Design Principles of Perimeter Passive Chilled Beams

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SUMMARY

Perimeter zone is considered as an area near building's windowed facade. Window construction has significant effect on perimeter zone's cooling conditions. If solar heat gains are not properly eliminated this can be sensed as thermal discomfort. One solution in the demanding cases is to use perimeter passive chilled beams parallel to the window façade. For the design of perimeter passive chilled beam, summer time cooling requirements in a typical perimeter office room were calculated with DOE-2.1 energy simulation software. Then experimental measurements with calculated solar loads were performed with different distances between the passive chilled beam and window surface. Measurement results were compared to the manufacturer's product data. This is done to found does the warm window plume enhance the performance of passive beam. Temperature and velocity in the perimeter zone are measured to compare the thermal conditions in the perimeter zone with different installations. Measurement results showed that the cooling capacity of perimeter passive chilled beam is smaller than standard cooling capacity of passive beam. Installing the perimeter beam enough far from the window surface should minimize this. The measured thermal conditions in the perimeter zone are good with perimeter passive beams.

INTRODUCTION

Building's perimeter zone is considered as an area near building's windowed facade. Cooling requirements within the perimeter zones have increased greatly due to increased popularity towards glazed facades, and the growth of electrical equipment in European office buildings within the past decades. Total cooling demand per square meter can be quite high in office premises, where solar gains are not properly eliminated in summer time, and that is why thermal discomfort is often sensed in the occupied zone. Therefore, the solar gains should be minimized, especially in the western and southern side of building where the maximum solar heat loads occur normally in daytime. Otherwise, special perimeter cooling solutions should be considered, such as perimeter passive chilled beam systems. These cooling systems should be designed so carefully, so a risk of draught is small and the quality of the indoor air is uniform in the occupied zone.

The main target for this paper was to study how the heat loads are handled efficiently from the perimeter zone in office space cooling with perimeter passive chilled beams, and to define basic design principles for the system.

METHODS

For the design of perimeter passive chilled beam, summer time cooling requirements in a typical perimeter office room were calculated with DOE-2.1 energy simulation software.

Simulations were carried out in the perimeter office room 4.6 m x 2.8 m x 3.0 m (H), where the external wall 2.8 m x 3.0 m (H) was almost fully glazed except 2.8 m x 0.4 m (H) area from top. This kind of office space layout, which has the window to wall surface ratio (WWR) nearly 90 %, represents one of the most difficult cooling situations. Internal wall structure was lightweight with the insulation U-value of 0.25 W/m2K.

Simulations were performed with weather conditions of Helsinki and Paris with typical commercial window types, which were directed both in south and west. In table 1, the window types that were chosen for the simulations are arranged in descending order by U-value and total solar transmittance. First three windows have standard glasses, fourth is absorbing window and following are low-emissivity windows of which last one has argon filling. Hourly cooling requirements for the chilled beam application were simulated in summer cooling conditions with the supply water temperature of 15 °C and the primary airflow rate of 2.0 l/s per floor-m2. The primary airflow rate was fixed to maintain design temperature 24 °C, which corresponds to high quality level of indoor air. Chilled beam's operation period corresponded to normal European working hours, which were from Monday to Friday between the 07 and 18. Night ventilation was used after the work hours and in the weekends. Internal heat loads consisted of 2 persons (150 W), lighting 15 W/m2 (190 W) and equipment 20 W/m2 (260 W).

Table 1. Window properties for different used window types

Window type	No.	mm	Fillgas	U [W/m^2,K]	Total %	Direct %	Visible %
1xclear	1	6	-	5.20	82	78	88
2xclear	2	6+6	Air	2.54	70	60	78
3xclear	3	6+6+6	Air+Air	1.68	61	47	70
Antisun green+2xclear	3	6+6+6	Air+Air	1.68	40	28	57
Sunblue cool+2xclear	3	6+6+6	Air+Air	1.68	22	13	24
Suncool bronze+2xclear	3	6+6+6	Air+Air	1.68	12	4	8
Ipasol Natura+2xclear	3	6+4+4	Argon+Air	1.00	32	25	60

No = Number of glasses
mm = Glass layer thickness [mm]
Fill gas = Fill gas between glasses
U = U-value of the glass center [W/m^2,K]
Total % = Total solar transmittance [%] (='SHGC' or 'g-value')
Direct % Direct solar transmittance [%] (='Tsol')
Visible % = Visible light transmittance [%] (='Tvis')

Simulation results include chilled beam cooling requirements with and without internal blinds. Blinds were either fully open or fully closed (in 45 degree angle), and they were inserted between the window glasses. The cooling requirements are maximum peak loads within the cooling period in summer design day.

