Technologies for natural cooling in the experimentation of eco efficient housing in the Mediterranean

F. Tucci
Dept. DATA Design Architecture Technology Environment,
Università degli Studi di Roma "La Sapienza", Via Flaminia 70, 00196 Rome, Italy

ABSTRACT

The main objective of the present study is to evaluate the design strategies applied in the redevelopment of a housing estate located in Southern Italy, in Puglia - more specifically in Lecce's Province, aimed at optimizing three aspects: the improvement of summer thermal comfort conditions, the overall energy saving and the reduction of CO2 emissions into the atmosphere.
The core hypothesis that justifies this kind of experimentation, can be found in the consideration that currently the housing sector represents the privileged interface for environmental design experimentation oriented towards passive cooling and energy saving in the Mediterranean area; the difficult task it has to accomplish is to set a good example for the undertaking of a correct and responsible behavior towards such topics and to become a virtuous reference model that demonstrates to the designers and, most of all, to the people who will be inhabiting the houses, the possibility to apply "good practices" in the attempt to enact principles that are not easily manageable and implementable.
From a methodological point of view such a research branch is completely projected towards the role that architectural design should undertake in regards to what we could consider as the core matter that needs to be addresses and solved in territorial, urban and architectural realities in the Mediterranean area: passive cooling and the use of natural ventilation, in particular, in the design of exterior, intermediate and interior spaces and in the design of their technological components and devices.
The main strategy adopted by such a design setting is the integrated standardization of the different technological passive systems that are available to us today, aiming at the improvement of the results from an energy and bioclimatic point of view, as an outcome of the joint effort of the devices applied in the project.

1. INTRODUCTION

The contemporary project aimed at the rehabilitation of the vast housing estate patrimony cannot avoid confronting itself with matters concerning environmental sustainability and energy efficiency on one hand, and the monitoring of constructive feasibility and the effectiveness of the project actions on the other hand. An occasion to experiment approach strategies to solve the above mentioned double aspect of the problem has been offered by the renewal project of a housing estate in Southern Italy, where the aim is to apply a systemic and integrated series of passive and active technological devices aimed at obtaining a consistent improvement in the energy efficiency standards of the estate, a strong reduction of heat consumption, an improvement of the bioclimatic comfort and an increase of the overall ecological efficiency, while respecting technical and technological feasibility and keeping in tune with the typological-morphological traits of the location that the projects intends to emphasize.
During the last years the debate about renovation, renewal and retrofitting operations acted upon the housing patrimony is experiencing a new awakening wave all around Europe, to a lower extent also in Italy, without being able to reach the number of renewal actions realized in other nations which show a higher degree of sensibility towards this topic. Moreover, the renewed interest shown towards the innovative conveying of housing estate redevelopment has grown to include the contemporary aspects of eco efficiency and environmental sustainability, ordered during the past ten years by three major European Directives: the 2002 EPBD Directive, the 2006 EE-EEI Directive and the most

recent 2010 EPBD; key matters, that had never been dealt with in the past in relation to the housing theme, mostly because of the limits in the applicability and transferability of many morphological-technological solutions adopted in other climatic zones to the Mediterranean area and to Italy.
The design approach that we are about to illustrate, which we have been undertaking in the last years, in the field of several experimentations, is based upon a double research action: on one hand through the controlled application of simple technologies from a construction point of view, but also efficient and effective from a performance point of view, and on the other hand through an integrated standardization of the numerous devices applied; for both cases we believe that the overall thermodynamic and fluid dynamics behavior needs to be simulated from the very first stages of the building's or housing estate's renewal project concept.
Such a methodological setting has led to the consideration of traditional elements' rehabilitation form a point of view that goes beyond the purely formal aspects that characterize them, aiming at the definition of their technological potential from a contemporary point of view. An example of this approach can be offered by the old tanks and the cave considered as part of an advanced plant system or the re-proposition of a traditional artistic (but at the same time functional to the design requirements) wind chimneys working for the exhaust air extraction system, based on the use of existing smokestack.

2. THE EXPERIMENTATION IN A LOW-ENERGY RESIDENTIAL CASE STUDY

The case study we are presenting is geographically and climatically located in the southern part of Italy, in Puglia - more specifically in Lecce's Province, characterized by a warm and temperate climate. It consists in the redevelopment of an ancient housing estate located close to the old town centre, aimed at improving the environmental quality, thermal and moisture comfort, the natural cooling conditions and the overall energy balance.
The architectural project is by S. Dierna and V. Cecafosso, the energy-bioclimatic one by F. Tucci and F. Cipriani, where Tucci worked on the passive bioclimatic aspects, Cipriani on the active systems; M. Cimillo led the simulations with Energy Plus software.

2.1. The environmental microclimatic context and the lighting and ventilation characteristics

Temperatures
The project site presents a mild climate, characterized by low temperature ranges during the year, with lowest temperatures that never go below 8°C and maximum ones that stop at 29°C. The relative humidity levels reach medium-high levels during the entire year period, with average values that range from 69 to 79%.

