Implementing the Results of Ventilation Research
16th AIVC Conference, Palm Springs, USA
19-22 September, 1995

Cooling Performance of Silent Cooling Systems Built by Free Convective Coolers

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Synopsis

For the planning of "silent cooling" systems built by free convective coolers, it is necessary to support characteristic data for the cooling performance and the effect of different installation and operating parameters on the cooling performance. At the "Institut für Angewandte Thermodynamik und Klimatechnik" at the University of Essen measurements of the cooling performance of free convective coolers were carried out by using a testing chamber as well an enlarged and modified testing room with dimensions near to practise.

The investigations have shown that the cooling performance of convective coolers varies with different parameters like dimensions of the room, distibution of heat sources and positioning of the coolers in the room. A realistic investigation of these coolers and an objective comparison with other systems like chilled ceilings is only possible, if the investigation takes place under realistic operating conditions and arrangements of coolers and heat sources. Otherwise, the results from different systems are not comparable. The effects of different installation parameters have shown, that an accurate planning of the installation is necessary to guarantee sufficient cooling performance.

List of symbols

C		regression coefficient
ε	[-]	emission coefficient
n		regression coefficient
$\dot{q}$	[W/m^2]	heat-flux density
t_i	[°C]	initial temperature of the heat distribution medium
t_r	[°C]	return temperature of the heat distribution medium
t_R	[°C]	room temperature inside the testing chamber
Δt_R	[K]	logarithmic temperature gradient between room and heat carrier

1. Introduction

Nowadays chilled ceilings in combination with ventilation systems are often installed, so that the total energy consumption can be reduced by the separation of cooling and ventilation. This reduction can be reached because it is more effective to transport energy using water systems instead of air to deliver cooling energy to the consumers. Instead of using chilled ceilings to deliver the sensible cooling to the room it is possible to install free convective coolers inside the room or above an intermediate ceiling to compensate the cooling loads.

For the planning of these systems it is necessary to support characteristic data, which describe the cooling performance of these systems. In Germany there are two different standards for measurements of cooling performance at these systems available. The DIN 4715 /1/ of the German standard organisation regulates the measurements at chilled ceilings as well as the investigation of the cooling performance of free convective systems. The guide-line /2/ of the the German FGK e. V. (Fachverband Gebäude-Klima e. V.), in which the leading manufacturing, planning and installation companies are represented, defines the boundary conditions for measurements of cooling performance of chilled ceiling modules in a testing chamber.

During the last few years these two standards were often used to investigate the cooling performance of chilled ceilings, where the heat transfer to the room bases mainly on radiation. But up to now little has been published about the use of these standards in the determination of cooling performance of free convective coolers. In this paper the experiences with measurements of the cooling performance of free convective coolers in the testing chamber, which is described in the guide-line of the FGK e. V., at the "Institut für Angewandte Thermodynamik und Klimatechnik" at the University of Essen will be presented as well as results from measurements in a modified enlarged testing room. A proposal for measurements at free convective coolers and the main aspects of the installation of these systems will be discussed.

2. Testing chamber and conditions for measurements

The testing facility, that is explained in the guide-line of the FGK e. V./2/, bases on thermal measurements at chilled ceiling elements with closed or open surfaces in a testing chamber as shown with plan and side view in Fig. 1. The conditions for measurements and the testing chamber are described in detail in the guide-line of the FGK e. V. as well as in /3/, so that only the main parameters will be repeated.

