

# **Use of Chilled Beams in Air-conditioning System Design**

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## **1 OVERVIEW OF CHILLED BEAM SYSTEM**

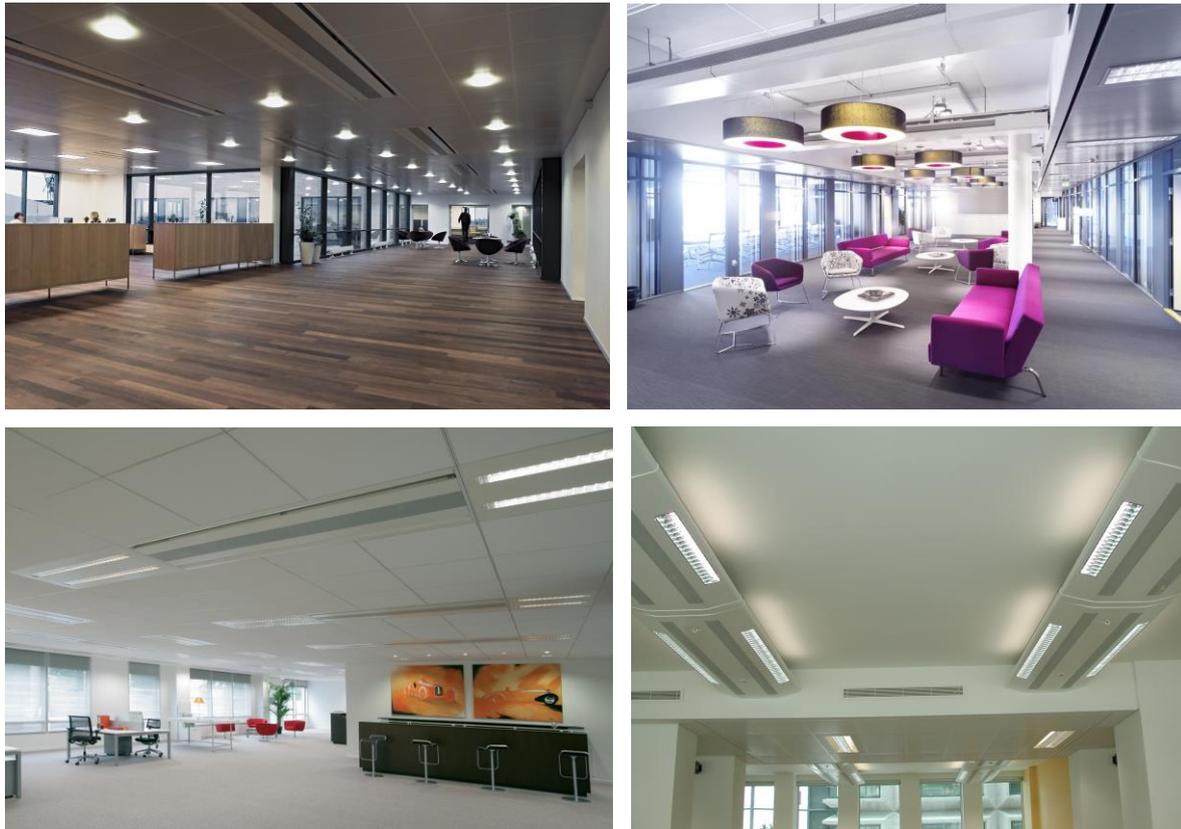
The chilled beam system is one of the newest HVAC systems in commercial buildings. The chilled beam systems are primarily used for cooling and ventilation in spaces, where requirement for good quality environmental conditions and individual space control is needed and where the internal moisture loads are moderate. Systems can also be used for heating in some applications.

One or more active chilled beams installed in the space are connected to the ventilation; cold water and if required low pressure hot water systems. The main air-handling unit supplies primary air via distribution ductwork into the various rooms through the chilled beam. Delivery of the primary air induces room air to recirculate through the beam's heat exchanger. The heat exchanger cycles either cold (60-70 °F or 16-20 °C) or warm (90-110 °F or 30-45 °C) water, thus cooling or warming the room air. Recirculated room air and primary air mix prior to supply into the space. Regulating the flow of water through the beam's heat exchanger controls room temperature.

Passive chilled beams includes only a heat exchanger for cooling and if required for heating. The operation is based on natural convection of room air through the heat exchanger. The primary air is supplied to the space using separate diffusers either in the ceiling or through raised floor.

