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Perceived Comfort of Indoor Environment and Users' Performance in Office Building with Smart Elements – case Study

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Abstract

A greater degree of awareness of comfort and productivity of building users according to post-occupancy evaluation and feedback of users in intelligent buildings is necessary. This report presents a summary of the results from a physical measurements, a post-occupancy evaluation study on perceived comfort of indoor environment and self-evaluation of occupant's performance in the new multifunctional 5 floor-building in city of Kosice, Slovakia. There were investigated degree of perceived comfort and user's performance with regard to objective measurement, respondents' response and building character. This case study has highlighted that influence of monitored factors of building with smart elements is positively received and wasn't determined their negative impact on perceived comfort of indoor environment and occupants' performance. Results show that respondents are mostly satisfied with their indoor environment conditions of workplace. Interviews with respondents detected they have not been perceived (negative) factors in workplace because they have been too concentric on the work and they have not felt discomfort.

Key words: indoor environment, perceived comfort of indoor environment, performance of users, smart building

1 Introduction

Automation of technologies affects industrially developed society at the present. Intelligent building can be described as a building that is suitable for its users and provides comfort, good and efficient work and housing. An intelligent indoor space should be an adaptable and dynamic environment that optimizes user services and management processes using smart systems. Intelligent indoor environment can provide better workplace conditions for users. Cook and Das defined intelligent environment as one that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment [1]. Intelligent buildings issue in the world is the subject of numerous studies but in Slovakia involves amount of still yet unexplored fields. One of these issues is the impact of building intelligence rate on perceived comfort of indoor environment. Even all indoor environmental standards are met the users are usually not satisfied in the smart buildings. Some discomforts and negative factors in smart residential buildings like electro smog, loss of contact with exterior and nature, loss of physical deployment and privacy and "Master-Slave" Syndrome were investigated. Compact work space, electro smog, absence of personal space and inconvenient indoor air quality were marked as main limitations of office intelligent buildings [2, 3]. There is no sufficient knowledge about perceived comfort of indoor environment of new-built smart office buildings in Slovak conditions. Therefore the aim of research is oriented to analyzing the impact of factors on perceived state of indoor environment of selected multifunctional building with smart elements and quantification of the degree of influence of building intelligence on perceived comfort of indoor environment and user's performance. Measurements of physical and chemical factors of indoor environment using appropriate measuring instruments have been realized within the frame of experimental part of the research work. Subjective evaluation of the perceived comfort of indoor environment and performance of building users was realized concurrently.

2 Monitored object

The new multifunctional 5 floor-building in city of Kosice, Slovakia representing an office and salesroom workplace was selected for the research purposes. Heating and cooling is covered by VRV system with recuperation that is controlled by intelligent touch controller. Central air conditioning system of building can join various indoor units on one external unit. Users can control indoor air temperature, indoor air quality and ventilation in their workplace by using the spatial thermostat with air mechanical ventilation option or open the windows.

The experimental room (R1) - the office room (10 x 6,2 m) selected for monitoring can be described as closed and shared with other users. There are new furnishings and several equipments such as personal computers, copiers and printers. Administrative sedentary work was performed by 7 employees in the evaluating area of workplace.

The experimental room (R2) - salesroom (21,2 x 7,6 m) selected for monitoring can be described as open space. There are equipments like sales counter with a cash register, photocopy machine, glass display cases, shelves and boxes of goods, further chairs with tables used for placement of goods and promotional leaflets. Three permanent members of staff work in the space of salesroom, two employees work in the service and one employee works in a warehouse.

There are no plants in both experimental rooms. Experimental rooms have windows directed to the south-east. Occupants can control indoor vertical blinds.

3 Methodology

Evaluation of indoor environment state is based on:

- Measurements of physical and chemical factors

Evaluation of occupants' comfort and performance is based on:

- Occupants questionnaires in paper form with questions focused on:
- Assessment in the moment
- Assessment in general

Measurements

Physical measurements were conducted for 5 days in winter at intervals 12:00 – 18:00. The measurements were carried out during normal operation of building. Measurements for thermal comfort, air quality, acoustics and lighting were taken in two experimental rooms on 1st (R1) and 5th floor (R2). Measurements were analyzed against occupant's response for each element of indoor environment in the moment and in general. The following factors were measured in both experimental rooms:

- air temperature,
- globe temperature,
- air velocities,
- relative humidity,
- CO2 concentrations,
- particulate matter (PM) concentrations,
- volatile organic compounds (VOCs),
- level of lighting,
- level of noise.

