Testing the use of an active chilled beam technology in a hospital ward mock-up

This article describes a research to study the performance of an active chilled beam at cooling and heating modes in a mock-up of a hospital ward. The research was conducted in accordance with ASHRAE 55-2004 and ANSI/ASHRAE/ASHI 17-2013 standards in a certified aerodynamics laboratory.

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Within the framework of the research a test chamber was built up to represent a typical hospital ward for three patients.

Air velocity and temperature measurements were taken in the test chamber to quantitatively determine the critical air parameters in humans' occupancy zone at cooling and heating scenarios using chilled beams technology.

Introduction

In mixing ventilation systems indoor air quality is highly dependent on air mixing effectiveness. In cooling case it is necessary to control air distribution in order to prevent excessive air velocity and draft rate occurrence in human's occupancy zone. In heating case there is a risk of air stratification in the room, when a layer of fresh and warm air mass builds up right below the ceiling, whereas layer of stuffy and relatively cooler air mass settles in human's occupancy zone. Therefore it is important to select the right system to deliver fresh air at the desired temperature and to meet comfort requirements.

Hospital wards have strict hygienic requirements, therefore a proper and regular air exchange is critical. Fresh air cannot be simply delivered by opening the window, therefore an advanced technology shall be used that can meet the strictest hygiene and comfort criteria.

Chilled beam technology is primarily used for cooling and ventilation. Active chilled beams deliver primary (fresh) air into the room and recirculates secondary (room) air through its heat exchanger. Recirculated secondary air and the fresh primary air are mixed prior to diffusion in the space. Chilled beam system provides an excellent thermal comfort, energy conservation and efficient use of space due to high heat capacity of water used as a heat transfer medium. The system operation is simple and trouble-free with minimum maintenance requirements. It can also be used for heating.

Typical applications for beam system are office spaces, hotel rooms, hospital wards and retail shops. This study was focused on the application of the active chilled beams technology in hospital wards for heating and cooling purposes.

Methodology

Studies on air movement and distribution within the enclosed spaces are conducted using full-scale test methodology. Full-scale test rooms are used for identification of air terminal devices with regard to the flow they generate.

In this study a full-scale testing methodology was applied to simulate the beam performance in a hospital ward in summer and winter conditions. For that purpose a specially designed test chamber was assembled to represent a three-patient hospital ward (**Figure 1**).

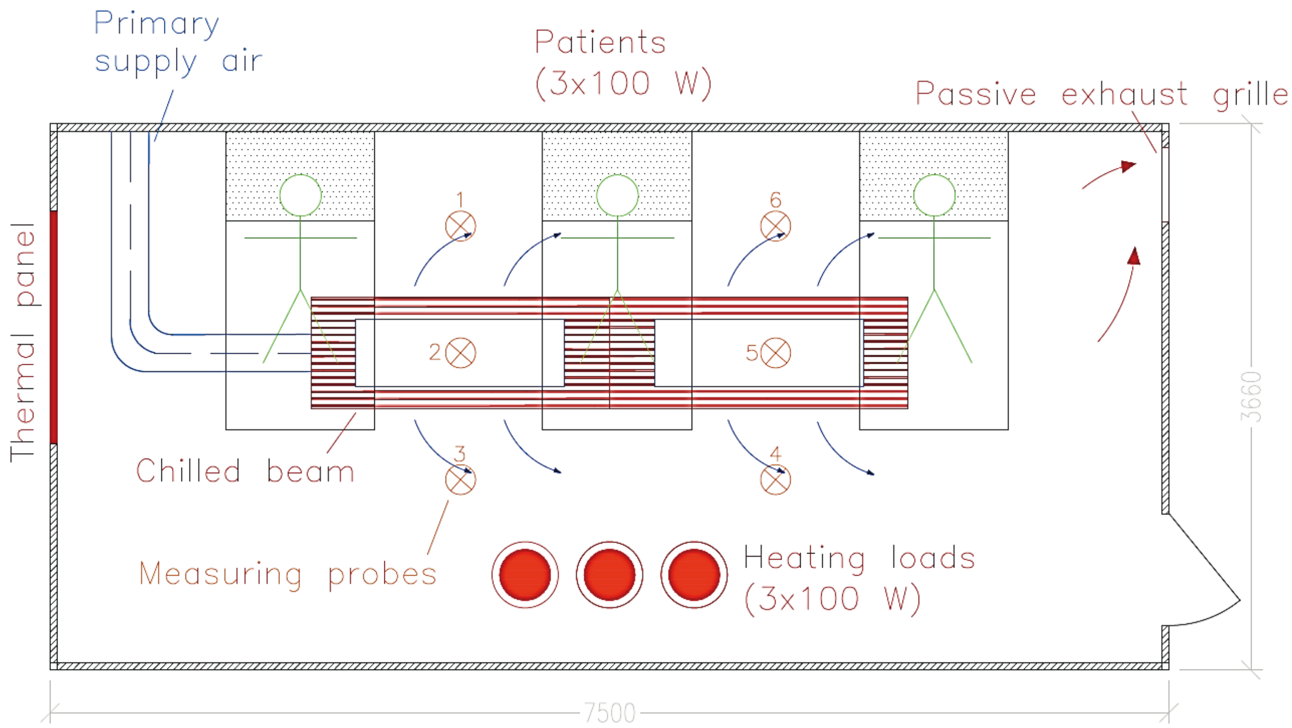

Figure 1. The layout of a full-scale test chamber.

