** estimated consumption 751,68 kWh/year

The installation of led lightning applications is an intervention that must be considered in any energy efficiency solution to day. The lightning system replacement is easy to apply, and it could bring considerable energy savings and economic benefits.

The luminous efficiency (luminous/power) is a necessary parameter to dimension the power that the new led lightning system needs. Each type of lamp has its own luminous efficiency value and approximately it is estimated that a led lightning lamp requires 60% less the power used by a fluorescent lamp to achieve the same efficacy result (luminous value).

Table 26 is a schematic presentation of   florescent-led lamps conversion:

fluorescent-led power conversion		
fluorescent lamp power [W]	**conversation factor**	**led power estimation [W]**
36	0,4	14,4
18	0,5	9
24	0,91	2,2

Table 26: *a schematic presentation of   florescent-led lamps conversion*

Following the substitution of lamps, the system will have the following estimated characteristics and energy consumption

- **304 led tubes power 14,5 W** estimated consumption 4’760,64 kWh/year
- **148 led tubes power 9 W** estimated consumption 1’438,56 kWh/year
- **29 led lamps   power 2,2 W** estimated consumption 68,904 kWh/year

- **Total lightning power: 5,8 kW** estimated consumption: 6’264 kWh/year

I have chosen for this purpose three led lamps with different power in order to satisfy the demand of lightning spots requested:

14,5 W lamp Philips CorePro Ledtube (Figure 66)

Pros :

- ✓ Energy saving: 60%
- ✓ Fluorescent power substitution 36 W
- ✓ Useful life: 30’000 hours
- ✓ No maintenance requirements
- ✓ Clean energy

Figure 66 *14,5 W lamp Philips CorePro Ledtube*

Technical and economical characteristics are detailed in **Table 27**

Lamp Philips CorePro, Ledtube		
load	W	14,5
lightning flow	Lumen	1600
Efficiency	Lm/W	110
Dimension		
length	mm	1200
diameter	mm	28
shape	-	T8
Price		
	€ / unit	6,9

Table 27: *economical and technical characteristics of Philips CorePro, Ledtube*

9 W Noxion Avant LED T8 Tube Standard EM (Figure 67)

Pros:

- ✓ Energy savings: 50%
- ✓ Fluorescent power substitution 18 W
- ✓ Immediate ignition
- ✓ Useful life 25’000 hours
- ✓ No maintenance
- ✓ Clean energy

Figure 67: *The 9 W Noxion Avant LED T8 Tube Standard EM Ledtube*

Technical and economical characteristics are detailed in **Table 28**

Noxion Avant LED T8 Tube Standard EM		
load	W	9
lightning flow	Lumen	810
efficiency	Lm/W	90
Dimension		
length	mm	600
diameter	mm	28
shape	-	T8
Price		
	€ / unit	3,5

Table 28 *technical and economical characteristics of the Noxion Avant LED T8 Tube Standard EM Ledtube*

2,2 W Philips Classic LED lustre (Figure 68)

Figure 68: 2*,2 W Philips Classic LED lustre*

Pros:

- ✓ Very high energy savings
- ✓ Fluorescent power substitution 25 W
- ✓ No mercury inside
- ✓ Useful life 15'000 hours
- ✓ No maintenance
- ✓ Clean energy
- ✓

Technical and economical characteristics are detailed in **Table 29**

Philips Classic LEDlustre		
load	W	2,2
lightning flow	Lumen	250
Efficiency	Lm/W	113
Dimension		
Diameter	mm	45
Shape		P45
Price		
	€ / unit	3,1

Table 29 *technical characteristics of the Philips Classic LEDlustre*

Installation of a building integrated PV system

The installation of the Building Integrated Photovoltaics (BIPV) system in combination with a heat pump would make the operation of our heating system more efficient.

Among different solutions I have chosen propose technique for BIPV based on flat tiles in which PV modules are tightly joined with rooftop tiles. This sophisticated solution allows to preserve the beauty of the building according to the "Fine Art" restrictions.

In addition to the PV module many other components compound the PV plant:

- **a power box** that collects the PV arrays in one string.
- **a surge arrester** is an electrical power distribution system that protects people and equipment from overvoltage.
- **a fuse** that protects components by overcurrent loads.
- **an inverter** is a box that transforms the direct currents (DC) coming from PV modules to alternant current (AC) injected into the grid.

- **a meter** that accounts the electricity produced, self-consumed, or injected into the grid.
- **an electric panel** that switch on and off the system components.

Moreover, the PV flat tiles installation should be projected considering the solar irradiation and thus choosing surfaces facing South rather than North.

Gasser Ceramic s.p.a, product PAN 29.is an offer on the market that suits the requisites. (Figure 69) .

Table 30 is a presentation the technical features of the system

Figure 69 *The Gasser Ceramic PAN 29*

PV tiles, PAN 29	
power	
nominal power	29 Wp
nominal power tolerance	[-5%; +5%]
nominal power [m^2]	87 Wp/m^2
other characteristics	
voltage	43,3 V
current	0,675 A
counter-circuit current	0,759 A
temperature limits	[-40°C; +85°C]
module efficiency	13,50%
cell type	mono-crystalline
dimensions	
length	380 mm
width	155 mm
depth	9 mm

Table 30 technical characteristics of the *Gasser Ceramic s PAN 29*

Technical analysis

Heat pump

Given that the total load capacity of the heating system should remain the same of the previous installation (639 kW)., a parametric coefficient (α) was used to determine the sizing of the new installations

The parametric coefficient (α) stands for the percentage of load covered by the electric heat pump. Assuming α = 0,8. , the heat pump load to be installed is **639 kW x 0,8 = 511 kW**

The in-series installation of the two heat pumps CXCN245 and CXCN270 gives the power of **511 kW (243 kW + 268 kW)** that is exactly the requested target.

The small condensing methane furnace has thus a percentage load power of $(1 - \alpha) = 0,2$.

This means that the condensing methane furnace should have a power of **639 kW x 0,2 = 128 kW.**

By adopting the CONDENSAPRO135 condensing methane furnace is possible to achieve a load capacity of 131 kW.

Heating diffusion system

I have considered to replace all the 101 presently active radiators with the same number of fan coils. The power in each fan coil should be at least: **639 kW/101 = 6,3 kW** in order to fully cover the heating system capacity.

The heating capacity of the Daikin fan coil (2-pipe), FWL06C fan coil is 6,36 KW

Electricity consumption of the building after the intervention

- **Lightning**:

  Power 5,8 kW

  Energy consumption 6,264 MWh/year.

- **Electrical devices**:

  Power 12 kW

  Energy consumption 20,922 MWh/year.

- **Electrical heat pump (heating)**:

  During the thermal period, the heat pump operates at different loads depending on the external weather conditions. The heating power operation during the thermal period has been calculated according to the mean Degree Day (Oct-May 2015-2020) and is presented in **Figure 70** and **Table 31.**

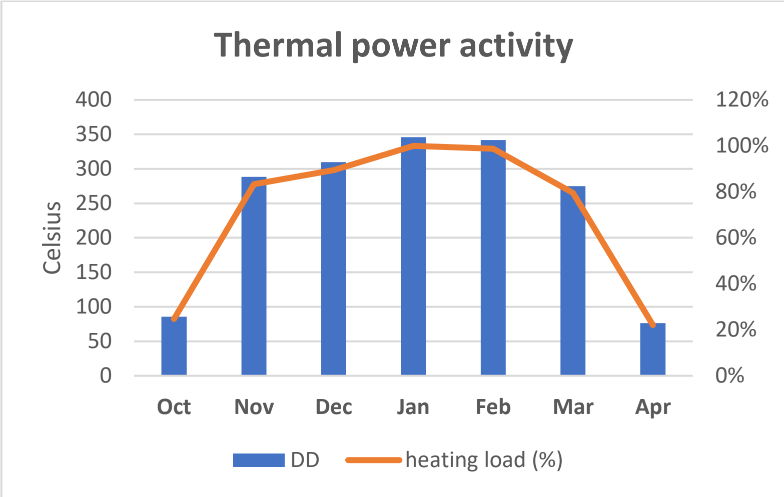


Figure 70: *Heating power operation during the thermal period calculated according to the mean Degree Day (Oct-May 2015-2020)*

Milan	Oct	Nov	Dec	Jan	Feb	Mar	Apr
DD	85,66	288,4	309,69	346,09	341,66	275,13	76,37
heating load (%)	25%	83%	89%	100%	99%	79%	22%

Table 31 *Heating power operation during the thermal period calculated according to the mean Degree Day (Oct-May 2015-2020)*

- ✓ **Total number of heating operation hours** (in the thermal season: 1927
- ✓ **Maximum input electricity load capacity** : 78,7 kW (CXCN245) + 89,8 kW (CXCN270) = 168,5 kW

Estimated load of the heating system and energy consumption during the thermal year are below reported

October	(160 hours – energy load 25%)		
CXCN270	load 22,45 kW	energy consumption	3592 kWh
CXCN245	load 19,675 kW	energy consumption	3148 kWh
November	(348 hours – energy load 83%))		
CXCN270	load 74,534 kW	energy consumption	25938 kWh
CXCN245	load 65,321 kW	energy consumption	22732 kWh
December	(234 hours energy load 89%)		
CXCN270	load 79,922 kW	energy consumption	18702 kWh
CXCN245	load 70,043 kW	energy consumption	16390 kWh

January	(338 hours – energy load 100%)		
CXCN270	load 89,8 kW	energy consumption	30352 kWh
CXCN245	load 78,7 kW	energy consumption	26600 kWh
February	(324 hours - energy load 99%)		
CXCN270	load 88,902 kW	energy consumption	28804 kWh
CXCN245	load 77,913 kW	energy consumption	25244 kWh
March	(359 hours - energy load 79%)		
CXCN270	load 70,942 kW	energy consumption	25468 kWh
CXCN245	load 62,173 kW	energy consumption	22320 kWh
April	(164 hours - load 22%)		
CXCN270	load 19,756 kW	energy consumption	3240 kWh
CXCN245	load 17,314 kW	energy consumption	2839 kWh

The total electricity heating consumption accounts for 255,37 MWh

Electric heat pump (cooling)

It is difficult to give an estimate for this issue since cooling has never been taken into consideration for this as for the majority of school building in Italy and in Milan.

Maximum input electricity load capacity	168,5 kW
Estimated cooling operation hours June1st – July 31st Jul	400 h

June (estimated hours of functioning 200 – estimated load 60%)
load 101,1 kW energy consumption 20.220 kWh

July (estimated hours of functioning 200 - estimated load 100%)
load 168,5 kW energy consumption 33,700 kWh

Total estimated electricity cooling consumption accounts for 53,92 MWh

For the above mentioned reasons energy consumptions for cooling will not considered in further economical calculations.

Fan coils consumption:

Electrical power requested	0,44 W unit
n° fan coils	110
Total power requested	48,4 W

n° operating hours

- Heating 1927 hours
- Cooling 400 hours

Total fan coils electricity consumption

- Heating 93,267 kWh
- Cooling 19,360 kWh

Overall electricity requested:

- power capacity: 234,7 kW
- consumption heating 375,823 MWh/year
- consumption cooling (571,679 MWh)

Electricity production by the Building Integrated Photovoltaics (BIPV) system

Here below is reported a survey conducted by Politecnico of Milan that gives a good approximation about the electricity amount produced by 1 kWp of PV plant installed in Milan:

The amount of DC electricity yearly produced is 1'646 KWh/KWp.

The alternating current (AC) produced is not equal to the direct current (DC).

It even depends on the efficiency of all the set of devices (e.g. power conversion system) that are necessary to transfer the energy produced by the photovoltaic modules to the power grid.

The efficiency of the balance of the system (BOS) involved is estimated consistent at a value equal to 85%.

At the end, the amount of AC electricity yearly produced is equal to 1'399 kWh/KWp.

An estimate calculation of the rooftop surface (m^2) available for the installation of PV flat:

The total under rooftop surface has been obtained by the available map of the building (Figure 71)

- **Frontal under rooftop**: 36,5 m × 13,75 m = 501,875 m^2
- **Lateral under rooftop**: (20,4 m × 7,65 m) × 2 = 312,12 m^2
- **Total under rooftop:** 501,875 m^2 + 312,12 m^2 = 814 m^2

Due to the rooftop inclination, the encumbrance of BOS and the different orientation towards the terrestrial poles. It appears not feasible to exploit all the available surface previously calculated.

Since it was not possible for me lead further inspections on site an estimate calculation of the rooftop surface available for the installation of PV plant was conducted through Google Maps.

On the West-South facing rooftops, it is possible exploit two rectangles (Figure 72):

- 16 m × 4,5 m = 72 m^2
- 9 m × 3 m = 27 m^2

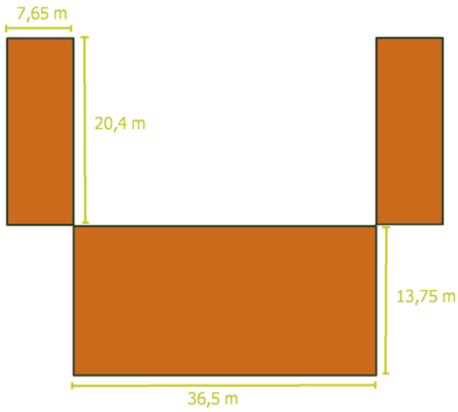


Figure 71 *Total roof top surface of the building*

Figure 72: *Total surface available for the installation of PV flat in the South-West facing rooftops according to an analysis conducted using through Google Maps*

On both the left and right side of the main building entrance it is possible to exploit one rectangle and triangle (Figure 73) :

- (7 m × 2 m) × 2 = 28 m^2
- [(9 m × 4,5 m) / 2] × 2 = 40,5 m^2

On both the wings of the building with it is possible to exploit again two rectangles (Figure 74).

- (15 m × 3 m) × 2 = 90 m^2
- (12 m × 3,5 m) × 2 = 84 m^2

No PV installations have been considered in North side of the rooftop due to poor solar irradiation during the day.

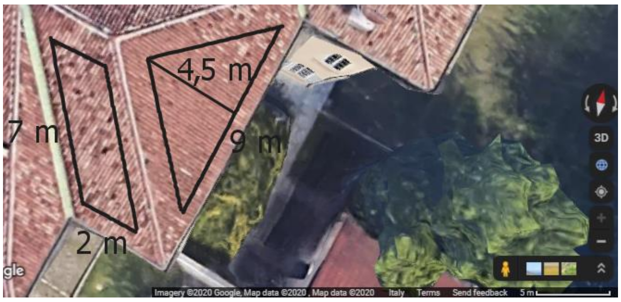


Figure 73 *Total surface available for the installation of PV flat in in the left ad right sides rooftops according to an analysis conducted using through Google Maps*

Figure 74 *Total surface available for the installation of PV flat in in both the rooftops of the wings according to an analysis conducted using through Google Maps*

According to these figures, the total rooftop surface available for PV tiles installation is 341,5 m^2. Considering a nominal power of 87 Wp for each m^2 installed according to catalogue, the following estimate for the Building Integrated Photovoltaics (BIPV) system can be calculated

Total capacity installed is 29,71 kWp

Total year electricity production of: 29,71 kWp × 1'399 kWh/kWp = 41,564 MWh

The project has not considered an energy storage system. It is thus reasonable estimate an electricity consumption rate for the building utilities of 35%. The remaining produced energy is fed into the grid:

Energy self-consumption: 14,547 MWh

Energy fed into the grid: 27,017 MWh

The methane furnance consumption

During the thermal period, the methane furnace operates at different loads depending on the external temperature conditions. The heating power operation during the thermal period has been calculated according to the mean Degree Day (Oct-May 2015-2020) as already reported in (Figure 70 and Table 70.

- Heating operation hours comes 1927 hours
- Gas consumption at peak load 13,91 m^3/h

October (160 hours – energy load 25%)
Load 32,75 kW Methane consumption 556,4 m^3

November (348 hours - load 83%)
Load 108,73 kW Methane consumption 4'017,7 m^3

December (234 hours - energy load 89%)
Load 116,59 kW Methane consumption 2'896,9 m^3

January (338 hours - energy load 100%)
Load 131 kW (100%) Methane consumption 4'701,6 m^3

February (324 hours - energy load 99%)
Load 129,69 kW Methane consumption 4'461,8 m^3

March	(359 hours - energy load 79%)		
	Load 103,49 kW	Methane consumption	3’945 m^3
April	(164 hours - energy load 22%)		
	Load 28,82 kW	Methane consumption	501,9 m^3

The **total estimated methane consumption** in a theraml year is 21’081,3 m^3

Economic analysis

Investment Costs

Lightnening:

Philips CorePro LedTube: 6,9 €/unit x 304 unit installed = 2’098 €

Noxion Avant LED T8 Tube Standard EM: 3,5 €/unit x 148 unit installed = 518 €

Philips Classic LED-lustre: 3,1 €/unit x 29 unit installed = 90 €

Tota lamp costs: 2’706€

Condensing methane furnance:

Methane furnance CONDENSAPRO 135: 15’525 €

Electric heat pump:

CXCN270: 45’000 €

CXCN245: 40’000 €

Electric heat pump costs: 85’000 €

Fan coil:

Daikin fan coil (2-pipe), FWL06C: 340 €/unit x 101 unit: 34’340 €

BIPV system intervention:

PV tiles, PAN 29: 3500 € / kW x 29,71 kW: 104.000 €

Management costs and savings

In order to detect the yearly electricity and methane savings, it is necessary to match the figures before and after the enegy efficiency interventions.

Methane consumption:

Before intervention (Unical, 639 kW): 106’406,5 m^3/year.

After the intervention (Riello, 131 kW): 21’081,3 m^3/year.

The **price of methane** is fluctuating and variable. The Municipality of Milan receives a discount on the full price methane due to the huge amount of combustible used. It seems a quite good approximation to consider for analysis the price of methane as 0,6 €/m^3 + IVA (22%) = 0,73 €/m^3.

Following the above proposed intervention Villa Simonetta could achieve **a reduction of methane consumption** and consequentely a **saving** that is below figured :

(106’406,5 m^3/year – 21’081,3 m^3/year) x 0,73 €/m^3 = - **62’287 €/year**

Electricity consumption:

The e **cost of electricity also** ar fluctuating and variable.. It seems a quite good approximation considering the price of electricity as 0,18 €/kWh + IVA (22%) = 0,22 €/kWh.

Lightening renovation could make possible to achieve **a reduction electricity consumption** and consequentely a **saving** that is below figured:

(15’488 kWh/year-6’264 kWh/year) x 0,22 €/kWh = - **2029 €/year**.

The **heat pump energy consumption** (heating) should increase the electricity expense:

255’370 kWh/year x 0,22 €/kWh = **+ 56’181 €/year.**

When considering to **fan coils** as the new heating diffusion system, the expenses due to electricity consumption are:

93,267 kWh/year x 0,22 €/kWh (heating) **+ 20,52 €/year.**

Energy production through PV plant

For this analysis an annual performance reduction of the system of 1% should be considered .

