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Evaluation of Indoor Environment Subjective Perception in Large Office Building

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ABSTRACT HEADING

Office buildings are significant contributors to energy consumption and greenhouse emissions, and it is obvious that office building occupants and their behavior play an essential role in building energy performance. However, how buildings, respectively, their indoor environment, influence building occupant´s behavior, wellbeing, and productivity is not so clear and easy to predict. The main problem is that this correlation is very subjective and influenced by many factors. This paper deals with the evaluation of subjective perception of indoor environment in two large open spaces of office buildings, each for approximately 250 persons. Based on long-term monitored data, it is possible to state that this refurbished building with high-level modern HVAC system is operated according to the best practice, respecting hygiene and technical standards related to air temperature, humidity, and CO_2 concentration, however the occupant's level of complains on IEQ is relatively high. Data for evaluation of real status was collected through an anonymous questionnaire survey of occupants, focused on thermal comfort, indoor air quality, acoustics, illumination, health conditions, concentration, and psychological wellbeing. Based on the questionnaire evaluation, the paper shows how indoor environmental quality of a large office building is perceived by occupants and how this can subjectively influence not only their thermal comfort, perceived air quality, acoustics, and illumination but also their work concentration, health, and psychological wellbeing.

INTRODUCTION

The indoor environment of buildings consists of a set of physical, chemical, and social reactions between users and the building, which includes phenomena affecting the technical, natural, and medical sciences. To describe and quantify the parameters of the indoor environment of buildings, we commonly use a simplified model, describing and evaluating the individual components of the environment separately - thermal comfort, air quality, acoustics, lighting, electromagnetic, electrostatic and other fields that co-create the final state of the environment. The goal of creating an indoor environment is to achieve a state we call "comfort" - an optimal state of mind where the user does not perceive the environment and can fully concentrate on the activity, which can be work, sports, relaxation or entertainment. The problem is that objectively measured quantities of individual components of the environment affect individuals differently, and especially in rooms where more people work in one environment, there is a different perception and in the case of negative feelings of complaints of people or groups of people about the quality of the environment. In practice, we often encounter situations where the same thermal environment is unsatisfactory for one subject as cold, while for another, an equally dressed and active subject is too warm. One of the reasons may be the fact that a person

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perceives the environment as a whole, which the current practice of environmental assessment does not fully reflect - we usually evaluate the individual components independently without mutual connections. We then determine that even though all parameters of the individual components of the internal environment are seemingly OK, the user still complains about the environment.

To examine the quality of the environment, we use objective methods - measurement of physical quantities and anamnestic methods - determination of the subjectively perceived quality of the environment based on a questionnaire survey. In the presented study, the results of extensive research conducted on the site of office open space, in which there was a high percentage of differently focused complaints about the environment, although all operating parameters of the HVAC system showed more or less optimal values. In the offices we monitored selected parameters of the indoor environment and we did an anonymous questionnaire survey, which used the original system of identification of the workplace in a large administrative space with more than 300 working places. The results of the objective and subjective survey were correlated and the conclusions leading to the identification of the causes of dissatisfaction were drawn. The general benefit of this study is, in addition to an example of a methodological procedure for solving similar problems, the way of locating respondents and also a contribution to understanding the importance of subjective perception of the environment and the evaluation of dependencies between objective and subjective perception of the environment in real conditions of large office.

CASE STUDY

The case study is an indoor environment analysis of three floors of an office building (52 employees on the 2nd floor, 258 on the 3rd floor, and 251 on the 4th floor - open space of 3150 m^2 / 3rd and 4th floor), occurred from June 2018 to May 2019. The aim of the analysis was to determine what is the cause of long-term repeated complaints of employees about the quality of indoor environment and to locate them.

A system of cooling beams in combination with radiators is installed in the building to ensure ventilation, heating, and cooling. 38,200 m^3/h of air is supplied to the monitored floors, of which 29,700 m^3/h of fresh air. According to information from May 2019, there are a total of 561 people on the affected floors, i.e. 53 m^3/h of fresh air is supplied per person, which is slightly more than required 50 m^3/h.

