Bioclimatic design, assisted by numerical simulation in a transient state.

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ABSTRACT: The bioclimatic design aims to realize designing, localizative technological, plant-engineering choices, in order to have a housing model that satisfies comfort requisites through microclimate passive control and the control of the energy for heating plants.

The study in this field is booming and, thanks to fast and effective calculation systems, the researchers can achieve reliable outcomes in reasonable times. Starting by a good thermal-energetic design and a bit of intuition, the bioclimatic design issue has been tackled scientifically and sistematically. So, we reached specific and general conclusions useful to quantify and select the most used technics in this field.

Our work doesn't aim at a strict demonstration but at a study through which verify, understand and increase the knowledge of thermal-energetic phenomenon of building-environmental interaction.

Many of the simulations in transient state have been made on matters we considered the most influential on the global behaviours of residential buildings. The matters on which we focused are: thermal cover (thermal insulation and inertia), glazed surfaces, screenings (static and mobile), in direct geothermal energy, vent (natural and artificial, diurnal and nocturnal). All this work has the aim to create the right balance between naatural cooling and heating during a while year, in order to guarantee thermal comfort to residents, thereby decreasing to a minimum the use of plants during the summer and the winter.

The consequent designing-technical choices come from scrupulous interpretation of the outcomes, achieved by extrapolating from generic treatment the compatibility with the climatic conditions. In this perspective, the authors, with the research, are using their knowledges to get innovative outcomes and integrate the research with empirical matters.

1 INTRODUCTION

The bioclimatic design study cannot lead to the realization of a standard constructive model that could be exported as it is in any climatic contests.

The bioclimatic design, therefore, cannot dismiss the climatic evaluation of the place, since it suffers even from little latitude, exposure and climate changes. But it can provide us generic notions and hints to conform at best the building to the climate where it stands, realizing a thermal comfort condition.

From a theoretical point of view, the analysis approach, having a general value, is adapted for any climate. The specific outcomes and output data, instead, have considerable value only in the selected climatic contest (Rome) or in others similar (for temperature, dampness, sun position, solar radiation intensità, altitude etc.)

The "bioclimatic designer" works constantly in balance between beneficial solar effects and overheating.

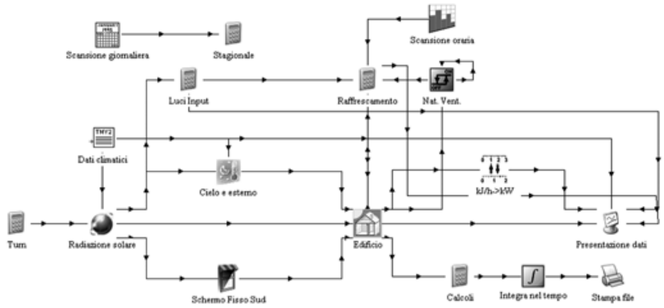
The external temperature changes during the day, and it is often more considerable during the summer than during the winter. Therefore, we cannot base the thermal load calculation only on transmittance U, that starts from a hypothetical but non-existent steady state of heat transmission.

Much more important is the influence, that can be more or less significant for a standard building, but anything but irrelevant for a passive building, due to insolation.

2 SIMULATION METHOD

For our study, we used the calculation software TRNSys, with which we developed a more elaborate model, including types or equations that could represent all concepts of bioclimatic design, allowing a quantitative evaluation.

The outcomes are trustworthy, since the used calculation method, by exploiting statistical data, sets



Picture 2.1: TRNSys simulation project

the interaction of the building with the environment, considering the solar load, the highest passive energy source for our building.

The research, developed step by step, starts from the creation of a input system for solar and weather data, made more realistic by the interaction among more types, thought for this pur pose (Types 69, 16, 89).

The second step was the introduction of the main component through the type 56 that schematize our building. This type will be, then, modified to vary the design parameter and acquire the simulation outcomes with a deductive procedure.

