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Displacement Ventilation

REHVA published 2002 the first version of displacement ventilation guide. The aim of this revised Guidebook is to give the state-of-the art knowledge of the technology.

The idea of this guidebook is to simplify and improve the practical design procedure.

Rehva Guidebook on Displacement Ventilation

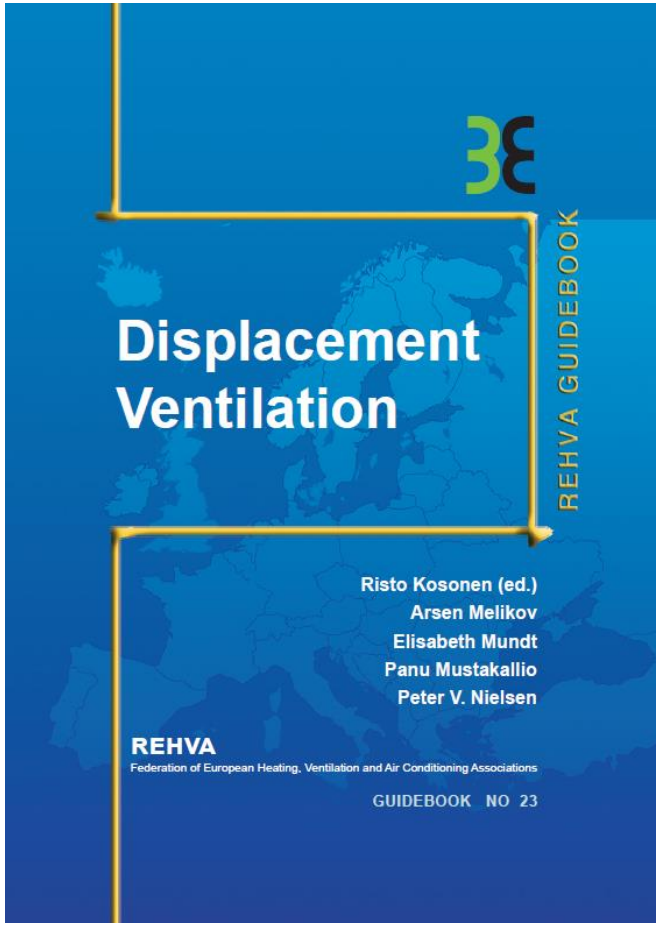
Aimed at:

- **the practising engineer**

Discussing:

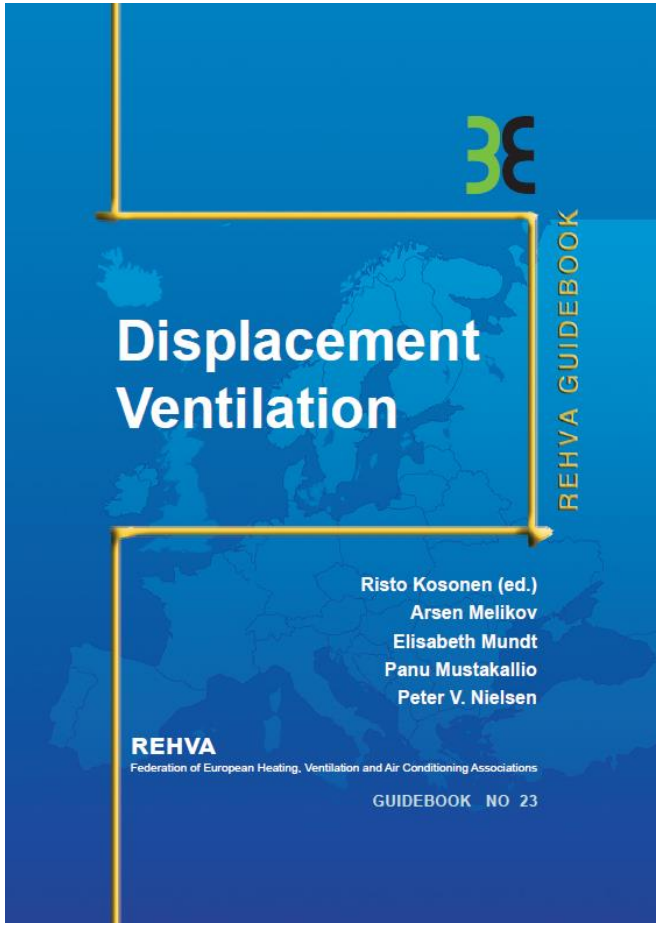
- **what is displacement ventilation?**
- **what are the pros and cons ?**
- **How to design displacement ventilation system ?**
- **What are the critical factor in design ?**

This guide also show practical case studies in some typical applications and the latest research findings are discussed.



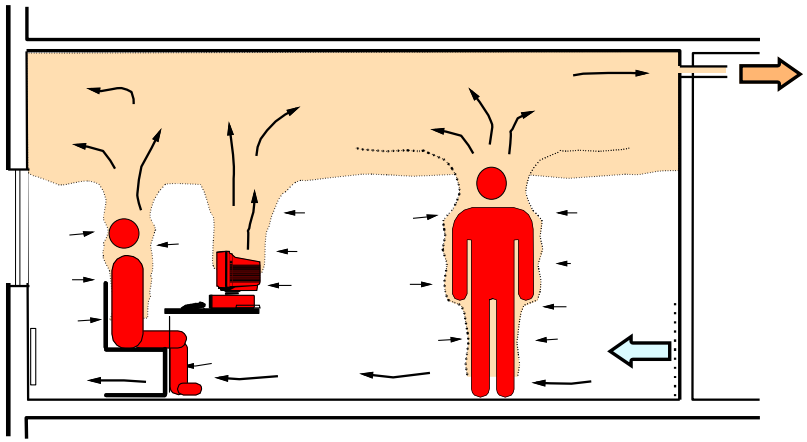
Contents of the book

1. Disp.vent in a nutshell
2. Terminology, symbols and units
3. Room air distribution
4. Performance of disp. ventilation
5. Calculation of supply airflow rate
6. Air diffusers for displ. ventilation
7. Design of disp. ventilation
8. Case studies
9. Research findings
10. References

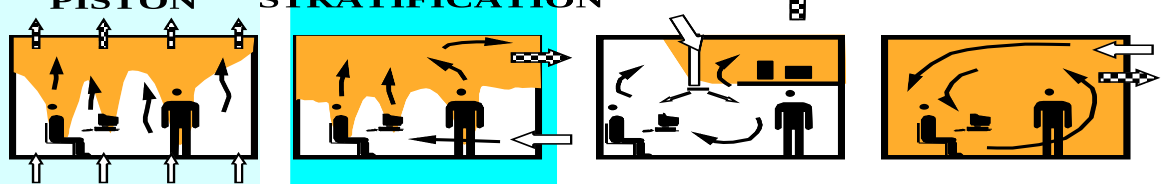
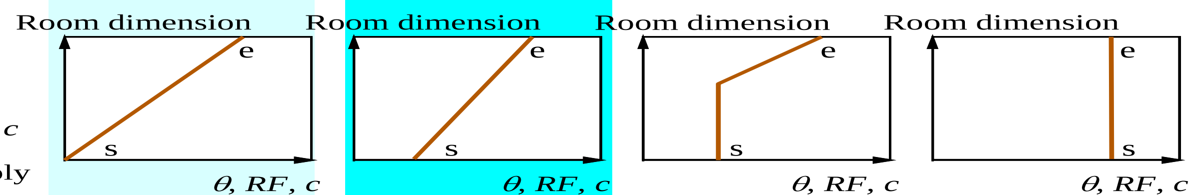


The basic idea

Displacement ventilation is considered to be the technique of supplying clean, cool air at floor level, letting warm air and contaminants rise to the ceiling and extracting the contaminated air at ceiling level.

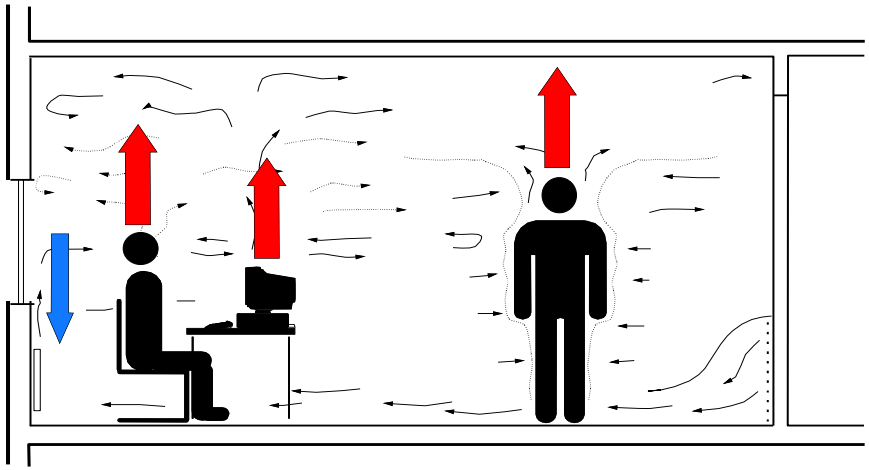


Possible ventilation strategies in the room space

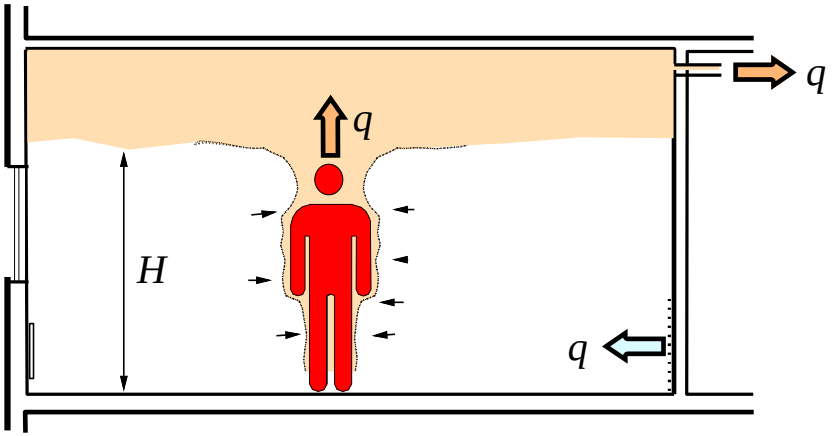
	DISPLACEMENT		ZONING	MIXING
Strategy	PISTON	STRATIFICATION		
				
Description	Unidirectional flow through the room	Utilise density differences	Air flow from clean zones to contaminated zones	Uniform conditions in all parts of the room
Air quality; · temp, θ · humidity *RF* · contaminants, *c* s = supply e = exhaust				
Main characteristics	Flow pattern controlled by low momentum supply air, strong enough to overcome disturbances	Flow pattern controlled by buoyancy	Flow pattern controlled partly by buoyancy and partly by supply air momentum	Flow pattern controlled by high momentum supply air
Ventilation effectiveness		$\varepsilon_\theta = \frac{\theta_e - \theta_s}{\theta_{oz} - \theta_s}$	$\varepsilon_c = \frac{c_e - c_s}{c_{oz} - c_s}$	
	∞ ⟵	⟶	⟶	1