The chilled beam system promotes excellent thermal comfort and the energy and space saving advantages, which the use of water as a cooling medium provides. The system operation is simple and trouble-free, with limited maintenance requirements. Beam system design complements the flexible use of available space, whilst the high temperature cooling and low temperature heating maximize the opportunity for free cooling and heating.

Typical applications for beam systems are: cellular and open plans offices, hotel rooms, ward rooms in hospitals, retail and banks either in exposed installation or integrated into a suspended ceiling (Fig. 1). Due to dry coil operation, the beam system should be used in spaces where the internal moisture loads are moderate, the primary air is dehumidified and infiltration through the structures is in control.



*Figure 1. Typical chilled beam installations with and without suspended ceiling.*

The full air systems are often a better choice in spaces where the primary airflow requirement is high, like conference areas, meeting rooms and classrooms. The variable air volume (VAV) is recommended if heat and contaminant loads are varying according the occupancy. Also the spaces, where internal moisture loads are high or there is an increased risk of infiltration e.g. through open doors, the full air systems or wet operating cooling systems (e.g. fan coils) are recommended.

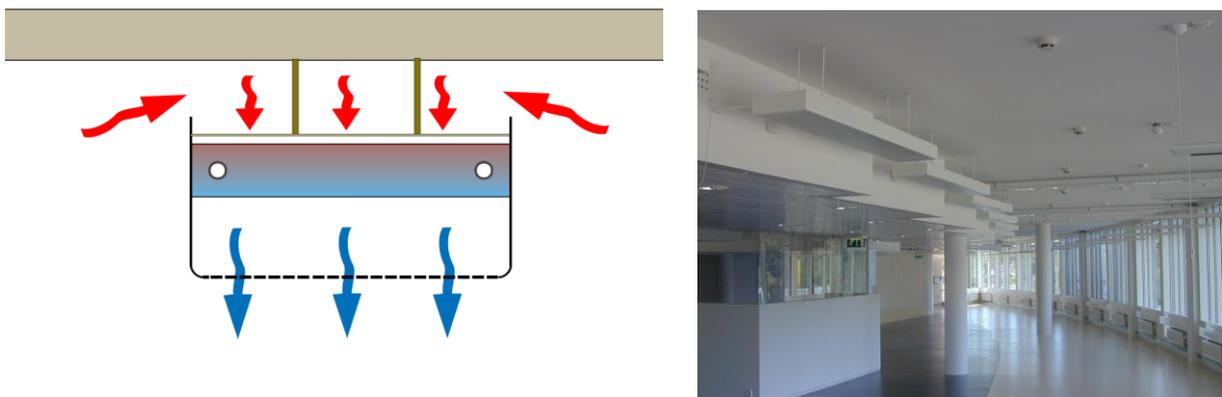
## 1.1 Passive Chilled Beams

Heat transfer from passive beams occurs mainly by natural convection with a minor part by radiation. Warm room air in contact with the cooled surface of the heat exchanger flows downwards through the beam into the room. Passive chilled beams are not connected to the ventilation system and can be positioned fully exposed, recessed within a suspended ceiling or above a perforated ceiling (Fig. 2). Supply air can be introduced either from high or low level.

Ventilation air supply (outdoor air) arrangements need to be designed carefully in order not to interfere with the operation of passive chilled beam. When the air is supplied using ceiling diffusers, the air jet should not obstruct the convective flow of passive chilled beam. In some cases where this could be exploited to prevent draught from a beam, the reduction in capacity of the chilled beam should be taken into account (e.g. in full scale mock-up).

Passive chilled beams can also be used with under floor supply or with sidewall displacement terminals. This arrangement typically creates a good mixed flow system, where the convective down flow from passive chilled beams mixes with the low velocity air supply.

Room air quality can be improved using high supply airflow rates. However, the size and number of diffusers should be selected so that the air velocities in the occupied zone are low.



