DYNAMIC SIMULATION REGARDING THE CONDENSATION RISK ON A COOLING CEILING INSTALLED IN AN OFFICE ROOM

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ABSTRACT

Ceiling radiant cooling with its many advantages on thermal comfort or energy reduction, didn't become a leader in this domain because of the fear of condensation on the chilled surface of the ceiling, especially in hot and humid climates. Using the building simulation code named Trnsys we have been able to simulate the risk of condensation on a cooling ceiling installed in an office room for different France climates. The problem underlying the current paper was to investigate the control system to be used to completely avoid the condensation risk and to see the effect of the ventilation rate on the radiant ceiling performances. As a conclusion, even though the system has more potential in temperate climate, it was also observed, as the simulations indicated, that the system is still able to ensure acceptable indoor conditions even in a hot and humid climate without any condensation on the cold surface of the ceiling.

KEYWORDS

Building simulation; cooling ceiling; capillary mat; condensation risk

INTRODUCTION

The majority of air-conditioning devices function on the principle of pulsated air, where the hot air of the room is recycled, cooled and returned into the room. In modern offices the increased use of computers and associated tools contributes to higher levels of thermal loads which must be evacuated from these buildings.

To maintain comfort under these conditions, a greater volume of cooled air must be provided to the work area. This increase in loads has lead to, on certain installations, residual air circulation speeds which are unsatisfactory for the comfort of the occupants. Classic air-conditioning systems that use air to reduce the indoor temperature and to create the necessary thermal comfort are habitually used in hot periods. The systems are likely to create uncomfortable environment caused by draught and air temperature differences between the human head and foot. Many complaints about air-conditioning systems have been claimed, especially in summer by female occupants (Imanari et al. 1999). The disadvantages show that a new cooling system needs to be proposed.

PROBLEM ANALYSIS

An alternative to air cooling is radiant cooling ceiling which is using water to chill the surface and so to reduce the air temperature inside the room. The energy transferred to the room by a classical air-conditioning is made only by convection but in the case of a cooling ceiling it's a sum of radiation and convection. The warm air rises near the cold surface of the ceiling then cools down and moves down at low velocities in the occupancy zone creating a comfortable indoor space.

The main key piece of the considered system is the mat of capillary pipes manufactured from polypropylene. This mat, comparable to a heat exchanger, consists of a grid of flexible tubes of a very small diameter, welded onto supply tubes. Water flows through the device at temperatures between 15°C and 35°C. The very small thickness of the heat exchangers capillary pipes allows them to be embedded into the surface of walls, ceilings and floors. Passive elements of construction are thus transformed into heating and air-conditioning surfaces by using the natural principles of energy exchange between two radiant bodies. Each mat element is connected in parallel to the overall cold water collector in order to induce a homogeneous distribution in the ceiling's surface temperature.

This cooling technique has many advantages not only on the thermal comfort aspect (Catalina and Virgone 2006) but also on the energy savings. The study of (Jeong et al. 2003) showed that radiant panel cooling systems consume 42% less energy as compared to conventional VAV systems with all air economizers. Despite the number of advantages, the system is vulnerable to condensation risk on the cold surface of the ceiling. The risk is higher in hot and humid climates but with a good control system or an air dehumidification it can be easily avoided. Another weak point is the limited specific cooling power, however for ordinary offices where internal charges are no more than 50-60W/m^2 the system is well suited. The price for the radiant system is still high by comparing to air-conditioning systems.

In Japanese market, where the summer is not only hot but also humid with an average dew point in August exceeding 22°C, the radiant ceiling definitively require dehumidification to avoid water condensation on the panels (Imanari et al. 1999).

In our simulations, we have managed to avoid the phenomenon of condensation on the radiant ceiling by using a dew point probe regulation and an efficient system of ventilation without using any dehumidification of the air.

(Imanari et al. 1999) analyzed by experimentation the thermal comfort and the energy consumption by simulations, (Miriel et al. 2002) developed a simulation model that was validated by experimentation and (Niu 1994) has modeled a space with cooling ceiling system, his main interest being the effect of the system on the indoor air quality.