The estimate for energy gaining at the first year are reported below.

Savings due to the **direct consumption of energy produced by the PV plant** are:

14'547 kWh/year x 0,22 €/kWh **- 3'200 €**

For a PV plan up to a power of 500 kW, the italian law gives the possibility to benefit of the net meetering mechanism scheme. This a discounted rate tha is applicated on the energy price s when purchase adjunctive energy by the distributor . This allows the grid to act as a sort of "virtual storage" system.

The formula used for the follwing calcolations is the following:

net meetering fee: energy quota + service quota

National Unit Price for energy (PUN, 2019): 0,0554 €/kWh

Network and system charge (N&S, 2019) 0,0558 €/kWh

Energy quota: energy fed into the grid x PUN = 27'017 kWh/year x 0,0554 €/kWh = 1497

Service quota: energy fed into the grid x N&S = 27'017 kWh/year x 0,0558 €/kWh = 1507 €

Net meetering fee: 1497 € + 1507 € = 3004 €

Overall benefit of the PV plant for the first operative year (PV performance: 100%) :

3'200 €/year + 3'004 €/year = 6'204 €/year

When considering the annual PV performance reduction of 1%, **overall benefits of the PV plant** for following operative years are below calculated.

Savings due to the direct consumption of energy produced by the PV plant

year 2: 3168 €/year; **year 3**: 3136€/year; **year 4**: 3104 €/year; ….; **year 10**: 2912 €/year

Net meetering fee:

year 2: 2974 €/year; **year 3:** 2944 €/year; **year 4**: 2914 €/year; ….; **year 10**: 2734 €/year

Overall PV benefits:

year 2: 6142 €/year; **year 3**: 6080 €/year; **year** 4: 6018 €/year; ….; **year 10**: 5646 €/year

Table 32 below reports a summarry of what we have already calculated according to a useful value of 20 years, for energy production through PV plant

.

year	1	2	3	...	18	19	20
PV performances	100%	99%	98%		83%	82%	81%
PV production [MWh]	41,6	41,1	40,7		34,5	34,1	33,7
self-consumption [MWh]	14,5	14,4	14,3		12,1	11,9	11,8
fed into the grid [MWh]	27,0	26,7	26,5		22,4	22,2	21,9
taken from the grid [MWh]	268,0	268,2	268,3		270,5	270,7	270,8
bill reduction [€]	3200,4	3168,4	3136,4		2656,4	2624,4	2592,3
net metering contribution [€]	3004,2	2974,2	2944,2		0,0	0,0	0,0
cash inflows [€]	**6204,7**	**6142,6**	**6080,6**		**2656,4**	**2624,4**	**2592,3**

Table 32 *A synthetic report of energetic and economic results according to a useful value of 20 years for energy production through PV plant*

Financial Analysis

The economic analysis performed takes into account different possible scenarios and financial indicators:

Different scenarios for economic analysis

- **A voluntary replacement:** considering the intial investment cost as the full cost of the installation.
- **A reinforcement replacment:** cosidering the intial investment cost as the difference between the new technology and the old installation.
- **A replacment without incentives:** considering just the economic returns given by the energy savings.
- **A replacment with incentives:** considering an appropriate tax duduction scheme according to the technology adopted during a time frame of 10 years.

Financial Indicators

- **Net Present Value (NPV):** *"it is the difference between the present value of cash inflows and outflows over a period of time."* It is used to analyse the profitability of a project.
- **Pay Back Time (PBT):** *"is the amount of time it takes to recover the cost of an investment"*
- **Internal Rate of Return (IRR):** *"is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis"*

Financial analysis: replacement of the Thermal System

For our economic analysis the followings principles should be considered :

- ✓ The **cost of capital (k)** is equal to 2%.
- ✓ The **useful life** for a methane furnace and of a heat pump is estimated to be 15 years and is consistent with the time frame of analysis.
- ✓ The **tax deduction** for interventions on the heating system is 65%.

Pre-intervention:

CAPEX (Capital Expenditure)

- The reference cost for methane furnace 640 kW + 40'000 €
- Costs for radiators 220 € x 101 units + 22'220 €

OPEX (Operating Expense)

- Operation & Maintenance + 500 €

Post-intervention:

CAPEX

- Electric heat pump CXCN245 and CXCN270 + 85'000 €
- Methane furnance CONDENSAPRO 135 + 15'525 €
- Daikin fan coil (2-pipe), FWL06C + 34'340 €

OPEX

- Operation & Maintenance + 500 €

ENERGY SAVINGS

- Post – Pre energy consumption - 6'106 €

Table 33 is a synthesis of the value of the financial indicators according to different economic analysis. Since the substitution of the heat diffusion system (from radiator to fan coil) is not strictly requested an economic analysis was made with or without fan coils.

In any case only incentives can make the investment economically sustainable.

VOLUNTARY REPLACEMENT							
without incentives				with incentives			
without fan coils (I)		with fan coils (II)		without fan coils (III)		with fan coils (IV)	
NPV	-28492	NPV	-68832	NPV	30201,3	NPV	15911
IRR	-2%	IRR	-5%	IRR	6%	IRR	4%
PBT	22,5	PBT	33,1	PBT	9,2	PBT	11,3
REINFORCMENT REPLACEMENT							
without incentives				with incentives			
without fan coils (V)		with fan coils (VI)		without fan coils (VII)		with fan coils (VIII)	
NPV	17933	NPV	5793	NPV	53271	NPV	48228
IRR	6%	IRR	3%	IRR	13%	IRR	11%
PBT	11,2	PBT	13,9	PBT	6,6	PBT	7,3

Table 33 *Thermal system substitution: a representation of the value of the financial indicators according to different economic analysis*

NPV = net present value - IRR= Internal rate of return - PBT payback time

Figure 75 is a graphic presentation of **summed discount cash flow** during the useful life of the installed thermal system with or without coils.

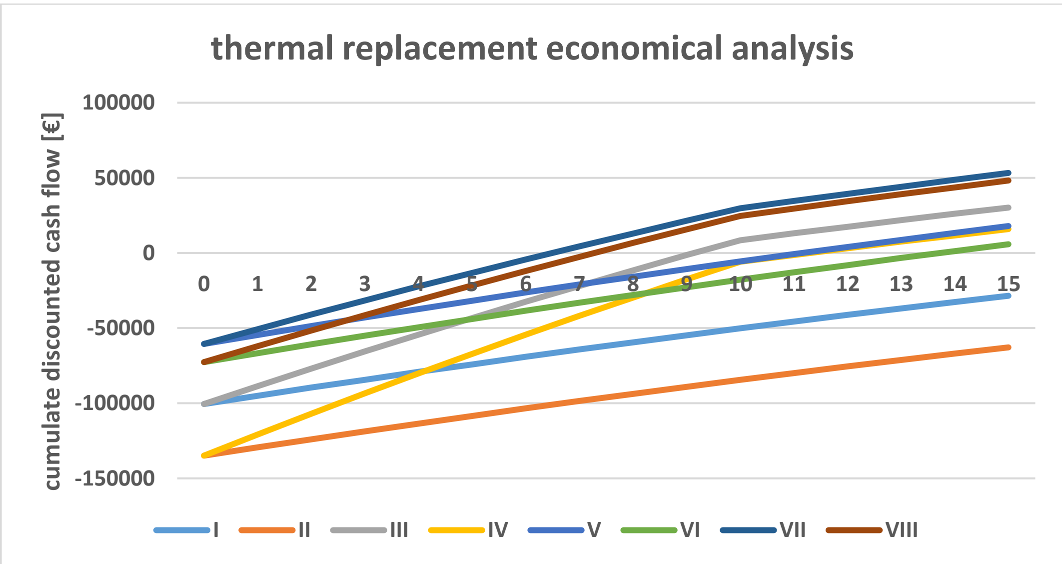


Figure 75 *Thermal system substitution: a graphic presentation of summed discount cash flow during the useful life., according to different scenarios (I-VIII) that have been presented in Table 32*

I–

Financial analysis: building integrated PV system

The followings principles should be considered:

- ✓ The **cost of capital (k)** is 2%.
- ✓ The **useful life** of a PV tile is estimated to be 25 years and it is consistent with the time frame of the economic analysis.
- ✓ **Tax deduction**. According to the present regulation, a tax deduction is available for the installation of PV plants with a power < 20kW. New indication are however probably soon available . For this reason I have supposed a tax deduction of 50% in 10 years.
- ✓ **No reinforcement replacement analysis** can be led because this is not a substitution of any pre-existent PV system.

Post-intervention:

CAPEX (Capital Expenditure)

PV tiles installation 104’000 €

OPEX (Operating Expense)

Operation & Maintenance 600 €

Energy savings: variable during the years (see Table 32)

Table 34 is a synthesis of the value of the financial indicators according to different economic analysis. Only incentives can make the intervention economically advantageous.

PV tiles intervention					
without incentive			with incentive		
NPV	-7252	€	NPV	94270	€
PBT	28 2	year	PBT	11 1	Year month
IRR	1%	%	IRR	9%	%

Table 34 *Photovoltaic tiles installation: value of the financial indicators with or without incentives*
NPV = net present value - IRR= Internal rate of return - PBT payback time

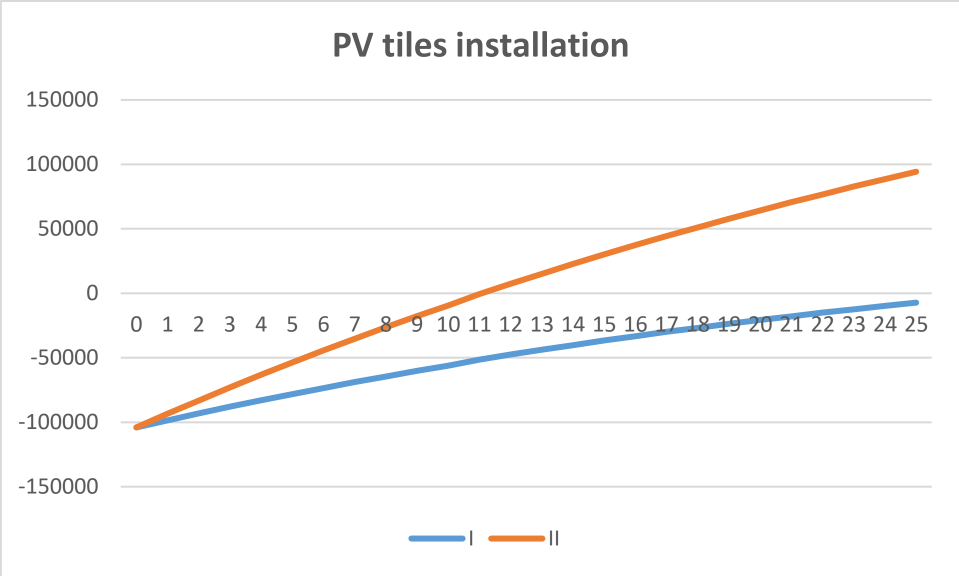


Figure 76 *Photovoltaic tiles installation: a graphic presentation of summed discount cash flow during the useful life., according to different scenarios with (I) or without (II) incentives.*

Financial analysis: light substitution

The followings principles should be considered:

- ✓ The **cost of capital (k)** is 2%.
- ✓ The **useful life** for lightning is estimated to be 10 years and is consistent with the economical time frame of the economic analysis.
- ✓ No **tax deduction** is available for lightning substitution.

Pre-intervention

CAPEX (Capital Expenditure)

Total fluorescent costs (-40% led): + 1’624 €

OPEX (Operating Expense)

Operation & Maintenance fluorescent costs (10%): + 162 € / year

Post-intervention

CAPEX

Total led lamp costs: + 2'706 €

OPEX

Operation & Maintenance led (10%): + 270 € / year

Energy savings - 2’029 € / year

Table 35 is a synthesis of the value of the financial indicators according to different economic analysis for lights substitution. The positive economic impact is evident for all financial indicators.

LIGHTS SUBSTITUTION			
voluntary replacement (I)		**reinforcement replacement (II)**	
NPV	13094	NPV	16174
IRR	65%	IRR	178%
PBT	1,7	PBT	7

Table 35 *Lightening: value of the financial indicators according to voluntary / reinforcement replacement.*
NPV = net present value - IRR= Internal rate of return - PBT payback time

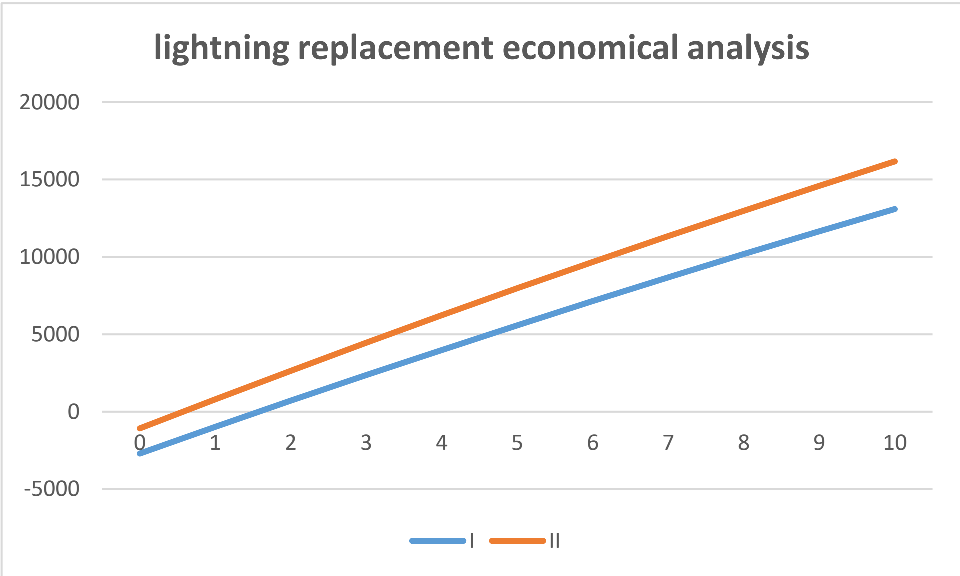


Figure 76 *Lightening: a graphic presentation of summed discount cash flow during the useful life., according to different scenarios voluntary (I) or reinforcement (II) replacements*

Final and comprehensive financial analysis of the energy efficiency Project in *Villa Simonetta* – Claudio Abbado Music School

Table 36 and **Figure 77** are a synoptic and final presentation of the economic feasibility of the intervention. It is evident that the restoration project would not be economically viable without incentives from the Public Administration (PBT with out: 27 and 21 years) . As a matter of fact, if we look at the above presented analysis for any single intervention, only light substitution turned to be rapidly and significantly economically advantageous without incentives.

On the other hand it has to be remarked that incentives make possible to estimate what in this economic analysis cannot be directly calculated: atmospheric pollution benefits and environmental increased comfort of the school ambiences.

Claudio Abbado, music school building											
voluntary replacement						reinforcement replacement					
without incentive (I)			with incentive (II)			without incentive (III)			with incentive (IV)		
NPV	78082	€	NPV	253197	€	NPV	187192	€	NPV	291834	€
IRR	4	%	IRR	9	%	IRR	7	%	IRR	11	%
PBT	27	year	PBT	10	years	PBT	21	year	PBT	7	years
	5	month		0	month		4	month		10	month

Table 36: *Claudio Abbado Music School. Comprehensive economic analysis of intervention according to different economic scenarios*
NPV = net present value - IRR = Internal rate of return - PBT payback time

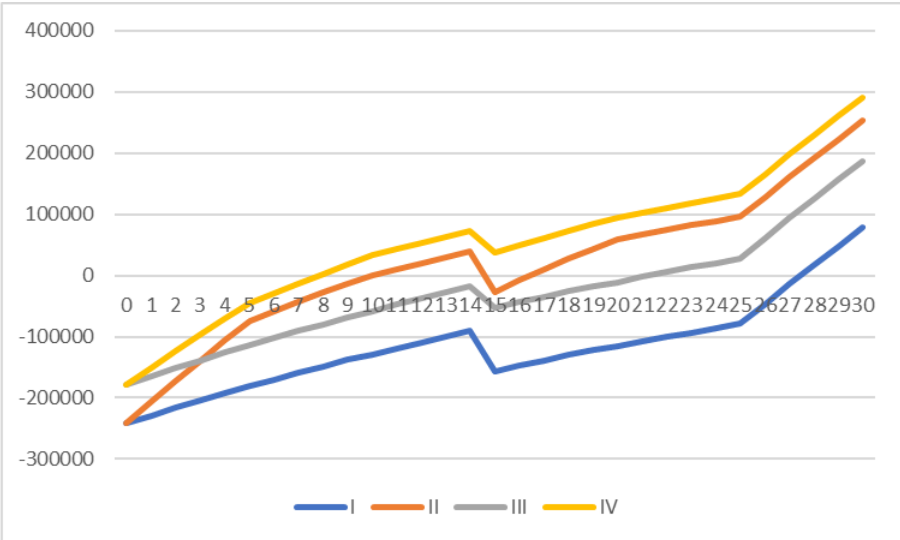


Figure 77: *Claudio Abbado Music School. Comprehensive economic analysis of intervention according to different economic scenarios.*
I = voluntary replacement without incentives
II= voluntary replacement with incentives
III= reinforcement replacement without incentives
IV: reinforcement replacement with incentives

Building n°2: Stoppani Comprehensive School

Name: Comprehensive School, *Antonio Stoppani*
Location: Via Antonio Stoppani 1-3, Municipality 2 - Milan
Year of construction: 1901-1903
Intended use: nursery school, kindergarten, primary school
Heated volume: 50’687 m^3
Number of floors: 3
Heating source: natural gas

Inspection

Two site inspections were conducted on February 2020 following permission and by appointment with a technician from “Municipality of Milan”. Adjunctive inspections were unfortunately no longer possible later in the lock down period.

On-site inspections allowed to retrieve information concerning the structural condition of the building and of the thermal components of the HVAC system in place and critical issues concerning sustainability.

Structural building characteristics-

The school was built in 1901-03 and has the typical characteristics of a school belonging to the Giolittian Age (see results Paragraph 6D). and, in synthesis, refers to the *school-barrack* model.. A thick U concrete board delimits the structure from the surrounding streets, giving a feeling of magnitude, robustness and essentiality to the building.(**Figure 78A-B and 79**). It is composed by three floors: the ground, the first and the second plus one basement. The school has two main accesses for different school destinations (primary school and kindergarten).

Large and high classrooms (projected for overcrowded classes) and large corridors characterize inner spaces. A wide inner concrete garden fill the inner part of the U of the building.

The thermal room can be reached from the garden through a flight of stairs.