plan and side view of the testing chamber

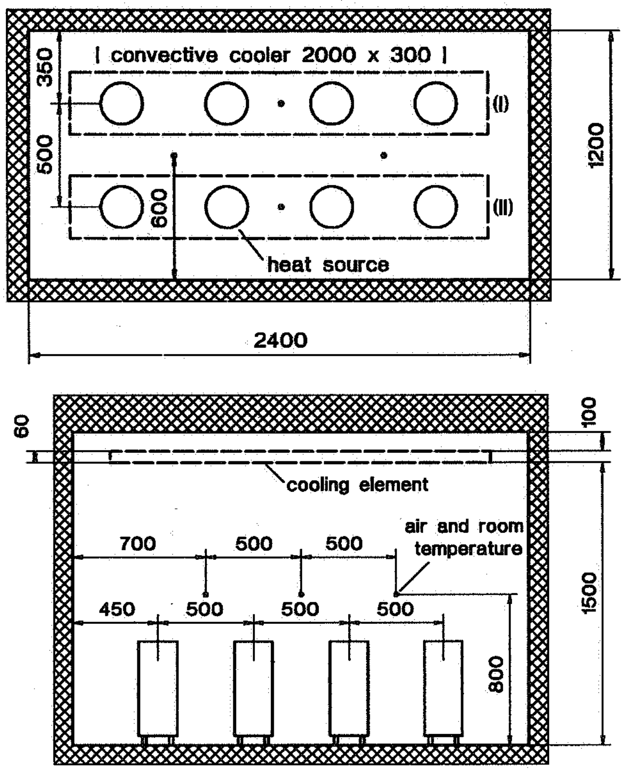

Figure 1

All elements of this testing chamber have to be well insulated. The thickness of insulation with a thermal conductivity less than 0.04 W/mK must be more than 0.1 m for walls and floor. For the ceiling the thickness has to be more than 0.2 m. The emission coefficient ε of the inside surfaces of the chamber must be higher than 0.9. Also it must be possible, that air circulates around the chamber while the temperature difference between the ambient air and the air inside the testing chamber has to be less than 1 K. The reference temperature inside the chamber is the so called room temperature, which will be measured by a temperature sensor inside a black ball (diameter of 35 mm). The shown installation in Fig. 1 with two convective coolers (2000 x 300 mm) is not provided in this guide-line. The cooling load will be simulated by 8 clearly defined cylindrical heat sources with a black surface (ε > 0.9).

The room and air temperatures inside the testing chamber have to be measured at at least 4 positions as marked in Fig. 1. Additional temperature sensors have to be installed at the center of the wall and bottom surfaces. Each water temperature has to be measured by two separate temperature sensors, while a difference of less than 0.05 K between these sensors is allowed. Otherwise they have to be exchanged.

The investigation of the characteristic of a chilled ceiling element includes at least 3 series of measurements with different initial temperatures of heat carrier medium. The rated temperatures are 12, 14 and 16°C with a tolerance of ± 0.5 K, while the room temperature inside the chamber has to be 26°C ± 0.2 K.

During a period of at least one hour with stationary operating conditions 10 measurements have to be taken to describe the cooling performance of the chilled ceiling elements. The chosen measuring device allows up to 60 measurements during a period of one hour.

3. Analysis of measurements

If the heat transfer bases mainly on convection, the cooling performance should be described by a "room characteristic". The results of the measurements of cooling performance in the testing chamber can be described by

$$\dot{q} = C \cdot \Delta t_R^n \qquad \Delta t_R = \frac{t_i - t_r}{\ln \frac{t_R - t_r}{t_R - t_i}}$$

The parameters C and n have to be determined by a regression basing on the measured parameters and Δt_R, the logarithmic mean temperature gradient between heat carrier and room temperature, as measured with the "black balls".

4. Results from measurements

Investigations at free convective coolers, which are installed in the testing chamber as shown in Fig. 1, were carried out to characterise the cooling performance and the effects of operating conditions and distribution of heat sources on the performance. The cooling performance of the convective coolers has been described in a modified room characteristic, in which the cooling performance per length of cooler instead of the cooling performance related to the surface of the cooler (2000 mm x 300 mm) was chosen.

Figure 2 shows three room characteristics of the measurements that were carried out to describe the effect of asymmetrical and symmetrical arrangements of coolers and heat sources on the cooling performance. The room characteristic of the cooler I with both coolers and groups of heat sources active was chosen as reference for the two asymmetrical cases, where only the cooler I and the heat sources beside or below the convective cooler were active. The maximum cooling performance can be reached with an asymmetrical arrangement of coolers and heat sources while the positioning of the coolers just above the heat sources leads to a minimum of cooling performance, while the differences are near neglectible.

