Radiant cooling and ventilation strategies in low energy buildings

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ABSTRACT

In mild climates due to the increase of request of comfort of people there is a growing number of installation of low cost and low efficient cooling system even in new buildings. In designing low energy buildings it necessary nowadays to consider this trend and offer proper solution (envelope and plants) able to reduce the consumption of primary energy. An interesting solution capable to guarantee high levels of comfort is the control of surface temperature of wall and slabs (both from the envelope and plant side) because acts mainly on radiative heat transfer between human body and the indoor environment. This approach recours to cool surfaces and the role of ventilation in terms of comfort and condensation risk became essential. The study presented here is focused on this topic and has the aim to investigate the techniques of ventilation (natural, mechanical or hybrid) in order to reduce the use of energy and at the same time to guarantee a good level of comfort for the inhabitants using geothermal inertia. The outcome of this study are simple diagrams able to guide the designer in choosing the right strategy according to external climate (a coupled concept for radiant cooling and ventilation). The sensitivity of the selected strategy in respect of the boundary conditions (internal loads, thermal mass, shading coefficient etc…) is also presented. All the results are based on dynamical simulations sufficient to represents the more reliable strategies for a city in a mild climate where both heating and cooling season (even with high level of humidity) are important.

1. INTRODUCTION

Global warming and frequent heat waves have produced an increasing evolving demand of cooling comfort expectations. Over the last few years the new affordable technological developments have contributed to raise the peak of energy consumption related to cooling mechanical plants or air conditioning systems. Furthermore the heat island effect in urban environment is another cause of this summer discomfort, an issue which researchers have now to face and analyse. In most cases the use of cooling systems is not so efficient and lacks an integrates approach with the architectural projects (i.e. air conditioning systems hanging out of building facades). The attention on the decreasing heat space energy in the buildings of the Mediterranean countries should be related to the improvement of the suitable strategies to control the indoor climate during the not-cold period. Many studies focus on cooling potential and the rational use of energy due to the combined radiant cooling panels and natural or hybrid ventilation strategies.

A radiant cooling system consists of a cooled surface that uses a medium (water) working with a temperature close to the room temperature and employs long-wave (infrared) radiation to remove heat load from a space. Technical developments, produced in the last 30 years, allow now to find sophisticated solutions able to optimize the efficiency and the control of critical aspects such as the occurring of condensation. The aim of this study is to investigate the techniques of ventilation (natural, mechanical or hybrid) in order to reduce the use of energy and at the same time to guarantee a good level of comfort for users, connecting the whole performance to the envelope features. The research highlights the use of radiant cooling in the region Lombardia, at the centre of Padana plain in Italy: for simulations Milano Linate climate data have been used (available in the De Giorgio database). An increasing cooling potential, not counted in this research, consists in the presence of moving phreatic surface in the soil of Milano, useful for the effects of dehumidification combined with underground exchanger.In a context like a sub-continental region with Mediterranean influences, it is very important not only to project a correct plant concept but above all to evaluate the real potential for the use of low energy and power technologies.The first assumption to guarantee few loads and a more efficiently integrated building system is to control gains through the envelope by reducing solar heat radiation. Well insulated walls or roofs are requested not only to limit the heat waves but also to prevent energy losses in winter. The reduction of CO_2 emissions and the use of low exergy plants are other goals closely connected to a sustainable building philosophy. Optimizing climate control relies on:

- the solar heat gain controls;
- the use of building inertia;
- the dissipation of heat excesses by ventilation strategies or cooled surfaces.

The prevalent aim is to analyze the energy savings potential in summer period by using a comfort parameter more suitable for natural (or hybrid) ventilated building. According to ASHRAE Standard 55 NV, the optimum temperature is calculated as a function of the average monthly temperature of exterior air recorded in those regions in which it is possible to apply the theory of the adaptive approach: T comf = 17,8 + 0,31 Tm_{ae}.

2. EVALUATION METHOD

The research has been conducted using a mathematical model determined by using a transient system simulation program, TRNSYS, combined with a multi-zone air flow mode, TRNFlow. In such a way it is possible to trace the mutual effect due to air changes on dynamic thermal model. A set of simulations has been planned in order to quantify the results obtained by hypothesis based on natural or hybrid ventilation and focused on the evaluation of indoor thermal comfort, working period of radiant cooling system, potential cooling based on the risk of condensation.