The experimental measurement room with perimeter passive beam had same dimensions and same whole façade size window as in the energy simulations. The measurements were conducted at the Halton facilities. Arrangement of electric heated foil for solar load and installation of the perimeter passive beam is presented in the figure 1. The distance from the window covered with heating foil was 2.5 m. This was based on the solar altitude and how far the solar gain penetrates in the room on design day.

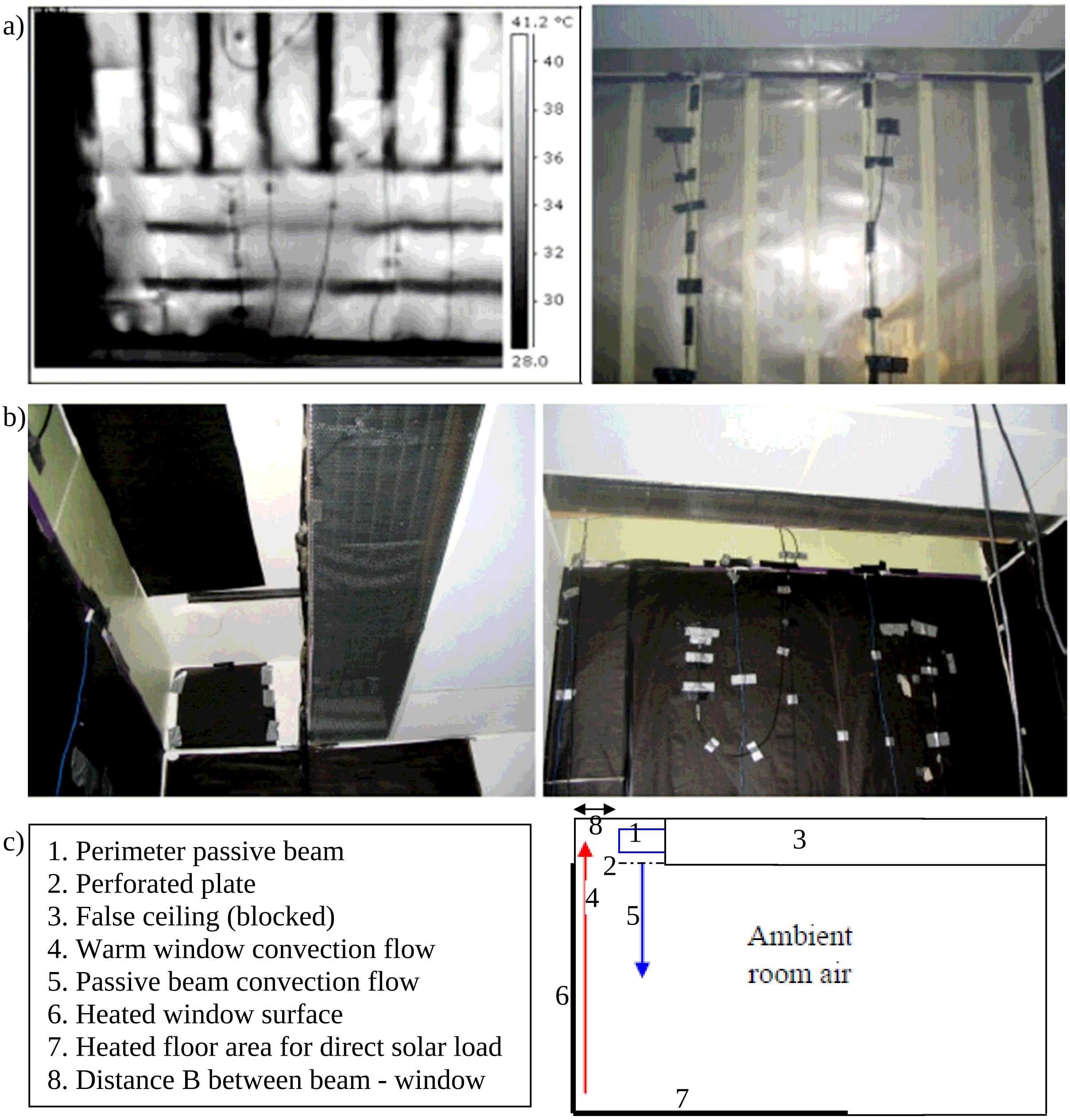

Figure 1. a) Arrangement of electric heated foil for solar load (infrared picture on left), b) installation of the perimeter passive beam and c) side view of installation with different components

Measurements were performed with a typical passive chilled beam (CPT-105-2800-2600-305) with dimensions 2600mm (L), 305 (W) and 105mm (H). Passive chilled beam's dimensionless distance B from window was varied between 0.5 (150 mm) and 2.0 (600 mm). Passive chilled beam was mounted over the level of suspended ceiling. Warm uprising induction air was stopped above the chilled beam and captured to chilled beam's inlet, by placing a thin cardboard between the other side of the chilled beam and the ceiling. The gap between chilled beam's top surface and the ceiling was 150mm. This was derived from the research report of BRE [1] and is also according the beam manufacturer's recommendation. The passive chilled beam was tested with a perforated plate, which was placed under the chilled beam, so that the distance between the perforated plate and beam's bottom surface was approximately 145 mm. Spacing between the perforated plate and chilled beam's bottom surface was blocked with thin cardboard. Perforation in this plate was 50 percent, which was acceptable level according earlier research. The passive chilled beam was also tested without the perforated plate in high window temperature conditions.

The chilled beam's cooling performance and thermal conditions inside the measurement space were measured, when the environment temperature outside the measurement space was kept in 25 deg C and the measurement room temperature was let varied according the heat load settings and efficiency of the operation of the passive beam in each case. The inlet water temperature was 15 deg C and water mass flow rate 0.08 kg/s. there was supply or exhaust air flow in the measurement space. Chilled beam's average cooling performance and thermal comfort near the heated simulation window and within the occupied zone was investigated by temperature and air velocity measurements. Measured cooling capacities were compared against the reference cooling capacities, which were derived from manufacturer's product data.