Convection flows – the engines of displacement ventilation

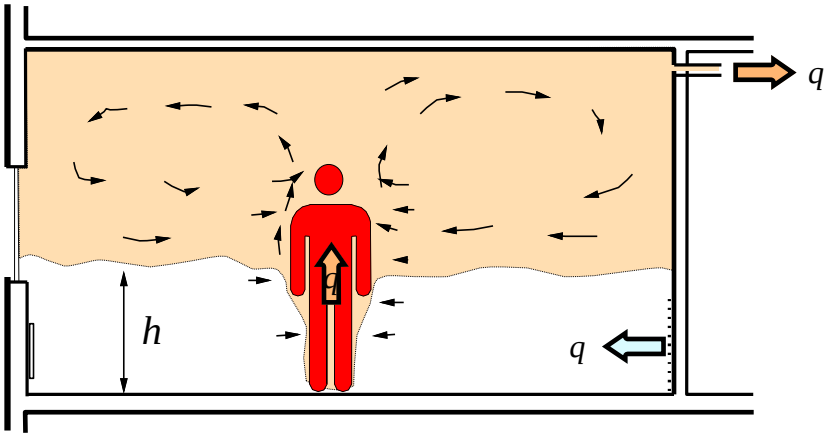
Natural convection flows are the engines of displacement ventilation. A natural convection flow is the air current that rises above warm objects like people or computers, rises along a warm wall, or descends from cold objects like windows or outer walls, due to buoyancy



Basic principles – Convection currents



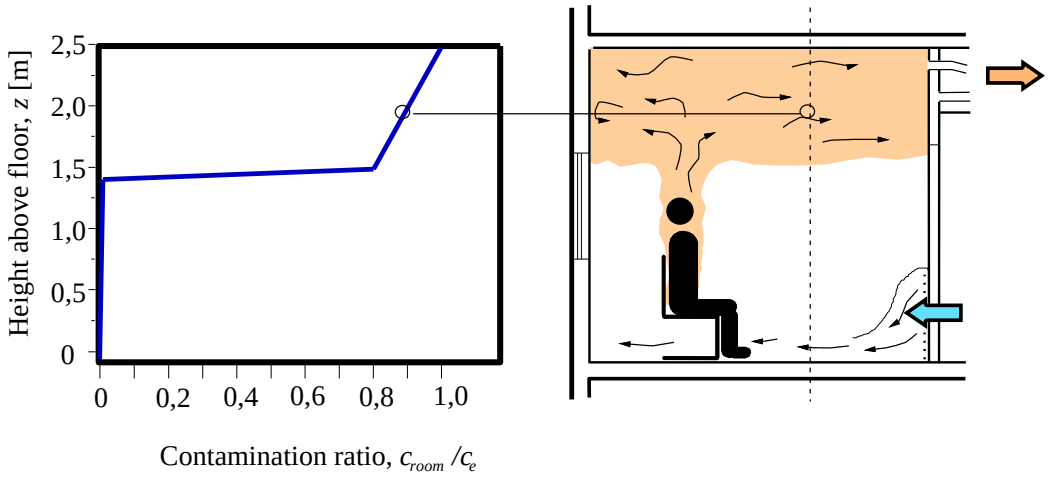
The air that rises in the convection current must be replaced by new air. This makes a two-layer flow, where the polluted, “used” air stratifies in the upper layer.



Less supply air lower the interface between the two layers.

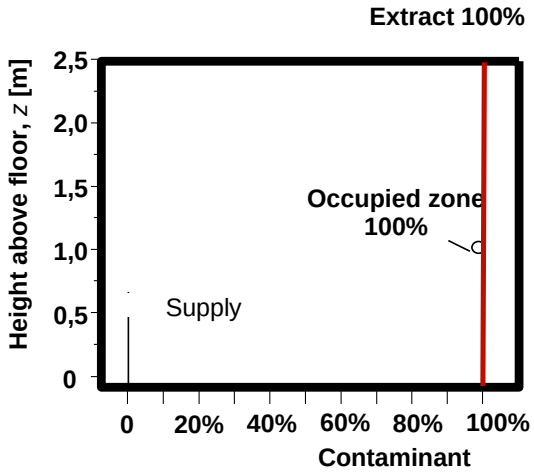
Contamination distribution

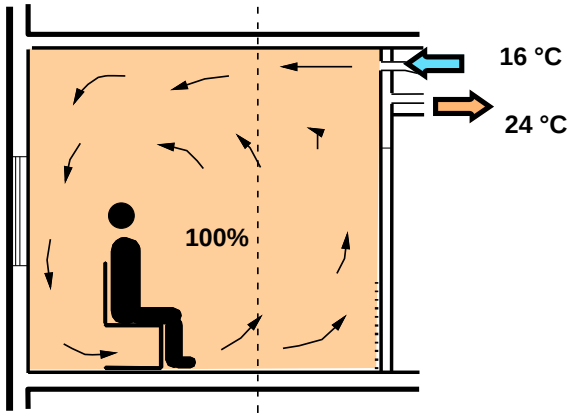
The contamination distribution in a displacement-ventilated room depends on the position of the contamination sources and if the heat sources are also the contamination sources. In the ideal case with warm concentrated contamination sources all contaminants are transported directly into the upper zone by the convection flows



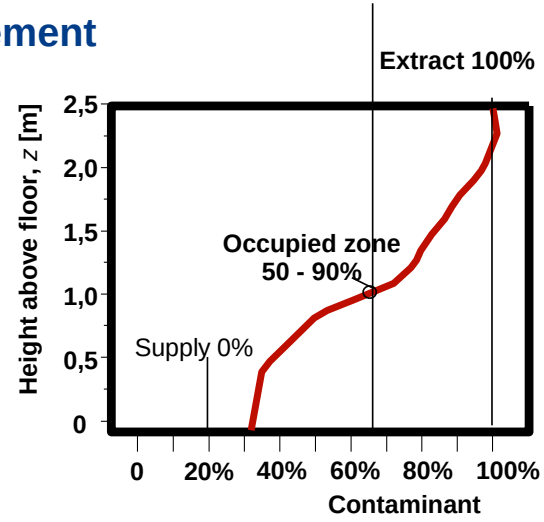
Contaminant distribution in normal rooms

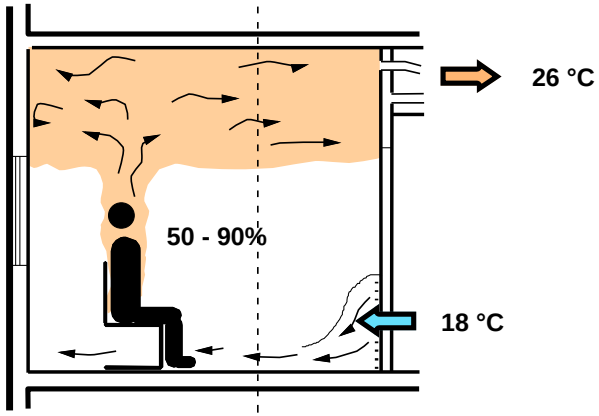
Mixing





Displacement

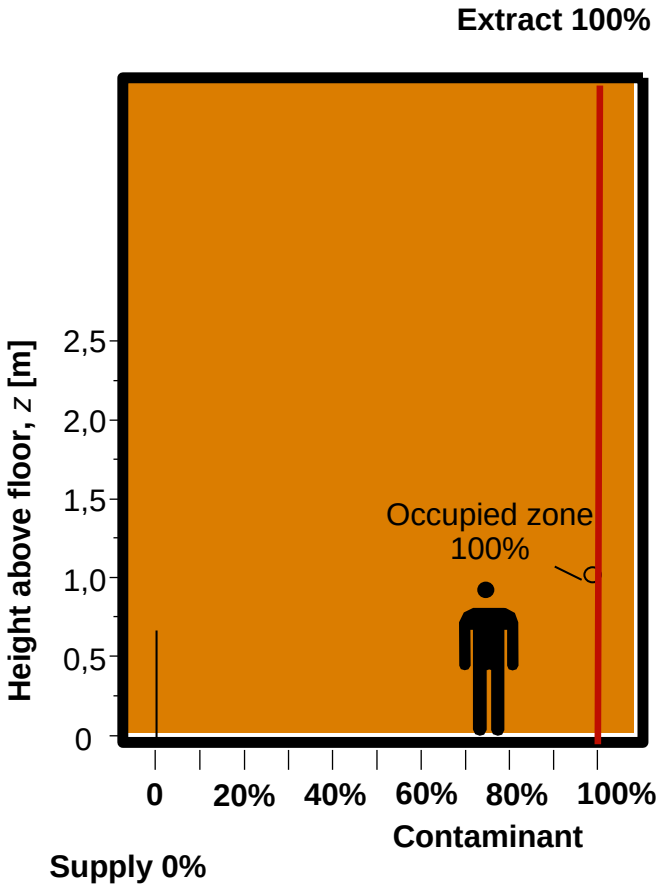




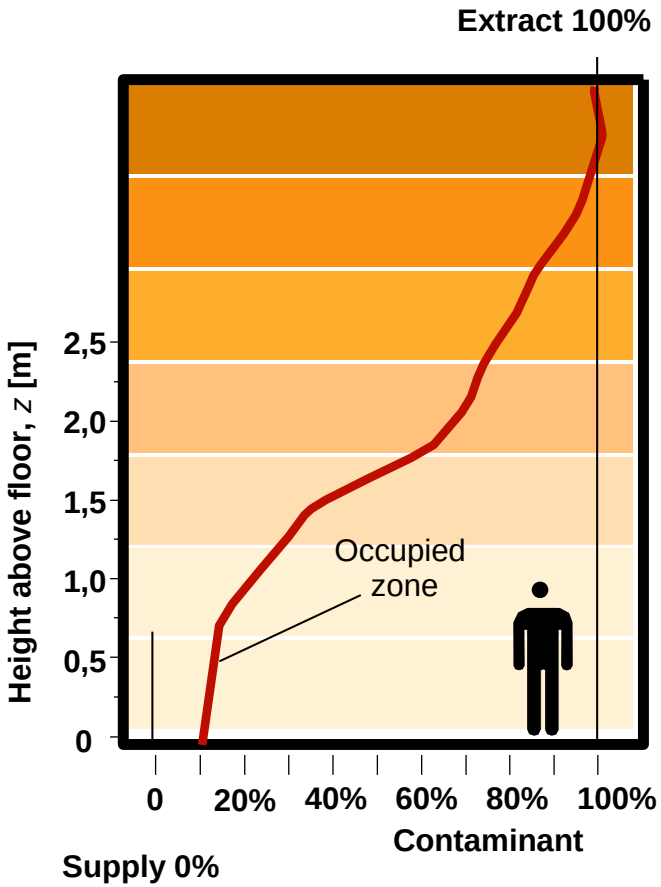
For the same ventilation rate, we may get better air quality with displacement ventilation