Figure 78 A-B: A picture of Stoppani Comprehensive School in the mid 50S (A) and its present aspect (B)

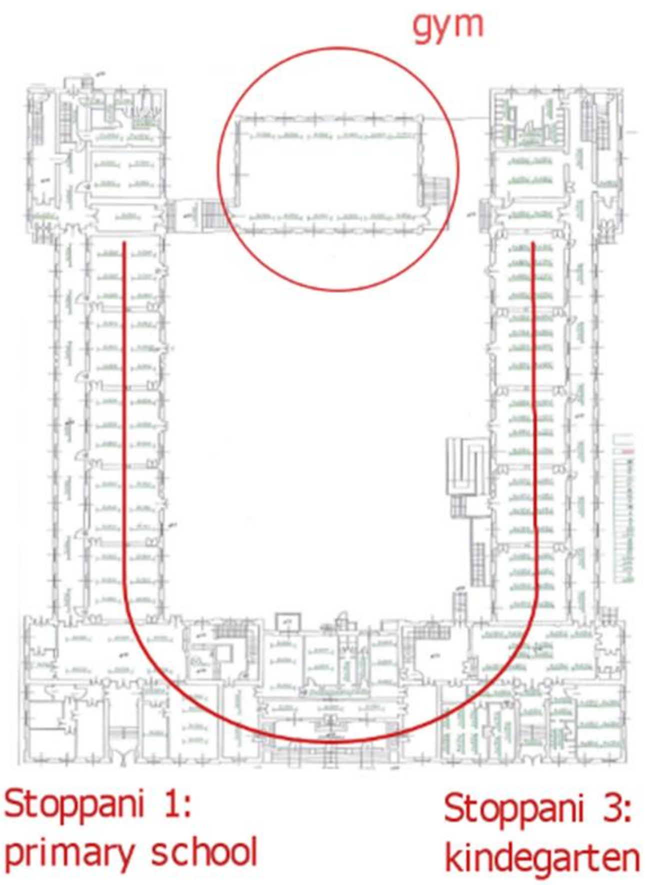


***Figura 79**: the typical U shape of the the Stoppani Comprehensive School*

Technical characteristics

- **Load-bearing structures:** Masonry
- **Useful and walkable surface** : 10'510,2 m^2
- **Heated volume**: 50'687 m^3
- **Height of the ceilings** 7 m
- **Total Dispersing surface of the building** 12970,2 m^2
- **Opaque surface** 5631 m^2
- **Transparent surface** 1499,2 m^2
- **Ground surface** 2875 m^2
- **Rooftop surface** 2965 m^2
- **Surface to volume ratio (S/V):** 0,26 m^{-1}

Different materials that characterize dispersing surfaces, account for different values of transmittance coefficients that are below reported.

- **Opaque surface**	5631 m^2	U =	1,48 $W/m^2 K$
- **Transparent surface**	1499,2 m^2	U =	5,30 $W/m^2 K$
- **Ground surface**	2875 m^2	U.=	1,28 $W/m^2 K$
- **Rooftop surface**	2965 m^2	U.=	1,28 $W/m^2 K$

Heat diffusion and ventilation modality

Heating diffusion is provided by 258 radiators (**Figure 80)**

The transparent surface is composted by 336 double glasses windows (**Figure 81**) delimiting by aluminium frames.

No mechanic ventilation system is in place to exchange air with the outside ambient. Natural ventilation is the only way to guarantee air exchange. and is facilitated by height and in general large size of rooms.

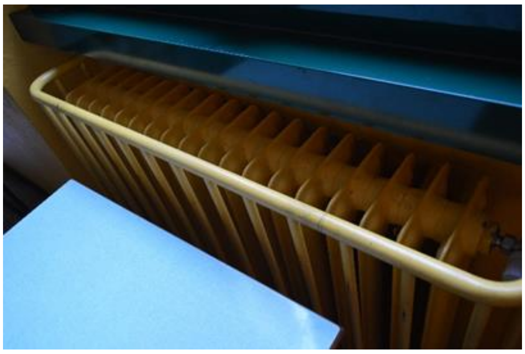


Figure 80 A sample of the 256 radiators of Stoppani Comprehensive School

Figure 81 A sample of the 336 double glass window of Stoppani Comprehensive School

Energy exchange: lost, gained, and requested

Table 37 and **Figure 82** below report energy exchange and energy request during the thermal year

Energy exchange [MJ]										
Month	**To**	**Text**	**Qv**	**Qh**	**Ql**	**Qs**	**Qi**	**Qg**	**b**	**QR**
October	20	12,4	39566	229585	269151	79289	55284	134573	0,967	139019
November	20	7,9	125986	696236	822222	106377	110568	216945	0,996	606145
December	20	3,1	175963	949107	1125070	82933	110568	193501	0,999	931763
January	20	1,7	190540	1022862	1213402	93409	110568	203977	0,999	1009629
February	20	4,2	164510	891158	1055668	148518	110568	259086	0,997	797359
March	20	9,2	112450	627750	740200	230167	110568	340735	0,974	408324
April	20	13,2	37483	219048	256531	139643	55284	194927	0,891	82851

Table 37 *Energy lost gained and requested requested during the thermal year in the Stoppani Comprehensive School* ***Qv*** *= natural ventilation. -* ***Qh*** *heat diffusion through walls and glasses -* ***Ql*** *energy loss -* ***Qs*** *solar irradiation -* ***Qi*** *internal energy contribution from people and things -* ***Qg*** *total energy gain* ***Qr*** *energy requested -* ***p*** *correcting utilization factor*

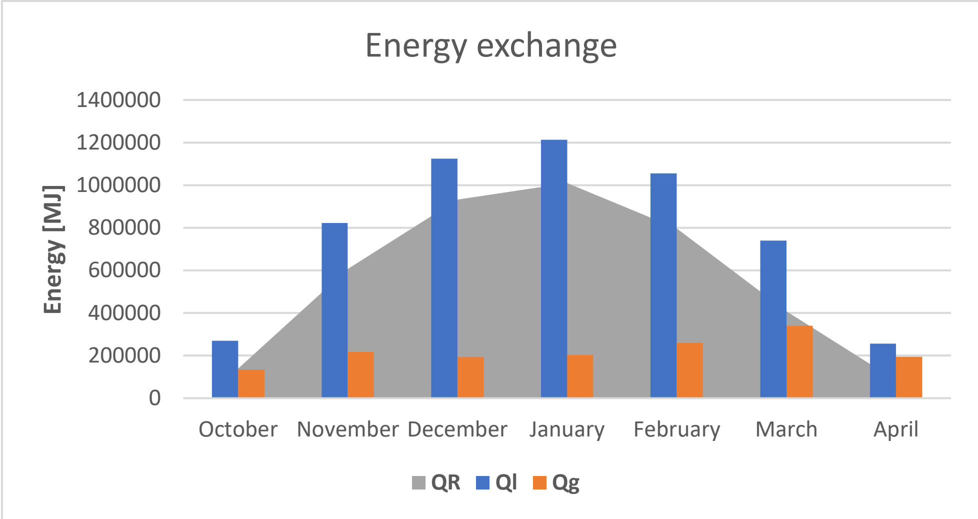


Figure 82 *Energy requested during the thermal year in the Stoppani Comprehensive School*

The thermal plant

The thermal room is located on the basement floor that can be reached through independent stairs located in the inner yard. This paragraph has the purpose to give the list of the main components adopted in it and how the heating generation is distributed by the different sub-circuits.

Figure 83 gives a schematic representation of the thermal of the zone of the Stoppani Comprehensive School with the sub-circuities and the main components involved.

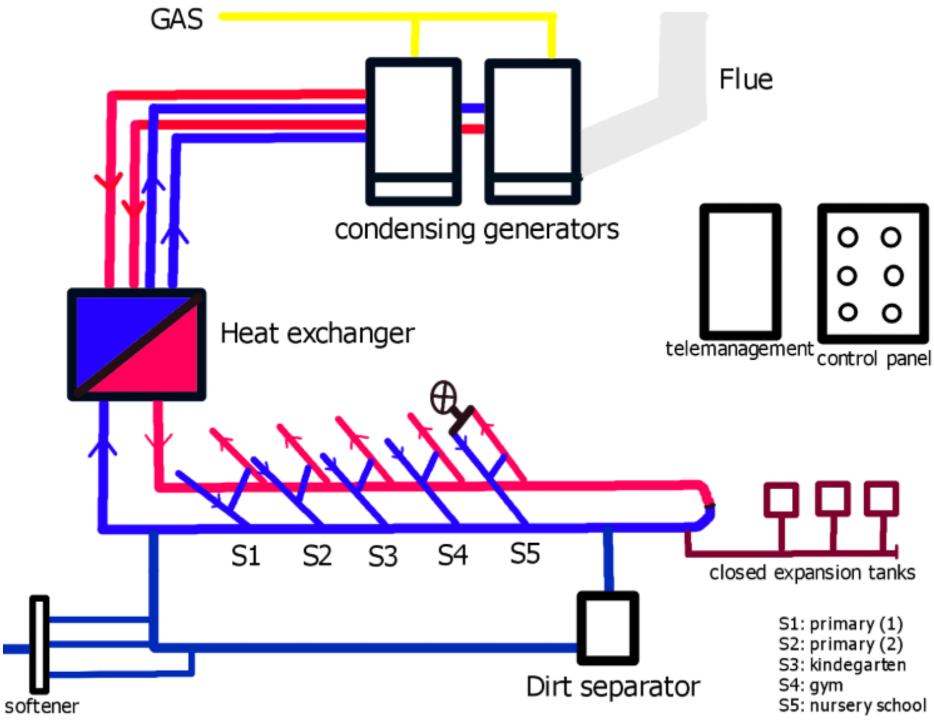


Figure 83: *a schematic representation of the thermal plant, heat generator and distribution system, of Stoppani Comprehensive School*

As already mention, *Stoppani* is a comprehensive school, and hosts different destinations (nursery, kindergarten and primary).

This rise the necessity to guarantee different target temperatures at the same time and sometimes different heating supplies to reach them: kindergarten and primary, 20°C; nursery 22 °C, gym, 17 °C.

Moreover, the building is characterized by huge volumes with different exposures to the sun. For this reason, different heating supplies are sometimes necessary to reach the same target temperature.

Given these preliminary conditions, it is extremely important to design a heating system composed by more sub-circuits that guarantee the inner target temperature avoiding at the same time loss of energy and unnecessary related costs.

In the thermal room is possible to recognise five different sub-circuits that are involved in the building: primary school first floor (**S1**), primary school second and third floor (**S2**), kindergarten (**S3**), gym (**S4**) and nursery school (**S5**). For S5, no connections are already in place, since the institution of a nursery school is a project that unfortunately has never been realized.

A crucial role in the system is played by the three-way valves (COSTER, VSF380) that mix the supply return water in the collectors and, at the same time, allow to inject the suitable delivery flow and water temperature into the system. (**Figure 84 A-B**). A detector system (named "clarinetto") aimed at controlling the external pressure of water outflows before its introduction in the distribution system **(Figures 85 – 86)**

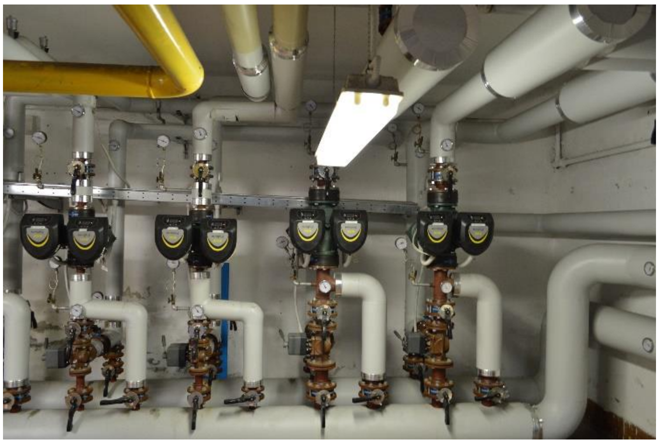


Figure 84 A: *a schematic representation of the 4 sub circuits (S1-S4) of the system.*

Figure 84 B: *a schematic representation of the inactive sub circuit S5*

Figure 85*: the system named “clarinetto” aimed at checking pressure and temperature of water before its introduction in the distributing system*

Figure 86*: the valves that separate water outflows and inflows in the distributing system*

List of other main components placed into the thermal room:

1. Two methane condensing furnaces (*Riello*. Power: 720 kW each) **(Figure 87)**
2. One flue: to collect out the combustion fumes in a safety way A heat exchanger box: to regulate the delivering and returning temperature of water inside the circuit
3. Five close expansion tank with capacity of 300 l each: to avoid excessive inflow and outflow water pressures that might injury the system **(Figure 88).**
4. One dirt and one softener separator (Termoacqua): to purify and maintain performant the water inside the system **(Figure 89).**
5. Six single twin pumps (DAB) and five three-way valves (COSTNER, VSF380): to regulate the water flow inside the heating system
6. A remote control panel **(Figure 90)**.

Figure 87 *the methane condensing furnaces, part of the heating system.*

Figure 88 *the expansion tanks to avoid excessive pressure inside the collecting tubes*

Figure 89*: the water softener system*

Figure 90*: the electric panel*

Thermal loads

Thermal loads were estimated according to the school operating hours during the thermal year 2018/19. (see **Table 10)**

Table 38 gives a figure of operating hours throughout the 2018/2019 thermal year. Additional 116 hours were required to lead extracurricular activities in that period.

heating operative hours during the thermal period 2018/2019	
month	**operation hours**
October (15th-31st)	130
November	210
December	162
January	200
February	212
March	222
April (1st-15th)	164
Extra-hours	116
Total	1416

Table 38 *operating hours throughout the 2018/2019 thermal year – Stoppani Comprehensive School*

The thermal loads during one week in December 2016 were analysed in details. (**Table 39** and **Figure 91**).

The thermal power plant activity hours do not correspond with school operating hours. : The heating system is fully activated in the morning two hours before school opens in order to reach the target indoor ambient temperature. At the same time it is switched off before school activities end. According to the school timetable the heating system activity is almost inactive during week-ends.

Operating hours and Thermal loads: during one week of the thermal year 2018/19			
DAY		HOUR	load [kW]
Monday	12-dic	0.00	0,00
		7.00	1071,14
		12.00	938,68
		18.00	1007,79
Tuesday	13-dic	0.00	0,00
		7.00	1128,79
		12.00	898,37
		18.00	1042,34
Wednesday	14-dic	0.00	0,00
		7.00	1163,28
		12.00	898,37
		18.00	1065,38
Thursday	15-dic	0.00	0,00
		7.00	1307,25
		12.00	961,72
		18.00	1134,48
Friday	16-dic	0.00	0,00
		7.00	1370,59
		12.00	1140,24
		18.00	1266,94
Saturday	17-dic	0.00	0,00
		7.00	0,00
		12.00	0,00
		18.00	0,00
Sunday	18-dic	0.00	0,00
		7.00	0,00
		12.00	0,00
		18.00	0,00

Table 39 *operating hours throughout the 2018/2019 thermal year Stoppani Comprehensive School*

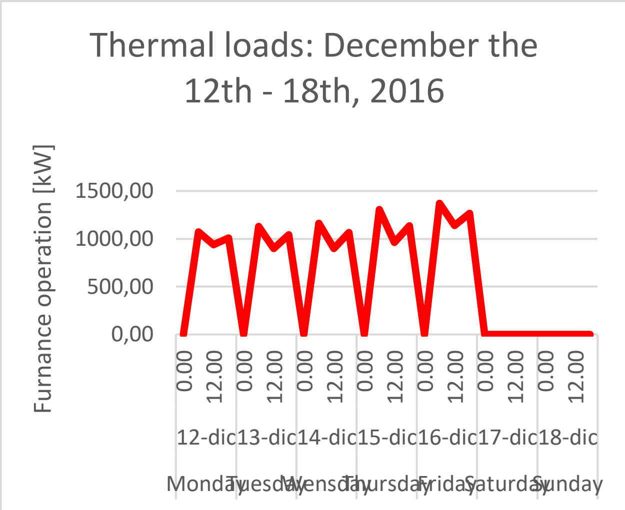


Figure 91 *a graphic presentation of operating hours of the thermal power plant during one sample week in December 2016 - Stoppani Comprehensive School*

A few figures should be added to have a better picture of the building emissions and costs.

- **Methane consumption** 125’156,56 m^3/yr (2016).
- **Energy heating consumption** 1251 MWh
- **Thermal + electrical energy** 145,68 TOE/year (TOE = Tonnes of Oil Equivalent)
- **CO_2 emissions** 340,41 tons/year
- **NOx emissions** 304,12 tons/years
- **Energetic class** F (the worst possible)

Electrical loads

In this section we briefly report the electrical loads of the lightening spots and devices operating in the building.

The estimated **total yearly electricity demand** in 2018 was 130’286,52 kWh/year.

- **Fluorescent lamps** 50’451,12 kWh/year
- **Other electrical devices** 79’835 kWh/year

At full load, the electrical system requires 101,926 kW power to satisfy the entire demand.

Table (40 A-B) are a representation of the year electrical loads of the Comprehensive School Stoppani

Lightning electrical loads						
Type	N° spot	N° lamps per spot	Load per lamp [Kw]	Total load [kW]	Yearly operation hours	Estimated consumption [KWh/year]
Fluorescent lamps	358	2	36	25,776	1080	27838,08
Fluorescent lamps	3	1	36	0,108	1080	116,64
Fluorescent lamps	45	2	18	1,62	1080	1749,6
Fluorescent lamps	2	1	18	0,036	1080	38,88
Fluorescent lamps	235	4	18	16,92	1080	18273,6
Fluorescent lamps	1	1	58	0,058	1080	62,64
Fluorescent lamps	6	2	58	0,696	1080	751,68
Metal iodide	6	1	250	1,5	1080	1620
total	**656**	**1770**		**46,714**		**50451,12**

Table 40 A *electrical loads lightening of the Comprehensive School Stoppani during the school year activity 2018/2019*

Other electrical loads					
Device	N°	Power for unit [W]	Total power [kW]	Yearly operation hours	Estimated consumption [kWh/year]
Computer + monitor	60	275	16,5	1760	29040
Coffee machine	4	250	1	1760	1760
Refrigerator	4	200	0,8	8760	7008
telephone	18	10	0,18	8760	1576,8
Photocopier	3	100	0,3	1760	528
Wi-fi	11	20	0,22	880	193,6
Other	-	-	36,212	-	39729
Total	**-**	**-**	**55,212**	**-**	**79835,4**

Table 40 B *loads for electrical devices of Comprehensive School Stoppani during the school year activity 2018/2019*

Improvement analysis and proposal

-Building Energy Management System (BEMS)-

A **BEMS** is a system aimed at monitoring and controlling services such as heating, ventilation and air-conditioning, ensuring the building operates at maximum levels of efficient and removing wasted energy usage and associated costs. The optimal level of efficiency is achieved by continuously maintaining the correct balance between operating requirements, external and internal environmental conditions, and energy usage.

