Eco-efficient and sustainable settlement experimentation in Mediterranean housing

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ABSTRACT

Settlement experimentation in Europe is currently characterized by the attempt to promote energy efficient and environmentally sustainable housing in an evolutionary, organic and integrated sense; this approach could become a guiding tool for the transformation of the built environment, the latter consisting in the development and construction of an urban environment that shows sensibility towards ecological-environmental issues and social ones.
The focal points of such research experiences are housing projects built in Northern and Central European countries; the latter being very interesting projects that have become models for the rest of EU countries, showing what can be achieved in the contemporary experimentation field. In respect to these study cases, now all we need is to find ways to transfer the acquired knowhow in Mediterranean countries and therefore to adapt the new sustainable strategies to the Mediterranean climate. In this framework the paper wishes to offer an exploration on a research case study, carried out in central Italy, dealing with the evolution of a Mediterranean sustainable development.
The proposed settlement has the aim of addressing the above mentioned issues and reinforcing the progressive awareness that we need, in order to invert the processes and systems of energy consumption and power supply, but also to start applying passive heating and cooling technologies again, for these solutions guarantee an eco-efficient urban development. The settlement experimentation carried out in the presented research represents an attempt to transpose into architectural and urban terms the potential that lies within the local cultures and in the sustainable use of Energy resources.

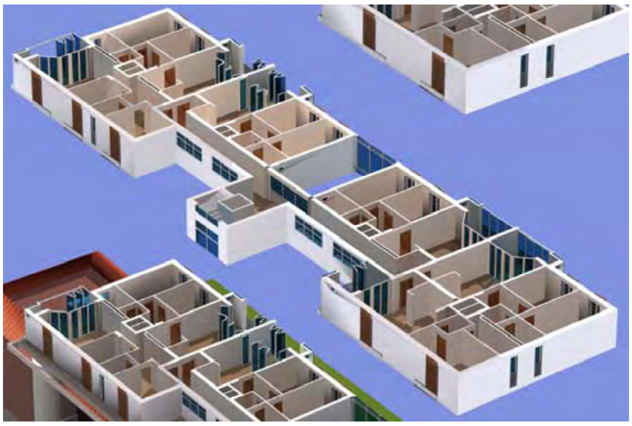
1. INTRODUCTION

In recent years the debate concerning the construction of new dwellings – in particular social housing dwellings - has become a major issue in Europe, and in Italy, although it is still failing to reach the number of social dwellings expected by other nations, such as Holland and England, who have proven to be more sensible towards this topic. Moreover the renewed interest towards Housing has acquired the new enriching aspect of energy efficiency, regulated by two important European Directives in the last ten years: the EPBD 2002/91/EC on Energy Performance of Buildings and the EEE-ESD 2006/32/EG Directive on Energy End-use Efficiency and Energy Services.
In this logical framework the ever increasing global energy demand and the environmental problems that emerge, which are intrinsically linked to the city, have generated numerous methodological tools aimed at an environmentally sustainable and energetically efficient design in Northern and Central Europe; this gave birth to a sustainable architecture, with recognizable traits, that takes into account the complexity of the urban built environment. Such a complexity ranges from central urban structures to peripheral ones, down to the building itself, the building skin and the building's HVAC system, following an integrated design approach that applies passive and active technologies with the aim of optimizing comfort through minimal energy consumption and CO_2 emissions.
At an European level the European Commission has recently decided to focus on the housing sector due to its high savings potential, considering that social dwellings account for 35 million dwellings

on a European scale and for around 18% of total energy consumption in the European Union housing sector.
This kind of approach urgently requires a specially formulated design process, aimed at Southern Europe, to avoid the mere tout court transfer of the knowhow acquired in central and northern European contexts – the latter contexts having been committed to the eco-efficiency topic for a long time – focalizing the energy savings strategies mostly on cooling and natural ventilation. The approach also requires adequate tools capable of implementing a new Mediterranean housing market, energetically efficient and low cost, in order to reach the objectives set by the EC SET-PLAN, involved in facing the worldwide climate changes, between 2020 and 2050, to produce quality urban settlements, with low energy consumption, zero emissions and all of the above at low cost, as effectively synthesized in the “Low Energy - Low Cost” motto.