Assessment in the moment

The questionnaire intent on assessment in the moment covers a wide range of variables related to:

- demographic characteristics of occupants
- perception, sensational evaluation and preference of indoor environmental conditions,
- impact of indoor environment' conditions on occupants performance,
- perception of SBS and health symptoms during assessment,
- overall evaluation of indoor environment' conditions.

Assessment in general

The questionnaire intent on assessment in general covers a wide range of variables related to:

- demographic characteristics of occupants
- perception of workplace' characteristics,
- perception, sensational evaluation and preference of indoor environmental quality,
- satisfaction with indoor environment' control,
- impact of indoor environment' factors on occupants performance,
- perception of other indoor environment' factors,
- overall evaluation of indoor environment' conditions.

A perception of other indoor environment' factor was investigated. Other factors include visual contact with exterior and nature, rest rooms and monitoring of occupants. There were evaluated only factors which are specified in chapter 4 selected for purpose this study

The questionnaires intent on evaluation in the moment was distributed to all staff working in both experimental rooms and generally was collected on the same time. 118 questionnaires

were obtained from all respondents from both rooms during all evaluation days. Respondents consisted of 10 men and 1 woman and they were aged 20 to 40 years.
The questionnaires intent on evaluation in general was distributed to all staff working in experimental building. 30 questionnaires were obtained from all concerned respondents. Respondents consisted of 22 men and 8 woman and they were aged 20 to 50 years.

3.1 Satisfaction ratings

Different types of evaluation scales are used in questionnaires. There were used scales of perception, scales of sensational evaluation, scales of preference (tab. 1), satisfaction scale, overall evaluation scale and scale of self-evaluation of performance (tab. 2).

Table 1: The evaluation scales

	The perception	The sensational evaluation	The preference
Indoor air temperature	3 hot 2 warm 1 slight warm 0 neutral -1 slight cool -2 cool -3 cold	0 comfort 1 slight discomfort 2 discomfort 3 very discomfort	3 hotter 2 warmer 1 slight warmer 0 neutral -1 slight cooler -2 cooler -3 colder
Indoor air quality	0 no odour 1 slight odour 2 mild odour 3 strong odour 4 very strong odour 5 sublime odour	0 comfort 1 slight discomfort 2 discomfort 3 very discomfort	1 higher 0 no change -1 lower
Indoor air humidity	2 humidity 1 nominal humidity 0 neutral -1 nominal dry -2 dry	0 comfort 1 slight discomfort 2 discomfort 3 very discomfort	1 higher 0 no change -1 lower
Draught	0 no draught 1 slight draught 2 mild draught 3 strong draught 4 very strong draught 5 sublime draught	0 comfort 1 slight discomfort 2 discomfort 3 very discomfort	1 higher 0 no change -1 lower
Lighting	2 very high 1 high 0 acceptable -1 low -2 very low	0 comfort 1 slight discomfort 2 discomfort 3 very discomfort	1 higher 0 no change -1 lower
Noise	2 very high 1 high	0 comfort 1 slight discomfort	1 higher 0 no change

	0 acceptable -1 low -2 very low	2 discomfort 3 very discomfort	-1 lower

Table 2: The evaluation scales

<table>
<tr><th></th><th>Satisfaction</th><th>Self-evaluation of performance</th><th colspan="2">Overall evaluation</th></tr>
<tr><td>Indoor air temperature</td><td rowspan="6">3 greatly increases
2 increases
1 slight increases
0 neutral
-1 slight decreases
-2 decreases
-3 greatly decreases</td><td rowspan="6">3 greatly positive
2 positive
1 slight positive
0 neutral
-1 slight negative
-2 negative
-3 greatly negative</td><td rowspan="6">- more acceptable than unacceptable