Three beds with 100 W heating load source each were placed within the test chamber to simulate the heat release of a human. On one side of the chamber a thermal panel with integrated heat exchanging copper pipes was installed to simulate solar radiation input for summer case or cold window surface for a winter case. On the other side of the test chamber a passive overflow grille was integrated to eliminate the risk of overpressure and to ensure a heat exchange between the test chamber and adjacent spaces. An additional heating load of 300 W (3x100 W) was placed to account for other factors such as visitors, medical personnel or electrical equipment heat release.

Integrated into suspended ceiling two beam technology prototypes were connected in series to deliver fresh air into the chamber and to ensure heat exchange with max 2 000 W of capacity.

Table 1 shows the testing conditions for summer (cooling) and winter (heating) cases. Airflow rate was set according to the ANSI/ASHRAE/ASHE 170-2013 requirements. Other parameters were set up according to specific characteristics of chilled beam prototypes used for this study.

To check the air mixing effectiveness within the test chamber a smoke test was conducted. A smoke test visually demonstrates an air distribution and diffu-

Table 1. Testing conditions.

Parameter	Cooling	Heating
Airflow, m^3/h	342	342
Supply air temperature[1], °C	18.0 ±0.5	24.0 ±0.5
Room set temperature[2], °C	23.0 ±0.5	21.0 ±0.5
Temperature in the heat exchanger (in/out), °C	14/18	50/42
Room heating/cooling loads, W	1 600	1 768
Beam cooling/heating capacity[3], W	1 638	1 786
Thermal panel temperature, °C	40.0 ±1.0	16.0 ±1.0

[1] In the beam outlet.
[2] Desired temperature at the height level of 1.1 m above the floor.
[3] Cooling capacity to compensate the heating loads; heating capacity to compensate the heating loads.

sion pattern and shows the appearence of such risks as air mass stratification, short-circuiting or excessive turbulence.

Air temperature measurements were taken constantly every 60 seconds throughout the test. Temperature measurement probes were placed at 3 levels of a standing occupant ankle, waist and head area (0.2, 1.1 and 1.8 m above the floor accordingly) and at 2.2 m above the floor level (400 mm under the beam) as it is shown in **Figure 2**.

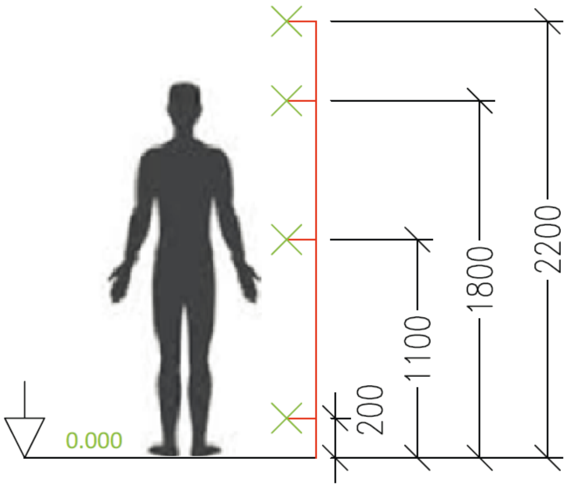

Figure 2. Vertical profile of the measurement points (human's silhouette is added as a height level reference).

Results and discussions

Cooling scenario

In the cooling case the supply air temperature from the beam outlet was set to 18.0±0.5°C in order to keep room temperature below 23.0°C.

Some turbulence was observed near the thermal panel area as the panel was heated up to imitate the input solar radiation through the window. Cool supply air from the beam confronts the warm air mass near the window area and this creates intense mixing which leads to increased air velocity and excessive turbulence. When the thermal panel was off, the turbulence did not occur.

In the patient area under the beams air velocity was relatively low (*$v < 0.2$ m/s*) with insignificant velocity deviation factor, eliminating the risk of excessive turbulence and draft rate (*$T_u < 40$, $DR < 20$*).

In cooling case no concerns appeared regarding the air mixing effectiveness as the smoke coming from the beam dissipated quickly and evenly within the volume of the test chamber and did not stratify in one particular zone. Also, the passive overflow grille did not disrupt the air circulation pattern. No short-circuiting or extract effect occured through the grille.