The analysis was based on a questionnaire survey in the form of electronic questionnaires at all workplaces in the area, on a processing of data from the measurement and control system and dataloggers installed in the building from June 2018 to May 2019, as well as on medium-term control measurements of selected indoor parameters in individual working sections in the period from 22 March to 18 June 2019, and also on a detailed measurement of selected parameters of workplaces selected on the basis of the questionnaire survey results and on a local investigation.

Long-term measurement

For the analysis of data from 64 dataloggers (air temperature, CO_2 concentration, and air humidity were measured from 06/2018 to 05/2019 - 1 681 920 values) was used VISIEQ procedure from the "Methodology for assessing indoor environment quality in buildings" (Kabele 2019), developed at the Department of Indoor Environmental and Building Services Engineering, Czech Technical University in Prague. The method of data evaluation is based on the need to obtain a year-round quantified picture of the course of individual quantities. Data from individual sensors were evaluated for the whole year (monthly summaries), for individual months (daily summaries), and for individual days (hourly summaries) in two ways - 1) all measured data, 2) data concerning only working hours (8: 00 - 17:00). For the purposes of this evaluation, air temperature and relative humidity data were classified into 8 categories (± 4, respectively), and in the case of CO_2 into four categories. Limits of the categories were set based on CSN EN15251, Czech decree No. 268/2009 Coll. and the above Methodology for assessing indoor environment quality in buildings (Kabele 2019) so that category "I" corresponds to optimal values and category "IV" to values that are unsatisfactory.

The evaluation by the VISIEQ method (Kabele 2019) showed that the requirements for indoor environment quality (IEQ) given by the valid regulations are met for most of the time in the assessed areas. The evaluation also confirmed the user's perceived local overheating in July 2018, when 24 % of the working time is reached category + IV, i.e. the air temperature is ≥ 27 ° C. For relative humidity, from October to May, are reached categories III and IV, resp. RH <35 % and 86 % of working hours in January are category IV, i.e. RH < 30 %.

Medium-term measurement

The medium-term control measurement, usually lasting for 1 week, was focused on individual working sections (the location of the sensors is evident from Figure 1) and its aim was to map the course of air temperature, relative humidity, and CO_2 concentration and

- ✓ determine the differences in the measured values in the horizontal plane of individual working sections,
- ✓ assess the measured values,
- ✓ compare the MaC temperature sensor data for the relevant working section with the actual measured temperatures.

Output of medium-term measurement was a finding that the data from the MaC temperature sensors in most cases give not entirely accurate information about the actual temperature in the zone. Provided data did not capture extremes, in rare cases there was a completely different trend. Relative humidity measurements confirmed very low values in some working sections. CO_2 measurements identified sections in which the HVAC performance did not correspond to the number of persons.

Short-term detailed measurements at selected working places

The short-term detailed measurement was performed based on the results of a questionnaire survey in 20 selected workplaces, see Figure 1. There were measured following quantities: air temperature, relative humidity, air flow rate, and surface temperature. The aim of the measurement was to determine the immediate state of air flow and temperatures in places with an increased incidence of comfort complaints. Measurements confirmed higher air velocities (in some places up to 0.5 m / s), higher surface temperature equipment of some workplaces (up to 30 ° C), and the occurrence of differences in the vertical and horizontal temperature distribution.

