# Comfort in the Auditorium

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**The special conditions in large rooms, such as theatre auditoriums and exhibition halls, impose particular requirements on the ventilation and air conditioning installations. Depending on the constructional characteristics of the building and on the requirements imposed by its utilization, there is a choice of several different methods of airflow distribution. Since the number of such large halls is relatively small and the constructional characteristics of the building as well as the mode of utilization vary significantly, only a slight degree of know-how transfer is possible. This therefore places greatly increased importance on design and airflow model testing by appropriate specialists (*Fig. 1*), not to mention close cooperation between all concerned.**

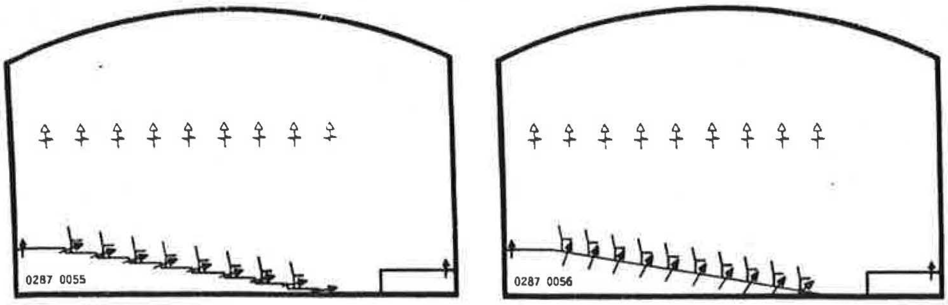
**1 Model tests in conjunction with an installation for the Swiss Radio and Television Service (Italian-speaking Section) being carried out in the Sulzer Air Flow Laboratory.**

Large rooms, such as congress halls, lecture theatres, auditoriums and stages in theatres, as well as exhibition halls, require tailor-made ventilation and air conditioning installations. Such matching is necessary, so that the installations can be used to best effect and operated efficiently. Particularly during the design engineering phase of such plants, account has to be taken of the multiplicity of parameters arising from the mode of utilization and from the constructional characteristics of the building. For example, room geometry and room height exert significant influences on the air flow within the room. Moreover, the type of seating (fixed or movable), the generally stringent requirements regarding acoustic quality and the utilization modes to be expected also have an effect on the choice of system. Further important characteristics which place particular requirements on ventilation and air conditioning technology are:

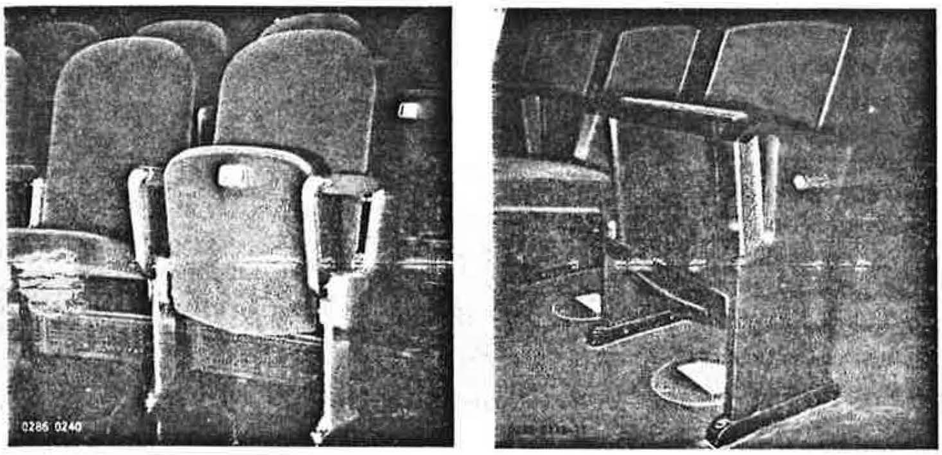
- built-in fittings and room sub-divisions, such as curtains and movable, floor-to-ceiling dividing screens
- large differences in the levels occupied by the users, for example, stage, orchestra pit and audience seating areas such as stalls, circle, upper circle and balcony
- different times for which the building is used and/or different user densities
- rapid and high-amplitude changes of internal thermal loadings caused by the presence/absence of people and lighting
- occupants' clothing

In order that purpose-oriented installations can be determined to take into account the above, close cooperation between all concerned with design and building construction is required, i.e. builders, architects and air conditioning specialists. This is particularly important since the number of such buildings is small and, in general, no significant degree of know-how transfer is possible.

