GUIDANCE AND TOOLS FOR CHILLED CEILINGS COMBINED WITH A WET COOLING TOWER

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ABSTRACT

The combination of an open wet cooling tower with chilled ceilings is a CFC free, cheap and low energy cooling solution. The efficiency of this alternative to mechanical cooling is very dependent on climate. There is a need for specific tools to help designers to size the system and to estimate its energy and water consumption.
A building simulation tool, called ConsoClim, has been used to predict the performance of this system for different French climatic locations, thermal inertia, internal loads and solar gains. Since the system is climate dependent and has a limited maximum cooling power, an adapted control strategy is proposed to take advantage of the building thermal mass, allowing night cooling.
The air conditioning plant and its control strategy are presented. A radiant system model and an open wet cooling tower model with possible air flow rate variation have been implemented in the simulation tool ConsoClim. From the calculations of the detailed design tool, pre-design guidance are given.
The results show the promising potential of this technology in most of the climatic zones of France when associated with an anticipative control strategy and for buildings with low or medium loads.

KEYWORDS

Chilled ceiling, cooling tower, simulation tool, sizing, control strategy

INTRODUCTION

Chilled ceiling is a fully developed technology which is commonly used in central and northern European countries. Its main advantages are the thermal comfort, no ground cluttering, the low maintenance and the energetic efficiency. Since the heat transfer is mainly due to thermal radiation, heat loads can be carried off at relatively small temperature differences between room air and cooled ceiling surface. The system can so run at supply water temperatures between 16 and 20°C. The system generally runs with a chiller but it could be possible to deliver the cold water with a cooling tower only. Sprecher et al. (2000) have experimented this solution on a building in Switzerland. The tests have shown that the combination of a chilled ceiling with a closed cooling tower can maintain indoor air temperature below 27°C.
The use of this technology for cooling buildings results in a low energy consumption, a low cost and a CFC free cooling system. The initial and running costs are low compared with a conventional (all-air) air-conditioning system (Oliveira, 2000). The energy consumption is limited to the pumps and the tower fan. This results in high coefficient of performance and so in lower CO_2 emissions. The cooling tower takes advantage of the evaporation of water in air and the cooled water approaches the outdoor air wet-bulb temperature depending on the

effectiveness of the heat transfer process. Thus, the minimum water temperature entering the ceiling panel is few degrees above the wet-bulb temperature. Since the cooling performance depends deeply on outdoor air conditions, short overheating periods can occur in the building. A night control strategy taking advantage of cooling energy storage in the building mass can reduce or even suppress the number of discomfort hours.
What is the potential of this technology combining chilled ceilings with cooling tower in France? The performance of this cooling system is simulated using ConsoClim (Bolher, 1999), a software package to calculate energy consumption of air-conditioned buildings. A control strategy, including night cooling, is introduced in the simulation. The applicability of the system is studied for few climatic zones of France, two building inertia, two internal loads and two solar gains.

METHODOLGY

Simulation tool
Consoclim (Bolher, 1999) is a building simulation tool in which HVAC equipments such as cooling coil, radiant panel and cooling tower have been implemented. The HVAC equipment models have been developed in order to be simple to parameterize by using one nominal rating point available in manufacturer's catalogs.

Meteorological data
For sizing, the simulations are carried about from a reference hot day defined in (RT2000 Règles Th-E, 2000). As the cooling system is very dependant on wet-bulb temperature, the daily variation of the humidity ratio is taken into account (Bolher et al., 2001). The selected climates of France are those of Trappes (near Paris), Carpentras (South of France) and Nice (South Est of France). Figure 1 shows the frequency of occurrence of wet-bulb temperatures in France in two climatic zones : Nice close to Mediterranean sea and Trappes close to Paris.