Measurement cases with different kind of heat load arrangements and cooling load levels are presented in table 2. When all is set on window surface, the chosen values correspond roughly to window's conduction heat loads calculated with energy simulations software, and they are as follows: 65 W/floor -m2 ~ 840 W ~ 43.0 deg C, 50 W/floor-m2 ~ 645 W ~ 38.0 deg C and 35 W/floor-m2 ~ 450 W ~ 35.0 deg C.

Table 2. Measurement cases with heat load arrangements and cooling load levels

	HEAT LOADS					
	Total CL		Window		Floor area	
	[W/m^2]	[W]	[%]	[W]	[%]	[W]
CASE 01	65	837	100	837	0	0
CASE 01*			100	837	0	0
CASE 02			50	419	50	419
CASE 04	50	644	100	644	0	0
CASE 05			50	322	50	322
CASE 07	35	451	100	451	0	0
CASE 08			50	225	50	225

Gap between beam and window	**B**	**$W_b/2$**	**W_b**	**$2W_b$**
	[mm]	150	300	600
Environment temperature [°C]	25,0	**Floor area [m^2]**	12,9	
Water inlet temperature [°C]	15,0	**Perimeter area [m^2]**	7,0	
Water mass flow rate [kg/s]	0,080			
* **Without perforated plate**				

Visualization with smoke was used to see the interaction between the warm uprising thermal plume from the window surface and cold air plume/jet from the perimeter chilled beam. Velocity and turbulent intensity were measured with omni-directional hot sphere anemometers (accuracy +/- 0.02m/s with velocities 0.05 - 1.0m/s), and temperature with PT100 sensors (accuracy +/-0.1degC). Readings are three minutes average values. There were sensors in the heights of 0.1, 0.5, 1.1, 1.3, 1.8 and 2.3 m. The measurement pole was located in the middle, under the chilled beam and 1.3 meter away from the window surface. The other room temperature measurements were performed from two points: 2.5 m away from the window at the height of 1.3 m from the floor level and 1.3 meter away from the window at the height of 1.1 meter from the floor level. The latter room measurement probe was used together with the velocity measurement and the globe thermometer to determine the mean radiant temperature. Also window surface, environment, supply and return water, air going into the chilled beam and leaving the beam temperatures were measured.