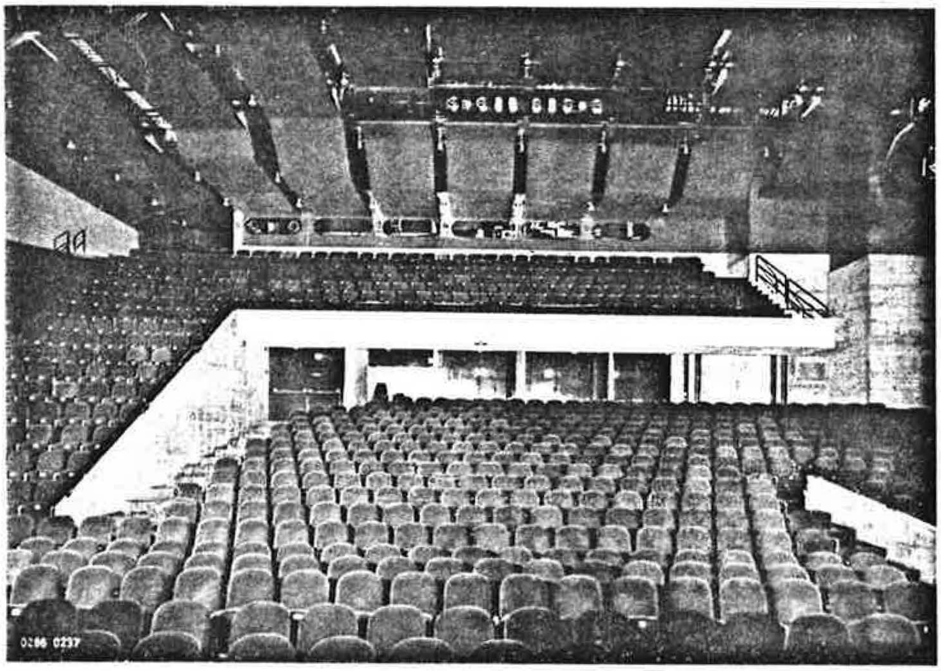
Two basically different ventilation systems come into consideration for large rooms. Each is associated with particular building characteristics and assumptions regarding usage and users.




2 **Room air flow where air introduction is from the floor; left, stepped floor; right, sloping floor.**



3 **Two floor air outlet variants; left, Municipal Theatre, Berne; right, Municipal Theatre, Winterthur.**



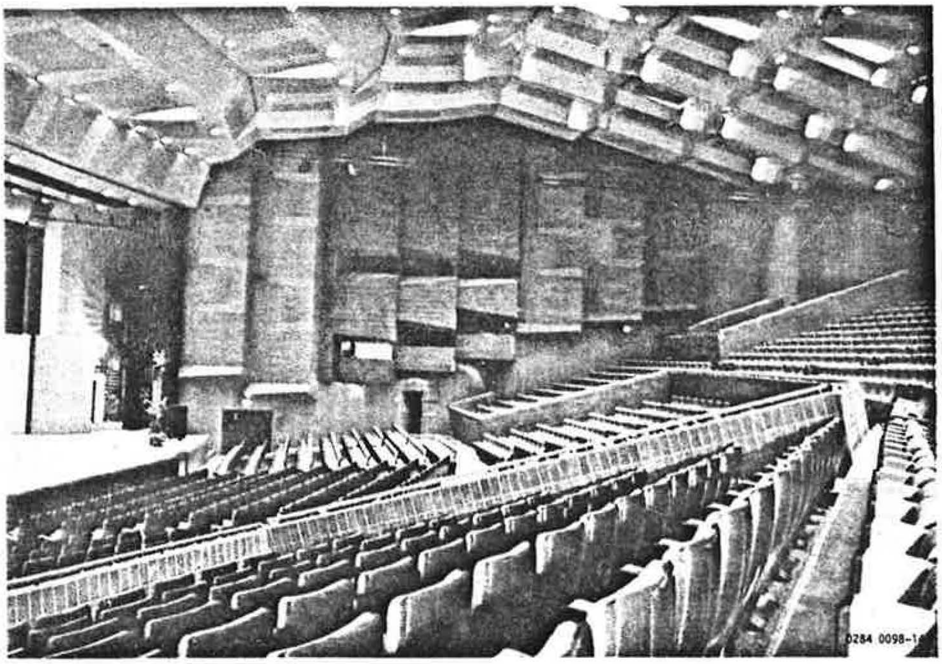
4 **Auditorium of Municipal Theatre, Winterthur.**

## Displacement airflow

The treated supply air is introduced directly to the seat or workplace. There are two different processes for this.