The system is composed by **one central station** that communicates through wireless connection with the outstations spreader distributed in the building.

The outstations capture the out-side signals and give them back to the central station for regulating the comfort conditions inside rooms. For instance, there are sensors able to recognize the human being activity in a room through the concentration of CO_2 presented in the ambient air and to regulate the building system operations as consequence.

The Stoppani comprehensive school building meet the criteria for the introduction of Building Energy Management System technology due to following main building characteristics:

- **High volumes (50'688 m^3)**: energy connected variables are more difficult to manage in huge spaces. Different ambiences have different exposures to solar irradiations (North, West, South and East) and structural characteristics (doors, windows and partitions) that require different levels of energy supply during the day.
- **Different destinations:** Stoppani is a comprehensive school. Different destinations (nursery, kindergarten, primary school) require different and specific ambient conditions (temperature and humidity) .
- **Variable operation hours:** Different destinations also involve different heating activity hour

Pros of a BMS

- Reduce energy consumption and meet environmental targets.
- Give economical returns.
- Guarantee safety through a quick alarm detection.

- Improve comfort conditions for users inside the building.
- Minimize maintenance and repair costs.

The product chosen for the installation is the **Energy Revolution-Building Energy Management System (ER-BEMS - Algowatt s.p.a.)** that “allows the monitoring and management of technological systems to optimize consumption and improve the perception of comfort in the environments.” It is modular an bears multi-context software:

- **Energy Smart Optimisation System (ESOS):** for monitoring and analysing energy consumption. It is the ideal solution for a complex multi-site system including loads of different nature (electricity, gas and water)
- **Energy Data Management (EDM)**: for cost analysis and timely verification of energy bill.
- **ADVERTO:** for the automation of technological systems, with advanced centralized coordination functions, which allow levels of precision and completeness that guarantee high energy performance.

The system can communicate and interact with different devices through an **IP network**, allowing the monitoring and control of areas.

The hardware used by the system is the **RTu-GO** “used to create integrated systems and solutions for every application needed. It is a modular, compact, and reliable technology conceiving with the aim of flexibility, both in terms of application areas and of quality and type of field points managed. The device consists of a communication and data processing module and four different input / output modules. The dimensions contained by the various modules make it possible to offer customers customized and simple to configure solution”

The cost of the Energy Revolution-Building Energy Management System (ER-BEMS - Algowatt s.p.a.) **is** 25’000-30’000€

Photovoltaic modules installation

Due to the huge rooftop surface, another solution that appears valuable is the installation of **photovoltaic modules** in the available surfaces, favouring those South orienting.

Since the building is not under further authority restrictions, it is possible to exploit a classic **PV nanocrystal solution** attached to the surface through a steel case support . This solution has lower initial investment costs as compared to the BIPV, PV tiles solution.

Through this intervention, it is possible to self-sustain the school electricity consumption and to obtain economical returns during all the useful life of PV modules operation.

Additional to the PV module many other components compound the PV plant:

- **a power box** that collects the PV arrays in one string.
- **a surge arrester** is an electrical power distribution system that protects people and equipment from overvoltage.
- **a fuse** that protects components by overcurrent loads.
- **an inverter** is a box that transforms the direct currents (DC) coming from PV modules to alternant current (AC) injected into the grid.
- **a meter** that accounts the electricity produced, self-consumed, or injected into the grid.
- **an electric panel** that switch on and off the system components.

No accumulation battery is included in the system. This enable to increase self-consumption of PV electricity production.

It was possible to find in the market a possible solution that meet the requested requirements.

This is the Q-PEACK-DUO-G8 (*Q-Cells*) **(Figure 92).**

Table 41 is a presentation of the technical and economical features of the product

Figure 92: *The Q-PEACK-DUO-G8 PV nanocrystal panel*

Q-PEACK-DUO-G8	
power	
nominal power	350 Wp
nominal power tolerance	[-5%; +5%]
other characteristics	
voltage	38,38 V
current	8,05 A
counter-circuit current	8,65 A
temperature limits	[-40°C; +85°C]
module efficiency	19,00%
cell type	mono-crystalline
dimensions	
length	1740 mm
width	1030 mm
thickness	32 mm
weight	19,9 kg
unit price	
	140 €

Table 41: *Technical characteristics of the Q-PEACK-DUO-G8 PV nanocrystal panel*

Technical analysis

Methane consumption before BEMS installation

The **total estimated methane consumption** in a theramal year according to the energy performance certificate is 125’156,56 m^3.

Electricity consumption before BEMS installation.

Lightning

- ✓ Power: 46,714 kW
- ✓ Consumption: 50,451 MWh

Other devices

- ✓ Power: 55,212 kW
- ✓ Consumption: 79,835 MWh
- ✓

Overall electricity requested before interventions

- ✓ Power: 101,9 kW
- ✓ Consumption: 130,289 MWh

According to the applications installed and the telephone consulting received from *Algowatt s.p.a*, it is possible to expect a thermal and electricity savings due to ER-BEMS solution of approximately 30% and 50% respectively.

Overall consumptions after interventions

- ✓ Thermal consumption: 87’609 m^3
- ✓ Electrical consumption: 65,145 MWh

Electricity production

The purpose is to install PV modules, on the two upper roofs of the main entrance building that are South-East oriented.

Considering a rooftop inclination and an azimuth with respect to the south orientation respectively of 30° and -20°, the dimension of the available surfaces and solar irradiation received for PV plant are calculated as follow:

Available rooftop surface for PV plant installation (Figures 93 A-B-C):

Total rooftop surface for PV plant installation: 10 m x 5 m (left side) + 10 m x 5 m (right side) = 100 m^2

For each rectangle, it is possible to install a number of PV modules equal to 3 rows x 9 columns = 27 panels

The total number of PV modules installed on the rooftop is equal to 54 panels.

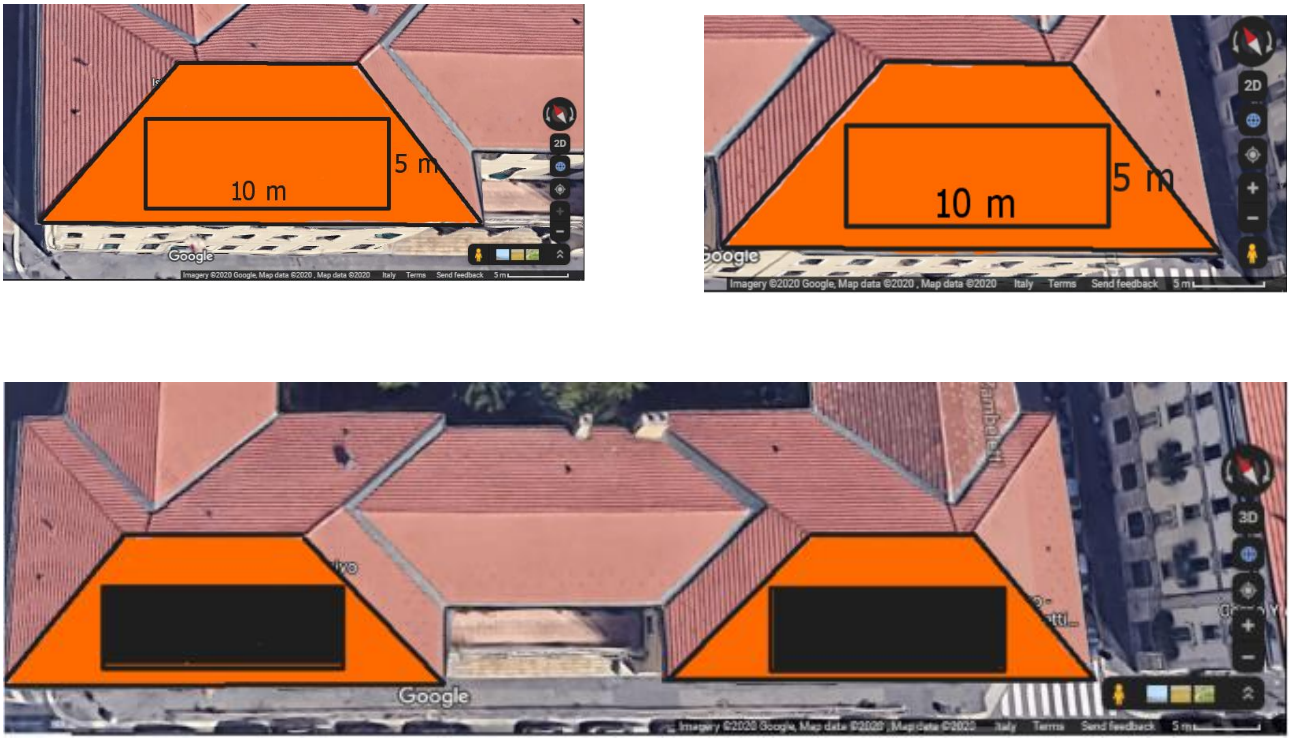


Figure 93: Available rooftop surface for PV plant installation on the two upper roofs of the main entrance building

The solar irradiations throughout the year can be calculated with the auxilium of a dedicated software **(Table 42)**

month	average daily irradiation			
	horizontal axis			inclined plane
	widespread	direct	total	
Jan	0,61	0,75	1,36	2,28
Feb	0,89	1,17	2,06	2,94
Mar	1,39	1,89	3,28	4,02
Apr	1,81	2,64	4,45	4,78
May	2,31	2,97	5,28	5,17
Jun	2,72	3,64	6,36	6,01
Jul	2,44	4,03	6,47	6,22
Aug	2,08	3,22	5,3	5,49
Sep	1,61	2,61	4,22	4,96
Oct	1	1,22	2,22	2,98
Nov	0,58	0,61	1,19	1,85
Dec	0,53	0,47	1	1,66

Table 42: *solar irradiations throughout the year*

According to a survey of "Politecnico di Milano" the amount of alternating current (AC) yearly produced in Milan by 1 kW is estimated to be 1'399 kWh / kWp

Knowing that the nominal power capacity of each PV panel is 350 Wp and that the overall number of panels installed on the rooftop is equal to 54. It is possible to calculate the year electricity production of the photovoltaic installation:

- **Total capacity installed** 350 Wp x 54 panel = **18,9 kWp**
- **Total year electricity production** 18,9 kWp x 1'399 kWh/kWp = **26,441 MWh**

The project has not considered an energy storage system. It is thus reasonable estimate an electricity consumption rate for the building utilities of 35%, the remaining produced energy is fed into the grid:

- **Energy self-consumption:** 26,441 MWh x 0,35 = **9,254 MWh**
- **Energy fed into the grid:** 26,441 MWh x (1 - 0,35) = **17,187 MWh**

Economic analysis

Investment Costs

BEMS system intervention

- ✓ ER-BEMS installation: 45’000 €
- ✓ Operation & Maintenance (10%): 4’500 € / year

PV system intervention

- ✓ PV system installation 26’069 €
- ✓ Operation & Maintenance: 380 € / year

Table 43 is a spitted representation of costs to be sustained for **PV system installation.**

Q-PEACK-DUO-G8 intervention		
Panel cost	29%	€ 7.560
PCS	13%	€ 3.389
Design and installation	39%	€ 10.167
Other constructive elements	19%	€ 4.953
Investment cost	-	€ 26.069

Table 43: *Costs for PV system installation.*

Operational costs and savings

In order to detect the yearly electricity and methane savings, it is necessary to match the figures before and after the interventions for energy efficiency.

Methane

Methane consumption Before intervention (720 Kw x 2): 125’156 m^3

Methane savings after the intervention: (125’156 m3 x 0,3) x 0,73 € / m3 = - 27’409 € / year

The **price of methane** is fluctuating and variable. The Municipality of Milan receives a discount on the full market price due to the huge amount of combustible used. It seems a quite good approximation to consider for analysis the price of methane as 0,6 €/m^3 + IVA (22%) = 0,73 €/m^3.

Electricity

The e **cost of electricity also** are fluctuating and variable. It seems a quite good approximation considering the price of electricity as 0,18 €/kWh + IVA (22%) = 0,22 € / kWh.

BEMS system could make possible to achieve **a reduction electricity consumption** and consequentely a **saving** of 50 % on the electricity previously consumed:

Electricity saving 130,289 MWh x 0,5 x 220 € / MWh = - 28’663 € / year

Energy production through PV plant

For this analysis, an annual performance reduction of the system of 1% should be considered.

The estimate for energy gaining at the first year are reported below.

Savings due to the **direct consumption of energy produced by the PV plant** are:

9,254 MWh x 220 €/MWh 2’036 € / year

For a PV plan up to a power of 500 kW, the italian law gives the possibility to benefit of the net meetering mechanism scheme. This a discounted rate tha is applicated on the energy price s when purchase adjunctive energy by the distributor . This allows the grid to act as a sort of “virtual storage” system.

The formula used for the follwing calcolations is the following:

net meetering fee: energy quota + service quota

National Unit Price for energy (PUN, 2019): 0,0554 €/kWh

Network and system charge (N&S, 2019) 0,0558 €/kWh

Energy quota: energy fed into the grid x PUN =

17,187 MWh x 55,4 € / MWh = 952,16 €

Service quota: energy fed into the grid x N&S =

17,187 MWh x 55,8 € / MWh = 959,03 €

Net meetering fee: 952,16 € / year + 959,03 € / year = 1’911,2 €

Overall benefit of the PV plant for the first operative year (PV performance: 100%):

2’036 € / year + 1’991,2 € / year = 3’947,2 € / year

When considering the annual PV performance reduction of 1%, **overall benefits of the PV plant** for a useful value of 25 years are below calculated. **Table 44**

year	1	2	3	...	23	24	25
PV performances	1	0,99	0,98		0,78	0,77	0,76
PV production [MWh]	26,44	26,18	25,91		20,62	20,36	20,10
self-consumption [MWh]	9,25	9,16	9,07		7,22	7,13	7,03
fed into the grid [MWh]	17,19	17,01	16,84		13,41	13,23	13,06
taken from the grid [MWh]	55,89	55,98	56,08		57,93	58,02	58,11
bill reduction [€]	2035,96	2015,61	1995,25		1490,71	1471,60	1452,48
net metering [€]	1911,16	1892,05	1872,94		1588,05	1567,69	1547,33
cash inflows [€]	**3947,13**	**3907,66**	**3868,18**		**3078,76**	**3039,29**	**2999,82**

Table 44: *Economical benefits during the useful life of the installed PV plant*

Financial analysis

The economic analysis performed takes into consideration different possible scenarios and financial indicators.

Different scenarios for the financial analysis

Voluntary replacement accounts the intial investment cost as the full cost of the installation

- ✓ **Without incentives:** considering just the economic returns given by the energy savings
- ✓ **With incentives:** considering an appropriate tax duduction scheme according to the technology adopted

Renforceiment replacement is not considered a possible solution since BEMS and PV pannel do not substitute any traditional solutions already installed in the building.

Financial Indicators

- **Net Present Value (NPV):** "is the difference between the present value of cash inflows and outflows over a period of time." It is used to analyse the profitability of a project.
- **Pay Back Time (PBT):** "is the amount of time it takes to recover the cost of an investment"
- **Internal Rate of Return (IRR):** "is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis".

Financial analysis: BEMS technology

For our economic analysis the followings principles should be considered :

- ✓ The **cost of capital (k)** is equal to 2%.
- ✓ BEMS is a scalable device with different kind of software to be installed. The **useful life** of the technology appears difficult to calculate, it is possible to assume 10 years.
- ✓ The **tax deduction** for BEMS system is 50% in 5 years.

CAPEX (Capital Expenditure)

- **ER-BEMS installation:** **+** 45'000 €

OPEX (Operating Expense)

- **Operation & Maintenance (10%):** **+** 4'500 € / year

Energy savings

- Methane - 27'409 € / year
- Electricity - 28'663 € / year

Table 45 is a synthesis of the value of the financial indicators according to different economic analysis following the installation of a BEMS system. It is evident the and positive impact of the intervention on all the indicators.

BEMS INSTALLATION			
without incentives (I)		**with incentives (II)**	
NPV [€]	418250	NPV [€]	439469
IRR	115%	IRR	124%
PBT [months]	11	PBT [months]	10

Table 45 *BEMS Technology: a representation of the value of the financial indicators according to different economic analysis .*
NPV = net present value - IRR= Internal rate of return - PBT payback time

Figure 94 is a graphic presentation of the **summed discount cash flow** during the useful life of the BEMS system.

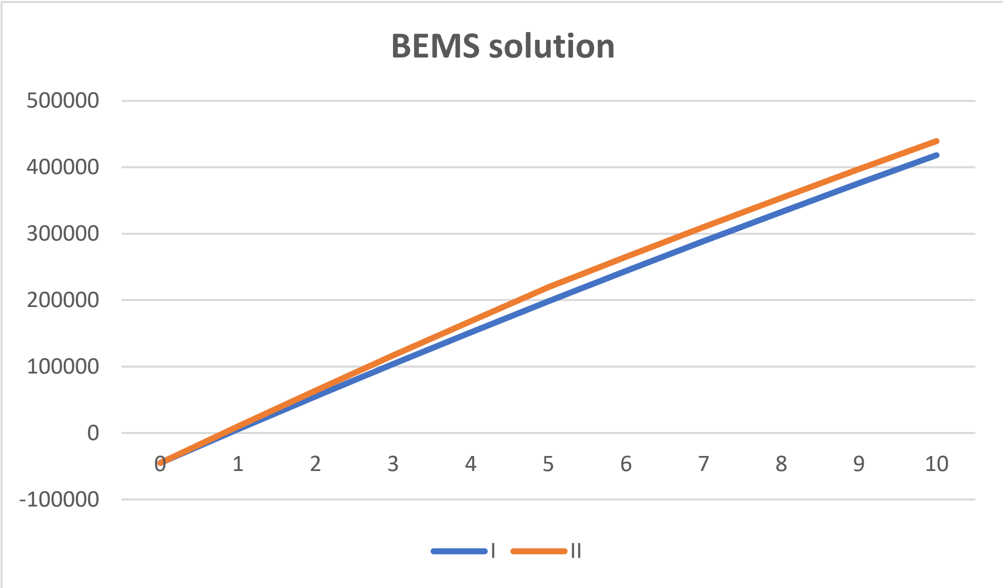


Figure 94 *BEMS installation: a graphic presentation of the summed discount cash flow during the useful life., according to different scenarios.*
I= without incentives - II _ with incentives

Financial analysis: PV plant

The followings principles should be considered:

- ✓ The **cost of capital (k)** is equal to 2%.
- ✓ The **useful life** for lightning is estimated to be 25 years and it is consistent with the time frame of the economic analysis.
- ✓ **Tax deduction** for PV plant installation is available up to 20kW, however I suppose a tax deduction of 50% in 10 years.
- ✓ **No reinforcement replacement analysis** can be led because of it is a new implementation.

