"base configuration", the windows surface of the south façade is the 30% of the overall surface. Comparing the hourly trend of indoor air temperature in the base configuration with the ones in the others configurations, the maximum, minimum and average deviation in different hours of the day have been evaluated considering the dynamicity of the envelope and the influence on inner comfort conditions using, during summer period, the adaptive comfort theory.

Key words: building envelope, thermal comfort, thermal inertia, parametric analysis.

Introduction

In the field of energy saving in the building sector, the Italian Decree-Law n. 311/06 (that has been issued after the Decree-Law 192/05 implementing the European Directive 2002/91/CE) focused its attention above all on energy saving in winter time giving some limits both on thermal transmittance U-value of the building envelope and on the primary energy requirements. For what concerns summer, however, only a generic indication was given on the value of envelope superficial mass, to be higher of 230 kg/m^2 in those places with a monthly average solar irradiation over 290 W/m^2 in the hottest month (usually July). The new Decree-Law n. 59/2009, instead, introduces also the periodic thermal transmittance Yie (that is the product of stationary thermal transmittance U and attenuation factor) giving a maximum value of 0.12 W/m^{2}K for walls and 0.20 W/m^{2}K for roofs. Till now, however, two important aspects are missing:

1. first, a calculus methodology for summer loads and cooling requirements that takes into account dynamic simulations and not only a stationary approach (not appropriate for summer conditions)
2. second, and may be more important, an integrated approach to building design during summer in order to achieve both energy saving and human comfort conditions minimizing the use of cooling system by means of an appropriate building shape and the use of passive devices.

So, it is important to carry on studies not only on the energy efficiency of cooling systems and on the possibility to run them with the minimum use of non renewable energies, but even on the "passive side" of the building design: materials, shape, openings, shutters, inner disposition of rooms, relationship with the environment and so on.

In this paper, a research is presented where the performance of a model building has been studied taking into account some specific parameters between which the position of the thermal mass of both the envelope and the inner horizontal partitions (floors), the windows percentage on the south façade, the influence of inner heat gain, of shutters, of night passive ventilation.

Methodology

The research is based on the parametric analysis of a virtual building. The model building has been designed with a rectangular plant and the main axis along the east-west direction in order to maximize the amount of solar radiation on the envelope. The configuration of the model is given by the sum of six simple squared modules for each floor. The main spaces (rooms, dining and living room) are facing south while the serving spaces have a north exposure (Figure 1).

The 30% of the south façade of the virtual model called "base model" (that will be used as reference for all the others) is glazed, while the other sides have less glazed surfaces (Figure 2).

The "base model" represents a parametric scheme of a residential building whose envelope and internal slabs physical characteristic will be changed from time to time in order to evaluate inner temperature variations. In particular, six different combinations have been considered with the same thermal transmittance U-value of the main building components: walls have a U value of 0.33 W/m^2K, the roof has an U value of 0.29 W/m^2K, inner floor has an U value of 0.64 W/m^2K. Thermal insulation is always placed on the outer side of the wall.

The different configurations are summed up in Figure 3. Model A1, the lightest, has a total mass of 383.5 Kg/m^2. Model A2 has the same envelope of A1 but inner floor is heavier and it has a total mass of 597.5 Kg/m^2. Model B1 is characterized by heavy walls and light inner floor and it has a total mass of 615.5 Kg/m^2 while model B2 has heavy floors (including roof) and light envelope. At last, model C1 has a heavy envelope and light inner floor and model C2 is the heaviest (heavy envelope and heavy inner floor). By "total mass" it is intended the sum of the mass, per square meters, of walls, floors, inner slab.

In all the models, the inner vertical partitions have the same mass of 28.2 Kg/m^2 and the same U-value of 0.59 W/m^2K, while only inner floor mass changes from time to time.
Moreover, all the models have a periodic thermal transmittance Yie lower than 0.10 W/m^2K and an inner superficial thermal capacity approximately of 55 KJ/Km^2.