Trnsys is an energy tool which helped us to simulate the cooling system and the control system.
We have carried out simulations for several cities in France in order to study the influence of climate on the control system.

The main goal of our study is to examine the control system that will avoid the condensation on the chilled surface of the ceiling, including the effect of the ventilation rate.

CONDENSATION PROBLEM

When the air is cooled, the relative humidity increases, until reaching saturation for a certain temperature, called the dew point temperature. More condensation of the water vapor in excess will be produced if the cold surface of the ceiling is lower than the dew point temperature of the air (DPTA). The basic condition to avoid the phenomenon of condensation on the cold surface of a wall, ceiling or floor is:

$$T_{surface} - T_{dew.poin.temperaturet} \geq 1°C \quad (1)$$

The condensation risk on the chilled ceiling panel is high because of the high humidity ratio in the region close to the panel. To prevent condensation on the panel, it is important to properly control the system for transient regimes, such as startup and shutdown periods (Novoselac and Srebic 2002). Several methods exist and can be used either to reduce or to eliminate completely the risk of condensation on the cold surface of the ceiling. First requirement is the ventilation system that not only will ensure the requirement level of fresh air in the indoor space but also regulates the latent or moisture load of the space reducing the value of the DPTA. A good solution to reduce the risk of condensation is also to dehumidify the air but this solution will increase considerably the price of the system but however it cannot be used alone, a control system being necessary for perfect safety against the condensation.
The simplest solution is to use a condensation sensor that will modulate the water flow. The inlet temperature of the water is controlled and modulated for the whole building in function of the temperature and humidity of the outdoor air. The condensation sensor will shut down the pump or it will close a security valve (Figure 1).

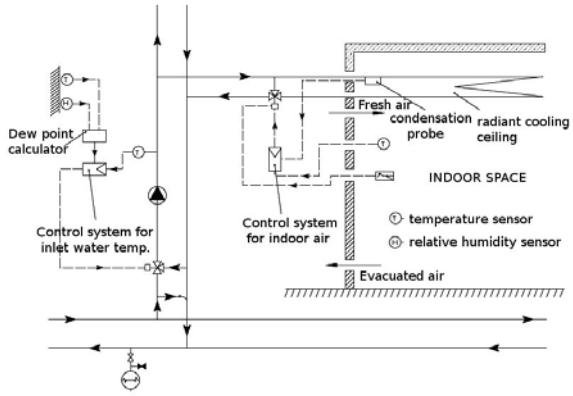

Figure 1 Central control of water temperature and local detection of the condensation

Since condensation of water occurs when the dew point temperature is reached, proper water temperature control will avoid any condensation. To prevent the formation of condensation, a sensor monitoring the dew point temperature of the room is used in conjunction with a controller which modulates the inlet water temperature accordingly. Therefore, if a risk of condensation is present, the water temperature is raised.

This is the best way to avoid the condensation because the water temperature is modulated centrally and locally and a permanent surveillance for each zone being active. The DPTA is calculated for each zone and the water temperature is adjusted to be always superior to this value. The DPTA is calculated by mean of air temperature and relative humidity and so the water temperature is compared with this calculated value (Figure 2).

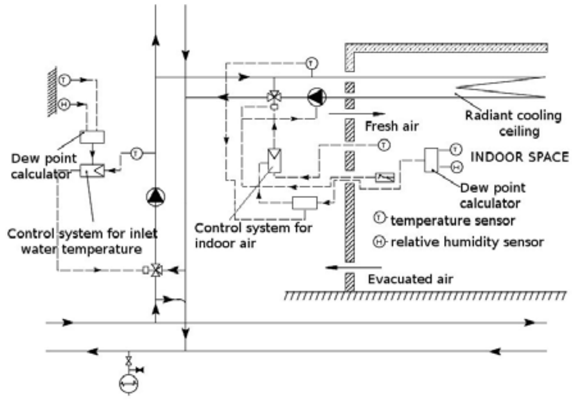

Figure 2 Central and local control of water temperature with zone surveillance

SIMULATION STUDY

We have simulated the chilled ceiling system by using the Trnsys simulation code. To simulate the system we created a virtual office room adjacent to a meeting room. The interest of creating two spaces for the simulation was to see and to compare the effect of latent production on the radiant cooling ceiling and in the same time to check the control system for both rooms. The purpose of analyzing the meeting room was to see the effect of the controller in the case of large latent source at one moment of the day.