In the next steps will be added more types to make reproducible specific design behaviours, that gradually improve the global thermal behaviour, addressed to a decrease of conventional conditioning systems.

The parameter adopted to determine the building thermal energetic quality is the energy efficiency, moving towards a gradual increase. The analysis moves towards a decrease of primary energy consumption, without modify or reduce the comfort.

Often, the outcomes are indicated in function of the temperature progress in the module, the needed primary energy or the achieved energy efficiency. The energetic evaluations have been achieved considering the required sensibile heat amount (indicated in absolute value SQHEAT for warming, and SQCOOL for cooling). Such a method allowed us to accumulate general simulations and perfect the model knowingly.

According to the complexity of the model, the computer responded speedily (5-15 s), showing that the calculation system could be implemented in other commercial use softwares with design purposes.

The numeric and graphic outcomes of simulation will be reported when illustrated the design technics, underlining the qualitative and quantitative progress of intervention.

3 BUILDING COVER

The thermal cover is one of the main elements to achieve a high-level energy efficiency, in any climate.

In particular, our simulations show the dual effectiveness of limiting summer and winter consumptions. It is essential, for thermal inertia, the choice of heat-insulating materials and the cover, above all for the building reaction during the summer.

3.1 *Thermal insulation*

We tried to verify the importance of adopting high-performance building cover (low transmittances or/and high thermal inertia) in order to guarantee considerable primary energy saving and the approach to a standard of low-energy house and passive house.

Starting from a standard cover, without any energetic improvement, we analysed, step bye step, an increase of the insulating layer for the three types of installation: external, middle and internal.

In picture 3.1, you can see the outcomes of simulations on the same module characterized by steady air infiltration (then at ambient temperature) equivalent to 0,3 volume/h, glazed surfaces with southern exposure (the widest for thermal storage) and northern exposure and with constant transmittance (U=0,777 W/m^{2}K) of the surface in contact with the soil. The simulations are repeated varying the thickness of the insulating layer of low-density rock wool (λ = 0,144 W/mK, c = 0,84 kJ/kgK, δ= 80 kg/m^3), distributed on vertical and roofing walls.

As you can see, the energy efficiency of the module enormously increase already with little insulating layers. The big layers (> 0,20 m) are, then, economically unjustified regarding the achieved advantages. In the diagram are, also, related the outcomes for insulating installation methods: internal, middle and external.

In the internal one, the thermal inertia lows and the walls stop having that important stabilizing function for the internal temperature. This leads to an ineluctable increase of consumptions compared with the other two methods.

It is evident that a building without thermal insulation wastes a lot of energies; suffice it to think that in our housing module, with an insulator of 0,02 m, the annual costs for conditioning are halved.

This statement encouraged the authors to make researches on the european situation, in order to assess the current situation. In the bar graph in picture 3.2, you can see the average value of insulators thickness, used in many european states for vertical walls.

3.2 *Thermal inertia*

Thermal inertia is difficult to estimate numerically, but thanks to the transient calculation we can have information on how certain design choices can influence the building thermal behaviour, moving over time (and quantitatively) the thermal response of the building.

High-massed covers (masonry, concrete, high-thicknesses) function as tanks for cool and warm and they cool and warm slowly; there follows the reduction of internal temperature peaks and the out of phase introduction of heat, that is delayed late in the afternoon and the evening (at lower external temperatures).

Our researches have been developed through iterative simulations, varying external walls, on the thermal capacity of the layers, using materials with different conductivity/mass relations, in order to register, layers being equal, the thermal response of the building. It is specified that it has been kept the same global transmittance of the walls, changing properly the insulating layers thickness (rock wool).

An exmple of ouput is relates in picture 3.3, where you can notice the distinguishing aspects of the phenomenon, assessable in the temperature progress in two different cases: concrete or perforated bricks walls, compared with each other and with the external temperature.

As you can see, a larger thermal inertia cover leads to a global reduction of thermal cycling (durino the day) on (comfort) average value. It is underlined a temporary shift of the building thermal response.