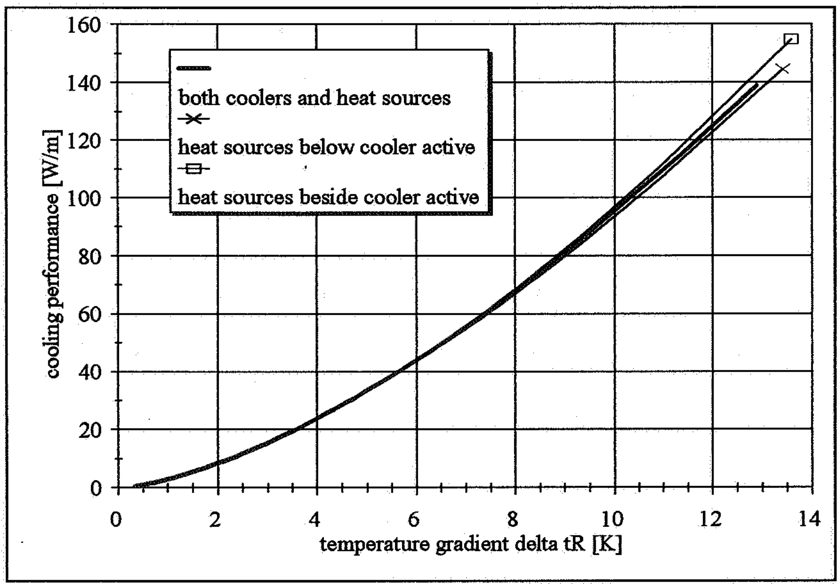

Figure 2: "room characteristic of cooler I with symmetrical and asymmetrical arrangement of coolers and heat sources

Parallel investigations of the cooling performance of convective coolers in a test room with the dimensions of a "real" office room had shown significant higher cooling performance. The small distance between the floor and the cooling element in the testing chamber may have been one reason for this effect, because natural convection at the cooling elements can be limited by this kind of installation. More realistic values of the cooling performance can be determined by investigations in a larger "full scale" testing room with dimensions similar to the dimensions of offices in reality. Such a testing room is shown in fig. 3. It was built according to most of the requirements described in the FGK guide-line. But the dimensions of the testing room deviate from some paramters fixed in the guide-line and the German DIN-standard 4715 as well as the chosen asymmetrical arrangement of the heat sources and coolers.

The width of the testing room is characteristic for single office rooms with two axis of the buil-ding while the length was limited because of the available space in the laboratory. The testing room represents an office room with a length of three axis with a board at the inside wall. The test room is as well insulated as the smaller testing chamber. The heat sources were located at the "outside wall", because the desks are normaly positioned near the windows. Additional to the internal heat sources the direct solar gain will be absorbed near the windows, so that this part of the cooling load will be set free near the outside wall too. So it is possible to simulate main parts of internal as well as external cooling loads by the installed heat sources. The convective coolers should be installed as described by the manufacturing and installation companies.