Contaminant distribution in tall rooms

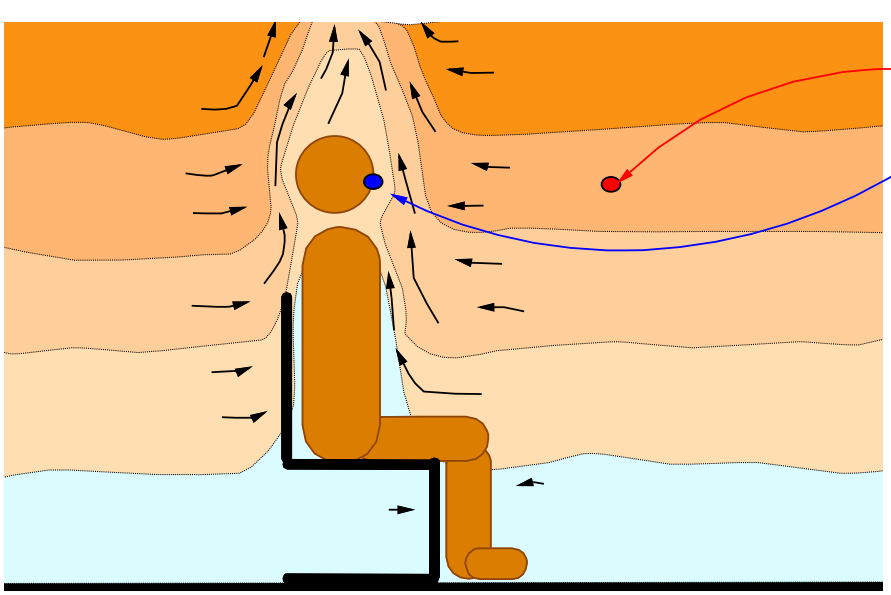
Perfect mixing



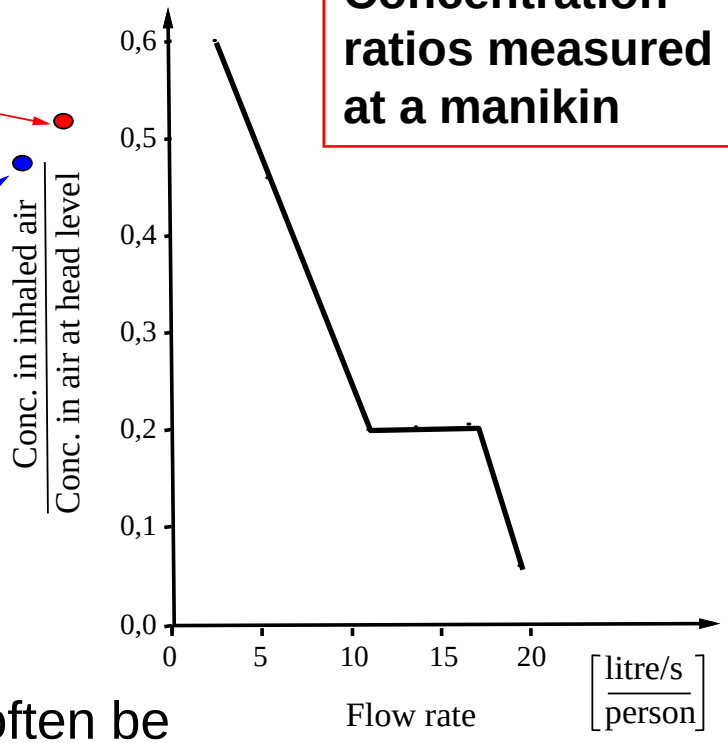
Displacement



Contamination in inhaled air



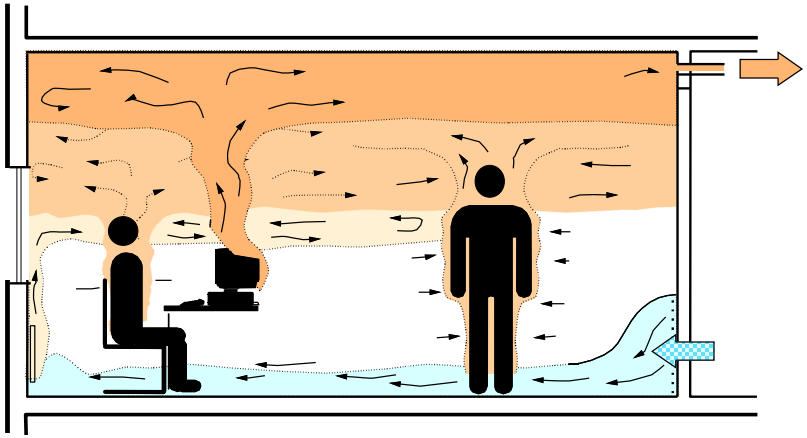
Concentration ratios measured at a manikin

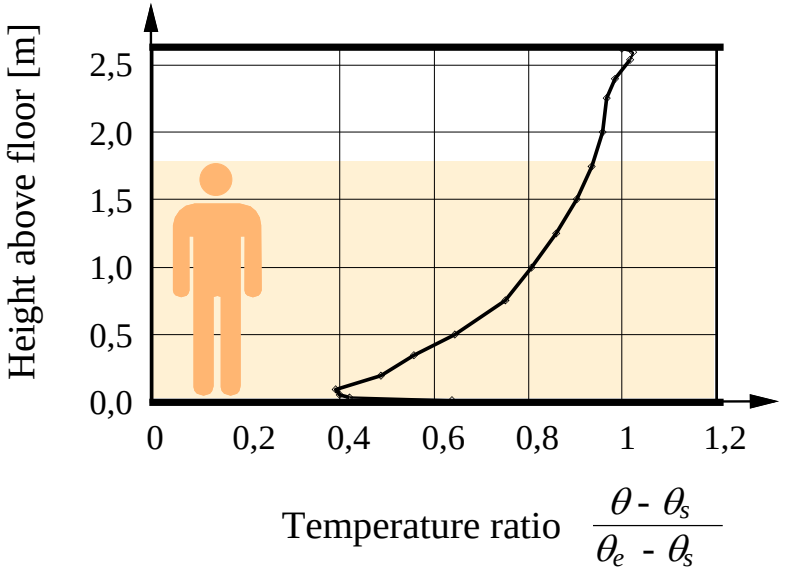


The personal exposure index will often be larger than the local ventilation index because clean air is moved from the lower part of the room up to the breathing zone by the free-convection boundary layer around the person

Basic principles – Thermal stratification

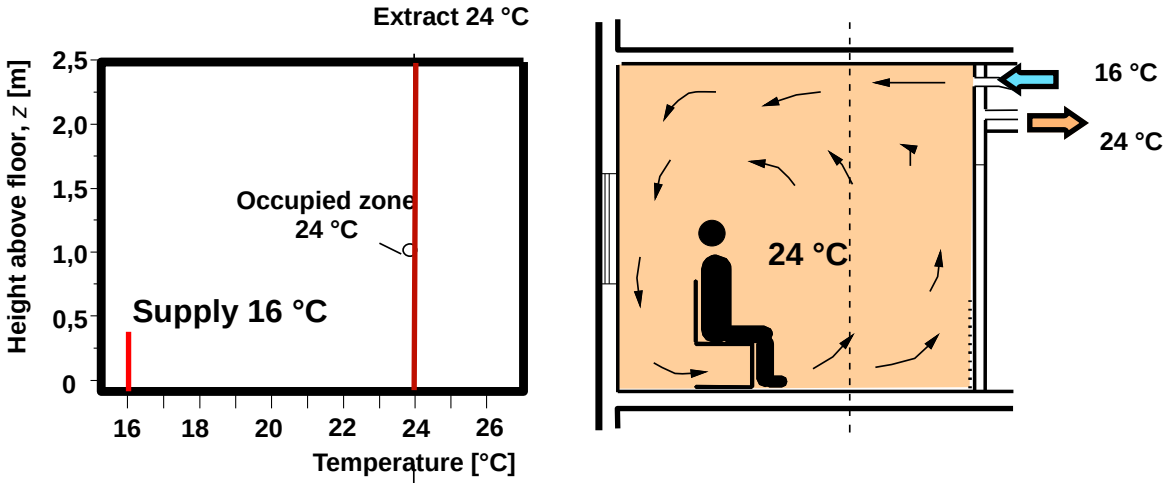
The air will stratify in many layers, making the temperature rise from floor to ceiling.



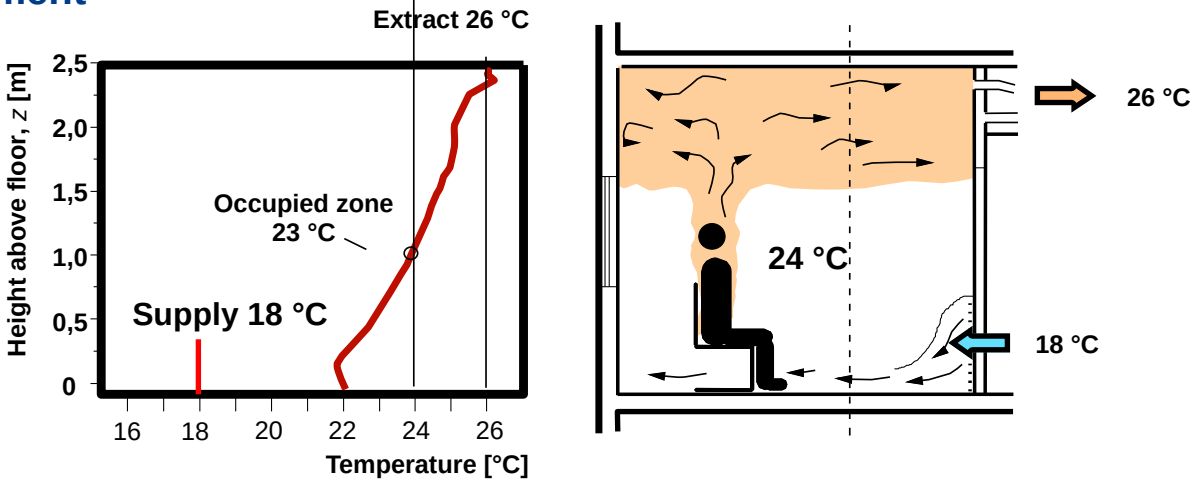


Temperature distribution - normal rooms

Mixing



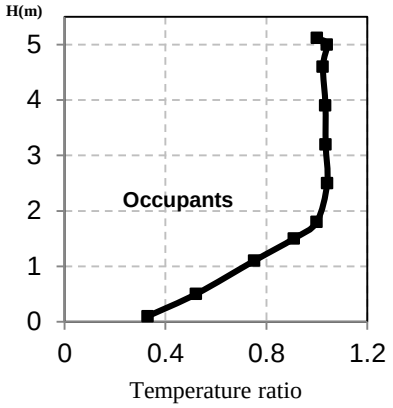
Displacement

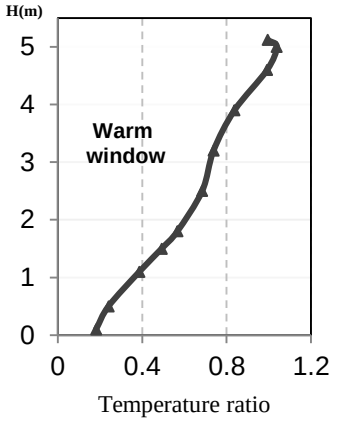


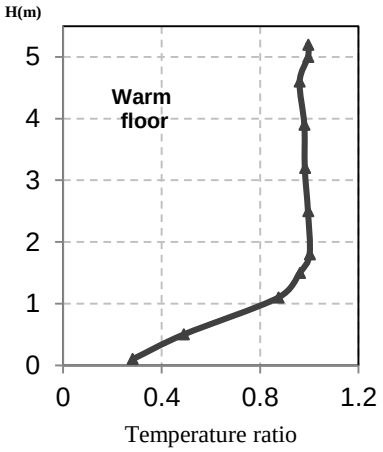
Less cooling is needed to obtain the desired temperature in the occupied space