2. SUSTAINABLE SETTLEMENT EXPERIMENTATION IN MONTEROTONDO

The housing complex analyzed in this study is located in Monterotondo, a town 20 km to the North-East of Rome and it is the result of a careful design based on the application of bioclimatic strategies for the achievement of the greenhouse gasses emissions’ reduction and energy savings objectives – in relation to cooling and heating – in line with the Kyoto protocol. To this extent a careful integrated study of the energy, environmental and financial aspects has been carried, in order to identify the most effective strategies to reduce primary energy consumption and greenhouse gas emissions, always trying to keep the construction costs low.
The building is composed by 18 bioclimatic residential social housing dwellings in the Monterotondo town, located at the bottom of a hill side, it has a rectangular block shape with a side ratio equal to ¼, taking advantage of the natural slope of the site. The building block has four floors, one basement with the garage and three floors above ground which add up to 2.392 m^2 of residential surface divided in 18 dwellings (six for each floor).
The net surface area of each residential floor is around 600,00 m^2 , including the stair shaft and the distribution hallways.



The dwelling layout types of the eighteen units are the following:

- Twelve dwellings with 74,00 m^2 net floor area, divided into living room/dining room/kitchen, two double bedrooms and a bathroom;

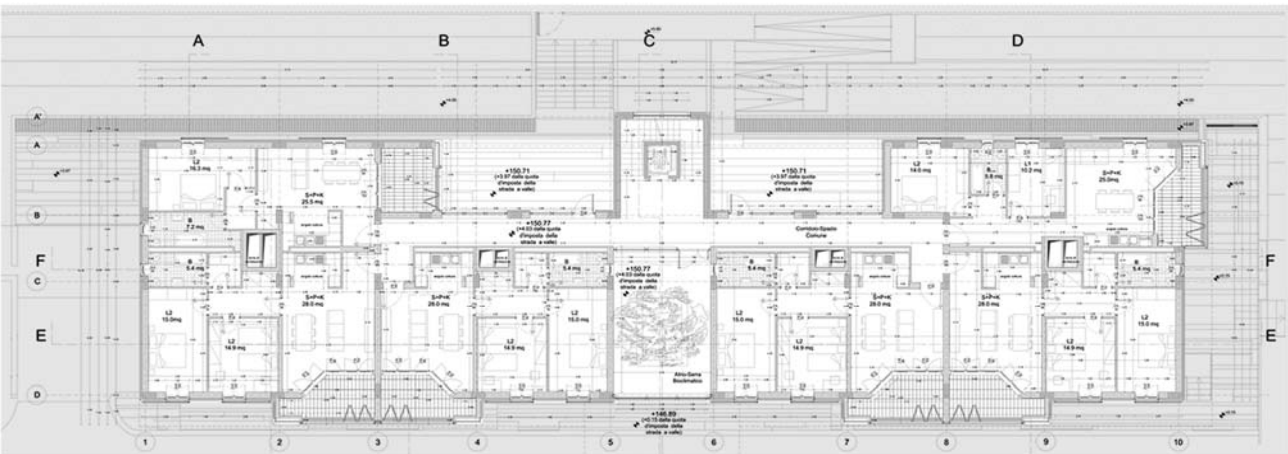


Figure 1-2. Building block 3d model and floor plan example

- Three dwellings with 54,00 m^2 net floor area, divided into living room/dining room/kitchen, one double bedroom, one single bedroom and a bathroom;
- Three dwellings with 61,00 m^2 net floor area, divided into living room/dining room/kitchen, one double bedroom and one bathroom.