CAPEX (Capital Expenditure)

- **PV panels, Q-PEACK-DUO-G8:** 140 €/panel x 54 panel = 26’069 €

OPEX (Operating Expense)

- **Operation and Maintenance cost:** 380 € / year
- **Energy savings:** are variable during the years

Table 46 is a synthesis of the value of the financial indicators according to different economic analysis

PV PLANT SOLUTION			
without incentive (I)		**with incentive (II)**	
NPV	35116	NPV	46825
IRR	12%	IRR	16%
PBT	8,4	PBT	5 and 10

Table 46 *PV plan installation: a representation of the value of the financial indicators according to different economic analysis .*
NPV = net present value - IRR= Internal rate of return - PBT payback time

Figure 95 is a graphic presentation of the **summed discount cash flow** during the useful life of the BEMS system

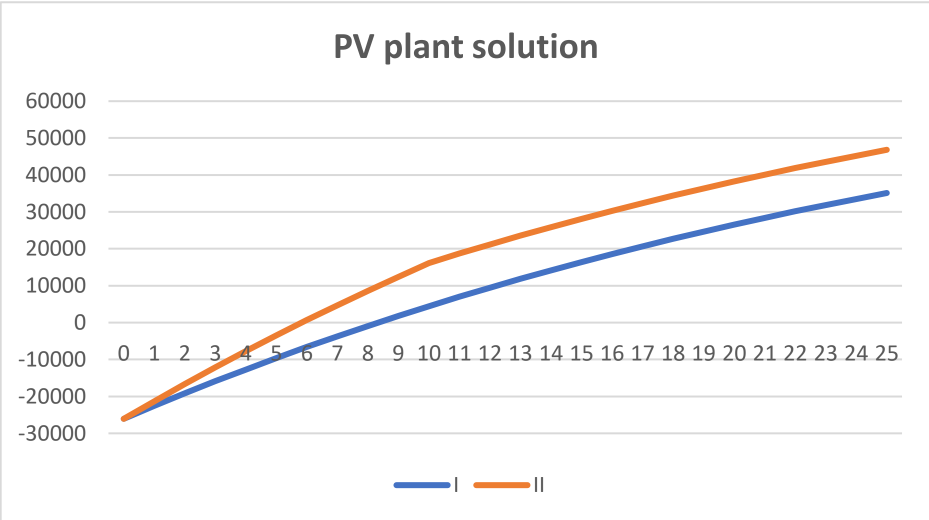


Figure 95 *BEMS installation: a graphic presentation of the summed discount cash flow during the useful life., according to different scenarios .*
I= without incentives - II _ with incentives

Final and comprehensive financial analysis

Table 47 and **Figure 96** are a synoptic and final presentation of the economic feasibility of the entire intervention. It is evident that the refurbishment project (BEMS + PV plant installation) is highly economically viable regardless incentives.

Antonio Stoppani School					
without incentive (I)			with incentive (II)		
NPV (25 year)	936482	€	**NPV (30 year)**	955511	€
IRR	77	%	**IRR**	85	%
PBT	2	year	**PBT**	2	year
	4	month		2	month

Table 47: *Antonio Stoppani Comprehensive Institution. Economic analysis of global intervention according to different economic scenarios. With or without incentives NPV = net present value - IRR = Internal rate of return - PBT payback time*

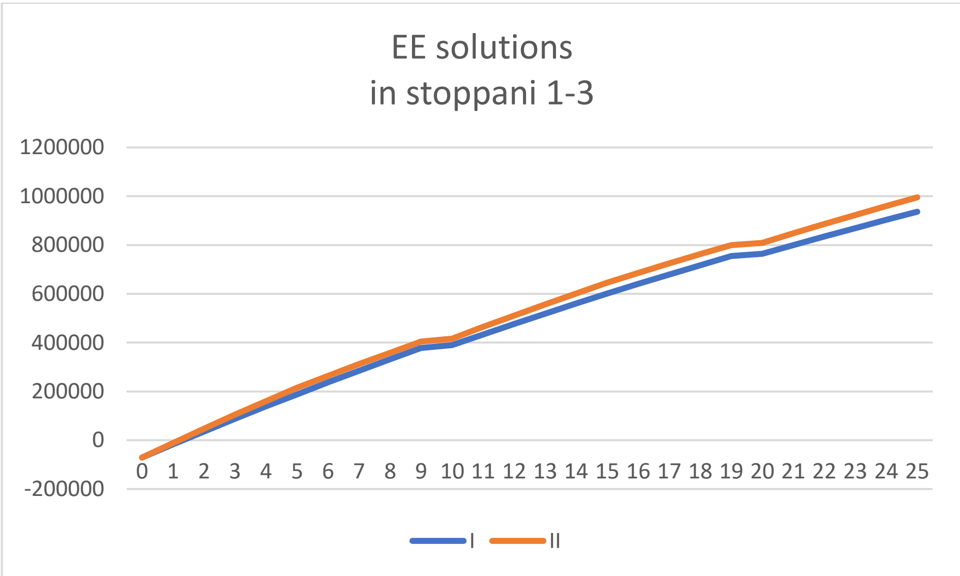


Figure 96 *Antonio Stoppani Comprehensive . Economic analysis of the global intervention according to different economic scenarios. With or without incentives.*
I = without incentives
II= with incentives

Building n°3: Comprehensive School, *Einaudi Pascoli*

Name:	Comprehensive school, *Einaudi Pascoli*
Location:	Via Val d'intelvi 11, Municipality 7- Milan
Year of construction:	1974
Intended use:	Primary School
Heated volume:	24'027 m^3
Number of floors:	3 (basement excluded)
Heating source:	natural gas
Contracting company:	

Inspection

Two one-site inspections were conducted on February 25-26 , 2020 following permission and by appointment with a technician from "Municipality of Milan . Adjunctive inspections were unfortunately no longer possible later in the lock down period

During the on-site inspections it was possible to retrieve information concerning the structural condition of the building and of the thermal components of the HVAC system in place and critical issues concerning sustainability.

Structural characteristics of the building

The building is located in Baggio, originally a small village close to Milan , that became , during the post war economic boom, a suburban area of Milan mainly dedicated to the working class. .

It was built it in 1974 and it is a traditional example of the so-called "*prefabricated schools*" constructed during and soon after the demographic post-war boom. In those years, due to the large request of new buildings the idea was to use a single project for many destinations.

Material of constructions used are typical of the early 70s at the time the first post-war economic crisis, and do not meet the requested standards. The pure quality of new material of constructions adopted such as aluminium doors and windows, synthetic membrane, and compost wood has brought to a rapid deterioration of the building **(Figures 97 A-B)**

It is a three-story building with an open garden delimiting the entire structure. Aside in Val d' Intelvi 11A a second smaller building is the location of a kindergarten with an independent entrance and thermal room (**Figure 98).**

Figure 97 A-B two external pictures of the Einaudi Pascoli primary school

Figure 98 Einaudi Pascoli primary school: external picture of the independent kindergarten a

The plant of the structure has an H shape, the entrance of the Primary school operates as a separator between the gym and the classrooms **(Figure 99).**

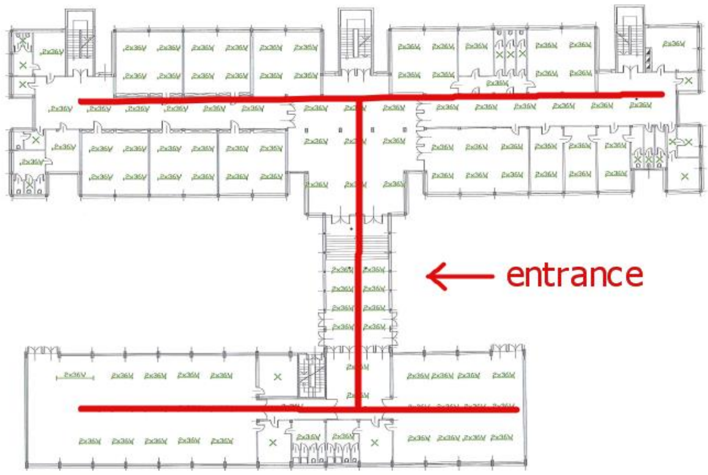


***Figure 99**: the H-shape plant of the Einaudi-Pascoli comprehensive school*

Technical characteristics

- **Load-bearing structures:**	Reinforced concrete beams
- **Useful and walkable surface** :	6’682,5 m^2
- **Volume**	24’027 m^3
- **Height of the ceiling**	3 m.
- **Total Dispersing surface of the building**	9260,08 m^2
- **Opaque surface**	3354,88 m^2
- **Transparent surface**	1314,32 m^2 242 double glasses wood and aluminium window
- **Ground surface**	2350,57 m^2
- **Rooftop surface**	2240,31 m^2
- **Surface to volume ratio (S/V):**	0,38 m^{-1}.

Different materials that characterize dispersing surfaces, account for different values of transmittance coefficient that are below reported.

- **Opaque surface** (3354,88 m^2) U = 2,07 $W/m^2 K$
- **Transparent surface** (1314,32 m^2) U = 5,3 $W/m^2 K$
- **Ground surface** (2350,57 m^2) U.= 0,68 W/m2 K
- **Rooftop surface** (2240,31 m^2) U.= 1,63 $W/m^2 K$.

Heat diffusion and ventilation modality

Heating diffusion is provided by **164 radiators**

The transparent surface is composted by **242 double glasses windows** delimiting by aluminium frames

No mechanic ventilation system is in place. Natural ventilation is the only way to guarantee air exchange.

Energy exchange: lost, gained, and requested

Table 48 and **Figure 100** below report energy exchange and energy request during the thermal year.

Energy exchange [MJ]										
Month	**To**	**Text**	**Qv**	**Qh**	**Ql**	**Qs**	**Qi**	**Qg**	**b**	**QR**
October	20	13,4	32167	264087	296254	149315	56849	206164	0,889	112974
November	20	7,9	72791	557440	630231	108456	70300	178756	0,99	453263
December	20	3,1	101667	759373	861040	83958	70300	154258	0,998	707091
January	20	1,7	110089	818272	928361	93817	70300	164117	0,998	764572
February	20	4,2	95049	713097	808146	156959	70300	227259	0,991	582932
March	20	9,2	64970	502750	567720	247957	70300	318257	0,934	270468
April	20	13,2	27034	220954	247988	202453	46335	248788	0,772	55924

Table 48 *Energy lost gained and requested during the thermal year in the Einaudi-Pascoli Comprehensive School* ***Qv*** *= natural ventilation. -* ***Qh*** *heat diffusion through walls and glasses -* ***Ql*** *energy loss -* ***Qs*** *solar irradiation -* ***Qi*** *internal energy contribution from people and things -* ***Qg*** *total energy gain* ***Qr*** *energy requested -* ***p*** *correcting utilization factor*

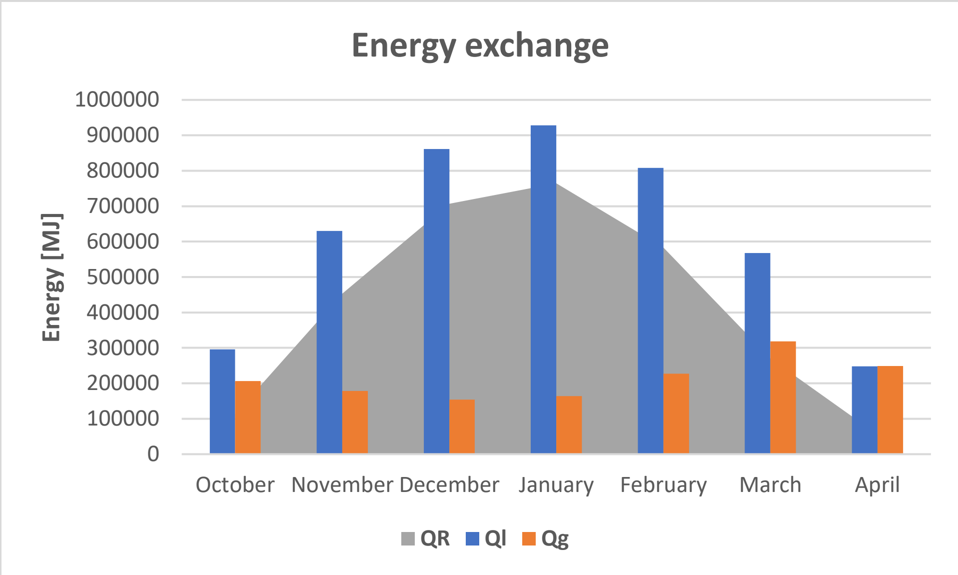


Figure 100: *energy requested during the thermal year in the Einaudi-Pascoli comprehensive school*

The thermal plant

The thermal room is located on the basement of the main building and can be reached through an independent stair situated at the front-right side of the building.

This paragraph has the purpose to give the list of the main components adopted in it and how the heating generation is distributed by the different sub-circuits.

Figure 101 gives a schematic representation of the thermal system of the school

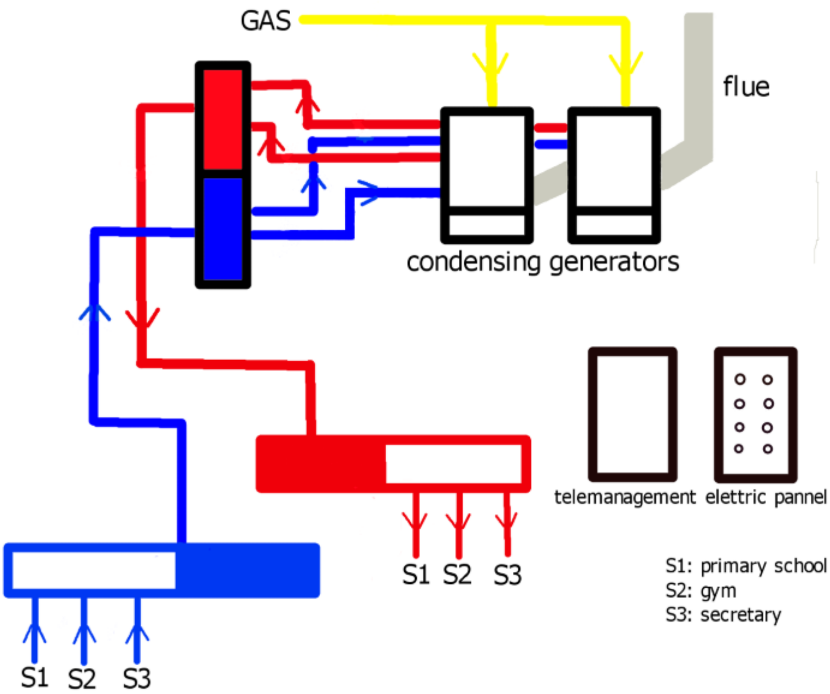


Figure 101 *a schematic representation of the thermal plant, heat generator and distribution system, of the Einaudi-Pascoli comprehensive school*

Einaudi-Pascoli is a comprehensive institution (primary school and secondary school of first level). Target temperature required and duration throughout the day are the same for the type of institution (primary versus secondary of first level).

The sub-circuits in place are thus developed according to the different destination services and operating hours characterized in each.

The thermal power plant is composed by three sub-circuits:

- Classroom (S1): target temperature, 20 °C - operating hours 8.00 - 16.30.
- Gym (S2) target temperature, 17 °C - operating hours 8.00 – 16.30.
- Secretary (S3) target temperature, 20 °C - operating hours 8.00 – 18.00.

The main components involved in the thermal system are:

- Two condensing methane furnaces (Hoval, 400 kW) with a total thermal load of 800 kW and the two related flues **(Figure 102).**
- Eight single electric pumps (Wilo): two top s50\10, two top s80\7, two ipl 65-115 and two strtos 65 1-2 (**Figure 103).**
- Two close expansion tanks, 400 l each **(Figure 104).**
- One dirt separator (Termoacqua) and one water softener (Termoacqua).
- One electric and tele-management panel **(Figure 105).**

Figure 102 *The condensing methane furnace of the thermal system l*

Figure 103 *The electric pumps of the thermal system*

Figure 104 *The expansion tank of the thermal system*

Figure 105 *The electric panel*

Thermal loads

Thermal loads were estimated according to the school operating hours during the thermal year 2018/19. (see **Table 11)**

Table 49 gives a figure of operating hours throughout the 2018/2019 thermal year. Additional 30 hours were required to lead extracurricular activities in that period.

heating operative hours during the thermal period 2018/2019	
month	**operation hours**
October (15th-31st)	80
November	210
December	164
January	200
February	200
March	210
April (1st-15th)	110
Extra-hours	30
Total	1204

Table 49 *operating hours throughout the 2018/2019 thermal year – Einaudi-Pascoli Comprehensive School*

The thermal loads during one week in December 2016 were analysed in details. (**Table 50** and **Figure 106)**.

The thermal power plant activity hours do not correspond with school operating hours. : The heating system is fully activated in the morning two hours before school opens in order to reach the target indoor ambient temperature. At the same time it is switched off before school activities end . According to the school timetable the heating system activity is almost inactive during week-ends.

furnace operation			
DAY		HOUR	load [kW]
Mon	12-dic	0.00	0,00
		7.00	937,44
		12.00	821,52
		18.00	882,00
Tue	13-dic	0.00	0,00
		7.00	987,84
		12.00	786,24
		18.00	912,24
Wen	14-dic	0.00	0,00
		7.00	1018,08
		12.00	786,24
		18.00	932,40
Thu	15-dic	0.00	0,00
		7.00	1144,08
		12.00	841,68
		18.00	992,88
Fri	16-dic	0.00	0,00
		7.00	1199,52
		12.00	997,92
		18.00	1108,80
Sat	17-dic	0.00	0,00
		7.00	0,00
		12.00	0,00
		18.00	0,00
Sun	18-dic	0.00	0,00
		7.00	0,00
		12.00	0,00
		18.00	0,00

Table 50 *operating hours throughout the 2018/2019 thermal year Einaudi-Pascoli Comprehensive School*

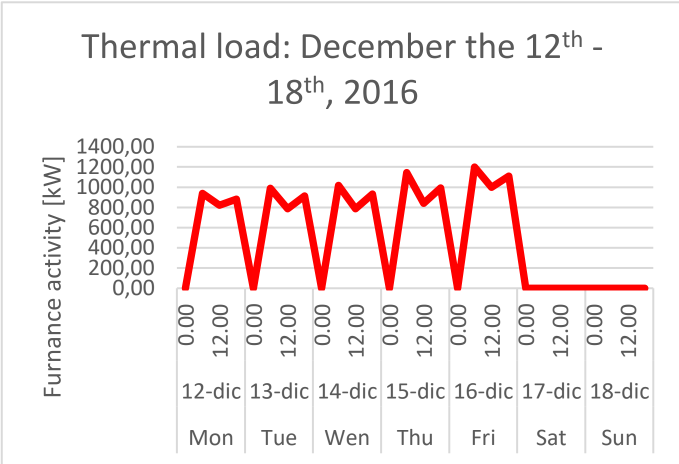


Figure 106 *a graphic presentation of operating hours of the thermal power plant during one sample week in December 2016 - Einaudi-Pascoli Comprehensive School*

A few figures should be added to have a better picture of the building emissions and costs.