RESULTS

The calculated summer time cooling requirements calculated with DOE-2.1 in a typical perimeter office room is presented in the figures 2-3. The presented room cooling requirements are maximum peak loads within the cooling period in summer design day. The heat loads are effective loads where the cooling effect of thermal mass of building structures during the peak condition has been taken off whereas the window surface temperature is the momentary peak value. By approximating the plume air flow rate with equation for heated vertical plate, these kinds of window surface temperatures would generate uprising plume between 100 and 180 l/s from unprotected window, whereas the protected window surface would generate plume less than 100 l/s. The portion of thermal radiation from warm window surface is over half of conduction heat load.

Regardless of the window type and location, cooling requirement increase drastically if the solar heat gains are not cut off. The most effective way to decrease the total cooling requirement, including solar heat loads, is to cut off the solar gains through the windows. As shown in Figure 2 and Figure 3, cooling requirement is decreased when the blinds are assembled between the window glasses or over the window's inner surface. Total cooling requirement also decrease when window’s insulation (U) value and total solar transmittance (SHGC) are improved, because the total heat gain through the window is decreased also.

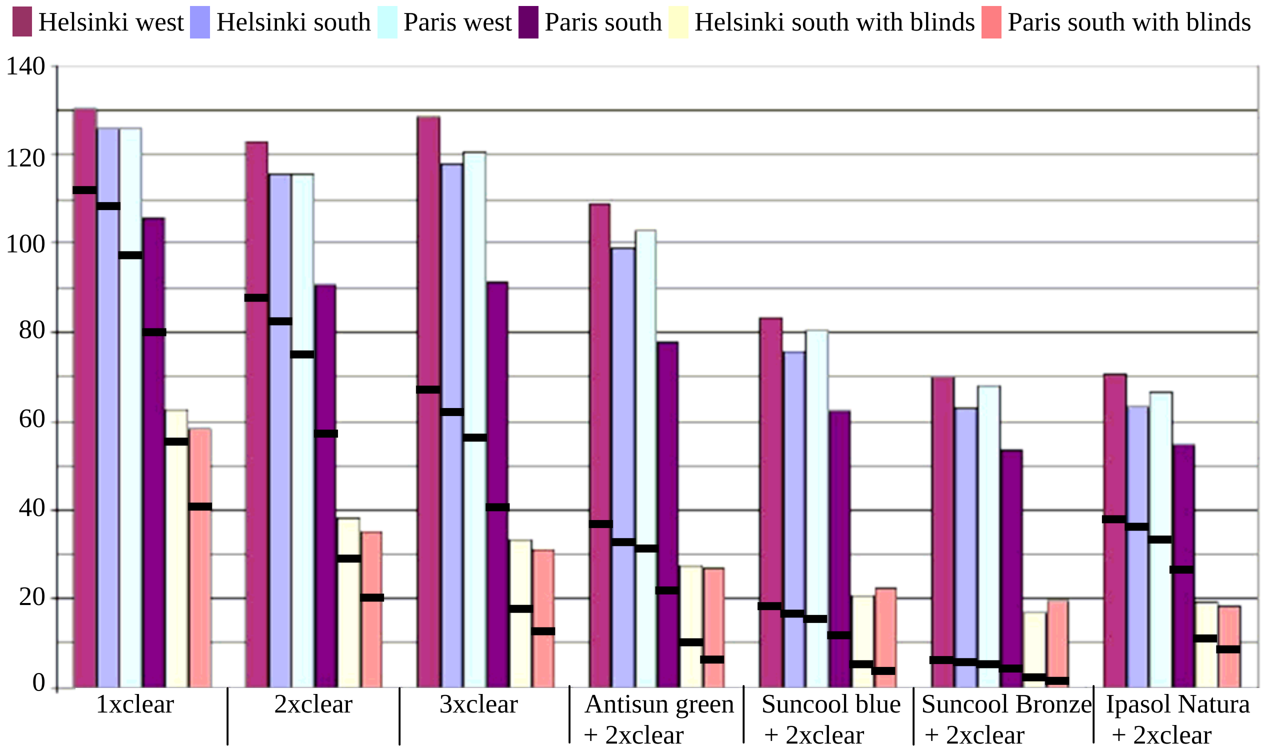

Figure 2. Total heat load [W/m$^2_{floor}$] from the window with different window types. Direct and diffuse solar radiation heat load portion [W/m$^2_{floor}$] below thick parting line