4 TRASPARENT SURFACE

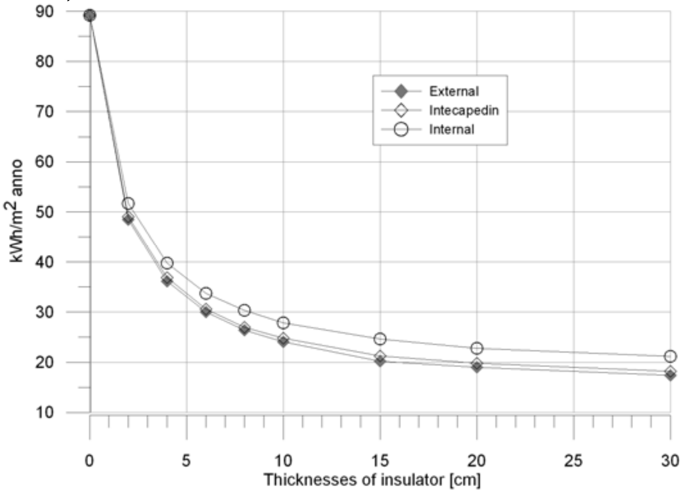
The main function of glazed surfaces is to allow the natural illumination, to which it is added (not less important) the ability to make pass the solar radiation, essential natural thermal energy source for the building.

Since high-performance glass-windows (able to join a good transparency to a low transmittance) cost a lot, the dimensioning of glazed surfaces is not easy to approach, and it has the aim to optimized, finding the right compromise between given thermal loss and allowed solar load, in relation to materials, various typologies and surfaces, as well as to their space location towards solar source.

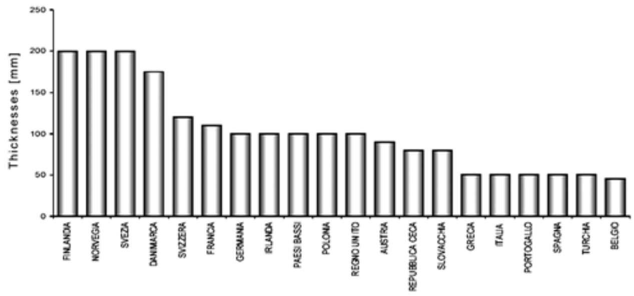
4.1 *Windows orientation*

The analysis on the influence of glazed surfaces orientation on internal temperature progress has been developed putting the model to a rigorous rotation. At this simulation phase, the module is characterized by a heterogeneous building cover on border surfaces with infiltrations equal to 0,5 volumes/h.

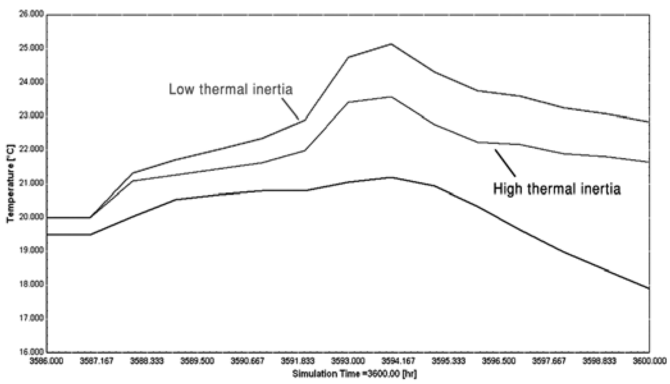
To visualize the qualitative progress of the phenomenon we put only one 20 m^2 double-glazing surface on one side and we made four simulations, making turn the module and realting the outcomes for the main four orientations (North, South, East, West).



Picture 3.1: Energy efficiency progress when varying the thicknesses of insulator.



Picture 3.2: Range thicknesses of insulator use by european states



Picture 3.3: Internal temperature ranger during the day with covers of different thermal inertia.

