Loading strategy for measuring relative humidity and temperature gradient for winter season in ventilated classrooms

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Abstract: - The loading strategy presented in the paper wants to present the relative humidity and air gradient temperature for classrooms simulated in laboratory conditions. The study will take place only for winter season; the air humidity will be increased with an electrical steam humidifier and the air temperature by the heating coil of the air handling unit. The supplied air is provided with an air handling and swirl diffusers with adjustable blades for a better distribution in the room. For exhaust is used one ventilator, matching the supplied air flow by the air handling unit. The thermal comfort sensation will be evaluated by questionnaires filled out by occupants for winter time in sessions of three hours and analytic calculation based on SR EN ISO 7730 (2006) .

Key-Words: - relative humidity, air gradient temperature, mixing ventilation, operative temperature, supply, exhaust, velocity

1 Introduction

The indoor air quality in classrooms it's an important factor for the thermal sensation and acceptability for the occupants. The parameters that define the indoor air quality are: dry air temperature, air velocity in the room, turbulence intensity, relative humidity, the mean air temperature, the occupant activity, and the cloth thermal resistance.

Also the indoor parameter depends on the exterior parameters as: dry air temperature, outdoor humidity, atmospheric pressure and the velocity of the wind. It's very hard to define a general indoor environment because the judges are different from people to people and as we know, not everybody perceive these parameters the same way.

The ASHRAE standard 55 (2003) [1], CR 1752 (1998) [2] and SR EN ISO 7730 (2006) [3] indicated a range for the comfort zone where the occupant is considered as a passive subject of thermal exchange.

The predicted mean vote can be calculated, but also made with test fill by the occupants regarding the general thermal comfort. The occupied zone is in the centre of the room. For sedentary occupants the measurement sensors are on three levels: knees 0,1 meter; abdomen 0,6 meter and head 1,1 meter.

Aim of the paper is the evaluation of thermal comfort condition in university classrooms for winter season for heating with static radiators, mixing ventilation with recirculation and with 100% fresh air.

The temperature and relative humidity will be set for simulating different ambient conditions which will be measured by sensors and evaluated by occupants with questionnaires.

2 Literature review

The experimental measurement in university classrooms (3 classrooms) with ventilation systems was reported in research work [5] where the thermal-hygrometry comfort where the data measurements where made in 2, 3, 4 points depending on the classroom size. The inside parameters measured were: dry bulb temperature, wet bulb temperature, air velocity, globe thermometer temperature, atmospheric pressure, air temperature at the neck (1,10 m from floor), floor temperature, radiant asymmetric temperature, carbon dioxide concentration CO_2. The outside parameters were: air temperature, relative humidity, atmospheric pressure and carbon dioxide concentration CO_2 . With these measured parameters mentioned were calculated : relative humidity, mean radiant temperature, operative temperature, PMV(predicted mean vote), PPD(Predicted Percentage of Dissatisfied), turbulence intensity, PPD for thermal gradient, PPD for floor temperature, PPD for radiant asymmetry and PPD for current of air. The occupants from classrooms were men and women.

The adaptation from the occupants was behavioural, physiological and psychological. Also is a difference between men and women perception regarding the thermal comfort, because women have a lower metabolism and the hotter environment is accept better like men.

Environment was analyzed by these criteria:

- Thermal sensation;
- Comfort;
- Thermal preference;
- Acceptability;
- Tolerability;
- Individual microclimate control;
- Satisfaction of individual control;

Classrooms without windows produce also dissatisfaction. Another environmental problem was the low air movement and the occupant related a dissatisfaction regarding the vertical gradient. Also if the air velocity in the room is to high the percent of dissatisfaction increases presented in figure 1.