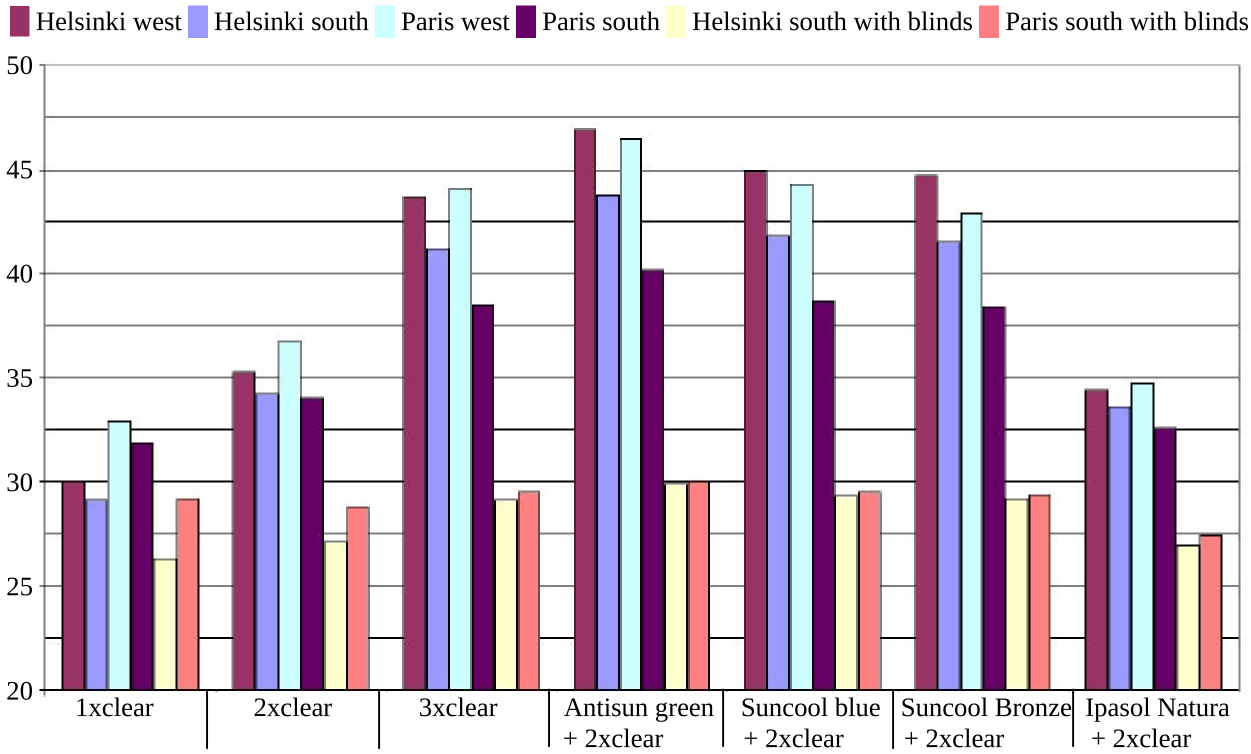

Figure 3. Window surface temperatures [deg C] during peak moment

Similarly, the U- and SHGC-values are improved as the glass layers are increased and the glasses are tinted with selective coating material, as for example Ipasol Natura with double glazed clear glass.