2.1 Model definition

The study is meant to give parameters useful on preliminary stage of design and calculations and relies on a simple monozone building with the following features:
- floor gross surface..........................44,0 m^2
- S/V ratio...1,22
- north window surface ....2,24 m^2
- south window surface....................5,32 m^2

The envelope consists of traditional compositions with U mean coefficient U = 0,4 [W/m²K]:
- U wall ....0,35 [W/m²K];
- U roof ....0,33 [W/m²K];
- U floor ....0,33 [W/m²K];
- U window ....1,40 [W/m²K].

This is a well insulated building (referred to the Milano climate) and with a good internal inertia (m > 550 kg/m²floor). Insulation is between a double brick boarding for walls, on the exterior side of the roof (concrete flat roof) and under 7 cm flush in the foor.
According to Italian standards this building can be defined as a low energy building: the heat energy demand varies from 9 to 35 kWh/m²y, depending on the presence and the efficiency of a recovery heat system on the outlet air.
During summer time (June-September) 7 hypothesis of different scenarios have been simulated:
1 [VN] free running (without plants system);
2 [RC + VN] radiant cooling + natural ventilation;
3 [RC + VN + SC] radiant cooling + natural ventilation + geothermal exchanger
4 [RC + VN + SC + RE] radiant cooling + natural ventilation + geothermal exchanger + recovery heat system;
5 radiant cooling + mechanical ventilation without dehumidification;
6 radiant cooling + mechanical ventilation with dehumidification;
7 All air system.
As it can be seen from scenario 1 to 7, the role of plants in indoor climate control is increasing. For each scenario the envelope and the value of internal loads (illumination and electric component) are considered as constant (5 W/m²). The variables vary as per the following description:
- users' crowding (1, 2, 4 persons);
- occupancy time (morning, afternoon, daily, constant - 24 hrs);
- natural ventilation regime (morning, daily, constant - 24 hrs);
- solar shading coefficient (0; 40%, 80%).

Referred to simulations including heat exchanger device there are 4 hypothesis of supply air flow (n = 0; 0,3; 0,6; 1 [1/h]).
Radiant cooling system is dimensioned on a peak thermal load of 1,2 kW and temperature regulation assumption is described by the following equation:

$T_{\_set\text{-}point} = 26\ °C$
$T_{\_inlet} = T_{\_dew\text{-}point} + 1\ °C\ (14\ °C < T_{\_inlet} < 18\ °C)$
$T_{\_outlet} = T_{\_\ inlet} + 3\ \ °C$

This study results into simple diagrams capable to guide the designer in the choice of the right strategy according to external climate, coupling the concepts for radiant cooling and ventilation using meaningful parameters. Internal loads, as specific power referred to 1 m² of floor (W/m²), can be used by designer in relation to the kind of space use (i.e. residency, office…). The model of occupancy (i.e. morning, afternoon…) describes an important project variable which is defined at the preliminary phase of designing. Seasonal solar gains (kWh/m²) represents an important parameter to evaluate solar control devices (g value of glasses, tent, Venetian blinds, external geometry) coupled with the context (climate, orientation). Design choices are related to possible results in term of percentage of comfort hours, based on Standard 55 NV and working period of radiant cooling system (indicator of possible energy consumption). In order to get to a correct evaluation of the results it is important to underline how scenarios 5, 6, 7 are used as comparison cases between traditional plants and studied strategies (scenarios 1 to 4) and the comfort temperature is calculated as reported in standard ISO 7730.
In this paper diagrams for daily occupancy (h 8:00- 18:00) are shown as example of the results.

3. ANALYSIS OF THE SCENARIOS

3.1 Scenario 1 – free running

In free running regime the building behaviour is very connected to climatic variations . From the graphs it appears clearly difficult to guarantee a good percentage of comfort even with a narrow crowding and an occupancy different from the morning. An increasing comfort period is seen proportionally to the reduction of solar heat gains but for a constant occupancy it is impossible to assure an acceptable indoor climate. In particular considering a daily occupancy, a 90% level of comfort is reached only with internal loads below 8 W/m^2 (global internal load related to users and project choices) and a seasonal solar gains below 13 kWh/m^2.

3.2 Scenario 2 – radiant cooling + natural ventilation
In a natural ventilation regime radiant cooling allows to reach a good level of comfort only for low solar loads and occupancy preferably in the morning (internal loads < 10 W/m^2 and solar gains < 15 kWh/m^2). Considering different hypotesis of occupancy and solar control device, a longer working period of the radiant cooling system is noticeable but a consistent high discomfort is reached already from 6..7 kWh of seasonal solar gains.