- more unacceptable than acceptable</td><td rowspan="6">0 very well tolerable

1 well tolerable

2 quite tolerable

3 difficult tolerable

4 intolerable</td></tr>
<tr><td>Indoor air quality</td></tr>
<tr><td>Indoor air humidity</td></tr>
<tr><td>Draught</td></tr>
<tr><td>Lighting</td></tr>
<tr><td>Noise</td></tr>
</table>

4 Assessment of indoor environmental quality and occupants satisfaction

4.1 Physical measurements

The minimum measured air temperature was 21.2 °C, maximum 22.2 °C and mean value 21.98 °C in the experimental room R1. The minimum measured air temperature was 20.7°C, maximum 23.9 °C and mean value 21.83 °C in the experimental room R2.

The minimum measured air humidity was 36.5 %, maximum 48.4 % and mean value 43.3 % (R1). The minimum measured air humidity was 28.1 %, maximum 42.1 % and mean value 36.7 % (R2).

The minimum measured air velocity was 0.0 m/s, maximum 0.09 m/s and mean value 0.04 m/s (R1). The minimum measured air velocity was 0.0m/s, maximum 0.10m/s and mean value 0.05 m/s (R2).

Mean values of operative temperature were in R1 21.8 °C and in R2 21.36 °C.
The minimum measured CO_2 concentration was 972 ppm, maximum 2224 ppm and mean value 1546.4 ppm (R1). The minimum measured CO_2 concentration was 712 ppm, maximum 1403 ppm and mean value 1100.5 ppm (R2).

The minimum measured lighting level was 361 lx, maximum 585 lx and mean value of 470.1 lx (R1). The minimum measured lighting level was 190 lx, maximum 344 lx and mean value 254.83 lx (R2).

The minimum measured noise level was 48.39 dB, maximum 53.99 dB and mean value 51.9 dB (R1). The minimum measured noise level was 49.9 dB, maximum 51.7 dB and mean value 51.1 dB (R2).

The measurement of particulate matter (PM) concentrations and volatile organic compounds (VOCs) has been performed in 5-hour intervals for 5 days. Measurement instruments were located in the middle of the workplace, at the level of the breathing zone of a sitting person - 1.1 m above the floor.

The investigation of particulate matter included measurement for fractions of 0.5, 2.5 and 10.0 micrometers (PM0.5, PM2.5 and PM10). Measurements in R1 confirmed the existence of volatile organic compounds, expressed as isobutylene. The maximum concentration reached 149 μg/m^3 and averaged 70 μg/m^3. Occurence of volatile organic compounds in R2 wasn't confirmed by measurements.

Mean value of total PM concentrations was 225.7 μg/m^3 (R1) and 132.6 μg/m^3 (R2).

4.2 Occupants' perception of indoor environmental quality

The following figures show summaries of occupants' perceptions of indoor environmental quality in the moment and in general.