We have made simulations for different cities of France in order to see the effect of climate on the performances of the system. Cities like Lyon, Bordeaux, Ajaccio or Nantes were dynamically simulated for the whole summer period. Different parameters like indoor and outdoor air temperature were analyzed but also the water temperature or ceiling surface temperature.

The control system presented in Figure 2 was reproduced under the simulation program and was used to avoid completely the condensation on the cold surface of the ceiling. The main interest of the simulation was to observe the reaction of the control system and what are its effects on the performances of the radiant system. The dimensions of the two indoor spaces cooled by the radiant ceiling are presented in Figure 3.

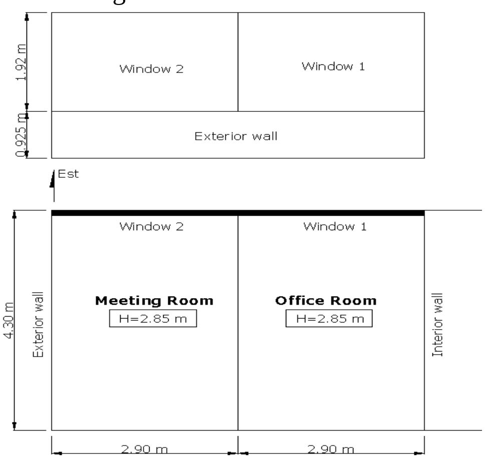

Figure 3 Office and meeting room used for the dynamic simulation

The exterior wall of each room has the dimensions of 2.9 m x 2.85 m and it has the following structure: 9.7 cm insulation (mineral wool) sandwiched between a 3 mm aluminum plate (outside) and a 2 mm steel plate (inside).The overall U value is 0.331 W/m^{2}K.

The facade has a double pane window with the dimensions of 2.9 m x 1.925 m. The overall U-value of the window is 1.76 W/m^{2}K. The transmissivity of the glass is 60%, and the absorptivity for each pane is considered 5% in both direct and diffuse radiation. Shades are installed over the windows, with a shading factor value of 0.35. The shading factor is defined as the ratio of non-transparent area of the shading device to the whole glazing area.

The interior walls consist of 8 cm layer of sheetrock sandwiched between 2- 4 mm layers of plaster. The ceiling (also roof for the building, as the simulated rooms are placed on the top floor) has the dimensions of 2.9 m x 4.3 m. Its structure consists of metallic panels with capillary pipes, 47 cm concrete, 1 mm vapor barrier, 10 cm roofmate insulation, 1 mm tar paper, 4 cm gravel, 12 cm concrete tiles. The overall U-value of the ceiling is 0.266 W/m^{2}K. The proprieties of the materials used are presented in Table 1.

Table 1 Materials proprieties

	ρ [kg/m3]	**Ct [kJ/kg-K]**	**λ [W/mK]**
Mineral wool	85	0.83	0.034
Plaster	1400	0.90	0.70
Sheetrock	1000	1.10	0.40
Concrete	2400	1.04	1.80
Roofmate	33	1.40	0.032
Gravel	1650	0.90	0.70
Plywood	800	2.50	0.15
Still air	1.2	1.00	0.59

The following occupancy pattern was simulated during the summer period:

Table 2 Occupancy pattern

	Occupants
Office room	2 occ. from 8:00 to 17:00
Meeting room	4 occ. from 10:00 to 11:00 and 15:00 to16:00

The working period is from Monday through Friday and the internal loads (computers) are following the same pattern. The internal loads from occupants are 120 W/occupant which corresponds to 65 W sensible heat and 55 W latent heat. The internal loads from office computers are supposed to be 140 W/terminal.