### Air introduction at floor level

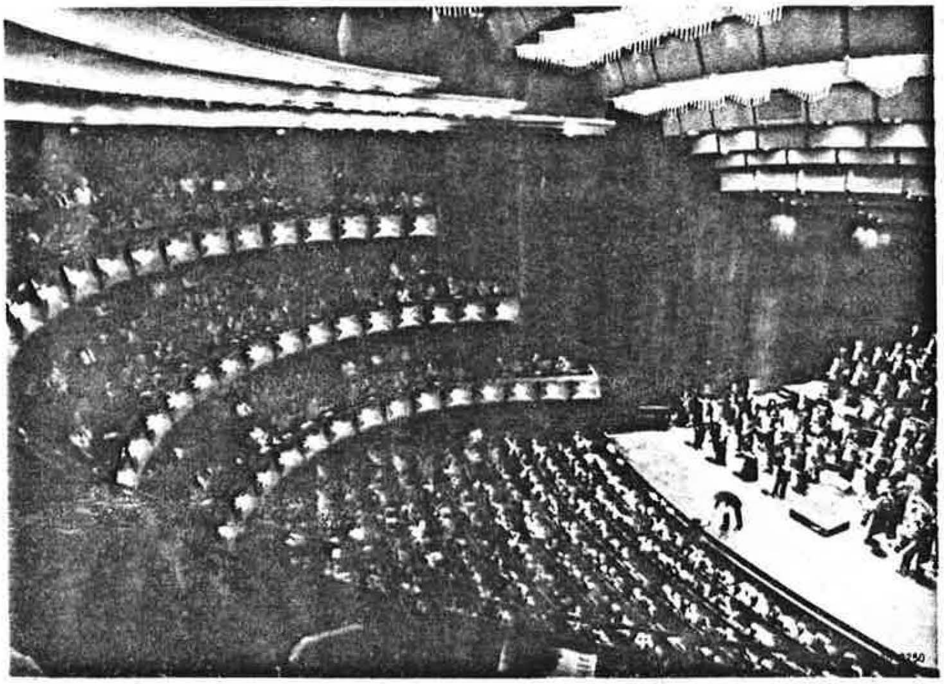
The treated supply air is introduced at or near the floor by special floor or chair-support outlets. The air outlet has to be so designed that the supply air leaves the immediate vicinity of the



**5 Auditorium of the Concert Hall in Lille (France), which is fitted with floor outlets.**

floor under stable flow conditions. This is important, otherwise the generally cooler supply air flows to the lowest level of the room (waterfall effect) and thus draught conditions are caused at ankle level, with consequent loss of comfort. The supply air should be thoroughly mixed in with the ambient air within 20 to 30 cm flow distance. The mixed air flows through the occupied zone from floor to ceiling (*Figs. 2* and *3*). Where a high degree of comfort has to be attained, the temperature difference between supply and room air should not exceed 3–4 K. In practice, at room temperatures of 23–24 °C, the supply air is admitted at temperatures of at least 20–21 °C. Supply air is admitted at a rate of 30–40 m³/h per seat.

Air admission from the floor is possible primarily in rooms with fixed seating. Hence this process is used mainly in the auditoriums of theatres and lecture halls (*Figs. 3* to *6*). The constructional characteristics of the floor and also of the seats themselves have a significant influence on the design and effectiveness of the air outlet.



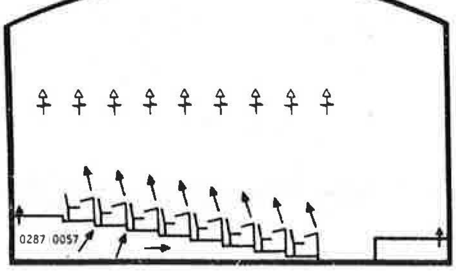
**6 Opera House, Hanover (Federal Republic of Germany); air introduction from seating supports and floor steps.**