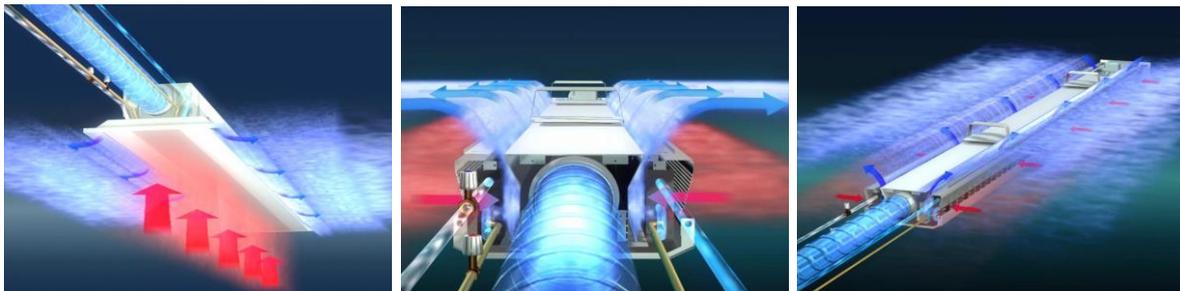
*Figure 2. Operation principle of passive chilled beam (left) and passive chilled beams positioned fully exposed into the corridor area (right).*

## 1.2 Active Chilled Beams

Active chilled beams combine the supply of ventilation air (outdoor air) and cooling in order to enable effective heat transfer due to forced convection, and ensure good air distribution also at high cooling capacity levels. Primary air is supplied into the space via a supply air plenum through nozzles along its length. The supply air jet induces room air through the heat exchanger.

The mixture of outdoor air and induced room air is supplied into the room through the longitudinal slots along both sides of the beam. Depending on requirements, available space and beam positioning, it is possible to supply air in one or two opposite directions.

An active chilled beam can be either open or closed with an integral induced air path. In closed chilled beams induced room airflows directly through the heat exchanger so that is not circulated via the suspended ceiling (Fig. 3).



*Figure 3. Operation principle of closed and exposed active chilled beams. Active chilled beam operation is based on induction of room air through the cooling coil. The induction rate varies between 1:3 and 1:5 depending on the design.*

## 1.3 Building Requirements

The operation in all climatic ceilings (chilled beams and ceilings) is based on dry coil operation and typically the units do not include any condensation collection system. This is why the moisture conditions in building must be in control whenever the system is operating and the primary air taken into the building must be dehumidified (cooled down). Typically the air is dehumidified in the central air-handling unit.

Building should also be tight enough to avoid too high infiltration (air transport through leakage paths in the shell). This infiltration is a result from temperature and pressure (e.g. wind) differences over the shell. This is especially important if building is located in hot and humid climate. In cases where there is an increased risk of condensation, it is recommended to design a system where building management system (BMS) is adjusting the inlet water temperature according the humidity level inside the building.

The condensation control is very important when building have openable windows with chilled beams. Another possibility is to equip all windows with window switch in order to close the water circulation in room when window is open.

All different type of climatic ceilings has also a limited cooling capacity especially if there are comfort requirements for spaces. This is why the building should have good enough solar shading to limit the cooling requirement under 35 Btu/h,ft<sup>2</sup>, floor (120 W/m<sup>2</sup>,floor) also in south façade.

#### **1.4 Energy Efficiency of Chilled Beam System**

Use of chilled ceilings and beams has a positive effect on energy consumption on buildings. Since water is used as an energy carrier instead of air, the system is using energy more efficiently. It is also possible to improve energy generation efficiency due to high temperature cooling and low temperature heating. Also the sustainable energy sources (waist heat, ground heat etc.) and free cooling is easier to use.

Energy efficiency of various systems can be compared using energy simulation software. This case study has been made using IDA-ICE program. Building has structures, which are typically used in Central-European temperate climate conditions today. The input values of this case study are presented in table 1 and the delivered energy consumption in table 2.

Table 1. Input values of energy simulation.