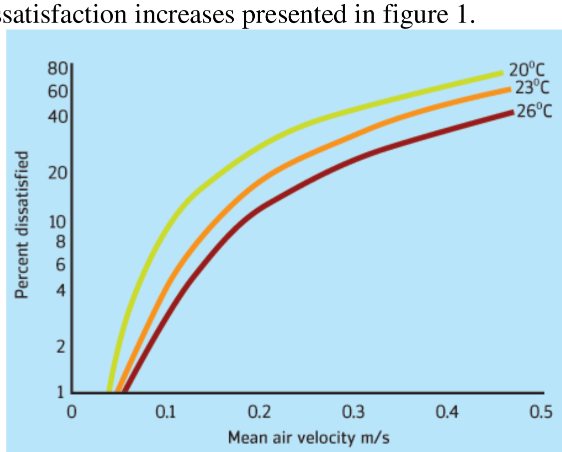

Fig.1: Dissatisfaction caused by room velocity

In the figure 2 is presented the evolution between dry bulb temperature and relative humidity from classrooms for average values measured [5] :

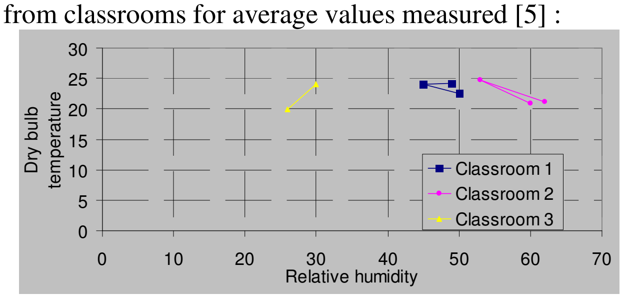

Fig.2: evolution between dry bulb temperature and relative humidity

From research work in offices [8] low relative humidity like 15% produce uncomfortably dry air and symptoms of the face and mucous membranes compared to 43% r.h. The humidification of dry air reduces the number of these symptoms, and reduces discomfort arising from low air humidity.

In figure 3,4,5 are presented the effect of temperature, dryness of air and draught for 39 office workers.

Also the relative humidity should not exceed 60% in order to avoid bacteria growth in ventilation ducts. Reinikainen et al [9] found that humidification of 30-40% r.h. reduced the number of complains of dryness of the skin and eyes compared to 20-30%.

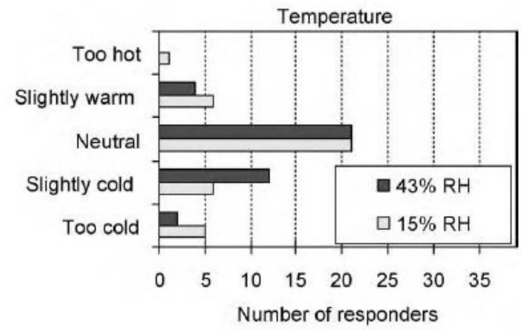

Fig. 3 Sensation of air temperature for low humidity (15%) and normal humidity(43%)

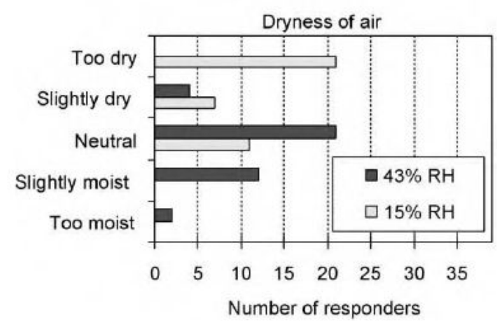

Fig. 4 Sensation of air dryness for low humidity (15%) and normal humidity(43%)

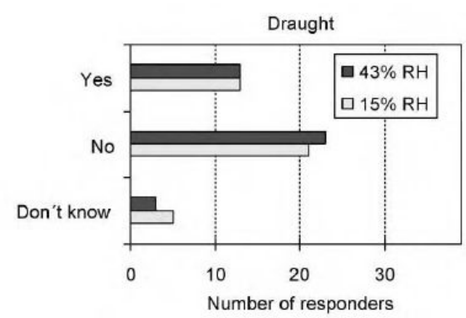

Fig. 5 Sensation of draught for low humidity(15%) and normal humidity(43%)

3 Problem Formulation

The space has 47 m^2 and a volume of 178 m^3 and the number of occupants is 12. The fresh air supply must be in accordance with CR 1752 (1998) for occupancy of 0.5 persons/m^2 is 6 $l/s{\cdot}m^2$. We had half of the occupancy number recommended by CR 1752 and with interpolation it result 3 l/sxm^2, and in the room the smoke was not allowed:

$$q_{fa} = 47 \cdot 3 = 141 \frac{l}{s} = 507{,}6 \frac{m^3}{h} \qquad (1)$$

The space is placed at the ground level surrounded by other classrooms witch are heated. The heat demands of the room for winter is 2.65 kW calculated for Timişoara at -15°C. For the study the mixed ventilation air flow used is q_{SUP}=1350 m^3/h corresponding to 7.5 h^{-1} necessary for heating up the room.