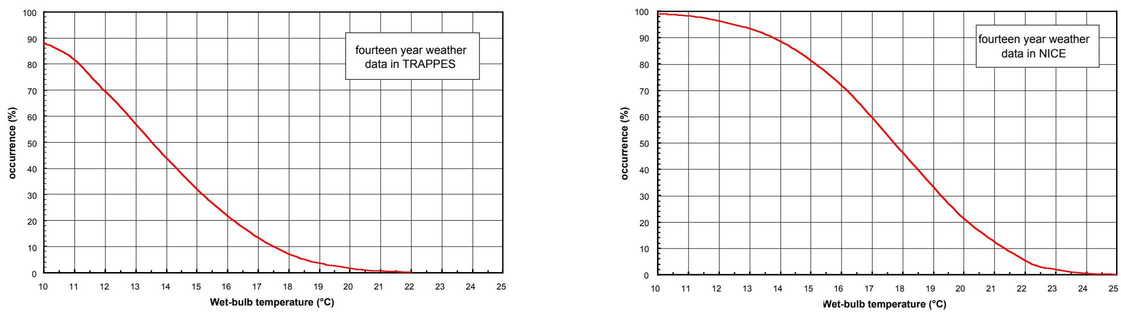

Figure 1 : frequency occurence of the wet-bulb temperature in Trappes and Nice

One can see that wet-bulb temperature in Trappes is rarely above 20°C. On the other hand, the wet-bulb temperature in Nice is 20% of time above 20°C. We can conclude that the cooling potential of the system will be more important in Trappes than in Nice. Moreover, the system will not be able to cool the building all the time in Nice.

Case studies
The test cases are office building zones with the following characteristics:
- floor area A_{room} : 3 m × 5 m = 15 m^2
- front wall : 3 m × 2.7 m including a window area, A_{glaz}, of 3 m × 1 m
- room height : 2.7 m
- double glazing window: two solar gains are studied.

The results are given in the form of a solar gain index defined as $A_{glaz} \times F_{glaz} / A_{room}$ where F_{glaz} is the solar factor. The minimal value is fixed at 0.05. In order to respect the new French thermal regulation (RT2000 Règles Th-E, 2000), the maximal value is fixed at 0.10 for medium inertia buildings and at 0.15 for high inertia buildings.

- Two thermal inertia are taken into account: medium and high according to the definition of RT2000 Règles Th-E (2000).
- Orientation : East, West

The other parameters are:

- occupation : 9 h to 18 h weekdays
- internal sensible gains (convection part : 0.5) : 10 W/m^2 and 30 W/m^2 during occupancy
- internal moisture gains : 110 g/h during occupancy
- airflow rates: 1 ac/h and the corresponding fan energy rate: 15 W.

SYSTEM DESIGN AND CONTROL

Description of the cooling system

The chilled ceilings consist of water pipe parallel circuits embedded on the upper side of metal panels. These large surface emitters transfer heat by radiation and convection. The chilled ceiling transfers directly heat with occupants, equipment (computers, fax…) and room surfaces by radiation, what brings better comfort and allows to operate at quite high inlet water temperature. The water temperature difference between the inlet and the outlet is about 3 K. In order to avoid the risks of condensation on the emitter surface, the water temperature should not be too low or a dew point sensor should be installed otherwise the supply air should be dehumidified. The cooling power depends on the total active surface of the ceiling which is generally limited to about 80% of total ceiling surface since some place should be reserved for the lighting… The heat transfer rate varies between 50 and 80 W/m^2 at 8K difference between air and mean water temperature depending on the conductance of the emitter.

The ceiling is fed with water cooled by using a cooling tower. Two cooling tower options can be selected: a closed wet cooling tower or an open wet cooling tower with a heat exchanger to separate the cooling tower circuit and the chilled ceiling circuit. In open cooling tower, the water could be dirtied by direct contact with outdoor air and it is better to use clean water in the ceiling to avoid maintenance. In the present study, open cooling tower has been selected since its price is much lower than closed cooling tower at same heat exchange capacity. The cooled water in the tower approaches the wet-bulb temperature of outdoor air with a pinch of 2 to 4 °C. As the water temperature entering the ceiling tube is always higher than air wet-bulb temperature, the risk of condensation is avoided unless the indoor moisture gains are very important.

Concerning ventilation, it has been chosen to cool the supply air by using a cooling coil fed with the water coming out of the tower. More comfortable supply air temperatures are obtained and the maximum indoor air temperature during occupancy is slightly lowered of 0.5°C (see Table 1).

TABLE 1
Impact of the use of a cooling coil in the air handling unit for a reference hot day in Trappes

Trappes	Air Handling Unit	
Building case : medium inertia, high solar gain, low internal gains	With cooling coil	Without cooling coil
Maximum supply air temperature (°C)	25.7	31.4
Maximum indoor air temperature during occupancy (°C)	26.8	27.3

The system is represented on Figure 2.