<b>Building envelope</b>	External wall	0,076 Btu/h ft <sup>2</sup> °F (0,43 W/K,m <sup>2</sup> )
	Window	0,46 Btu/h ft <sup>2</sup> °F (2,6 W/K,m <sup>2</sup> )
	Window g-value	0,48, no solar shading
	Infiltration	0,06 cfm/ ft <sup>2</sup> (0,33 dm <sup>3</sup> /s,m <sup>2</sup> ) at 0,02 in WC (4 Pa)
<b>Heating and cooling systems</b>	Boiler plant	Condensing boiler
	Chiller, air cooled condensers	One common chiller (64,4 °F) (2°C)
	Inlet water temperature	Chilled beams 59 °F (15 °C), AHU 44,6 °F (7 °C)
	Room conditioning	Active chilled beams
	Room control	P
	Room temperature	68,9 / 75,2 °F (20,5 / 24 °C)
<b>Air handling unit</b>	Airflow rates	DOAS 0,30 cfm/ft <sup>2</sup> (1,5 l/s,m <sup>2</sup> ) in offices, 0,83 cfm/ft <sup>2</sup> (4,2 l/s,m <sup>2</sup> ) in meeting rooms
	Airflow design	Constant airflow in all spaces
	Ductwork	Balanced
	AHU sizing: SFP	1,9 kW/m <sup>3</sup> ,s
	Heat recovery	Hydronic (40%)
	Filtration	EU7 in supply and EU 3 in exhaust
	Night purge ventilation	no
<b>Lights</b>	Lighting loads	4,8 Btu/h,ft <sup>2</sup> (15 W/m <sup>2</sup> )
	Controls	Time

Table 2. Energy simulation results as delivered energy.

	Btu/ft <sup>2</sup> ,a	kWh/m <sup>2</sup> ,
Heating of spaces	1965	6,2
Heating of ventilation	6942	21,9
Cooling of spaces	1902	6,0
Cooling of ventilation	824	2,6
Fan energy	3487	11,0
Pumps	222	0,7
<b>HVAC-SYSTEM TOTAL</b>	<b>15343</b>	<b>48,4</b>

Different selection strategies of chilled beam have also a significant influence on both room conditions and energy use (50-70 % reduction in cooling and heating of supply air). Variable air volume must be taken into account when selecting the beam model.

## **2 DESIGN OF ACTIVE CHILLED BEAM SYSTEM**

### **2.1 Comfortable indoor climate with chilled beams**

When indoor climate target values are specified for office building equipped with chilled beams, the values of international standards and recommendations like EN 15251, noticing some limitations of chilled beam system can be used (e.g sometimes higher primary air volumes are needed to achieve sufficient cooling capacity).

Specific cooling capacity and primary airflow rate should be limited due to avoid too high air velocities in the occupied zone. Higher the specific cooling output is, higher is also the induction rate (typically 1:3 ... 1:7) and this is why the risk of draught is increased with high linear cooling capacities. Inlet water temperature is selected based on dry coil operation. To be able to create the comfortable conditions to spaces, it is recommended to design the building so, that heat loads can be limited under 35 Btu/h,ft<sup>2</sup>,floor (120 W/m<sup>2</sup>,floor).

Heating capacity is limited mainly to keep the mixed airflow rate cool enough to mix with the room air. High supply air temperature and high specific heating capacity decreases the efficiency of ventilation and increases the temperature difference between the floor and ceiling. Cold and high window surface increases the risk of stratification.

### **2.2 Cooling design with active chilled beams**

Having selected the design room temperature and established the external design ambient condition, sensible heat loads together with casual gains can be calculated. The thermal capacity of the construction should be taken into account using dynamic simulation software to calculate its effect on the cooling load. Over design of system increases the installation cost of system and even the thermal comfort criteria is fulfilled, the percentage of satisfied people is reduced due to increased air velocity in the occupied zone.

When the chilled beam system is used for heating, the required capacity is calculated in the normal way i.e. fabric heat loss and infiltration assessment.

The chilled beam system primary airflow rate is calculated to satisfy design comfort conditions (cooling and heating capacity), minimum ventilation requirement and internal humidity level. A typical office space requires a ventilation rate of 0,3 - 0,8 cfm/ft<sup>2</sup> (1,5 - 4 l/s,m<sup>2</sup>). In order to keep humidity levels within the design parameters the primary air handling plant normally requires the facility to dehumidify the supply air. The primary airflow rate should also be high enough to absorb the moisture generated inside the space. Chilled beam systems, normally constant volume, operate with a primary supply air temperature according to the season 57 – 70 °F (14 - 21 °C). Warmer supply air temperatures are used in cold seasons.

When the specific length (length of heat exchanger) of chilled beam and primary air flow rate is selected, it is important to notice that each beam have a minimum operating air flow rate due to keep the minimum pressure inside the beam chamber as well as to guarantee the operation of air diffusion and throw pattern. On the other hand the primary airflow rate should not be too high to avoid too high induction ratio and this way to avoid too high air velocity in the occupied zone. The typical air flow rate for active beam is 3,3 - 10 cfm/ft (5 - 15 l/s,m).

