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The Hygrothermal Survey in Reconstructed Office Building with Chilled Beams System

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Abstract
The study introduced field measurements of hygrothermal microclimate in a reconstructed office building in the Czech Republic. The work includes subjective measurements of this space with occupants. Subjective method was provided by questionnaires survey filled by workers. Within objective measurements was measured several values, included a non-uniform constituent in space. Problems are found in many cases of unacceptable temperature or inadequate function of air-conditioning system with induction units.

Keywords – chilled beams system; thermal discomfort; open-plan offices; questionnare survey.

1. Introduction

Along with a need for more energy efficient buildings (reduced infiltration of ambient air), a combination of pollutants generated indoors and inappropriate ventilation have resulted in issues associated with indoor air quality. To provide optimal conditions is not easy task, especially for large rooms with occupants, a lot of equipment and workstations. Several studies of indoor environment in open-plan offices have shown that the most frequent complaints from employees are about the thermal comfort and acoustic quality at workstations, [1] and [2]. Complaints and problems occur in many cases of unacceptable temperature or inadequate function of ventilation and air-conditioning system [3]. As is well known, appropriate temperature positively affects work performance [4]. These findings are in accordance with [5]. That study deduced that indoor air quality and thermal comfort enhanced the occupant productivity in offices.

This study deals with subjective measurements using the questionnaires of hygrothermal survey in office building with chilled beams system.

2. Description of building and HVAC system

Experiments were carried out in a building with open-plan offices in the Czech Republic. The building has 4 floors and it was renovated in 2005. Changes has been made in mechanical ventilation and cooling systems as well. To reduce the thermal load (mainly in summer time and from office equipment) the chilled beams have been installed. The building has tall double glazed windows which most of them are blocked for opening. There is a quite large skylight in the middle of 4th floor ceiling. It supplies natural lighting for 3rd and 4th floor. Skylight and windows are equipped by blinds.

Measurements were carried out in winter and summer period. Periods were follows: at the 3rd floor for summer period and 3rd and 4th in winter period, where complaints of occupants had been reported.

Fig. 1 The view to 4th floor of open plan-offices and ceiling with chilled beams system

Supply of ventilation and requirement minimal hygienic amount of air provide two ventilation units into a space. Units are placed outside on roof ensuring supply and exhaust air into the building. Exhaust air is performed in the suspended ceiling using point exhaust diffusers and concentrated in two corners of the building.

For summer period the ventilation is equipped by mixing section which ensures a partly circulation and thus required amount of primary air for

chilled beams. To achieve a standard requirement [6] about relative humidity in this space in winter period, the supply air is humidified. Humidification is provided by electric steam generator.

Two compact cooling units with air cooled condenser in outside construction and year-round operation are used. Their cooling capacities are 350 kW for southwest part and 284 kW for northeast part of the building.

Fig. 2 The floor plan of 3rd floor with marked sections of cooling beams (in section "7" the schema one of the regulatory branch is shown)

Chilled beams (with induction principle) are installed in the level of suspended ceiling for exhausting space heat load (see Fig. 2). Chilled beams have dimensions of 600 × 3000 mm and 600 × 2400 mm. Cooling water exchangers have following parameters of water: 16/20 °C. The sections of cooling induction beams are fitted with standard shut-off valves. Cooling process is switched based on sensors located about 1.6 to 1.7 meters above the floor. In total is regulated 9 sections with chilled beams (for each floor - 3rd and 4th) and switching on of cooling is set for each section at the value level of indoor temperature at 24 °C.

3. Performed measurements

The objective measurements included the following variables: air temperature t_a (8 measuring points in workstations), air velocity v_a (m.s^{-1}), relative humidity *rh* (%), stereotemperature t_{stereo} and globe temperature t_g'. The last two mentioned variables were measured by a globe stereothermometer [7]. Outside temperature t_e and the temperature sensor values for controlling of ventilation and cooling systems are also available for future evaluation. Results of the objective measurements are not described in this work.

For evaluation of employees subjective feelings anonymous questionnaire have been made. The questionnaire survey was focus mainly in part of hygrothermal microclimate in indoor environment.

The survey was carried out at the 3th floor (3rd and 4th in winter period). There are around 150 – 200 workers at each floor who make PC work and some of them are at the management or administrative positions.

Questionnaires have been filled by the occupants at the same time as the experimental measurements were performed. Subjective measurements contained basic questions about the occupants, their behavior at workstation, sick building syndrome symptoms, occupant´s perception, thermal comfort – local and overall discomfort, clothing and notes from occupants. Questionnaire contains 26 questions in total.