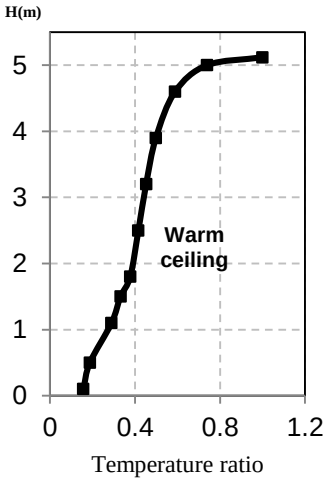
The occupied zones – the coolest part of the room

- In displacement ventilation, the air temperature increases from floor to ceiling.
- **Vertical temperature profiles varied with different individual types of heat load (occupants, warm floor, warm window and warm ceiling).**



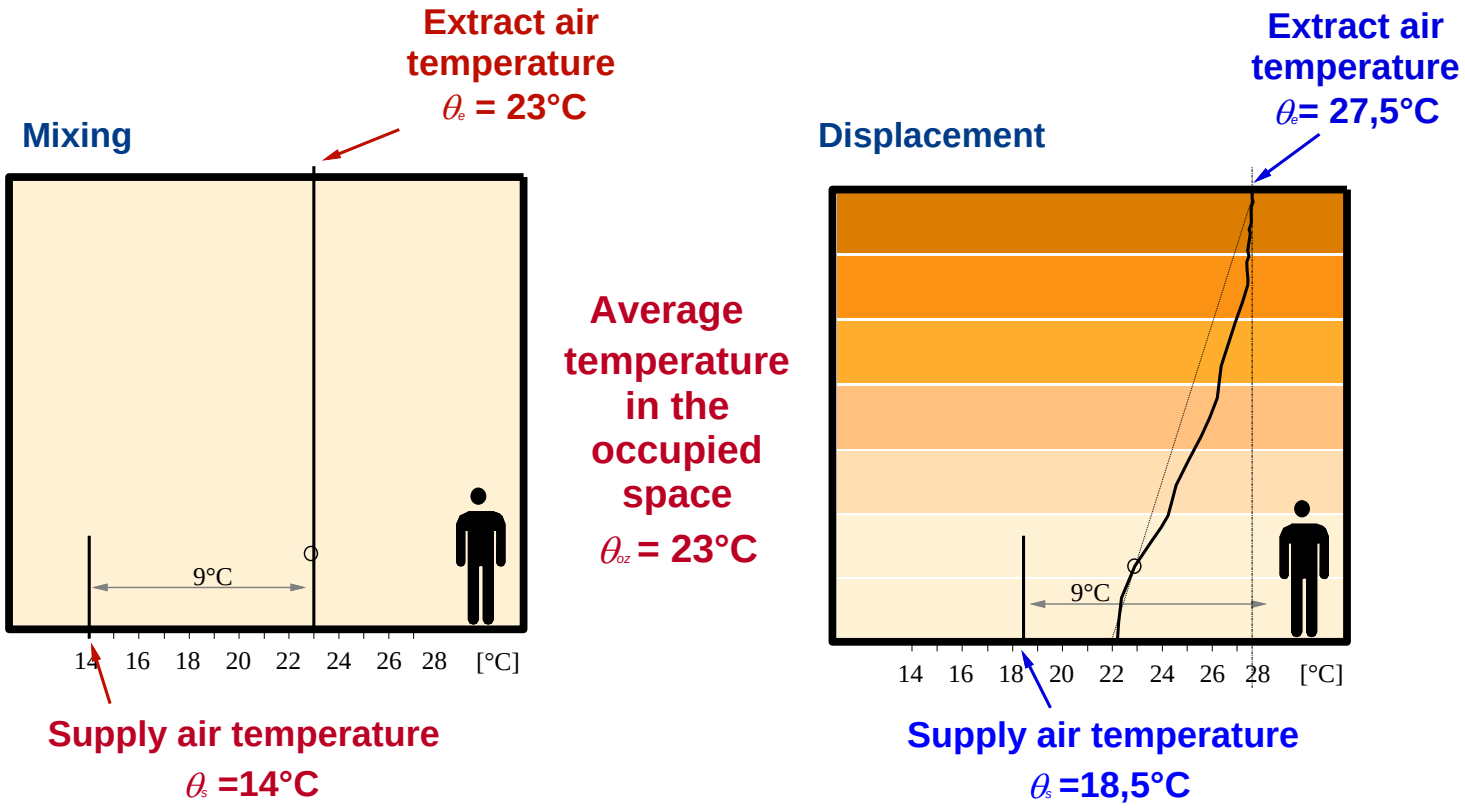






$$\textit{Temperature Ratio} = \frac{\theta - \theta_s}{\theta_e - \theta_s}$$

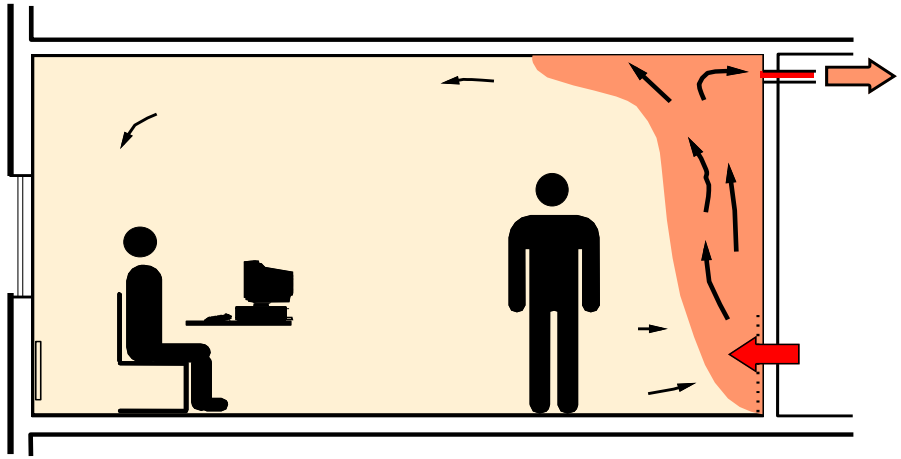
Temperature distribution - Tall rooms



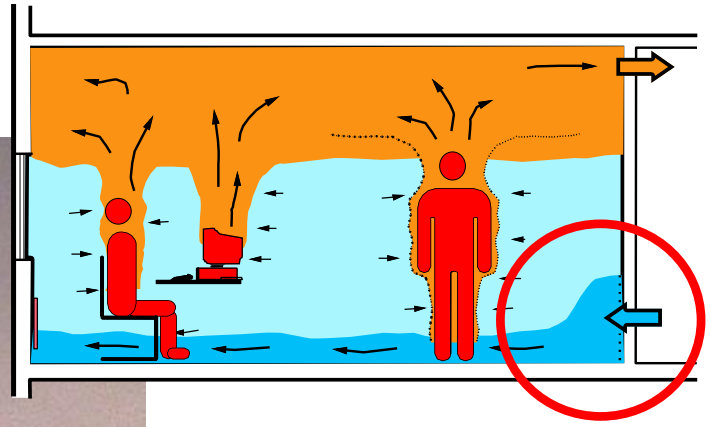
The cooling advantage is most pronounced for tall rooms, but the type of heat load affects a lot on the actual vertical temperature difference.

Do not heat occupied rooms with displacement ventilation

If warm air is supplied at floor level, in a room cooler than the supply air, it will rise due to buoyancy, and be extracted when it reaches the ceiling. Thus, the supply air will short circuit into the outlet and little of the clean and heated warm air will reach the occupied space.



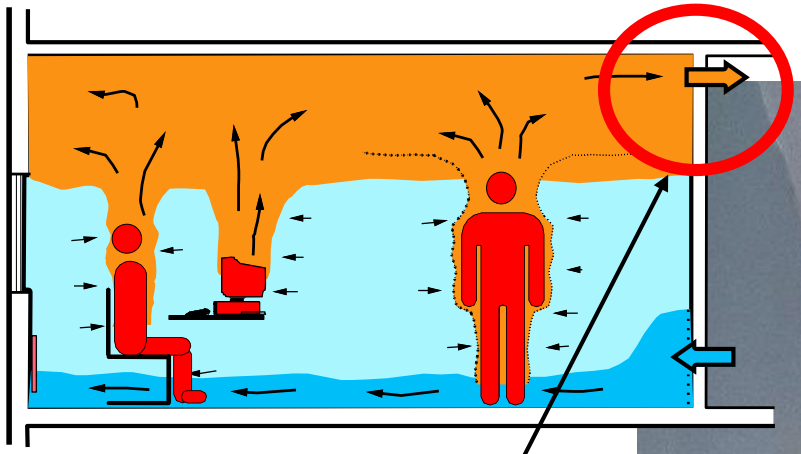
Air supply



Air supply units

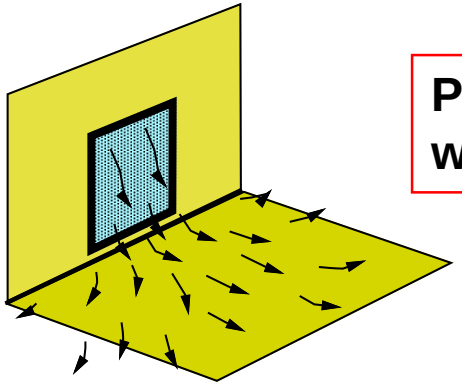
The air floats along the floor like water and fills the room from below

