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Occupant Satisfaction and Ventilation Strategy - a case study of 20 public buildings

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Summary: Occupant response in a good indicator of the effectiveness of a ventilation system. In a one-year study in the province of Quebec region, 20 public buildings were studied. Occupants were asked to answer questions on their perception of their environment and the ventilation at their workstation. Annual energy consumption for each building was recorded. The ventilation systems were studied as well as their rates; minimum outdoor air rates and average total air rates, at each workstation and at the ventilation system. Ventilation rates were plotted against energy consumption. Occupant satisfaction was plotted against ventilation rate and against energy consumption. It was found that as outdoor air rates at the work stations increased, the occupants perceived a better indoor air quality, a better ventilation, and a more constant ventilation frequency above 70 l/s/p. No trend was found from their perception of the air movement. As the total air supplied at the diffusers increased, the occupants perceived a better indoor air quality, a better ventilation, and a more constant ventilation frequency above 110 l/s/p. However, all these perceptions decreased to the original values above 130 l/s/p. No trend was found from their perception of the air movement. As the total air flow rates at the ventilation system increased, the occupants perceived a better indoor air quality, a better ventilation, a more constant ventilation frequency, and a better air movement above 200 l/s/p. However, all these perceptions decreased to the original values above 250 l/s/p. As the ventilation efficiency at the workstations increased from 27 to 70%, the occupants perceived a poor indoor air quality, an insufficient ventilation, and an irregular ventilation frequency above 25%. No trend was found from their perception of the air movement. As the maximum carbon dioxide concentration at the work place increased, the occupants perceived a worst indoor air quality above 800 ppm of CO_2, a worst air movement above 1000 ppm. The ventilation strategy resulting in the best perception from the occupants was of the type free cooling, with variable outdoor air supply, variable total air supply, and constant supply temperature.

TITLE: OCCUPANT SATISFACTION AND VENTILATION STRATEGY- A CASE STUDY OF 20 PUBLIC BUILDINGS

Introduction:

The occupant perception of the Indoor Air Quality and the Ventilation in 20 public buildings was sought through a survey by a building owner of 1500 commercial buildings in Canada. McGill University and ADN Inc. conducted this research whose objective is to seek which ventilation strategy satisfies best the majority of occupants. Twenty buildings were selected from across the province of Quebec, half from the cities of Montreal and Quebec, half in the countryside. The oldest building is 62 years old and the newest 6 years old. The tallest office building has 21 floors, the smallest 2 floors. There are a total of 8000 office workers in these 20 buildings that cover 350 000 m^2.

Methodology:

During the coldest months of winter 1991-1992 when fresh air rate was at its minimum rate, the field investigation was conducted by McGill University PhD students at 850 workstations (one out of 10 office workers) chosen by random to represent the building structure (perimeter and core), the office organizations (open plan versus closed offices) and the occupant population (temporary versus permanent workers, union versus management, female versus male, old versus young). At each workstation, a series of measurements was taken:

ventilation : fresh air ventilation rates (by decay of SF_6 tracer gas method) and total air rates (by balometer);

- contaminants: carbon monoxide, carbon dioxide (by direct reading infra-red instruments), formaldehyde, ozone, volatile organic compounds and total dust (the latter four contaminants were collected on appropriate media by sampling pumps following NIOSH official methods; the media was them analyzed in the chemical laboratory of McGill University by chromatography for chemicals and gravimetry for total dust);

- thermal parameters: ambient temperature, relative humidity, vertical gradient temperature, horizontal radiant temperature asymmetry and draft velocity (all these parameters were measured following the ASHRAE Standard 55-1981 specifications);

While a team of researchers was measuring at the workstations, a questionnaire was distributed to all the occupants of the buildings who were asked to answer the questions on the same day. The questionnaires were collected on the same day as the physical measurements.

Results and Discussion:

Indoor Air Quality: Results show that a two third majority of the occupant population was unsatisfied with the indoor air quality although most of the contaminant levels were below the recommended strict limits set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (standard 62-1989). The only contaminant that has relatively high concentrations is the Total Volatile Organic Compounds (or TVOC). The average measured TVOC concentration of 5000 $\mu g/m^3$ is in the discomfort range (3000 - 25000 $\mu g/m^3$) as defined by Dr.Molhave (3) in the European guidelines for Ventilation Requirements in Buildings (4). The TVOC concentrations may thus explain the high levels of dissatisfaction. Some TVOC measured values are in the toxic range (> 25000 $\mu g/m^3$) and are due to a single source: wet process photocopiers.

Thermal comfort: Occupant perception was very different from measured values. Average ambient temperature of 22.5 °C only satisfied 46% of the people, and for an average relative humidity of 37%, there was only 31% of satisfaction. And 60% of the occupants qualify the 0.09 m/s mean air speed as stagnant. Most of the measured values were within the ASHRAE standard 55-1981 and should satisfy 80% of the occupants. Analysis of the occupant responses show that it is not the actual measured values that are unsatisfactory but the variability of the thermal parameters. Humidity levels for example can vary from 5 to 35% within one day and temperature may jump from 20 to 26 °C in a few hours.

Occupant perception of Indoor Air Quality and Ventilation:

Questionnaire responses -- general: From the questionnaire responses, we notice that 44% of the occupants of all 20 buildings find the air ventilation to be insufficient, 45% of the occupants find it to be somewhat adequate, and 11% of the occupants find it to be adequate. In 6 of the 19 buildings, the questionnaire responses did not correspond to the measured data.

