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Indoor Air Quality and Thermal Comfort in School Buildings

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Abstract. This paper presents results to thermal comfort and environment quality questions in 21 school building rooms. Results show that about 80% of the occupants expressed satisfaction with their thermal comfort in only 11% of the buildings surveyed. Air quality scores were somewhat higher, with 26% of buildings having 80% or occupant satisfaction. With respect to thermal comfort and air quality performance goals set out by standards, most buildings appear to be falling far short. Occupant surveys offer a means to systematically measure this performance, and also to provide diagnostic information for building designers and operators. The odours from building materials as well as human odours were studied by field measurement. The odour intensity and indoor air acceptability were assessed by a sensory panel. The concentrations of total volatile organic compounds and carbon dioxide were measured. The odours from occupancy and building materials were studied under different air change rate. The case study of indoor air acceptability concerning to indoor odours and its effect on perceived air quality are also presented in this paper.

1. Introduction

The healthy building is the way we design and operate buildings, the amount of energy required to build, operate, and maintain them, and the resulting impacts on the quality of both the natural and built environments, [1]. A dominant assumption in the design of these modern buildings is that indoor environmental parameters can and must be carefully controlled to within the limits established in the prevalent codes, standards, and guidelines. There were found many limitations in the use of the heat balance model when used as a design tool including the need for the designer to anticipate what average clothing values and metabolic rate values could be expected in a building under design. Even when applied to occupied buildings where the metabolic rate and clothing insulation can be observed, heat balance models frequently fail accurately to describe or predict thermal comfort. There are a number of explanations offered including inaccurate observations of occupant activity or clothing insulation level, chair insulation value, non-uniformity of the thermal conditions; modelling assumptions including steady state conditions; and, thermal adaptation [1, 2].

For the indoor environment, these focus on four major categories: air quality, thermal conditions, illumination, and acoustics. Indoor environment is considered to be a basic requirement for human health and well-being. Indoor air quality and thermal comfort are two important aspects of indoor environmental quality that receive considerable attention by building designers. International and regional standards prescribe conditions intended to foster environments that are acceptable to occupants. Although there is considerable field data on air quality and thermal comfort [3,4], there is far less data that assesses occupant satisfaction across a large number of buildings using a systematic
method, and using occupant opinions as a measure of building performance is still far from standard practice [5].

A school environment has two significant components that lead to indoor quality unsatisfactory. One source is the building and furnishing itself, which in many cases can result in great amount of indoor pollutants that require removal or dilution. The second source is human odour produced by occupancies as a result of their activities. The anonymous, invite-style survey measures occupant satisfaction and self-reported productivity with respect to thermal comfort, air quality, lighting, acoustics and overall satisfaction with workspace. The questions asked in the survey have remained consistent over time to create a standardized database for benchmarking and analysis. This paper presents an analysis of the air quality and thermal comfort questions.

2. Research methods
The objective variables measured include gender, age group, type of study, proximity to windows and exterior walls. The perceived air quality in selected classrooms was assessed by panel of untrained persons. A sensory panel comprised 25 subjects. The age ranged from 22 to 26 years. The leader of the experiment assessed each subject's attitude and motivation concerning the experiment and subject's personal hygiene. There was no restriction on distribution of gender or smoking habits. The subjective variables measured include occupant satisfaction and self-reported productivity with the IEQ categories. In satisfaction and self-reported productivity questions we use a 7-point semantic differential scale with endpoints “very dissatisfied” and “very satisfied.” For the purposes of comparison, we assume the scale is roughly linear, and assign ordinal values to each of the points along the scale, from -3 (very dissatisfied) to +3 (very satisfied) with 0 as the neutral midpoint. The school building rooms surveyed are located in the southern Bohemia. Occupants in each classroom are invited to take the survey once over a two-week period through the lesson or examination. The survey has been conducted across seasons, but the majority of responses in our database were collected in the spring and autumn season. This paper focuses on occupant satisfaction with thermal comfort and air quality as well as self-reported productivity impacts. A satisfaction score for each building is calculated as the mean satisfaction vote of the occupants in that building. Similarly mean satisfaction scores for the entire database have been computed by averaging the scores for each building.