Beams are selected to satisfy the cooling loads with inlet and outlet water temperature difference typically 3,5 – 5,5 °F (2 - 3 °C). Water flow rates and connection method (beams connected in parallel or series) should also be considered. As the beam system is designed to provide sensible cooling only, the inlet water temperature must be selected to avoid condensation. The inlet water temperature (normally no lower than 57 °F / 14 °C) must be selected so that the surface temperature of the cooling water inlet pipe is above the dew point temperature of the room air. The inlet and outlet water temperature difference and water flow rate is selected to achieve the required cooling capacity. Cooling water mass flow rate is selected so that the flow is turbulent in the normal operating situation. This is depending on the pipe size inside the chilled beam. Beams can be connected in parallel or series. Parallel connection is normally used but for short length or low capacity beams series connection may also be used.

### 2.3 Heating design with active chilled beams

The design of heating system is started by defining the required heating capacity of the system. In traditional heating systems the design is often based on high safety margins to make sure that building is warm enough in all cases. When chilled beam system is used for heating, the over sizing of the heating system is fatal for proper system operation. Higher the heating capacity of unit is, more difficult is to get warm air in high level to mix to the colder room air.

Chilled beam heating capacity is  $8 - 16 \text{ Btu/h ft}^2_{\text{floor}}$  ( $25 - 50 \text{ W/m}^2_{\text{floor}}$ ), which is typically enough in a well insulated and tight building. If the heating inlet water temperature is higher than a.  $113^\circ\text{F}$  ( $45^\circ\text{C}$ ), secondary air is often too warm and do not mix properly with the room air (Fig. 4). The relatively low temperature gradient in the space increases the air temperature near the floor and improves the comfort in the space as well as increases the energy efficiency of system (decreases the short circuit and thus the exhaust air temperature).

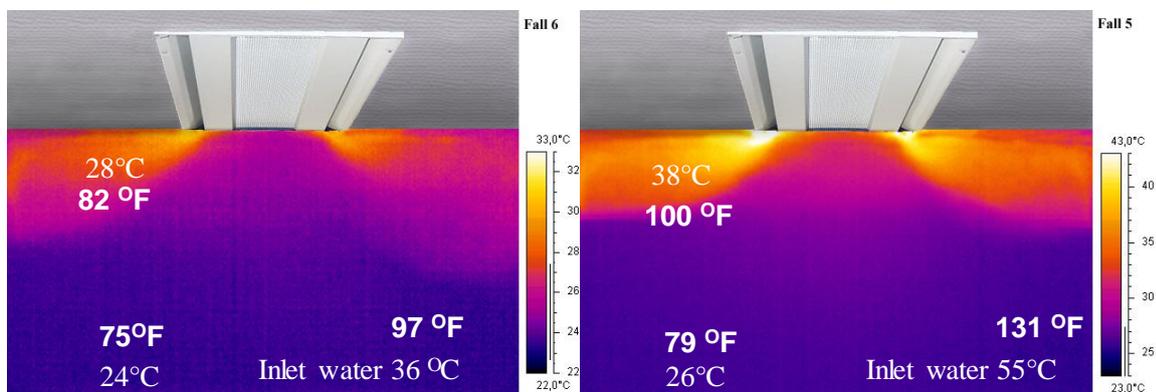


Figure 4. Temperature gradient in the space with different inlet water temperatures (infrared measurement in full scale mock-up).

The mixing is also depending on the window surface temperature and height. Higher and colder the window is, colder the air falling to the floor is, and temperature gradient between secondary air and room air becomes bigger. This is why it is recommended to use beams for heating only when windows are good enough (surface temperature is higher than a.  $57^\circ\text{F}$  /  $14^\circ\text{C}$ ).

The heating capacity of active beams is depending on the primary airflow rate. This is why the output of heating system is clearly decreased when ventilation is shut off during the nighttime. This is why the open active beams should be specified to meet the heating requirement without ventilation. Active closed beams do not perform at all without ventilation due to its closed construction and this is why the closed beams can be used for heating only when ventilation is operating 24 hours per day.

## **2.4 Prevention of condensation**

Chilled beam systems must be designed to ensure that there is no risk of condensation. This means selecting the inlet water temperature above the dew point condition. The inlet water temperature must be rescheduled accordingly if the internal humidity levels are affected by external influences.

Dehumidification of the primary supply air by the main AHU plant is used to control humidity levels and avoid condensation.