3.3 Scenario 3 – radiant cooling + natural ventilation + geothermal exchanger
The strategy of adopting a geothermal exchanger aims at reducing the dew point temperature and increasing the potential cooling of radiant panels. By dehumdificating the inlet air through the passage in a grounded pipe (3 m under) it is possible to reduce the temperature of the medium (water) flowing in the panels. This effect permits to have higher internal loads and a major occupancy maintaining rather high temperature of radiant surfaces (reduced energy consumption). Considering a daily occupancy, for instance, a 95% level of comfort is reached even with 10 W/m^2 of loads and high solar gains (> 15 kwh/m^2) already using an air exchange rate of 0,3 [1/h]. Increasing the exchange rate there is a lower level of comfort because of too low temperature of inlet air.

3.4 Scenario 4 - radiant cooling + natural ventilation + geothermal exchanger + heat recovery unit.
The role of a heat recovery unit is useful to reduce discomfort effect caused by low temperature of inlet air; indeed in a concept of plants adapted even for the winter conditions, it might be more appropriate. In the analysis a heat exchanger has been dimensioned in order to have an air temperature of nearly 14 °C. Nevertheless, a concrete benefit is not so evident using a recovery system for the summer period; in fact this strategy of hybrid ventilation allows a 95% level of comfort. Almost the same results as in the case without recovery unit (scenario 3), but a little more sensible to internal and solar loads.

VARIATIONS AND CONSIDERATIONS

To analyse the effects due to some variations, another set of simulations has been conducted. In particular for the scenario 3, two main hypothesis are reported in the following graphs:
- different working temperature of radiant panels;
- different position of radiant panels.

In the first case the temperature of the water inside the panels respects the equation:14 °C < $T_{\_inlet}$< 20 °C
It is noticeable that for higher working temperature (till 20 °C) there are benefits only for a constant occupancy period (h 0-24), decreasing the occupancy the comfort level is almost the same. As shown in the below graphs, the working period of a radiant cooling system set on a maximum temperature of 20 °C is longer than the case with 18 °C.
Considering the radiant cooling panels placed on the floor it is noticeable that there are consistent improvements in comfort levels only in the case of natural ventilation scenario [RC_NV]. Using a heat exchanger system there is still some benefit mainly due to the bigger mass contained in the floor technological layers but not so evident like the cases without exchanger. So a correct use of hybrid ventilation guarantees the same comfort levels even if there is less mass.

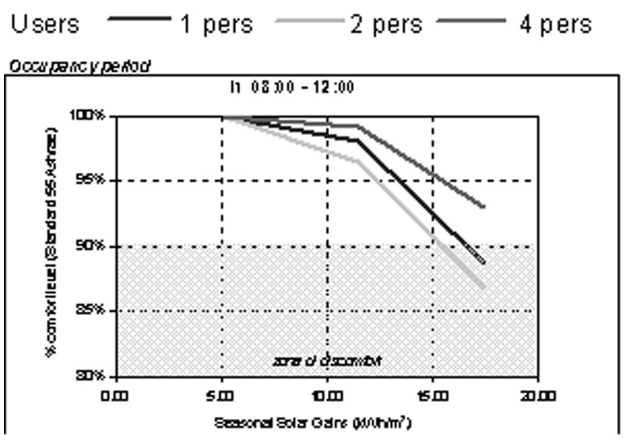

Figure 1: comfort levels related to solar gains -scenario 1

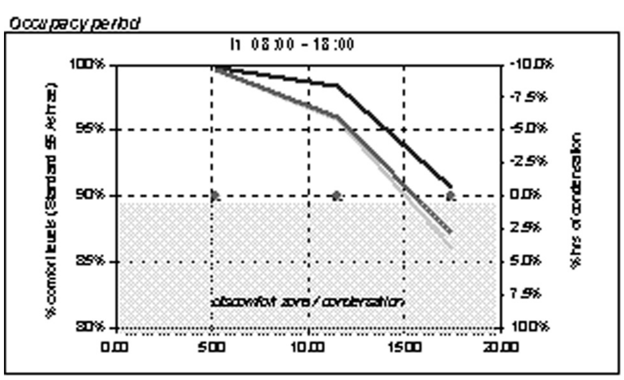

Figure 2: comfort levels for scenario 2.

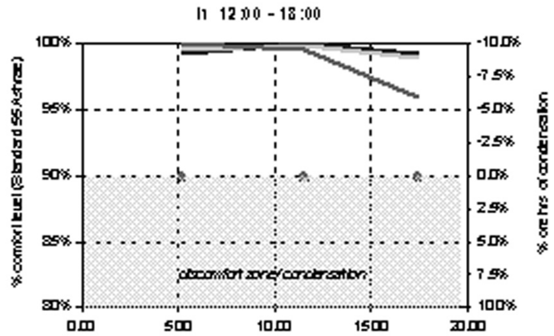

Figure 3: comfort level for scenario3 considering an airflow rate n = 1 [1/h].