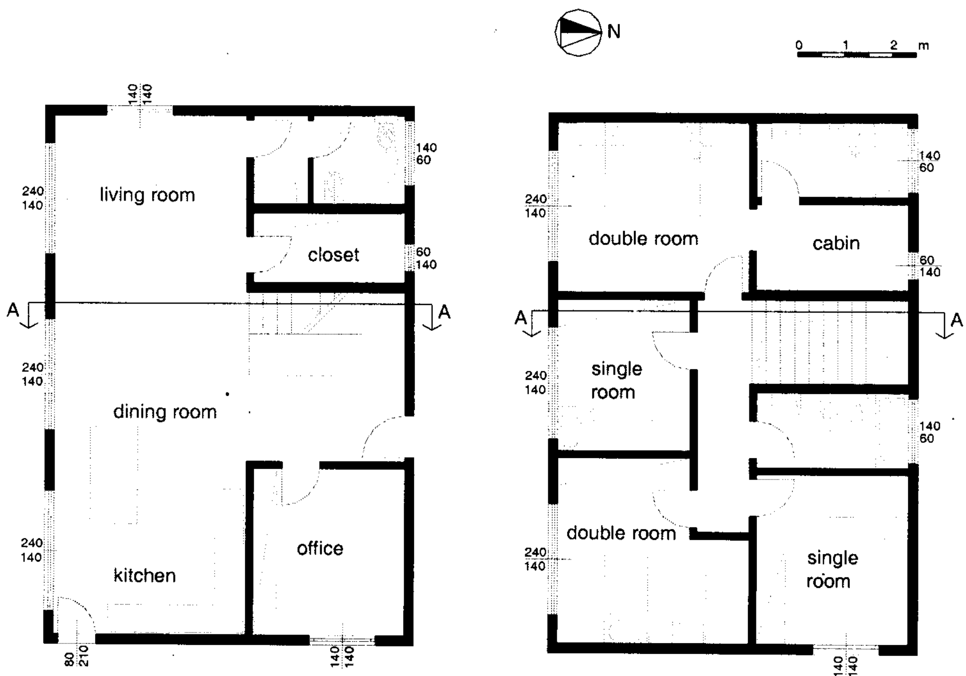

Figure 1 : Layout of the base model building

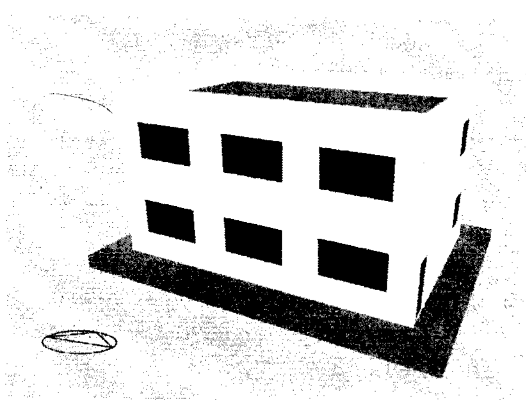

Figure 2 : 3D view of the base model building

The dynamic simulations, the study of the virtual model and the parametric analysis have been made on the whole building and not only on parts of it.

Dynamic simulations have been run considering the weather file of Sigonella, a town in Sicily representing warm conditions typical of a Mediterranean climate and where hourly weather conditions are known (a great difficulty for this kind of simulation, in fact, is that often the TRY – test reference year file is not available for a certain place. At the time this research has been done, for Mediterranean climate only the TRY of Sigonella was available). Only July has been taken into consideration, being the hottest month of the year and been the research focused on summer conditions.
Output considered have been inner air temperature and operative temperature in the living room, dining room, kitchen and office at the ground floor, as well as all the bedrooms at the first floor.

