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ASSESSMENT OF WORKPLACE THERMAL COMFORT, LIGHTING AND NOISE

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Abstract. *Workplace comfort refers to how individuals control, adapt to, and manage their work environment to ensure their own well-being. In addition to basic requirements such as safety and health, the work environment also needs to provide adequate support. Physical comfort includes standards and regulations that ensure a safe, healthy and pleasant environment for work. It includes adequate temperature, air quality, sufficient lighting, acceptable noise levels, sanitary facilities and general cleanliness. Functional comfort means the working environment supports the execution of specific tasks performed by individuals. Psychological comfort refers to the feeling of control over one's workspace, privacy and social dynamics, which affects the sense of safety, belonging and responsibility. Special attention must be paid to the microclimate, as it is a key factor in workplace comfort. When temperature, relative humidity, and air velocity are appropriately adjusted to the nature of the work and physical demands on employees, we speak of thermal comfort. Deviations, such as high temperature (above 28 °C), draughts or very dry air, can cause discomfort and reduce work efficiency. Employers are obligated to ensure suitable thermal conditions in line with legislation and employees' needs. Adequate lighting should provide sufficient and uniform lighting, appropriate colour temperature, adequate contrasts and avoid glare or flickering. In addition to artificial lighting, the availability of natural light is also important. Noise levels at the workplace must remain within permissible limits to avoid impairing concentration or causing stress. In December 2024, we carried out measurements of microclimatic conditions, lighting and noise levels in two buildings, covering 15 offices and 37 employees. The results showed low relative humidity in three offices, excessive air velocity in six offices, and insufficient lighting in two offices. Based on the findings, recommendations for improving the conditions were made and shared with the management of both organisations.*

Key words: *occupational safety and health, office, microclimate, lighting, noise levels*

Introduction

To ensure a safe working environment, it is essential to adhere to the prescribed regulations and standards for specific work environments. Key factors in a safe work environment include thermal conditions (microclimatic parameters), lighting, noise, vibrations, hazardous gases and vapours, and dust [1]. Measuring microclimatic parameters, lighting levels, noise and CO_2 concentration in different indoor workplaces enables us to determine whether there is a risk to employees' health and safety or whether adequate thermal comfort is ensured. These parameters are important not only for occupational safety, but also for overall well-being at work, which nowadays often exceeds the traditional eight-hour working day. Good working

conditions protect workers' health, reduce absenteeism and enhance efficiency and psychophysical capacity for work [2].

Indoor environmental quality (IEQ) is a key factor that can affect the health and well-being of building occupants [3]. Office workers frequently report health problems associated with sick building syndrome (SBS), which may be linked to factors such as elevated indoor temperature, high light intensity, insufficient ventilation, higher-than-recommended levels of air pollutants, and inadequate cleaning practices [4]. Furthermore, IEQ is recognised as crucial in promoting the productivity and decision-making capacity of office workers [5-9].

Office environments may contain equipment that acts as a heat source, leading to elevated indoor temperatures and consequently affecting employees' comfort. The main sources of heat are electronic equipment, occupancy density and lighting, with electronic devices frequently identified as the most significant contributors to internal heat gains in office buildings [10].

Indoor workplaces have specific lighting requirements to ensure that visual tasks can be performed efficiently and accurately, while maintaining energy efficiency and visual comfort. The assessment of lighting conditions is primarily based on the measurement of lighting, defined as the luminous flux incident on a given surface. The distribution of lighting within the work area and its surroundings represents an important parameter, as it directly influences the visual performance, safety, and comfort of workers. Another key factor related to lighting quality is the correlated color temperature, which affects the visual perception and overall comfort of occupants [11].

In the office environments of two public institutions analyzed in this study, hazardous gases, vapors, and dust generally do not pose a significant risk, as they may be present only under exceptional circumstances (e.g., during maintenance work). Therefore, this study focuses primarily on microclimate, lighting, and noise. The aim of the study is to determine the impact of microclimate, lighting and noise in office spaces on the working conditions and well-being of employees in two public institution. The analysis is based on measurements of the thermal comfort of the employees, the lighting of the individual workstations and the noise level. The results will enable risks to be identified and contribute to further improvements in occupational safety and health in these workplaces.