Aver. T month.	Tlow (°C)	Tmed (°C)	Tmax (°C)
January	**8,0**	10,0	12,0
February	**8,0**	10,5	13,0
March	9,0	11,5	14,0
April	11,0	14,0	17,0
May	15,0	**18,0**	21,0
June	19,0	22,0	25,0
July	21,0	24,5	28,0
August	22,0	25,5	**29,0**
September	19,0	22,0	25,0
October	16,0	18,5	21,0
November	12,0	14,5	17,0
December	9,0	11,5	14,0

Figure 1. Monthly average temperatures in Salve, Lecce

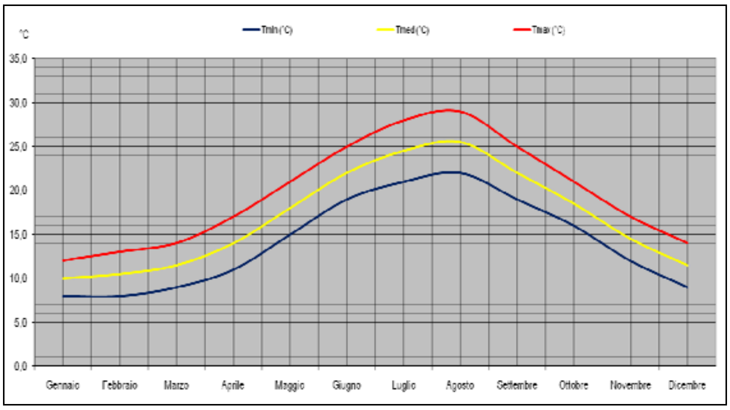

Figure 2. T comparative yearly trend in Salve, Lecce

Ventilation

Ventilation is characterized by the alternation between weak breezes coming form the south-west quadrant during spring and summer and by stronger currents coming from the opposite direction during autumn and winter. The average wind speed is 4 meters per second and they are considered adequate to install a micro wind turbine, from which we can expect a production, concentrated mostly in the winter period, equal to at least a 0,3 kW peak.

Prevailing Winds (direction-m/s)		
January	N-NE	4,4
February	N-NE	4,4
March	S	4,4
April	S	4,4
May	WSW	2,6
June	SSW	2,6
July	SSW	2,6
August	WSW	2,6
September	WSW	4,4
October	N	4,4
November	N	4,4
December	N	4,4

Figure 3. Prevailing winds' monthly average direction and speed in Salve, Lecce

Relative humidity and precipitation

Relative humidity varies during the year between a minimum value equal to 68% in July and a maximum value equal to 80% in November and December. Precipitation is concentrated during autumn with a yearly total of 615 mm. This value translates into 253 cubic meters of rain water on the waterproof surfaces of the area, from which is possible to obtain around 180.000 lt. of water that can be reused for compatible uses, such as green area irrigation, car wash and paving wash, water for air conditioning and toilet flushing.