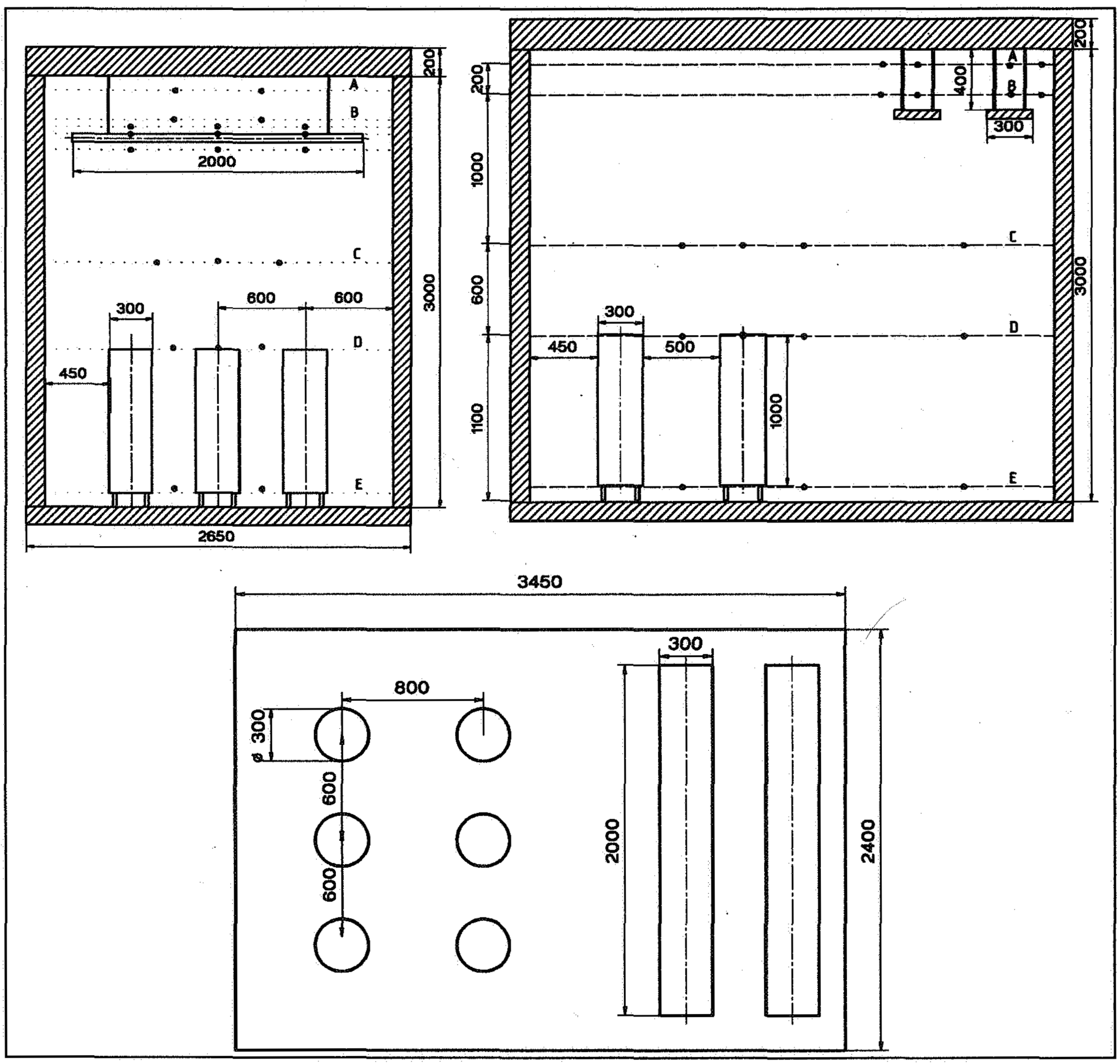

Figure 3: plan and side views of the enlarged testing room

A realistic cooling load of 55 W/m^2 leads to a total demand of 455 W of cooling inside the testing room. The estimated cooling performance of the investigated convective coolers is about 165 Watt per length of cooler at a difference of 10 K between mean water temperature and air temperature inside the testing room, so that two coolers with a length of 2000 mm and a width of 300 mm had been installed near the inside wall as shown in figure 3. This kind of installation was prefered by the installation company, which uses this kind of cooler to build the convective cooling systems.

During the measurements of cooling performance in the enlarged testing room the differences between simulated cooling load and total performance of the coolers was always less than 30 watt, so that the requirements fixed in the German DIN 4715 were met. During some measurements this difference was less than 12 watt, so that the requirements of the FGK guide-line could be fulfilled although the test room is much larger than the FGK testing chamber. Also the parameters to guarantee stationarity during a measuring period of at least one hour could be met as it is fixed in the FGK guide-line, so that the air flow pattern inside the test room appears to be stable and stationary.