Picture 4.1 visualizes the different behaviours among Southern, Northern and Eastern and/or Western exposure. As a matter of fact, an Eastern and Western exposure means cold winters and hot summers.

The Northern exposure is characterized by temperatures that are lower than other dispositions during the year, with little daily ranger.

The Southern exposure maximizes the solar loads, particularly during the winter. It is excellent for cold climates, but without adequate screenings could overheat the interior during the summer.

4.2 *Dimension and typology*

Dimension and typology are the most important parameter for dimensioning, since they have a significant influence on the thermal behaviour of the building.

To formulate this concept, we developed some simulations varying dimensions and glazed surface type (South-facing) in our module and setting out the outcomes in a graph (pic. 4.2). To make the outcomes expressive, we decided to adimensionalize the glazed sufaces extension on the whole South-facing front. Such a simulation has been repeated for three different glazed surfaces types:

Type	Thicknesses	U	g
Single	2,5	5,74	0,87
Double	2,5 12,7 2,5	2,95	0,777
Triple	2,5 12,7 2,5 12,7 2,5	2	0,7

The model provides for a change of air with the exterior equal to 0,5 volumes/h and for the absence of static and/or mobile screenings.

The comparison parameter, this time, was the energy efficiency produced in kWh/m² year.

Even in this case, we can easily get important quantitative data. The graph progress highlights another aspect we have meet in our research: the possibility to optimize, since, for example, increasing the window size unconditionally doesn't improve the situation but causes a summer overheating.

4.3 *Window inclination*

Another element experimentally assessed is that of windows inclination on the vertical.

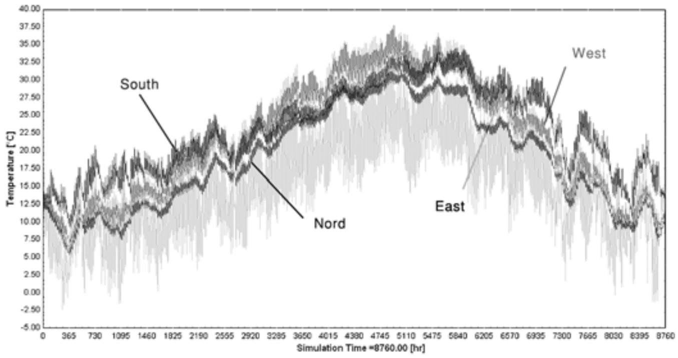
By inclining the glass on an angle different from the vertical standard one (90°), we have a response that boosts the azimuth orientation choices. Consecutively, the response of our model will be described and interpreted from a conceptual and physical point of view.

Depending on the angle of incidence and on the glass type, the solar radiation on our flat glazed surface will be in part reflected, in part absorbed and in part it will cross it. In general, it is expressed through the variations of the coefficient of transparency, reflection and absorption. The transparency values for angles of incidence upper than about 60° ÷ 65° will be very high.

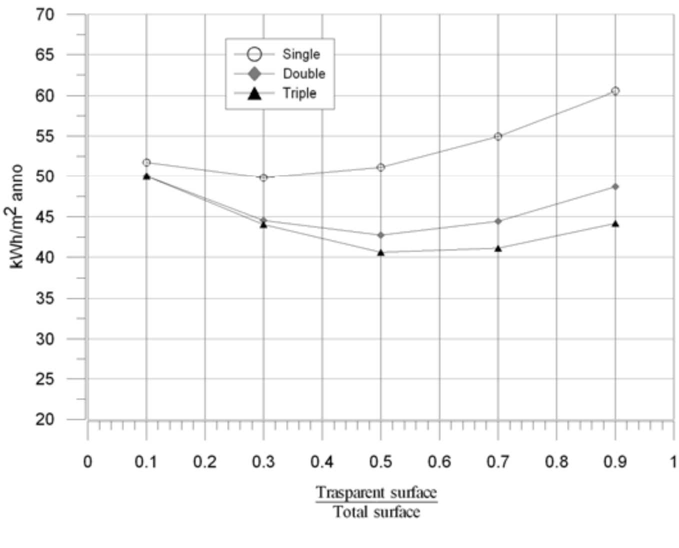
The idea is to optimize the loads through the window by inclining it, in order to achieve, during the winter, an angle of incidence as much as possible upper than 60° ÷ 65° and vice versa for summer.