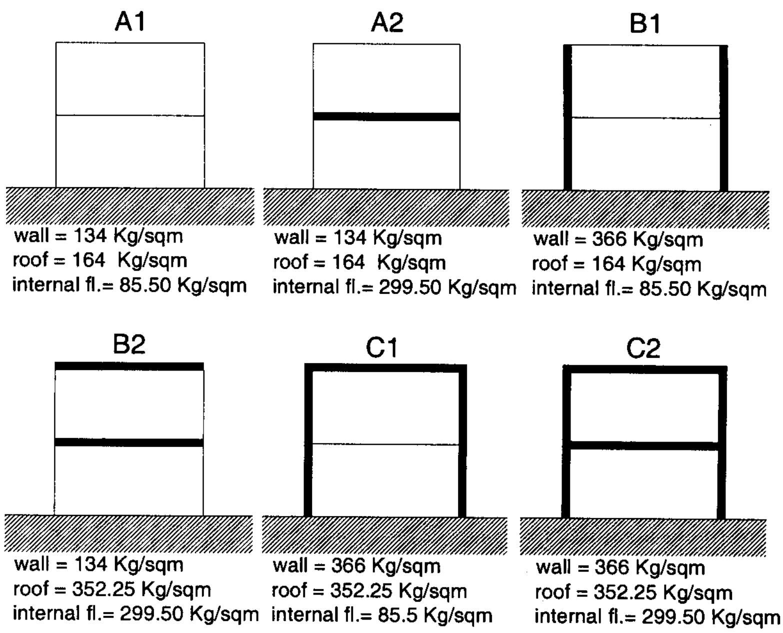

Figure 3 : The 6 different configurations considered

Results

The so called "based model" is a very simple one with the following characteristics (additional to the ones previously exposed): no shading devices, no air ventilation and infiltration, no internal heat gains. Of course, these are non real conditions, but they are necessary in order to have a common starting point to be a "comparison stone" for the other models created with successive variant performances. In fact, the second step is to modify some features of the base model, one at a time, and to evaluate the influence of those changes on the whole building behaviour. The evaluation of the same geometrical model with different thermal mass value and different characteristics will provide the best strategy to be used in the design as well as in the management phase.

Here follows the main results obtained by introducing step by step the specified changes.

Base Model

Comparing operative temperature trend in the sitting room, we can notice that lowest temperature are provided in model C2, while highest one in model A1 (see FIG. 4). Instead, temperatures in models A2, B1 and B2 have more or less the same maximum values.

Of course, a massive envelope is important in order to decrease inner temperature, but a greatest effect is obtained by the interaction of outer walls and inner elements, like in model C2. In particular, the inner temperature decrease of 0.9 °C when a massive slab is considered.

So, if we do not consider inner heat gain, night ventilation and shading devices, mass is the most important parameter to be taken into consideration if U value and Yie value are not changing between the models (that is, thermal characteristic of the materials are the same, otherwise even thermal conductivity has an important role).
In a second phase, the discomfort index has been evaluated considering two cases: the upper limit of 26°C for summer comfort conditions in living rooms with mechanical systems (as suggested by actual standards) and the adaptive comfort theory following the UNI EN 15251:2008 [1]. Considering the importance of a bioclimatic design, here the results of the latter investigation will be exposed.

Rooms at the ground floor give low discomfort index values (it is almost zero in the office). At the first floor, the index varies more or less from 100°Ch to 600°Ch in some cases. Generally speaking, the index trend is proportional to the mass increase. Anyway, models B1 and B2 have similar values in all the rooms and, in particular, the kitchen (placed on the south-east side) has a constant value in models A2, B1, B2, C1. Of course, here the room exposure is very important. For example, the office is north-east oriented, and temperatures are always in the comfort zone both in model A1, the light one, and in model C2, the heaviest.

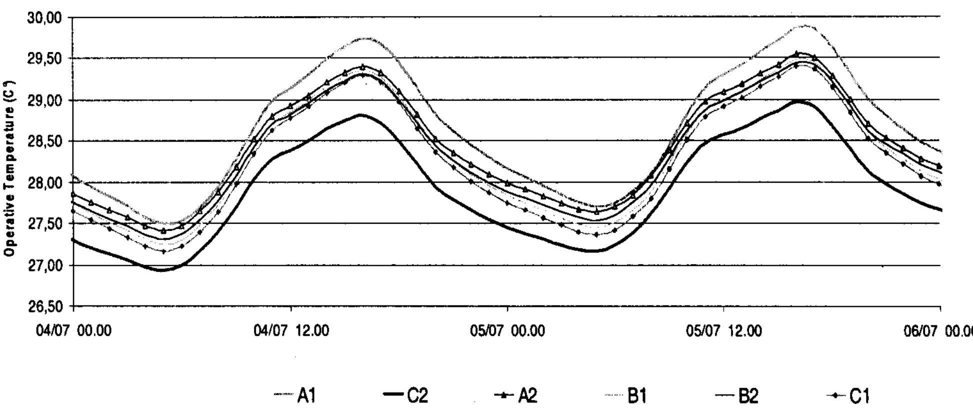

Figure 4 : Operative temperature trend in the sitting room in the different configurations

Glazing Percentage

Southern facade of the base model is characterized by a glazed percentage of 30%. It is considered to be good average values at Italian latitude in order to allow an appropriate inner spaces lighting reducing summer overheating and winter heat dispersions. This percentage has been reduced step by step to 20% and 10% in simulations.

We can notice that the variation of glazing surface has a great influence on temperature in light models. In particular, temperature average values increase of 0.2 °C every 10% of glazing surface increase.