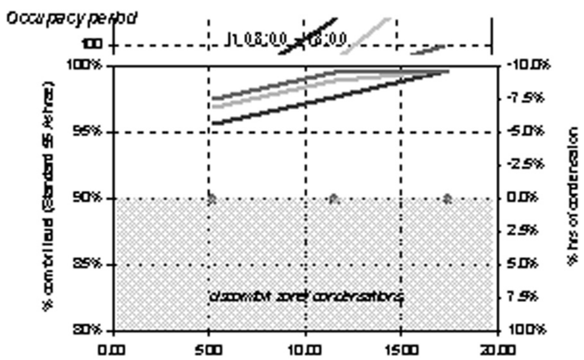

Figure 4: comfort levels for scenario 4, considering an air flow rate n = 1 [1/h].

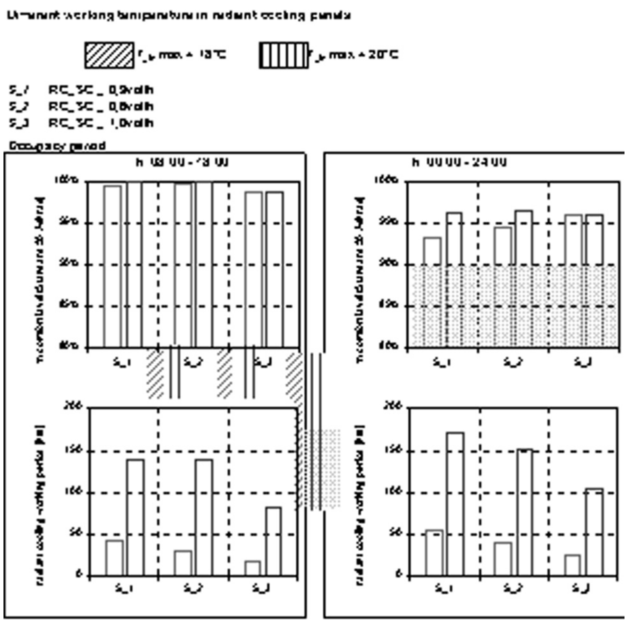

Figure 5: comparison between the use of two different working maximum temperatures in order to evaluate benefits.

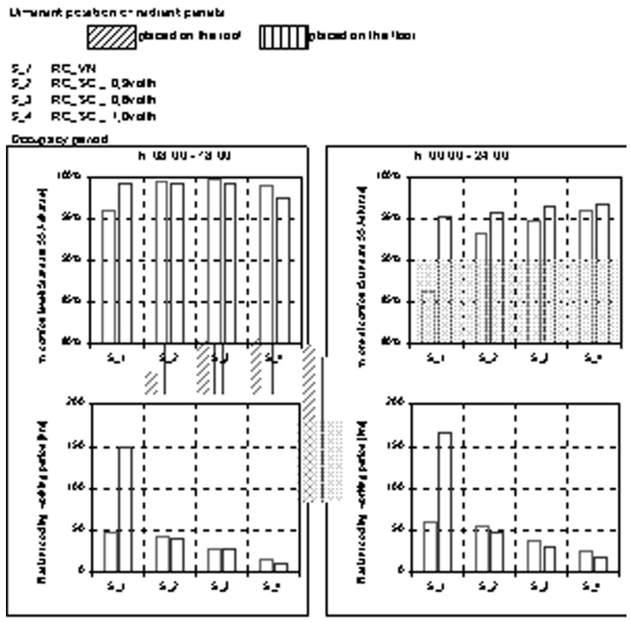

Figure 6: comparison between the use of radiant panels on the ceiling or on the floor.

