Air-conditioning and ventilation engineering

#6712

# Cooling Ceiling Systems

## An information brochure from the Professional Institute for Air Conditioning and Ventilation in Buildings (Fachinstitut Gebäude-Klima e. V.)

# 1. Aim

This brochure is planned to give planners, architects and building owners an overview of the possibilities for room cooling using cooling surfaces – in particular cooling ceiling systems. Moreover, it is also planned to clearly show the significance of cooling ceiling systems under the overall aspect of the air-conditioning task.

# 2. 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 a comfortable and healthy indoor air condition. The air handling system hereby has to perform a lot of functions, such as air heating, air cooling, air renewal, air humidification and dehumidification. Air number ventilation plants thus create a room climate which fulfils the needs of most human beings, whereby thermal comfort in particular plays a very important role. In order to obtain a pleasant indoor air condition the cooling loads created in the room, for example, have to be removed, in other words the room has to be cooled.

The method of cooling rooms with cooling surfaces has been around for some time. Recently, interest in Central Europe has once again focussed on cooling ceiling systems. In the meantime, large areas have been fitted with such systems. Experiences with previous plants have shown that such systems have to be carefully planned, whereby aspects such as thermal comfort, the removal of pollutants and the acoustics must be given special attention. One should not forget that air-conditioning does not refer to just cooling, but also entails the maintenance and adjustment of defined air conditions and that a minimum air change is necessary depending on the room's use.

Rising room cooling loads on the one hand, e.g. through EDP equipment, and increasing demands on comfort on the other have set air-conditioning technology a difficult task. And this is precisely where cooling ceiling systems can help in a number of cases. Surfaces which surround rooms and which are cooled by water or air can be appropriately combined with lighting equipment: this enables the creation of aesthetically pleasing room designs even in consideration of the acoustic requirements of the room. The technical side of the solution is not emphasized in this case.

# 3. Definition

The removal of a cooling load from a room can be achieved through the introduction of cooled air or by cooling structural elements. If the room's ceiling is completely or partly brought down to and maintained at a temperature below that of the room itself one speaks of a cooling ceiling system. The cooling of the structural element is normally done by means of a closed water or air cycle. If air constitutes a heating medium an open cycle is also possible, whereby the air is initially used to cool the ceiling and is then transferred into the room. In such cases a differentiation must be made between the cooling through the structural part and direct cooling through the supply air when calculating the cooling capacity. A cooling ceiling system always has a direct effect on the heat sources inside the room (radiation), and also via the indoor air (convection). The radiation/convection shares may differ depending on the design of the cooling ceiling system and the movement of air in the room.

# 4. Cooling surfaces and air distribution

Heat transfer through radiation in a room depends solely on the surface temperatures of the cooling ceiling system, the walls, persons etc., the geometric arrangement and the corresponding radiation properties of the surfaces.

Irrespective of the air supply system used in the room part of the heat is carried off by cooling the room air, in other words convection, if cooling ceiling systems are used. The size of the convective share largely depends on the indoor air movements in the vicinity of the ceiling. These indoor air movements can be greatly influenced through selective 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 cooking 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 fresh air flow rate.

Through their convective contribution to the energy exchange with the room, cooling surfaces are interactive with the respective air distribution system. Thus, different indoor air movements can be created, in particular turbulent mixing air flows and laminar air flows.

## 4.1 Cooling surfaces and high-turbulence mixing air flows

High-turbulence mixing air flows are planned to achieve a highly intensive mixture of supply air and indoor air. This results in an almost homogeneous air condition in the room so that both thermal and material loads are evenly distributed.

The mixing air flow is caused by external influences on the room; it is mainly due to the inlet momentum of the supply air. The situation, design, loading and characteristics of the supply air outlets have a significant effect on the air movements arising inside the room. The situation and design of the return air inlets have hardly any effect on the room air movement.

The intensive exchange of momentum during the supply of air through ceiling outlets alters the temperature boundary at the cooling ceiling system and hereby increases the convective heat transfer. The input of air also affects the movement of air in the whole room. This is also true of other induction-type systems which are combined with cooling ceiling systems.