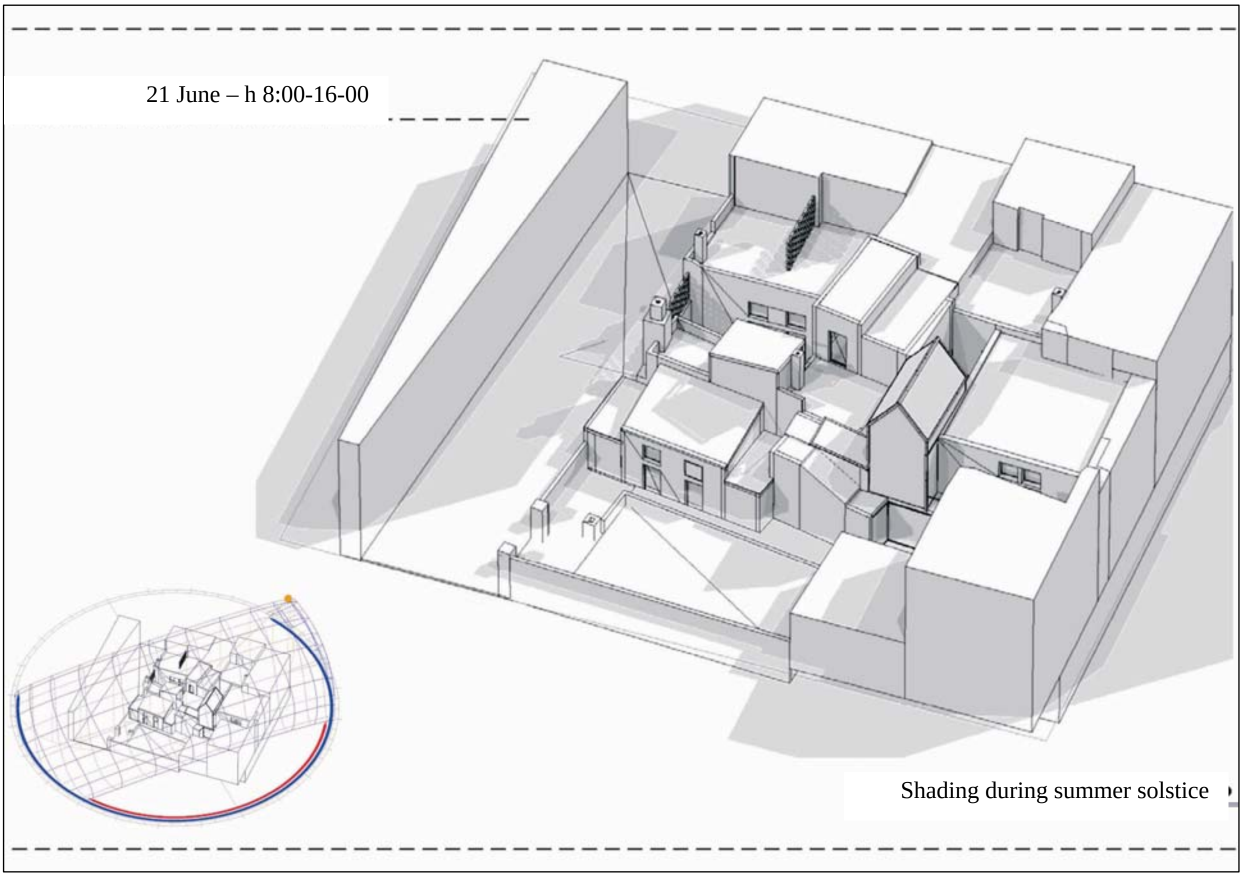

Figure 4. Axonometric view of the housing complex with shading trend during summer solstice

2.2. Passive strategies adopted in the housing complex

The overall working of the passive bioclimatic system, that is perfectly integrated with active systems, is based on a standardization of innovative and traditional technological devices fully integrated with existing structures and with new construction components, with the ambitious aim of transforming this redevelopment and retrofitting project applied to the examined case study a model for sustainable environmental design, effective from the ecological compatibility and bioclimatic comfort point of view, and highly efficient in regards to passive management of energy aspects.

From a bioclimatic point of view the yearly behavior of the housing complex is organized in a series of strategies and related integrated devices that, even if operative all year long, have different behaviors and performance in the hot and cold period.

Both in summer and winter, there are a series of air intakes that catch prevailing winds, channeling air in three different sub systems: the buried horizontal air ducts integrated with ventilgeo mini plus, the buried vertical air ducts ventilgeo 500 and the existing tank that is reused and integrated by means of an appropriate vertical air duct located inside.

This set of ventilation ducts triggers a thermal exchange between air and soil mass that, in its different forms, cools the air in summer and produces heat during winter. In this way the preprocessed air is then channeled in a plenum and introduced - with the support of a integrative fan, which only works if there is not enough speed – in the large underground space that is already constantly at a lower temperature in summer and a higher one in winter compared to the exterior temperature, thanks to its shape and characteristics. From this large air basin, the underground space, the air quantity needed for the necessary fresh air intake in all the rooms of the housing complex is regularly drawn, using, again, ducts and wind chimneys that distribute the thermally pretreated ventilation to all the rooms. In the end there is a recovery of air from all the interior spaces through the bioclimatic reuse of existing chimneys, integrated with two new ones in the new extension of the house; these chimneys expel thanks to the ascending motion of the Venturi effect. The winter condition is solved by adding a bioclimatic greenhouse that, thanks to the greenhouse effect triggered by its glazed vertical cladding system exposed to the south-eastern and south western sun and to the sloped roof oriented towards south-east, produces warm air that is used for fresh air intake in all the rooms of the housing complex, as an integration of the air produced by the above mentioned air duct system. During summer the greenhouse cladding system is integrated with an shading device system formed by highly reflective sliding tents; moreover, some parts of the cladding can be opened, favoring cross ventilation that lowers air temperature and allows for the hot air to be expelled from the indoor spaces towards the outdoor space.

.

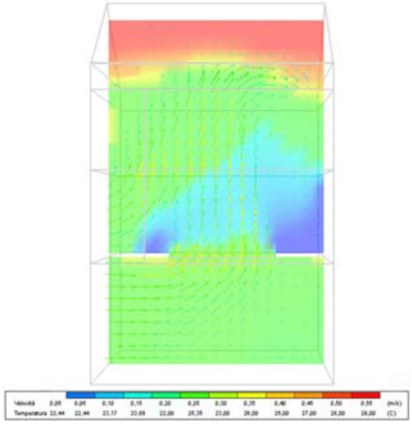

Figure 5. The longitudinal cross section on the main volume of the green house shows, by means of a vector representation, the direction and speed of the air flow all around the space. The colors are associated with the air temperature distribution. The image shows the summer condition, with the cladding partially open and the wind coming from south-west (from the left in the image). The combined effect of wind pressure and convective movements generated by the air coming in contact with interior surfaces, produce an entrance flow predominantly from the lower openings in the windward side and an exit flow from the higher openings on the opposite side. The air movement involves the entire volume, guaranteeing a good level of air exchange in all the zones. [simulation led in a typical day in June]

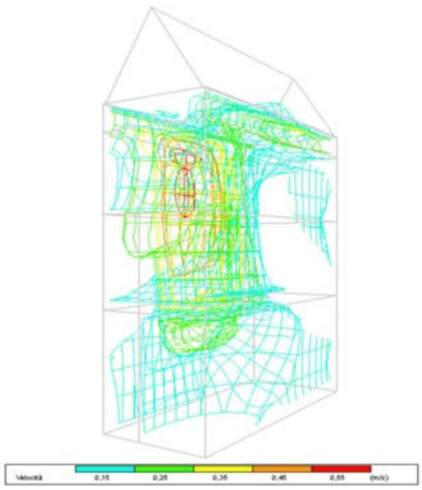

Figure 6. The image shows the three-dimensional surfaces affected by the air speed variations. The speed values recorded during the simulation are moderate and the maximum values are reached in the double height space. In this area the air flow doesn’t encounter many obstacles and the effects generated by all the forces that produce the air movement are summed up. [simulation led in a typical day in June]