The vertical connections are guaranteed by a single block containing the staircase and the elevator located centrally on the northern façade; whereas horizontal connections are guaranteed by a glazed linear hallway system. The functional layout of the building and the dwelling's interior distribution system have been defined following the best possible sun and ventilation exposure, favoring south-west facing living rooms/dining rooms and bedrooms and north-east facing accessory spaces, distribution hallways and shafts. The aspects related to energy efficiency were crucial during the various design phases and, in particular, during the construction phase, in fact, due to the extremely low construction cost (2.217.228 euro for 2.392 m^2), the design strategy has been targeted towards simple, but still effective and efficient, passive control devices. Special attention has been paid towards 4 passive bioclimatic devices and one active device; these devices contributed in achieving optimal energy performances which have already been verified by simulation software – EnergyPlus – but they will also be monitored and controlled from June 2010 – when the construction phase will end – and for the following 5 years.

3. LOW ENERGY LOW COST BIOCLIMATIC STRATEGY

From a cooling point of view are three passive bioclimatic devices characterize the project: 1- Four ventilation towers connected to a series of outdoor "buried earths pipes", that guarantee passive ventilation and cooling to the dwellings. During summer the primary air mass is extracted form the exterior and is then channeled underground through buried earth pipes where it is thermally pre treated through radiation exchange with the ground that cools it during summer and heats it up during winter. The pre-cooled or pre-heated air is then introduced in pre-mix chambers and, at last, it is channeled towards the ascendant input ducts where it is distributed to the different rooms.

Figure 3. Cross sections showing the ventilation systems

Moreover the ventilation towers house the ducts that extract and expel the stale air and, therefore, they are 3 meters taller than the building's roof structure. In the specific, the ducts of the ventilation towers have been buried for a 30 meter extension; these ducts convoy in a series of concrete manholes located at the bottom of the tower in the floor slab against the ground, these elements house the vacuum engine connected to the buried ducts' sockets. The walls that house the intake and

exhaust chambers are made of monolithic cellular conglomerate blocks. Intake and exhaust nozzles with regulation shutters have been installed in each apartment.
An air extractor and a centrifugal ventilator have been installed on the roof.
2- The double height greenhouse hall located centrally in respect to the building, which contributes to the passive accumulation during wintertime and to cross ventilation during summer; together with the stair shaft it becomes some sort of ‘cut’ within the building volume with a double function: in winter the greenhouse-atrium will be clad by a glazed exterior surface, made by movable glass louvers – low E double glazing elements – and small window heat resistant frames that will accumulate heat through he air mass thanks to the greenhouse effect; the hot air will be distributed in the dwellings through the plenum located above the distribution hallways, contributing to passive heating. During summer the skin of this hallway is completely open, with all the glass louvers rotated to favor natural ventilation - thanks to the difference between indoor and outdoor pressure; the ventilation is also favored by intake gaps at each floor near the distribution hallways, where the air mass can move longitudinally.
3- The sun lodges contribute to winter passive heat gain in winter and cross ventilation in summer, just like the bioclimatic hall. There is a lodge for each dwelling. During summer they are open to ensure direct ventilation access and shading thanks to the overhang of the floor slab; in wintertime, a system made of vertical glazed folding partitions that guarantee thermal heat gain when closed through greenhouse effect and transmit heat to the neighboring rooms (living room, dining room and kitchen) in a direct way.
The greenhouse behavior in the winter configuration is backed up by a series of Trombe Walls, one for each greenhouse, whose high heat gain capacity through the exterior glazing/intermediate air chamber/interior absorbing wall system is capable of increasing – despite their contained dimension (about 1,2 meters long and 40 cm thick) – by almost 50% the passive energy efficiency of the greenhouse system with which they are integrated.

Figure 4. Building block façades

4. BUILDING ENERGY SIMULATION

The building's behavior, as previously mentioned, has been simulated through the analysis of a thermal/physical model processed by the EnergyPlus software. This analysis refers to a one year period of time, and it is therefore based on climatic conditions and use trends considered the most probable ones to occur during an actual year.

Moreover two days in extreme climatic conditions are considered in the analysis. The latter reproduce similar conditions to the ones used when designing HVAC (heating, ventilation and air conditioning) systems, considering extreme environmental conditions in a stationary regime for the winter and in a variable one for the summer.