Air is extracted at ceiling level

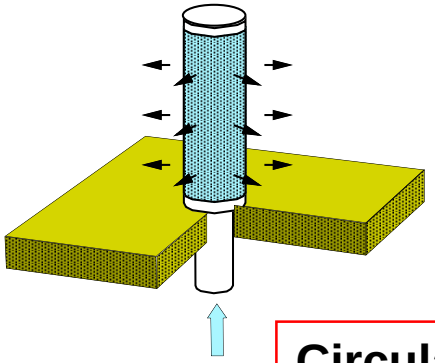


The extract opening can be located anywhere in the highest part of the room

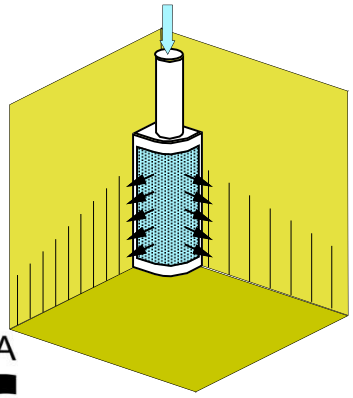
Air supply can be arranged in many ways



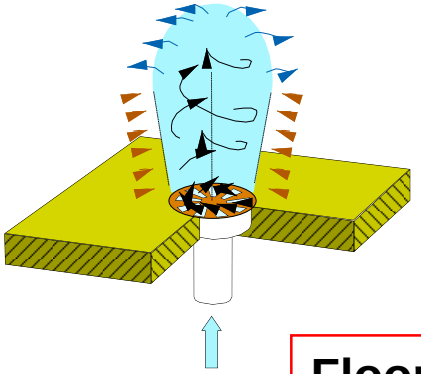
Plane, wall-mounted



Circular, free-standing



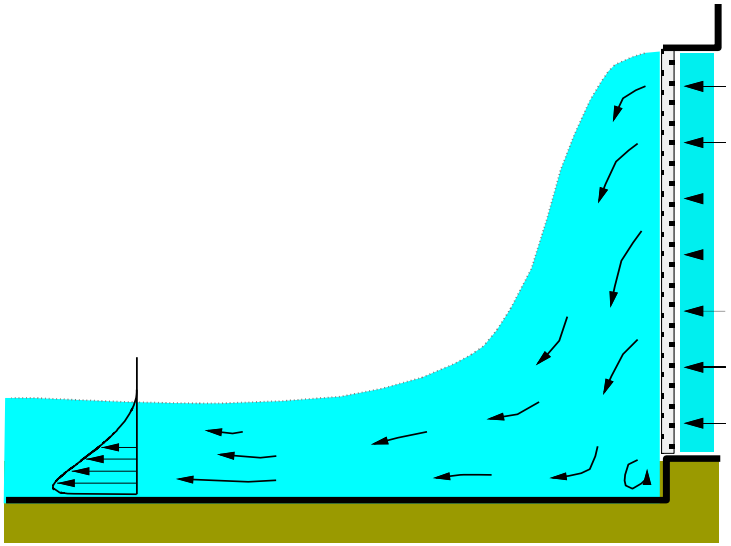
Semi-circular, corner-mounted



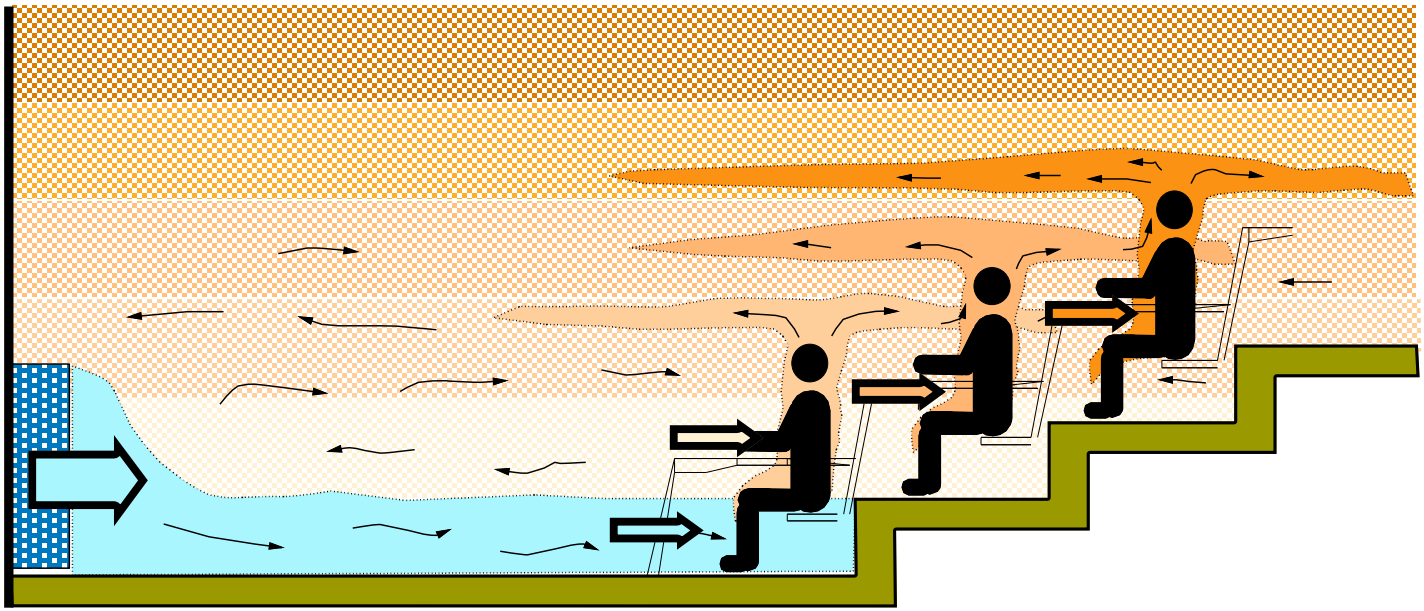
Floor-mounted

The air supply diffuser – a crucial factor

Most draught problems reported in rooms with displacement ventilation are due to high velocity in the zone adjacent to the diffuser. It is important to choose a diffuser that is suited for the application and only utilise diffusers from manufacturers that supply robust documentation together with the products.

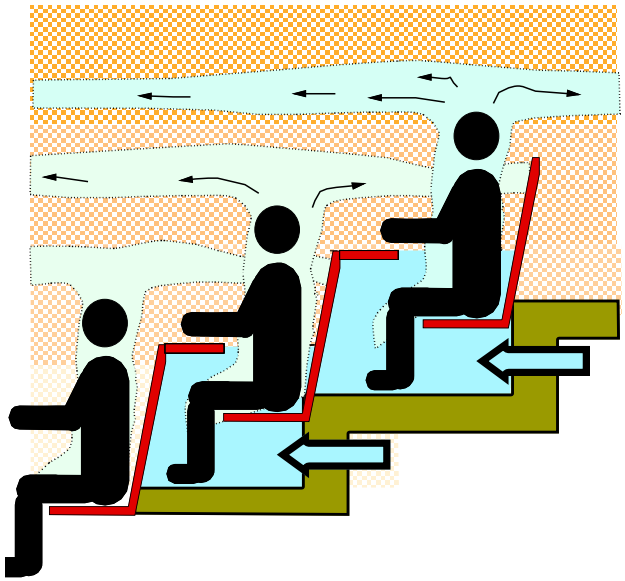


Auditoria – air flow pattern

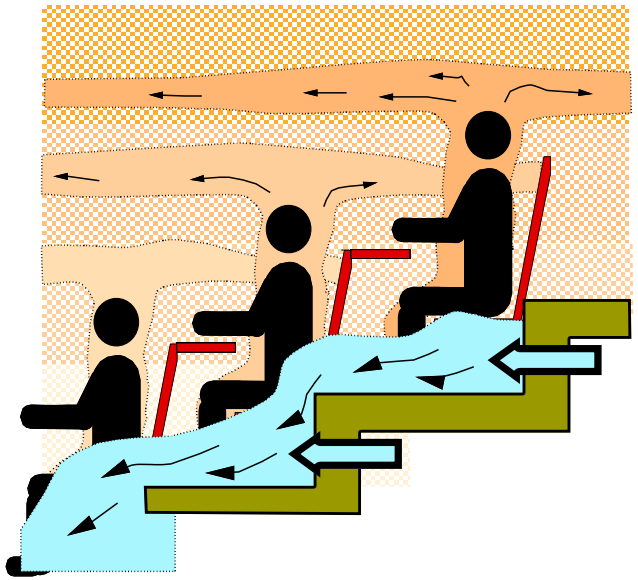


Thermal and contaminant stratification

Auditoria – air flow pattern



Supply air is contained between the rows.



Supply air is floating down the stairways.

Collaboration with the architect is required

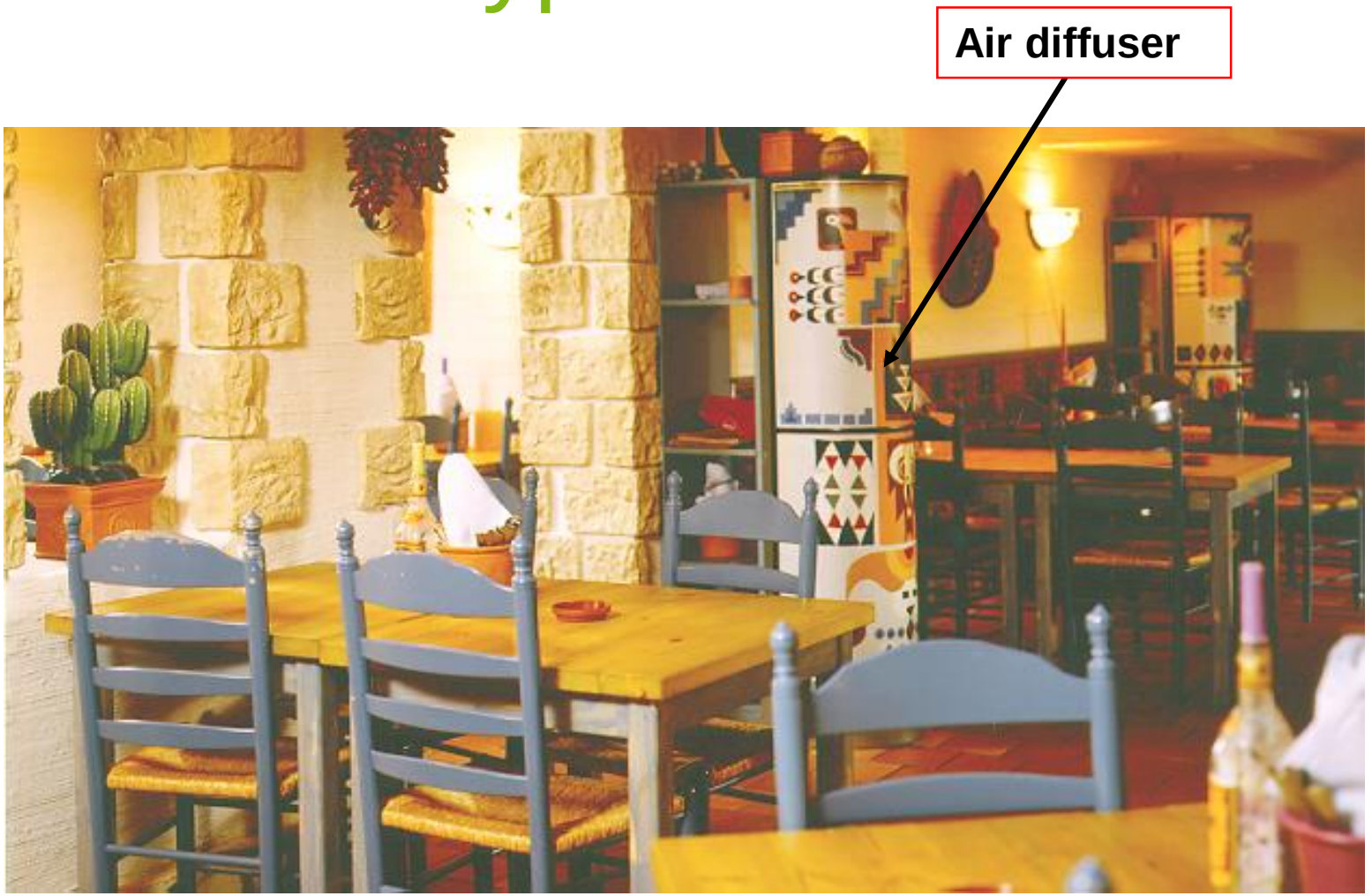
The diffusers require a certain amount of wall area, or space in, or on, the floor. Close cooperation with the architect is required to find a suitable location for the air diffusers. The supply units can also be designed to fit different architectural requirements: units could be invisible or be an exposed architectural element.

Diffuser types - Casino

Air diffusers behind columns

Diffuser types - Atrium

Diffuser types - Restaurant



Diffuser types - Department store

Calculation of supply air flow rate

Two principal methods can be used when the supply air flow rate of displacement ventilation system is calculated: 1) temperature based design, where the design criterion is the air temperature in the occupied zone of the room and 2) air quality based design where the design criterion is the air quality in the occupied zone.

In commercial buildings, the removal of the excess heat is likely to be the main concern. The cases where cooling is the main issue, the temperature based design is the most commonly applied method.