For setting the mentioned air flow of the air handling unit it will be use an adjustable frequency drive unit. The supplied air flow can be calculated with the formula:

$$q_{SUP} = \frac{Q}{\rho \cdot c_p \cdot (t_{SUP} - t_i)} \times 3600 \qquad (2)$$

where:

q_{SUP} - Flow rate of supply air [m^3/h];
Q - Heat demand [kW];
ρ - Density of air [kg/m^3];
t_{SUP} - Supply temperature [°C];
t_i - Room temperature [°C];

The fresh air quantity must be provided for the occupants comfort and it is recommended that the rest of air to be recirculation for saving heating energy.

The draught in the room is determined by the average velocity $v_a(x,t)$ at a x position and t time and the turbulence intensity (Tu) . The instantaneous velocity at a moment i is composed of a mean velocity $\overline{v}_i$ and fluctuating component, v'_i:

$$DR = (34 - t_i) \cdot (v_a - 0{,}05)^{0{,}62} \cdot (0{,}37 \cdot v_a \cdot T_u + 3{,}14) \qquad (3)$$

$$v_a = \overline{v}_i + v'_i \qquad (4)$$

The temperature distribution in the room was studied by Cox and Elkhuizen [6] which defined the temperature effectivity depending on the temperature of exhaust, supply and at a point x in the room as:

$$E_T = \frac{(t_{ex} - t_{sup})}{(t_x - t_{sup})} \qquad (5)$$

t_{ex} – Exhaust temperature [ºC];
t_{sup} – Supply temperature [ºC];
t_x – Temperature at x point [ºC];

The vertical temperature gradient is determined by the heat load in the room, the air change rate and the diffusion flow.

Figures 6 and 7 shows the classroom in 3D view and top view with the ventilation system where the fresh and recirculated air is treated by the air handling unit and it's supplied by 4 ceiling diffusers with plenum box in the room. The diffusers are swirl type permitting the possibility to have horizontal and vertical jet patterns. The exhaust is made by a roof fan mounted outside. On the exhaust pipe are mounted two duct grills.

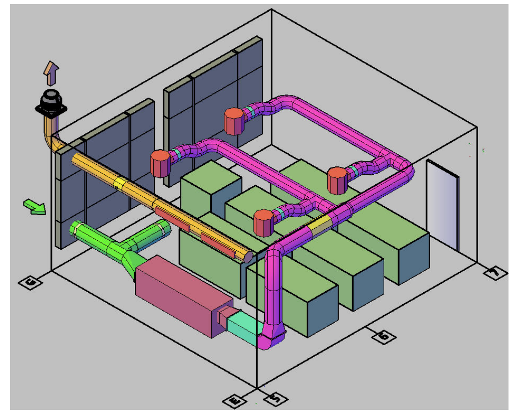

Fig.6 3D view of the ventilation system for the laboratory (exhaust and supply)

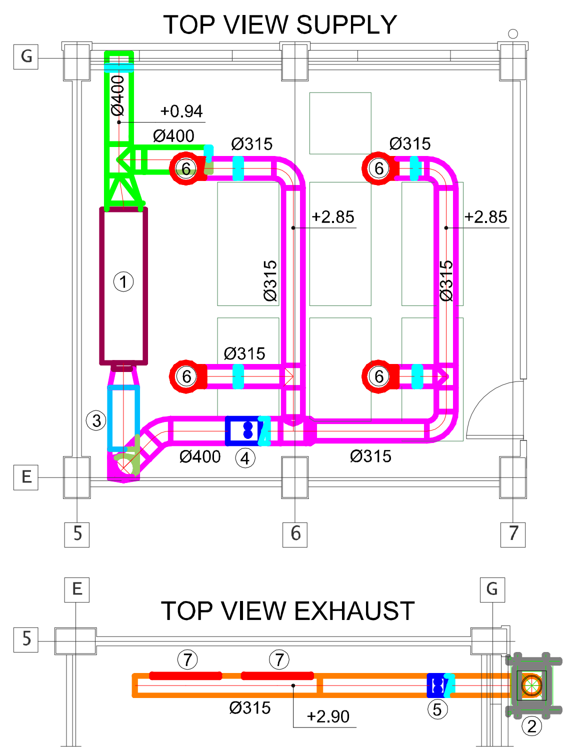

Fig.7 Top view of the ventilation system for the laboratory (exhaust and supply)