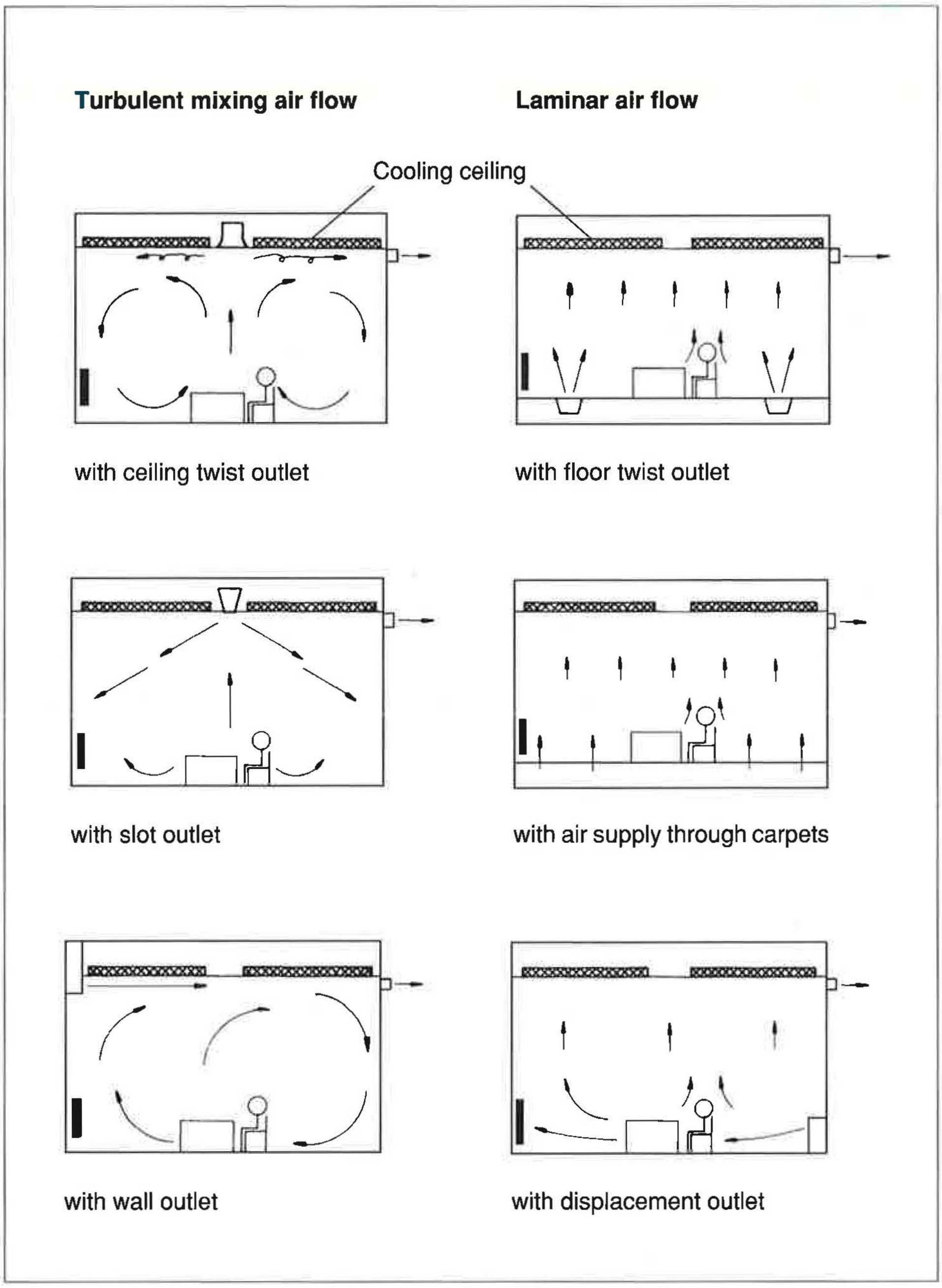
# 4.2 Cooling surfaces and laminar air flows

The idea behind a laminar air flow is to limit the influence of heat and material loads to certain parts of the room through the creation of layers of air of different conditions and to prevent their effect on the rest of the occupied zone. This requires that the supply air be suitably discharged into the room according to position, velocity and distribution and that the exhaust air is removed at the correct point so as to be able to exploit the internal loads as a source of propulsion for the room air movement.

