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Cooling Ceiling Systems and Displacement Flow

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300.000 m² in 1.3.93

Synopsis

For several years the technology of chilled ceilings has been a favourite issue among HVAC technicians and underwent a boom in the past few years.
According to the survey of a German technical journal, on March the first 1993, a total of 308,490 m^2 of chilled ceilings had been installed in German buildings, out of which 69 per cent had been installed in new buildings and 31 per cent in modernized projects.
Cooling ceiling systems are the ideal application where high demands are placed on comfort requirements and where the energy loads are very high compared to material loads. Given the fact that cooling ceiling systems fulfill only one thermodynamical function, i. e. the cooling requirements, and do not contribute to the renewal of the indoor air, they have to be combined with an additional ventilating system.
This article and the poster description describe different cooling ceiling systems in conjunction with ventilating systems, the main focus being on displacement flow.

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Introduction

The task of air-conditioning plants, for example in offices and administrative buildings, in meeting and conference rooms, warehouses and concert halls, hotels and restaurants, in hospitals and numerous other buildings, is to ensure comfortable and healthy indoor air conditions as well as the rational use of energy. In order to obtain pleasant indoor air conditions the cooling loads created in the room have to be removed, in other words the room has to be cooled.
Rising room cooling loads on the one hand, e. g. through EDP equipment, and increasing demands on comfort on the other hand have set air-conditioning technology a difficult task. And this is precisely where cooling ceiling systems can help in a number of cases.

The various types of cooling ceiling systems

In the meantime, a large number of different cooling ceiling systems has become available on the market. Thanks to the large number of designs, cooling ceiling systems are suitable both for new buildings and the modernisation of older buildings (see also the results of the survey mentioned in the synopsis).
In principle, cooling ceiling systems can be divided into radiation ceilings and convection ceilings. Radiation ceilings have a closed surface. The heat transfer takes place primarily through radiation. They can be constructed as plastered ceilings or also precast ceilings. Generally they require no more space than the construction of a normal ceiling without cooling system (see figure 1).

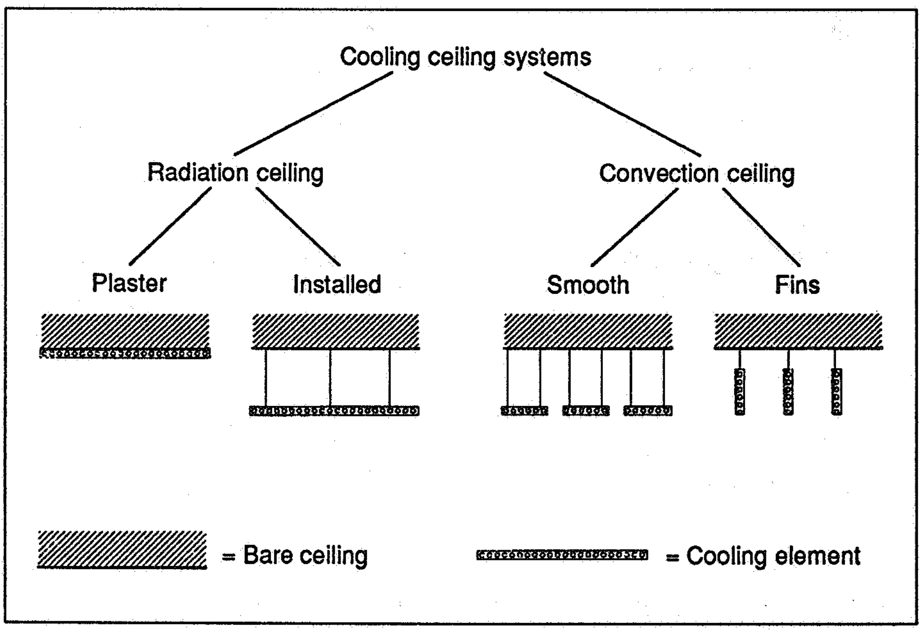

Figure 1: Classification of types of cooling ceiling systems

Cooling surfaces and air distribution

Since cooling surfaces make no contribution to air renewal they should always be operated in conjunction with a ventilating or air-conditioning plant, which also ensures the necessary dehumidification. If appropriately combined the cooling surface can relieve the air-conditioning system, i. e. the air flow rate is decoupled from the energy load. This leads to smaller air flow rates, which in the ideal case correspond with the supply air flow rate. The minimal outdoor air flow rate meets with an air flow rate of about 7 to 9 m^3 (h x m^2). This is only a small share of the air