4. CONCLUSIONS

In a controlled ventilation regime without dehumidification (scenario 5) it is impossible to guarantee an adequate indoor comfort level and above all, as reported in De Bear research for adaptive approach, it is possible that users could feel worse than in case of natural ventilation, in comparison to the same indoor temperature. Even with a short occupancy and low internal loads neither the fans or radiant panels have a positive effect. By using mechanical ventilation combined with dehumidification unit and radiant panels very good comfort levels are reached and this is the usual concept of radiant cooling use. Scenarios 5 and 6 are studied only as some examples of the traditional strategies far from the adaptive approach theory The study allows to define potential benefits and limits of radiant cooling combined with natural or hybrid ventilation, in a hot and sultry summer as Milano has. The analysis has not neglected a vision for strategy suitable for the whole year (reference year), simulating plants scenarios adapt to winter and summer, focusing on the behaviour of the building during the overheated period. In general terms it is possible to assume that radiant systems are up-to low energy strategies in comparison to all air plants or fan coil. This is mainly due to relatively high temperature of working set point of the fluid (14° – 18° C instead of a range 7° – 10° C for other systems), reducing energy consumption. The condensation is a problem to control through the use of a correct ventilation strategy, in particular combining radiant cooling panels and natural ventilation it is possible to have a good level of comfort only with a short occupancy and low internal load. Increasing the number of users (crowding factor) or considering a long period of occupancy the benefit of a heat exchanger underground is noticeable. The hybrid ventilation is a sustainable strategy and the energy demand is related to electricity need of the fan. In such a condition it is possible to better control the dew point and guarantee a supply airflow with dehumification effect. For high air exchange rate there is a condition of discomfort due to low air temperature value and possible airstreams. A heat recovery unit can be used to limit this stressing situation and guarantee a higher temperature of inlet air; unfortunately the cooling effect of this strategy does not bring any evident increase in comfort levels (in summer period). Above all, it is worth to underline how introducing the recovery unit acts in terms of working period of radiant cooling and consequently in energy consumption. To have the same comfort level radiant cooling combined with recovery unit has to work twice in comparison to the case without recovery unit.

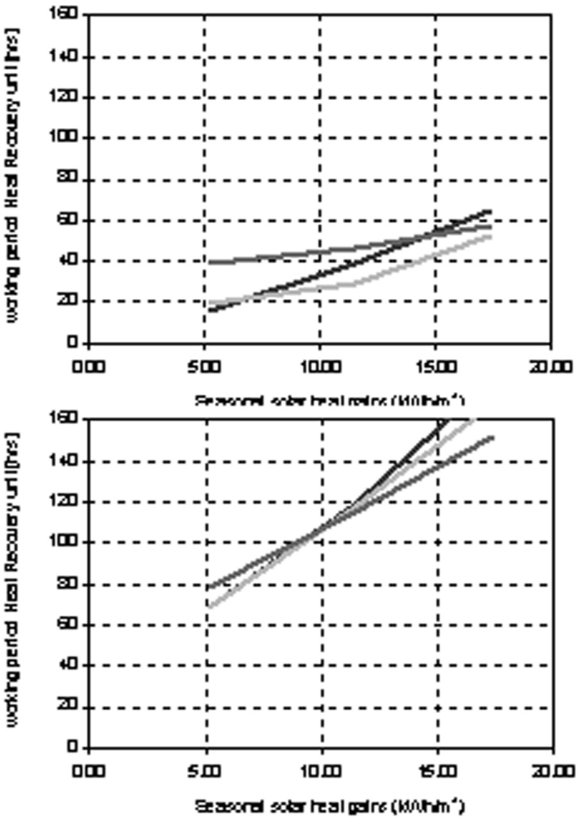

Figure 7: working period of radiant cooling system related, considering an airflow rate n = 0,6 [1/h] for scenario 3 (above) and scenario 4 (below).

The research has shown that it is possible to reach good levels of comfort using radiant cooling and hybrid ventilation even in sultry climate, demonstrating an effective alternative to the “traditional” cooling system. The designer has to pay attention to a correct dimensioning of solar control devices and it is appropriate to have a sustainable dehumidification using ground inertia.

The variations in use and in control of the radiant cooling devices are related to the working temperature flowing of the panels and the use of cooled floor or ceilings. By increasing the temperature value of the fluid a lot of benefits are possible in many cases but not considering long occupancy and a high internal load (in comparison to a simulation with the same boundary conditions). It is important to underline a higher temperature of the surfaces, reducing the risk of condensation, and increasing the working period of radiant cooling system.

The different position of radiant panels, on the floor or ceilings, in terms of comfort levels is almost the same. The role of inertia for massive layer placed on the floor can be equalize by cooled ceilings (light layers) and a correct use of ventilation. This means that in both variations, working temperature or position of the panels, the choice criteria must be based on the generator system of the cooled fluid medium.The use of heat recovery unit produces a relevant rise of working period of radiant cooling panels: it influences the energy consumption. Considering only summer period, it might be appropriate to use heat recovery unit only in case of constant occupancy and high internal loads. In these cases the research demonstrates an effective benefit in comfort and a similar working time of radiant cooling panels.

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