As moisture will most likely appear first on the valves it is recommended good practice to insulate the valves and associated pipe work up to the heat exchanger. The system can be further safeguarded with condensation sensors mounted on the surface of the connecting pipe work. If condensation is detected then either the inlet water temperature is elevated, the beam cooling water circulation pumps are switched off or control valves are switch off locally. However in the case of a building with openable windows individual contact sensors to the windows can be applied to isolate and shut off the cooling water supply to that area.

## **2.5 Air and water distribution systems**

Schematic diagram (Fig. 5) shows an example of an active chilled beam system for both cooling and heating. A dedicated buffer vessel separates the beam cooling water circuit from the primary chilled water system. Cooled water is pumped around

the system with temperature control achieved by a 3-way mixing valve. Water inlet temperature supplied to the beams is generally higher than primary chilled water supply temperature to the air handling unit for dehumidification of the primary supply air. The heating system has equally two separate water circuits, low temperature circuit for chilled beams and high temperature circuit for air handling unit and other heating elements.

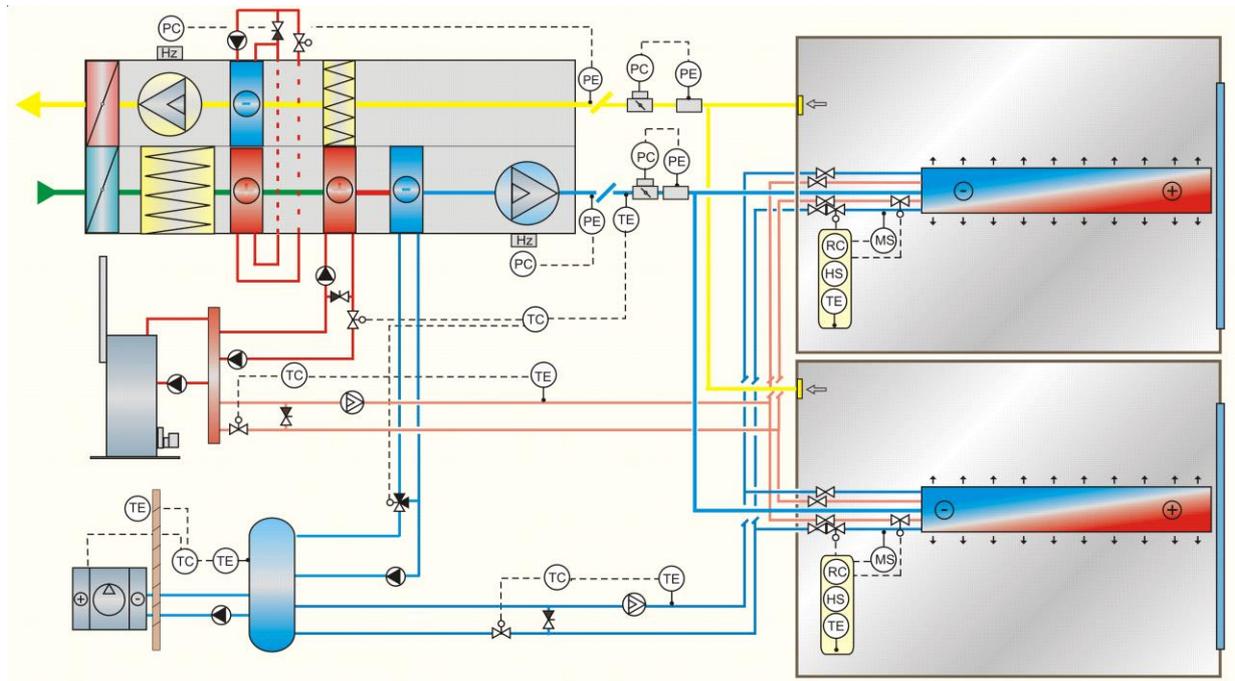


Figure 5. An example of a schematic diagram of an active chilled beam system with both cooling and heating functions.

## REFERENCIES

Virta, Butler, Gräslund, Hogeling, Kristiansen, Reinikainen, Svensson (2005) "Chilled Beam Application Guidebook", Rehva Guidebook no 5.

Virta, Itkonen, Mustakallio, Kosonen, Jokisalo, "Optimization of Cooling System in a View of Energy Saving and Indoor Environment Quality", The International Congress on Heating, Refrigerating and Air-Conditioning, Beograd, 2009.