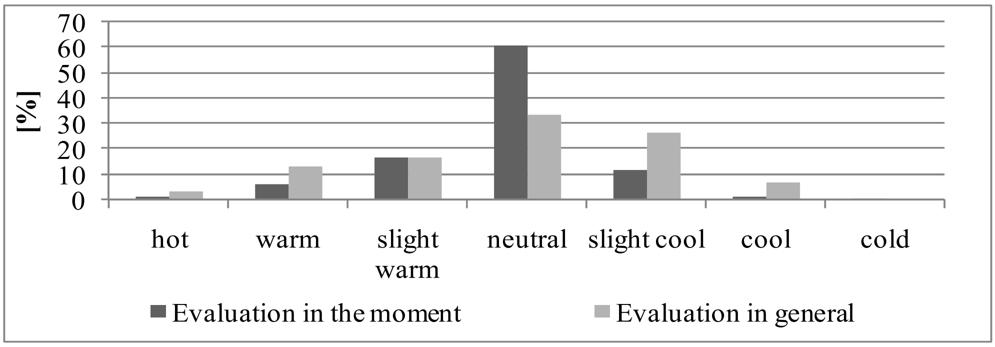

Figure 1: Summary of occupants' perception of indoor air temperature

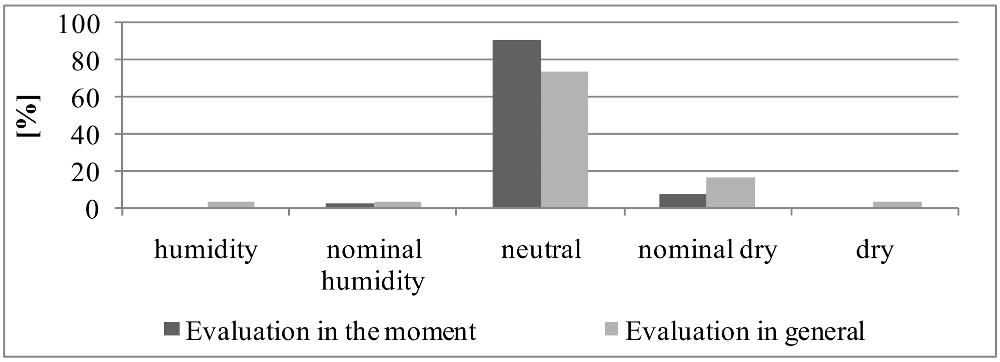

Figure 2: Summary of occupants' perception of indoor air humidity

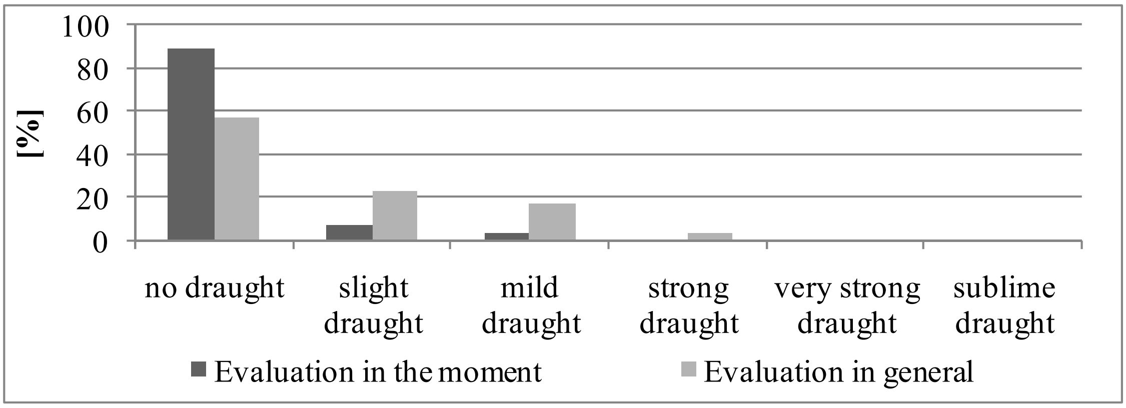

Figure 3: Summary of occupants' perception of indoor air velocity

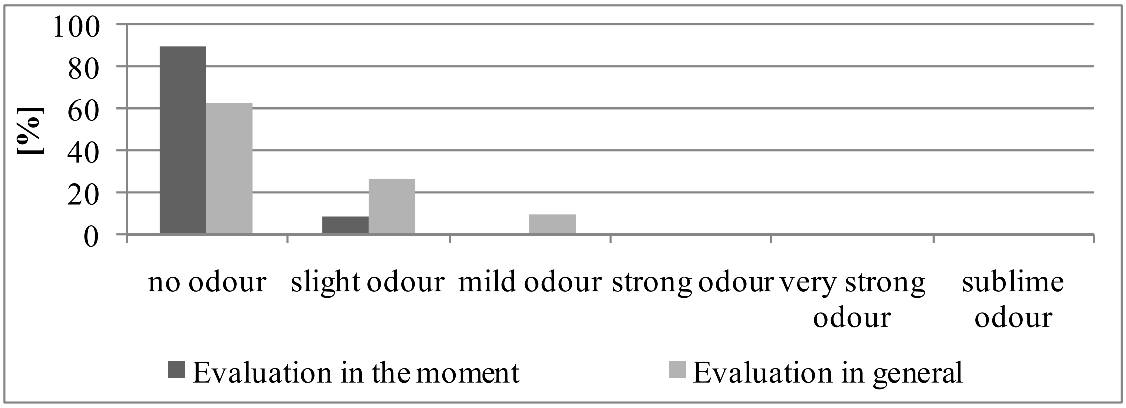

Figure 4: Summary of occupants' perception of indoor air quality

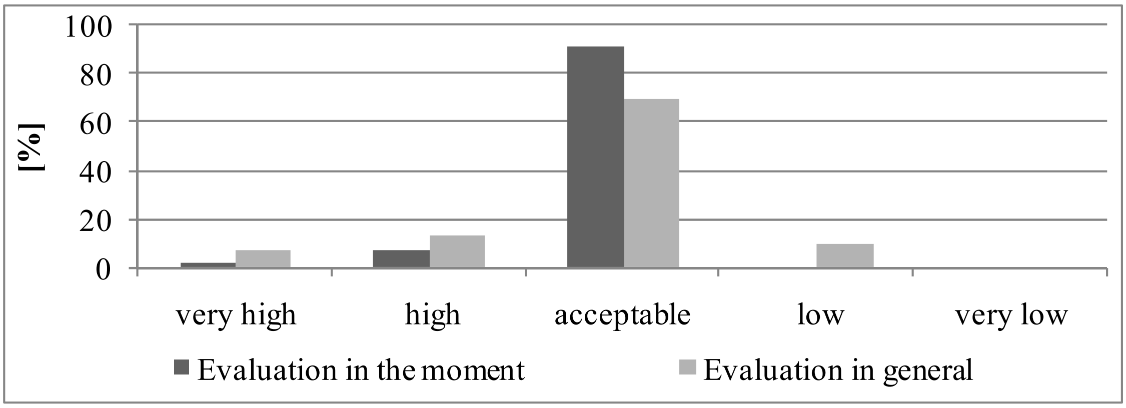

Figure 5: Summary of occupants' perception of lighting

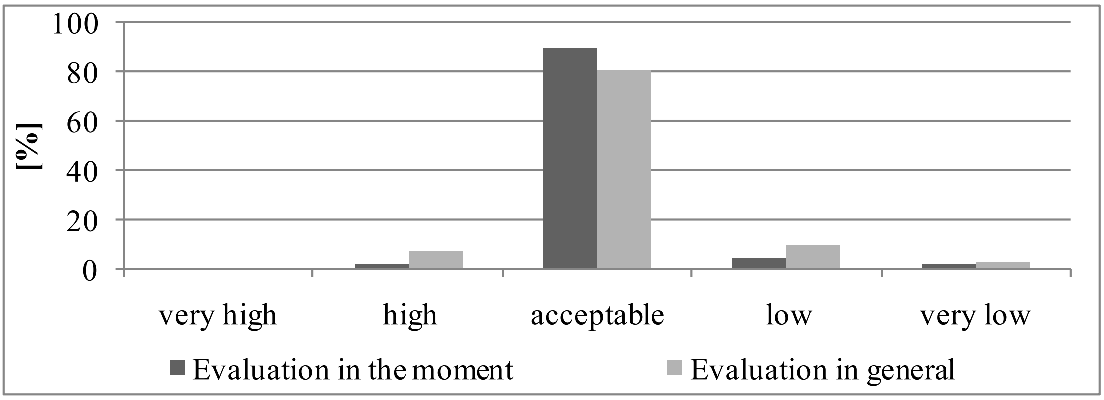

Figure 6: Summary of occupants' perception of noise

Results show (figure 1 - 6) that perception of the individual factors of indoor environment in general is more negative than in the immediate evaluation. Factors were perceived as acceptable, neutral or mostly weren't perceived.
Visual contact with exterior has positive effect (33%) on respondents' comfort and has neutral effect (30%). Contact with nature from exterior has neutral effect on comfort (33%) and has positive effect on comfort of 27% respondents. 67% of users would like to have more plants in their workplace and 70% of them prefer flowerless plants. Contact with plants in interior has slight positive effect (30%), positive (20%) and greatly positive (20%) effect on comfort. Results show that 30% of respondents evaluate the stay in rest areas as greatly positive and 30% as positive.

4.3 Occupants' sensational evaluation

The following figure shows summary of occupants' sensational evaluation of indoor environment factors in general.