The results shown by the simulation are valid within the limits imposed by the model which includes:

- the description of exterior environment (atmosphere and soil) through the available climate

TABELLA 1 — RIEPILOGO DEI VALORI CLIMATICI REGISTRATI DURANTE LA SIMULAZIONE

	Temperatura media a bulbo secco [C]	Temp Max a bulbo secco [C]	Temp Max a bulbo secco [Registrata il]	Temp Min a bulbo secco [C]	Temp Min a bulbo secco [Registrata il]	Umidità Relativa [%]	Velocità del vento [m/s]
Gennaio	7,63	20,00	31-JAN-12:00	-2,00	06-JAN-06:00	80,57	3,03
Febbraio	8,04	19,60	27-FEB-13:00	-4,00	11-FEB-06:00	78,24	3,40
Marzo	10,17	20,60	31-MAR-13:00	-2,80	13-MAR-05:00	71,17	3,18
Aprile	13,02	22,40	19-APR-13:00	2,90	09-APR-04:00	73,98	2,93
Maggio	17,18	27,20	14-MAY-12:00	8,00	09-MAY-00:00	73,51	2,18
Giugno	20,98	33,40	28-JUN-12:00	12,40	17-JUN-03:00	74,46	2,41
Luglio	24,18	35,00	17-JUL-15:00	14,20	12-JUL-03:00	63,16	2,64
Agosto	23,96	35,10	07-AUG-11:00	14,70	25-AUG-04:00	70,22	2,35
Settembre	21,15	32,00	08-SEP-13:00	12,80	23-SEP-05:00	73,36	2,29
Ottobre	16,02	25,00	03-OCT-13:00	6,80	31-OCT-23:00	78,87	2,50
Novembre	12,41	21,40	04-NOV-15:00	0,80	17-NOV-06:00	81,73	3,25
Dicembre	8,43	16,80	01-DEC-15:00	-2,40	31-DEC-09:00	81,22	3,07
Media Annuale	15,31					75,01	2,76
Min Valori Mensili	7,63	16,80		-4,00		63,16	2,18
Max Valori Mensili	24,18	35,10		14,70		81,73	3,40

Figure 5. Table with the summary of climate data registered during the simulation

Elemento \ Caratteristiche		Spessore [m]	Condutt. [W/(m*K)]	MassaVol. [kg/m³]	Cal. Spec. [J/(kg*K)]
Coperture Appartamenti e Distribuzione	acciaio zincato	0,0015	80	7.450	425
	fibra di cellulosa	0,160	0,400	840	150,7
	laterocemento	0,230	0,800	1.000	880
Coperture Serra	fibra di cellulosa	0,120	0,400	840	150,7
	cls di argilla espansa	0,080	0,390	880	1.200
	pannelli di fibre di legno	0,020	0160	900	800
Pareti Esterne	intonaco di cemento e sabbia	0,030	0,900	1800	910
	fibra di cellulosa	0,120	0,400	840	150,7
	laterizio	0,300	0,590	1.600	840
	intonaco di calce e gesso	0,020	0,700	1.400	1.700
Pareti Piastre Termiche (coeff. assorbimento strato esterno: 0,85)	laterizio	0,100	0,590	1.600	840
Pareti Interne	intonaco di calce e gesso	0,020	0,700	1.400	1.700
	laterizio	0,150	0,590	1.600	840
	intonaco di calce e gesso	0,020	0,700	1.400	1.700
Solaio piano terra	laterocemento	0,230	0,800	1.000	880
	fibra di cellulosa	0,080	0,400	840	150,7
Solai Interni		0,300	0,800	1.000	880
Solaio piano seminterrato*		0,300	0,800	1.000	880
Vetri**		0,004	0,900	-	-
Vetri interni serra e Piastre di accumulo termico		0,004	1,000	-	-

Figure 6. Table with the thermophysical characteristics of the construction elements