For example, picture 4.3 shows that the aim is an optimization process through the inclination of transparency surfaces (double-glazed) between 70° and 130° (with < 90° angles with an inclination towards the interior). The glass window is South-disposed with infiltrations equal to 0,5 volumes/h, the energy efficiency is expressed in kWh/m² year. We make simulations for increasing surface glass windows: 10 m^2, 15 m^2 and 20 m^2.

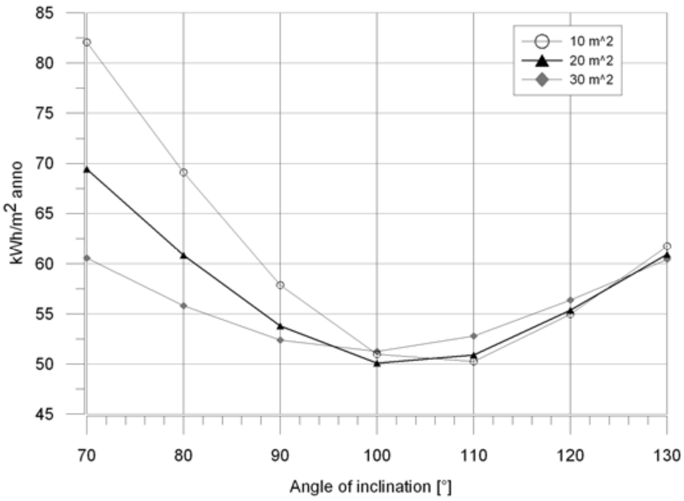
In our simulation, the height of efficiency is given by a 100° inclination. A right inclination provide a percentage saving directly proportional to their surfaces.



Picture 4.1: Energy efficiency progress varying the glazed surfaces orientation.



Picture 4.2: Energy efficiency progress when varying the size of glazed surfaces for three different typer of glass windows.



Picture 4.3: Energy efficiency progress when varying the angle of inclination of different sized glazed surfaces .

The angle of optimization changes only with latitude. For want of space, there aren't the outcomes of other simulations developed with other parameters, that, anyway, confirm what have been said.

5 SCREENINGS

The shady elements have to allow the passing of solar radiation during the winter and its reflection during the summer, in order to avoid internal overheating. Moreover, they have to guarantee a natural lighting during the year.

Therefore, the shady elements have to be:

- external situated
- adaptable to the angle of solar incidence.

The authors expanded on the different possibilities given by mobile or static screenings, discovering interesting outcomes glimpsing interesting applicative openings.

In picture 5.1, it is reported the module internal temperature progress in the absence of conditioning with a horizontal static screening of 1,3 m of overhang (like a balcony) on the big South-facing glass window. By making a comparison with the temperature progress in the absence of screening, you can notice how this one can influence during the whole year, above all during the summer.

Picture 5.2 is the result of a more complex but much more successful system. We tried to realize an automatic response model, that used the screening only if really needed.

The adaptability to external and internal conditions is developable through an intelligent control interface, able to balance the screening level, even guaranting an adequate natural illumination, independently of human intervention.

In the model, the key parameter for this kind of simulation is the screening coefficient on the South-facing window. The system intervenes only when needed, that is, through Type 2, when the internal temperatures are near to overheating in a range of 24 °C ÷ 22 °C and with variable values, given automatically by a cubic function of the solar radiation on the South-facing surface, in order to consider the natural illumination.

During the winter there is no variation of internal temperature (since the screening doesn't intervene), while during the summer the thermal saving is outstanding.