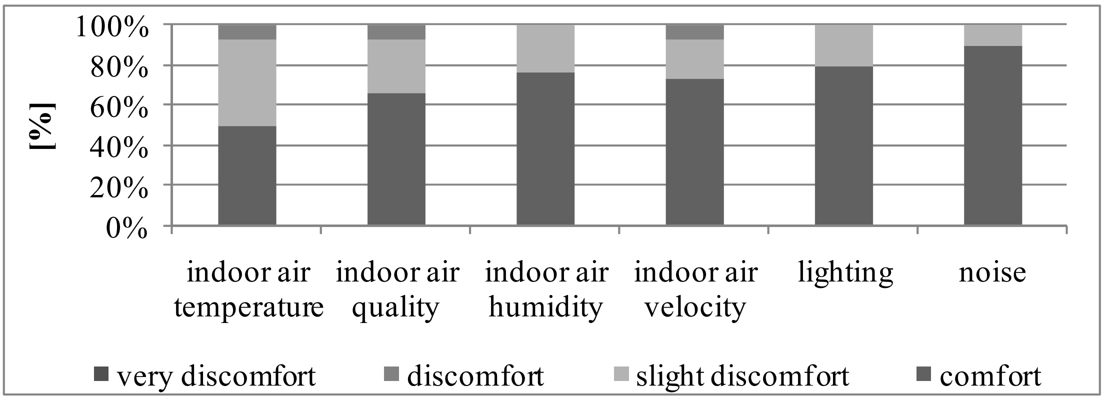

Figure 7: Summary of occupants' sensational evaluation of indoor environment factors in general

Results show that noise level was evaluated as the most comfort state from all factors in general, as shown in figure 7.

4.4 Occupants' preference

The following figure shows summary of occupants' preference of indoor environment factors in general.

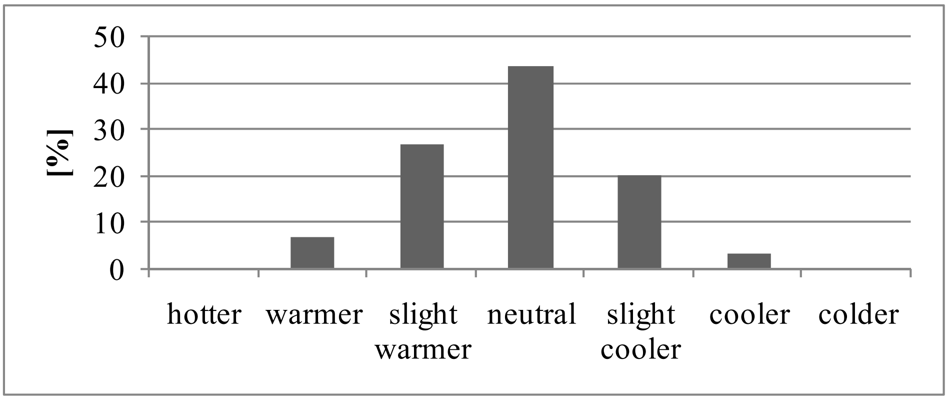

Figure 8: Occupants' preference of indoor air temperature in general

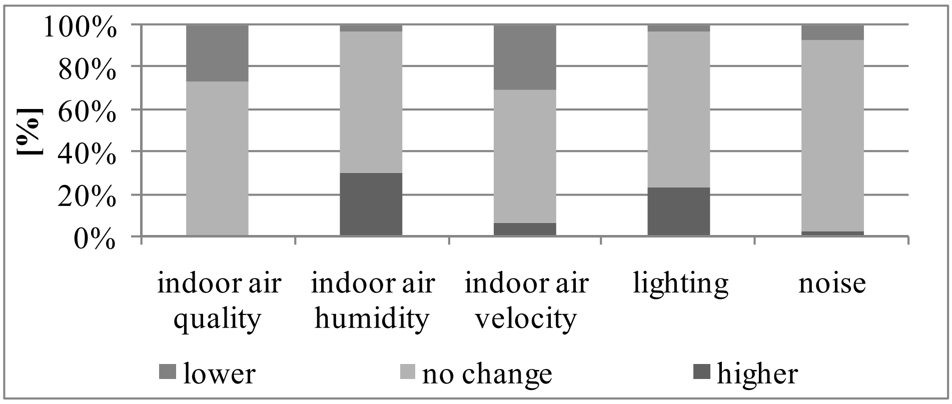

Figure 9: Occupants' preference of indoor environmental factors in general

Results show that majority of respondents require no change in general, as shown in figure 8 and 9.