### Air introduction at desktop level (desk edge ventilation)

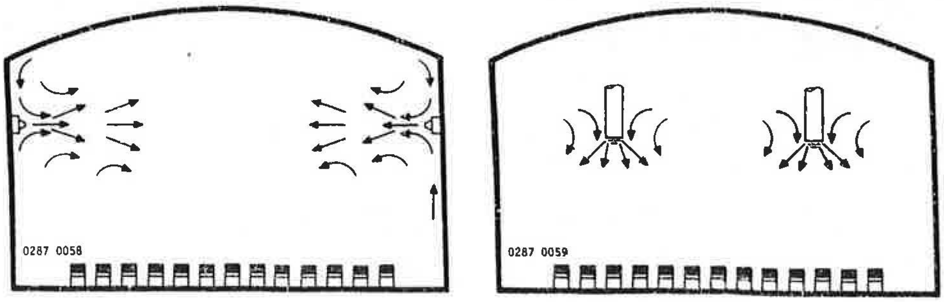
Unlike air admission close to the floor, the treated air is introduced near to the front edge of the desks. The air outlets are so designed that the primary air is mixed with ambient air before being discharged from the front edge of the desk. This is achieved by exploiting the Coanda effect. Also in the case of desk edge ventilation, the air mixture flows through the occupied zone towards the ceiling (*Fig. 7*). Special provisions at the air outlet direct the air flow and diffuse it to such an extent that the heads of seated persons are not in the direct airstream but in the induction zone. Using desk edge venting, it is possible to obtain precise climatic conditions at head height.

When desk edge ventilation is applied, the primary air has a temperature of at least 19–20 °C, being therefore some 2–3 K cooler that the room air. Per seat, a maximum of about 50 m³/h supply air can be introduced directly into the room. This amount is composed of 20–35 m³/h primary and 0–15 m³/h induced secondary air. The primary air is passed in from a pressure plenum or from a ducting system through specially designed desk inlets. Generally, one desk inlet supplies two seats with primary air. This type of air introduction requires fixed furniture and is particularly suitable for lecture theatres (*Figs. 8* and *9*).

Both variants of displacement airflow lead the conditioned supply air directly into the user zone. The room air flow in the user zone is easily stabilized in this way. There are scarcely any influences from changes above this zone, for example, heat loads associated with the lighting. Thus a more precise temperature stratification can be formed above the user zone. Temperature differences between supply and extract air of up to




7 Room air flow using desk edge ventilation.




10 Room air flow: left, air introduction from the side; right, from above.

about 10 K are possible. Thus, for example, for 0.5 m² floor area per seat and 35 m³/h air supply, heat loads of up to more than 200 W/m² can be dealt with. Since the air outlets are located near to the occupants, they have to satisfy stringent requirements with regard to flow and acoustic characteristics. Where air introduction is from the floor, an accurately scaled laboratory test has to be carried out in each case to optimize the floor-chair-outlet combination (*Fig. 1*).

As far as the building structure is concerned, both systems require a pressure plenum or a comprehensive ducting system located in the void beneath the floor. In order that all outlets receive the same supply air quantity, a corresponding pressure loss of 30–50 Pa is required. It should be noted, however, that upward airflows with velocities of 1 m/s can arise at front edges of balconies.

## Mixed airflow

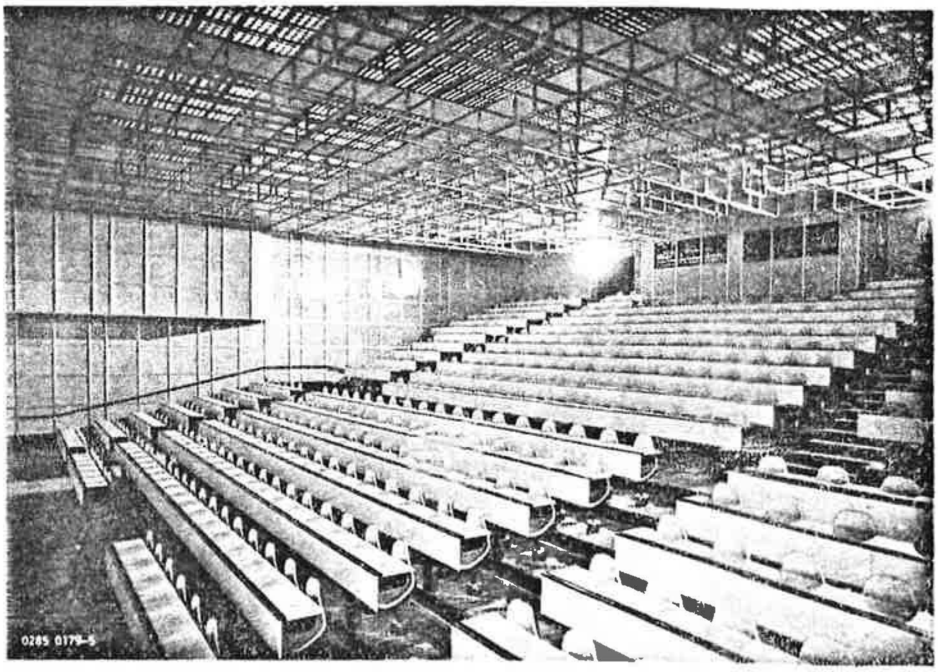
Unlike the two variants of displacement airflow, mixed airflow features air introduction from above or from the side through special induction swirl-air outlets or long throw jets (*Figs. 10* and *11*). These outlets have a high induction capacity. The conditioned air thus intermixes intensively with the room air and forms large-volume room air circulation. In the case of side wall outlets installed with horizontal discharge, a part of the induction air comes directly from the occupied zone, the other from the upper zone of the room. Where supply is from above, mainly air from the upper zone of the room is induced (*Fig. 12*).