2.3. System of devices related to air mass movement for passive cooling

The system, running all year long, is an efficient and effective tool that guarantees the optimization of the four air mass use phases in the bioclimatic and energy redevelopment project of the housing complex: the first phase consists of the outside air intake, both during summer and winter; the second phase concerns the thermal pretreatment of the air, and its journey through the rooms and the buried air ducts; during the third phase the pretreated air (cooled during summer and heated during winter) is distributed through the ducts and in the rooms; and, at last, the fourth phase when the air is extracted form the rooms and expelled outside.

The passive cooling/heating devices' system that operates through the air mass movement is composed by the following elements:

- *air scoops:* they ketch the prevailing winds all year long, both during the summer extreme condition, when the outside air temperature is high, and winter, when the outside air is cold. The air intake system, with air scoops located 2-3 meters above the ground level, introduces the captured air in the systems;
- *earth pipes:* they consist of polyethylene piping in direct contact with the ground, located 2 meters underground. The ground temperature, reaching a value close to the outdoor air yearly average temperature (about 17° C), is used to lower the difference between indoor air and the air introduced in the interior spaces, by means of a thermal exchange through radiation between the air in the ducts and the ground's mass;
- *Ventilgeo mini plus*: it works just like earth pipes, but the thermal Exchanges are increased by the use of copper instead of polyethylene and by their winged silhouette; 6 meters stretches of ventilgeo mini plus are used in the 9 meters long horizontal paths of the above mentioned earth pipes;
- *Ventilgeo 500*: it works like the previous element but it is buried in the vertical position, as a consequence the air introduced reaches a depth of 9 metes. The air is free to go up and down thanks to the coaxial shape of the duct;
- *existing tank* : it is shaped similar to the ventilgeo 500, although in this case the exchange surface is constituted by the rocky surface of the reservoir; in the project configuration the tank houses a vertical duct that is placed along the main axis of the tank itself in order to trigger a behavior that cools the air during summer and heats it up during winter, always due to the thermal exchange with the surrounding rocky soil mass, through radiation;
- *compensation plenum*: this is where the three kinds of ventilation ducts merge, the ones that lie horizontally 2 meters underground integrated with the ventilgeo mini plus, the ones which are also horizontal and buried underground, but closer to the surface and deriving from the vertical ventilgeo 500, and the ones, again horizontal and buried, but located closer to the surface than the first ones; all these elements merge in a plenum from where a duct that c pushes the air towards the large underground space originates; only in case of insufficient air movement speed an additional fan will be activated;
- *underground space*: the air that has been treated by all the previous components ends up in this space, that exchanges heat through contact with the cave's walls; it is important to highlight the fact that in the cave the air temperature is itself already considerably lower in summer and higher in winter, and that the set of above mentioned devices triggers air exchanges that further improve both, the temperature level throughout the seasons, and the quality of the air that will be extracted form this space to be introduced in the rooms of the house;
- *air distribution ducts*: a main duct originates from the underground space, this duct leads to a ventilation system joint, centrally located in respect to the volumes of the housing complex, from which the vertical air duct that works as a ventilation tower, with an ascending air movement, originates; thanks to the secondary horizontal duct network located above the floor slabs integrated with the flooring system, the ventilation tower supplies air to all the rooms of the house that need to be heated or cooled;
- *ventilation chimneys*: lastly, the existing chimneys, one for each room, plus two new chimneys that ought to be built in the new extension constructions, are used to extract indoor air and, by

pushing it towards the top, expel it outside, in line with the new passive bioclimatic structure of the housing complex;

- *Bioclimatic greenhouse*: thanks to the greenhouse effect, during the wintertime the *bioclimatic greenhouse* heats part of the air, contributing to the supply of warm air to the above mentioned system, introducing it in the central bioclimatic plenum joint of the house, whilst still being shaded and naturally ventilated during the warm summer season; the *shading* is needed to lower the air temperature by protecting the surfaces form direct incident sun radiation; the *ventilation* is guaranteed by louvers that rotate acquiring the position of the four greenhouse claddings, in order to trigger air movement, thanks to the Venturi effect, and with the double goal of expelling hot air on and lowering the overall interior air temperature through convection.

Figure 7. On the left: Ground Floor Plan, natural intake system and passive air treatment.
On the right: First Floor Plan, air distribution and extraction system.

2.3. System's bioclimatic behavior during the summer and winter

The operation of the devices is regulated according to indoor environmental requirements and the thermal loads at different times of the year. During the heating period the outdoor air is preheated in the underground spaces before reaching the air treatment unit together with the air coming form the bioclimatic greenhouse. Here there is a thermal heat exchange battery (charged by a heat pump located on the roof) that, if needed, heats the air up more before it is directed towards the rooms. The air extraction is operated by existing chimneys and by two new ones, on top of which wind extractors have been installed.