Legend: 1- Air handling unit with fresh and recirculated air, q_{supply}=1350m^3/h; 2- Exhaust roof ventilator, $q_{exhaust}$=1350m^3/h; 3- Electrode steam humidifier, steam output q_{steam}=10kg/h; 4- Damper with flow meter for supply; 5- Damper with flow meter for exhaust; 6- Supply swirl diffuser with adjustable blades for changing air pattern; 7- exhaust duct grille

The operative temperature shall apply to a location in the centre of the room at a height of 0,6 m above the floor.

The mean room temperature specified by CR 1752 for classrooms is 22±3°C, but ASHRAE (1992) limit the minimum operative temperature at 18°C.

$$t_o = \frac{t_i \cdot \sqrt{10 \cdot v_a} + t_{mr}}{1 + \sqrt{10 \cdot v_a}}; \qquad (6)$$

Where:
t_o – Operative temperature [ºC];
t_i – Indoor temperature [ºC];
v_a – Ambient velocity [m/s];

The questionnaires for the occupants (men and women) have contained the following questions regarding the thermal comfort sensation:

- Occupant clothing type(clothing ensembles)
- Occupant activity level
- Predicted mean vote(PMV)
- The occupant location in the classroom

The calculation of PMV(predicted mean vote) will be made by filling the measured values from the classroom needed to be substituted in the analytic formula and after compared with the results from the questionnaires.

4 Loading strategy

The study was conducted during the heating period(January-April) in a laboratory from the university with controlled indoor climate. The indoor temperature used for the measurements will between 20°C and 28°C and the indoor relative humidity will be set from 20% to 50% with a humidity sensor which commands the steam humidifier. For every temperature step will be four measurement with relative humidity increased with 10%. These measurements will be made on recirculated air and 100% fresh air.

The duration of a measurement it's from 1 to 3 hours.

Also the temperature of the walls, ceiling and floor will be measured with an infrared camera for verifying the values measured by the black globe-thermometer.

The steam humidifier maximum steam output is 10 kg/h which is set by the desired indoor relative humidity.

The air temperature and relative humidity in the room will be measured in the room in fifteen points disposed at three levels. The mean radiant temperature and the velocity will be measured in the middle of the room at 0,6 m.

The measuring points will be chose considering the position of students, the position of cold and warm surfaces (i.e. windows - minimum 1 meter distance from them [7], laboratory equipment). The measurement will be made for mixing ventilation with recirculated air, with 100% fresh air and heating provided by static radiators without ventilation.

The fresh air and recirculated is heated up till the desired supply air temperature with a heating coil placed in the air handling unit. The hot water which pass through the coil is provided by the central heating system of the school and the hot water temperature is set by a 3 way valve with servomotor which mixes the water for the desired temperature. This temperature is influenced by the exterior parameters like dry bulb temperature and relative humidity of the air which are also measured.

The indoor measured values will be:

- dry bulb temperature [°C];
- relative humidity [%];
- air velocity in the classroom [m/s];
- mean radiant temperature [°C];
- ceiling, wall and floor temperature
- CO_2 concentration

The outdoor measured values will be:

- dry bulb temperature [°C];
- relative humidity [%];

5 Conclusion

The measuring strategy in this paper respects the evaluation procedure of thermal moderate environments currently in use. The questionnaires will be filled by the occupants and compared with the ones from experimental measurements to give an image about the value of PMV.

The dimension of the laboratory simulates at small scale a classroom from our university. The classrooms from the university have only static radiators without ventilation that's why it will be made a comparison between the two systems and evaluated by the occupants.

Also very important is the vertical gradient because in research work [5] the air velocity in the classroom was to low and this problem occurred. Because in the classroom are measuring points on different heights it can be measure the vertical gradient and calculate the effectiveness of the ventilation system.

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