Smoke visualizations of convection flow from perimeter passive beam are presented in the figure 4. Visualization is from the measurement case with distance B=1 (300 mm) between window and passive beam. Passive chilled beam generated thermal plume, which turned against the window surface, when the perforated plate was place under the chilled beam, as shown in the left side of the figure 4. Plume turned against the window although the window surface was not heated in every measurement situation. The phenomenon is caused by pressure difference and is known as Coanda effect. Size of the clearance void B had only slight influence to plume's deflection angle. Part of the plume circulated back over the passive beam and generated short circuit between the air going into beam and the air leaving the beam, when the dimensionless distance B was smaller than one and the perforated plate was placed under the chilled beam. Cooling capacity increased as the distance B was increased, because there was more free space for the return airflow. After the perforated plate was removed, the plume directed more downward and turned only slightly against the window, as shown in right side of the figure 4.

Conductance of the passive beam based on cooling capacity and inversely proportional to the difference of room air and water average temperature, are presented in the figure 5. The temperature differences between air going into passive beam and room air are presented on left side and relative cooling capacities of the beam on the right side of figure 5 where is compared to the manufacturer's cooling capacity data [2] in the room temperature. Temperature efficiencies were higher with higher window surface temperatures and higher window heat loads. The cooling capacity was not as high as expected, even though the window surface temperatures and temperature differences between the window surface and ambient room air were very high. Perforated plate obstructs the airflow through the heat exchanger much and reduces achieved cooling capacity, because the supply and return airflows generate short circuit between each other.

Velocity measurements under the beam and at 1.3m distance from the window are presented in the figure 6. That compares the conditions in the perimeter zone with different heat load situation in the cases with 0.6 m distance between the beam and window. The measurement data from this distance is shown because it is most optimum for the beam cooling capacity according the figure 5. The velocity level is similar also in other cases and when calculating draft rate indexes they stay under 15% in all measurement points, according which the local thermal conditions are at good level [3].

Figure 4. Smoke visualization of convection flow from passive beam. Measurement with perforated plate under the beam (left) and without perforated plate (right)

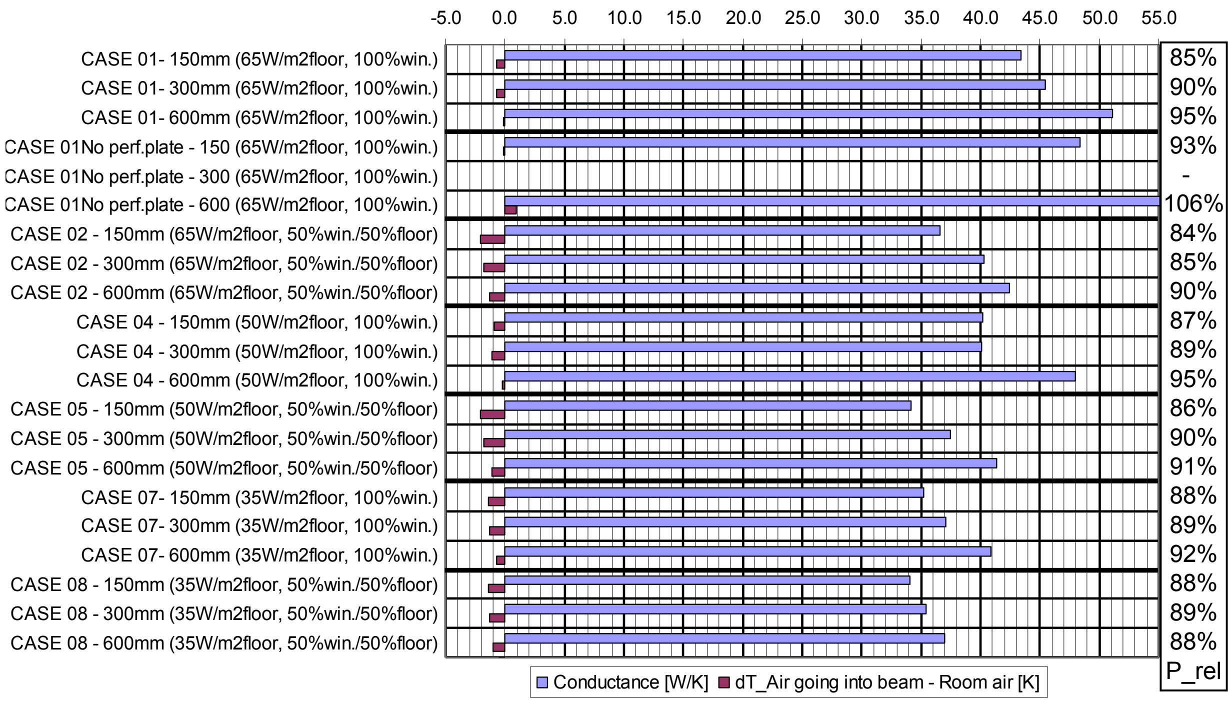

Figure 5. Conductance of the chilled beam and temperature difference between air going into passive beam and room air. Relative cooling capacities of the beam on the right side.