If the supply air is brought into the room at a negligible input momentum (displacement flow, flow through carpets) the layer thicknesses only occur under the influence of the internal loads and the extent of the supply air flow rate; the layer thickness can be influenced through the use of supply air outlets with a higher input momentum (local mixed air flow).

If the supply air is discharged into the room at floor level with such systems at a slightly lower temperature than the room air it disperses over the floor and the indoor air flow is greatly affected by the buoyancy in the vicinity of heat sources.

The cooling load which can be removed with such an air distribution system alone is very low or in some cases leads to undesirably high vertical temperature gradients. However, if combined with cooling ceiling systems much higher loads can be carried off with a more uniform vertical temperature profile.




**Cooling ceiling systems and air distribution systems**

# 5. Heat transport mechanisms and thermal comfort

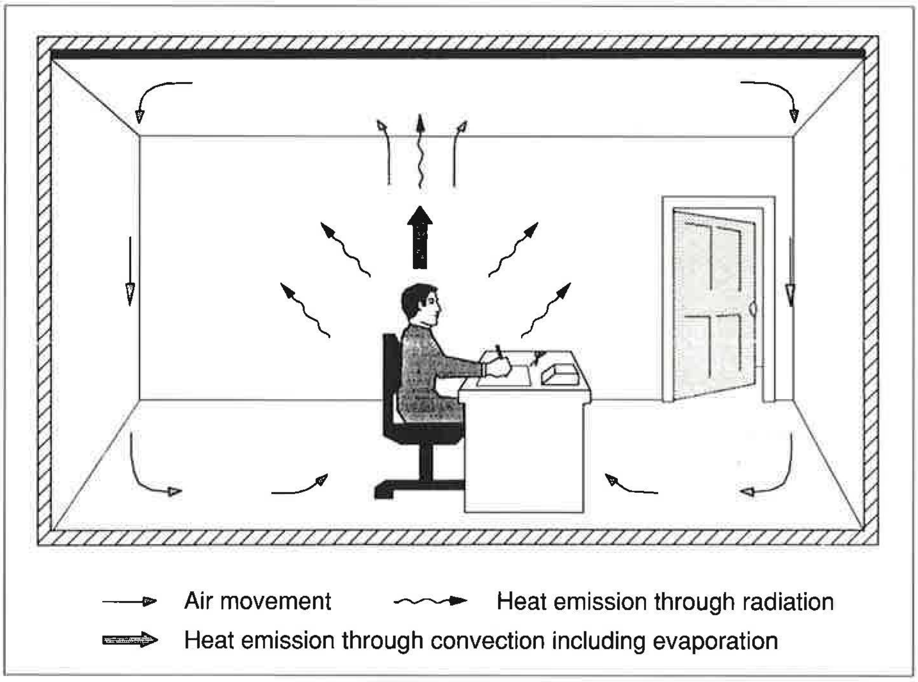
Human beings are always exchanging heat with their environment. They must constantly emit heat to maintain their body temperature. This takes place in three different ways:

- convection
- evaporation
- radiation

Exchange through convection depends to a large extent on the temperature and movement of the air. Evaporation is also influenced by the air humidity. The temperature and surface condition of the enclosing areas are decisive in the case of exchange through radiation.

With a rising air temperature the human body increases the share of heat given off through evaporation (sweating). The convection and/or radiation shares have to be increased if this is to be avoided. The convection share can be increased by a higher air velocity.

On account of the thermal comfort, the average values and degree of turbulence for the air velocities have certain limits depending on the temperature (draughts). The radiation share can be increased by reducing the temperature of the enclosing surfaces. There are certain limits too in this case which depend on the comfort, since if the temperature differences are too great so-called radiation draughts can arise (the same effect as cold window panes in winter). Such an influence on the thermal comfort within a room does not usually occur with the normal method of operation of cooling ceiling systems.




**Heat emission of a person in a room with ceiling cooling system**

# 6. Fields of application and limits

Cooling ceiling systems are ideal for applications where high demands are placed on the comfort requirements and the energy loads are very high in relationship to the material loads. If the air flow rate necessary to remove the material load is the same as that required to remove the energy load the use of cooling ceiling systems is not recommended.