Different thermal loads influence the formation of the room air circulation. An optimum arrangement of the air outlets is important in order to obtain room air flow conditions which are as stable as possible even under large variations of thermal load. The outlets have to be so arranged that the depth of air penetration can be changed to match the mode of operation (heating, cooling). The supply air can be admitted at temperatures of down to about 10 K (min. 15 °C) below and up to about 15 K (max. 35 °C) above the room temperature.

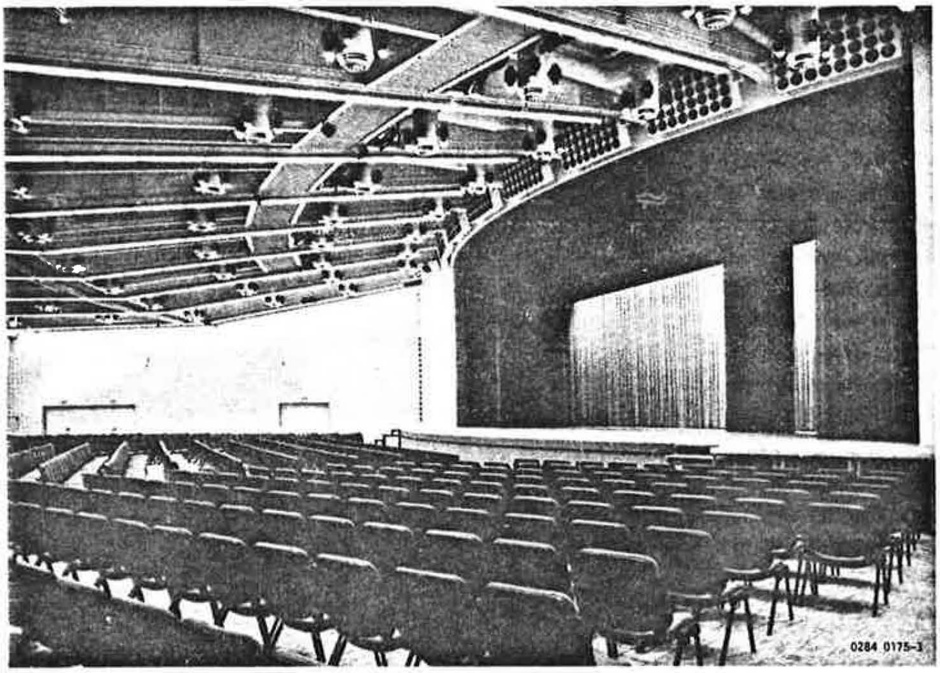
A special mixed air system with air introduction from above has been developed for trade fair and exhibition halls (*Fig. 13*). Essential components of this system are terminal units (Temcoils) which are either fitted directly to the ceiling or suspended from it. Each unit conditions the air of the room zone to which it has been allocated (*Fig. 14*).