The ventilation rate was set to 1.1 ach (39 m^3/h) without any air treatment and with an infiltration of 0.1 ach (3.5 m^3/h). The supply rate is 0.55 ach (19.3 m^3/h) during the night and the weekends.

The water flow is 300 l/h (0.083kg/s) per each chilled ceiling installed. The water is supplied at a temperature that was adjusted by the control system presented in Figure 2. The ceiling pipes are made out of polypropylene, have 4 mm exterior and are spaced by 1.5 cm.

RESULTS

The first results consist of a comparison between the case when we don't have any air-conditioning system and the case when using the radiant cooling ceiling. In all these simulations the control system was used and no condensation was detected during the whole period, the surface temperature of the panels always be higher than the dew point temperature of the air .

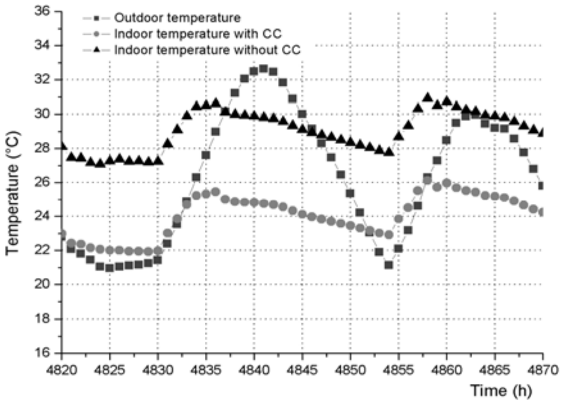

Figure 4 Office room air temperatures for two days simulation with/without the cooling ceiling (CC)

It can be observed the good effect of the radiant ceiling on the air temperature compared to the non improved case. If the CC was able to keep a value of air temperature at 26°C, in the case without any system the indoor air temperature could have reached 31°C, so it is possible to lower the air temperature with more than 5°C and in the same time to stay protected from the condensation. The simulation presented in Figure 4 corresponds to Lyon climate for a maximum outdoor air temperature of 33°C.

The control system behavior was correct, adjusting accordingly the inlet water temperature of the two cooling ceilings installed in the two rooms. In Figure 5 it can be observed that the water temperature adjusted its value increasing relative quickly because of the high risk of condensation due to the outdoor conditions. The ventilation system introduces the outdoor air with a high relative humidity and coupled with the internal latent loads is increasing the risk of condensation, the cooling system being obliged to receive the water at higher values that could reach values of 22°C.

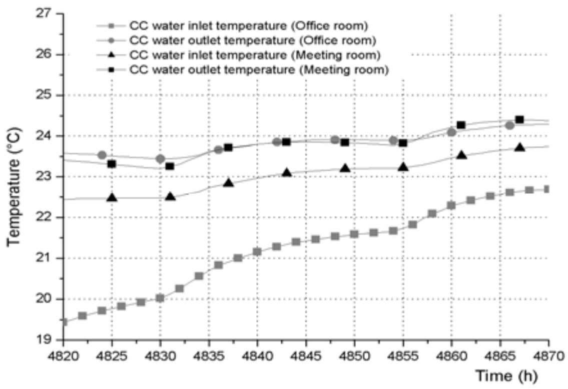

Figure 5 Inlet/outlet water temperatures of the CC for the two indoor spaces

The relative high amount of latent load dissipated in the air by the four occupants in the meeting room is translated by a higher inlet water temperature than in the office room where in the same surface as the meeting room only two persons are the humidity sources, however for a longer period.