If the water input temperatures are too low or the room humidity too high there is a risk that the water in the air will condense on the cold structural parts. In order to avoid condensation a sufficient distance from the dew point temperature must be ensured through controlling and air-conditioning measures.

The cooling capacity per square metre of cooling ceiling system with a mainly radiation share is only limited by the possibility of condensation. In the case of cooling ceiling systems with a predominantly convection share the capacity is also limited by the requirements of thermal comfort.

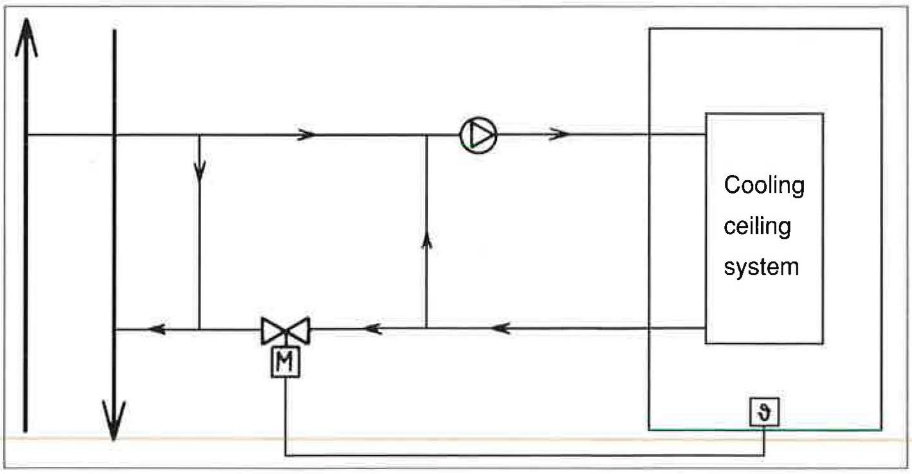
# 7. Control of cooling ceiling systems

The room temperature is controlled by the cooling capacity of the cooling ceiling system. The ventilating plant ensures the supply of fresh air and removal of moisture. In order to control the room temperature as a function of the room cooling load the

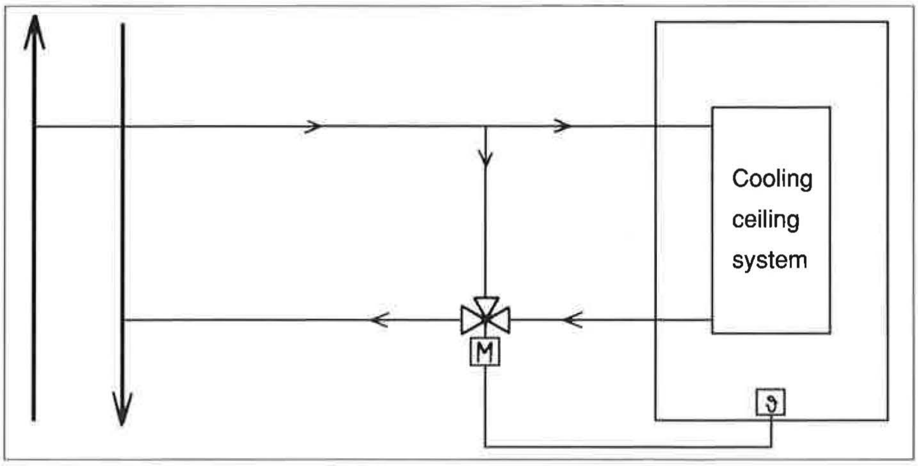
- water inlet temperature and/or
- the water flow rate

are altered. The change in the water flow rate can be carried out with or without auxiliary energy, i.e. with motorized control valves or thermostat valves.