Methods

Data Collection Methods and Techniques

In December 2024, we measured the microclimatic conditions, lighting, and noise levels in 15 offices, covering 36 employees across two public institutions in the Slovenian capital. Building 1 is situated in the western part of Ljubljana, along the main road leading to the city centre, while Building 2 is located in the city centre, away from major traffic routes.

Measuring equipment and measured parameters

We used a Testo 445 to measure microclimatic parameters, a FLIR E6 thermographic camera to measure radiant temperature and a Testo 545 to measure lighting. Noise levels were measured using a Brüel & Kjaer 2260 Investigator modular sound level analyser.

The measurements were carried out in accordance with the requirements of SIST EN ISO 7730:2006 [12], SIST EN 12464-1:2021 [13] and SIST ISO 9612:2009 [14]. The PMV and PPD indices were calculated using a special online calculator [15].

The criteria for assessing the thermal conditions were taken into account, namely the requirements of two regulations [16-17]:

(a) the appropriate air temperature shall be 22-26 °C during non-heating periods and 19-24 °C during heating periods. In working areas, it shall not exceed +28 °C;
(b) the temperature difference, measured at a heights of 0.1 m and 1.1 m, shall be less than 3 K;
(c) the floor temperature must be 19-26 °C;
(d) relative humidity: 30-70 %;
(e) a mean air velocity: 0.15 m/s during heating/cooling and 0.2 m/s at other times (up to a maximum of 0.5 m/s at 26 °C);
(f) the PMV index shall be between -0.7 and +0.7;
g) the PPD index shall be up to 15 %.

The requirements of SIST EN 12464-1:2021 [13] have been taken into account for lighting. Different activities require different lighting levels depending on the complexity of the visual tasks involved. Slovenian regulation [18] stipulate that the natural and/or artificial lighting of the room should be 400 lx ± 100 lx if possible. Depending on the type of work carried out in offices, SIST EN 12464-1:2021 prescribes the minimum lighting values shown in Table 1.

Table 1: Minimum lighting requirements for different types of office work [13].

OFFICE WORK	**E (lx)**
storage, copying	300
office surfaces	300
writing, computer use	500
reading, data processing	500
conference and meeting rooms	500

Legend: E (lx) – lighting in lux

In accordance with Regulation [19], the lower exposure action value is defined at 80 dB(A), the upper exposure action value at 85 dB(A), and the exposure limit value at 87 dB(A). However, substantially lower noise levels are recommended for office environments. In Slovenia, maximum permissible equivalent continuous noise levels have also been specified to ensure optimal conditions for office work. These recommended levels range from 40 to 55 dB, depending on the type of office activity,

and refer to noise generated by non-occupational sources (e.g., ventilation, air conditioning, adjacent premises, or traffic).

Results and discussion

The results for microclimatic parameters, lighting, and noise levels are presented in Table 2. As shown in Table 2, the air temperature at a height of 1.1 meters (T1.1) ranged from 22.0 °C to 26.0 °C. In Building 1, the average temperature was 25.23 °C (SD 0.67), whereas in Building 2 it averaged 23.19 °C (SD 0.96), which is just over 2 °C lower. All measured temperatures were within the recommended limits and complied with the requirements of the regulation on ensuring the safety and health of workers at work. Air velocity during the heating period exceeded the recommended values in six offices, ranging between 0.13 and 0.17 m/s. The PMV and PPD indices were above the acceptable limits in only one office, while the measured artificial lighting was below the recommended level in two out of fifteen offices. The equivalent continuous sound level was within the recommended range; however, the highest value (62.0 dB(A)) was recorded in Office 8, as a video call was taking place during the measurement period.

In the observed offices, the primary sources of internal heat gains, apart from the heating system, were computers and other electronic equipment, the number of occupants, and artificial lighting. Similar findings were reported by Li and Zhang (2022), who identified electronic devices in office environments as one of the major contributors to heat dissipation in office buildings [10].

