Evaluation of Design Strategies for Improving Summer Comfort Conditions in a Low-Energy Residential Building

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ABSTRACT

The aim of the present study is to evaluate the design strategies for improving the summer thermal comfort conditions in a low-energy residential building located near Rome. The evaluated strategies include the natural air-flows through the windows: a) opening of windows for 24 hours and b) opening of windows during night hours only. The evaluations have been carried out by means of simulations using EnergyPlus building energy simulation programme. Results have shown that the comfort level can be improved substantially by adopting the "intelligent" strategies in the use of windows (close during the day in the warmer days and always open during the night); moreover, the limited use of ceiling fans (mechanical ventilation) results only few hours of condition of discomfort. Further the evaluations have also been made regarding the use of ground source cold water through a heat pump and radiant floor system for ensuring the comfort in all the days, also the hot one, without the requirement of air-conditioning system.

1. INTRODUCTION

In the building sector in Europe, amazing results can be achieved: the present average consumption for space heating of the European existing building stock is between 160 and 220 kWh/m^2 year, on the other hand, for new buildings, it is no longer an exceptional event to design a dwelling requiring 15-30 kWh/m^2 year. To reduce energy consumption by a factor 10 is not an utopia, and the European Directive on Energy Performance of Buildings (EPBD) is a concrete step in this direction. Such savings can be obtained either with an appropriate design or renewal of the envelope and with the use of more efficient technologies.

Within buildings, one of the fastest growing sources of new energy demand is for cooling. This growth is especially fast in Southern European countries, but is significant also in the Central European ones. Cooling is growing not only in commercial buildings – caused both by the large internal gains due to equipment load and by the architectural fashion of fully glazed facades, but also in residential buildings, because of the combined effect of the higher comfort levels expected by the dwellers, of the increasing frequency of heat waves due to climate change and of the urban heat island effects.

The use of low-energy cooling techniques combined with a reduced cooling load may result in a good thermal summer comfort and therefore save substantially cooling energy consumption. Two interesting and promising low-energy cooling techniques are the natural night ventilation through windows and use of radiant cooling systems. Intensive natural night ventilation is driven by wind and thermally (stack) generated pressures and cools down the exposed building structure at night. As a consequence, heat may accumulate the next day and temperature peaks will be reduced and postponed consequently.

The use of radiant heating/cooling systems in houses has been growing in recent years. In Europe, for example, the use of radiant heating/cooling technique represents more than 50% in newly constructed houses (Athienitis and Chen, 1993; Klkis et al., 1994). The intent of radiant systems is to lower thermostat set point temperature in winter and to increase it in summer, resulting in a substantial energy savings for heating and cooling as compared with conventional systems. The energy savings from radiant heating/cooling may reach more than 30%, as demonstrated in some theoretical/experimental case studies (Feustel and Stetiu, 1995; Yost et al., 1995; Stetiu, 1999).

The performances of these low-energy cooling techniques depend on multiple building and environmental parameters. Firstly, climatic parameters (temperature difference inside-outside, average outdoor temperature range), building characteristics (thermal inertia of the building and convective heat transfer between ventilation air and thermal mass) and technical parameters (ventilation rate by night and control strategy) define the performance of natural night ventilation (Givoni, 1998). In the present study, these low-energy cooling strategies have been evaluated for improving the summer thermal comfort conditions in a residential building. The work is focussed mainly on the summer performance of the building, but will also briefly discuss the winter performance. The results are presented on the simulated performance and the impact of the low-energy cooling techniques on the improvements in summer thermal comfort conditions.

2. THE LOW-ENERGY RESIDENTIAL BUILDING:

Edificio ben temperato Lunghezzina

The residential building '*Edificio ben temperato Lunghezzina'* in the periphery of Rome has been designed by F. Tucci and T. Herzog according to passive energy saving strategies (AS, 2006). The building has four floors with sixteen apartments, four in each floor (Fig. 1). The principles of this low-energy office building are the reduction of the heating and cooling load and the use of passive cooling and heating.