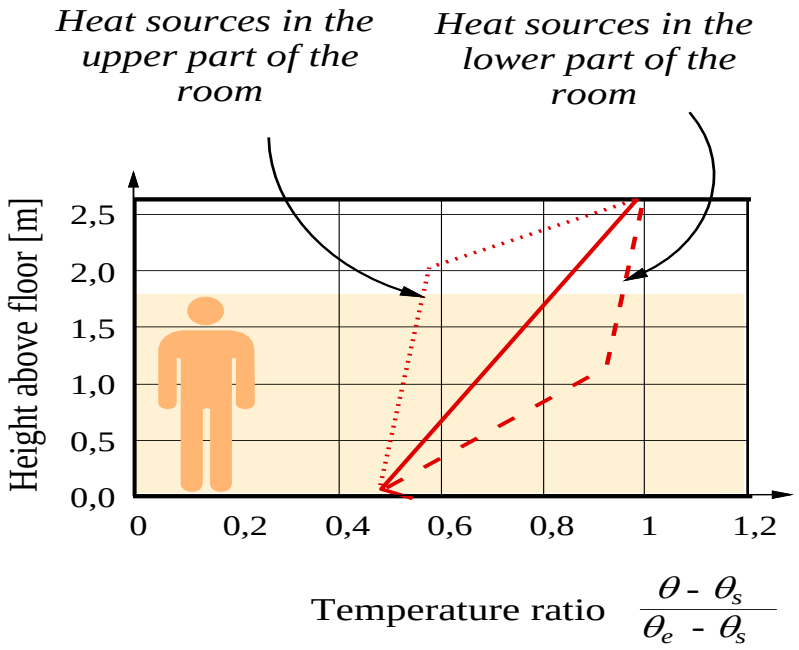
Temperature based design methods

Two principal methods can be used when the supply air flow rate of displacement ventilation system is calculated: 1) temperature based design, where the design criterion is the air temperature in the occupied zone of the room and 2) air quality based design where the design criterion is the air quality in the occupied zone.

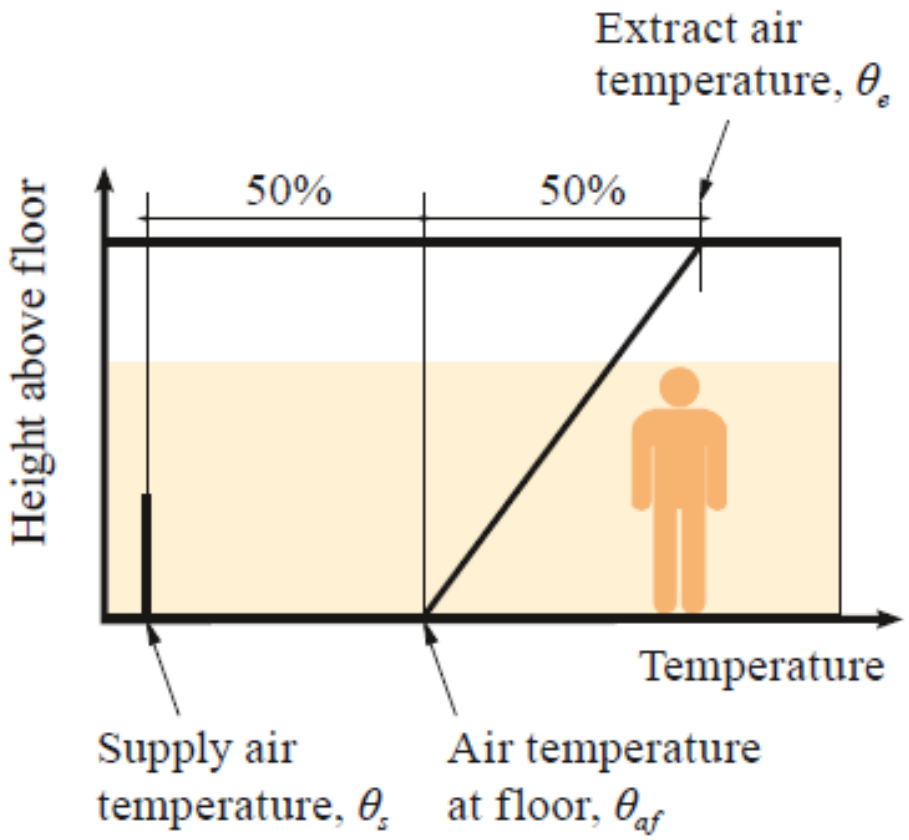
In commercial buildings, the removal of the excess heat is likely to be the main concern. The cases where cooling is the main issue, the temperature based design is the most commonly applied method.

Challenge of design

In the design process, the challenging task is to estimate vertical contaminant or temperature gradients in the room space.



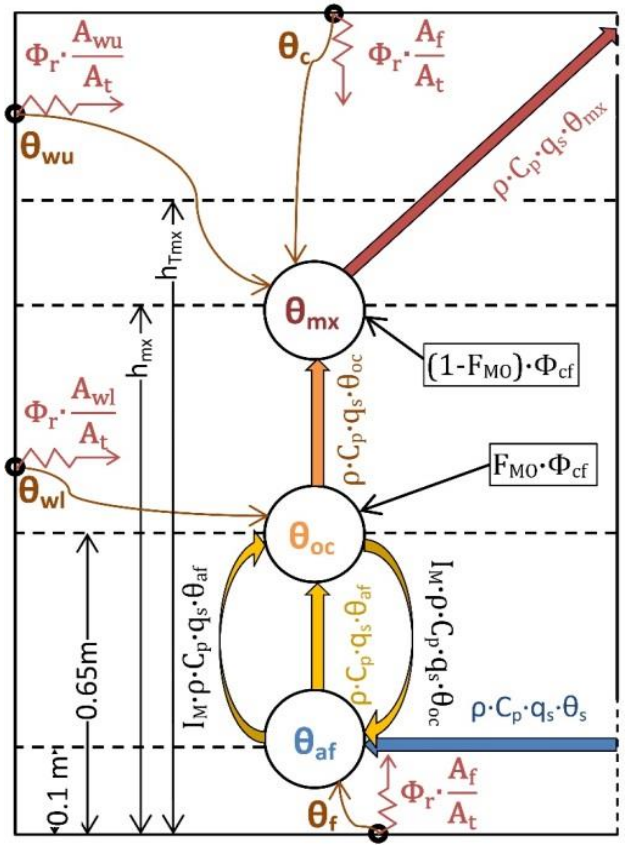
Linearized vertical temperature distribution calculated by Mundt model is the most common model.



Commonly used other methods

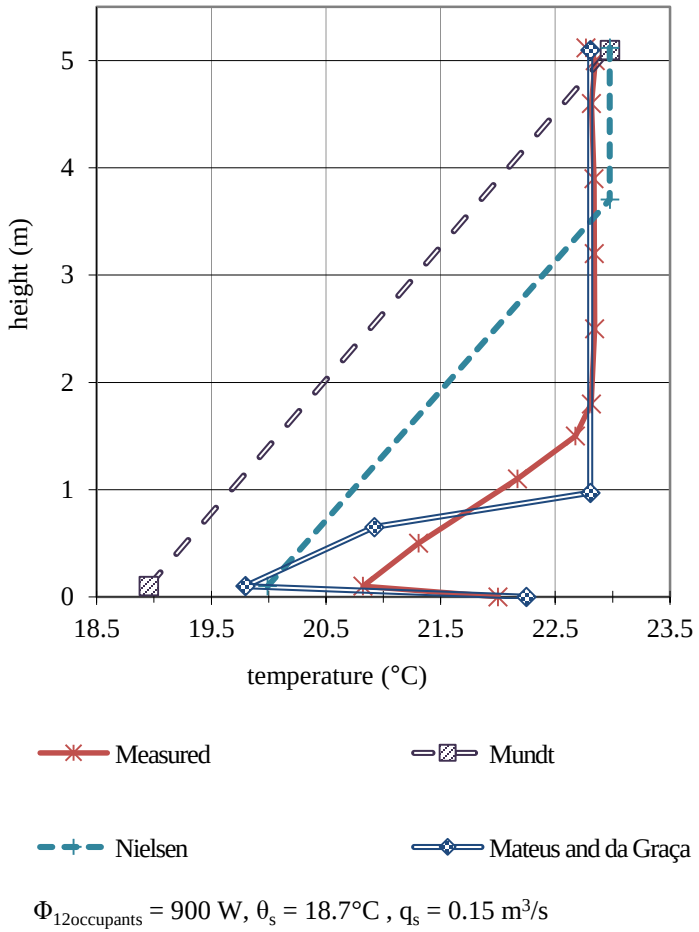
- In Nielsen model, a linear temperature gradient between floor and the height of mixing layer (stratification height) is predicted. Over the mixing layer, the room air temperature is assumed to be constant.

- The estimation accuracy of the vertical temperature distribution can be improved by modelling based on three nodes (Mateus and da Graça)



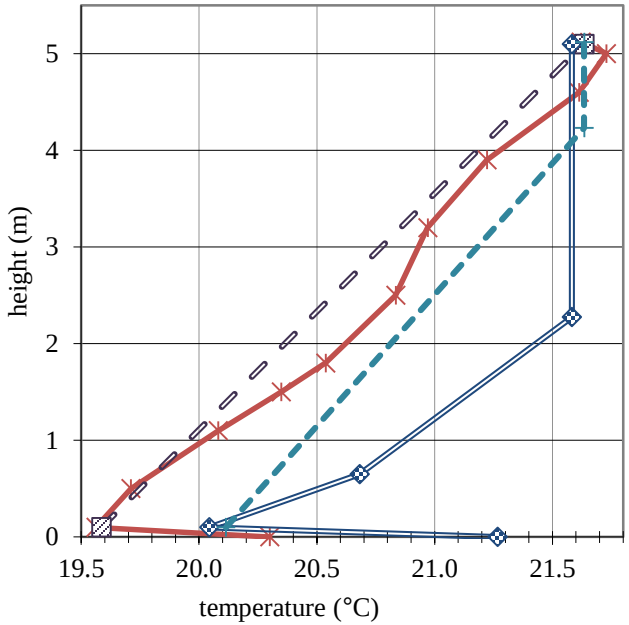
Comparison of calculated and measured vertical temperature gradients- persons

Mateus and Da Graça's model works fine with occupants, computers and floor heat loads. The linear two node models cannot accurately describe heat loads that exist in the occupied zone.



Comparison of calculated and measured vertical temperature gradients- warm window

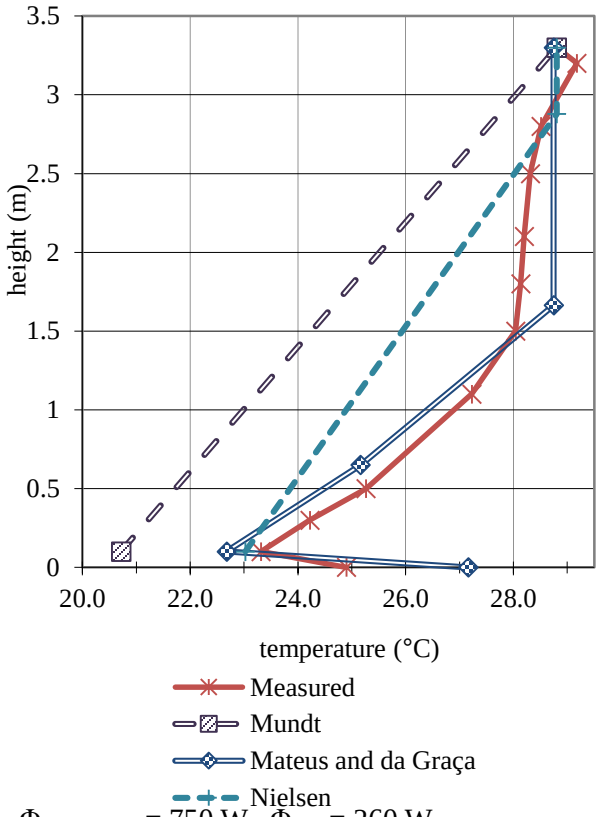
The linear two node models (Mundt) works well with a warm window. However, accuracy of Mateus and Da Graça's model with the warm window and warm ceiling were not so good.