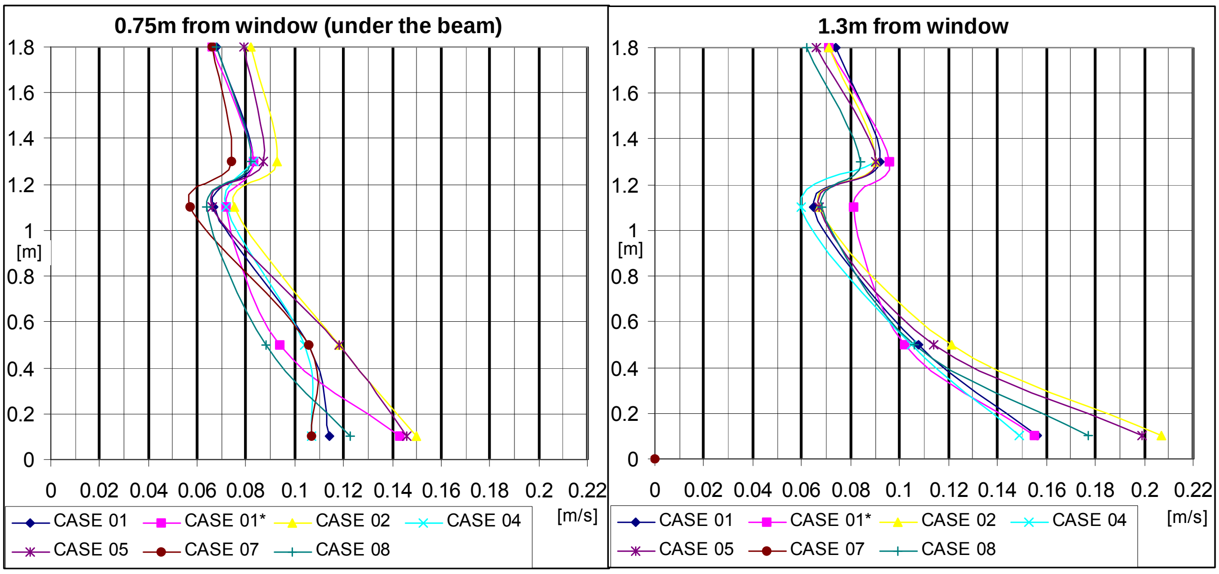

Figure 6. Velocity measurements at different heights from floor under the beam and at 1.3m distance from the window

CONCLUSIONS

Perimeter passive chilled beam produced good thermal comfort conditions under the chilled beam and in the occupied zone. Measured cooling capacities were lower than expected, because there was not achieved temperature efficiency between the air going into the beam and room air, until the perforated plate was removed and the beam was furthest away (0.6 m) from window. Also if big part of the solar load comes as direct load onto the floor, the beam cooling power is lower. The perimeter passive beams are good option for the perimeter zone cooling in the demanding cases especially with fully glazed facades when solar gains can’t be properly eliminated. Following design principles should taken into account:

- The design cooling requirement fro perimeter zone should be calculated with energy simulation tool.
- If there is big portion of solar load into the perimeter zone as direct load, it lowers the beam’s cooling capacity (in this study 50% direct portion means about –10%).
- The distance between the beam and window surface should be approximately 0.6 m. When the distance half or less, it lowers the cooling capacity because of short-circuit air flow (in this study 0.3m distance means about –10%, 150mm –15%).
- The perforated plate under the perimeter passive beam should have more than 50% free area especially if the beam is installed to nearer than 0.6m from window.

ACKNOWLEDGEMENT

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3. ISO-7730 (1994). Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. 1994.