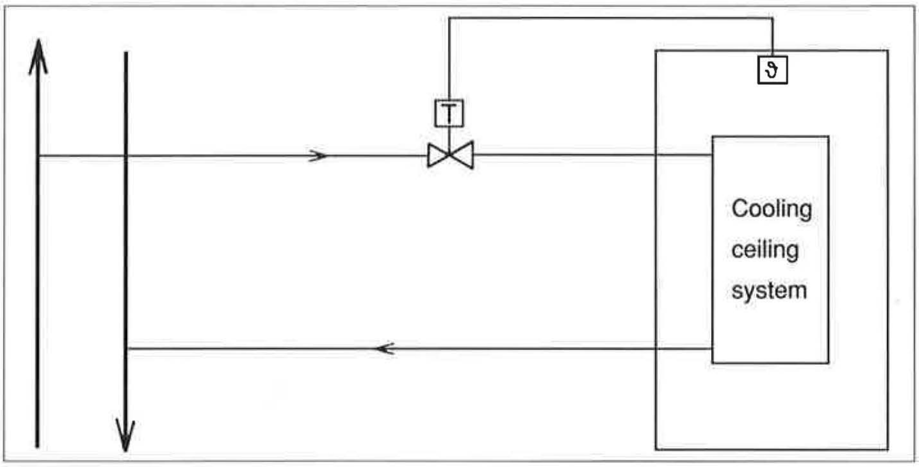
The ventilating plant must dehumidify the supply air under all load conditions to such an extent that the dew point temperature of the room air remains below the water inlet temperature (approx. 16 °C/61 °F. If ceiling outlets are used the supply air can be discharged into the room at this




**Room temperature control by altering the water inlet temperature**




**Room temperature control by altering the water flow rate (with control valve)**




**Room temperature control by altering the water flow rate (with thermostat valves)**

temperature. In the case of floor outlets and displacement ventilation systems higher supply air temperatures are necessary.

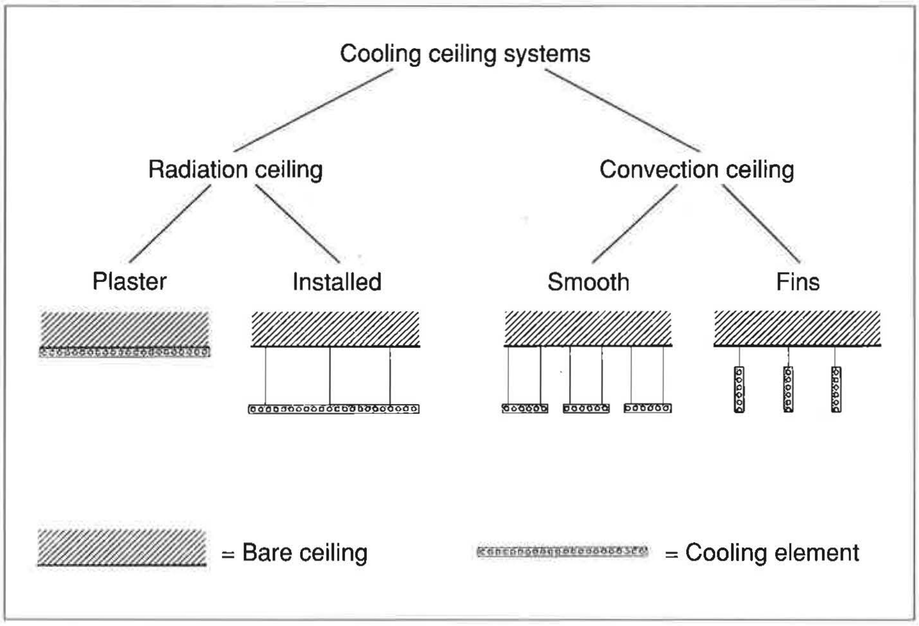
In order to ensure that the water inlet temperature remains above the room dew point temperature a dew point monitoring system should be installed. If the temperature drops to near the room dew point temperature either the water inlet temperature is raised or the water flow rate reduced.

On account of the complexity of the processes a common control concept for the cooling ceiling, the ventilation and heating systems is necessary.

# 8. Design features

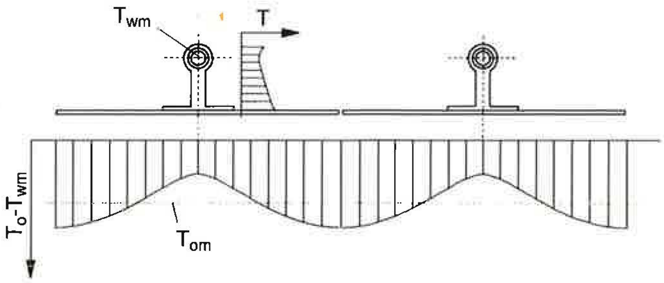
Thanks to the large number of designs, cooling ceiling systems are suitable for both new buildings and the modernisation of older buldings.