During summer the process is the same, although, in this case, the battery cools the air. The only exception is the greenhouse which is isolated from the circuit and independently ventilated thanks to openings in the cladding system, as specified in paragraph 6. Moreover, the glazed surfaces are shaded by means of light color tents on the exterior surface of the windows. The paths inside the different elements are further explained in the following table.

The effects expected when applying such devices concerns most of all thermal-hygrometric comfort inside the building. The operation of the system is such that we can reasonably expect to meet the expected requirements, for a long period of the year, with minimal energy use, only needed for the elementary movement of air masses. Also when the above mentioned does not occur, the thermal plants cover only the essential requirements that cannot be covered by passive devices, guaranteeing a high degree of energy savings. The advantages will appear quite clearly during the summer season, when the loads are increased in order to exploit the potential that lie within the devices and guarantee an improved indoor air quality.

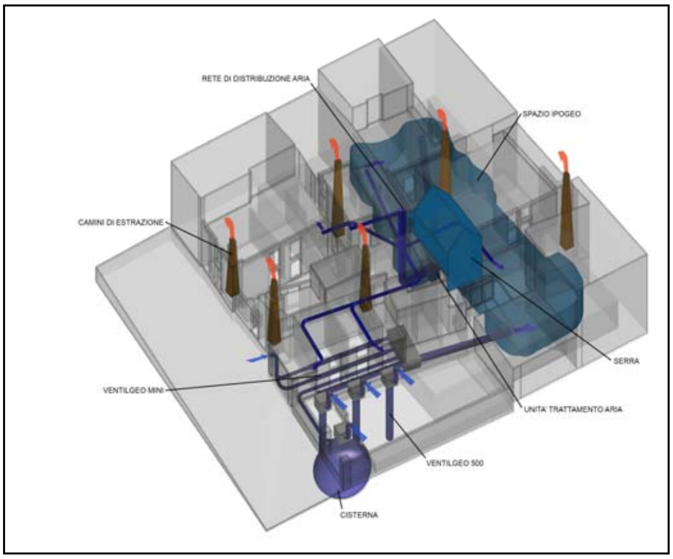

Figure 8. Summer passive bioclimatic system

A.1. Summer passive behavior: **passive cooling through movement and treatment of air masses.**	**A.2 Winter passive behavior:** **passive heating through movement and treatment of air masses.**
1. Primary air origins 1.1. Originated from 3 ventilgeo 500 1.2. Originated from one of the existing tanks 1.3. Originating from 2 ventilgeo mini plus 2. Confluence plenum of the lines where 1 buried duct 2 m deep originates. 3. Access to the buried duct into the underground compensation volume 4. Intake canal on the opposite side of the underground compensation volume 5. Regulation system, injection fan and post heating (cooling) battery charged by a heat pump on the roof 6. Connection of the underground space with: n.7 residential units vestibule space kitchen/dining room 7. Air extraction from the above mentioned spaces through chimneys with passive extractor: n.5 existing n.2 new construction 8. In the green house the air is expelled through high openings on opaque and transparent vertical walls. At the top there will be nebulizers under the sloped roof structure or on the exterior of the glazed surfaces to prevent the air form overheating. On the exterior surface of the glazed surfaces with S-E and S-W exposition a shading device consisting in movable tents will be applied.	1. Primary air origins 1.1. Originated from 3 ventilgeo 500 1.2. Originated from one of the existing tanks 1.3. Originating from 2 ventilgeo mini plus 1.4. Bioclimatic Greenhouses *Greenhouse configuration:* *-glazed sloped roof than can be shaded facing SE and opaque facing NW* *-intermediate glazed sloped roof* *- S-E e S-W facing transparent vertical walls that can be shaded and opened at the top* *- N-E e N-O opaque vertical walls, that can be opened at the top* 2. Confluence plenum of the lines from where 1 buried duct originates, buried 2 m. underground 3. Access of the buried duct into the compensation volume 4. Intake canal on the opposite side of the underground compensation volume, air confluence plenum coming form the greenhouse 5. Regulation system, injection fan and post heating (cooling) battery, charged by a heat pump on the roof 6. Connection of the underground space with: n.6 residential units vestibule kitchen/dining room 7. Air extraction from the above mentioned spaces through chimneys with passive extractor: n.5 existing n.2 new construction

3. BUILDING ENERGY SIMULATION

3.1. Evaluations carried out by means of the Energy-Plus simulation system

The Energy performance of the building-plants system (including in the definition also the passive devices), have been evaluated through dynamic computerized simulations.
In order to obtain verification on passive systems' contribution, we simulated also the behavior of a building identical to the one of the project, but without the described systems: greenhouse, earth pipes, ventilgeo, the tank and cave used for air pretreatment.
The housing complex, passive systems, plants and local climate have been represented, operating the intrinsic simplifications, in a physical model containing all the relevant information.
Such a model has been built taking into account the following assumptions:
- the climate data was drawn from the Santa Maria di Leuca weather analysis station;
- the cladding system follows the design guidelines;
- indoor thermal loads are modeled following the UNI TS 11300 norm;
- the heating season is set between the 1st of November and the 15th of April, the cooling one between the 1st of June and the 30th of September;
- the fresh air intake rate is equal to 0,3 vol/h at night time and 0,6 vol/h during the daytime, throughout the year and excluding the cooling season, when it is set to 3 vol/h;
- in regards to the ventilgeo performance we based our evaluations on the information given by the producer.