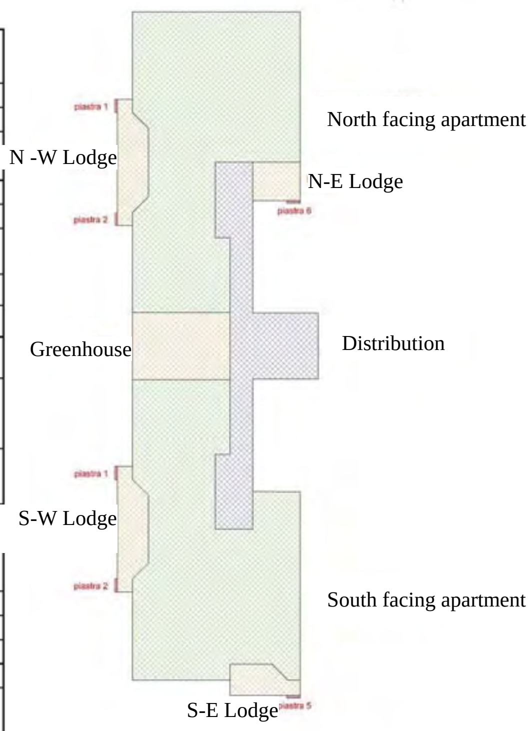


Figure 7. Diagrams showing the thermal zone layout

data for Rome-Ciampino. The climate data registered during the simulation is summarized in table 1.
- the physical-geometric description of the building through thermal zones, exchange surfaces, gain masses, openings and shading surfaces. The identified thermal zones are schematically presented in figure 1;
- the description of construction elements through their thermophysical properties, as specified in table 2;
- the description of indoor thermal loads caused by lighting, home appliances and kitchens, according to intensity and use;
- the description of thermal loads caused by people and their conditions in relation to the activity they are undertaking, the clothes they are wearing, their number and the time schedules;
- the description of air flow that occurring between the building and the exterior space and between the different zones.
By law the minimum air exchange (0,5 vol/h) have been doubled between 7:30 and 23:30 in order to improve indoor comfort conditions.
The air introduced in the apartments comes form the buried ducts, the lodges and window infiltrations.
Natural ventilation caused by opening the windows is calculated considering a 10 vol/h air exchange with all the windows open and modifying this value according to the most likely behavior of the occupants; the windows are partially opened in the warmest periods of the day in winter and closed when the outdoor temperature reaches the highest values in summer, when they must be shut anyway because the air conditioning is in function. In the greenhouse and in communal spaces the exterior windows are always considered closed in winter and open in summer.
The greenhouse has been considered in direct contact with the communal connection spaces during the daytime in winter, when these areas need to be heated.
- the description of the buried ventilation ducts through their capacity, their geometry and thermophysical characteristics;
- the description of the shading devices that protect glazed surfaces;
- the description of how the HVAC systems work.
The model was then tested in different conditions:
- *Solution 1: Building without HVAC systems*. This first condition is meant to verify passive system's behavior without considering the contribution of HVAC systems;
- *Solution 2: Integrated control.* Building's conditions are tested in the presence of an integrated environmental control between passive systems and active HVAC systems;
- *Solution 3: Building without bioclimatic systems.* These simulations measure the Energy savings obtained by using bioclimatic systems.
The HVAC systems have been modeled as a theoretical system, considering an efficiency equal to 1, that feeds the energy needed to maintain the rooms in the imposed climatic conditions, operating on the air and without considering distribution circuits; all the air conditioning consumption rates are referred back to this system.
In addition to the energy consumption needed to feed the building, the indoor and outdoor thermohygrometric conditions and people's comfort levels have been calculated. The more detailed data elaborated and synthesized in the tables and charts (appendixes excluded), are the following:

- absolute consumption for heating systems
- specific consumption for heating systems
- annual and monthly power consumption for lighting
- annual and monthly natural consumption for kitchens
- hourly outdoor air temperature
- hourly outdoor air relative humidity
- average hourly radiant temperature in every zone
- hourly operating temperature in each zone
- hourly indoor air temperature for each zone
- hourly indoor air relative humidity in each zone

- hourly people's PMV in the 2 zones occupied by the dwellings

The hourly data is expressed also through statistics on different time basis.