6 INDIRECT GEOTHERMICS

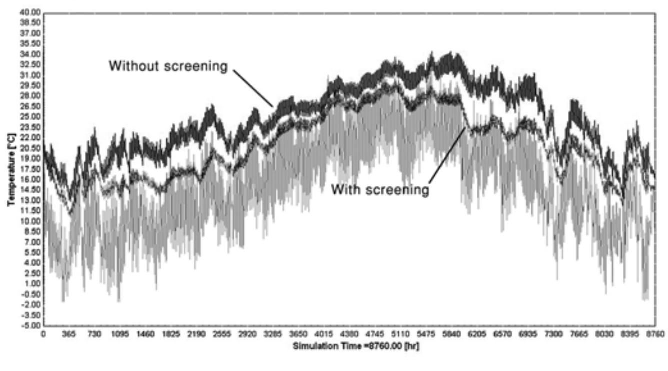
Some TRNSys Types have been used to compare the outcomes achieved with the M. Santamouris' simplified calculation method, showing harmony among the outcomes: from 1% to 8% of difference on cooling loads on annual base; from 0% to 15% for monthly base loads..

The TRNSys Types allow many simulation opportunities for many earthed heat exchangers, as:

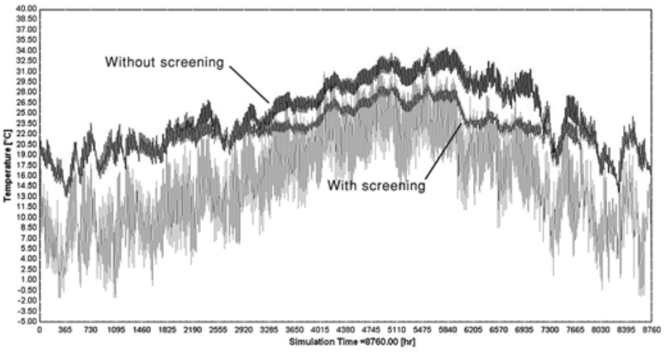
- earthed tube, horizontal disposition, without heat load;
- horizontal disposed linear probe with heat load;
- vertical probes, concentric pipe type;
- vertical probes, U pipe type.

The dimensioning of theese systems is not easy and suffers from many indeterminations, due to the proper moulding of the ground and to the influence of the variation of the seam high. The authors with other colleagues carry on with the researches in this sector, that seem already to near to some practical rules for a provisional dimensioning of a earthed exchanger:

- length not lower than 10 m;
- pipe diameter between 0,20 m and 0,30 m;
- earthed depth between 1,5 m and 3 m;
- air speed in the pipe between 4 m/s and 8 m/s.



Picture 5.1: Influence on the temperature progress on the static screening.



Picture 5.2: Influence on the temperature progress on the mobile screening.

7 VENTILATION

Ventilation can be natural or induced, meaning that the air flow (in this case the heat transfer fluid) is achieved naturally for density difference between two air masses at different temperatures or through a mechanical system that gives, against a waste of energy, a certain kinetic energy to the fluid.

We made our assessments by simulating an induced ventilation to simplify the model (data interpretation with undoubted hypothesis), against a loss of efficiency, irrelevant in this field, but to be studied since the study of and adequate ventilation, even natural, give high levels of comfort in our rooms, reducing to the maximum the internal thermal gradients and allowing a change of air with the exterior, thermally controled.

Ventilation has to be good designed to guarantee an adequate winter thermal load and an effective summer cooling for heat removal

7.1 *Infiltration*

For infiltrations are meant changes of air with the exterior of temperature and humidity no-dependent on an adequate conditioning system, but characterized by values equal to those of external environment.

A bioclimatic building takes its efficiency from the ability of saving, at low cost, thermo-hygrometric situations different from those at the exterior. Then, limiting the air infiltrations from the exterior to a minimum and regulating the entering air output rates, temperature and humidity are essential to avoid them to be wasted.