- **Methane consumption** 122’139,73 m^3 (2016).
- **Energy heating consumption** 1168 MWh
- **Thermal + electrical energy** TOE/year (TOE = Tonnes of Oil Equivalent)
- **CO_2 emissions** tons/year
- **NOx emissions** tons/years
- **Energetic class** E

.

Electrical loads

In this section we briefly report the electrical loads of the lightening spots and devices operating in the building.

The estimated **total yearly electricity demand** in 2018 was 45357 kWh/year..

- **Fluorescent lamps** 24183,36 kWh/year
- **Other electrical devices** 21173 kWh/year

At full load, the electrical system requires 27,73 kW power to satisfy the entire demand.

Tables 51-52 are a representation of the year electrical loads of the Einaudi-Pascoli comprehensive School

Lightning loads						
Type	**N° spot**	**N° lamps per spot**	**Load per lamp [W]**	**Total load [Kw]**	**Yearly operation hours**	**Estimated consumption [KWh/year]**
Fluorescent lamps	311	2	36	22,392	1080	24183,36
Total	311	622	-	22,392	-	24183,36

Table 51 *electrical loads for lightening of the Comprehensive School Einaudi-Pascoli during the school year activity 2018/2019*

Yearly electrical loads					
Device	**N°**	**Power for unit [W]**	**Total power [kW]**	**Yearly operation hours**	**Estimated consumption [kWh/year]**
Computer	10	275	2,75	1760	4840
Coffee	1	250	0,25	1760	440
Refrigerator	1	150	0,15	8760	1314
Beverage	1	1500	1,5	8760	13140
Photocopy	1	100	0,1	1980	198
Wi-fi	3	20	0,06	1760	106
Other devices	-	-	0,526	-	1136
Total	**-**	**-**	**5,336**	**-**	**21173**

Table 52 *loads for electrical devices of the Einaudi-Pascoli comprehensive Institute during the school year activity 2018/2019*

The electrical load during one "sample" week in December 2016 were analysed in details **Figure 107**. Unlikely what happens for thermal loads, electrical loads almost completely match school activity schedule.

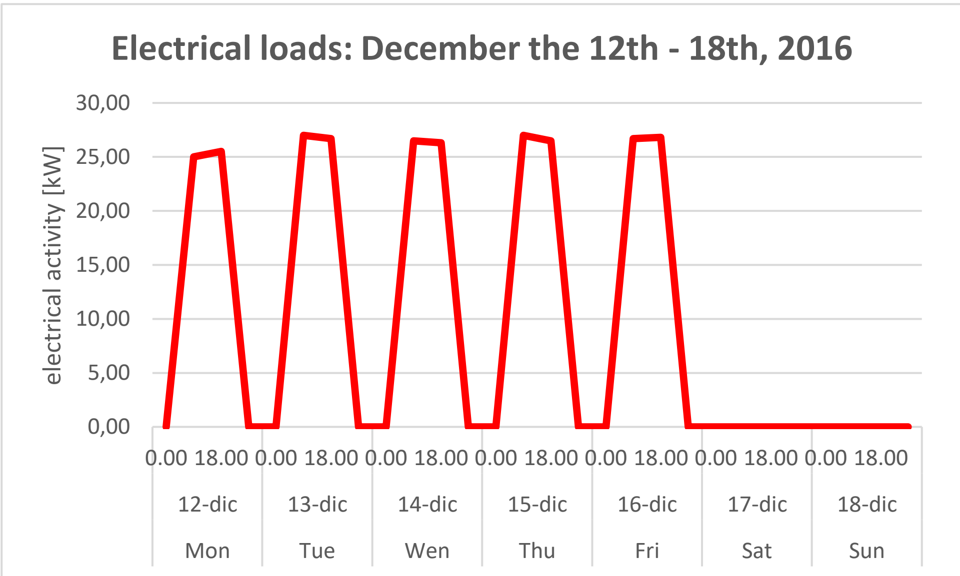


Figure 107 *a graphic presentation of electrical operating hours during one sample week in December 2016 - Einaudi-Pascoli Comprehensive Institute*

IMPROVEMENT ANALYSIS AND PROPOSAL

District heating

District heating systems are an alternative, safe ad economical solutions for heating production. District heating is a system for distributing heat generated twenty-four hours a day in a centralized location through a system of insulating pipes for both residential and commercial heating. With district heating the production of heat is thus centralized and is assigned to a single high-efficiency plant.

Compared to decentralized heat production heating district ensure s a primary energy saving and a reduced emission of pollutants in the atmosphere.

A possible solution for energy saving of our building is to replace the condensing methane furnaces (Hoval 400 kW × 2) presently active in the building with a **heat exchanger** connected with a district heating source and heating source coming from the district heating system provided by “”.

The Metropolitan Area of Milan is provided with Four different central plants that produce energy for different areas of the city using different energy sources: cogeneration (Novate-Comasina), geothermal (Canavese) or waste to energy (Silla 2).

The Einaudi-Pascoli Comprehensive School (Via Val d’ Intelvi 1) is located in the West side of the city of Milan. The Silla 2 (*a2a Calore e Servizi*) central heating plant is located in the north-west suburbs of Milan . It is a waste-to-energy plant that is able to produce electric energy and hot water for heating by treating 500.000 tons of wastes/year. Energy and hot water is distributed in the district network of the north west area of Milan.

Via Val d’Intelvi is not presently part of the district network of Silla 2 central plant. A connection has however been considered and will be hopefully soon realised.

A schematic and graphical representation of the district heating distribution in the Western area of Millan supplied is below presented **(Figures 108-109)**

As already mentioned *Silla2* is a waste to energy plant with three lines of combustion and a load of 212,6 MWe . The plant has been active since 2001.

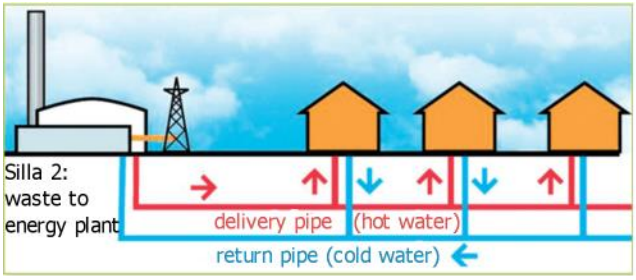


Figure 108 *a schematic presentation of the Silla2 waste-to-energy plant.*

Figure 109 *the distributing network of the Silla2 waste-to-energy plant*

The main benefit of district heating are the following:

- ✓ It is a **high efficiency** heating source of supply.
- ✓ Compared to decentralized heat production heating district ensures a **primary energy saving** and a **reduced emission of pollutants in the atmosphere**
- ✓ It has **no-restriction on the operating hours** per day.
- ✓ It is **a safety heating provision.**
- ✓ The **maintenance is simple and low-cost**.

Technical analysis (District heating)

The heat exchanger, fluid to water, between the heating district and the school building has to be modelled according to the energy savings before mentioned

Total energy savings = partition and rooftop insulation + natural ventilation:

178,128 MWh + 75,188 MWh **253,316 MWh**

An estimation of the new power needed for heating is below reported:

- ✓ **Thermal consumption before the interventions:** 1168 MWh
- ✓ **Thermal consumption after the interventions**: 1168 MWh – 253 MWh 914 MWh
- ✓ **Thermal consumption savings:** 253 MWh / 1168 MWh 21,66 %
- ✓ **Heat power capacity before the interventions:** 800 Kw
- ✓ **Heat power capacity after the interventions (78,34%):** 627 kW

Economic analysis (District heating)

The heating district price depends on the kind of destination and year-quarter of supply considered:

In *Einaudi-Pascoli* building the price is given by non-residential usage, with a power capacity beyond 700 kW and it is divided in two quotas: the energy consumed, and power installed. Below the prices reported from October to April 2019/20 by the supplier (A2a).[32]

- ✓ October - December 2019 (292,48 MWh): energy price 0,062798 €/kWht
load price : 12,398 €/kWt
- ✓ January-March 2020 (557,54 MWh): energy 0,063348 €/kWht
load price : 12,398 €/kWt
- ✓ April 20 (63,98 MWh): energy price 0,058384 €/kWht
load price : 12,398 €/kWt

According to the price reported above, we have calculated the expected expenditures for heating:

- ✓ **Energy consumption expenditure:** 57’416 € / year
- ✓ **Load expenditure:** 7’775 € / year
- ✓ **Total heating district expenditure:** 65’191 € / year

In order to calculate the energy savings due to the heating district installation, it is necessary to estimate the methane consumption due to heating from a condensing methane furnace of 627 kW,

- ✓ **Methane e consumption** 95’684 m^3 /year.

The **price of methane** is fluctuating and variable. The Municipality of Milan receives a discount on the full price methane due to the huge amount of combustible used. It seems a quite good approximation to consider for analysis the **price of methane** as 0,6 € / m^3 + IVA (22%) = 0,73 € / m^3.

- ✓ **Methane expenditure for heating** ; 95’635 m^3 / year x 0,73 € / m^3 69’813 € / year

IT is now possible to extimate the overall saving obtained by mean a connection to the heating district network

- ✓ **Overall savings heating district** **- 4’622 € / year**

Air handling unit

An **air handler**, or **air handling unit** (**AHU**), is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning system. An air handler is usually a large metal box containing a blower, heating or cooling elements, filter racks or chambers, sound attenuators, and dampers. Air handlers usually connect to a **ductwork ventilation system** that distributes the conditioned air through the building and returns it to the AHU. Sometimes AHUs *supply* and *return* air directly to and from the space served without ductwork.

The air handling unit is thus a multi-functional solution for both heating and air treatment supply.

The water inside the building heated or cooled)ì by the district system reaches the **air handling unit** installed in the building. The heat exchange coil, located in the machine, is the mean through which water releases heat to the air that is composed by an inside and outside mixture usually 80 and 20 in percentage.

The heated air reaches the indoor ambiences through an adequate air **distribution system** which releases hot air through wall terminals that are installed around the building. Cold air is subtracted from inside the rooms and brought back to the air handling unit.

The pros related to this solution are the following. Air handling units

- Allow also to treat the ambient air by mean of a filtering mechanism that is part of the system.
- Meet hourly air-exchange requirements imposed by law.
- Avoid heat losses caused by natural air exchange through windows and doors
- Are suitable for both air heating and cooling

A schematic presentation of an air handling unit connected to a heating district plant is below. Presented **(Figure 110).**

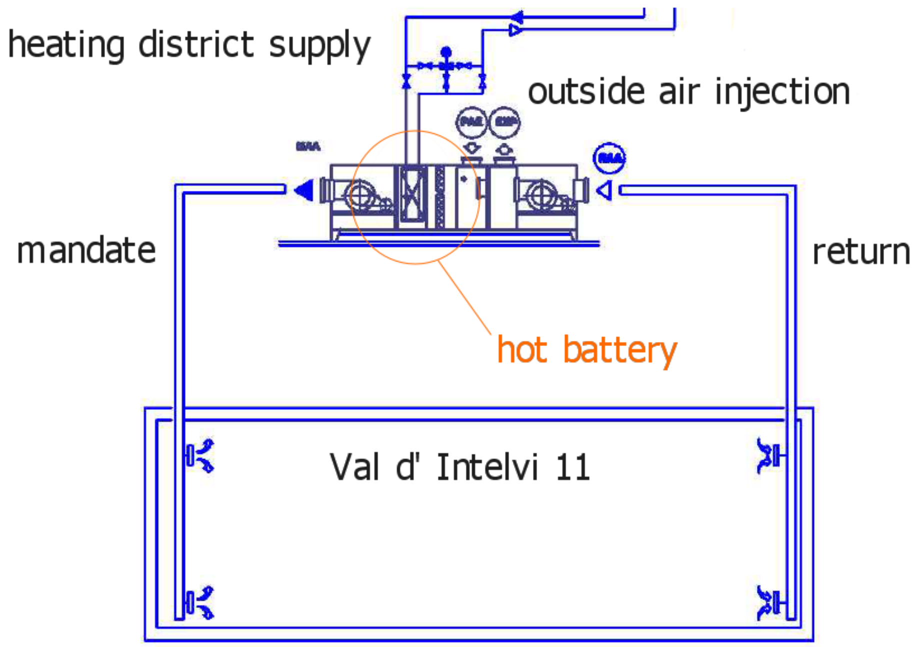


Figure 110 *a schematic presentation of an air handling unit and its distribution system, connected to a heating district plant*

It was possible to identify in the market a product (*Sites Technologici Company* - **UTS18.12)** that meets the requirements of the building. The characteristics are reported below in **(Table 53)**

Figure 111: *The UTS18.12 air handling unit.*

(UTS18.12) general features	
air flow [m^3 / h]	24000
water flow [l / h]	9647
air speed [m / s]	2,31
hydraulic head [Pa]	300
ventilator	
type	plug fan
air flow [m^3 / h]	12000
N° engine revolutions [rpm]	1579
absorbed power [kW]	2 x 3,4
sound power level [dBa]	79
heating battery	
inlet temperature air [°C]	16,5
outlet temperature air [°C]	30
inlet temperature water [°C]	70
outlet temperature water [°C]	60
price [€ / unit]	
28000 € / unit + iva (22%)	

Table 53: *The UTS18.12 air handling unit. Technical characteristics*

Technical Analysis (Air Handling Unit)

The air handler installed operates with one air exchange per hour:

Air flow: **24'000 m^3 / h**

Energy savings related to natural ventilation during the thermal period due to air handling unit installation can also be estimated:

Natural ventilation energy savings = energy losses before (due to natural ventilation)

= 270'678 MJ * 0,00027777 MWh / MJ = 75,188 MWh

Economic analysis (Air handling Unit)

It is necessary to estimate **the methane savings** due to air handling system intervention in economic values:

- Thermal energy consumption before the intervention: 1168 MWh
- **Thermal energy saving after**: 75,188 / 1168 **6,4%**
- Methane consumption before the intervention: 122’139 m^3
- Methane savings saving after: 122’139 m^3 / year x 0,064: 7’817 m^3 / year
- Methane price: 0,6 € / m^3 + IVA (22%) 0,73 € / m^3
- **Savings coming from the intervention**: 7’817 m^3 x 0,73 € / m^3: **- 5’706 € / year**
-

Cost for electricity consumption from the air handling unit system (UTS18.12)

- Power requested for ventilator: 3,4 kW / ventil
- n° of ventilator 2 ventil / mach
- Tot power requested 6,8 kW / mach
- n° of operating hours 1204 hours/ year
- Tot electricity requested: 8’187 kWh / year
- Electricity price: 0,18 + (22%) c€ / kWh 0,22 c€ / kWh
- **Tot electricity cost**: **+ 1’801 € / year**

The initial investments are:

Air handler machine

The air handler (UTS18.12) = 28’000 € + 22 % **+ 34160 €**

Distribution and diffusion channel

Price channel: 30 € / m

Length of the channels required

Classrooms

- mandate and return channel: 2 channels / floor
- n° floors: 4 floors / school

- channel length: 75 m / channel
- **total length classrooms**: 600 m

Gym

- mandate and return channel: 2 channels / floor
- n° floors: 1 floor / gym
- channel length: 55,3 m / channel
- **total length gym:** 110,6 m
-
- **Total length requested**: (600 m / classrooms + 110,6 m / gym) **710,6 m**

- **Total price distribution and diffusion channel**: (30 x 710,6 m) **+21'318 €**

Rain screen cladding

As already mentioned in previous paragraphs, the Einaudi-Pascoli comprehensive institute is a typical example of a school built the early 70s and is characterised by the poor quality of material of construction.

Energy performances of the building are significantly limited by high heat losses from the poor quality of the envelope of the construction.

- **Transmittance value (U) of the partitions** 1,4 W/m^2K
- **Transmittance values (U) of the rooftop** 1,63 W/m^2K.

A possible solution to this major inconvenient is to make a major renovation of the envelop through an additional protective layer denominated **rainscreen cladding.**

A rainscreen is an exterior cladding infrastructure that sits away from a building's outside wall's weather-resistant barrier, creating an air cavity directly behind the cladding that helps to protect the buildings important weather-resistant barrier.

The structure is composed by several layers with different materials having high resistance coefficient performance and a space between walls allowing the air flow exchange from down to upside the building partitions.

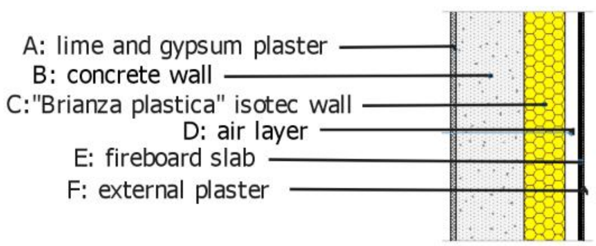
The air flow mechanism leads important multi-functional results during winter keeping the heat inside the building, summer releasing the heat from the building to outside and all the year through the depuration of condensing water and humidity on the external partitions of the building.

The benefits of this solution are various:

- ✓ **Energy savings** that limit the dispersions both in summer and winter due to the space between walls and insulating materials
- ✓ **Soundproofing improvement**.
- ✓ **Surface condensation and humidity removal** allows less degradation on the envelope of the building.
- ✓ **Architectonic and aesthetic value** of the façade through colour and shape modelling

Looking at different solutions available, I have chosen a proposal from "*Brianza Plastica s.p.a*" both for partition and rooftop insulation.