We also notice that 65% of the occupants are unsatisfied with the air quality, while 35% of the occupants are satisfied. In 2 of the 19 buildings, the questionnaire responses did not correspond to the measured data.

It was found 60% of the occupants find the frequency of ventilation to be irregular while 40% of the occupants find it to be constant.

Finally, 60% of the occupants found the air movement to be stagnant, 24% found the buildings had a good air movement, while 16% of the occupants found the air movement to be too drafty.

Outdoor air ventilation: We found that for 89 workstations tested, the mean outdoor air rate was 40 l/s/pers. The maximum outdoor air rate found was 375 l/s/pers while the minimum outdoor air rate was 1 l/s/pers (the standard deviation was 89 l/s/pers). For a confidence interval of 95% we found that the lowest value was 21 l/s/pers and that the highest value was 58 l/s/pers.

As the measured average outdoor air rate increased from 9 to 69 l/s/p, there was no change in responses from the occupants; they perceived the ventilation to be insufficient. The same phenomenon was noted when comparing the average measured outdoor air rate and the occupant perception of indoor air quality. They perceived the indoor air quality to be poor up until an outdoor air rate of 76 l/s/p. Their perception of the ventilation frequency also followed the same trend. The occupants felt the ventilation to be quite irregular with an outdoor air rate of less than 76 l/s/p. However, when comparing the occupants' perception of the air movement to the amount of outdoor air supplied, no trend was found.

Diffuser supply rate: We found that for 89 workstations tested, the mean diffuser supply rate was 80 l/s/pers and the standard deviation was 63 l/s/pers. For a confidence interval of 95% we found that the lowest value was 77 l/s/pers and that the highest value was 84 l/s/pers.

As the measured average diffuser supply rates increased from 31 to 111 l/s/pers , there was no change in the responses from the occupants; they perceived the indoor air quality to be poor. The same phenomenon was noted when comparing the average measured diffuser supply rates and the occupant perception of ventilation. They perceived the ventilation to be insufficient. Their perception of the ventilation frequency also followed the same trend. The occupants felt the ventilation to be insufficient. However, when comparing the occupants' perception of air movement to the average diffuser supply rate, no trend was found.

Total air flow: We found that for 89 workstations tested, the mean total air flow rates in the ventilation system was 123 l/s/pers and the standard deviation was 106 l/s/pers. For a confidence interval of 95% we fond that the lowest value was 102 l/s/pers and that the highest value was 144 l/s/pers.

As the measured average system supply rates increased from 11 to 194 l/s/pers, there was no change in responses from the occupants; they perceived the indoor air quality to be poor. The same phenomenon was noted when comparing the average measured supply rates and the occupants perception of ventilation. They perceived the ventilation to be unacceptable. The occupants felt the ventilation frequency to be irregular. However, when comparing the occupants' perception of the air movement to the average system supply rate, no trend was found.

Ventilation efficiency: We found that for 89 workstations tested, the mean ventilation efficiency at the workstations was 40% and the standard deviation was 20%. For a confidence interval of 95% we found that the lowest value was 37% and that the highest value was 43%.

As the measured average ventilation efficiency increased from 27 to 70%, there was no change in responses from the occupants; they perceived the indoor air quality to be unacceptable. The same phenomenon was noted when comparing the average ventilation efficiency measured and the occupants perception of ventilation They perceived the ventilation to be insufficient for an average ventilation efficiency between 27% to 70%. The occupants felt the ventilation to be quite irregular with an average ventilation efficiency higher than 27%. However, when comparing the occupants' perception of the air movement to the average ventilation frequency, no trend was found.

Carbon dioxide: We found that for 89 workstations tested, the mean arithmetic carbon dioxide concentration was 580 ppm and the standard deviation was 136 ppm. For a confidence interval of 95% we found that the lowest value was 575 ppm and that the highest value was 584 ppm.

As the measured maximum carbon dioxide concentration increased from 700 to 2200 ppm, there was no change in responses from the occupants; they perceived the indoor air quality to be poor. The same phenomenon was noted when comparing the maximum measured carbon dioxide concentration and the occupant perception of ventilation. They perceived the ventilation to be insufficient above 625 ppm. Their perception of the ventilation frequency also followed the same trend. The occupants felt the ventilation frequency to be irregular when the maximum carbon monoxide is higher than 625 ppm However, when comparing the occupants' perception of the air movement to the maximum carbon dioxide concentration, we noted that when the concentration of carbon dioxide is higher than 700 ppm the occupants perceived the air movement to be stagnant.

Conclusion:

This research study leads us to conclude that:

- office ventilation systems must be able to reduce Total Volatile Organic Compounds below the recommended 5000 $\mu g/m^3$ level;
- ventilation systems must provide stable ambient conditions of temperature and humidity within one day at the work stations;
- ventilation systems should be able to provide sufficient fresh outdoor air to reduce Carbon dioxide below the 650-700 ppm range.

The ventilation strategy resulting in the best perception from the occupants and based on above three conditions was of free cooling type, with variable outdoor air supply, variable total air volume and constant diffuser air temperature. The ventilation systems should be equipped with carbon dioxide and VOC monitors which would regulate the percentage of fresh air intake. These considerations will be taken into account in the design of future office building ventilation systems.

References:

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