4.5 Overall evaluation of indoor environment

Occupants (96.7%) marked indoor environmental conditions as more acceptable than unacceptable in general. 46.7% of respondents considered the indoor environment as very well tolerable and 43.3% as well tolerable, as shown in figure 10.

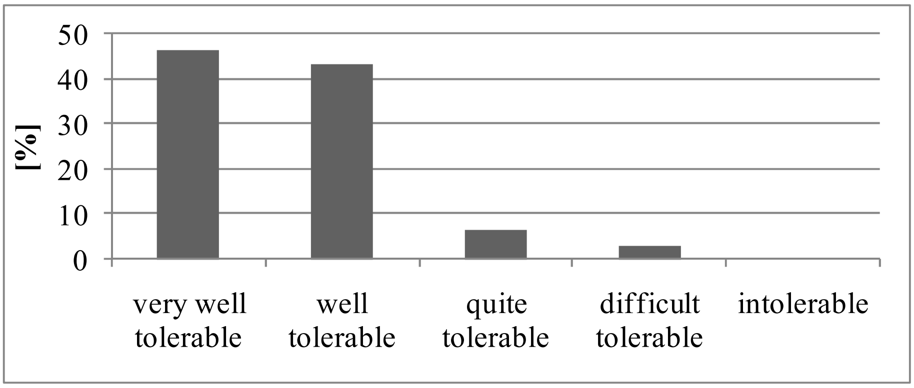

Figure 10: Occupants' tolerance of indoor environmental conditions in general

4.6 Impact of indoor environmental factors on occupants' performance

Respondents from R1 self-evaluated their performance in the range 80-100% due to immediate conditions of indoor environment during the course of the research. Respondents from R2 self-evaluated their performance in the range 70-90% due to immediate conditions of the indoor environment conditions during the course of the research.

Thermal state of indoor environment was rated as slight increasing (23%) and slight decreasing (20%) of respondents' performance. Indoor air humidity and air quality has greatly increasing (30%) and neutral (27%) effect on the performance of occupants. Effect of air velocity was rated as slight increasing (30%), the strongly increasing (23%) and increasing (20%) the performance. Lighting in the workplace has increasing (33%), the strongly increasing (27%) and neutral (20%) effect on the performance of respondents. The noise has strongly increasing (23%), increasing, neutral and slight reducing impact (17%) on performance, as shown in figure 11.

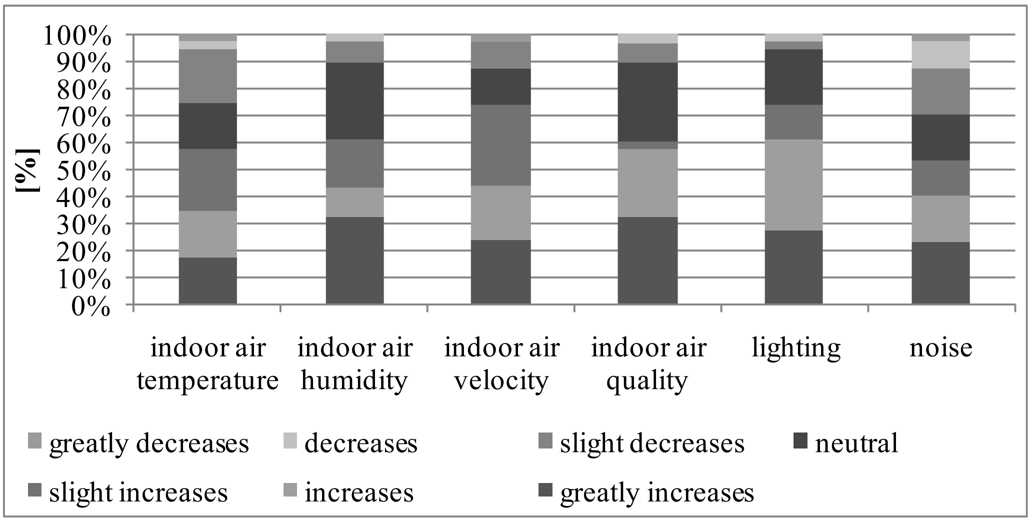

Figure 11: Impact of indoor environmental conditions on occupants' performance in general