A schematic presentation of technical characteristics of the rain screen partitions and rooftop is presented below in **Figures 112 A-B** and **Table 54**



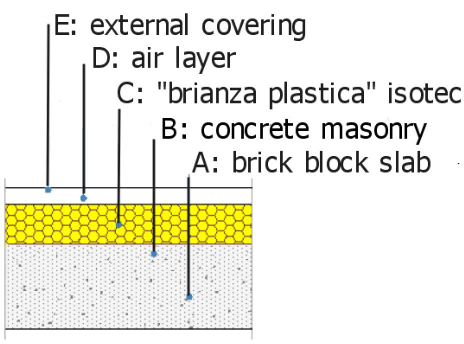


Figure 112 A-B : *A schematic presentation of the rain screen partitions (A) and rooftop (B)*

	layer	thickness (mm)	conductivity (W/m K)	resistance (m^2K/W)	density (kg/m^3)	capacity (kJ/kg K)
	Rooftop insulation					
	Int inductance	-	-	0,13	-	-
A	brick block slab	200	0,485	0,413	1800	1
B	concrete masonry	60	1,06	0,057	1700	1
C	isotec	120	0,022	5,455	38	1,25
D	air	40	0,5	0,08	1	1
E	external covering	10	0,825	0,012	1800	0,84
	Ext inductance	-	-	0,04	-	-
	Total	430		6,187		
	Partition insulation					
	Int inductance	-	-	0,13	-	-
A	lime and gypsum plaster	15	0,7	0,021	1400	0,84
B	concrete wall	200	0,58	0,345	1400	1
C	isotec	120	0,022	5,455	38	1,25
D	air layer	40	0,5	0,08	1	1
E	fireboard slab	12	0,23	0,052	856	0,23
F	external plaster	7	0,9	0,008	1800	1
	Ext inductance	-	-	0,04	-	-
	Total	394		6,13		

Table 54: *technical characteristics of the rain screen partitions and rooftop*

Technical analysis (Rain screen cladding)

The new transmittance coefficients after the application of rain screen cladding are here reported:

- **Rooftop transmittance (U)** = (1 / rooftop resistance) = 1 / 6,187 = 0,162 W / m^2 K
- **Partition transmittance (U)** = (1 / partition resistance) = 1 / 6,13 = 0,163 W / m^2 K

Following the building MAP, it is easy to retrieve information about the opaque surface of the partitions and rooftop that should be interested by the intervention. . This allows to calculate the dimension of the procedure and the related costs.:

- **Partition surface:** 3354,88 m^2
- **Rooftop surfaces**: 2240,31 m^2

According to data obtained in the energy report and through some transformations, it is possible retrieve the energy losses [kWh] due to heat diffusion through partitions, glasses and rooftop that are briefly reported in **Table 55**

Energy exchange through walls, rooftops and glasses							
type of surface	**surface [m²]**	**transmittance [U]**	**S*U**	**energy losses [%]**	**energy losses [MJ]**	**exchange coefficient [kWh / MJ]**	**energy losses [kWh]**
opaque	3354,88	1,4	4696,832	30%	404891	0,278	112470
transparent	1314,32	5,4	7097,328	46%	611826	0,278	169952
rooftop	2240,31	1,63	3651,705	24%	314796	0,278	87443

Table 55: *Estimated energy losses through walls, rooftops and glasses following a rainscreen cladding intervention*

Energy savings due to insulation intervention can be estimated as follows:

energy losses (before) – energy losses (after) or [1 - U (after) / U (before)] x energy losses (before)

- **partition insulation energy savings** = [1 - 0,163 / 1,4] * 112,47 MWh = 99,375 MWh/yr
- **rooftop insulation energy savings** = [1 – 0,162 /1,63] * 87,443 MWh = 78,753 MWh/yr

Economic analysis (rain screen cladding)

It is necessary to estimate the methane savings due to air rainscreen cladding system intervention in economic values:

- Total thermal insulation energy savings: 178 MWh
- Thermal energy consumption before the intervention: 1168 MWh
- **Thermal energy savings**: 178 MWh / 1168 MWh **15,3 %**
- Methane consumption before the intervention: 122’139 m^3
- Methane savings: 122’139 m^3 / year x 0,153: 18’687 m^3 / year
- Methane price: 0,6 € / m^3 + IVA (22%) 0,73 € / m^3
- **Savings coming from the intervention**: 18’687 m^3 x 0,73 € / m^3: **- 13’641,7 € / year**

The square meter price for rooftop and partitions insulation is 98,5 € / m^2.

Table 56 report the different items that cover the total cost price of 98,5 € / m^2:

rainscreen cladding price	
isotec partitions	30,5 € / m^2
isoband	1,5 € / m^2
block	7 € / m^2
isotec batten	1,5 € / m^2
fibre cement slab	8 € / m^2
screws, mesh, glue	6 € / m^2
finish with water-based paint	10 € / m^2
installation	34 € / m^2
total	**98,5 € / m^2**

Table 56 *: Rain screen cladding shade: the different items that cover the total cost price*

Rainscreen cladding total cost = (rooftop [m^2] + partitions insulation [m^2]) x price [€ / m^2]

(2240,31 m^2 + 3354,88 m^2) x 98,5 € / m^2 = 551’126 €

Financial analysis

The economic analysis performed takes into consideration different possible scenarios and financial indicators.

Different scenarios for financial analysis

- **A voluntary replacement:** considering the intial investment cost as the full cost of the installation.
- **A reinforcement replacment:** cosidering the intial investment cost as the difference between the new technology and the old installation.
- **A replacment without incentives:** considering just the economic returns given by the energy savings.
- **A replacment with incentives:** considering an appropriate tax duduction scheme according to the technology adopted.

Financial Indicators

- **Net Present Value (NPV):** *"it is the difference between the present value of cash inflows and outflows over a period of time."* It is used to analyse the profitability of a project.
- **Pay Back Time (PBT):** *"is the amount of time it takes to recover the cost of an investment"*
- **Internal Rate of Return (IRR):** *"is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis"*

Financial analysis: Rainscreen cladding

- ✓ The **cost of capital (k)** is **2%.**
- ✓ The **useful life** for screen cladding installation is estimated to be **30 years** and it is consistent with the time frame of analysis.
- ✓ The **tax deduction** for intervention on the heating system is **75%** during a time frame of **5 years.**
- ✓ **No reinforcement replacement analysis** can be led because this is not a substitution of any pre-existent solution.

Post-intervention:

CAPEX (Capital Expenditure)

Rainscreen cladding installation: + 551'126 €

OPEX (Operating Expense)

Operation & Maintenance: 0 €

Energy savings due to insulation: **- 13'641 € / year**

Table 57 is a synthesis of the value of the financial indicators according to different economic analysis

rainscreen cladding installation					
without incentive I			with incentive II		
NPV	-245616	€	NPV	144041	€
IRR	-2	%	IRR	6	%
PBT	83	year	PBT	13	year
	2	month		8	month

Table 57: *rainscreen cladding installation: value of the financial indicators with or without incentives*
NPV = net present value - IRR= Internal rate of return - PBT payback time

Figure 113 is a graphic presentation of the **summed discount cash flow** during the useful life of the of the rainscreen cladding

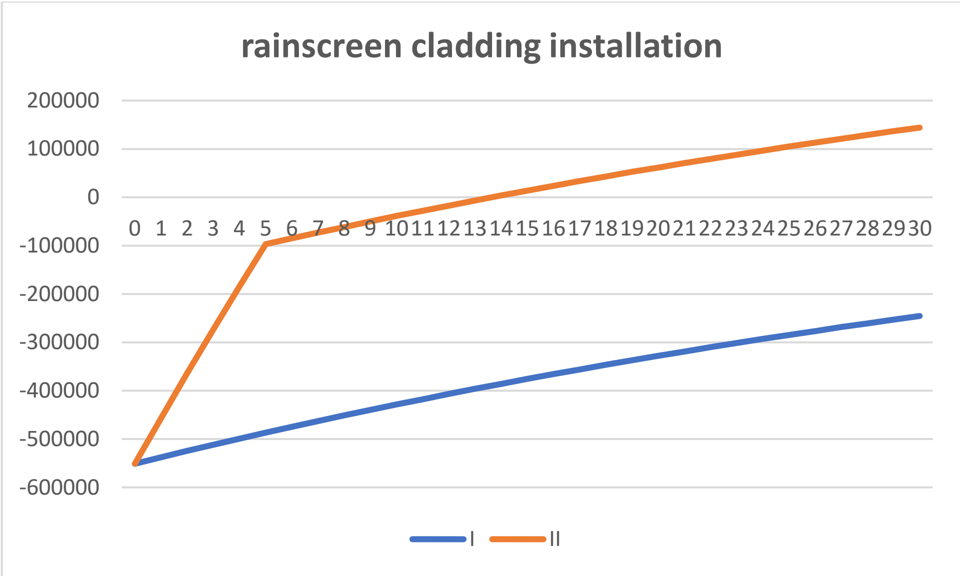


Figure 113: *Rainscreen cladding: a graphic presentation of the summed discount cash flow during the useful life., according to different scenarios.*
I= without incentives - II _ with incentives

Financial analysis: Air Handling Unit (AHU)

- ✓ The **cost of capital (k)** is 2 %.
- ✓ The **useful life** for AHU system is estimated to be 20 years and it is consistent with the time frame of analysis.
- ✓ The **tax deduction** for intervention on the heating system is 65 % during a time frame of 5 years.
- ✓ **No reinforcement replacement analysis** can be led because this is not a substitution of any pre-existent solution.

Post intervention:

CAPEX (Capital Expenditure)

AHU machine UTS18.12: + 34’160 €

Distribution & diffusion channel: +21’318 €

OPEX (Operating Expense)

- Operation & Maintenance + 500 € / year
- Electricity consumption + 1801 € / year

Energy saving

Heating diffusion due to natural ventilation: - 5’706 € / year

Table 58 is a synthesis of the value of the financial indicators according to different economic analysis

air handling unit system					
without incentive (I)			with incentive (II)		
NPV	198,6	€	NPV	34192,76	€
IRR	2	%	IRR	10	%
PBT	19	year	PBT	6	year

Table 58: Air handling unit: value of the financial indicators with or without incentives
NPV = net present value - IRR = Internal rate of return - PBT payback time

Figure 114 is a graphic presentation of the **summed discount cash flow** during the useful life of the of the air handling unit.

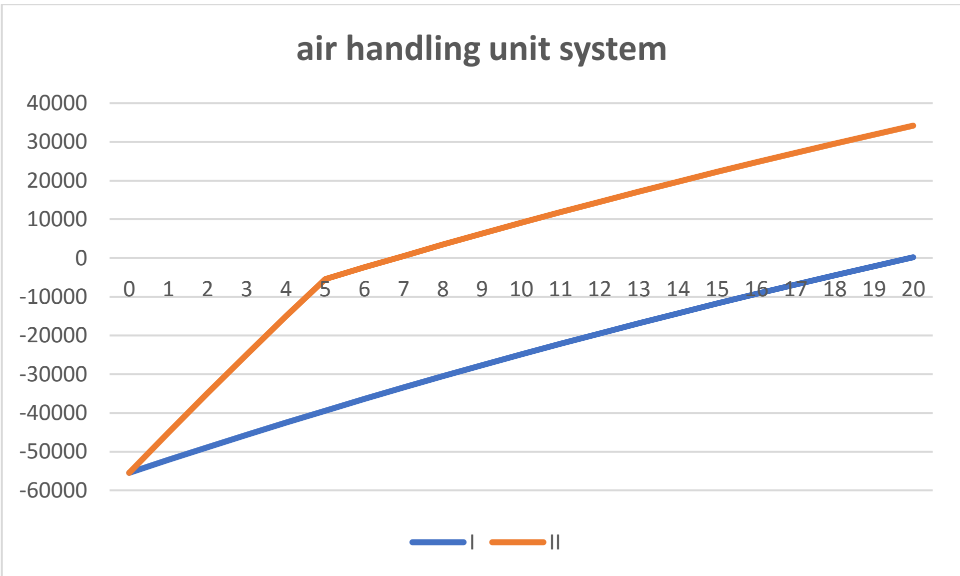


Figure 114 *Air handling unit: a graphic presentation of the summed discount cash flow during the useful life., according to different scenarios . I= without incentives - II _ with incentives*

financial analysis: heating district

- ✓ The **cost of capital (k)** is equal to 2%.
- ✓ The **useful life** of the methane furnace that I want to replace is estimated to be 15 years and it is consistent with the time frame of analysis.
- ✓ **No tax deduction** is considered in the analysis.

Pre-intervention:

CAPEX (Capital Expenditure)

- The reference cost for methane furnace, 627 kW + 36’000 €

OPEX (Operating Expense)

- Operation & Maintenance + 500 € / year

Post-intervention:

No CAPEX involved in the installation; the district heating system is charge of of *A2a Calore e Servizi.*

- Energy savings (before – after): **- 4’622 € / year**

Since no initial investment cost can be considered (the connection th the heating district network in in charge to A2a Calore e Servizi) meaningless to calculate the pay-back time and internal rate of return of the investment.

The economic analysis will be thus concentrated mainly on the NPV over 15 years (the useful mean life of a local heating system) in different economic scenarios: voluntary and reinforcement replacement.

- **Voluntary replacement** NPV = 59’389 €
- **Reinforcement replacement** NPV = 101’814 €

Final and comprehensive financial analysis

Table 59 and **Figure 115** are a synoptic and final presentation of the economic feasibility of the intervention. It is evident that the refurbishment project would not be economically viable without incentives from the Public Administration .

On the other hand it has to be remarked that incentives make possible to estimate what in this economic analysis cannot be directly calculated: atmospheric pollution benefits and environmental increased comfort of the school ambiences.

Pascoli-Einaudi Primary School											
voluntary replacement						reinforcement replacement					
without incentive (I)			with incentive (II)			without incentive (III)			with incentive (IV)		
NPV	-141901	€	**NPV**	281688	€	**NPV**	-48727	€	**NPV**	374923	€
IRR	0	%	**IRR**	8	%	**IRR**	1	%	**IRR**	10	%
PBT	46	year	**PBT**	9	year	**PBT**	35	year	**PBT**	7	year
	8	month		4	month		0	month		2	month

Table 59: Pascoli Einaudi Primary School. Comprehensive economic analysis of intervention according to different economic scenarios. With or without incentives
NPV = net present value - IRR = Internal rate of return - PBT payback time

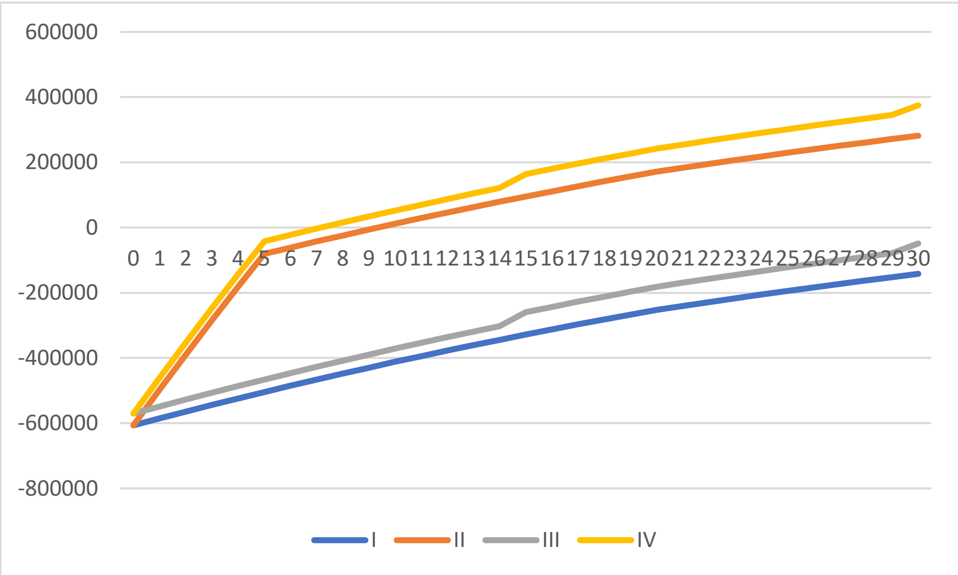


Figure 115 *Pascoli Einaudi Primary School. Comprehensive economic analysis of intervention according to different economic scenarios. With or without incentives.*
I = voluntary replacement without incentives
II= voluntary replacement with incentives
III= reinforcement replacement without incentives
IV: reinforcement replacement with incentives

Building n°4: *Citylife, Nursery School*

Name:	*CityLifeNursery School*
Location:	Via Demetrio Stratos 8, Municipality 8 - Milan
Year of construction:	2018
Intended use:	nursery school
Heated and cooled volume:	3359,92 m^3
Number of floors:	1
Heating source:	heat pump and district heating

CityLife, nursery school: an example of Nearly Zero Emission Building (NZEB)

The purpose of this paragraph is to illustrate a new building (2018) and to illustrate the innovative solutions adopted to reach the ambitious target of Nearly Zero Emission Building. For this reason it is evident that a project aimed at improving the energy efficiency of the building has not been conducted.

Structural characteristics of the building

This nursery school is located in the centre of the new district of *Citylife*

In order to have a complete figure we report below the main structural characteristics of the building:

- **Volume**: 3'359,92 m^3
- **Walkable surface**: 841,98 m^2
- **Dispersing surface**: 2'362 m^2
- **S/V ratio**: 0,7
- **Transmittance coefficient (Yie):** 0,01 W/m^2K
-

Energetic characteristics

The nursery school exploits different energetic sources that are reported below together with their year consumption:

- **PV energy**: 24'835,46 kWh
- **Electricity from the grid**: 15'980,07 kWh
- **Heating district**: 62'646,7 kWh
- **Heat pump**: 11'997,76 kWh

In addition, it adopts different energetic services to better satisfy the thermal-comfort conditions inside the building:

- Cooling

- Heating
- Mechanical ventilation
- Domestic hot water production
- Domestic energy production for Lightning

Among these it is worth mentioning that mechanical ventilation and cooling systems are not present in almost any other school building under the administration of the Municipality of Milan.

Table 60 below reports energy characteristics of the building.

Energy performance, Citylife Nursery School					
Energy service	**type of installation**	**energetic vector used**	**nominal power [kW]**	**EP,ren [kWh/m² year]**	**EP,nren [kWh/m2 year]**
Heating system	district heating	district heating	120	25,08	27,39
	heat pump	electricity	61,3		
Cooling system	heat pump	electricity	86,2	12,6	9,08
Domestic hot water production	district heating	district heating	120	6,79	17,57
Mechanical ventilation	-	electricity	3,33	9,18	9,29
Lightning	-	electricity	7,76	15,39	16,08
Production from renewable sources	PV plant	-	24,9	-	-
	heat pump	-	61,3	-	-

Table 60 *Energy performance - Citylife Nursery School*

The energy performances of the building are in a considerable part derived from renewable sources:

- **EPgl, nren**: 79,42 kWh / (m^2 year),
- **EPgl, ren**: 69,04 kWh / (m^2 year)
- **EPgl, tot**: 148,46 kWh / (m^2 year)

EPgl nren = global energy performance non-renewable sources
EPgl, ren **=** *global energy performance renewable sorces*
EPgl, tot: = EPgl, ren + EPgl nren

The building emits in atmosphere 35,01 kg/ (m^2 year) of CO_2 and it has been classified as A4 the highest energy rating possible. Any further intervention aimed at improving the energetic performance of the building seems to be thus useless.