5. ANNUAL ABSOLUTE AND SPECIFIC CONSUMPTION

Specific Consumption	Without buried pipes	With buried pipes	Savings
Heating [kWh/m²]	21,26	16,78	21,07%
Cooling [kWh/m²]	19,01	15,98	15,92%
Total Wh/m²]	40,27	32,76	18,64%

Figure 8. Table showing the specific consumption data

Following up we are reporting the data related to the annual consumption values.

It is important to remember that air conditioning consumption values are not referred to real HVAC systems, but to the fictitious ones described in the previously described specifics and that actual consumption values will be different compared to HVAC system efficiency and to distribution circuits' characteristics.

Moreover, as far as the data concerning cooling go, they are referred to a hypothetical HVAC reference system that has the task of determining summer energy gain. As a matter of fact, in the HVAC system design active cooling is not contemplated.

6. THERMOHYGROMETRIC CONDITIONS AND COMFORT

The following table reports the minimum, average and maximum hourly temperature, relative humidity and PM values, registered during the simulation.

Valori Medi ed Estremi

Valori Medi ed Estremi Senza Impianti	Min	Med	Max
Envir: Outdoor Dry Bulb [°C]	-3,96	15,30	35,04
App NORD: Zone Operative Temp [C]	17,46	22,16	27,96
App SUD: Zone Operative Temp [C]	17,07	22,19	28,12
Distr: Zone Operative Temp [C]	9,67	19,64	31,45
SERRA: Zone Operative Temp [C]	7,46	19,86	34,78
Semint: Zone Operative Temp [C]	10,59	19,16	28,65
LOGGIA NO: Zone Operative Temp [C]	7,34	20,22	38,22
LOGGIA SO: Zone Operative Temp [C]	7,93	20,34	37,91
LOGGIA SE: Zone Operative Temp [C]	10,12	21,64	36,39
LOGGIA NE: Zone Operative Temp [C]	8,16	19,30	33,60
Envir: Outdoor Relative Humidity [%]	17,13	75,00	100,00
App NORD: Zone Air Relative Humidity [%]	15,92	53,47	86,97
App SUD: Zone Air Relative Humidity [%]	15,02	53,33	86,11
Distr: Zone Air Relative Humidity [%]	16,53	59,31	92,95
SERRA: Zone Air Relative Humidity [%]	14,48	60,77	96,38
Semint: Zone Air Relative Humidity [%]	19,52	58,30	86,75
LOGGIA NO: Zone Air Relative Humidity [%]	9,49	61,68	96,01
LOGGIA SO: Zone Air Relative Humidity [%]	9,39	61,05	95,62
LOGGIA SE: Zone Air Relative Humidity [%]	6,45	57,66	94,90
LOGGIA NE: Zone Air Relative Humidity [%]	11,41	62,42	95,93
RESID. Nord: Fanger PMV	-0,94	0,15	1,27
RESID. Sud: Fanger PMV	-0,93	0,16	1,31

Figure 9. Table showing the minimum, average and maximum hourly temperature, relative humidity and PM values, registered during the simulation

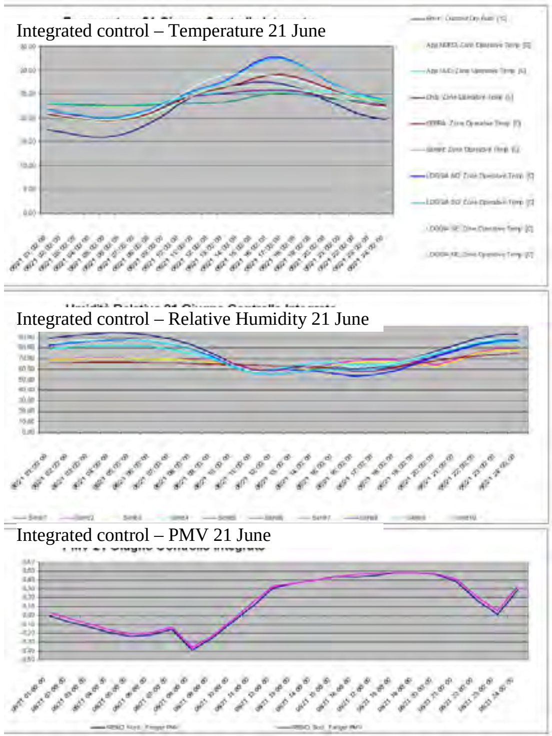


Figure 10-12. The charts describe the outdoor and outdoor thermohygrometric trends during the 21st of June.