Temperature gradient for cooling scenario also showed that the air was distributed and mixed properly throughout the test. As it is shown in **Figure 3** the temperature profile has a steady and uniform shape without substantial deviations at any of 4 height levels. A little cooler temperatures are observed right above the floor at the ankle area and right below the beam which indicates, that at the humans activity area the heat loads are present at a denser degree and thus keep the temperature slightly higher. Wider temperature range right below the beam also indicates that air induction takes place.

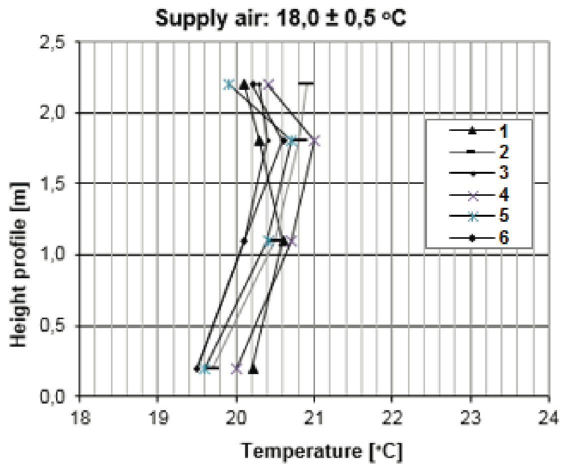

Figure 3. Temperature profile for cooling scenario.

Heating scenario

In the heating case the supply air temperature from the beam outlet was set to 24.0 ±0.5°C in order to keep the room temperature at 21.0 ±0.5°C.

Thermal panel in this case was connected to a cold water circuit to imitate a cold window surface. This did not cause any turbulence, as the air velocities throughout the test chamber were considerably below 0.2 m/s.

Some degree of air mass stratification was observed as the temperature measurements at the upper level differed quite significantly from those below. At the ankle area temperature ranged between 20.5÷21.1°C, whereas at the 2.2 m height level temperature varied from 23.2 to 23.9°C (**Figure 4**).

Smoke test validated that warm supply air tends to accumulate at the upper part of the test chamber prior to entering the human's occupancy zone. However, after continuous observation the air within the test chamber mixed thoroughly. So, while the temperature gradient stays relatively high (>3,0°C), the overall air mixing effectiveness was satisfactory ensuring that at certain point the fresh supply air will dilute with stuffy room air.

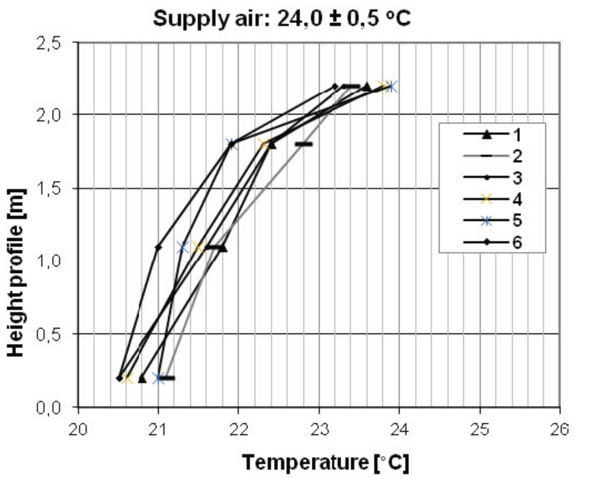

Figure 4. Temperature profile for heating scenario.

Conclusions

This study solely focused on the performance of beam technology at cooling and heating scenarios when strict hygiene and temperature conditions are to be met.

In the cooling scenario the main concern is the occurence of excessive air velocities, turbulence intensity and draft rate in the human's occupancy zone, however, this study showed that with chilled beams technology these parameters are kept below the critical values even when additional heating loads and solar radiation were introduced into the room.

Smoke tests validated that the air mixing throughout the test chamber was sufficient ensuring the necessary exchange rate.

When analyzing the measurements for the heating scenario, the risk of air stratification and insufficient mixing emerged, however, the smoke test showed that at a certain point the fresh supply air will dilute with stuffy room air ensuring the necessary air exchange.

If the building envelope is tight enough and outdoor air infiltration risk is prevented, airborne cooling and heating via beam systems is an effective way to deliver fresh air and ensure the desired room temperature significantly reducing the costs for other cooling or heating equipment.

Supply air flowrate and water inlet temperature in the beam can be varied to maintain room temperature setpoint according to the air temperature conditions outdoors and heating loads indoors. Increasing the supply air temperature and decreasing supply air flowrate can save energy, but it causes reduced air circulation and thus leads to low indoor air quality risk. Increasing the supply airflow will improve air circulation and mixing effectiveness within the room, but it will increase energy consumption. ■