AN ECOLOGICAL COOLING SYSTEM USING CHILLED CEILINGS AND CLOSED WET COOLING TOWERS

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ABSTRACT

This paper describes work done under a European research project to develop a cooling system integrating a closed wet cooling tower with chilled ceilings. Major features include the development of a new tower prototype, CFD modelling of the tower, measurement of tower performance, system simulation under different climatic conditions and field testing of system in a real building. Results indicate that the system is efficient and economically interesting.

KEYWORDS

Chilled ceiling, cooling tower, measurement, simulation, system performance

INTRODUCTION

Increased use of IT equipment and higher thermal comfort requirements have led to an increased demand for cooling in offices. A simple and economic way of cooling office buildings is to use chilled ceilings combined with an indirect contact cooling tower. The use of chilled ceilings offers several advantages over conventional cooling systems, like reduced ventilation rate and smaller distribution system. Due to heat transfer by combined convection and radiation, chilled ceilings enable rooms to have low air movement and a comfortable indoor environment.

Because moderately high water temperatures can be used in chilled ceilings (18-20°C supply temperature), it is possible to cool water in a closed wet cooling tower during most of the cooling period. The cooling tower could be combined with a supplementary refrigeration plant, or used alone if a short period of overheating is allowed or energy storage or night-cooling techniques are used. Closed wet cooling towers have been used to remove excess heat from various industrial processes with hot water temperatures between 32 and 46°C and typical cooling capacities above 40 kW. For chilled
ceilings, **cooling towers** with lower capacities and smaller tower dimensions can be used with inlet water temperatures ranging from 22 to 25°C.

This paper describes work done under a European research project to develop such a cooling system. One prototype of a closed wet cooling tower, adapted for use with chilled ceilings, was built and tested. Both experiment and CFD simulation were used to predict and improve tower performance. Results allowed the manufacture of a high performance cooling tower unit.

A model was developed to simulate the cooling system behaviour, using the TRANSYS environment. A module for the cooling tower was specially developed. Simulation results for the whole cooling season will be shown, for different European locations. Results indicate that the system is viable and efficient and has running costs which are lower than those of a conventional cooling system, using a refrigeration machine.

A real system is being tested in an office building, using an adequate control strategy. Preliminary performance results are reported.

**COOLING TOWER DEVELOPMENT**

A first prototype of a closed wet cooling tower was built. Design conditions were a cooling capacity of 10 kW, for a cooling water rate of 0.8 kg/s, an inlet water temperature of 21°C and a wet bulb air temperature of 16°C. A crossflow fan was used, located at tower inlet. This configuration was preferred to an axial fan located at tower exit because it allows a lower air pressure drop and noise level. It also improves air distribution in the tower. The resulting tower had a section of 0.6 m x 1.2 m and a height of 1.55 m. The heat exchanger was a tube bundle with 10 mm tubes, with a total area of 8.6 m² (228 staggered tubes).

A CFD model of the tower was developed to study air and spray water distribution, (Gan and Riffat, 1999). The FLUENT software package was used, (Fluent, 1993). It was found that both air and spray flows could be improved, resulting in a better tower performance.

Measurements were carried out in a test facility to evaluate tower performance. The influence of spray water rate in tower thermal efficiency is shown in Fig.1.

![Fig.1 - Effect of spray water rate in tower efficiency, for different air and water rates: $\eta_{\text{spray}}$ = 1.39 kg/s, wet bulb temperature = 12.6°C.](image)

Fig.1 – Effect of spray water rate in tower efficiency, for different air and water rates: $\eta_{\text{spray}}$ = 1.39 kg/s, wet bulb temperature = 12.6°C.
An increase in spray rate increases tower efficiency (and cooling capacity) up to a certain level – lower spray rate values. Above that – around 1 kg/s - an increase in spray rate does not improve significantly tower thermal performance, because tube surface wetness is not improved. This means that spray rate can be optimised, leading to a reduction in water and energy (pumping) consumption.

It was concluded that if spray rate is kept close to the optimum, tower efficiency is a function of only 3 operating variables: air rate, cooling water rate and wet bulb air temperature. Experiment showed that tower thermal efficiency was lower than design values. It was also concluded that power consumption could be reduced.

A new tower prototype was built with improved air and spray distribution, as well as power consumption. The new prototype has a radial fan at tower inlet and a more compact heat exchanger: 262 staggered tubes of 12 mm outside diameter, with a total transfer area of 12.1 m². Tower dimensions are a section of 0.52 m x 1.23 m and a height of 1.74 m. This unit has the design cooling capacity but with a lower air flow rate: 1.7 kg/s. Power consumption is equal to 1080 W for the fan at design flow rate and 200 W for the spray pump with a rate of 1.4 kg/s. Fig.2 shows a view of the new prototype. It has a transparent plastic material in one side to allow spray water flow visualisation.