The air quality case study measurements were carried out in selected model classroom with a volume 168 m³. The relation between air change and sensory response was investigated. Vertical walls and ceiling were built from painted masonry. There were plastic windows, wooden door and plastic furniture materials inside of the classroom. The floor was constructed of linoleum covering. The significant sources of odours were considered surface materials, especially furniture and occupants. The measurements were performed before lectures and after lectures in common custom mode conditions. The air temperature and relative humidity was set with data logger Testo 175-H2 (measurement accuracy: ±3% Rh, ±0.5°C).

The indoor air acceptability concerning to odours from building materials and human odours under occupancy were studied by sensory assessment. The data of sensory assessment were processed by standard test method at the condition of field measurement. The panel stayed in the good ventilated room without odours between the assessments. Then the subjects entered the classroom and indicated their immediate evaluation on two continuous scales regarding intensity (scale from 0 - no odour to 5 - overwhelming odour) and acceptability (scale from +1 - clearly acceptable to -1 - clearly unacceptable) of the indoor air. The standard test method was used for calculation of acceptability and estimation of odour intensity.
3. Results and discussions

Figure 1 shows the satisfaction with air temperature and distribution of thermal comfort satisfaction scores for all occupants. Overall, more occupants are dissatisfied (40%) than satisfied (37%), with 20% of occupants neutral. Of note is the relatively high percentage of responses in the –2 and -3 categories (24%). To look at the proportion of occupants satisfied with temperature in each classroom and plot these in a frequency distribution, another picture is given within the Figure 1. It can be seen that 80% and more are satisfied with air temperature just in 11% of the evaluated rooms. The occupants who vote the dissatisfaction were asked for the reasons of their perceived thermal discomfort. The main reasons were estimated as follows: not sufficient area uniformity, air movement, drafts, incoming sun radiation, humidity, etc.

Air quality satisfaction is somewhat higher than thermal satisfaction in the buildings we surveyed. Figure 2 shows the satisfaction with the air quality and distribution of air quality satisfaction votes across all occupants. In contrast to the thermal satisfaction votes, more occupants voted satisfaction (42%) than dissatisfaction (32%), and the neutral vote was 24%. The mean air quality satisfaction vote was positive (0.19). The occupants who vote the dissatisfaction were asked for the reasons of their perceived air quality. The main reason was estimated as stuffy air, voted to be a major problem for 72%, 64% rated air as odorous to be a major problem.

![Figure 1](image1.png)

**Figure 1.** Satisfaction with the temperature and distribution of satisfaction rates

![Figure 2](image2.png)

**Figure 2.** Satisfaction with the air quality and distribution of satisfaction rates
Both thermal comfort and air quality can have important impacts on productivity. The previous results confirm the anticipated negative effect on performance and productivity in poor indoor air quality in the building with higher occupancy. The occupants are likely to be less attentive and concentrate, which over time may lead to detrimental effects on higher productivity attainment [6]. In addition to the satisfaction questions, the survey asks occupants to rate the impact of each environmental category on their productivity. We found a very high correlation between satisfaction and self-assessed productivity impacts. Figure 3 shows the average thermal comfort productivity response binned by satisfaction response for entire database.

It was shown very clearly that personal control over environmental conditions has a significant positive impact on occupant satisfaction. One means of achieving higher occupant satisfaction would be to provide such control to more occupants. Occupant surveys provide a standardized and systematic method for assessing occupant satisfaction with the indoor environment. They also provide a means for collecting diagnostic information to help identify problems. This can be done for an individual building in detail, or to learn about trends across many buildings.