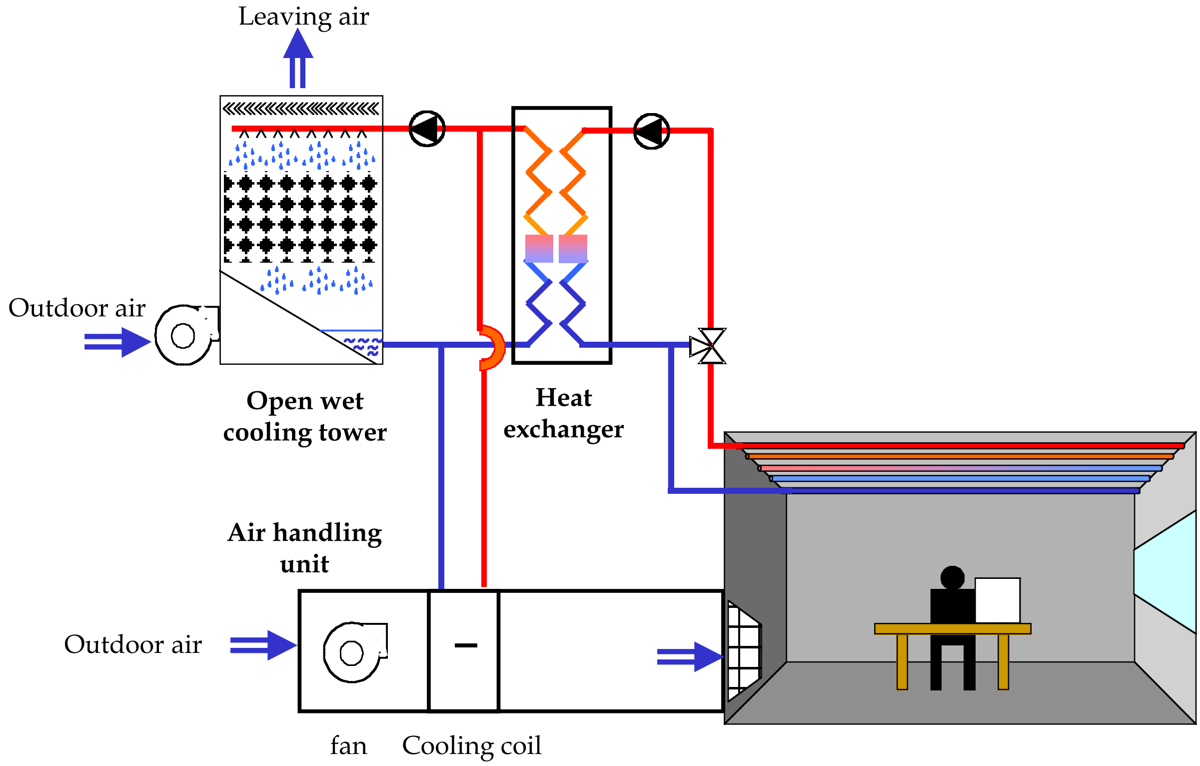

Figure 2: schematic representation of the cooling system using chilled ceiling combined with a cooling tower

Control Strategy

The set point indoor air temperature is 25°C during occupancy and 22 °C during inoccupancy. The inoccupancy set point value is lowered in order to pre-cool the building during night. The water flow rate in the emitter tubes is adjusted to maintain the set point conditions. The set point supply air temperature is fixed at 25°C during occupancy. The air handling unit is off during inoccupancy in order to limit fan consumption and because cooling potential of the ceiling emitter is more important than the one of the night ventilation. The cooling tower operates as long as cooled water is required in the radiant panel to keep the set point conditions.

Sizing parameters

Chilled ceiling panel have large surface area. The influence of the emitter surface on the cooling power and the operative temperature on a reference hot day is presented in Figure 3. In this example, a surface emitter between 60% and 100% of total ceiling surface can keep acceptable indoor air conditions. The deviation of the maximum operative temperature is quite small when the emitter surface decreases since the night control strategy allows to compensate the diminution of maximum cooling capacity and the slight increase of room air temperature augments the heat transfer between the room and the chilled ceiling. However, below a certain limit of emitter surface, the chilled ceiling is not anymore efficient to remove internal loads. Afterwards, an emitter surface of 80% of the ceiling surface is selected, which corresponds to the ceiling surface generally available in office buildings.