$\Phi_{window\_3.5}$ = 520 W, θ_s = 19.1°C , q_v = 0.15 m^3/s

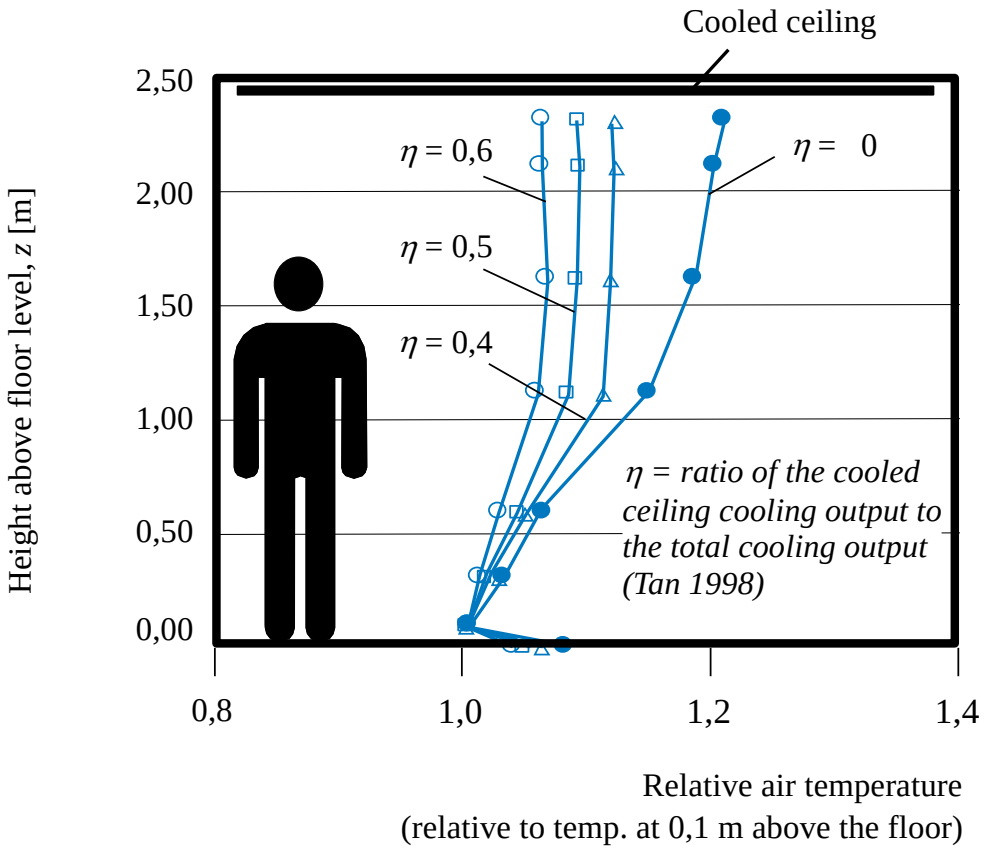
Comparison of calculated and measured vertical temperature gradients- compination case

Mateus and Da Graça's model works fine with occupants, computers and floor heat loads.



$\Phi_{10occupants}$ = 750 W, Φ_{floor}= 260 W,
Φ_{light}= 232 W, $\Phi_{win\_3.5m}$= 520 W,
θ_s = 18.1 °C, q_v = 0.1 m^3/s

Cooled ceiling - high temperature cooling

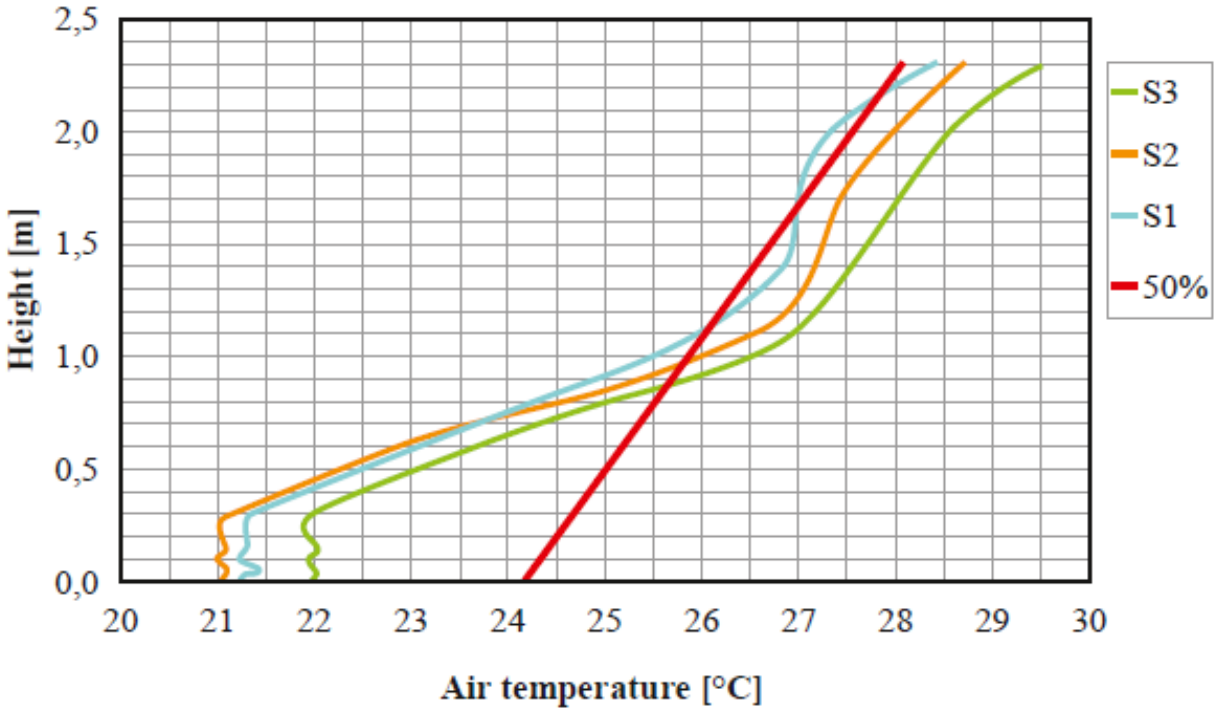


Cooled ceiling is ok when the cooling output of the ceiling is less than 40% of the total cooling.

Cooled ceilings, or cooling convectors, decrease the air quality benefit.

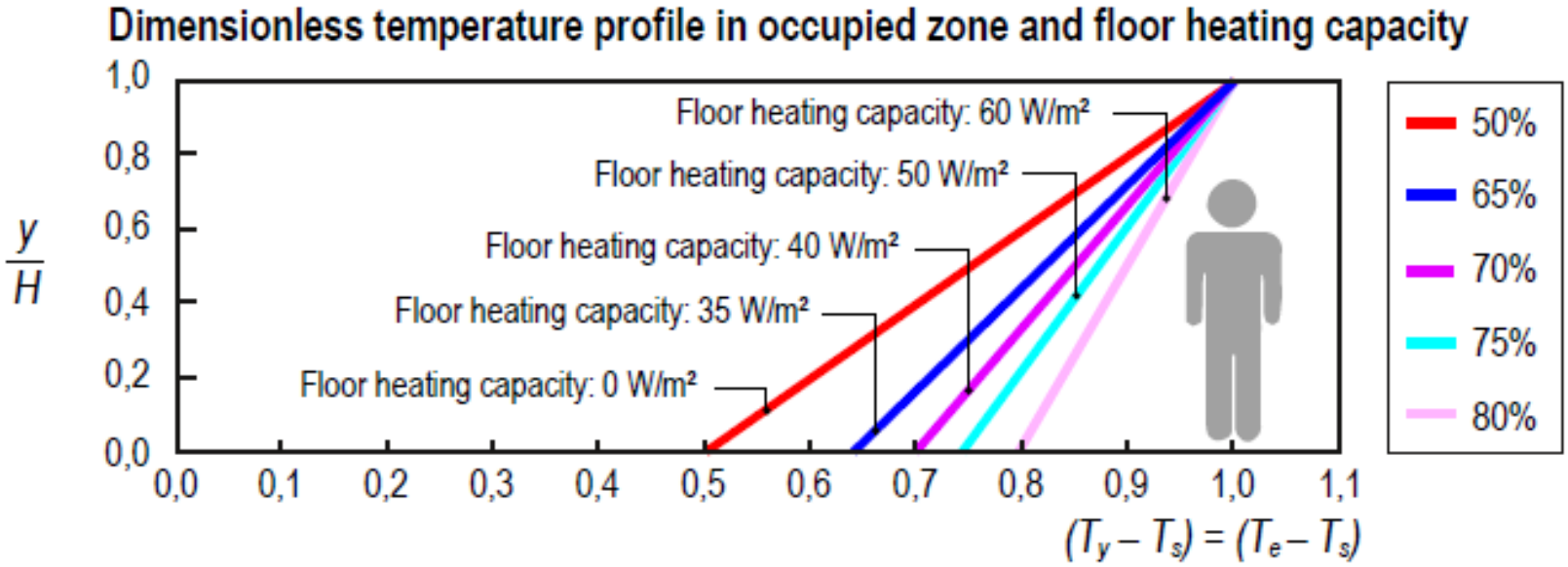
Mixing ventilation should be considered as an alternative.

Vertical air temperature profile with radiant floor at three locations (S1-S3).



The radiant floor effects the temperature gradient and higher vertical air temperature differences are expected. The “50%-rule” is not valid in the occupied area.

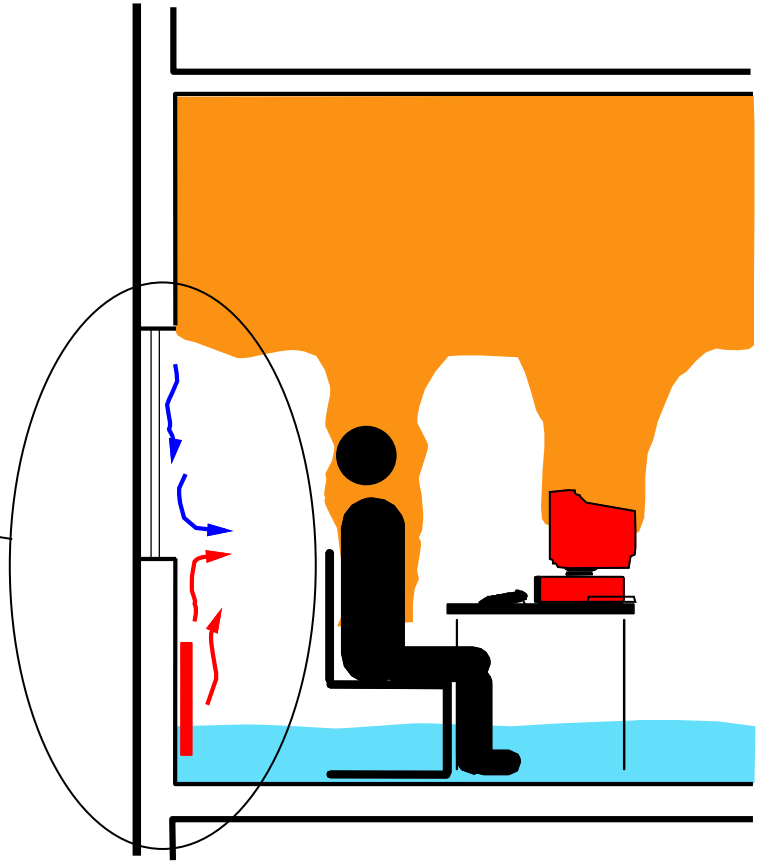
The dimensionless room air temperature profile in the occupied zone and the floor heating capacity



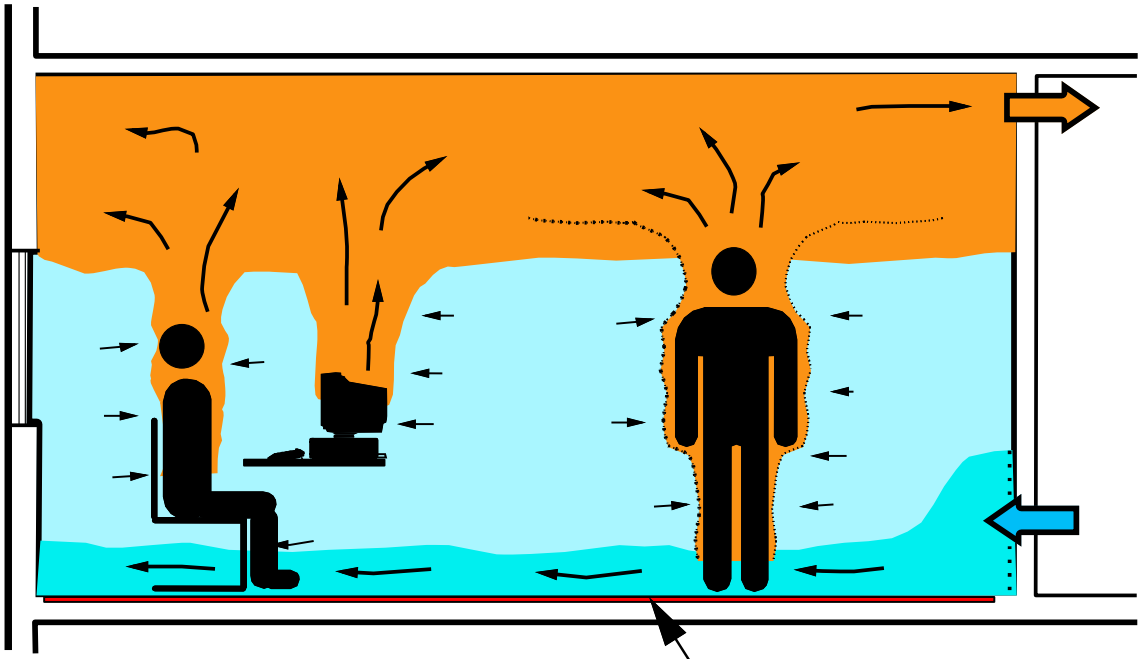
A new method of calculation is proposed, using an "80%-rule" as the limit, for a floor heating capacity of about 60 W/m^2.

Heating by radiator/convector

Warm air from radiator balances meets the cold air from window/wall

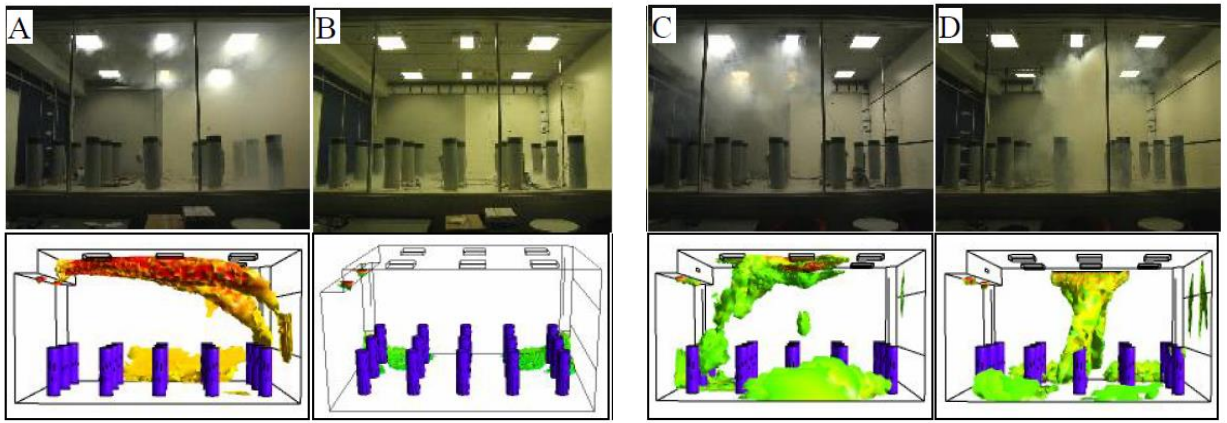


Floor heating - low temperature heating



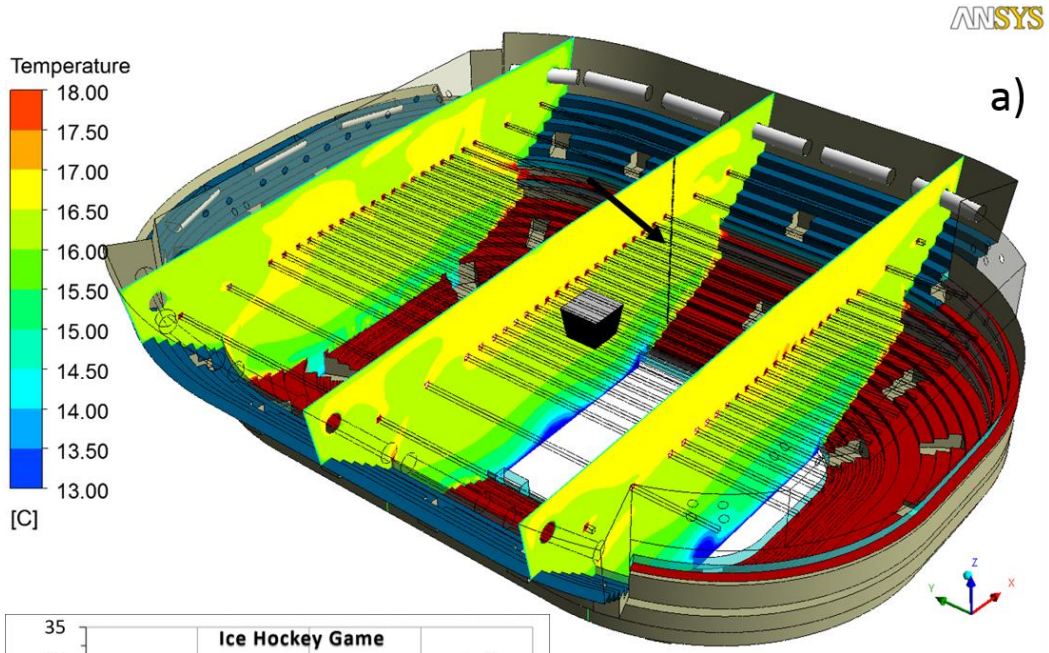
Floor heating is ok as long as the floor temperature is moderate (i.e. less than appr. 25° C)

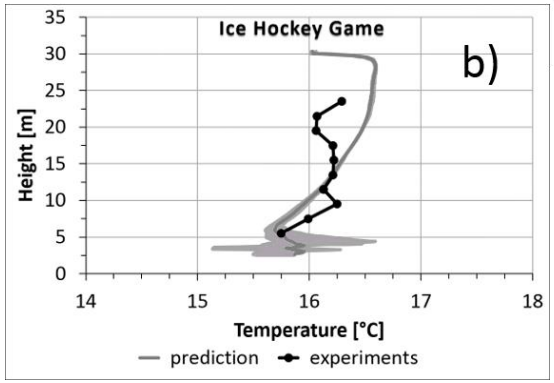
Case Study- Air distribution with four typical air supply methods in a classroom

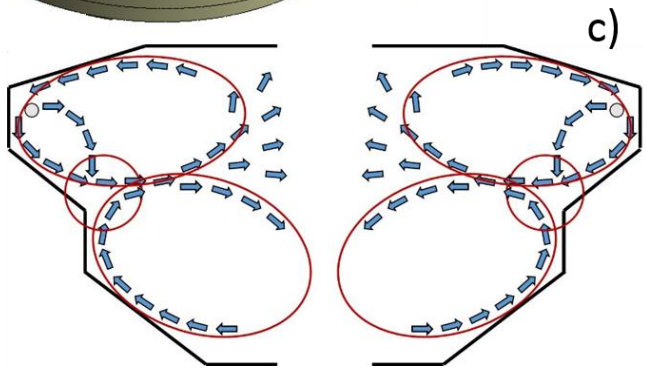


The performance of four typical air distribution methods in winter and summer conditions with different occupancy ratio was studied by physical measurements and smoke visualization in a mock-up classroom

Case Study- **Field measurements for a multipurpose arena**

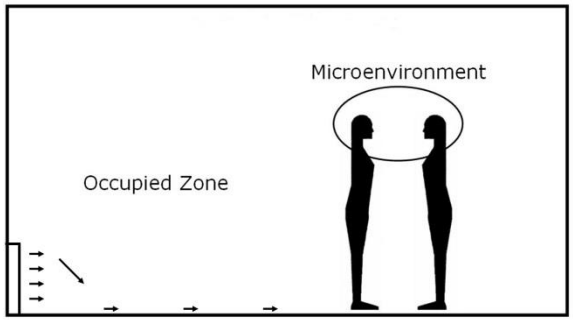






In the guide, there is also new resarch findings

- **Full-scale tests and CFD- simulations of indoor climate conditions**
- **Test on the performance of displacement ventilation– proper simulation of occupants**
- **Airborne Cross Infection Risk in a Room with Displacement Ventilation**
- **Displacement ventilation design based on occupants' response**
- **Convective boundary layer around human body**



Pros and cons of displacement ventilation

Best suited for:

- Gyms;
- Meeting rooms;
- Classrooms;
- Tall rooms: Convention centres, Lobbies, Sport arenas, Auditoriums, Theatres, Museums, Airports, Shopping centres, etc.

Advantages:

- Less cooling needed for a given temperature in the occupied space;
- Longer periods with free cooling;
- Potential to have better air quality in the occupied spaces;
- The system performance is stable with all cooling load conditions.

Less suited for:

- Where surplus heat is the main problem, and relatively low specific outdoor airflow rate is needed;
- Where there are space constraints for supply diffusers and duct work;
- When the requirement is to cool in low height rooms (in offices, consider mixing and cooling panels or chilled beams);
- Where there are significant disturbances to air flow near the floor (for example, furniture);
- Where the contaminants are cooler/denser than the ambient air

Thank you for your attention

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