A brief description of the main energy solutions available in the Citylife Nursery School

Air–water handling unit system (CLIVET CPAN-XHE3, size 4) both for cooling and heating services (Figure 116 – Table 61)

Figure 116 *Air–water handling unit system (CLIVET CPAN-XHE3, size 4)*

CLIVET, CPAN-XHE3 size 4	
compressor type	scroll
nominal air flow [m^3 / h]	7200
refrigerator power [kW]	58,4
heating power [kW]	32,9
sound power level [dB(A)]	80
performances	
EER	4,67
COP	7,8
dimensions	
length [m]	2,26
width [m]	2,465
depth [m]	1,735

Table 61 *Air–water handling unit system (CLIVET CPAN-XHE3, size 4). Technical characteristics.*

Fan Coils (Aermec FCU-01, FCU-02 and FCU-03)

Different types of fan coils are used to release heat and cool inside the schools: vertical movable and horizontal canalized.

The supplier company of the school is AERMEC with three different product lines installed: FCU-01, FCU-02 and FCU-03. Technical characteristics are detailed in **Table 62.**

fan-coils	FCU-01	FCU-02	FCU-03
type of piece	vertical installation	horizontal canalized	vertical installation
power			
cooling power [kW]	0,5	1,3	1,4
heating power [kW]	0,13	0,66	0,55
flow			
chilled water [l/s]	0,034	0,092	0,066
hot water [l/s]	0,01	0,02	0,02
air [m^3/h]	120	271	210
other parameters			
electrical absorbation [W]	7	37	7
sound level [Dba]	30	37	30

Table 62: *Fan Coils Aermec FCU-01, FCU-02 and FCU-03. Technical characteristics.*

Radial panels (swell system) distribute hot water in the inner tubes (**PE-Xa system**) hot water from the heating district generation, the tubes are shaped all around the ground and they diffuse homogeneously heat to the ambiences (**Figure 117 –Table 63**).

Figure 117: *The SWELL, PE-Xa system.*

SWELL, PE-Xa system	
physical characteristics	
oxygen permeability [g/m^3]	0,003
density [kg/m^3]	951
roughness [mm]	0,007
thermal characteristics	
max temperature service [°C]	95
thermal conductivity [W/Mk]	0,35-0,38
specific heat at 23°C [KJ/kg K]	2,3
mechanical characteristics	
tensile strength [N/mm^2]	> 22
elasticity module at 20°C [N/mm^2]	> 800
internal pressure resistance, s=4,6 Mpa, 95°C	> 165

Table 63: *The SWELL, PE-Xa system. Technical characteristics*

Materials of construction

The entire **building is constructed of coniferous trees wood (Figure 118)** provided by Binderholz Brettsperrholz, (products BBS 125 and BBS XL). The materials were tested by Holz Forschung (Austria) with the following technical results **(Table 64):**

Figure 118: *The wooden structure of Citylife Nursery School*

technical characteristics	**BBS 125**	**BBS XL**
number of layers (n)	3 < = n <= 9	3 <= n <= 5
width [m]	1,25	<= 3,5
length [m]	<= 5	<= 22
thickness [mm]	350	200
species	softwood, pine	
thermal transmittance [W/ (m^2 K)]	0,13	

Table 64: *The wooden structure of Citylife Nursery School . Technical characteristics*

The **glasses**, supplied by Guardian Configurator, have a transmittance coefficient of 0,576 W / m^2 K with a total thickness of 49,76 mm composed by different layers **(Figure 119).**

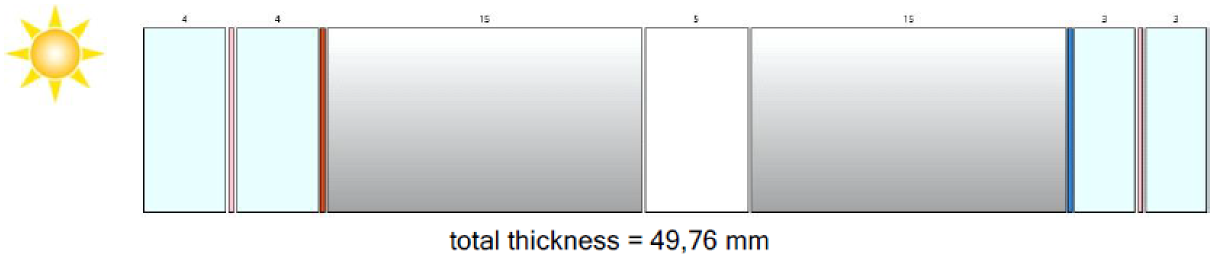


Figure 119: *A schematic view of the different layers that compose window glasses in the Citylife Nursey School*

The Citylife, Nursery School is a virtuous and rare example in Italy of a Nearly Zero Emission Building. For this reason an implementation project was not considered in the study.

8. DISCUSSION

According to data from MIUR[18] and recently reported by Fondazione Agnelli[19], nearly 39.000 school buildings are active in Italy, and are distributed homogeneously in the territory according to the Italian population density.

The number of students in Italy is estimated to be nearly eight million, with nearly one million teachers and roughly 200.000 administrative workers employed [19].

Kindergartens, primary and secondary school of first level accounts for 83% of school building destinations with secondary school of second level (*Lice*i and Technical Institutions) distributed in the remaining 17%.

Lombardy is the most populated region in Italy and the distribution of school building in its territory is consistent with the large student population that is estimated to be nearly 1.600.000.

According to ISTAT, Milan accounts for roughly 220.000 students that are homogeneously distributed in the institutions of its nine administrative municipalities. Only second level secondary school are more concentrated in its central municipalities.

The mean age of school buildings in Italy is rather old and is estimated to be 52 years (54 years in Lombardy). Two third of them is aged more than 40 years.

Most school buildings in Italy was constructed after second world war with a peak incidence (30% of the entire sample) that is concentrated in the time frame 1961-1976, during the years of the economic and demographic expansion in Italy.

Two earlier peaks of construction are related to the "*giolittian age"* at the beginning of the 20th century and to the *"fascist age"* between the two world wars. In those years the Italian school population rapidly increased as a consequence of the increased age to 12 years for compulsory school attendance that was established by law in 1904.

Architectural features in general and, more important for aims of this study, material of constructions of school buildings differs according to their age.

Larges spaces, load-bearing masonry structure and high quality of materials characterize the school buildings constructed before world war II . Smaller and more flexible spaces, concrete reinforced beams/pillar load bearing structures, partitions and in general poorer materials of construction are more typical of school buildings constructed during the Italian demographic expansion.

Europe in general and Italy in particular have suffered a severe and increasing demographic contraction in the last three decades. According to data Eurostat from the European Community recently reported by Fondazione Agnelli [19] a 13% further reduction of the school population is expected in Italy by 2030 and 5000 of the actual active classrooms will not be necessary by then.
For this reason, the construction of new school building is no longer a crucial issue for European Governments as it used to be in the past. Nevertheless, the restoration of the old school building heritage according to the recent severe national and European regulations has become the new challenge of the national and local administrations of the educational system.
According Fondazione Agnelli[18], 16% of school buildings in Italy have serious structural problems regarding vertical or horizontal load bearing structures and roof tops. In 1,3% of cases more than one of the three above mentioned critical issues have been acknowledged by the competent authorities.
Problems related to environment and energy sustainability, are even more frequent and affects the majority of the sample.
Heating and heat maintaining are, among these, one of the most relevant issue. The main deficiencies encountered are related to double glazed windows (61%), heating zoning (64%), photovoltaic and thermal panels (74%), rooftops insulation (78%) and external wall insulation (88%).
These are responsible for elevated operating costs that could be reduced up to one third by adopting simple technical measures.
At the same time, according to the United Nation Environment Programme[32], buildings are responsible for 40% of the global energy consumption and 30% of pollutant atmospheric emissions. Domestic heating is responsible for respectively 25%, 30% and 14% of PM_{10}, $PM_{2,5}$ and NO_x emissions in the Metropolitan area of Milan.
It is unfortunately impossible to estimate the incidence of school buildings in the total pollutants emission due to domestic heating. Nevertheless, considering the elevated mean age of school buildings in Italy, any project for their restoration should certainly take into account the new strict limitation to air pollution established by law and also indicated by the European Community and the necessity to comply with them.
One of the secondary aims of this study was to give an indication on the concentration of pollutants atmospheric agents derived from heating activities, in the Metropolitan Area of Milan, and more in general, in Lombardy, during the thermal season (October-April).

Carbon dioxide (CO_2) accounts for 80% of emissions in the atmosphere and is the principal human caused greenhouse gas that affects the Earth's radiative balance. According to a study recently conducted by Politecnico of Milan[8] on a sample of five Italian urban agglomerates, heating systems are responsible for CO_2 emissions up to six times larger than those produced by traffic and industrial processes. The Municipality of Milan has committed to taking corrective actions also addressed on heating systems for the reduction of 45% CO_2 emission in the next ten years and is expected to be a carbon free area by 2050.[9] Nevertheless, since CO_2 emission represents a global issue, our choice was concentrate our analysis on local pollutants derived from heating, with particular regard to PM_{10}, $PM_{2,5}$ an NOx.

The *concentration / year* of PM_{10} in the metropolitan Area of Milan has progressively decreased from 2002 and resulted to be maintained within the limit (threshold 40 µg/m^3), as defined by the DIRECTIVE 2008/50/EC, since 2013 with the only exception of year 2015. Nevertheless, although the number of days exceeding the maximum allowed concentration (threshold 50 µg/m^3) has also shown a descending trend and is more than halved as compared to 2002 (163 days), it still remains always consistently above the imposed limit (35 days) until now.

The higher concentration of PM_{10} were always reached during the thermal year with peaks registered in the 3rd and 4th week of January (mean 76 µg/m^3 and 69 µg/m^3) and the higher levels recorded in 2017 (81 µg/m^3 and 128 µg/m^3 respectively).

The same observations can be applied to $PM_{2,5}$: mean 60 µg/m^3 and 53 µg/m^3 and peak levels recorded in 2017 (57 µg/m^3 and 97 µg/m^3)..

The recent lock-down period (March-April 2020) imposed by the SARS-CoV-2 pandemia has given the opportunity to study pollutants' atmospheric concentration in the exceptional situation of a drastic industrial and traffic contraction.

Environmental concentration of PM_{10} and $PM_{2,5}$, did not significantly change as compare to mean values in the same months of the previous years. These figures can be perhaps explained by an increased pollution activity from residential heating system that has compensated lower emissions generated by traffic.

On the contrary, NO_x concentrations showed a consistent reduction during the shut-down period in Milan with values significantly below the historic registrations of the last five years.

Traffic represents, by far, the main source of NO_x emission (64%). Drastic traffic limitation has thus logically led to significant NO_x pollution reduction.

The main part of our study was conducted in four school buildings of Milan that had different characteristics according to age and materials of construction. The main objective was to perform a technical evaluation of the structure and economic analysis on costs, mainly derived from heating and to propose then a three restorations projects. Although any single restoration project for any single building has its own peculiarities, the idea was to create then three different models that could in the future be applicable to other constructions with similar characteristics.

Among the large number of schools under the administration of the Municipality of Milan, the choice fell on the following buildings:

Villa Simonetta seat of the Musical School Claudio Abbado: this historical building was erected at the end of XV century. Its main and peculiar characteristic is thus to be found in the ancient and vulnerable structural elements. Columns, frescos, and wooden ceilings characterize most of the spaces . For this reason the building is under the supervision of the authority of Fine Arts. Any renovation or refurbishment or even maintenance work should meet the conditions imposed by strict protocols.

The comprehensive School Stoppani built in the first years of the last century is the typical school building belonging to the Giolittian Age.

The Comprehensive School, *Einaudi Pascoli* built in 1974 is instead a traditional example of the so-called "*prefabricated schools*" constructed during and soon after the demographic post-war boom.

T**he Citylife, Nursery School** Built in 2018 is a virtuous and rare example in Italy of a Nearly Zero Emission Building.

Below we report some observation related to the main solution proposed in our study:

Thermal plant substitution.

The administration of the City of Milan has planned to outlaw gasoline powered thermal plant for residential heating by 2023. The majority of school buildings of the metropolitan Area of Milan (97%) have fortunately already accomplished this indication . Nevertheless methane represent still represent the main quarter of supply for heating (82%) with only 15% of school building supported by other more sustainable solutions (heating districts , renewables sources).

One of the solutions in our project was the substitution of a classic methane condensing furnace with a an electric heat pump thermal plant. This was the main proposed intervention for the Music School Claudio Abbado.

These innovative systems allow to satisfy the requests for both heating, and cooling, and at the same time for the production of hot sanitary water for the building.

The main technical advantage of the electric heat pumps is represented by its energetic efficiency. The electric heating pumps generate more than one unit of thermal energy for each unit of electrical energy consumed . This is expressed by the coefficient of performance (COP) value that is always higher when compared to traditional methane furnaces. In our project the two proposed heat electric heat pumps have a COP value of respectively 3,11 and 3,02.

The high initial investment required for the installation of an electric heat pump system as compared to that required for a traditional methane supported plant (85.000 € versus 40.000 €) is economically not sustainable without incentives from the administration. In our specific case , considering a useful life of 15 years, the Net Preserve Value in a Voluntary Replacement scenario of the intervention without incentives was – 28.492 € with a pay-back time of 22 years .

Nevertheless it has to be remarked that incentives make possible to estimate what in this economic analysis cannot be directly calculated: atmospheric pollution benefits and environmental increased comfort of the school ambiences

Fan coil.

The substitution of radiators with fan coils is a solution that can improve the performance of electric heat pumps. As a matter of the fact radiators are not the suitable to diffuse heat at the lower water temperature generated by these systems.

Fan coils connected to an electric thermal plant have the great advantage to support both heating and cooling necessities. For this reason, this solution was logically and consequently proposed in our analysis for Villa Simonetta.

The economic scenario of an electric thermal plant associated to an air diffusing system without incentives is even worse than that above presented. The above mentioned observation concerning air pollution and mainly environmental comfort of the ambiences are valid for fan coil.

Photovoltaic plants

These are renewable energy sources that can be quite easily and advantageously adopted in the climatic zone of Milan.

In our study the implantation of a photovoltaic system was considered in two cases (Villa Simonetta ad Comprehensive School Antonio Stoppani).

Different PV solutions are available on the market according to the characteristic of different buildings. In our study the more expensive and innovative solution of building integrated PV tiles (3500 €/kW installed) seemed to be the best solution for Villa Simonetta due to the limitations

imposed by the Fine Arts. For Antonio Stoppani Comprehensive School, the installation of more traditional an less expansive (1350 €/kW installed) PV panel was instead considered.
The implantation of a PV system not only can support the traditional electric load of a school building (lightening and other electric devices) but is also and mainly a source of clean energy for a more economically sustainable performance of an electric heat pump.
In our specific cases, considering a useful life of 25 years, the Net Preserve Value in a Voluntary Replacement scenario of the interventions without incentives was – 7250 € with a pay-back time of 28 years for PV tiles and + 35.000€ with a pay-back time of 8 years for PV traditional panels.

Building Energy Management System (BEMS)

A **BEM** system is aimed at monitoring and controlling services such as heating, ventilation and air-conditioning, ensuring the building operates at maximum levels of efficient and removing wasted energy usage and associated costs. The optimal level of efficiency is achieved by continuously maintaining the correct balance between operating requirements, external and internal environmental conditions, and energy usage.
The Stoppani comprehensive school building meets the criteria for the introduction of Building Energy Management System.
According to literature, the installation of a BEM system can guarantee high levels of thermal and electrical energy saving (30% and 50% respectively).
In our case study, considering a thermal energy saving of 30% (37.500 m^3 /year of methane) the bill for methane consumption was reduced from 91.360 €/ yr to 63.960 €/ yr
Electrical energy saving from BEM system installation were 28.660 €/yr
In our case study the implantation of a BEM system could be achieved with a pay-back time of 11 months.
BEMS are thus expected to be solutions for energy saving that will be increasingly adopted in the future particularly in large and multifunctional buildings such as the Antonio Stoppani comprehensive institution.

Rainscreen cladding.

The installation of a rain screen cladding is a solution aimed at improving the energy performances of buildings that are characterized by the poor quality of materials of construction. This was the case, in our study, of the Einaudi-Pascoli Primary School for all the reasons above mentioned.
Soundproofing improvement and humidity removal are other benefits of this solution.

In our case study, the most significant technical result expected from a rain screen cladding installation is the reduced heat dispersion of the building that is expressed by a decreased transmittance value from 1,4 W/m^{2}K to 0,163 W/ m^{2}K and from 1,63 W/m^{2}K to 0,162 W/m^{2}K for partitions and roof tops respectively.
This resulted in a 15,3 % thermal energy saving that was calculated to be - 13'641,7 € / year.
Due to the high cost of the intervention (550.000 € in our case study) incentives are also necessary for rain screen cladding to sustain the economical feasibility of the project.

Air handling system

An a**ir handling unit (AHU)**, is a device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning system.
In our study the installation of a AHU was considered particularly necessary for the Einaudi Pascoli primary school institute that is characterized by low values of natural air exchange due to the poor architectural design.
The most relevant economic advantage derived from a AHU system is provided, in our case, by the thermal energy savings obtained by the limitation of natural air exchange that is today possible only by opening windows. This was calculated to be 5.700 €/yr.
The installation of a AHU system without incentives has no economical advantage (pay-back time = useful life). Nevertheless the comfort benefits for the school population, not taken into account in this analysis, are evident and air handling units installations should be considered mandatory in all school building that do not meet the criteria requested by law for natural air exchange.

District heating

District heating systems are an alternative, safe and efficient solution for heating production. With district heating the production of heat is centralized and is assigned to a single high-efficiency plant. Compared to decentralized production, heating district ensures a primary energy saving and a reduced emission of pollutants in the atmosphere. A city network produces up to 20% of CO_2, 50% of NO_x and 100% of Sox less than the individual traditional thermal plants.
The Silla 2 central heating plant (*A2a Calore e Servizi*) is located in the north-west suburbs of Milan and its network could technically quite easily be connected with the area of Baggio were the Pascoli Einaudi Institute is located.

In our study we have thus simulated the expected economical benefits coming from a connection to the district heating system of the school.
One important economic advantage is represented by the absence of any initial and maintenance cost .
This make possible an immediate 6,6% year cost reduction for thermal energy that account in our case study for a saving of 4.622 €/yr
As already mentioned, no restoration project was proposed for the Citylife, Nursery School. We have included this building in our study mainly to briefly present the technical feature of a a Nearly Zero Emission Building, a sadly rare example in the public sector.

Our thesis has mainly considered technical deficiencies for heating production and conservation in the school building of the city of Milan . The implementation projects have investigated the economic viability of advantageous and up-to-date technical solutions. The main limit of this study is mainly represented by the lack of any economical consideration for the expected benefits of the implementations proposed on air pollution and mainly on comfort of the school ambiences.
For this reason, beyond any other consideration, restoration of the out dated architectural heritage of school building in Italy should be the primary goal in the next future of the central and locale public administrations.

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