Inner Heat Gains

Inner heat gains due to occupants, domestic appliances and diffuse solar radiation incoming from windows are one of the most important problems to be faced while evaluating building performance in summer. Inner heat gains have been applied to regularly occupied rooms considering the standard UNI/TS 11300-1:2008 [2] – tab. 9 "Temporal profiles of thermal gains due to occupants and apparatus" (Table 1).

The simulation output stresses that temperature profile is the same, even if absolute values are much higher and the trend exit from the comfort zone all day long. Temperature rise up till 36°C. Of course this is due to the fact that windows are always closed and no shading devices are used. These are the worst conditions for users.

Table 1 : Inner heat gain used, coming from Italian standard UNI/TS 11300-1:2008

days	hours	sitting room and kitchen W/m^2	rooms with refrigerating system W/m^2
mon-fri	7-17	8.0	1.0
	17-23	20.0	1.0
	23.7	2.0	6.0
	average	9.0	2.67
sat-sun		8.0	2.0
		20.0	4.0
		2.0	6.0
	average	9.0	3.83
average		9.0	3.0

Shading Devices

Next step has been the introduction of shading devices. We have decided for an automatic shading of windows when global solar radiation exceed the value of 400 W/m^2. From previous researches and on site monitoring, in fact, we have noticed that 400 W/m^2 is the limit in summer conditions when inner temperature begin to increase and occupants generally use window shadings.

Only model A1 has an high discomfort index, with values of 200-250 °Ch for ground floor rooms with southern exposure. This means that during the design phase it is important to put attention not only on the thermal characteristics of opaque building elements but even on the proper protection of glazed surfaces.

In particular, it is necessary to define the shading typology, color and material. In order to help the users to combine proper lighting with low solar gains and to avoid overheating due to a incorrect use of shading, an automation system can be used.
It is important to notice that not only windows exposed to direct irradiation should be protected. Indirect irradiation, in fact, is as important as direct one concerning temperature increase. So, all the windows of the building have been shaded, even the ones on the north façade.

Night Ventilation

During summer, night and early morning external temperatures are usually lower than inner ones. This fact should be exploited in order to ventilate rooms, to decrease inner temperature values and to cool down massive elements inside the building from the heat they have stored during the day.

So, the last variant to the base model, after the introduction of inner heat gains and of shading devices, has been the introduction of night cooling strategies through natural ventilation. In particular, in a first moment windows have been opened 100% from 8 p.m. to 7 a.m., but the output showed an excessive air temperature decrease, often out of the comfort zone. After having analyzed temperature trend and particularly in the period when it is out of the comfort zone, the proper ventilation interval has been identified to be from 8 p.m. to 12 p.m.. Even the percentage the windows are partially opened varies from day to day during the week. In this way, even if in summer period, night ventilation for 4 hours a day is sufficient in order to reach comfort conditions in all the models considered, independently from the mass value of the envelope.

In particular places and circumstances, in order to avoid pollution and acoustic problems, air can enter the building not only through windows but the same amount (in cubic meters) can be introduced by means of controlled mechanical ventilation systems.

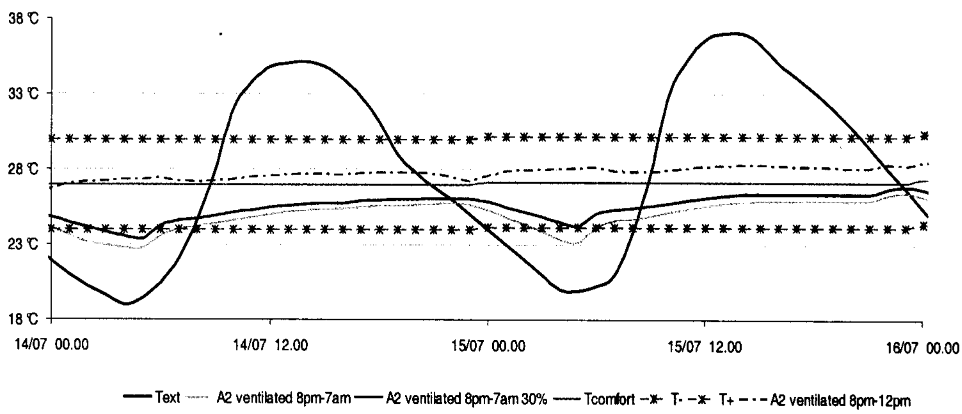

Figure 5 : Example of model A2 with operative temperature inside comfort zone if night ventilation is operated between 8 and 12 p.m.