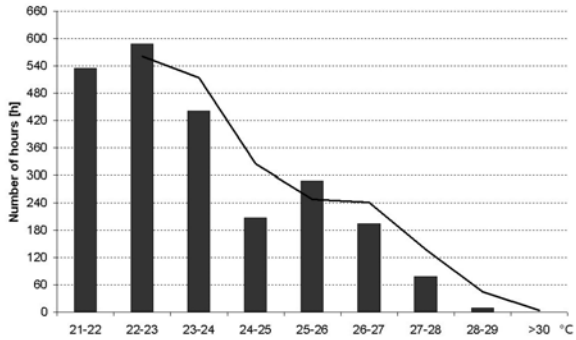

Figure 6 Air temperatures distribution for the summer period and for Lyon climate

In Figure 6 are presented the number of hours of temperatures when using the CC in the office room and for the Lyon climate. Only 9 times the air temperature is higher than 28°C. However the high value of the air temperature, the thermal comfort when using a chilled ceiling can take good values even the air temperature is higher (Catalina and Virgone 2006). The thermal comfort which is function of mean radiant temperature can be the same when using the CC at higher air temperatures with an AC system.

During the simulations we also analyzed the effect of the ventilation rate on the cooling ceiling performances. In fact, when we talk about the performances we are referring to the control system that will adjust the water in the radiant panels and so the surface temperature and we can see the effect on the air temperature. The ventilation rate varied from 0.5 ach to 1.5 ach. It can be concluded that the ventilation rate can be an influencing parameter for the chilled ceiling performances (see Figure 7).

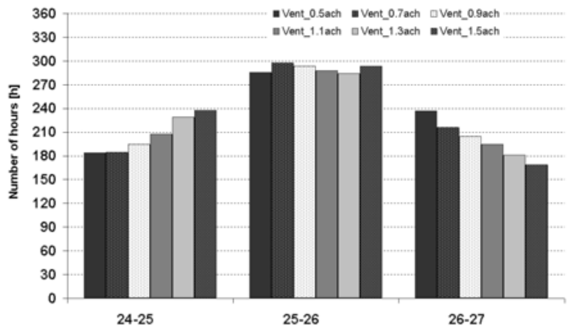

Figure 7 Air temperatures distribution when using the CC and for different ventilation rates

We can conclude on this part that higher the ventilation rate is, less values of the air temperature are passing 26°C. It is recommended that this value should be at least 0.9ach and higher when we have more latent loads or a humid climate. The cooling ceiling was simulated by (Stetiu 1999) who found that the decoupling of energy transfer mechanism from the ventilation function by means of radiant cooling systems results in a peak power savings that vary from 27% to 37%, depending on the geographical location.

We have analyzed also different cities from France were we obtained the same good results on air temperature even they are located in hot and humid climates. In Table 3 are presented the ceiling surface temperature when using the CC at a constant inlet water temperature (without control system) and when using the control system. We must precise that the set point of the CC was set at 26°C. For Bordeaux city climate the difference between the maximum temperatures of the CC with/without the control system is of 2°C. The control system has adjusted the water temperature to avoid the condensation on the surface of the chilled panels. For Ajaccio climate the minimum temperature of the ceiling was 19.76°C and a maximum of 26.5°C which corresponds to the limit that will avoid the condensation.

Table 3 CC surface temperature in the office room for different cities

With the Control System

Bordeaux		**Lyon**	
Min	Max	Min	Max
18.46	24.48	18.23	24.76
Ajaccio		**Nantes**	
Min	Max	Min	Max
19.76	26.5	17.91	24.91

Without the Control System

Bordeaux		**Lyon**	
Min	Max	Min	Max
17.73	22.44	18.03	22.41
Ajaccio		**Nantes**	
Min	Max	Min	Max
17.6	22.53	17.81	22.52

CONCLUSIONS

This study intention was dedicated to the control system to be used to avoid completely the condensation problem. Another important part of the study was to better understand the influence of the ventilation system and the climate on the radiant ceiling performances, more exactly the effect on the indoor air temperatures. The results clearly indicate that the condensation risk is higher when latent charges are increasing but they indicate also that the control system seems able to prevent the condensation at any moment.

The simulated control system has managed in any moment the ceiling surface temperature in order to prevent the condensation. For cities were the condensation risk was higher the temperature of the water and so the temperature of ceiling was adjusted accordingly.

We can conclude that radiant system can be used in office buildings without any problems regarding the condensation and the room air temperature can be set higher than with convective air conditioning systems (Catalina and Virgone 2006) creating a pleasant ambient to work.

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