Within the OFFICAIR project, researchers conducted an extensive investigation of indoor environmental conditions in office settings during working hours, including measurements of air temperature and relative humidity. Their results indicated that the average thermal conditions generally complied with OSHA recommendations. Reported mean air temperatures were 24.7 °C in summer and 23.7 °C in winter (heating season), while relative humidity averaged 46.4% in summer and 32.3% in winter [20]. These findings are comparable to our results, where the mean temperature in Building 2 offices during the heating season was 23.2 °C, and the overall average relative humidity across all offices was 33.8% (SD 3.97).

Similarly, Hedge et al. (2005) reported average indoor temperatures of 22.8 °C and relative humidity of 40.8% in an insurance company's offices during winter in the United States [21]. Comparable air temperature and humidity ranges have also been observed in other studies [22-25]. An exception was reported by Rios et al. (2009), who measured considerably higher winter humidity levels (72.5–85.2%) in unsealed office buildings in Brazil, corresponding to high outdoor humidity (approximately 85%) [24].

Overall, most studies indicate that air temperature and relative humidity levels in office environments typically remain within or slightly exceed OSHA recommendations, which are comparable to those applicable in Slovenia (20–24.4 °C and 20–60%) [26].

Table 2: Results of microclimate parameter measurements, calculation of PMV and PPD indices, lighting and noise

Office No. (persons)	**Building No. (floor)**	**$T_{1.1}$ [°C]**	**v [m/s]**	**RH [%]**	**PMV**	**PPD [%]**	**E [lx]**	**L_{Aeq} [dBA]**
Recommendation/ requirement		*22-26*	*0.15*	*30-70*	*–0.7 to +0.7*	*< 15*	*500*	*65/55*
1 (2 persons)	1 (1st floor)	25.5	**0.16**	36.8	0.41	8.5	692* **465****	44.5
2 (2 persons)	1 (1st floor)	24.4	0.13	31.1	0.47	9.7	837* 795**	32.8
3 (2 persons)	1 (1st floor)	24.3	0.14	**29.2**	0.31	7.0	1404* 1399**	36.5
4 (2 persons)	1 (2nd floor)	25.9	0.13	**29.6**	**0.74**	**16.4**	1320* 1319**	33.5
5 (3 persons)	1 (3rd floor)	25.3	**0.17**	34.8	0.51	10.4	845* 694**	35.0
6 (3 persons)	1 (4th floor)	26.0	0.14	30.4	0.70	14.3	970* 908**	33.6
7 (4 persons)	1 (5th floor)	25.7	0.14	34.2	0.70	14.3	976* 569**	31.8
8 (2 persons)	1 (5th floor)	24.7	0.15	33.4	0.48	9.8	1088* 592**	62.0
9 (5 persons)	2 (ground floor)	22.9	**0.17**	**28.4**	0.03	5	895* 645**	58.3
10 (3 persons)	2 (ground floor)	22.6	**0.16**	31.0	-0.16	5.6	996* 928**	53.6
11 (1 person)	2 (1st floor)	24.0	0.14	32.0	0.38	7.6	545* **320****	32.0
12 (2 persons)	2 (1st floor)	24.2	**0.17**	38.6	0.29	6.8	717* 710**	60.3
13 (2 persons)	2 (1st floor)	24.3	0.14	40.5	0.36	7.6	648* 599**	61.5
14 (2 persons)	2 (2nd floor)	22.3	**0.18**	38.7	0.08	5.1	897* 888**	58.8
15 (1 person)	2 (2nd floor)	22.0	0.15	38.30	-0.17	5.6	675* 659**	49.8

Legend: $T_{1.1}$ – temperature at a height of 1.1 metres, v – air velocity, RH – relative humidity, E – lighting, * Combined lighting values; ** Estimated artificial lighting values

The PMV and PPD indices were also calculated for office workplaces by other researchers, who obtained PMV values ranging from -0.58 to 0.34. The PPD was 10%.

The authors concluded that the low relative humidity levels recorded in offices were likely to be the cause of thermal discomfort [27]. Woo et al. (2021) also found PMV values ranging from slightly cool to neutral and PPD levels up to 16% in Australian offices [25], which is similar to our study.