Solution 2: building with integrated control

7. BURIED EARTH PIPES

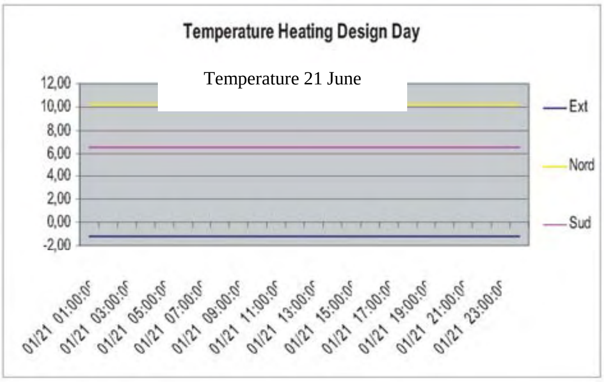
In the following paragraph we describe the behavior of the buried pipes, analyzing temperature trends inside the later during the year and comparing the global performance expressed so far with the ones of the building without these elements.

Diameter [m]	0,35	Portata [m^3/s]	0,078 (x6)
Thikness [m]	0,0087	Air speed [m/s]	0,8
Average length [m]	Nord:57(x3); Sud:30(x3)	Ventilation	forzata
Diameter [m]	2	Condutt [W/(m*K)]	0,35

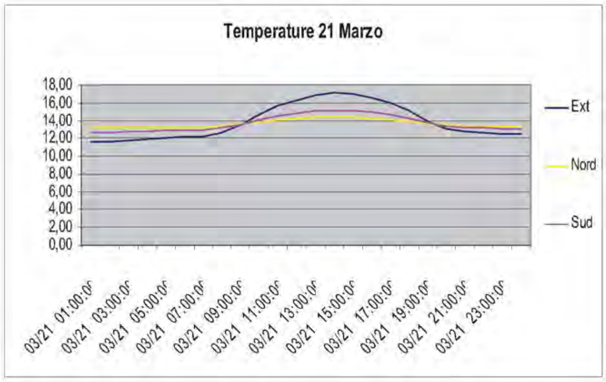
The comparison will allow us to quantify their actual contribution and the resulting savings, giving useful elements for the evaluation of financial convenience. The characteristics and the performance of buried pipes, already described earlier on, are synthesized in the following table and charts.

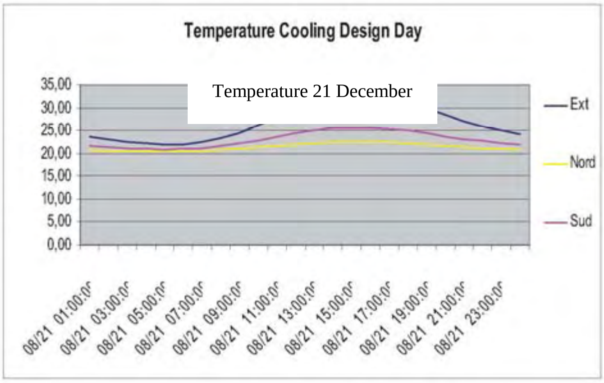
The charts c Temperature 21 March or air temperature trend and the behavior of the air introduced in the building through the pipes during the usual six days commonly used to synthesize the annual behavior.