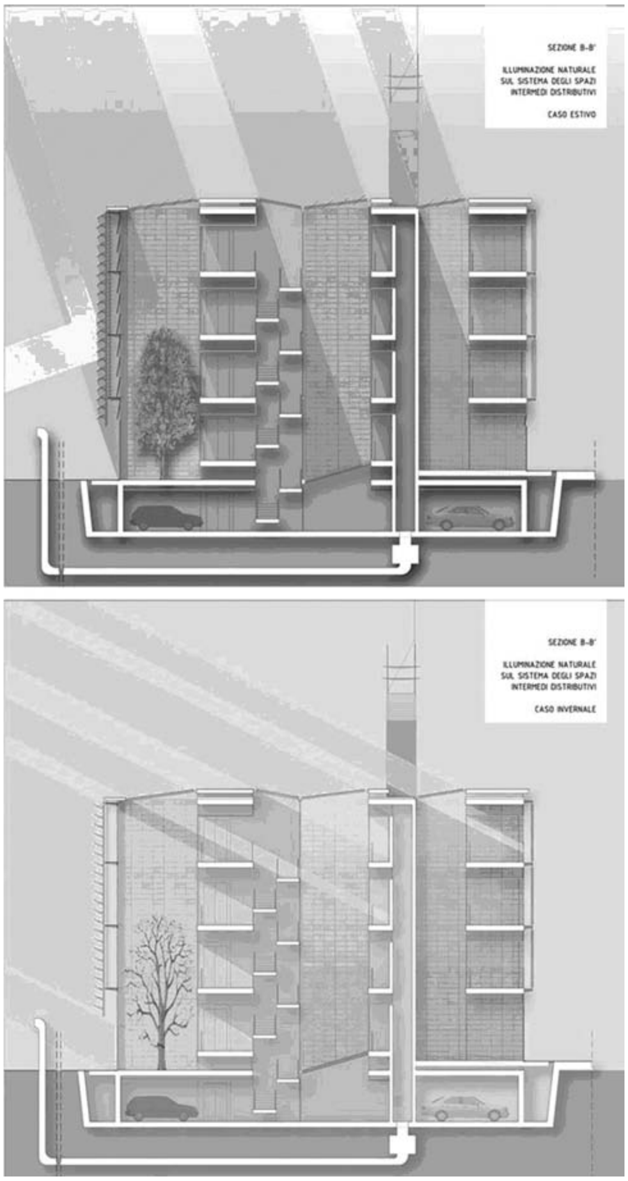

Figure 1. The low energy residential building

3. BUILDING ENERGY SIMULATION

The simulation tool employed in the present study for predicting the energy performance of the building is the EnergyPlus building energy simulation programme (Crawley et al. 2004). The climatic data is used for the Rome (Ciampino). The various input parameters used for simulation are shown in Table 1.

3.1 Winter performance

First of all, the external walls, roof, floor and windows are very well insulated (AS, 2006), therefore, the transmission heat losses are minimized.

Table 1: Input parameters for simulation

Set points HVAC system	Dry bulb Temperature (°C)	Winter-20 Summer-26°C (Radiant system)
	Humidity (%)	Winter - 50 Summer - None
Ventilation	Air change (V/h)	Winter - 0.5 Summer-Natural ventilation
Internal load	Person	Heat production- 108 W/person Clothing: Winter - 1clo Summer -0.5 clo
	Lighting & Equipments	5 W/m^2
	Cooking	1 W/m^2
Heating Period		1 Nov. – 15 April

Further, the ventilation heat loss is reduced by heat recovery system. It has been observed that minimizing the transmission and ventilation heat losses in the building results a very high level of energy performance with a specific heating energy demand of about 8 kWh/m^2 year (AS, 2006). It should be noted that this value could not be compared with that of the Passivhaus (15 kWh/m^2 year) because of quite different climatic conditions (either in terms of degree-days or the availability of solar radiation) of Rome as compared to the central-north Europe.

3.2 Summer thermal comfort

The complex interaction of four indoor climatic parameters; air temperature, mean radiant temperature, air velocity and humidity constitutes the human thermal environment. For comfort assessment of the indoor environment, several standardized methods are available. Most common method based on PMV (Predicted Mean Vote) indicator, typically uses six parameters, required as input, four indoor climatic parameters and two parameters related to the occupants: metabolic heat production and clothing insulation. In case of natural ventilation the external climatic parameters have a strong effect on the thermal comfort conditions.