In picture 7.1, are reported the outcomes of the simulations on our model, requiring the same internal thermal and hygrometric conditions, but varying the output rate per hour.

7.2 *Nocturnal cooling*

Among all assessments, here are reported the most interersting and worthy to be expanded ones: the natural cooling through nocturnal ventilation.

During the summer, at our altitudes, the passive solar buildings risk the overheating. The module, in fact, accumulates heat during the day where solar radiation and external temperature simultaneously increase the internal temperature of air and walls.

During, the night, external temperatures descreaseand are often lower than the internal ones.

The idea is to counter the overheating by developing in these hours an intense thermal exchange, to put the module again to lower temperatures, by absorbing the thermal load in excess and cooling the building.

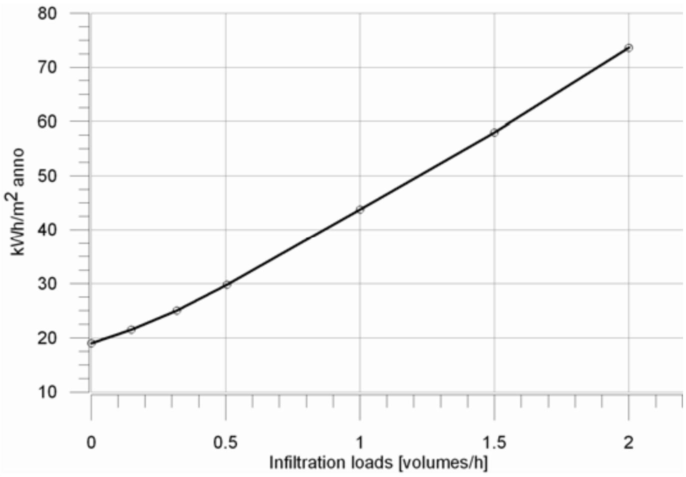
The designing intervention concludes with a high thermal inertia og the building, that guarantees the maintenance of thermal conditions, got during the night, even during the day.

Practically, we tried to make night thermal exchanges between the building and the exterior, supporting as much as possible the natural maintenance of summer night thermal conditions, naturally nearer to thermal comfort.

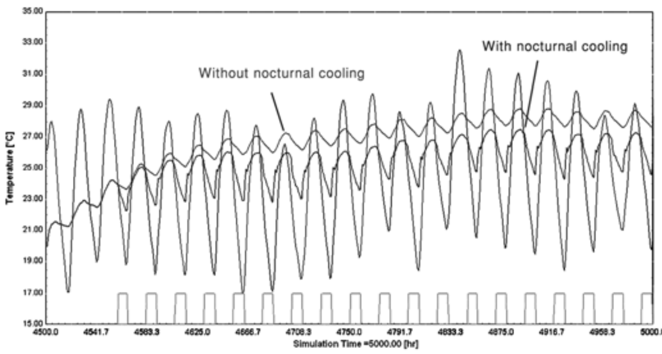
Obviously, to realize all this we need thermal control systems that can open the appropriate openings automatically and allow the natural ventilation or the ventilation system, if present (as it should be in a passive building) to make air recycling.

In picture 4.11, you can see the outcome of a simulation made by the introduction in our night module of a cooling automatic system. This system has a complex evaluative autonomy, determining, on some parameters, the running time of the nocturnal cooling system: an artificial intelligence element for an efficient house.

The system makes automatically a verification on three parameters: external temperature, internal temperature and time. The cooling starts with steady load (3 volumes/h), in set night hours (0÷6 and 21÷24), each time the external temperature is lower than the internal one and the internal temperature upper than 23°C and it stops if the internal temperature reaches 19°C.



Picture 7.1: Energy efficiency variation on infiltration loads expressed in volumes/h.



Picture 7.2: Comparison between module with and without night automatic ventilation system for the summer cooling, with a ventilation state of 3 volumes/h.