The simulation has been carried for an entire solar year, with 10 minute calculation intervals. The results are presented on an annual, seasonal or hourly basis.

3.2. Evaluation of bioclimatic comfort

The comfort conditions in indoor spaces have been evaluated based on the temperatures registered during simulations.
Both the conditioning plant's operation and the ones where environmental control is totally managed by passive systems have been analyzed.

	Optimal comfort	Acceptable comfort	discomfort
Without passive systems	5576	2784	400
	63,7%	31,8%	4,6%
With passive systems	6448	2247	65
	73,6%	25,7%	0,7%

In these time intervals the benefit of passive systems' contribution appears more evident.
The temperatures used in the following diagrams and charts are:
- outdoor air temperature, extracted form the Santa Maria di Leuca climate data;
- Indoor air temperature. Extracted from the simulations, representing an intermediate value between air temperature and the temperature of the surfaces enclosing the space. Referred to the average temperature of air conditioned rooms.

In order to obtain a comprehensive framework of energetic behaviors during the year two temperature intervals have been defined. The first one, that represents optimal conditions, considers temperatures between 20 and 26°C, while the second one, which represents an acceptable condition, includes temperatures ranging from 19 to 27°C. The calculations, recorded in the following table and chart, also report night hours and it is comprehensive of the time lapses when air conditioning plants are not running.

In order to verify more in detail the effects caused by passive systems, a series of representative days have been examined more in depth.
The first two, a cold and a hot one, fall in the plant operational period. It this case it’s possible to record a slight improvement of indoor conditions, even though the plan operation control brings the two conditions close to one another. The devices are, therefore, useful mostly to guarantee energy savings.
The last two days have been chosen in a time laps falling right after the heating and cooling period. In this case the temperature difference is more evident and it proves the systems’ capability to obtain a fair, totally passive, environmental control in moderate climatic conditions.

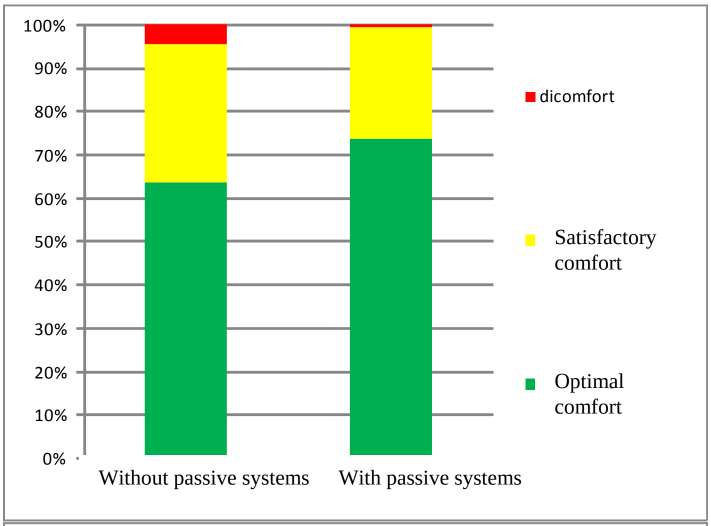

Figure 10. Graphic analysis of percentage comfort degrees reached in one year

The temperature trend during the hottest months of the year, therefore not only during summer, but also during spring and autumn, is shown in the three following charts, which confirm how the contribution of the passive systems used in the hosing complex retrofitting project is quite positive throughout the summer season and beyond, in fact the highest temperature value variations are reached during the intermediate seasons.