![Figure 3. Self-reported productivity binned by satisfaction votes for indoor temperature](image)

The mean indoor odour intensity (the scale from 0 to 5) and indoor air acceptability (the scale from -1 to +1) vs. air change rate is shown in Figure 4. The perceived air was unacceptable by air change rate lower than 0.8 1/h in the classroom both before and after lecture. The indoor air quality was acceptable before lecture in the range of air change rates from 0.8 to 1.5 1/h however after lecture the indoor air quality was completely unacceptable. Only the air change rate 2.5 1/h guarantee acceptable indoor air also after lecture in the classroom.

The difference in perceived air quality and odour intensity was obvious between the different ventilation conditions. The room with higher air change level had better perceived air quality because of the dilution of pollutants. The percentage dissatisfied with perceived indoor air quality before lecture decreased with higher ventilation rates. The ventilation rate 0.8 1/h guarantees the acceptable indoor air quality before lecture without additional contribution of human odours. As no significant differences between low ventilation conditions (0.2 – 1.0) after 90 minutes of using studied room were found, it could be stated that bio effluents including CO₂ had a major influence on the subject’s votes. The acceptability of indoor air after lecture increased with ventilation rate 1.51/h, but the percentage dissatisfied was still high enough, so the perceived air quality was still not acceptable. Finally, the ventilation rate 2.5 1/h guaranteed the acceptable indoor air also after lecture.
Figure 4. Odour intensity and air acceptability

The acceptability of air quality assessed by the sensory panels showed significant correlation with the values of CO₂ and TVOC concentrations. The main source of carbon dioxide in buildings are occupants, so low ventilation rates relative to occupancy levels is associated with high CO₂ levels and vice versa, so increased number of building users results in increased CO₂ levels. Carbon dioxide concentration is one of the base parameter for ventilation systems design and managing of fresh air supply. Perceived air quality is closely connected to hygienic limits recommendations. In the case of lower ventilation rates and higher occupancy carbon dioxide level tend to rise. Unfortunately, the lower ventilation also causes the higher occurrence of odorous compounds and a lot of additional health problems are found. The screening measurements confirmed that the TVOC occurrence and their odour loading indoors lately increased mainly with a great number of new used materials [7]. The chemical analysis show that building products affect the perceived air quality, even when the concentrations of almost all primary VOCs (except butylaldehyde) are well below their odour detection thresholds. Odour indices less than 0.1 for individual VOCs cannot guarantee that the building products have no impact on perceived air quality. The mixtures of VOCs may affect the perceived air quality although every individual compounds are below their odour thresholds. The perceived air quality can be also affected by other VOCs not captured by sample technique [8].

The results confirmed that odour problems occurred in school buildings are caused by inadequate ventilation and high occupancy. The dominant source of indoor odour is human being in spite of the other types of indoors where the adequate sources are building materials. The results of the presented study suggest that for perceived odour and indoor environmental odour loading, the source control and hygienic limits follow is recommended as the remedy for poor indoor air quality rather than increase of not objective ventilation rate.

4. Conclusions
It was shown very clearly that personal control over environmental conditions has a significant positive impact on occupant satisfaction. One means of achieving higher occupant satisfaction would be to provide such control to more occupants. Occupant surveys provide a standardized and systematic method for assessing occupant satisfaction with the indoor environment. They also provide a means for collecting diagnostic information to help identify problems. This can be done for an individual building in detail, or to learn about trends across many buildings. The results of this study show the
state of indoor environmental quality in school buildings, and highlight the importance of post occupancy evaluation. This information has important implications for how buildings are designed, built, and operated to increase occupant comfort and productivity.

Modern architectural and engineering practice has spawned specialists for each of the major environmental categories whereas in historical times the architect addressed the entire building and its indoor environmental quality. This proliferation of specialists leaves the architect to coordinate inputs from a variety of disciplinary specialists who independently seek to optimize those factors within the scope of their increasingly narrow discipline.

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