Figure 2 show the hourly data of temperature and relative humidity for the month of July (the hottest one) corresponding to Test Reference Year (TRY) of Rome used for the simulations. It can be observed from the data that from the second half of the month the values of highest temperature includes between 30 and 35°C for a number of successive days. Even though the values are rather high, two positive aspects can be observed: large diurnal temperature difference and the low relative humidity values in correspondence to high values of temperatures. The first aspect is positive because it can be exploited through proper design strategies (e.g. night ventilation), however, the second favors directly the thermal comfort.

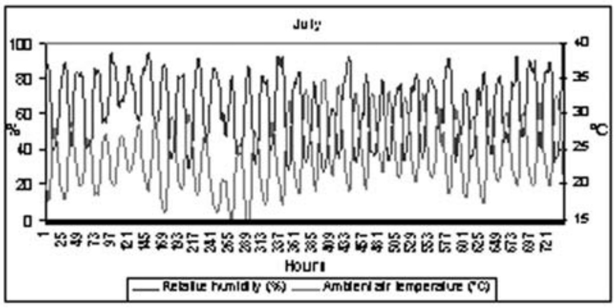

Figure 2. TRY climatic date for Rome (July)

3.2.1 Natural ventilation

To evaluate the effect of natural ventilation on the thermal comfort conditions of the different apartments of the building, the simulation have been carried out. The evaluated strategies include the natural air-flows through the windows: a) opening of windows for 24 hours and b) opening of windows during night hours only.

3.2.1.1 24 hours ventilation through windows

It is quite obvious that the different apartments are characterized by different conditions of thermal comfort during the summer period. Therefore, each apartment is simulated individually. The PMV indicator is used to evaluate the thermal comfort conditions. For the preliminary evaluation of the quality of thermal comfort conditions, the positive values of PMV have been summed up (quite often during the nights the PMV values are negative) for different apartments. Having verified that the month of July is most critical, as the values of ambient air temperatures are higher and persistent with respect to other months, all the elaborations of the simulation results were limited to this month. The results obtained are shown in Fig. 3.

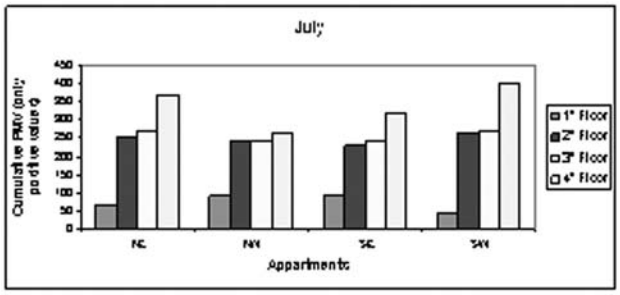

Figure 3. Cumulative positive PMV values

The cumulative PMV value supplies a first indication of the quality in terms of thermal comfort; in fact higher is the number, more time is found to be distant from the thermal comfort conditions. The figure clearly shows that the apartments of 4° floor are the most unfavorable, while the most favored are those of the 1° floor. However, the 2° and 3° floors represent intermediate behavior. The apartment having most critical conditions in absolute is the 4° floor of SW exposition.

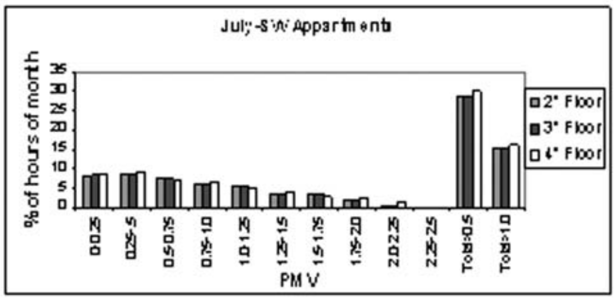

Figure 4. Frequency distribution of PMV

Entering more in the detail for SW apartments, the Fig. 4 show the percentage of the total number of hours of the month corresponding to the different values of PMV.

It can be observed that for the 4° floor apartment, for example, about 30% of the hours are above the PMV threshold of 0.5 and about 15% of the hours the PMV exceeds the value 1.