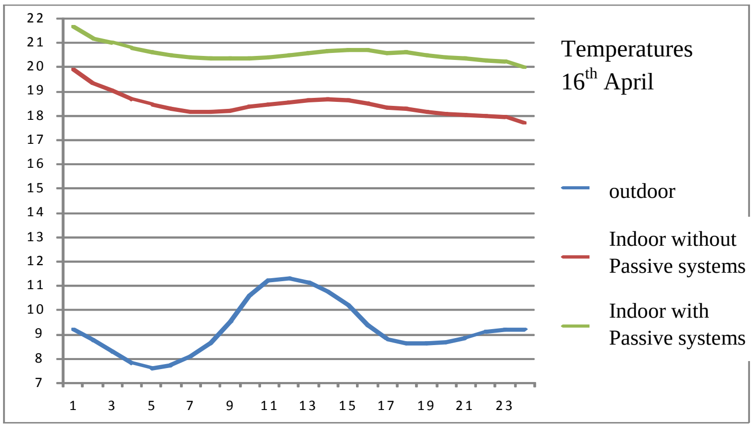

Figure 11. Comparative temperature trend during a typical spring day

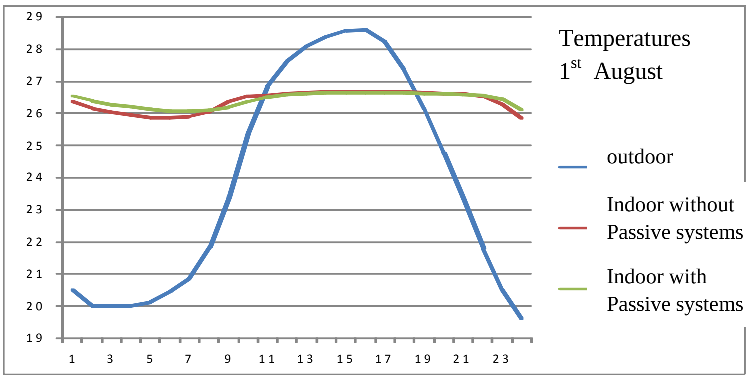

Figure 12. Comparative temperature trend during a typical summer day

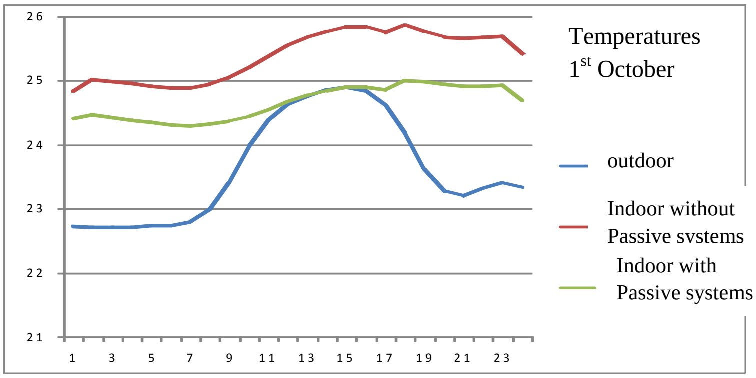

Figure 13. Comparative temperature trend during a typical autumn day

3.3. Evaluation of energy savings

The advantages introduced by passive systems for Energy savings can be summarized in two main aspects: the energy consumption reduction (the values recorded in the following tables are not referred to the final energy consumption, they concern the thermal requirements instead) and the reduction of peak power needed for the thermal plants. The first aspect enables us to have lower building management costs, while thanks to the second aspect it is possible to lower the power needed to keep the machines running, compensating the expenses for the application of the new passive systems. In the following charts and tables we illustrate the outcome of the simulation, which can be further synthesized in three particularly meaningful facts:

- energy requirements are reduced altogether by 65%
- the winter peak power is reduced by 41%
- the summer peak power is reduced by 62%

Hypothesis	Heating	Cooling	Total
Basic solution (kWh/m2 y)	62,29	26,12	88,41
With buried system (kWh/m2 y)	24,62	6,10	30,72
Percentage variations	**-60,47%**	**-76,66%**	**-65,25%**

Figure 14. Parametric and percentage variations of specific requirements for summer and winter air conditioning

	November	December	January	February	March	April	
Without passive systems (W)	3.035	6.834	21.491	**22.539**	7.049	2.568	
With passive systems (W)	7.522	9.513	12.684	**13.333**	11.599	7.784	
Percentage variations	147,8%	39,2%	-41,0%	-40,8%	64,5%	203,1%	**-41,0%**

Figure 15. Peak power for heating

	June	July	August	September	
Without passive systems (W)	7.947	10.780	**13.243**	6.612	
With passive systems (W)	2.435	5.018	**6.504**	1.860	
Percentage variations	-69,4%	-53,5%	-50,9%	-71,9%	**-62,1%**

Figure 16. Peak power for cooling

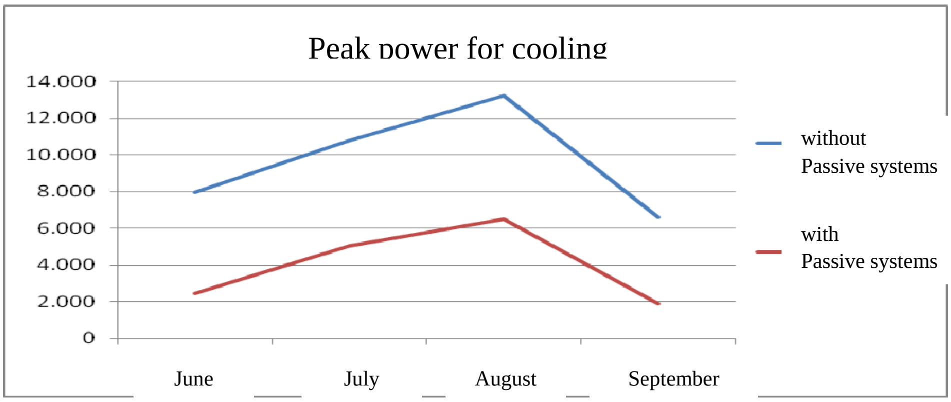

Figure 17. Comparative graphic analysis of peak power for cooling

3.4. Evaluation of harmful Emissions' containment

The emissions have been evaluated in equivalent CO_2 Tons, using a conversion factor euqual to 0,585 TonCO_2eq/MWH and assuming a seasonal average CoP for the heat pump equal to 3, for both heating and cooling purposes. The auxiliary energy needed for pumps, fans and control systems has not been considered.