The integral fan draws room air into the unit via its base. The air is either warmed or cooled as required by heat exchangers and then re-admitted to the room through two or four sides of the

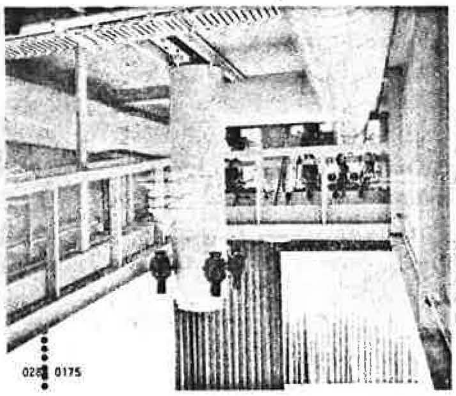

8 Desk edge outlets in the large lecture theatre, University of Zurich-Irchel.



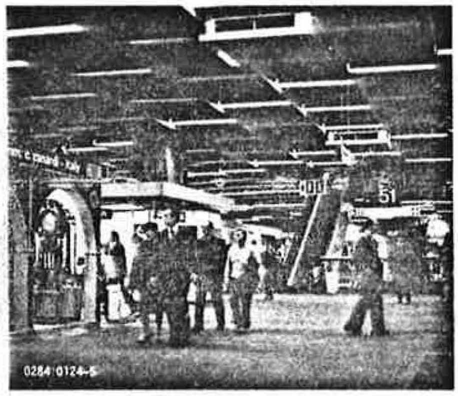

9 Lecture theatre in the Vienna General Hospital (Austria) with desk outlets. ▶



11 **"San Francisco" congress hall in the Swiss Trade Fair Complex, Basle (MUBA).**



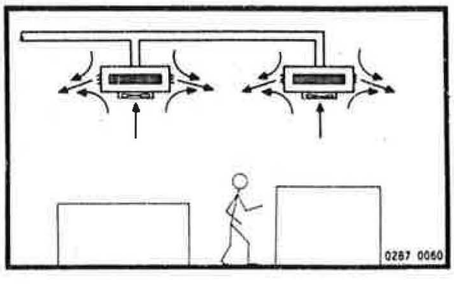
12 **Supply air duct with swirl-air outlet, "San Francisco" congress hall, Swiss Trade Fair Complex, Basle (MUBA).**



13 **Exhibition hall with Temcoil air conditioning units, Swiss Trade Fair Complex, Basle.**

unit. Regulation of the direction of supply air is by appropriate setting of adjustable blades. The outside air required is supplied from a separate air conditioning plant.

By dividing the space into zones, large areas can be provided with optimum air conditioning and ventilation using the appropriate number of units. Since each unit (Temcoil) has its own room temperature controller, heating or cooling loads are dealt with wherever they occur.



14 **Room air flow pattern using Temcoil units.**

**Table 1: Comparison of the most important parameters – offices and large halls**

| | | | *Office* | *Large Hall* |
|---|---|---|---|---|
| Room height | | (m) | 2.3–3 | 15–20 |
| Occupied zone | (head height) | (m) | 1–1.7 | 1–1.7 |
| Ratio of room to head height | | (–) | 1.4–3 | 9–20 |
| Density of occupation | (persons/10 m²) | | 1 | 15–20 |
| Thermal loading | (including lighting) | (W/m²) | 25–50 | 150–300 |
| Acoustic properties | Room sound level $L_A$ | (dB) | 35–40 | 25–28 (theatre) |

## Wall ventilation to oppose down-draughts

Additional problems can arise since large rooms are often also particularly high. The room air flow in the edge zones is influenced significantly by the difference between wall surface temperatures and room air temperatures. Downward air flows of considerable strength can occur at high walls with cold surfaces. These have a deleterious effect on comfort, particularly near the walls, due to the draught effect.

Additional heating devices or wall ventilation arrangements are installed adjacent to the walls in order to prevent down-draughts. The warm air rising from these compensates the cool down-draught. Such wall ventilation arrangements can be achieved with warm extract air from the room. Comfort is considerably improved by such means, with minimum additional energy consumption.

## Conclusions, practical applications

Compared with application for offices, the air conditioning technology required for large halls is significantly more complex (*Table 1*). In particular, the evaluation of the room airflow conditions in conjunction with the high thermal loading requires comprehensive knowledge. The number of people per square metre is generally much higher in large halls than in offices, hence the room air is significantly more influenced by used air ($CO_2$) and smells. Comfort conditions comparable with those in offices can also be produced in large halls by specialist engineering design and the application of appropriate technology.

Nowadays, the displacement airflow arrangement has been widely accepted for rooms with fixed seating. This arrangement is advantageous particularly for dealing with the flow conditions in the occupied zone.

Mixed air flow is used mainly in rooms where the building structural characteristics do not allow displacement flow to be used, for example where the seating facilities are movable. Ω