3.2.1.2 Night ventilation

Different measures can be opted to mitigate the discomfort verified in the apartments of 2°, 3° and, above all 4° floor – before deciding the use of air-conditioning system. The first measure is based on the exploitation of the large diurnal thermal excursion through the behavior of the occupant, by means of the appropriate opening and closing of the windows. To verify the validity of this approach a new simulation of all apartments was performed hypothesizing that during the warmer hours of the day (from the 8:00 to the 20:00) the windows remain closed, and reopened during the night, ensuring so the ventilation during fresher hours. The results provide interesting indications. Fig. 5 shows the percentage of the total number of hours of the month corresponding to the different values of PMV. It can be observed that in the case of night ventilation, better comfort conditions are obtained: the percentage hours in which the PMV exceeds the value 1 is much lower than the 24 hours ventilation. The effects of this strategy further can be improved if the occupant takes care of using it in intelligent manner.

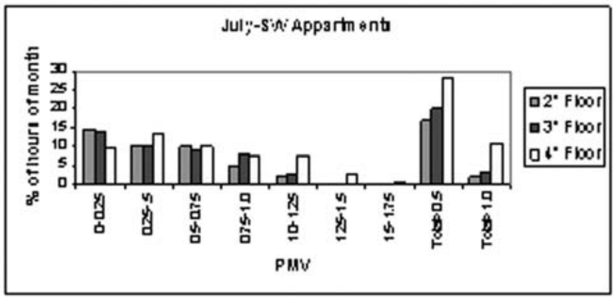

Figure 5. Frequency distribution of PMV (night ventilation)

3.2.2 Radiant Floor System

Another strategy studied for the mitigation of thermal discomfort is the use of ground source cold water through a heat pump and radiant floor system. The system selected for the simulation is the constant flow low temperature radiant system. Initially, it has been considered that the same optimised system for winter (tube length optimised for heating demand) is used for summer also. The simulations have been carried out for the set point temperature of 26 °C and the minimum inlet water temperature is considered as 17°C. Fig. 6 shows the results of thermal comfort conditions obtained for SW apartments using the radiant floor system.

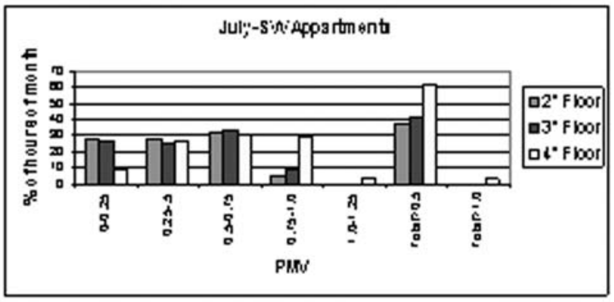

Figure 6. Frequency distribution of PMV (Radiant Floor System optimised for winter)

It can be observed that radiant floor system provides better thermal comfort conditions, and the values of PMV higher than 1 are obtained only for 4° floor apartment. However, the PMV values between 0.5-1.0 are still quite high for all the floors. It is quite evident that the radiant floor system optimised for winter is not able to provide appropriate thermal comfort conditions during summer period.

In view of the above observation, the radiant cooling system is further designed for summer conditions and a series of simulations have been carried out for different tube lengths to obtain the appropriate summer thermal comfort conditions. The optimised system for summer corresponds to the tube length about 4 times higher than the optimised system for winter. The results corresponding to optimised system for summer are shown in Fig. 7. It can be observed that the optimised system is able to provide the appropriate comfort conditions. However, it must be mentioned that for the selection of optimised radiant cooling system, the final energy consumption should be taken in to account.

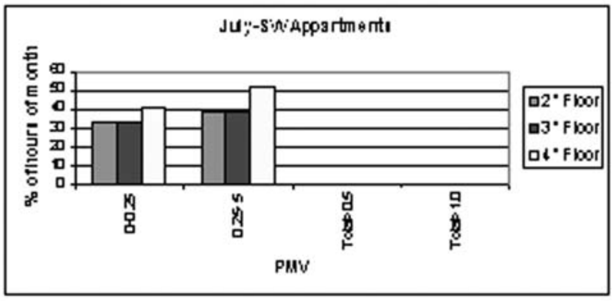

Figure 7. Frequency distribution of PMV (Radiant Floor System optimised for summer)

Fig. 8 shows the cooling power of the radiant floor system for SW apartments. In this case, the floors are cooled directly by the cool water coming from the ground heat exchangers (free cooling) and the cooling power corresponds to the energy required only for the operation of the water circulation pump of the radiant system and geothermal well.