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 for the construction of a normal ceiling without cooling system.

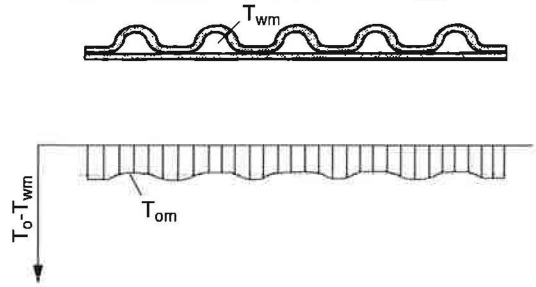



**Classification of types of cooling ceiling systems**

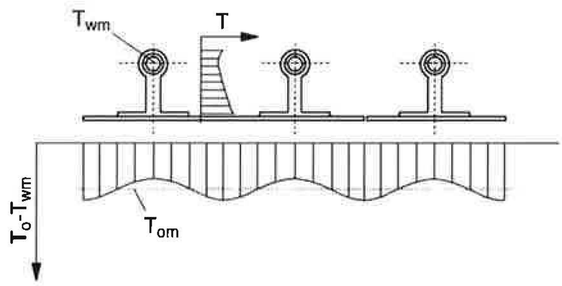
In the case of convection ceilings the convective share accounts for the majority of the heat transfer. The ceiling has openings for the air circulation necessary to increase the cooling capacity. The output can be increased even more by fins facing the room.



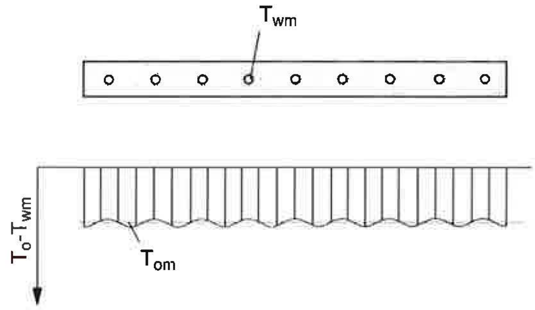

Temperature distribution in a variable ceiling system with large pipe intervals




Temperature distribution in a directly moistened area




Temperature distribution in a variable ceiling system with small intervals




Temperature distribution in a capillary tube ceiling system

Differences in temperature at the ceiling elements can occur in cooling ceiling systems on account of the design. These are shown above.

# 9. Efficiency

The efficiency of a cooling ceiling system depends on the room's cooling load, the period of operation of the system and structural features. Thus, no general statements can be made. The efficiency must in each case be calculated relative to the project. Compared to only-air systems:

- Higher investments are needed for cooling ceiling systems
- Lower investments are needed for the ventilating plant since the volume flow rate can be reduced to the minimum necessary for the air renewal. This means that less space is required for the central air handling unit and air ducts.
- If the cooling ceiling system is taken into account during the design of the building lower investment costs can also be calculated for the overall building on account of the lower space requirements.

Cooling ceiling systems have lower operating costs than only-air systems:

- The energy costs for the air transport are reduced on account of the lower air volume flow rates for the ventilating plant
- Free cooling via a re-cooling plant can be better exploited on acount of the higher inlet temperatures of the cooling water of approx. 16 °C (61 °F). This reduces the energy costs for the refrigeration machine.

**An information brochure from the Study Group "Heating and Cooling Surfaces" of the Professional Institute for Air-Conditioning and Ventilation in Buildings, Danziger Straße 20, 7120 Bietigheim-Bissingen, Germany. Tel. 0 71 42/5 44 98. Further information is available from this address. Member companies in this FGK Study Group are: B. Barath, Fläkt GmbH, Fraunhofer Institut für Bauphysik, ILK Institut für Luft- und Kältetechnik GmbH, Gg. Kiefer GmbH, Kraftanlagen AG, Krantz GmbH & Co., Rud. Otto Meyer GmbH, Heinrich Nickel GmbH, TKT GmbH, Gebr. TROX GmbH, Wasserkabel GmbH. Director: Prof. Dr.-Ing. Bruno Gräff**