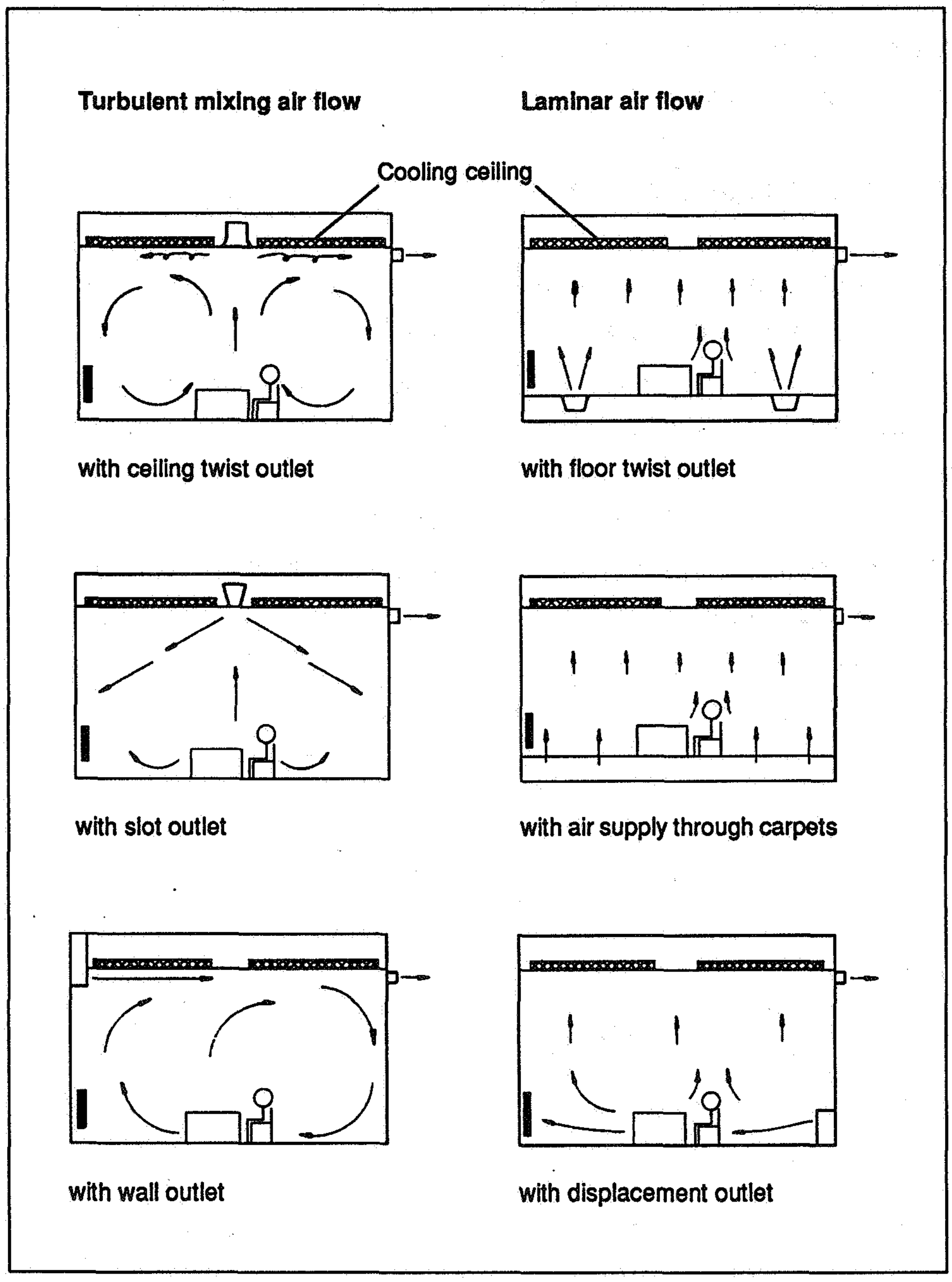

Figure 2: Cooling ceiling systems and air distribution systems

flow rate required to cover the room cooling load in the case of conventional air-conditioning plants. In general, cooling ceiling systems can be combined with any existing ventilating system (see figure 2).

Cooling ceiling systems and displacement flow

The air volume is supplied into the room by means of large-surface air outlets near the floor. It enters the room at low air-velocities of about 0.2 to 0.3 m/s and with a temperature of about 1 to 1.5 K below the temperature of the room air. As a result – caused by these conditions – the cooler supply air will uniformly spread over the entire floor space where it forms a "lake of fresh air" and will then flow evenly distributed over the entire room from that area to the ceiling. The flow velocities then existing in the room are very low (below 0.1 m/s), unstable, and can only be proved by smoke tests. A heat source in the flow just described – for example a person or a heat-emissing office machine – will modify this flow pattern. Due to thermal convection, produced by the temperature difference between the warm surface of the heat source and the cooler supply air from the lake of fresh air, the person or machine transports a continuous airflow towards the ceiling.