Fig.2 – View of tower second prototype.

Fig.3 – Predicted trajectories of water droplets in the new cooling tower (half tower shown).
Fig. 3 shows spray water distribution in the new prototype, using CFD model. Flow of water droplets between tubes is rather uniform and, as a result, tubes are fully wetted.

**SYSTEM SIMULATION**

A simplified model of a closed cooling tower was developed. Experimental data for the tower prototype were used to obtain a correlation for the mass transfer coefficient as a function of air flow rate, (Fação and Oliveira, 2000). The tower model was integrated in other models – chilled ceiling and building – using the TRANSYS environment, (TRNSYS, 1994). System control features were also added.

The system model was used to quantify system performance and energy consumption, for different climates. Test reference year (TRY) climatic files were used, for different locations in Europe: Helsinki, Zurich, London and Lisbon.

An office building was used for the simulations, composed of several identical rooms, each with an area of about 10 m² and with a typical construction. Chilled ceiling area was fixed at 67.5% of floor area. Internal gains and occupancy patterns typical of office buildings were considered. The use of only one cooling tower unit was considered. As a result, for each climate there is a maximum building area that can be cooled with one tower unit, with acceptable indoor thermal conditions.

As an example, Fig. 4 shows simulation results for the whole cooling season, for Zurich, with an office area of 580 m². During working hours, indoor temperature reaches a maximum of 27.5°C, but is above 26°C only 40 hours. System COP, defined as cooling capacity divided by fan and pumps energy consumption, varies with operating conditions and reaches a maximum of 12, with an average value of 6.6. Table 1 presents average system COPs and maximum cooling area with one tower unit, for the different locations (climates) studied. A maximum of 40 hours with T>26°C was imposed.

![Graph showing temperature and cooling power over time](image-url)

**Fig. 4 - System simulation results for Zurich**
Table 1 – Average COP and cooling area for different climates.

<table>
<thead>
<tr>
<th>Location</th>
<th>Helsinki</th>
<th>London</th>
<th>Lisbon</th>
<th>Zurich</th>
</tr>
</thead>
<tbody>
<tr>
<td>COP</td>
<td>5.3</td>
<td>4.6</td>
<td>4.0</td>
<td>6.6</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>800</td>
<td>420</td>
<td>220</td>
<td>580</td>
</tr>
</tbody>
</table>

Average system COP is higher than the average COP of a system using a conventional vapour compression machine (either using water or air distribution). This shows that the system has a lower energy consumption than conventional cooling systems.

SYSTEM FIELD TESTING

An office building located in Urdorf, Switzerland, was chosen for a system long term performance test. An area of 300 m² in the top floor with chilled ceilings, previously cooled with cold water from a conventional cooling machine, was connected to the present system. The second tower prototype was installed on the roof. The system uses two circuits, connected by a plate heat exchanger, as represented in Fig.5. The tower circuit is made with metallic tubes and the chilled ceiling circuit is made with plastic tubes. The tower power consumption is adapted to the cooling demand by controlling fan speed with a frequency controller. Spray water pump and circulation pump are running with constant speed because their energy consumption is of minor importance compared to fan consumption. Flow in the secondary circuit (rooms) is controlled by individual thermostatic valves.

![Diagram](image)

Fig.5 – Test system and control variables.

The system has been operating since July 1999. Fig.6 shows measured results during one week of September. Indoor temperatures were always at acceptable levels. A maximum of 27°C was measured in one room, with normal values below 26°C in all other rooms. During the same period outdoor air temperature went up to 32°C. Occupants showed satisfaction regarding indoor thermal conditions. Average system COP during this period was equal to 3.2.
CONCLUSIONS

An ecological cooling system for buildings, combining a closed wet cooling tower with chilled ceilings, was developed. A new cooling tower prototype, adapted for use with chilled ceilings, was built, taking into account CFD simulation and experimental results.

A global system model was used to predict system performance. Simulation results for different locations in Europe indicate that the system is efficient and has lower running costs when compared to a conventional cooling system.

A real system has been tested in an office building, confirming system efficiency. A detailed economical analysis of the system will be made after further results become available.

REFERENCES


TRNSYS (1994): A Transient System Simulation Program, Univ. Wisconsin, Madison, USA.

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