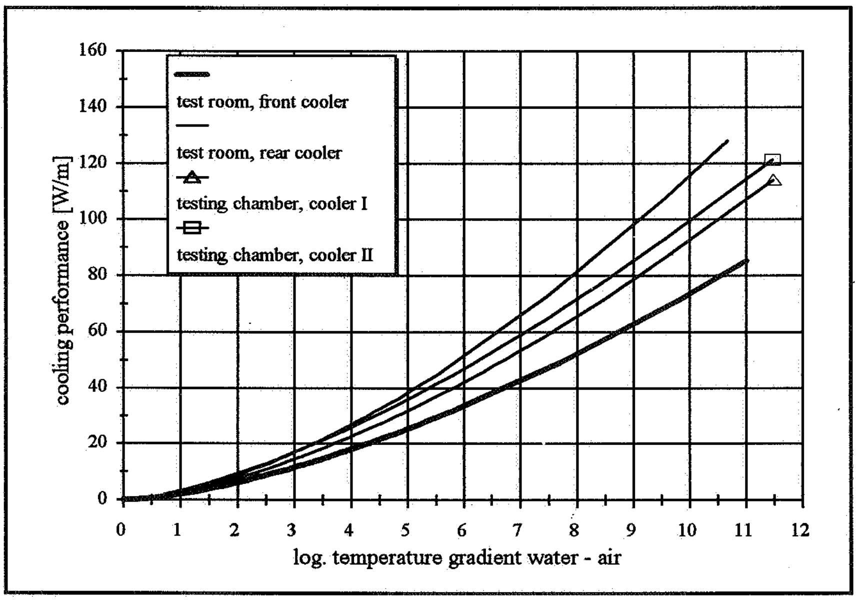

Figure 4: comparison of measured cooling performance of convective coolers -results from testing chamber and large test room

Figure 4 shows the room characteristic of the investigated convective coolers basing on measurements in the testing chamber and the test room. It has to be mentioned that different water flow rates per cooler had been adjusted (test room: 100 l/h, testing chamber: 140 l/h). But various measurements at these coolers with different water flow rates had shown, that these differences will have only a small effect on the cooling performance. The distance between cooler and ceiling inside the larger test room is twice the distance, that was adjusted in the testing chamber. This corresponds with the enlargement of the test room and the higher cooling load. The figure shows, that the arrangement of the coolers and the dimensions of the room have a significant effect on the performance of the convective coolers. There is only a small difference of performance between the two coolers during the investigations in the small testing chamber in comparison to the results for the large test room. The cooling performance of the rear cooler near the "inside wall" is much higher than the values, which could be found out for the front cooler. An analysis of the temperature distribution has shown, that there is a stable circulation of the air inside the test room. The buoyancy at the heat sources and the natural convection at the coolers leads to a stable air flow pattern. Because of the temperature distribution at the front cooler it could be estimated, that the air flows over the front cooler and the main part of the cooling will be supported only by the rear cooler. The natural convection at the front cooler is not able to sustain a sufficient air flow rate through the front cooler. This shows, that only the larger testing chamber allows an investigation of the convective coolers under operating conditions near to practice. During additional series of measurements the effect of different distances ot the coolers from the ceiling in a range from 50 mm to 400 mm on the cooling performance were examined as well as the effect of shafts of different length directly below the coolers to increase the natural convection (figure 5 - 6).