- *Questionnaires for summer period:*

Employees were addressed in two cases. In one case, questionnaires were sent by an authorized employee of the relevant department to the greatest number of employees located on the 3rd floor. The second case was addressed during one of the hottest days of the measurement period when the outside temperature reached pleasant $t_e = 26$ °C.

It should be emphasized that the survey is a purely voluntary act of an individual and it corresponds to the back number of returned and completed questionnaires (about 25 % in summer).

- *Questionnaires for winter period:*

Occupants were addressed in two cases. In one case, questionnaires were sent by an authorized employee of the relevant department to the greatest number of employees located on the 3rd floor (after date 19.2. 2015 to the 4th floor as well). The second case was addressed during measurements by paper form near the measurements points. Return percentage of questionnaires was better than previous period – about 40 %.

4. Perception results of occupants

In what follows, we present the results of the perception too hot or too low temperature, overall thermal sensation and intensive feeling of cold on body part of occupants during summer and winter period.

- *Summer period (August/September 2014):*

Questionnaires were distributed to individual workers who were sitting near the measuring 8 points and handed out 22 questionnaires from 18 of

them were returned filled (the second case described in chapter 3). The following paragraphs latter questionnaires evaluated for a preliminary assessment of the problem in the surveyed area. The questionnaires were filled at the beginning of September 2014 with outside temperature t_e = 22 to 26 °C.

Graph 1 and *Graph 2* summarize the occupants' answers to the question "Have you been bothered during the last month by any of the following factors at your workplace? *Graph 1* shows results for bothering factor – "The room temperature too low" and *Graph 2* shows results for bothering factor – "The room temperature too high". The possible answers were "No, never; Yes, sometimes; Yes, often (every week); Yes, daily". In sum 41 % of the respondents did not experience too high temperature and 5 % too low temperature during that last month. Although it is summer time, these results indicate that people felt cold at workplace (represented by a high percentage of answers: "yes, with postscript" in *Graph 1*).

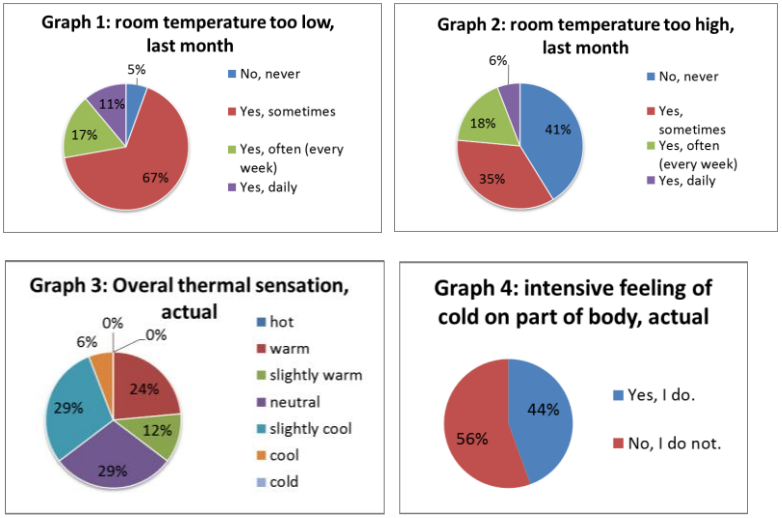

Fig. 3 Summer period. The *Graph 1* and *Graph 2* – Subjective evaluation of the room temperature in the last month on workstation; *Graph 3* and *Graph 4* – Actual subjective feeling of overal thermal sensation and discomfort on a part of body

Graph 3 shows the occupants' answer to the question: "Please, rate your overall thermal sensation (your body thermal sensation). How do you feel in this moment?" As a tool for evaluation by respondents a range of thermal sensations was used [8]. The greatest percentage is neutral and slightly cool feeling. There are not observed extremes of very high or very low temperatures.

Graph 4 summarizes the occupants' answer to the question: "Do you feel any intensive feeling of cold on any of your body part, now?" Even though, it was a summer period during the measurements, the results show that the occupants felt cold indoors. The question about local discomfort revealed 44 % intensive cold feelings on occupants' bodies.

- *Winter period (February 2015):*

The following processed results survey shows the response of 39 workers on the third floor who completed the questionnaire in the period from 17.2. – 19.2.2015 when outside temperature ranged from 0 °C to 4 °C.