It is clear the difference between the temperature progress with and without cooling for night ventilation. The internal temperature gets near to the external one in short time, cooling the whole building by wasting the heat loaded during the day. The temperature, during the day, raises without reaching the temperature in the absence of the system and guarantee even during the day a relevant temperature difference.

8 CONCLUSIONS

The bioclimatic design study cannot lead to the realization of a standard constructive model that could be exported as it is in any climatic contests.

But the current calculation systems can make simulations and verifications of great scientific and designing impact, that can lead to developments for the scientific, cultural and energetic evolution.

The authors, in fact, carry on with the research in this field, focusing on the chances of a real application of all the concepts, treated only theoretically.

8.1 *Influence of the factors of the cover on global energetic performances*

The research treated most of the representative bioclimatic design aspects, reporting the outcomes of the simulations that, statistically reorganized, provide a valid quantitative position to the choice of many technics and technologies to be imported in the realization stage of a design.

Graph 8.1 show how the parameters can influence the energetic performances of a building.

The thermal insulation of the cover and the air impermeability have a key role.

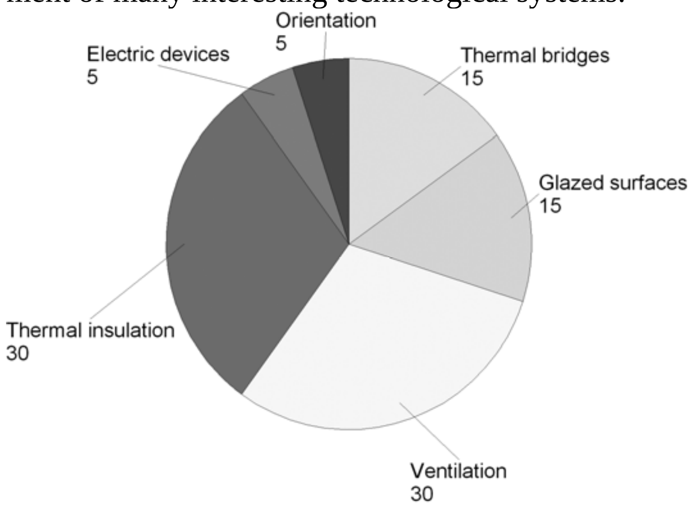
The quality of the cover insulation and its impermeability to the wind must be excellent; and excellent must be the quality of the glazed-doors and the prevention of heat bridge.

Glazed-surfaces and their orientation have to be studied for any climate: in a steady balance between good solar loads and excessive overheating, simulations in transient state are essential.

The external temperature changes during the day and this variation is more noticeable in summer season, the sun has specific trajectory and create shadows and angles of incidence with the other buildings.

The screening systems of a building are very important, since they protect from the overheating.

Such a systematic study can lead to the development of many interesting technological systems.



Picture 8.1: Percentage influence of many cover factors on building energy performances.

To restore the balance between the entering energy and the wasted energy, it is needed an innovative low-energy plant engineering with a low temperature system (35°C ÷ 40 °C, against 60°C ÷ 70 °C of traditional systems). This requires the use of condensing boilers (high performance) or heat pumps, that can be powered with thermally pretreated air (preheated in winter, precooled in summer, through earthed exchangers.The research carries on towards a total integration and the realization of a impactzero model with a positive energetic balance towards the national energetic system.

REFERENCES

Cefalo, Antonio 2007, *Progettazione bioclimatica: stato dell'arte e verfiche in regime stazionario e transitorio*, Degree thesis in Civil Engineering – University of Rome "Sapienza".

Cappellanti, Simone 2008, *Progettazione bioclimatica il comfort termico mediante l'uso razionale dell'energia*, Doctoral thesis - University Sapienza.

Sala, M. & Ceccherini,N. 2000, *Schermature solari*, Alinea.

AA. VV., 1997, *TRNSYS: A Transient System Simulation Program*. Solar EnergyMadison.

Santamouris, M. & Asimakopolous, D. 1996, *Passive cooling of building*.