The performance of the chilled ceiling is an important sizing parameter. A survey of manufacturer's catalogs shows that large differences of heat transfer exist versus the technology of the ceiling. The given performance data are based on the German standard DIN 4715 (1994).

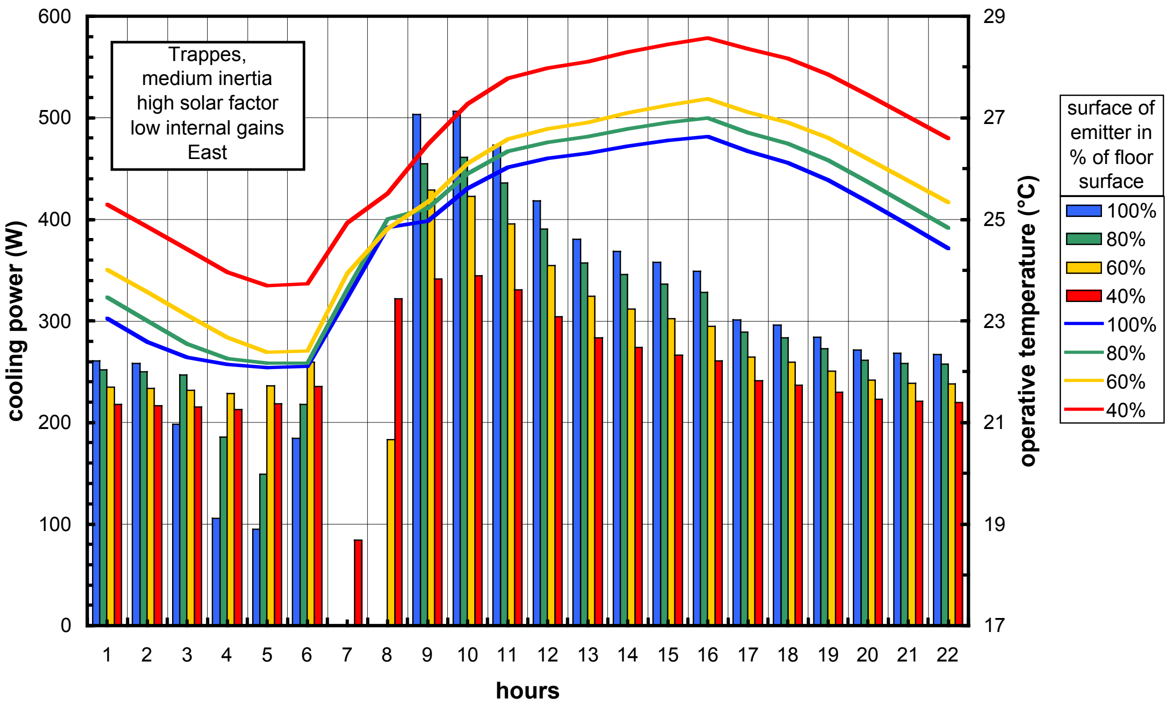

Figure 3: influence of emitter surface on operative temperature and cooling power on a reference hot day in Trappes

The simulations of cooling system are carried out with the following parameters:

- Counterflow open cooling tower performance: water temperature range of 32 / 28°C at 21°C wet-bulb temperature and fan energy rate of 45 W;
- Heat exchanger efficiency: 0.8;
- Radiant panel heat transfer rate: 30W/m^2, 40 W/m^2 and 50 W/m^2 at 6K difference between room air temperature and mean water temperature. Notice that 50W/m^2 at 6K corresponds to about 90W/m^2 at 10K.

SIMULATION RESULTS

The simulation results presented in Table 2 are:

- the mean indoor operative temperature on the three hottest hours of occupancy;
- the maximum total loads (sensible + latent) determined according to classical HVAC sizing procedure. The maximum loads determined with the software Consoclim are about 30% lower mainly because building thermal inertia is taken into account;
- the mean indoor operative temperature on the three hottest hours of occupancy reached if the building was not equipped with an Air Conditioning (A.C.) System (RT2000 Règles Th-E, 2000). In this case, the building is only cooled down by the opening of the window.