Results show that visual contact with the exterior increases the performance of 33% of respondents and have neutral effect on their performance (30%). Contact with plants from the exterior has a neutral impact on performance of 33% and improves performance of 27% respondents. 30% of respondents said that contact with plants in the interior slight increases their performance, has neutral impact (20%), increases and greatly increases the performance (20%) in the workplace. Most of respondents (37%) evaluated the stay in rest areas as increasing their performance, 27% as greatly increasing and 20% has neutral effect. 50% of users judged the impact of their monitoring on the performance as neutral, 17% as greatly increasing, 17% as increasing and 13% as slightly increasing, as shown in figure 12.

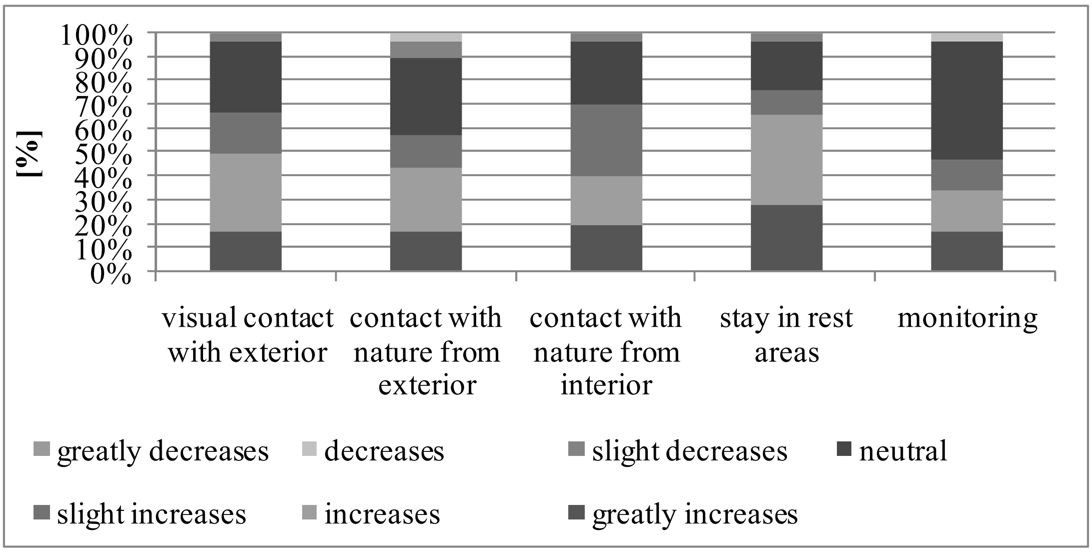

Figure 12: Impact of other factors on occupants' performance in general

5 Conclusion

Impact of monitored factors in selected building with smart elements is received positively by users and has not been found significant negative effect on perceived comfort of indoor environment and users' performance. Workplace environment with smart elements was rated as very well and well tolerable by users. Air quality is rated by respondents as comfortable and acceptable during excessive concentrations of carbon dioxide in indoor environment. Contact with plants in workplace is required by occupants. Interviews with respondents detected they have not been perceived (negative) factors in workplace because they have been too concentric on the work and they have not felt discomfort.

The perception of the individual parameters of indoor environment in general is more negative than in the immediate evaluation. Subjective assessment of perceived comfort of indoor environment and performance evaluation - feedback is a suitable tool for designing and creating future buildings and their environment. Evaluation of comfort and performance in relation to degree of building intelligence requires a comprehensive view. Greater degree of awareness of the feedback and its benefits is needed.

Another research in buildings with varying degree of intelligence can provide further insight into the impact of the intelligence building on perceived comfort and performance of users.

Acknowledgements

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