For comparison, we have left the same questions as above. *Graph 5* (the same question like in *Graph 1*) shows lower number of experienced cold temperature. As we can see a quarter of respondents did not feel any bothered low temperature. On the other hand, 23 % respondents answered that they felt every week too low temperature which it is little more than in summer time. Around half of occupants did not feel too high temperature in space (*Graph 6*).

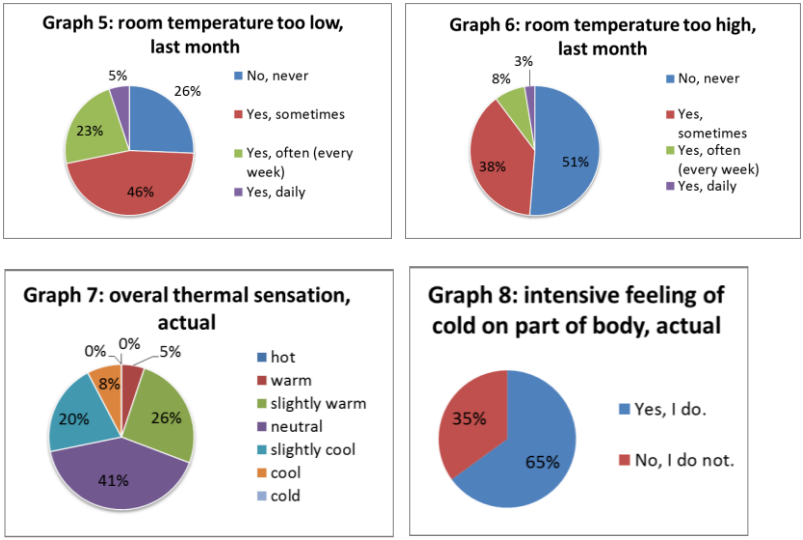

Fig. 4 Winter period. The *Graph 5* and *Graph 6* – Subjective evaluation of the room temperature in the last month on workstation; *Graph 7* and *Graph 8* – Actual subjective feeling of overal thermal sensation and discomfort on a part of body

The greatest percentage is neutral and slightly warm feeling in *Graph 7*. There are not observed extremes of very high or very low temperatures.

Interesting results show *Graph 8* where we can see 65 % answers of intensive cold feelings on occupants' parties of bodies.

These primary subjective measurement results will continue to be analyzed and then compared with the objective measurements in future work.

5. Discussion

Primary results of the subjective measurements of occupant's groups have shown problems with thermal comfort of the occupants. Even though, in the case of summer period, the results show that the occupants felt cold indoors. Moreover, occupants have had comments in the field of their thermal comfort, as: a) bothered by cold air on the body parts – neck, shoulders, hands, sometimes ankles (in relation with *Graph 4* and *8*), b) bothered by cold air "falls" from ceiling (from ventilation system), c) worse situation at mornings with temperature – during day it become more stabilized. Their comments also indicate that cold is annoying, especially in the summer when occupants have to wear warmer dress during their stay in office.

In spite of complains from occupants, it can be stated, that cooling system reacts well. Cooling system switches on when 24 °C is reached (summer period). However, the chilled beams regulation of each section, it seems to be unfavourable. One of the eight regulation section supplies cooling and fresh air for approx. 40 people.

As active chilled beams are normally mounted overhead, the neck region is usually the most critical. Comfort cooling applications should strive to minimize dissatisfaction levels, and in all cases limit the percentage of occupants objecting to these local conditions to 20% or less. [9]

To achieve high percentage of thermal satisfaction of occupants in space equipped by chilled beams systems is not easy task. Airflow and temperature zone are constant and it is not possible to change them (with respect to a fixed slots of exhaust air of induction units). If there is a feeling of discomfort (for example in the case bothering airflow) is better to relocate the person than try to solve it in other way [10].

In this case, the chilled beams system is controlled by sensors which can be influenced by bad installation in space e.g. in corridor or covering by furniture, etc. Between those sections (Fig. 2) there are significant differences. But surely, the role plays another several factors, e.g. annoying airflow, also often mentioned by occupants.

6. Conclusion

The microclimate hygrothermal survey in reconstructed building with open-plan offices was performed. The thermal discomfort was reported by the occupants. Results of the study show respondents' subjective perceptions. Problems were found in both measurement periods, mainly in the case of cool feeling - overall and local discomfort. Next of the observed problems has been proved to be in covering by furniture of the sensors and radiators, inappropriately designing of cooling sections of chilled beams and insufficient supply of fresh air for return to the work after weekend days.

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