Lighting at workstations was poorest in two offices, both of which (1 and 11) have north-facing windows. It is therefore important to provide these employees with additional local lighting, as the estimated artificial lighting was less than 500 lx. At the same time, we must also emphasize that we performed an assessment of artificial lighting because we took measurements during the day. We measured daily and combined illuminance and then calculated artificial illuminance. It would therefore be advisable to repeat the artificial illuminance measurements at night, when there is no influence from daylight. At the same time, it would be necessary to re-measure the illumination in the rooms with the rearrangement of the lighting and provide data on improvements, as was done in the study of office spaces in Poland [28]. The subjective assessment of individual workers regarding thermal conditions and lighting is also important, as was done, for example, in studies of office spaces in Ukraine [29] and Poland [28].

Noise measurements in our study range between 31.8 and 62.0 dBA and are within acceptable levels. In general, average noise levels ranging from 30 to 65.4 dBA have been recorded for offices around the world [25, 27, 30-31].

Conclusion

Recommendations for improving microclimatic conditions and lighting were submitted to the organization's management. Employees were informed about the results and provided with guidance on maintaining appropriate indoor temperatures, including regular ventilation during morning hours and the installation of suitable humidifiers. Additional local lighting will be procured for workstations where artificial lighting levels were found to be below 500 lux. Employees were also advised on the optimal placement of local lighting fixtures, as it is recommended that artificial light should complement daylight and come from the same direction whenever possible.

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PROCENA TOPLOTNOG KOMFORA, OSVETLJENJA I BUKE NA RADNOM MESTU

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Sažetak. *Komfor na radnom mestu odnosi se na to kako pojedinci kontrolišu, prilagođavaju i upravljaju svojim radnim okruženjem kako bi obezbedili sopstveno blagostanje. Pored osnovnih zahteva kao što su bezbednost i zdravlje, radno okruženje mora da pruži i odgovarajuću podršku. Fizički komfor obuhvata standarde i propise koji osiguravaju bezbedno, zdravo i prijatno radno okruženje. To uključuje odgovarajuću temperaturu, kvalitet vazduha, dovoljno osvetljenje, prihvatljiv nivo buke, sanitarne prostorije i opštu čistoću. Funkcionalni komfor znači da radno okruženje podržava izvršavanje konkretnih zadataka koje zaposleni obavljaju. Psihološki komfor odnosi se na osećaj kontrole nad sopstvenim radnim prostorom, privatnošću i socijalnom dinamikom, što utiče na osećaj sigurnosti, pripadnosti i odgovornosti. Posebna pažnja mora se posvetiti mikroklimi, jer je ona ključni faktor komfora na radnom mestu. Kada su temperatura, relativna vlažnost i brzina kretanja vazduha pravilno prilagođeni prirodi posla i fizičkim zahtevima zaposlenih, govorimo o toplotnom komforu. Odstupanja, poput visoke temperature (iznad 28 °C), promaje ili veoma suvog vazduha, mogu izazvati nelagodnost i smanjiti radnu efikasnost. Poslodavci su dužni da obezbede odgovarajuće toplotne uslove u skladu sa zakonima i potrebama zaposlenih. Odgovarajuće osvetljenje treba da obezbedi dovoljno i ravnomerno osvetljenje, odgovarajuću temperaturu boje, dovoljne kontraste i da spreči odsjaj ili treperenje svetla. Pored veštačkog osvetljenja, važna je i dostupnost prirodne svetlosti. Nivo buke na radnom mestu mora ostati u dozvoljenim granicama kako ne bi narušavao koncentraciju ili izazivao stres. U decembru 2024. godine sproveli smo merenja mikroklimatskih uslova, osvetljenja i nivoa buke u dve zgrade, u ukupno 15 kancelarija sa 37 zaposlenih. Rezultati su pokazali nisku relativnu vlažnost u tri kancelarije, preveliku brzinu kretanja vazduha u šest i nedovoljno osvetljenje u dve kancelarije. Na osnovu ovih nalaza, pripremljene su preporuke za poboljšanje uslova i prosleđene upravama obe organizacije.*

Ključne riječi: *bezbednost i zdravlje na radu, kancelarija, mikroklima, osvetljenje, nivo buke*