Using this system only the immediate surroundings of the heat sources are supplied with fresh air – the ventilation effectiveness of the loading zone is also excellent. On the other hand, draft annoyance still existing in many systems with the conventional "mixing flow pattern" does not exist here. As each heat source in the room covers its own air demands from the lake of fresh air on the floor (conditioned outside air), air quality and ventilation effectiveness as well are significantly better than with a system of mixing ventilation. However, this flow pattern largely excludes a horizontal flow. That means that there will be no overflow of smoke or odourous substances from one area to another.

On the other hand, air velocities in the room – caused by this air flow pattern – are mostly very low (below 0,1 m/s) and have also very low turbulences, which have an important effect on draughts.

This displacement flow system is often limited, nevertheless, due to the temperature stratification in the room and low temperatures at floor level. However, in conjunction with chilled ceilings this typical disadvantage can be avoided, as the only task of the supply air remains the renewal of the room air. The cooling is done by the ceiling. As a result of the human capacity of compensating radiation, the slightly lower temperature of the ceiling leads to a perceived temperature being 2 K lower than the actual room temperature – even at higher indoor air temperatures such as

26 to 28 °C. This effect increases comfort and helps to save energy as well as to reduce the size of the plant.

Power measurement of cooling ceilings

The standardized power control of cooling ceilings has always been an important matter of concern of the "Heating and cooling surfaces" working group of the Fachinstitut Gebäude-Klima e.V. (FGK) in which the leading German manufacturing firms and suppliers of cooling ceiling systems are represented. The purpose of uniform measurement techniques is to render the power indications comparable so that performance variations within +/- 20 per cent, possibly distorting competition, will become impossible.

At the end of 1992, the members of the FGK working group mentioned before presented their "thermic measurement of cooling ceiling elements". The power measurements are based on a so-called "box measurement" with a box of the following dimensions: 2.40 m x 1.20 m x 1.50 m (lenght x width x height). The advantages of this technique are obvious: it is neither time consuming nor too expensive and comparison measurements by manufacturers have shown furthermore that deviations between room and box measurements are about 3 per cent, i. e. they do not exceed normal measuring inaccuracy. According to the FGK guidelines for box measurements, the cooling ceiling elements are tested under clearly defined boundary conditions and the results are recorded in a test certificate. In view of the design and the relevant boundary conditions the testing box must meet explicit requirements.

The guidelines contain inter alia sketches of the testing box indicating the corresponding metering points. At least three series of measurements are required and the flow temperature is to be fixed at 12, 14 and 16 °C with a maximum deviation of +/- 0.5 K from the set value. The cooling performance as well as the steady state characteristic of both the cooling ceiling and the room must be indicated for evaluation and representation puposes. According to the FGK guidelines, both smooth and open (grid) cooling ceiling systems can be tested.

In the meantime, the German standard organisation (DIN) has outlined standards for the performance measurement of cooling ceilings. The difference between the applied measurement techniques is almost neglectable, the measurements being performed in a room (4 m length x 4 m width x 3 m height) and not in a "box".

Summary

"The ventilation and air conditioning industry should carefully avoid calling the cold ceiling – without concurrent ventilation – an acceptable air-conditioning system and offer it to customers: it is nothing but an integral component of an aggregate system, which – without controlled ventilation to eliminate humiditiy and odourous substances – is doomed to failure".
This was the résumé of the FGK symposium on cooling ceilings and room ventilation in which 200 air-conditioning experts took part in September 1990 in Stuttgart, Germany. The experts agreed that the cold ceiling is not the solution to all air conditioning problems, but that – if correctly applied and operated – it is capable of contributing greatly to an increase in thermal comfort in a room. With that, the supply air volume can be reduced to the flow necessary to eliminate odourous substances or humidity. Compared to conventional air-conditioning systems where the cooling load must be eliminated only by convection, this means a reduction of the supply air volume by approximately 60 to 80 per cent. On the one hand, this leads to considerable savings in fan energy and to a reduction of the peak power load. On the other hand, the low airflow velocities of displacement flow ventilation prevent draughts. Summing up the figures for the two air-conditioning components, one gets an overall capacity of about 100 W/m². Normally, this capacity suffices to ensure a removal of the load even in modern office rooms with high internal heat sources. Should the internal thermal loads exceed 100 W/m², the responsible people will have to rethink the overall planning of the room and/or building. In those cases either the architectural planning is wrong or someone forgot to provide the windows with effective sun protection devices. Given the fact that this system which in Germany has been installed for more than 300,000 m² in office buildings in the last two years, also has advantages as for the costs for installation and operating compared to conventional systems in case of room loads of approximately 50 W/m² onwards, it should only be a matter of time until this system prevails not only in the West European countries but also internationally.

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