Results show that set point temperatures can be respected in Trappes in most of building cases when the maximum loads are below 80W/m_. The chilled ceiling combined with a wet cooling tower can not keep comfort conditions in Nice except for building with very low loads. The wet-bulb temperatures are quite high in Nice and the water temperatures entering the ceiling are too high to provide the required cooling demand. In Carpentras, the cooling system is adapted provided that solar protections are used and the building inertia is high. A radiant panel with a high conductance can help to lower the maximum operative temperature up to 2.5°C.

TABLE 2
Simulation results

Building Case																
inertia	medium								high							
Solar gain index	0.05				0.1				0.05				0.15			
Internal gains (W/m?)	10		30		10		30		10		30		10		30	
Orientation	E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W
TRAPPES (closed to Paris)																
Max loads (W/m?)	37.5	49	57.5	69	62.5	75.5	82.5	95.5	37.5	49	57.5	69	88.5	103	109	123
Max. Temp. without A.C. system (°C)	29.5	30.5	33	34	31	33.5	34	36.5	29	29.5	32	32.5	31.5	33.5	34.5	36.5
ceiling panel heat transfer rate at 6 K	MEAN OPERATIVE TEMPERATURE on the three hottest hours (°C)															
30 W/m?	25.5	26	28	28	27.5	27.5	30	29.5	25	25	26.5	26.5	28.5	28	31	30.5
40 W/m?	25.5	25.5	27.5	27	27	27	29	29	25	25	26	26	27.5	27	29.5	29
50 W/m?	25.5	25.5	27	27	26.5	26.5	28.5	28	25	25	25.5	25.5	27	26.5	28.5	28.5
NICE (seaside Mediterranean climate)																
Max loads (W/m?)	54	63	74	83	85	93.5	105	114	54	63	74	83	116	125	136	145
Max. Temp. without A.C. system (°C)	31.5	33	34.5	36	33	35.5	35.5	38.5	31	32	34	34.5	34	36	36.5	39
ceiling panel heat transfer rate at 6 K	MEAN OPERATIVE TEMPERATURE on the three hottest hours (°C)															
30 W/m?	27.5	27.5	30.5	30	30	29.5			27	27	29.5	29.5	31.5	31		
40 W/m?	27	27	29.5	29.5	29	28.5	31.5	31.5	26.5	26	28.5	28.5	30.5	30		32
50 W/m?	26.5	26.5	29	29	28.5	28	31	30.5	26	26	28	28	29.5	29	31.5	31.5
CARPENTRAS (inland Mediterranean climate)																
Max loads	47	59.5	67	79.5	76	90.5	96	111	47	59.5	67	79.5	107	122	127	142
Max. Temp. without A.C. system (°C)	32.5	34	36	37.5	34.5	37	37.5	40	32	32.5	35	35.5	35	37.5	37.5	40
ceiling panel heat transfer rate at 6 K	MEAN OPERATIVE TEMPERATURE on the three hottest hours (°C)															
30 W/m?	26.5	27	29	29	28.5	28.5	31.5	31	26	26	28	28	30	29.5		
40 W/m?	26	26.5	28.5	28	28	28	30.5	30	25.5	25.5	27	27	29	28.5	31	31
50 W/m?	26	26	28	28	27.5	27.5	29.5	29.5	25.5	25.5	26.5	26.5	28	27.5	30	30

temperature between 28°C and 32°C
temperature over 32°C

CONCLUSION

The combination of a chilled ceiling with a cooling tower is a friendly air-conditioning solution which can maintain comfortable indoor air conditions in main climatic regions of France provided that the building loads are not too high. In the case of high building loads, the use of a chiller with its condenser cooled by the cooling tower in the peak cooling load days and the use of the cooling tower only by bypassing the chiller in medium cooling load days could limit energy consumption of air-conditioned buildings. The wet-bulb temperature is an essential parameter in sizing the cooling plant.
Inasmuch as HVAC designers have no experience in sizing of this air-conditioning solution unlike conventional air-conditioning system, building simulation tools can help them in this task. The ConsoClim software package remains at the moment a research product. A sizing guidebook for low energy cooling technologies will be published in 2003 including tables similar to Table 2 for all climate zones of France and giving energy consumption examples.

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