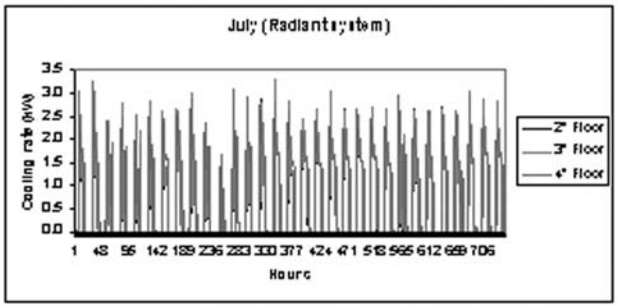

Figure 8. Cooling Rate (Radiant Floor System optimised for Summer)

3.2.3 Mixed Strategies

3.2.3.1 Radiant floor with night ventilation

In view of the fact that the radiant floor system optimised for summer might be resulted oversized (in present case the tube length is about 4 times higher than the winter optimised system), the mixed strategies (i.e. night ventilation with radiant floor) should be opted.

To evaluate the mixed strategy, further simulations have been carried out corresponding to winter optimised radiant system and night ventilation. The radiant system operates during the day (with closed windows) and is shut down during the night hours and windows are opened for ventilation. The results of the simulation are shown in Fig. 9. It is quite interesting to note that this mixed strategy is able to provides most of the time the required thermal comfort conditions except only about 5% hours with PMV values higher than 0.5.

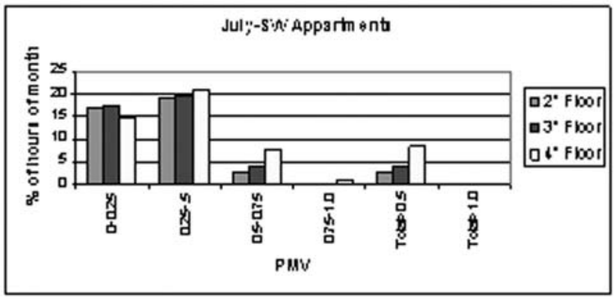

Figure 9. Frequency distribution of PMV (Radiant Floor System optimised for winter+ night ventilation)

3.2.3.2 Radiant floor with ceiling fan

Another mixed strategy considered in this study is the radiant floor system coupled with ceiling fans. The simulations were carried out for a winter optimised radiant floor system and a ceiling fan. The ceiling fan is simulated corresponding to different values of air velocity (0.25-1.0 m/s).

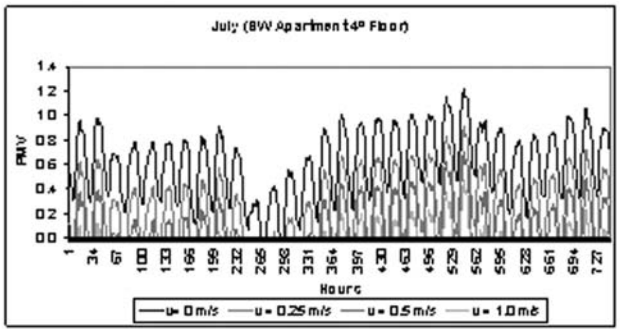

Figure 10. Hourly PMV for winter optimised radiant floor system as a function of air velocity

It can be seen from the Fig. 10 that using the radiant system along with ceiling fan the discomfort can be reduced substantially.

6. CONCLUSIONS

The simulation studies carried out in this study have shown that the low energy cooling techniques are quite effective to improve the summer thermal comfort conditions in a low energy building. In particular, the radiant cooling system and natural ventilation contribute substantially in the improvements of thermal comfort conditions. Therefore, the appropriate combination of suggested low energy techniques can contribute a high amount of energy savings. In fact, in this kind of system, the floors are cooled directly by the cold water coming from the ground heat exchangers (free cooling) and the system required much less energy in comparison to a conventional air-conditioning system, where the additional energy is required for the operation of the chillers.

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