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SCIENCE DIRECT®
Building and Environment 40 (2005) 29–37
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

A global approach of indoor environment in an air-conditioned office room

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Received 6 January 2003; received in revised form 20 February 2004; accepted 20 May 2004

Abstract

This study presents a multi-criteria method used for analysing the quality of an air-conditioned indoor environment. Indoor air flow induced by an actual Heating Ventilation and Air Conditioning system was experimentally studied under various conditions. The attention was focused on thermal comfort, acoustical comfort and indoor air distribution by considering spatial statistic studies of comfort indices. The compounded electric power of fan, compressor and pumps was measured in order to get information about energy consumption. A first analysis of these parameters showed that indoor comfort cannot be described by a general law. Thus, to reach the objective of a global approach of comfort by a spatial statistical study of the various discomforts, a multi-criteria analysis based on ELECTRE II method adapted to the comfort of air-conditioned indoor environment was applied. In this way the operating rules for coherent air conditioning systems can be defined, with a requirement for quality of indoor environment.

Keywords: Thermal comfort; Acoustical comfort; Air-conditioned; Building; Multi-criteria analysis

1. Introduction

Since 1973 and the first fuel shortage, the French government has conducted actions for a reduction of building energy consumption. First, building actors worked on insulation, then on equipment energy consumption reduction. In the last 10 years, the CIAT laboratory staff has been working on indoor environment quality in accordance with the European and international preoccupations. Fanger [1] showed that the occupants of offices are submitted to various local discomforts, due to temperature, draft and noise. In order to improve comfort, different types of HVAC systems can be applied. Rutman [2] carried out an experimental work to link the cold air jet characteristics and a global approach of comfort, which takes into account thermal and acoustical comforts. Furthermore, Rutman et al. [3] showed that the comfort criteria such as the PPD, DR, NR and ADPI indices do not vary in the same way with Archimede's number as reference. Thus, PPD index and ADPI index increase as NR level and DR index decrease. Lastly, they pointed out the difficulties of improving local comfort with occupants. In another way, many building designers use the multi-criteria analysis in their results [4] and some authors [5,6] have started using these tools to improve the ventilation of buildings. That is why, a multi-criteria method has been used to analyse the experimental results in this study.

2. Methodology and test conditions

The measurements [2] were carried out in the CIAT's laboratory located in Culoz, France. The longitudinal section of the experimental test chamber is shown in Fig. 1. The volume was equal to $5.2 \times 4.0 \times 2.5\,m^3$

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doi:10.1016/j.buildenv.2004.05.006

Nomenclature

A_0	supply area, m^2
ADPI	Air Diffusion Performance Index
a_{ij}	actions with $i =$ unit 1 or unit 2 and $j = 1, 2, 3, 4, 5$ or 6
Ar_0	inlet Archimede's number
C_{AC1}	acoustical criteria No. 1
C_{AC2}	acoustical criteria No. 2
C_{AI}	air diffusion performance criteria
C_{EC}	economical criteria
c_k	concordance indices ($k = 1, 2$ or 3)
C_{max}	maximum of concordance indices
C_{min}	minimum of concordance indices
C_{moy}	average of concordance indices
C_{TH1}	thermal criteria No. 1 for the DR
C_{TH2}	thermal criteria No. 2 for the DR
C_{TH3}	thermal criteria No. 3 for the DR
C_{TH4}	thermal criteria No. 1 for the PPD
C_{TH5}	thermal criteria No. 2 for the PPD
d_k	discordance indices ($k = 1$ or 2)
DR	draft rating
I	incomparability
L_T	thermal length, m
lo	low outclass
NR	noise rating
Pe	electrical power, W
PPD	predicted percentage of dissatisfied, %
Q_0	air flow rate, $m^3\,h^{-1}$
Re_0	initial Reynolds number
SO	strong outclass
T_0	inlet air temperature, °C
ΔT_0	inlet excess temperature, °C
U_0	inlet air velocity, $m\,s^{-1}$

Greek letters

μ	viscosity, $kg\,m^{-1}\,s^{-1}$
ρ	density, $kg\,m^{-3}$

bounded on five sides by air volume controlled at a constant temperature level. The sixth side is submitted to the influence of a climatic housing, where external air temperature can be simulated. For the present experiments, the value of external temperature was set at +30 °C. Real internal heat loads were simulated with a computer and two dummies. These thermal heat loads were balanced by a fan-coil unit mounted on the ceiling. Two fan-coil units, unit 1 and unit 2, were tested as shown in Figs. 1 and 2. For each unit, six tests with various supply conditions were carried out including two mechanical configurations of the fan-coil unit. For unit 1, the air jet had one supply direction (mechanical parameter 1) or three directions for the airflow (mechanical parameter 2). For unit 2, the direction of the jet was toward the ceiling (mechanical parameter 1) then toward the floor (mechanical parameter 2). In all the tests, the cold water temperature level was constant (6 °C/12 °C) and it was possible to select five air flow rates. In order to study the overall band of the air flow rate, the tests were carried out with three air flow rate values (low, medium and high) and the two mechanical parameters for each unit. For all the tests, the operative temperature in the occupied zone was equal to 24.5 ± 1.5 °C. Tables 1 and 2 give the parameters used for the experiments. The air velocity, the relative intensity of velocity turbulence, and temperature in the occupied zone of the room were measured with a thermoanemometric sensor (type DANTEC 54T21) placed at 76 different locations in the occupied zone. Vertical test points were located from the floor at 0.1 m for the feet, 0.6 m for the hips, 1.1 m for the head of an occupant in the sitting position and 1.7 m for the head of an occupant standing up [7]. This probe calibrated by DANTEC, is characterized by a precision of ±0.02 m/s for the air velocity and ±0.2 °C for the air temperature. The inner wall surface temperatures were measured with thermocouples type *K* calibrated with a precision of ±0.25 °C at the CIAT laboratory. The acoustical level was measured with a microphone sensor with a precision of ±3 dB type Bruel & Kjaer 4189 and a frequency analyser type Kontron FFT-AD3524. To calibrate the microphone, a pistonphone type Bruel & Kjaer 4231 was used. For the acoustical measurements, the probe was placed at 36 different locations in the occupied zone.

Archimede's number, $Ar_0 = g\beta\Delta T_0 A_0^{0.5}/U_0^2$, Reynolds number $Re_0 = \rho U_0 A_0^{0.5}/\mu$ and thermal length $L_T = (A_0/Ar_0)^{0.5}$ [8] define the supply conditions. The square root of the supply area A_0 was used because the ratio effective length (l_0)/effective width (h_0) is equal to 13 for unit 1 and more than 4 for unit 2. So in accordance with Rajaratnam [9], these values are characteristic of a three-dimensional jet. The mean value of the inlet temperature T_0 was measured with a Newport Omega, 0.051 mm diameter, *K*-type thermocouple calibrated with a precision of ±0.25 °C at the CIAT laboratory. For the velocity U_0, a Dantec laser doppler anemometer unidirectional system was used.

3. Experimental test results

The main results presented here consist in the spatial statistical studies of comfort indices and energy consumption.