Hypothesis	Heating	Cooling	Total
Basic solutions	7,24	1,47	8,71
With buried system	4,64	0,34	4,98
variation	**-35,90**	**-76,66**	**-42,79**

Figure 15. Harmful emissions due to heating and cooling systems in equivalent CO_2 Tons

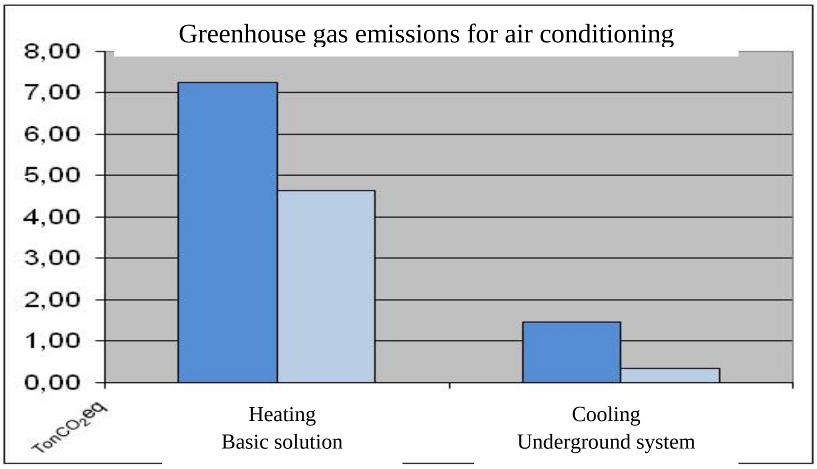

Figure 16. Comparative graphic analysis of harmful Emissions due to heating and cooling systems

4. CONCLUSIONS

The evaluation of the overall passive technological devices' effectiveness, carried out comparing the building's performance with the performance of the same building without the application of passive systems, produces a series of results that can be summarized in three categories: bioclimatic comfort, Energy saving and polluting emissions' containment.

Environmental comfort

Indoor comfort has been measured counting the annual hours during which the indoor operating temperature does not respect a series of preset intervals. The operation temperature takes into account both the air temperature and the temperature of surfaces that define the rooms, and it is the most significant value when evaluating thermal comfort.

Two temperature intervals have been used, an optimal one, between 20 and 26°C, and a satisfactory one, between 19 and 27°C.

In the building without passive systems the number of hours where the values fall outside the optimal interval is equal to 36,3% of the total, whereas the hours that fall beyond the acceptable limits are equal to 4,6%. With the application of passive devices the percentages decrease respectively to 26,4%and 0,4%,with a reduction of the total discomfort hours equal to 84%.

Energy savings

The building that results from the environmental Energy retrofitting, energetically certified in the A class according to recent Italian regulations, requires 24,62 kWh/m2 y for heating purposes and 6,10 kWh/m2 y for cooling ones. Simulations highlighted a reduction in the total thermal requirement equal to 65% of the total. The calculation is referred to the energy needed to maintain the desired temperature inside the rooms, without taking into account the plant operational needs. The supplementary energy needed to operate the underground system was not considered either.

Emissions' containment

The environmental benefits obtained by applying passive systems have been quantified on the basis of atmosphere polluting emissions' reduction. Based upon the calculated thermal requirements we estimated that the emissions can be reduced by around 64%.

REFERENCES

Allard, F., Santamouris, M. (1998). Natural Ventilation in Buildings: a Design Handbook, Hardcover.

Balocco, C., Farneti, F., Minutoli, G. (2009), I sistemi di ventilazione naturale degli edifici storici. Palazzo Pitti a Firenze e palazzo Marchese a Palermo, Florence, Italy: Alinea Editrice.

Battisti, A. (2005). La Qualità ambientale delle Architetture di Interno. Procedure e strumentazioni tecniche per la costruzione e gestione degli spazi a conformità ecologica. Florence, Italy: Alinea Editrice.

Cetica, P. A. (2004). L'architettura dei muri intelligenti. Esperienze di climatizzazione sostenibile nell'Ottocento, Florence, Italy: Angelo Pontecorboli Editore.

Cipriani, F. (2010). Il comportamento passivo degli edifici storici: una proposta di categorizzazione, Atti del 10° Congresso Nazionale CIRIAF, Perugia, Italy, avril 9-10.

Givoni, B. (1998), Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. Energy and Buildings, Italy.

Grosso, M. (2008). Il raffrescamento passivo degli edifici in zone a clima temperato, II edition, Santarcangelo di Romagna, Italy: Maggioli Editore.

Koch-Nielsen, H., Vrdoljak, K., D'Amours, R. (1999), Projectar Activamente com a Natureza, HØrve, Denmark: Development Advisory Group.

Leone, G. (2009). Torri del vento, Casa&Clima n.19, year IV, mai-june.

Neila González, F. J. (2004). Arquitectura bioclimática en un entorno sostenible, Madrid, Spain: Editorial Munilla Lería.

Santamouris, M. (2007). Advances in Passive Cooling, Earthscan Publications.

Santamouris, M. (2007). Advances in Buildings Energy Research, Hardcover.

Tucci, F. (2006). Involucro ben temperato. Efficienza energetica ed ecologica degli edifici attraverso la pelle degli edifici. Florence, Italy: Alinea Editrice.

Tucci, F. (2008). Tecnologia e Natura. Gli insegnamenti del mondo naturale per il progetto dell'architettura bioclimatica. Florence, Italy: Alinea Editrice.