Conclusion

This work shows that, considering a rectangular building with a good ratio surface/volume and an east-west disposure, even in the Mediterranean climate zone (hot summer climate), the main parameters to be taken into account for a proper design in order to decrease summer loads and maximize human comfort conditions are:

1. The mass value of the envelope and of inner components. In fact, the introduction of a massive floor cut by half discomfort hours (Figure 6, models

A1 and A2). Even considering the other models (B1-B2 and C1-C2) massive floor always improves inner conditions compare with the only envelope. In this respect, it is interesting to compare model C1-C2 where a massive roof is of course important, but the introduction of a massive inner floor improves the situation a lot. This is true considering materials with similar thermal conductivity λ-value, otherwise the periodic thermal transmittance Yie should be evaluated.

2. A proper management of shutters together with the presence of a building automation system for their control. In fact, considering the use of shutters the difference in discomfort hours between the models decreases (FIG. 7), so as the influence of mass even if it is still important (discomfort hours always decrease with mass increment).
3. Night ventilation. If properly managed, inner environmental temperature can be always included in comfort zone. Night ventilation can act in two ways: decreasing temperature values during the night (but this is a temporary effect); cooling down massive elements inside the building so that they are ready to absorb heat due to solar gain the next day (like a spring that has been released and it is now ready to be loaded again).

In addition to the three parameters now described, the shape of the building depending on local environment is fundamental. Local environment is in fact the first true resource for a sustainable design where energy issue and human comfort are considered at the same level. The research here briefly exposed is going on even in this direction with the same methodology but considering what happens when the shape of the building is changed (layout, section, exposure) and all the other parameters are invariant.

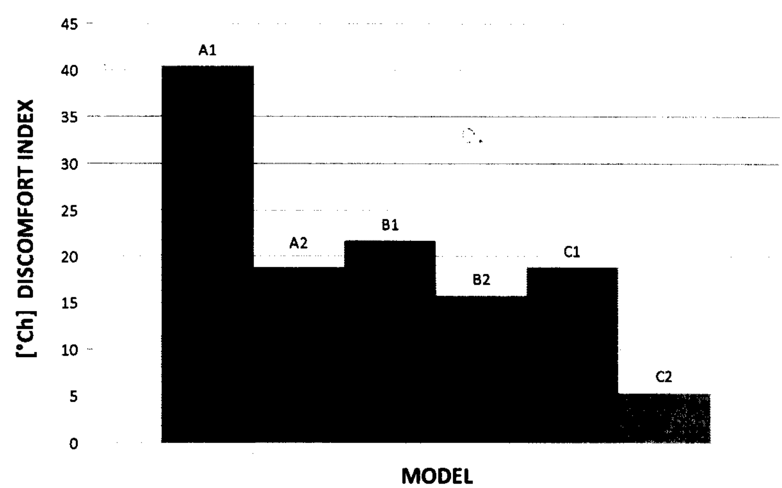

Figure 6 : Comparison of the discomfort index in the models depending only on mass values

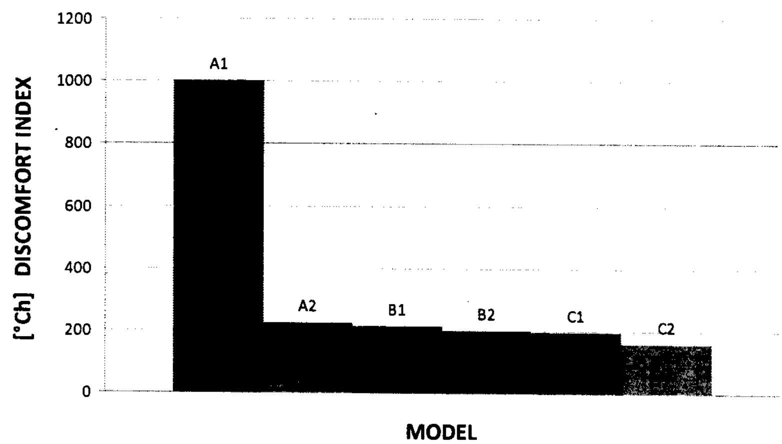

Figure 7 : Comparison of the discomfort index in the models depending on mass and shading

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1. UNI EN 15251:2008, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
2. UNI/TS 11300-1:2008, Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling