REHVA

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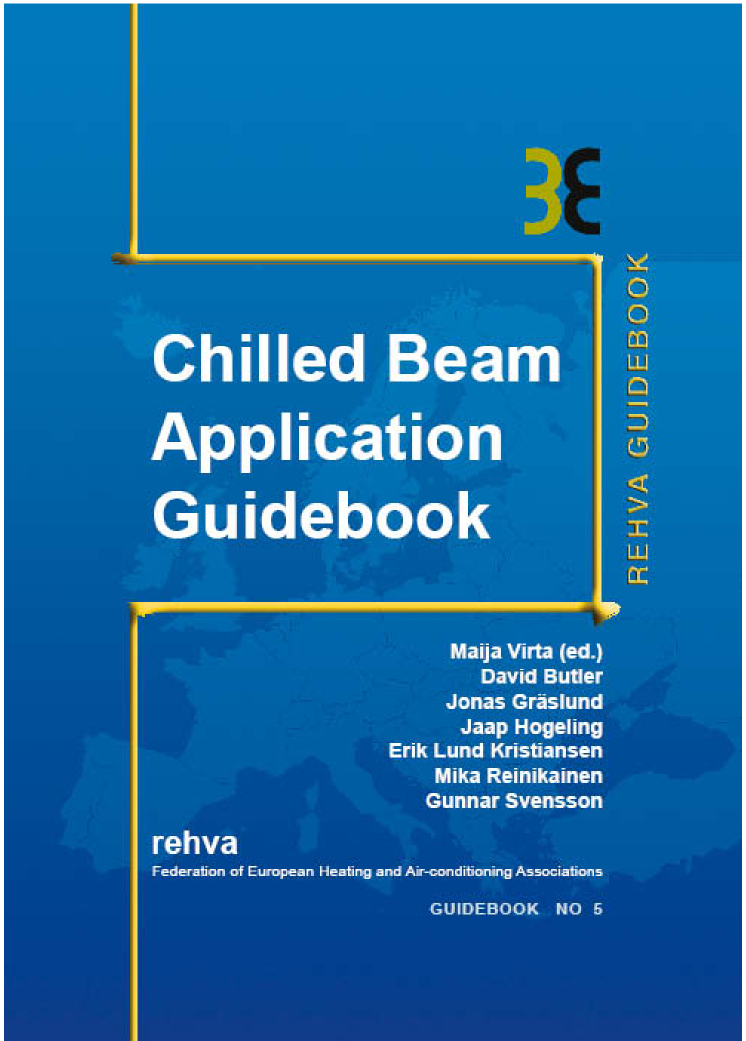
Chilled Beam Application Guidebook



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Chilled Beam Application Guidebook

- History of chilled beams:
  - Developed in Scandinavia in the middle of 1980's
  - Rapidly spread all over the Europe in the end of 1990's
  - Some installations in USA, Far East, etc.

- Chilled beam systems are primarily used for
  - cooling,
  - heating
  - ventilating

  spaces, where good indoor environmental quality and individual space control are appreciated.

- Chilled beam systems are dedicated outdoor air systems to be applied primarily in spaces where internal humidity loads are moderate.

Chilled Beam Application Guidebook

- This guidebook is aimed at
  - consulting engineers and contractors, who want to design and execute good chilled beam systems
  - facility owners, who want to develop life cycle cost efficient buildings and comfortable occupied spaces for people.

- This book provides tools and guidance
  - to achieve good indoor climate in the space using chilled beam technology,
  - to select chilled beams and other required components and
  - to design the air and water distribution system.
  - it also presents some case studies, where chilled beams are used.

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Chilled Beam Application

- The chilled beam system promotes excellent thermal comfort, energy conservation and efficient use of space due to the high heat capacity of water used as heat transfer medium.

- The operation principle of the system is simple and trouble-free. The high temperature cooling and low temperature heating maximise the opportunity for free cooling and heating.

- Typical applications are cellular and open plans offices, hotel rooms, hospital wards, retail shops, bank halls etc.

Room Air Conditioning System Selection

- **Chilled beams provides benefits in life cycle costs:**
  - Low maintenance cost
  - Good energy efficiency
  - Free cooling possible in cold and temperate climate

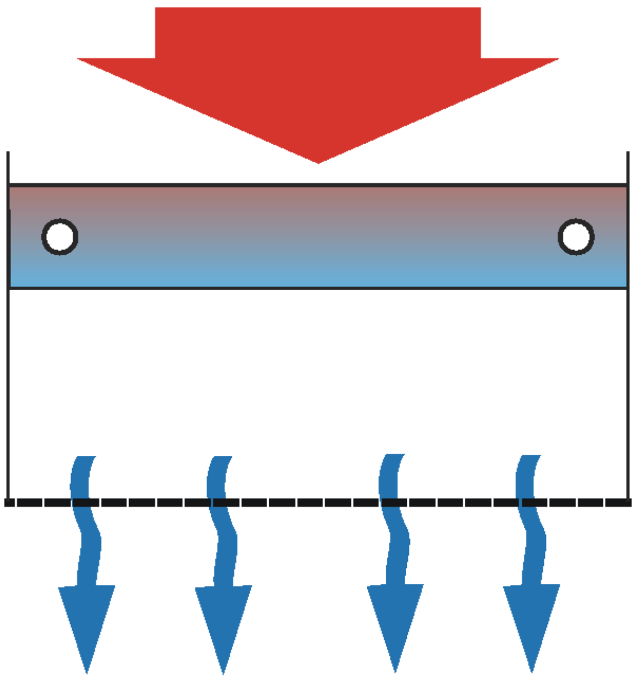
- **Chilled beams system is a hygienic system**
  - No filters to be changed or cleaning of drain pans for condensate
  - Easy cleaning of coils and surfaces, only once in every 5 years

- **Chilled beams operate with a dry cooling coil**
  - No condensate collection system
  - Primary air should be dehumidified in the air handling unit and/or
  - Control of water temperatures is needed to avoid condensation

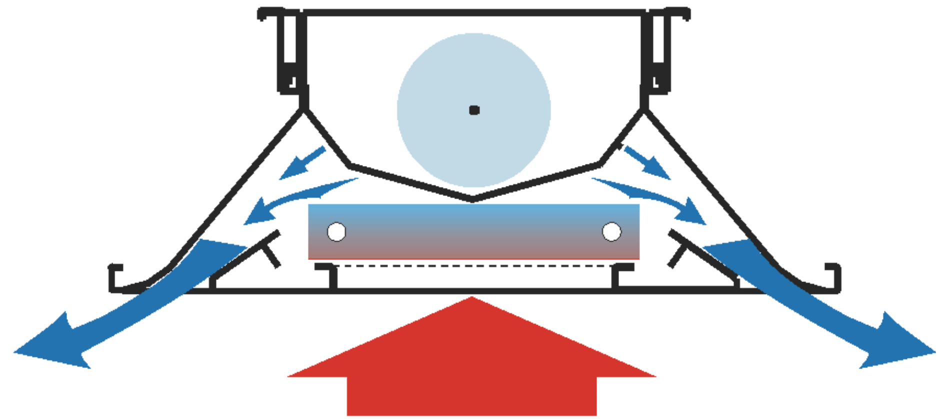
Building Conditions

- **Cooling demand in the space typically less than 80 W/floor-m2 (max 120 W/floor-m2)**
- **Heating demand less than 40 W/floor-m2**
- **Limited infiltration through building envelope**
- **Special attention to the building management system if windows are openable**

Chilled Beam Operation Principle

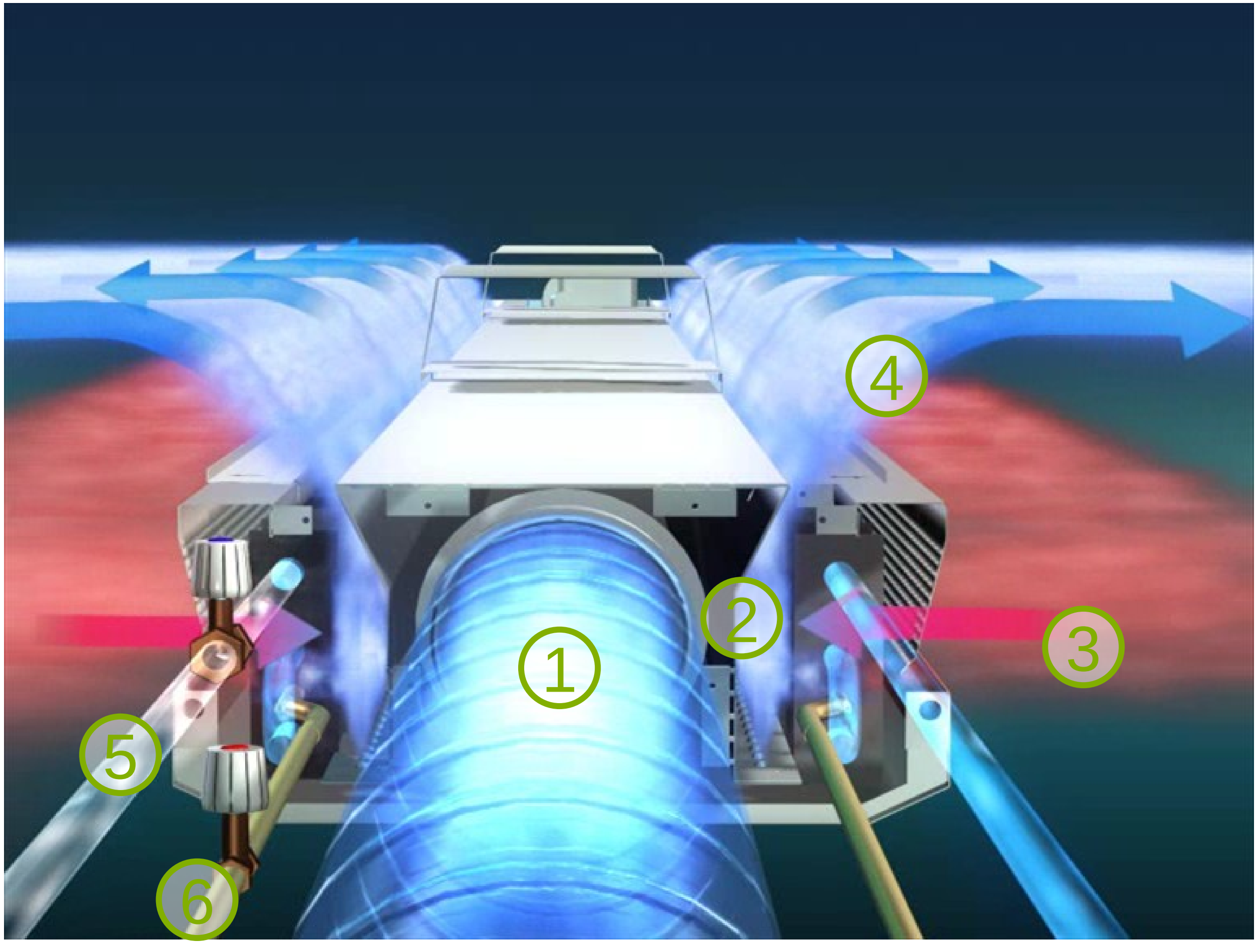


Passive Beam



Active Beam

Chilled Beam Operation



1. Primary air (dehumidificated outdoor air) supply into supply air chamber

2. Primary air is supplied through small nozzles.

3. Primary air supply induces room air to be re-circulated through the heat exchanger of the chilled beam.

4. Re-circulated room air and the primary air are mixed prior to diffusion in the space

5. Cold water connetion

6. Warm water connection

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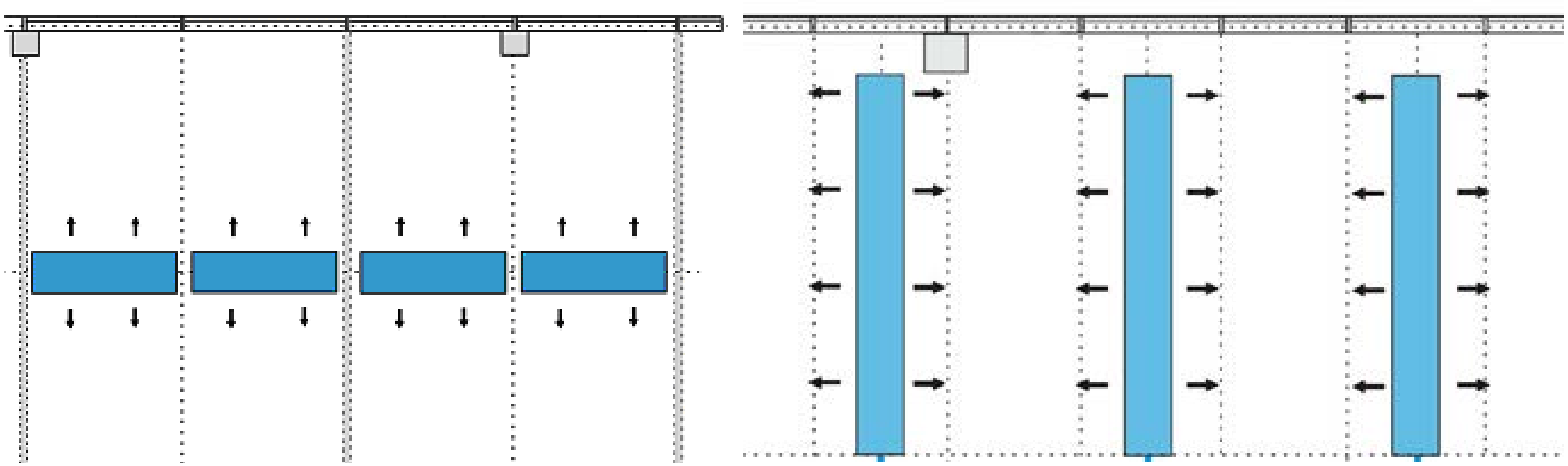
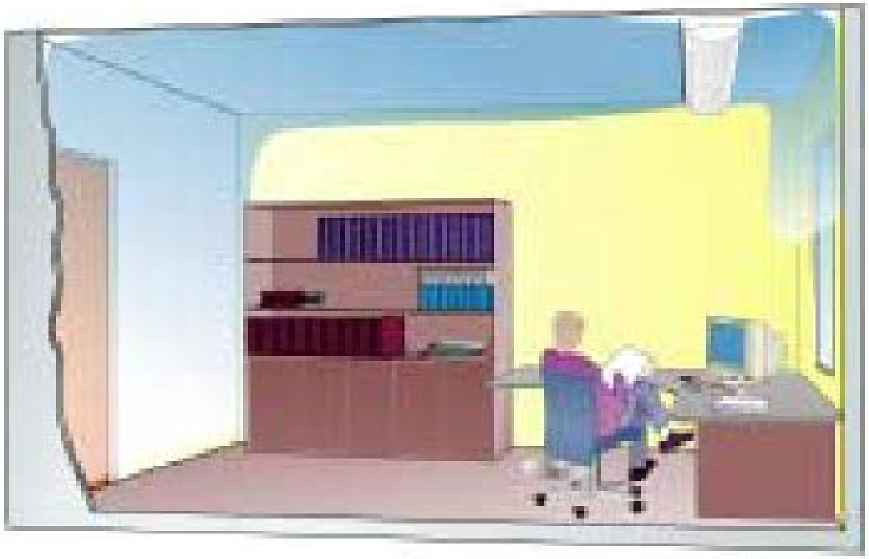
Typical Chilled Beam Installation

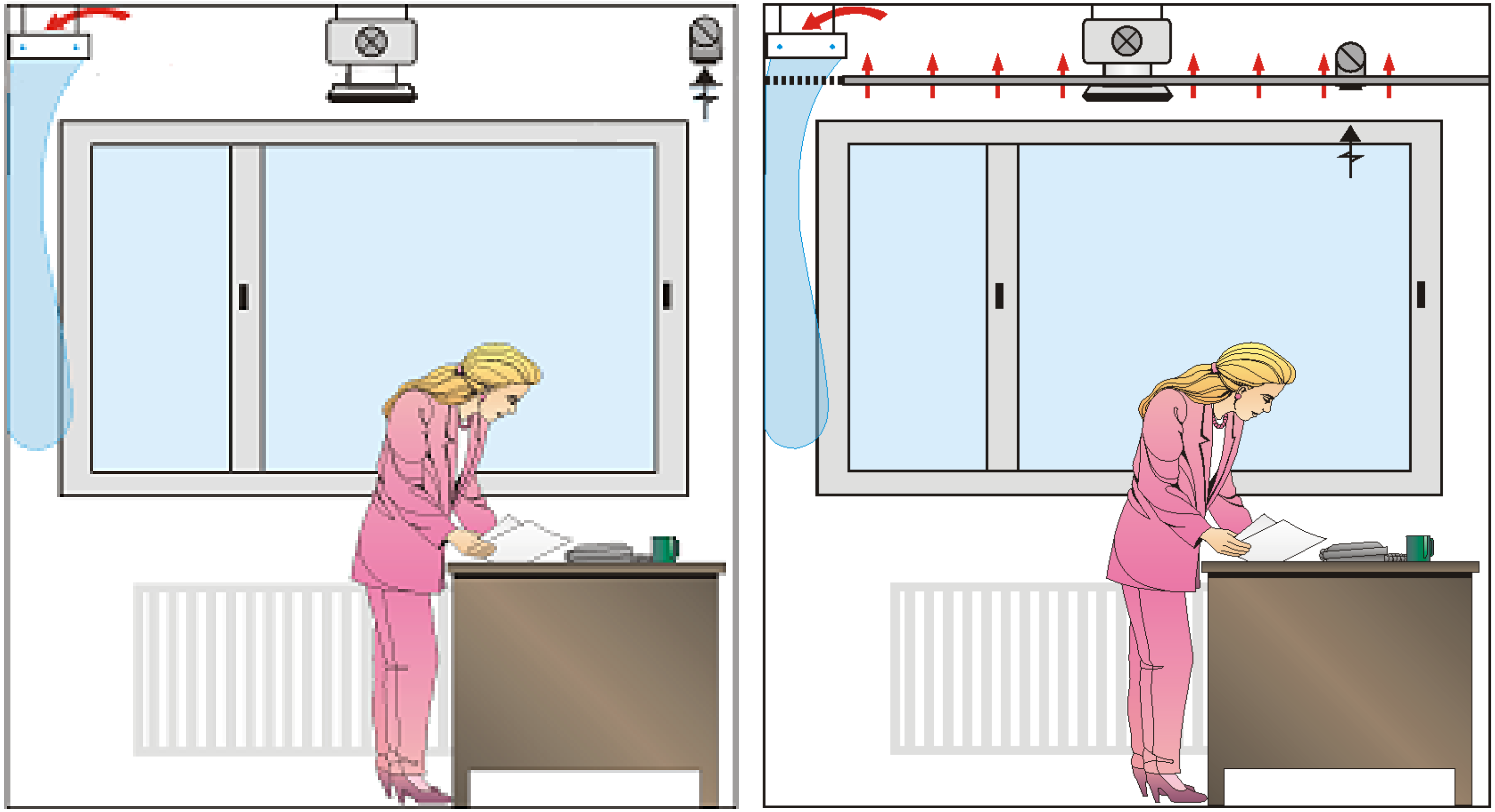


- Positioning of chilled beams influence the comfort conditions in the space
- Module size influences the installation costs and opportunities for flexibility in future
- Try to use only a few different type of beams (type, length, nozzle size etc.) in order to make
  - the tendering process,
  - logistics on the construction site
  - maintenance of building easier

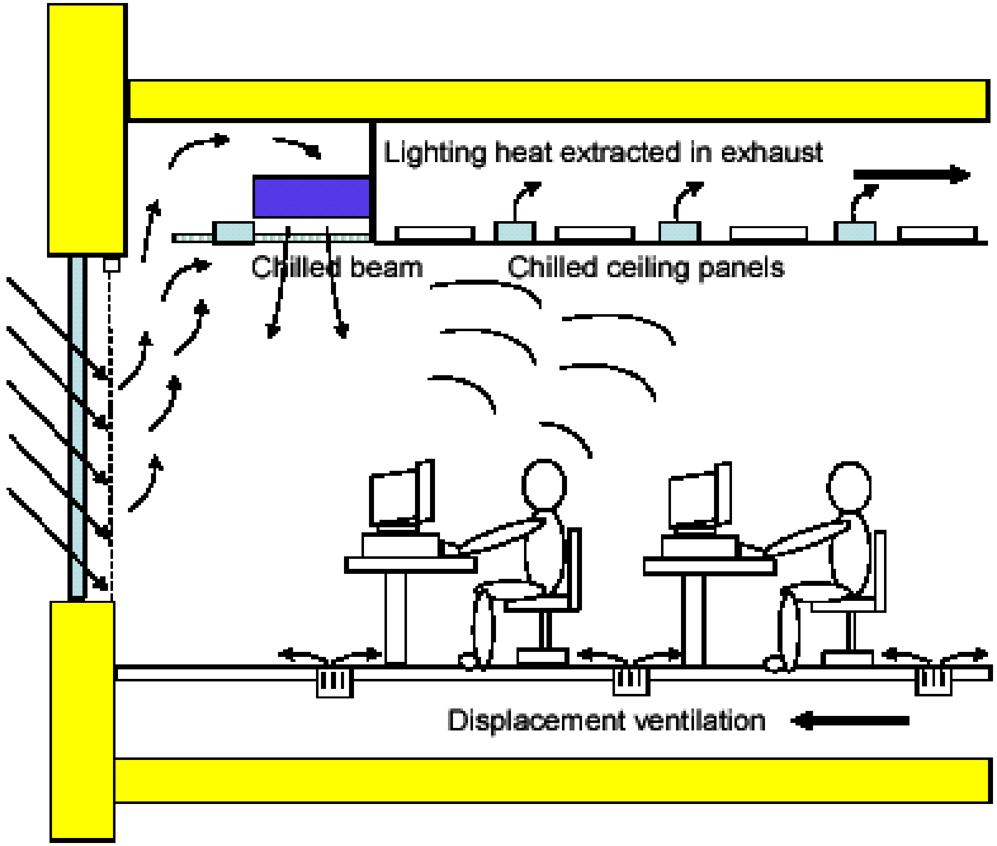
Position of Active Chilled Beams



Position of Passive Chilled Beams



Perimeter Chilled Beam



Benefits in Life Cycle Costs: maintenance

Fan coil in 300 rooms, 20-year life cycle:

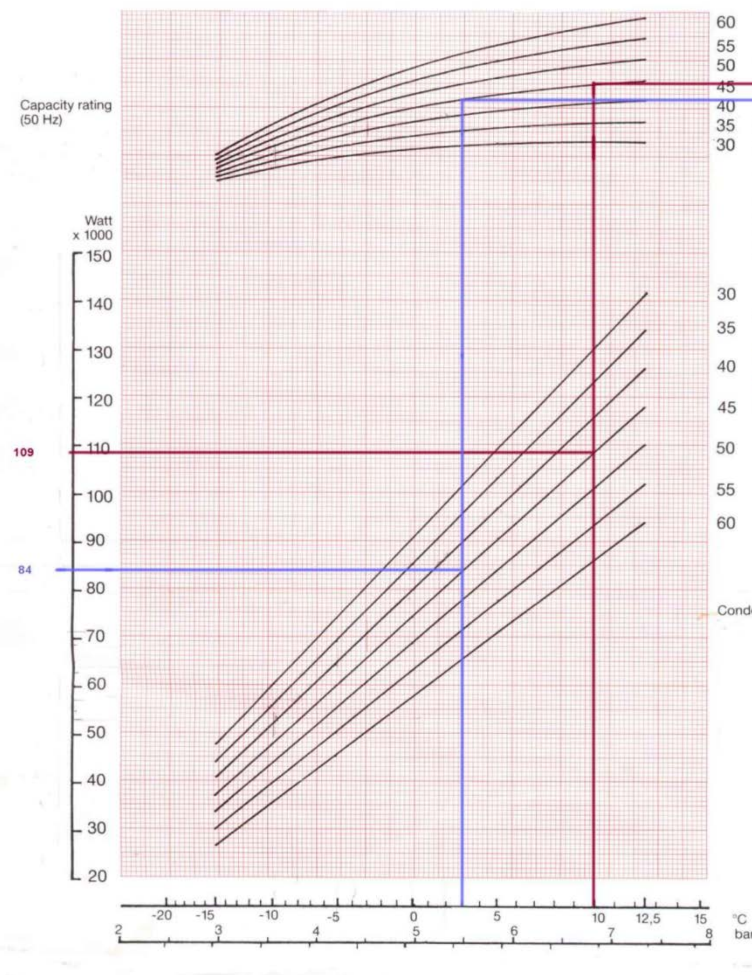
Filter change:	€25/filter twice a year	€ 300.000
	15 min to replace @ €20/hr	€ 60.000
Cleaning of condensation system: 3 times/year @ 15 min		€ 90.000
Motor replacement:	€200/motor	€ 60.000
	2 h work @ €20/hr	€ 12.000
Fan coil replacement:	€ 1000/ unit	€ 150.000
Total		**€ 672.000**

Chilled beam in 300 rooms, 20-year life cycle:

Cleaning of chilled beam:		
	once in every 5 years á 15 min @ €20/hr	**€ 6.000**

Difference in maintenance and replacement costs **€ 666.000**

Benefits in Life Cycle Costs: chiller efficiency



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Fan Coil 84/26.5 = 3.1

Chilled Beam 109/28 = 3.9

Percentage Increase 22%

COPELAND

D6RH - 3500

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Benefits in Life Cycle Costs: free cooling and heating

- **Chilled beams are designed and selected to use higher operating temperatures than fan coil systems (14-18°C Vs 6-12°C), increasing the available free-cooling period:**
    - chilled water from the buffer vessel can be circulated through the cooling coil of the air-handling unit during free-cooling operation and heat is transmitted from the chilled water to the supply air
    - dry air coolers
    - cooling towers
    - ground cold energy storages
- **Chilled beam system is a low temperature (30-45°C) heating system:**
    - sustainable heat sources are easier to use
    - higher efficiency of the heating boiler is achieved
    - heat pump system is particularly suitable for heat generation due to its high efficiency at the low temperature levels

Creating Good Indoor Climate

- **Cooling capacity to avoid draughts in the occupied zone:**
    - active chilled beams is typically 250 W/m (max 350 W/m)
    - passive chilled beams 150 W/m (max 250 W/m)
- **Heating capacity of active beams is typically150 W/m**
    - to create sufficient mixing between the supply air from the beam and the room air
- **Window draught (radiation and downward air movement) in cold seasons is eliminated**
- **Operation is designed taking into account the conditions during seasons (winter, summer, intermediate season)**
- **An efficient control system is used**
- **Chilled beams are installed and placed correctly in the space**

Creating Good Indoor Climate

- **Be aware of increased risk of draught if cold air from chilled beams is supplied towards the cold window surface or directly down to the occupied zone**

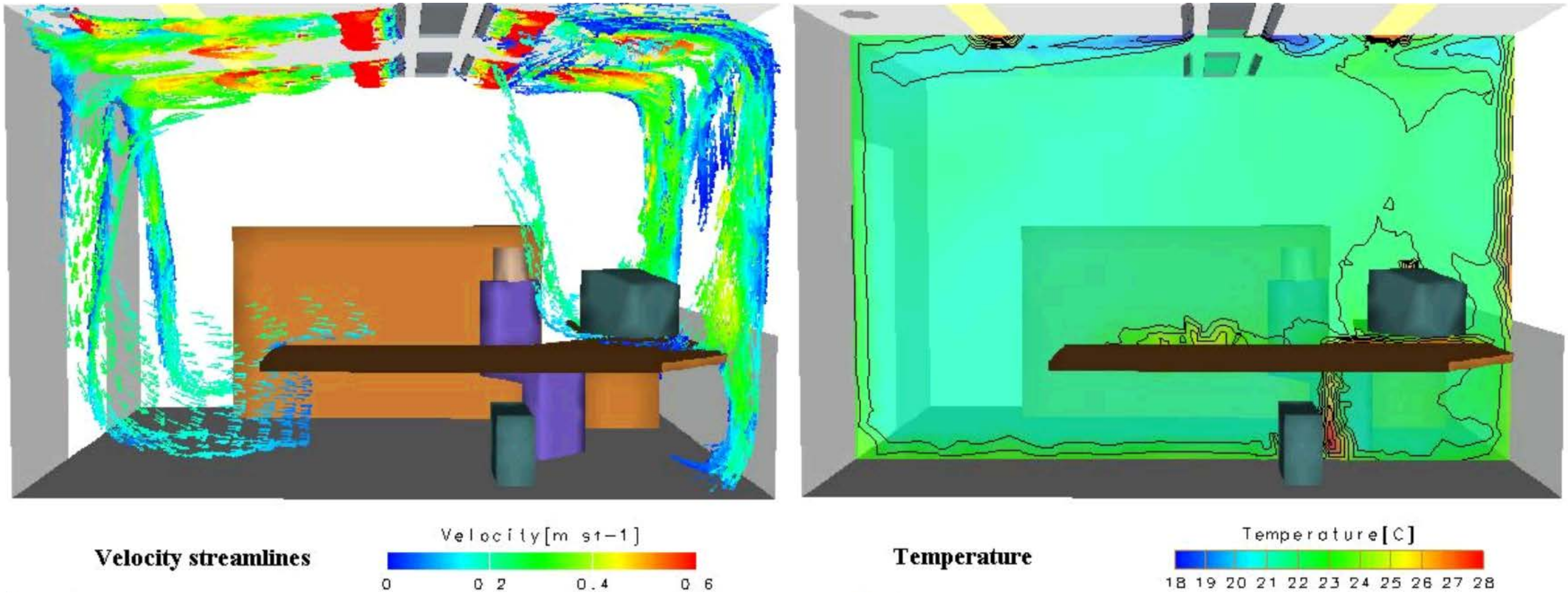
- **Chilled beams installed above the door can create draught problems if the internal loads near the window are strong enough to bend the air jet from the beam to the occupied zone**

- **Passive and open active chilled beams installed in the suspended ceiling always require sufficiently large openings in the ceiling for the induced room air path**

Recommended Design Values

	Cooling	*Heating*
Cooling and Heating		
Optimum heat loads / losses	*60…80 W/floor-m^2*	*25…35 W/floor-m^2*
Maximum heat loads / losses	*< 120 W/floor-m^2*	*< 50 W/floor-m^2*
Specific capacity of passive beam above occupied zone	*< 150 W/m*	*–*
Specific capacity of passive beam outside occupied zone	*< 250 W/m*	*–*
Specific capacity of active beams (highest class of indoor climate)	*< 250 W/m*	*< 150 W/m*
Specific capacity of active beams (medium class of indoor climate)	*< 350 W/m*	*< 150 W/m*
Supply air		
Specific primary air flow rate of active beam	*5…15 l/s,m*	*5…15 l/s,m*
Supply air temperature	*18…20°C*	*19…21°C*
Pressure drop of active beam	*30…120 Pa*	*30…120 Pa*
Room air		
Reference air temperature (air into the beam): active beam	*Room air temp.*	*Room air temp. + 0…2°C*
Reference air temperature (air into the beam): passive beam	*Room air temp. + 0…2°C*	*–*
Inlet water		
Water flow rate with pipe size of 15 mm (turbulent flow)	*> 0.03…0.10 kg/s*	*> 0.03…0.10 kg/s*
Water flow rate with pipe size of 10 mm (turbulent flow)	*> 0.015…0.04 kg/s*	*> 0.015…0.04 kg/s*
Inlet water temperature	*14…18°C*	*30…45°C*
Pressure drop	*0.5…15 kPa*	*0.5…15 kPa*

Chilled Beams in Cooling



Position of Active Chilled Beams Influences Room Air Velocities

Chilled Beam

12 l/s,m
25 W/m², 14 deg.C window
maximum velocity values (m/s)

	3.6 m	2.4 m	1.5 m	0.6 m
1.8 m	0.21	0.11	0.10	0.12
1.5 m	0.10	0.08	0.12	0.08
1.1 m	0.15	0.09	0.09	0.10
0.6 m	0.17	0.16	0.15	0.07
0.1 m	0.21	0.21	0.27	0.34

Door **Window**

Chilled Beam

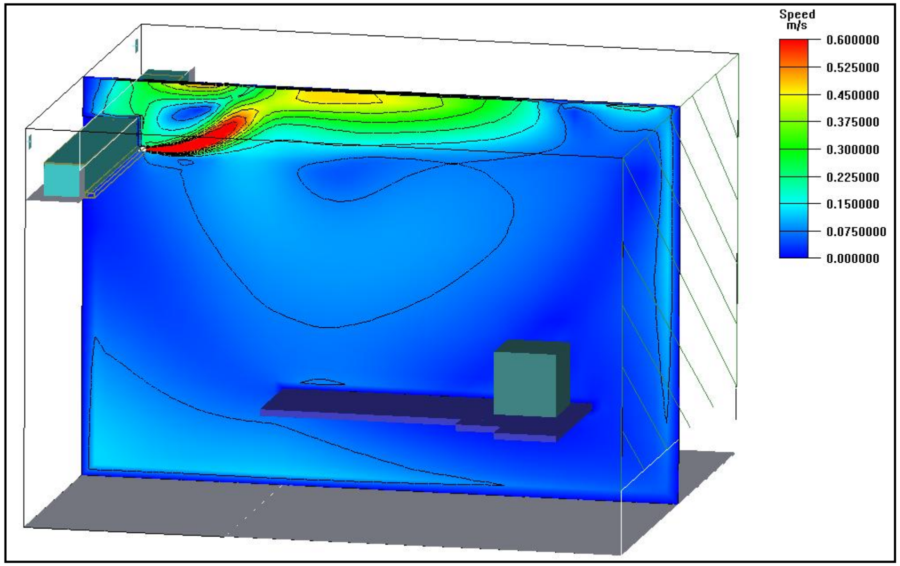
12 l/s,m
25 W/m², 14 deg.C window
maximum velocity values (m/s)

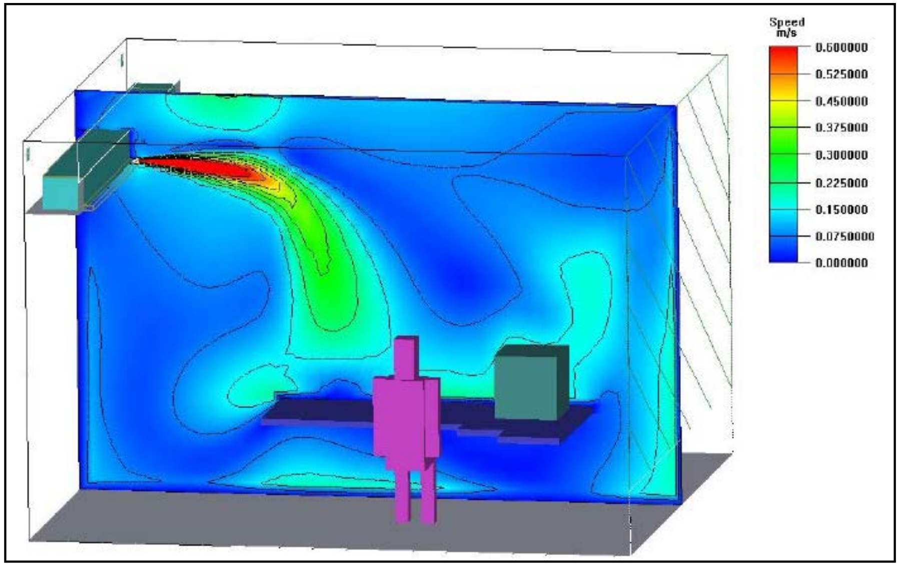
	3.6 m	2.4 m	1.5 m	0.6 m
1.8 m	0.14	0.11	0.09	0.11
1.5 m	0.07	0.08	0.11	0.09
1.1 m	0.15	0.11	0.13	0.12
0.6 m	0.09	0.15	0.16	0.10
0.1 m	0.17	0.23	0.25	0.15

Door **Window**

Room air velocities in the intermediate season with
same beam installed either crosswise or lengthwise in the room.

Room Loads Influencing Throw Pattern





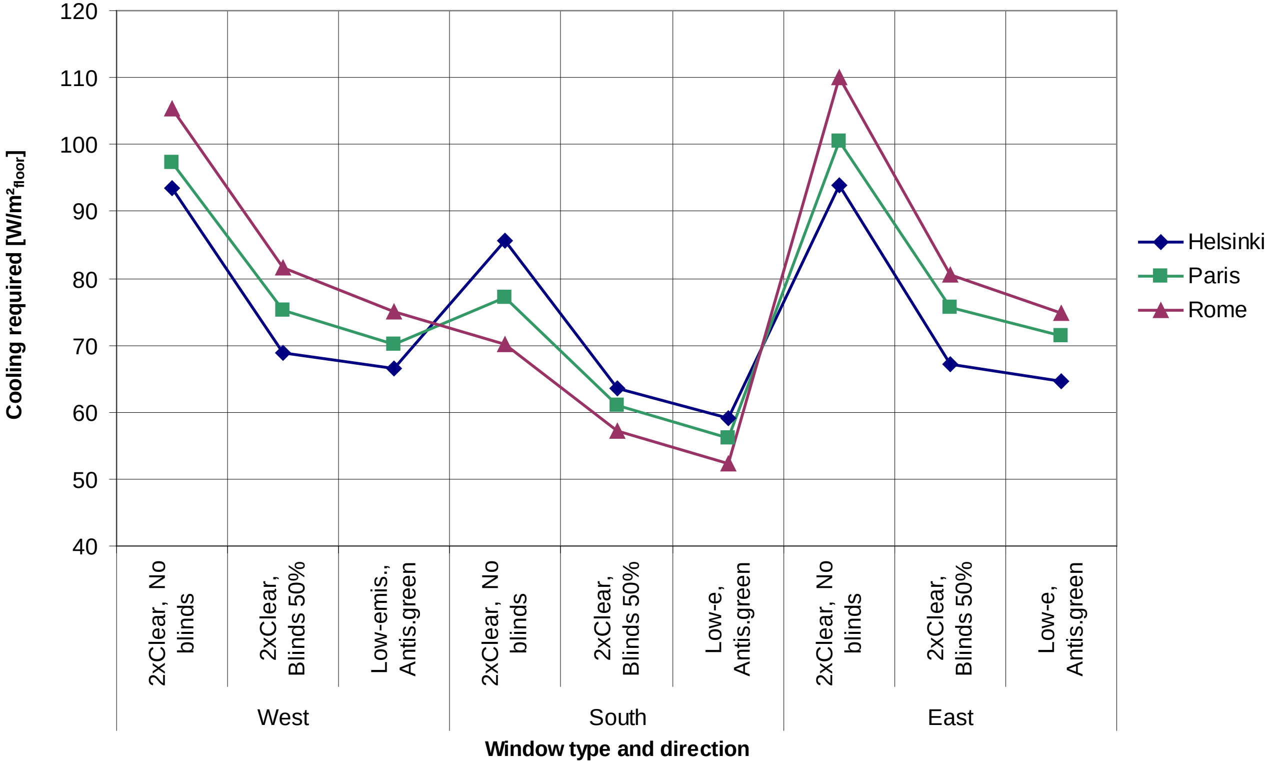
Door **Window** **Door** **Window**

No internal load in the space

Room is occupied and the window surface is warm.

Chilled Beam System Design

- **Design the chilled beam system based on real cooling requirements. Over design of the system makes it more expensive and decreases comfort**



Selection of Primary Air

- **Primary air should be dehumidified in most cases**

- **Airflow rate must be high enough to**
  - absorb the humidity generated in the space
  - fulfil the hygienic needs

- **Typical primary air volume is**
  - 1.5 – 3 l/s,floor-m2
  - 5 - 15 l/s,beam-m

- **Very high primary airflow rates increase the risk of draught in the occupied zone**

Management of Internal Moisture Loads

- **Management of internal latent loads in offices:**
  - Airflow rate 1,5 l/s,m2
  - 1 person / 10 m2
  - 60 g/h,person = 6 g/h,m2=0,0017 g/s,m2
  - Humidity ratio differential between room air and supply air
  - dx = m/(ρ*qv) = 0,0017 / (1,2*1,5) = 0,0009 kg/kg ~ 1 g/kg

- **Management of internal latent loads in meeting rooms:**
  - Airflow rate 4,2 l/s,m2
  - 1 person/ 2 m2
  - 60 g/h,person = 30 g/h,m2=0,008 g/s,m2
  - Humidity ratio differential between room air and supply air
  - dx = m/(ρl*qv) = 0,008 / (1,2*4,2) = 0,0016 kg/kg = 1,6 g/kg

Minimum Airflow Rate to Handle Internal Moisture Loads

Airflow rate (l/s,m²)

People density (1 person / m²)	Humidity ratio differential between room and supply air (kg/kg)			
	0,0005	**0,001**	**0,0015**	**0,002**
2	13,9	6,9	4,6	3,5
3	9,3	4,6	3,1	2,3
4	6,9	3,5	2,3	**1,7**
5	5,6	2,8	1,9	**1,4**
6	4,6	2,3	**1,5**	1,2
7	4,0	2,0	**1,3**	1,0
8	3,5	**1,7**	1,2	0,9
9	3,1	**1,5**	1,0	0,8
10	2,8	**1,4**	0,9	0,7

Typical meeting room

Typical office room

Office room

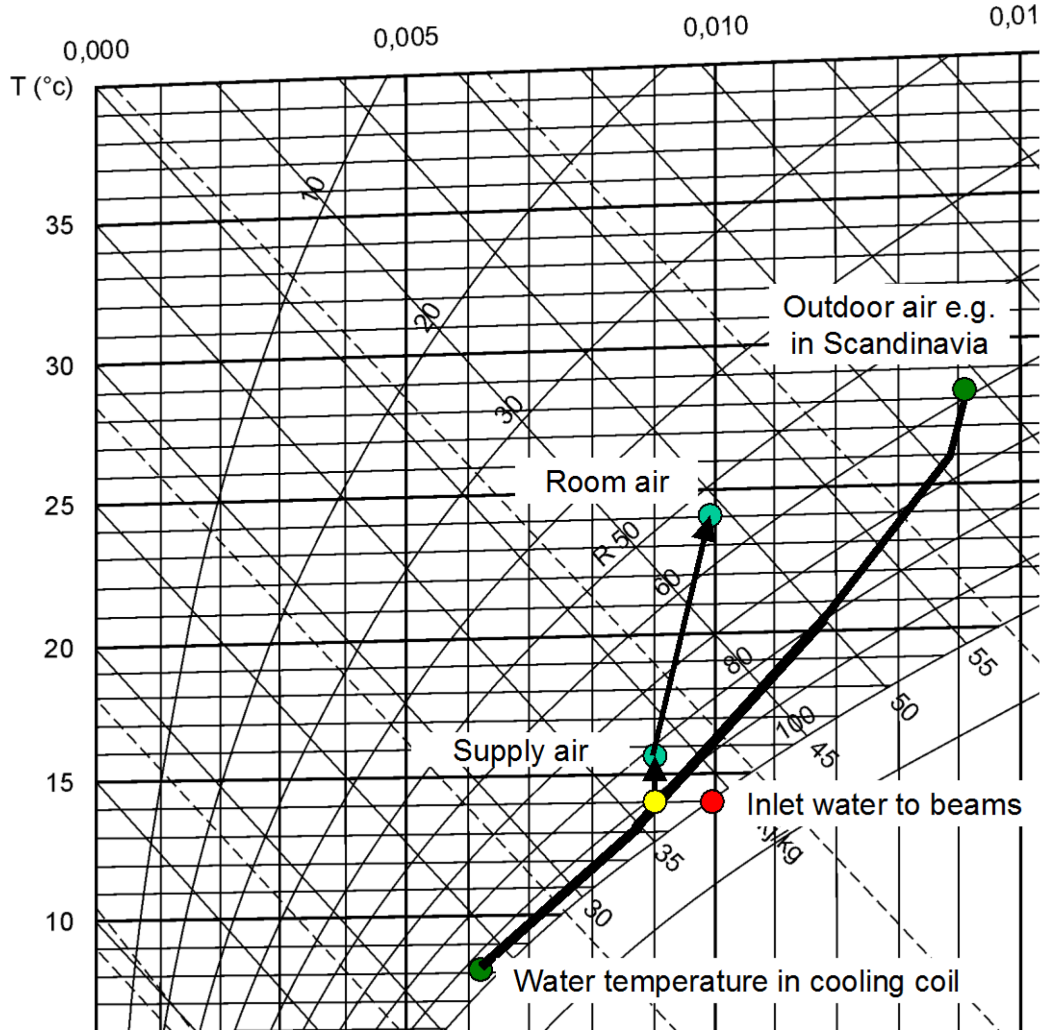
Condensation Shall be Prevented

- **Sufficiently high inlet water temperature, equal or above the dew point temperature of the room air**
  - 14°C or higher
- **Dehumidification of primary air**
- **Insulation of the valves and pipes**
- **Using condensation sensors on the pipe surface**
- **Raising the chilled water temperature or switching off valves locally if there is an increased risk of condensation**

Condensation Prevention and Building

- **Limited infiltration through building envelope**
- **Special attention to the building management system if windows are operable**
- **Building should be slightly over-pressurised in hot and humid climate to avoid infiltration**
  - Needs to be taken into account when designing building structures
  - Night ventilation is not recommended and the exhaust fans must also be stopped during the night time.
  - Morning start-up period: Condensation can be prevented by starting dry air ventilation about 30 minutes before the water-based cooling by adjusting the operating hours of the fans and the chilled water pump of the beam system.

Dehumidification process of primary air



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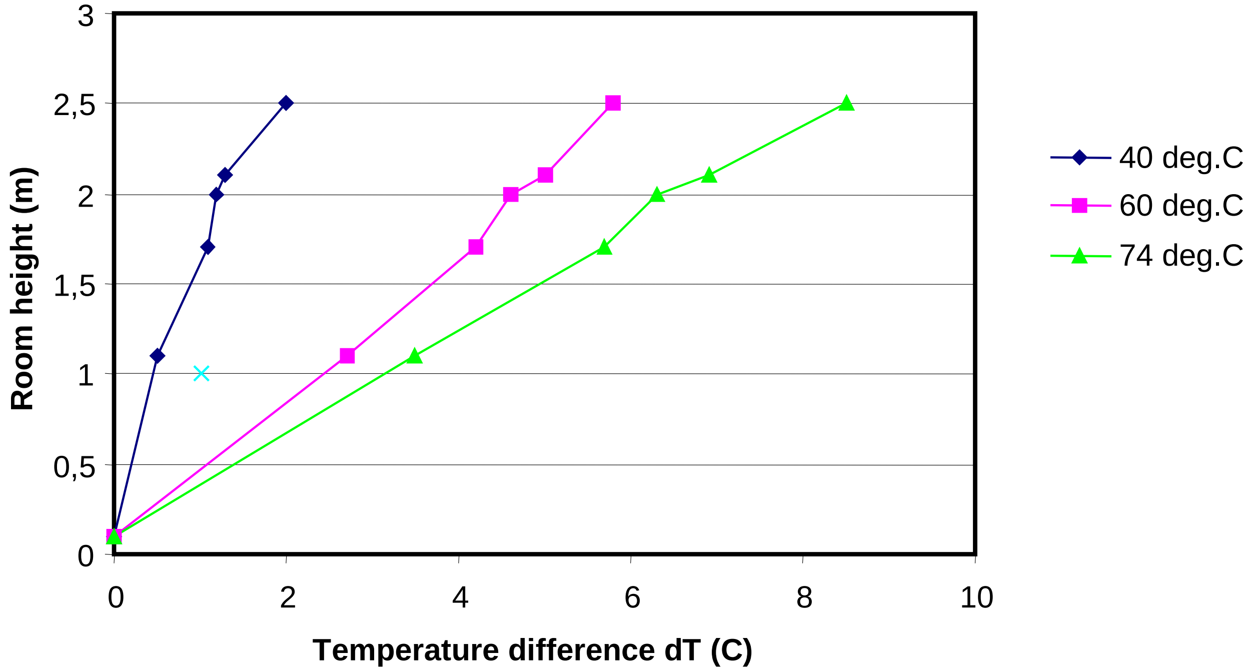
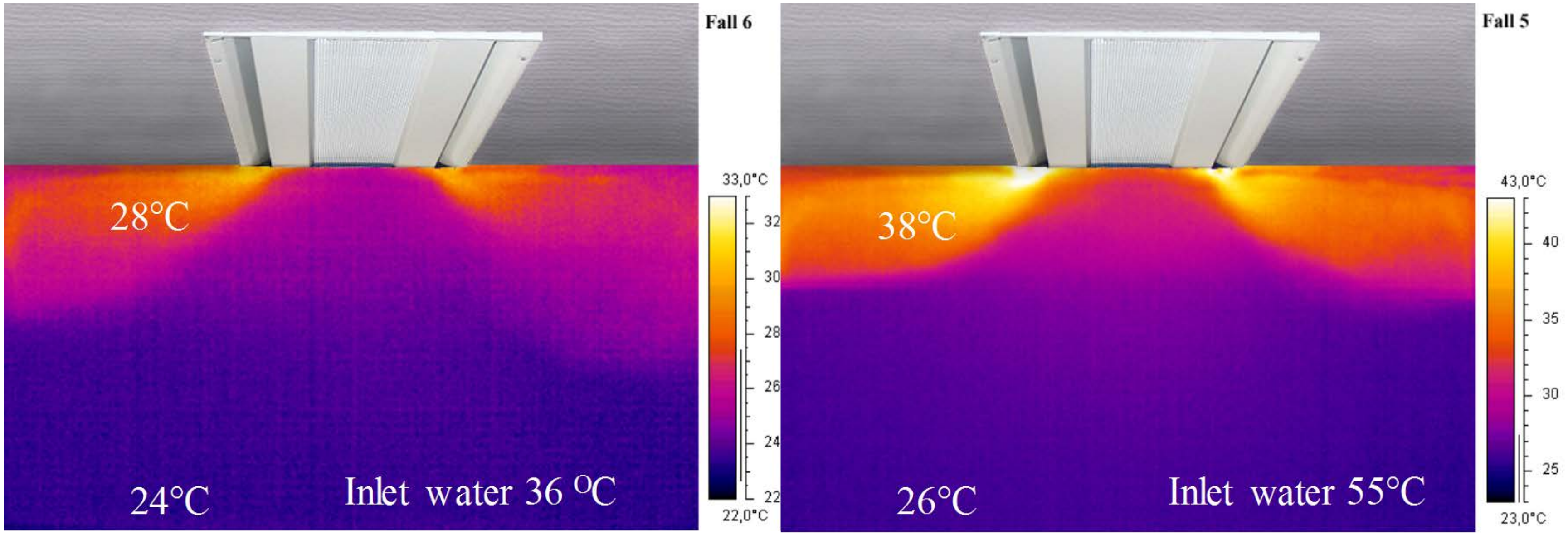
Chilled Beam System Design in Heating

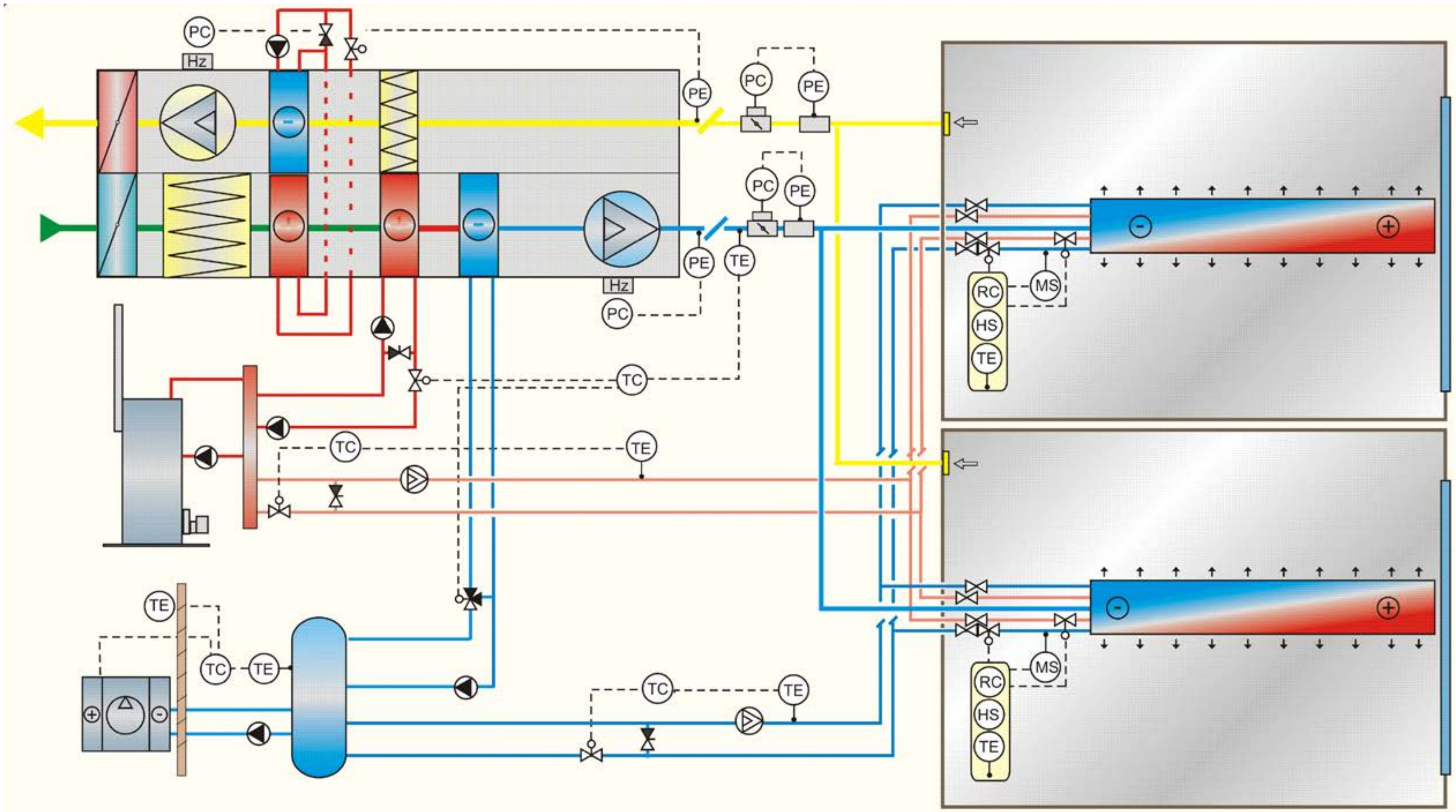
- **Over sizing of heating system may prevent the proper operation of chilled beams used as a heating unit. Use as low an inlet water temperature as possible (max 45°C)**



Chilled Beams in Heating



Chilled Beam System Design



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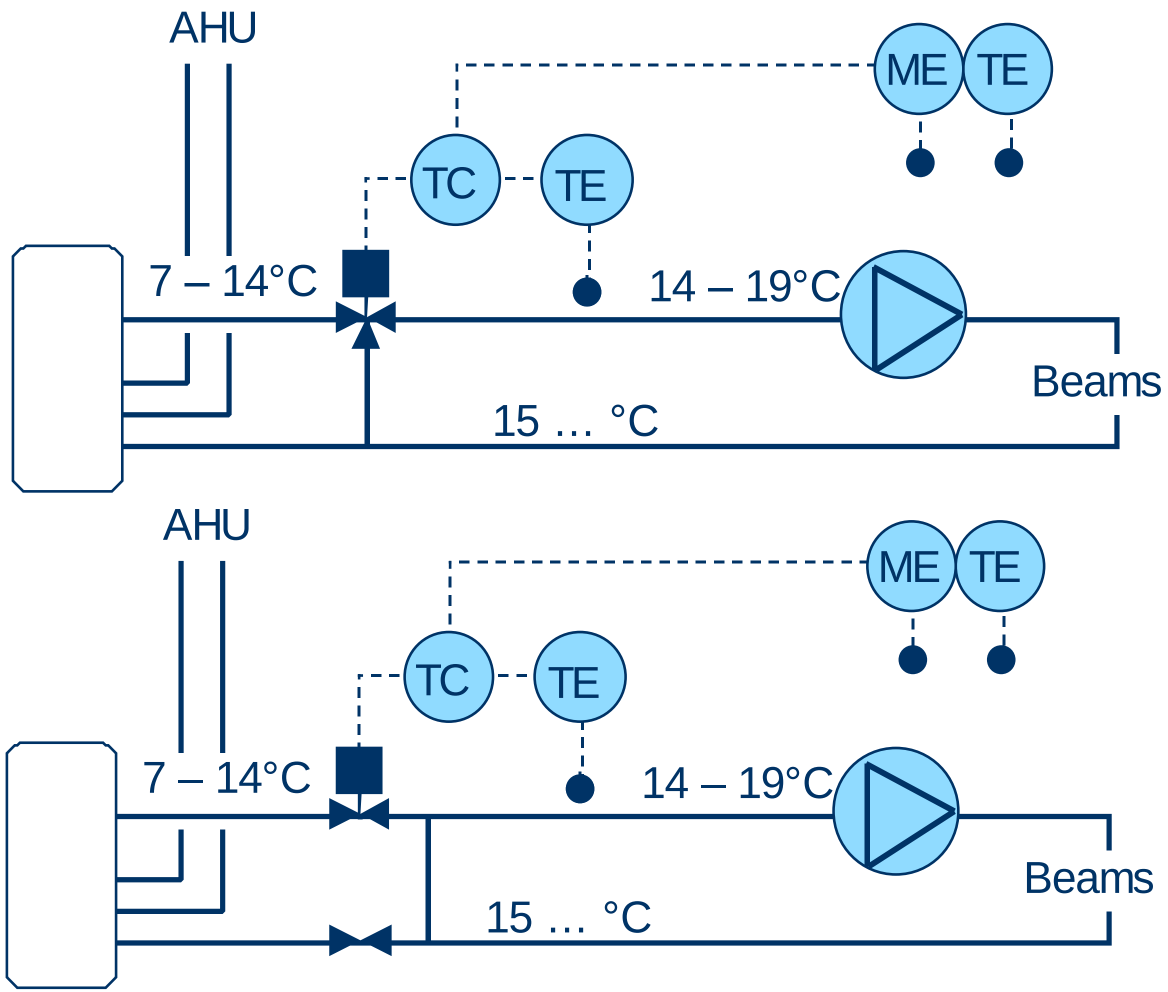
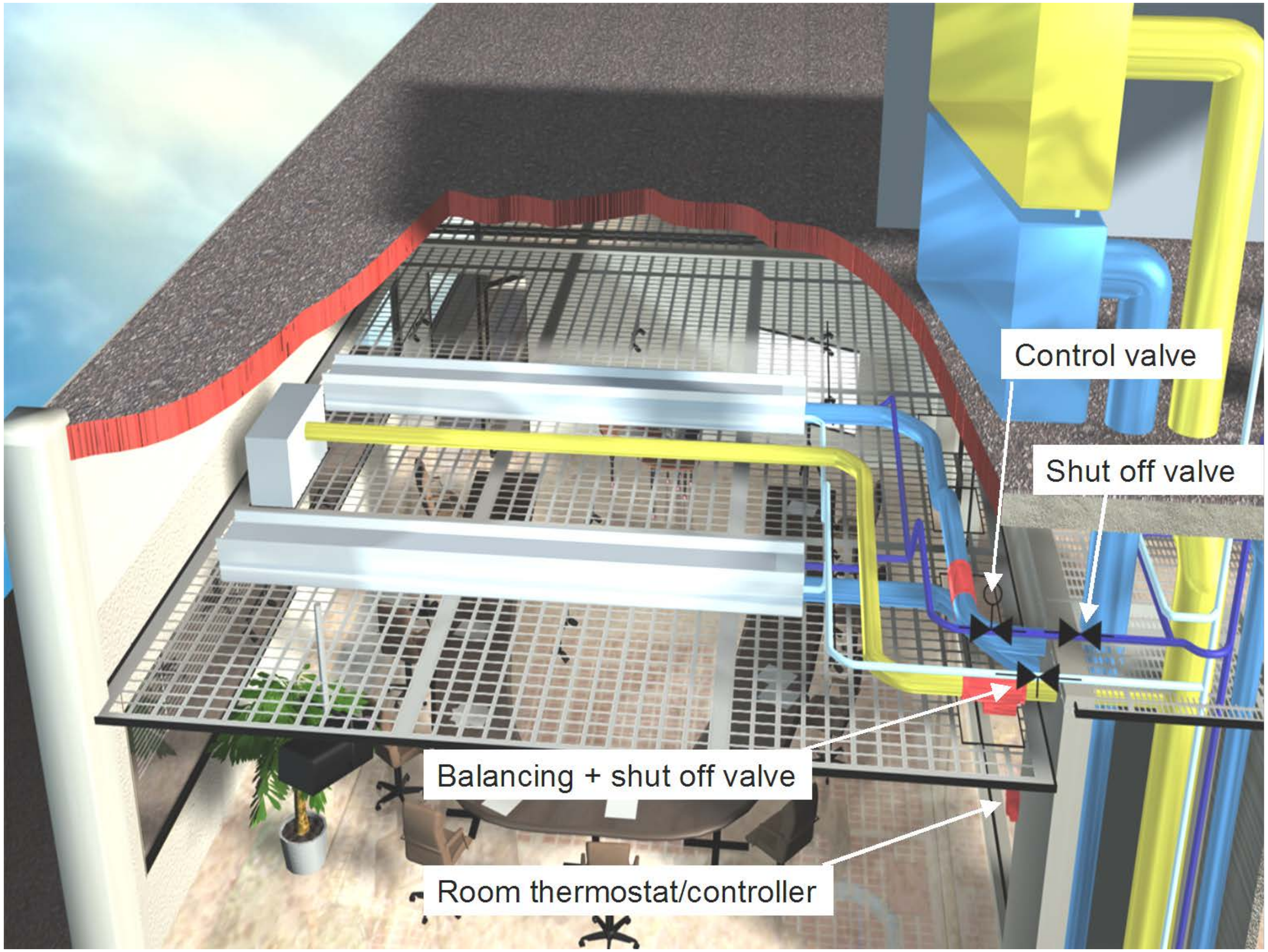
Mixing valve group



Room Control



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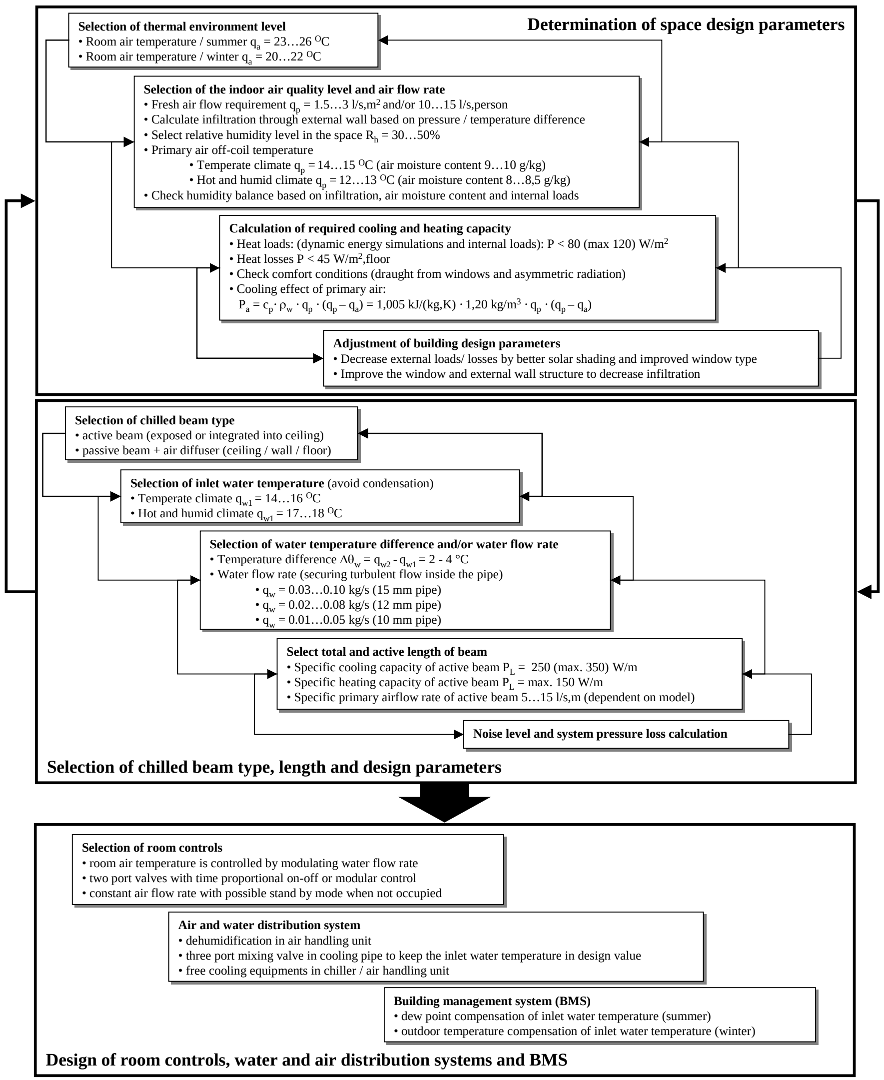
Design Methodology



Determination of space design parameters

Selection of chilled beam type, length and design parameters

Design of room controls, water and air distribution systems and BMS

Determination of space design parameters

Determination of space design parameters

Selection of thermal environment level

- Room air temperature / summer q_a = 23…26 ^{O}C
- Room air temperature / winter q_a = 20…22 ^{O}C

Selection of the indoor air quality level and air flow rate

- Fresh air flow requirement q_p = 1.5…3 l/s,m^2 and/or 10…15 l/s,person
- Calculate infiltration through external wall based on pressure / temperature difference
- Select relative humidity level in the space R_h = 30…50%
- Primary air off-coil temperature
  - Temperate climate q_p = 14…15 ^{O}C (air moisture content 9…10 g/kg)
  - Hot and humid climate q_p = 12…13 ^{O}C (air moisture content 8…8,5 g/kg)
- Check humidity balance based on infiltration, air moisture content and internal loads

Calculation of required cooling and heating capacity

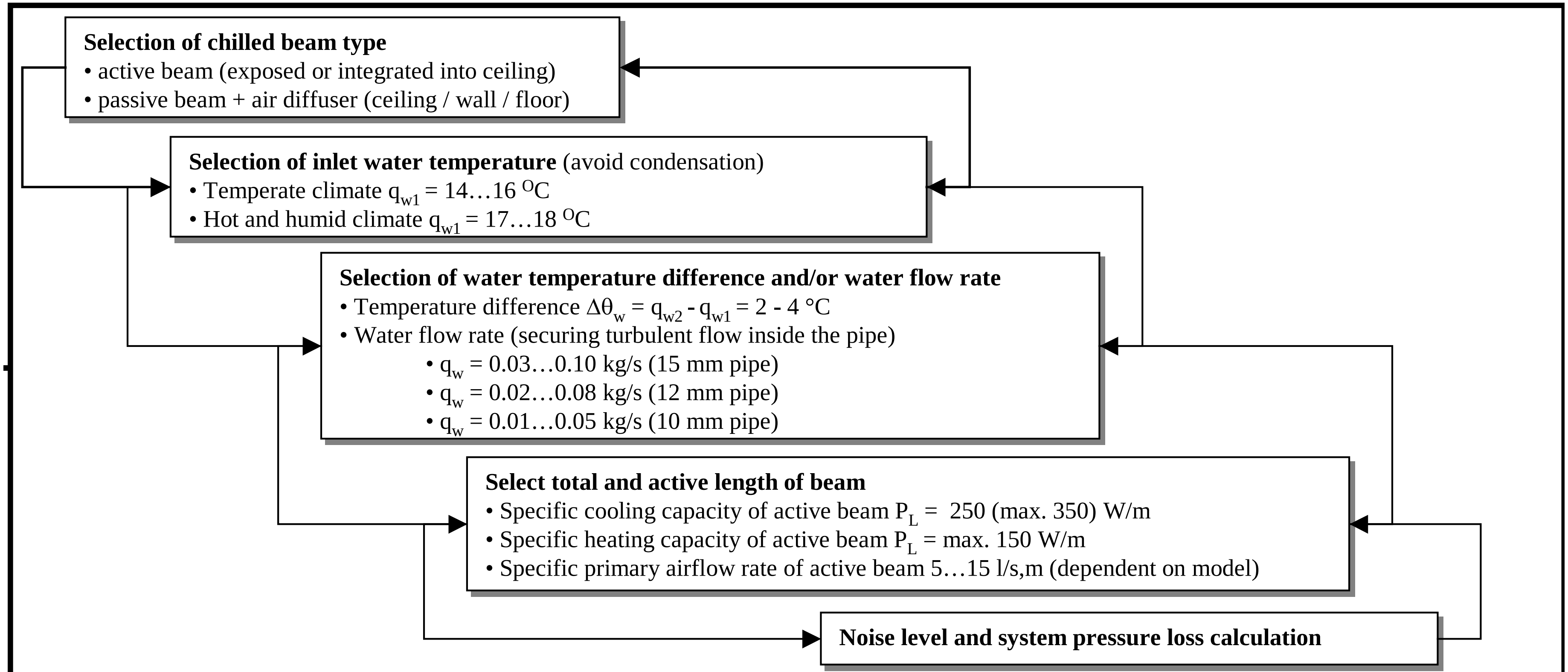
- Heat loads: (dynamic energy simulations and internal loads): P < 80 (max 120) W/m^2
- Heat losses P < 45 W/m^2,floor
- Check comfort conditions (draught from windows and asymmetric radiation)
- Cooling effect of primary air:

$$P_a = c_p \cdot \rho_w \cdot q_p \cdot (q_p - q_a) = 1{,}005\ \text{kJ/(kg,K)} \cdot 1{,}20\ \text{kg/m}^3 \cdot q_p \cdot (q_p - q_a)$$

Adjustment of building design parameters

- Decrease external loads/ losses by better solar shading and improved window type
- Improve the window and external wall structure to decrease infiltration

Selection of Chilled Beam Type, Length and Design Parameters



Selection of chilled beam type, length and design parameters

Design of Room Controls, Water and Air Distribution Systems and BMS

Selection of room controls
- room air temperature is controlled by modulating water flow rate
- two port valves with time proportional on-off or modular control
- constant air flow rate with possible stand by mode when not occupied

Air and water distribution system
- dehumidification in air handling unit
- three port mixing valve in cooling pipe to keep the inlet water temperature in design value
- free cooling equipments in chiller / air handling unit

Building management system (BMS)
- dew point compensation of inlet water temperature (summer)
- outdoor temperature compensation of inlet water temperature (winter)

Design of room controls, water and air distribution systems and BMS

Product Selection

- **The cooling capacity of chilled beams is one of the major selection criteria.**
    - However other criteria also need to be considered such as linear cooling capacity and airflow rate, air velocity profile etc.aaaaaa
    - The technical data of different manufacturers are comparable if the cooling capacity measurements are made based on CEN standards created for passive and active chilled beams.

- **The acoustic data should be based on measurements according ISO standards as well as the airflow rate and pressure difference**

Product Selection

- **It is also important to compare the velocity data in the occupied zone created by the active chilled beam.**

- **Each manufacturer has a unit specific data for each chilled beam type, because the air velocities are dependent on**
  - the construction of the chilled beam,
  - the dimensions and geometry of the supply air slot
  - the induction ratio of the chilled beam.

Product Selection

- **Use closed beams in suspended ceiling installations and exposed models in all other installation to avoid problems with wrongly directed throw pattern**

- **Pay attention also to accessories, ease of installation, and maintenance issues like cleanability of the coil and air plenum as well as access to the coil**

Example of Chilled Beam Selection

CBC/B-100-3300-3000			
INPUT DATA			
Room air temperature	Tr	°C	24.0
Relative humidity of room air	f	%	50
Supply air flowrate	qvs	l/s	30.0
Supply air temperature	Ts	°C	18.0
Inlet water temperature	Tw1	°C	15.0
Water flowrate	qmw	kg/s	0.060
Effective beam length	l	mm	3000
Duct connection	D	mm	100
CALCULATED DATA 1			
Supply air capacity	Pa	W	215
Water capacity	Pw	W	769
Total capacity	Pt	W	984
Temperature difference	dT	°C	7.5
Outlet water temperature	Tw2	°C	18.1
Sound pressure level (without damper)	LpA	dB	28
Total pressure drop (without damper)	dptot	Pa	87
Pressure drop of water flow	dpw	kPa	4.0
CALCULATED DATA 2			
Dewpoint temperature of room air	Tdew	°C	12.9
Supply air flowrate/radiator length	qv/a	l/(sm)	10.0
Supply air flowrate	qvs	l/s	30
Induced air flowrate	qvi	l/s	98
Air flowrate leaving the unit	qvtot	l/s	128
Temperature of air leaving the unit	Ta	°C	17.6

Different Kind of Chilled Beam Models from Various Manufacturers

Performance of Chilled Beam

There are two architecturally almost identical chilled beams. Chilled beam on the left does not perform well in exposed installation, whereas the throw pattern of the chilled beam on the right is directed correctly towards walls.

TENDERING: Checklist 1/2

- **Capacity of chilled beam**
  - Cooling capacity per meter
  - Heating capacity per meter
  - Supply airflow rate per meter
  - Air chamber pressure
  - Sound level
  - Mock-up test results
  - Test methods
- **Comfort requirements**
  - Air temperature
    - Room air temperature
    - Supply air temperature
    - Temperature gradient in space
  - Air velocity
    - Maximum velocity
    - Velocity in occupied zone
    - Draught rating
  - Surface temperatures

TENDERING: Checklist 2/2

- **Material**
  - Casing design
  - Material thickness
  - Surface treatment
  - Perforations
  - Coil fin thickness and fin pitch
  - Dimensions of pipe and duct connections

- **Installations**
  - Suspended ceiling integration
  - Ceiling connections
  - Hanging system
  - Water and air connections
  - Electric and other connections

- **Cleaning**
  - Access to coil
  - Removable bottom plate
  - Access to air plenum

- **Control system**

CONTRACTING: Checklist

- **Checking of drawings**
  - Number of beams
  - Installed cooling/heating capacity
  - Airflow rates
  - Locations of beams
  - Total / active length
  - Return air paths in the ceiling
  - Obstacles in front of the chilled beam
  - Pipe and duct connections
  - Connections to lights, sprinkler, speakers etc.

- **Installations**
  - Slab system
  - Suspended ceiling type
  - Plenum height
  - Distance to walls

COMMISSIONING: Checklist

- **Visual inspection**
  - Colour and gloss
  - Perforation for return air
  - Any protection / packaging left
  - Nozzle configuration
  - Access to coil / valves / damper
  - Supply air slots direction
  - Surface finish
    - marks
    - correct level
- **Inspection of plenum**
  - Free airflow at open beams
  - Return air openings
  - Thermal insulations of valves and pipes
  - Pipe and duct connections
  - Flexible hose connections
  - Air vents
- **Function**
  - Cooling / Heating capacity
  - Airflow rate
  - Air velocity in occupied zone
  - Inlet water temperature
  - Water flow rate
  - Thermal comfort (ISO 7730)
  - Sound level

Installation / Chilled Beam

- The beam can be fixed directly onto the ceiling surface or hung with threaded drop rods.
- The recommended positioning for the mounting bracket is about L/4 measured from the end of the beam.
- The weight of the beam (10–20 kg/m) must be taken into account when beam installation and logistics in building site are planned.
- Chilled beams are often supplied with factory installed protective covers to both the heat exchanger and the inlet to the supply air plenum. Protective end caps should also be fitted to the heat exchanger pipes. These must be
- removed during the installation.
- Plastic film protecting sheet metal
- surfaces should be removed just
- before commissioning.

Installation / suspended ceiling

- **Chilled beams can be installed**
    - fully exposed
    - recessed within a suspended ceiling
    - positioned above a perforated or an open grid ceiling.
- **For beams installed within or above a ceiling, suitable access must be provided for service and maintenance.**
- **With an open type of chilled beam a free area is required in the suspended ceiling for re-circulation of room air.**
    - As a guide, the minimum free area should be 30% of the beam front panel surface area.
- **Suspended ceiling should be in the same level than a beam bottom to avoid collision of the supply air with the ceiling.**

Installation / pipes

- **The main pipes are installed first.**
  - Pipes should be installed so, that they do not leave any “air pockets”, and a venting valve should always be installed at the highest point of the vertical main pipes in the shaft.
- **Beams are connected to the main pipes by using**
  - Crimp, screw or solder connection
  - Flexible hoses (air diffusion resistant hoses are recommended)
- **When beams are connected to the pipe, extra attention should be paid to attaching the pipe coupling when using a spanner.**
  - The pipe wall is relatively thin and the whole pipe might bend and break the heat exchanger joints.
  - Coupling rings should be used during the installation.

Flushing, Filling-up and Venting

- **Flushing**
  - To minimize the dirt and facilitate flushing, it is important to close open ends of pipes during the installation work.
  - Before starting the flushing it is important to close the shut-off valves of individual beams and flush the main pipes first.
- **Filling-up and venting the system**
  - Before filling up, all shut-off and control valves must be in the fully open position.
  - Pumps should not be running during the filling-up (static filling).
  - Continuous venting is necessary and it is recommended to have both manual and automatic venting systems installed.
  - Pump should only be started when filling is complete.
  - To remove all air from the system, the major part (>75%) of the system should be closed so that the water can circulate fast enough.
  - When each section is full, it should be closed, and the same procedure repeated for the rest of the system.

Commissioning

- **Airflow rates are typically adjusted with a blade or an iris damper.**
  - The iris damper should be positioned far enough away from the beam to ensure the even flow inside the duct before a beam. This safety distance (>3D) is needed to avoid any performance failure.
  - Measuring the airflow rate by using a chamber pressure measurement in the beam is recommended. This gives the most accurate measurement result due to the higher pressure level (50-150 Pa). In other methods e.g. pitot-tube measurement the pressure level is much lower.
- **The commissioning of the chilled and hot water circulation systems**
  - Balancing the water flow rates using balancing valves
  - Ensuring that all the shut-off valves are open
- **Check the function of chilled beam:**
  - As an example with an IR-sensor directed towards the chilled beam supply air slot after maximum cooling capacity is set on the room controller. This will highlight any malfunction of system (too low water flow rate, shut off valves closed, etc.)

Maintenance

- **Have easy access to the inside of the beam**
  - heat exchanger,
  - supply air plenum
  - primary air ductwork
- **Heat exchanger should be vacuum cleaned once every 1-5 years depending on the use of space.**
- **If either the beam surface or the finned coil becomes wet, it must be cleaned immediately.**
  - Dirt adheres more easily to the wet surface of fins. When the coil is dry again the fin surface is often coated with dirt.
- **There are no moving parts apart from the control valve, and systems do not include filters or condensation collection drains and pipes which require cleaning.**

Essential Issues in Beam Operation

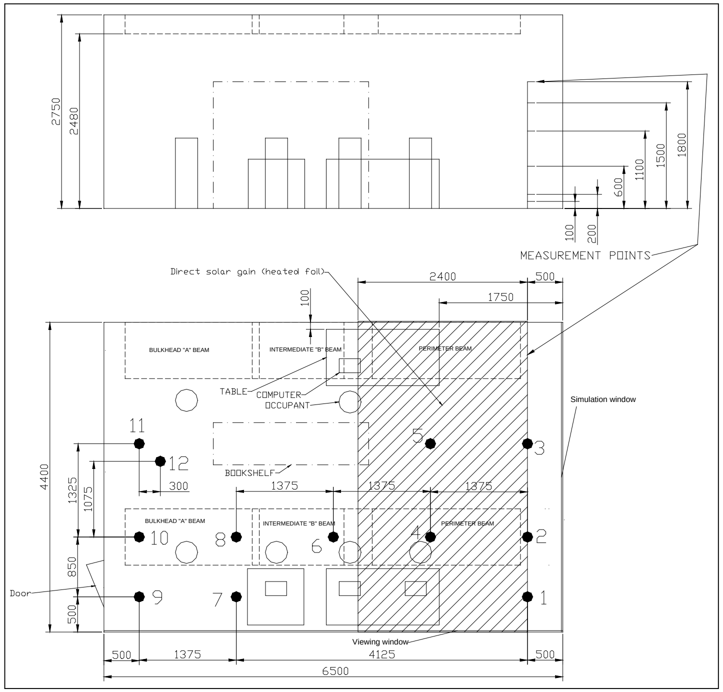
- **The chilled beam system is a dry-cooling system and therefore the inlet water temperature must always be above the dew point temperature.**
- **When condensation occurs, the water circulation in that area must be stopped, even before looking for the cause of the condensation.**
- **If the room air has become too humid, the ventilation should be switched on, and after the building has been dehumidified, the water circulation can be restarted.**
- **It is important that the dehumidification by the air-handling unit has been realised correctly and that the control operates properly.**
- **The operation of the 3-way mixing valve should be checked regularly.**

Solutions for Typical Complaints of Users

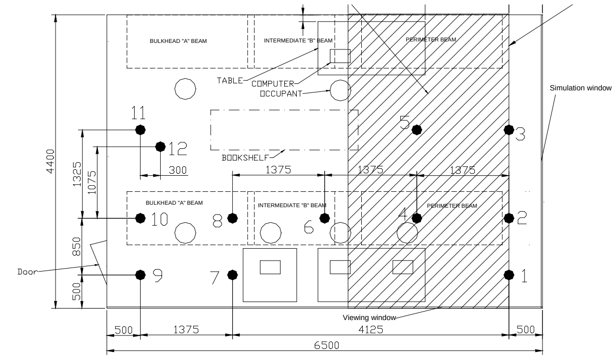
- **Draught**
  - Check that the room air temperature is not too low
  - Check that the airflow rate is not too high or too low
    - Too high an airflow rate may create draught near the floor
    - If the airflow rate is too low or too cold, the air jet may fall intentionally downwards, which may create draught at the neck level
- **High room air temperature**
  - Check that water flow rate is not too low
  - Check that the water flow temperature is not too high
  - If the heat loads in the space are significantly higher than the capacity of the chilled beam, the water flow rate could be increased. If this does not solve the problem, longer or additional units should be installed.

A Case of Office Building in United Kingdom

Project	Office Building in London
Space, where chilled beams are used	Office room
Window internal surface temperature	30°C
Sensible internal heat loads	50 W/ m^2,floor
External heat loads	30 W/ m^2,floor
Heat losses	25 W/ m^2,floor
Supply air properties	2.5 l/s,floor-m^2, supply air temperature in summer 16°C and winter 18°C
Room design parameters	Room air temperature in summer 24°C and winter 21°C
Flexibility	Flexibility of 2.65 m, beams installed lengthwise in every module
Chilled beam selection	Exposed, open active service chilled beam, total length 5100 mm, effective length 4200 mm, cooling output 370 W/m, heating output 120 W/m, primary air volume 11 l/s,m, cooling water flow rate 0.04 kg/s and inlet water temperature of 14°C, heating water flow rate 0.01 kg/s and inlet water temperature of 35°C



A Case of Office Building in United Kingdom



Measurement result: cooling

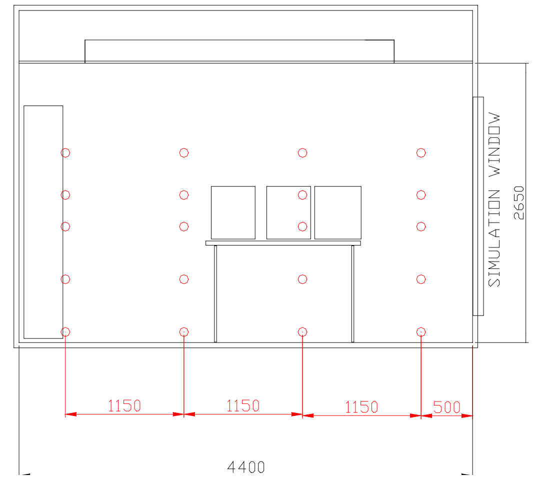
	10				8				6				4				2			
Height (m)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)
1.80	0.11	22.6	40	9	0.11	22.9	46	10	0.10	22.9	45	8	0.11	23.1	58	10	0.07	23.2	46	4
1.50	0.12	22.4	35	10	0.10	22.8	45	8	0.11	22.8	40	9	0.12	23.0	49	11	0.09	23.1	39	7
1.10	0.10	22.3	31	8	0.10	22.6	43	8	0.09	22.8	45	7	0.14	22.8	45	14	0.11	23.1	39	9
0.60	0.07	22.3	46	4	0.09	22.5	46	7	0.08	22.8	50	6	0.13	22.9	36	11	0.11	23.1	51	10
0.20	0.09	22.2	42	7	0.11	22.4	46	10	0.06	22.8	45	3	0.10	23.0	44	8	0.10	23.1	49	8
0.10	0.15	22.1	31	14	0.16	22.2	33	15	0.09	22.7	40	7	0.11	23.0	40	9	0.13	23.1	43	12

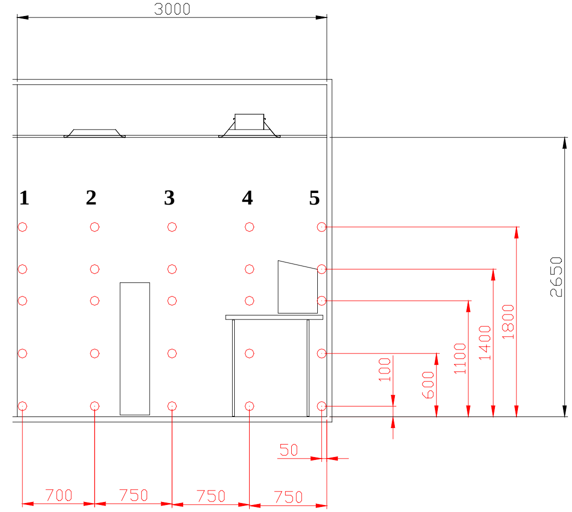
Measurement result: heating

	10				8				6				4				2			
Height (m)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)
1.80	0.04	21.7	52	-	0.08	21.7	33	6	0.08	21.7	42	6	0.08	21.4	35	6	0.07	21.2	44	5
1.50	0.03	21.5	50	-	0.07	21.5	52	5	0.08	21.5	44	6	0.09	21.4	41	8	0.08	21.2	39	6
1.10	0.03	21.2	46	-	0.04	21.2	79	-	0.03	21.2	43	-	0.10	21.3	34	9	0.08	21.2	34	6
0.60	0.02	20.6	32	-	0.02	20.6	27	-	0.02	20.6	33	-	0.06	20.8	53	3	0.07	20.9	59	5
0.20	0.02	20.4	30	-	0.02	20.3	20	-	0.03	20.2	36	-	0.06	20.2	40	3	0.11	20.5	37	11
0.10	0.02	20.3	28	-	0.02	20.1	28	-	0.03	19.9	35	-	0.05	19.6	32	-	0.09	19.9	34	8

A Case of Office Building in France

Project	Office Building in Paris
Space, where chilled beams are used	Office room
Window internal surface temperature	30°C
Sensible internal heat loads	45 W/m^2,floor
External heat loads	40 W/ m^2,floor
Heat losses	50 W/ m^2,floor
Supply air properties	2 l/s,floor-m^2, supply air tempera-ture in summer 14°C and winter 21°C
Room design pa-rameters	Room air temperature in summer 24°C and winter 21°C
Flexibility	Flexibility of 1.5 m, beams in-stalled lengthwise in every second module
Chilled beam selection	600 mm wide, closed active chilled beam, total length 3000 mm, effective length 2700 mm, cooling output 400 W/m, heating output 270 W/m, primary air vol-ume 9 l/s,m, cooling water flow rate 0.10 kg/s and inlet water tem-perature of 14°C, heating water flow rate 0.013 kg/s and inlet wa-ter temperature of 40°C





A Case of Office Building in France

Measurement result: cooling with standard air diffusion.

	1				2				3				4				5			
Height (m)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)
1.80	0.05	23.7	47	-	0.05	23.8	45	-	0.08	23.8	73	6	0.06	23.6	56	3	0.51	21.5	10	39
1.40	0.05	23.6	46	-	0.06	23.6	51	3	0.07	23.5	48	4	0.08	23.5	45	5	0.49	21.5	11	39
1.10	0.05	23.5	53	-	0.06	23.4	60	3	0.08	23.4	47	5	0.09	23.8	43	6	0.41	21.6	16	37
0.60	0.07	23.4	53	4	0.10	23.4	44	8	0.11	23.4	39	9	0.06	23.3	46	3	0.28	22.3	38	33
0.20	0.13	23.4	25	10	0.10	23.5	46	8	0.07	23.5	39	4	0.17	22.8	29	15	0.16	22.6	35	15
0.10	0.16	23.3	23	12	0.13	23.6	43	11	0.10	23.4	33	7	0.13	22.8	38	12	0.16	22.6	36	15

Measurement result: cooling with reduced induction in the right hand side of a beam (cooling capacity is reduced 11%)

	1				2				3				4				5			
Height (m)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)
1.80				-	0.09	23.6	42	6	0.07	23.7	59	4	0.11	23.8	44	9	0.11	23.6	57	10
1.40				-	0.06	23.6	48	3	0.06	23.6	48	3	0.08	23.6	49	5	0.10	23.5	47	8
1.10				-	0.06	23.5	52	3	0.08	23.4	44	5	0.08	23.4	58	6	0.11	23.4	41	9
0.60				-	0.07	23.5	45	4	0.08	23.4	38	5	0.13	23.3	39	11	0.13	2.5	28	30
0.20				-	0.06	23.5	47	3	0.08	23.5	42	5	0.15	23.3	23	11	0.08	23.7	35	5
0.10				-	0.12	23.5	35	9	0.09	23.5	47	7	0.16	23.3	30	13	0.10	23.6	32	7

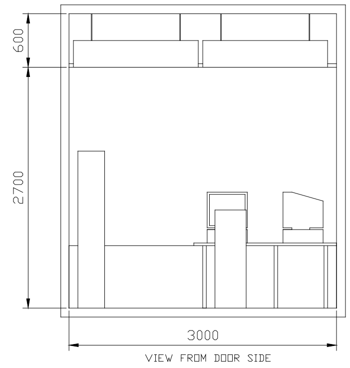
Measurement result: heating

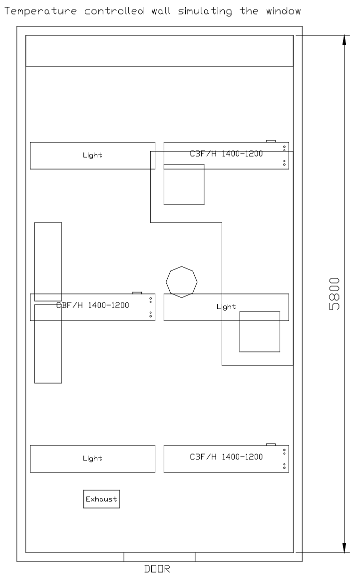
	1				2				3				4				5			
Height (m)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)	v (m/s)	T_a (°C)	Turb. (%)	DR (%)
1.80	0.40	22.3	11	29	0.10	22.0	37	8	0.09	21.4	54	8	0.09	21.8	31	7	0.13	22.3	31	11
1.40	0.23	21.4	46	31	0.12	21.7	30	11	0.04	20.7	53	-	0.05	20.9	33	-	0.07	22.0	45	5
1.10	0.10	20.1	56	11	0.05	19.8	46	-	0.03	19.7	39	-	0.03	20.0	59	-	0.03	19.8	36	-
0.60	0.03	18.8	22	-	0.03	18.8	34	-	0.02	18.7	46	-	0.02	18.9	23	-	0.02	18.5	24	-
0.20	0.05	18.4	24	-	0.05	18.0	27	-	0.03	18.0	36	-	0.02	18.3	31	-	0.02	18.0	35	-
0.10	0.04	18.2	29	-	0.06	17.6	20	3	0.04	17.6	28	-	0.03	17.9	33	-	0.02	17.5	26	-

A Case of Office Building in Belgium

Project	Office Building in Belgium
Space, where chilled beams are used	Office room
Window internal surface temperature	38°C
Sensible internal heat loads	35 W/m^2,floor
External heat loads	65 W/m^2,floor
Heat losses	80 W/ m^2,floor
Supply air properties	3 l/s,floor-m^2, supply air temperature in summer 15°C and winter 15°C
Room design parameters	Room air temperature in summer 25°C and winter 21°C, relative humidity in summer under 50%,
Flexibility	Flexibility of 1.5 m, beams installed crosswise in every module
Chilled beam selection	300 mm wide, open active chilled beam, total length 1400 mm, effective length 1200 mm, cooling output 500 W/m, heating output 380 W/m, primary air volume 15 l/s,m, cooling water flow rate 0.10 kg/s and inlet water temperature of 15°C, heating water flow rate 0.038 kg/s and inlet water temperature of 55°C

Room Lay-out:





A Case of Office Building in Belgium

Measurement result: cooling

Height (m)	1				2				3				4				5				6			
	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %
2.00	0.34	24.2	25	29	0.10	24.7	34	6	0.13	24.8	24	8	0.13	25.0	31	9	0.18	25.0	42	15	0.08	25.7	45	4
1.70	0.25	24.3	36	23	0.09	24.6	29	5	0.13	24.7	35	9	0.12	24.9	33	8	0.16	25.1	35	12	0.09	25.6	54	6
1.40	0.20	24.4	37	17	0.06	24.5	52	2	0.08	24.6	52	5	0.11	24.9	31	7	0.15	25.2	42	12	0.09	25.6	52	6
1.10	0.15	24.4	45	13	0.07	24.5	67	4	0.07	24.5	57	4	0.10	24.8	45	7	0.12	25.1	48	9	0.09	25.4	66	6
0.60	0.08	24.5	59	5	0.14	24.4	41	11	0.11	24.5	49	9	0.08	24.9	41	5	0.13	25.1	43	10	0.09	25.2	58	6
0.10	0.22	24.3	20	15	0.25	24.3	21	18	0.11	24.6	54	9	0.04	25.3	59	-	0.08	25.1	35	4	0.11	25.1	54	8

Measurement result: heating

Height (m)	1				2				3				4				5			
	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %	v (m/s)	T_a (°C)	Turb. (%)	DR %
2.00	0.15	22.8	28	13	0.07	22.6	45	4	0.07	22.6	48	4	0.03	22.7	44	-	0.06	22.3	48	3
1.70	0.09	22.5	42	7	0.05	22.4	58	-	0.03	22.2	42	-	0.03	22.2	41	-	0.05	22.0	47	-
1.40	0.12	22.4	44	11	0.04	22.2	34	-	0.02	21.9	36	-	0.02	21.8	30	-	0.03	21.8	34	-
1.10	0.12	21.9	37	11	0.04	21.6	32	-	0.02	21.5	39	-	0.02	21.5	25	-	0.04	21.4	30	-
0.60	0.04	21.1	18	-	0.03	20.9	23	-	0.03	21.0	19	-	0.03	21.1	25	-	0.02	21.0	19	-
0.10	0.03	20.6	19	-	0.02	20.5	29	-	0.02	20.5	16	-	0.02	20.2	24	-	0.03	20.1	35	-

Chilled Beam System Benefits

- Comfortable indoor climate conditions
  - desired air temperature
  - low room air velocity
  - low noise in operation
- Economical life cycle
  - competitive investment cost
  - savings in running cost
  - limited maintenance requirements
  - easy to use with free/low energy systems
- Hygienic solution
  - dry coil operation
  - no drains or filters
  - openable construction for serviceability and easy cleaning

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