In order to estimate the energy savings produced by buried pipes, a building without these elements and with the same ventilation level was analyzed (the air exchange is introduced directly from the exterior space). It is

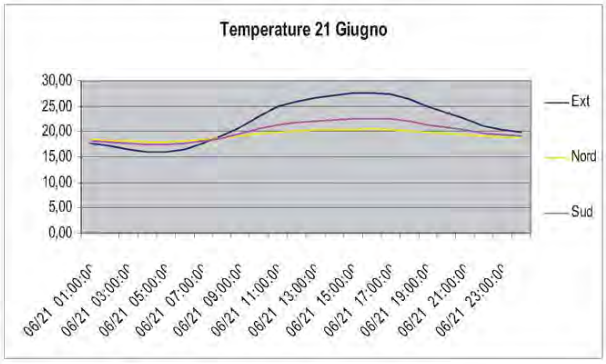


Temperature 21 June

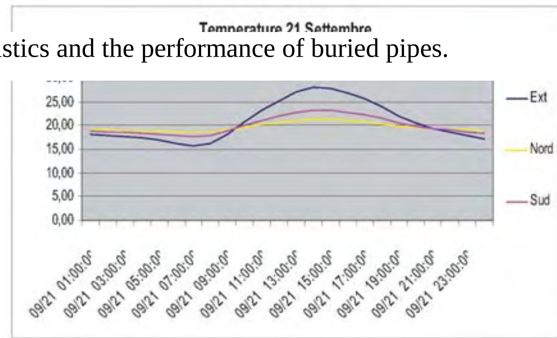


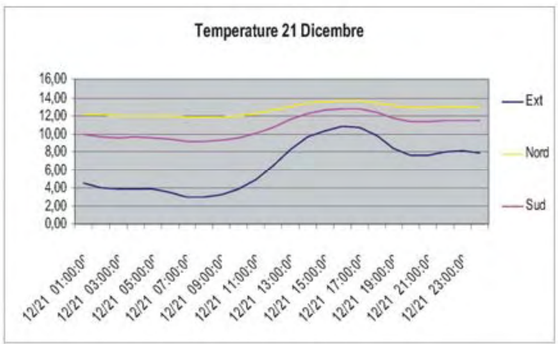


Temperature 21 December



the characteristics and the performance of buried pipes.





important to remember that the air exchange rate is superior to the minimum standards set by the law and, therefore, the estimated savings appear to be higher than we would have obtained a conventional ventilation system. Nevertheless, the adopted system guarantees a more elevated comfort and health standard in the rooms.

The savings appear significant, but they are not the same for both the apartment blocks because the respective pipes are not the same length: in the winter condition the disadvantage shown by the northern dwellings is entirely compensated and the consumption levels appear even lower than the levels in the south facing dwellings; in summer the difference increases, again, in favor of the Northern building block.

5. CONCLUSIONS

The building's overall Energy performance was good, the estimated consumption for heating is equal to 16,78 kWh per m² of conditioned area, and the one for cooling is equal to 15,98 kWh/m².

The passive behavior alone guarantees acceptable comfort conditions for more than 90% of the time, whereas optimal conditions are registered during about 65% of the yearly hours.

The introduction of the HVAC systems definitely improves the wellbeing of the people: with an environmental control integrated between HVAC systems and passive systems, working all year long, the discomfort time would be reduced under 0,3 % of the total, with optimal conditions during 80% of the time in the entire building.

The contribution of buried pipes guarantees 21% savings on heating and almost 16% on cooling, with benefits extended to the entire year. Moreover, the greater length of the ducts that reach the apartments on the North, uniforms winter consumption of the two sides, canceling the disadvantages caused by orientation. During the summer season the imbalance is amplified, penalizing the dwellings facing the south.

Sun systems reduce heating consumption by 30%, whereas they cause a slightly worse condition (2,2%) during summer. The overall balance is therefore extremely positive, even though the worse condition shown during summer could be relevant if there were no air conditioning systems at all.

To conclude we could say that the building is capable of guaranteeing a good comfort levels with contained consumption rates, although in summer, without air conditioning systems, discomfort situations can occur frequently: during the three summer months the acceptable levels could be surpassed for 30% of the hours, but the worse problems (PMV>2) concern less than 1% of the time. The simulation assumes that the occupants regularly use shading devices and, if this were not the case, the disadvantages due to the heat could get worse.

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