THERMAL COMFORT ANALYSIS IN OFFICE BUILDINGS WITH DIFFERENT AIR-CONDITIONING SYSTEMS

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It is a prime aim to ensure a suitable comfort level in case of office buildings. The productivity of office employees is directly influenced by the comfort. Thermal discomfort and poor indoor air quality deteriorate the intensity and quality of human work. We investigated the comfort in office buildings with on-site measurements during the summer season. The office buildings were operating with different HVAC (Heating, Ventilating and Air-Conditioning) systems: ducted fan-coil with suspended ceiling, installation, non-ducted fan-coil with floor-mounted installation, active chilled beam with fresh air supply.

We evaluated the thermal comfort under *PMV* (Predicted Mean Vote), *PPD* (Predicted Percentage of Dissatisfied), the local discomfort based on *DR* (Draught Rate) and the *IAQ* (Indoor Air Quality) based on carbon dioxide concentration. The comfort measurements were evaluated. The measurements were evaluated with scientific research methods, comfort categories based on the requirements of CR 1752. The results of this comparison were presented in this article.

Keywords: thermal comfort, *PMV*, *PPD*, carbon dioxide concentration, draft rate

1. Introduction

Fourty percent of the total energy consumption is generated by the energy consumption of buildings. With-in this, air conditioning represents a significant proportion. There is a need to reduce energy consumption and increase comfort at the same time [1, 2]. The thermal sensation may play an important role especially in office buildings because thermal discomfort deteriorates human productivity [3, 4]. Reducing the energy consumption cannot be at the expense of comfort, so it is a task to continuously control the comfort according to international practice [5, 6]. The comfort of the air-conditioned spaces can be characterised by the measurement and evaluation of the interior air state characteristics.

Continuous measurement requires a programmed measuring and data logger system. For the data processing and evaluation we developed a new measuring system assembly and a personally developed compu-

tational program. Parameters can be evaluated based on probability theory as discrete random variables. The rating of comfort according to comfort categories (CR 1752, EN 15251) is based on the 95% confidence range of the measured and calculated values.

On-site measurements were carried out in several office buildings, we evaluated comfort according to comfort categories. The tests were carried out in different spaces with different-air conditioning systems:

- ducted fan-coil with suspended ceiling installation,
- non-ducted fan-coil with floor-mounted installation,
- active chilled beam.

The air-conditioning systems of office buildings have already been adjusted and commissioned.

In this article we present the measurement method, evaluation methodology and the results obtained with each air-conditioning system.

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2. Methods

2.1. Measurement

On-site measurements were carried out in three office buildings with different HVAC systems: ducted fan-coil with suspended ceiling installation, non-ducted fan-coil with floor-mounted installation and active chilled beam system. The series of measurements were made in the summer period, which is critical for comfort and air-conditioning [5–7]. The measured physical characteristics and their sampling frequency are shown in Table 1.

Eight–twelve units of measuring rods with air temperature and humidity instruments and data loggers were installed in the office building. To measure the turbulence and the draught rate, two instrument clusters were assembled to provide the air velocity measurement for the required frequency (2 seconds) and the air velocity range (0.01–0.25 m/s) in the occupied zones. Every 3–5 days the measuring systems have been installed in different oriented single and landscaped offices. A well-founded evaluation could be carried out based on the results of 2–4 weeks of measurement in a building. It is apparent that 120,000–160,000 data had to be received, stored, processed and evaluated daily according to the data of Table 1.

2.2. Evaluation

Each characteristic of the thermal comfort in the enclosed space (air temperature, humidity, mean radiation temperature, mean air velocity, turbulence intensity) is probability variable. Their value can be characterised corresponding to mean value, standard deviation, confidence interval, etc. *PMV*, *PPD*, *Tu* and *DR* parameters have been used for the assessment of comfort applied in international practice [8–10]. We can

obtain a representative quantitative image of the given comfort space by determining the statistical characteristics after evaluating the measured data of comfort assessments. The measurement results were processed and evaluated based on the 95% confidence interval, comparing the requirements of comfort categories (in this case the CR 1752) [11, 12]. We have developed a theoretical model and a software tool for the comfort analysis to the efficient and quick execution of the calculation algorithm [13–15].

3. Results

3.1. Thermal comfort (Fig. 1)

From the thermal comfort point of view, the best result was given by the ducted fan-coil with suspended ceiling installation system (category “>C” 11.1%), while the least favoured result was given by the non-ducted fan-coil with floor-mounted installation system (category “>C” 55.6%).

3.2. Draught rate (Fig. 2)

From the draught rate point of view, the best result was given by the active chilled beam system (category “A” 90.3%).

3.3. Air temperature (Fig. 3)

From the air temperature point of view, the best result was given by the active chilled beam system (category “A” 38.6%).

3.4. Carbon dioxide concentration (Fig. 4)

From the thermal comfort point of view all systems achieved a very high level of comfort. The results for the category “A” were 73.7%–100%.

Table 1. The measured parameters

Measured parameter		Sign	Sampling frequency
Air temperature		t_a	5 min
Globe temperature		t_g	5 min
Relative humidity		f	5 min
Air velocity		v_a	2 sec
Carbon dioxide concentration		c_{CO_2}	5 min
Chilled beam / fan-coil	Entering – cooling water temperature	t_{we}	5 min
	Leaving – cooling water temperature	t_{wl}	5 min
Air handling unit	Supply air temperature	t_{sa}	5 min
	Leaving – cooling water temperature	$t_{wl/AHU}$	5 min

Fig. 1. The category distribution of thermal comfort measurements

Fig. 2. The category distribution of draught rate measurements

Fig. 3. The category distribution of air temperature measurements

4. Conclusions

Based on the results obtained, it is possible to assess the comfort parameters according to the individual categories. We can draw the following conclusions from the comfort parameters point of view:

- It is most difficult to ensure the highest level of category “A” expectations from the thermal comfort point of view (category “A” 0.0%–22.2%).
- More favourable situation in terms of the air temperature (category “A” 7.1%–37.4%).

Fig. 4. The category distribution of carbon dioxide concentration measurements

- The results are even better in case of draught rate (category “A” 72.2%–90.3%).
- Comfort studies have shown that considerably better comfort categories for carbon dioxide concentrations (category “A” 73.7%–100%) can be achieved, such as thermal comfort, draught rate and air temperature. The differences between the individual systems are also small. This is due to the fact that the carbon dioxide concentration depends essentially on the amount of fresh air, less on the type of air-conditioning system (if the proper air handling system is in the comfort room). The fresh air rate was 40–45 m³/h in the buildings.

It is also possible to evaluate the types of air-conditioning systems based on the results obtained. The climate control system can provide the best comfort for the draught rate and the air temperature. The design and implementation of the chilled beam system is a more complex task, the design of the cooling system differs from conventional fan-coil systems [16, 17].

The results of measurements gave assistance to the planning and can help to improve the regulation of HVAC (Heating, Ventilating and Air-Conditioning) systems.

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