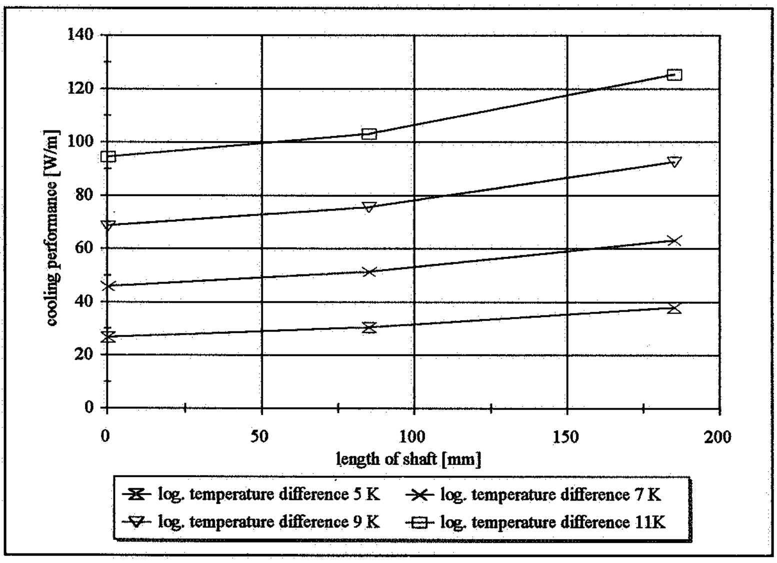

Figure 5: room characteristic of front cooler, 200 mm distance to ceiling

The analysis of the measurements has shown, that the cooling performance of both convective coolers increases nearly linear by with the distance from the ceiling in a range from 100 mm to 400 mm, while the gradient increases with the temperature difference between cold water and air temperature. The installation of shafts directly below the coolers leads to significantly higher cooling performances of both coolers (figure 5 and 6). So the investigations have shown, that there has to be sufficient distance between the coolers and the ceiling to guarantee the cooling performance. To increase cooling performance it is at first necessary to provide a sufficient distance between cooler and ceiling. If there is additional space available, it is possible to install shafts below the coolers, while the length of these shafts has to be at least 1.5 times the depth of the fins of the convective coolers. Otherwise the distance of the coolers to the ceiling should be further increased.

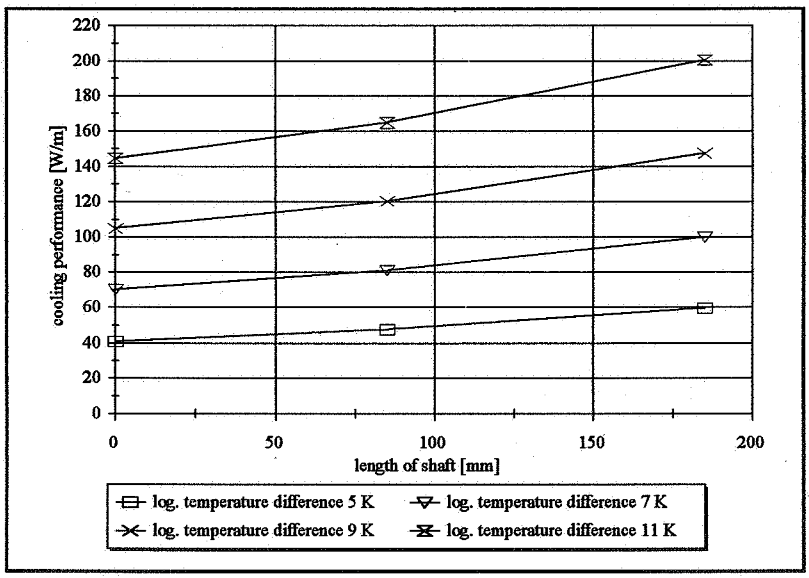

Figure 6: room characteristic of rear cooler, 200 mm distance to ceiling

Acknowledgement

The measurements were part of a research project, which was supported by the Bundesministerium für Bildung, Technologie und Forschung under the contract number 0329399A.

List of References

/1/ DIN 4715 Raumkühlflächen, Leistungsmessung bei freier Strömung Normenausschuß Heiz- und Raumlufttechnik, Germany (1993)

/2/ FGK Vorschrift KD-1, Wärmetechnische Messungen an Kühldeckenelementen, Fachinstitut Gebäude-Klima e.V., Bietigheim-Bissingen, Germany, 1992

/3/ F. Steimle, B. Mengede, K. Schiefelbein (1994), 'Standardised measurements of the cooling performance of chilled ceilings', Proceedings of 15th AIVC-Conference, 697-707