Questionnaire survey

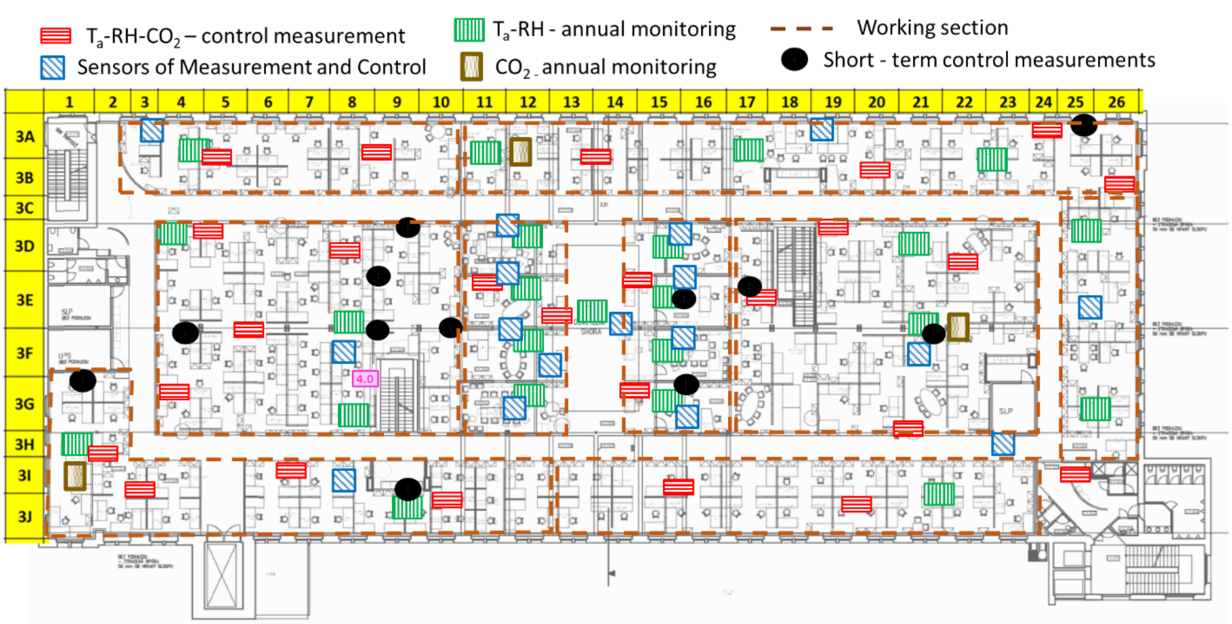

Figure 1 Overview of measuring points and selected working places for measurement – 3rd floor, floor plan

Questionnaire survey, resp. filling in the questionnaire by the respondents, occurred in the period from 17/05/2019 to 31/05/2019 using the online system. The questionnaire survey was preceded by the identification of working places in the form of the placement of numerical codes in the individual floors. These numeric codes were assigned to individual working places based on a system developed to identify the positions of individual employees (3A1 to 3J26) used for the questionnaires; see Figure 1, where the location of the numeric codes for the 3rd floor is shown.

Questionnaires were distributed and answers were collected electronically. 349 respondents out of 561 employees of the solved premises participated in the questionnaire survey and answered the questions (150 employees responded on the 3rd floor - 121 men, 27 women, 2 without specifying, i.e. almost 53 % of the current number of employees, and 157 employees responded on the 4th floor - 135 men, 20 women, 2 without specifying, i.e. almost 62 % of the current number of employees). For respondents who wished to remain anonymous, their exact location was removed from the results. The questionnaire was created bilingually in Czech and English, as employees are from different parts of the world, and contains 53 questions for data collection in the perceived indoor environment quality (IEQ) from the perspective of individual components of the indoor environment (thermal comfort, air quality, light, acoustics, psychical comfort) and their parameters (temperature, air movement, draft, humidity, surface temperature, feeling of stuffy and dry air, etc.) and from the point of view of the workplace and the space as such. Data from the questionnaire were evaluated for the immediate state of the indoor environment perceived at the time of completing the questionnaire, for perceived seasonal comfort in winter and summer, for overall satisfaction with IEQ, for satisfaction with the opportunity to participate on the IEQ and for influence of indoor environment quality on working concentration and on health and psychical state of users. The obtained data were evaluated in summary for the building, for individual floors, and for individual working sections of all analyzed floors.

Due to the scope of the outputs, we will look in more detail at only a summary of some data from the questionnaire survey of the 3rd floor, where 150 respondents participated (121 men, 27 women, 2 without identification), i.e. almost 58 % of the current number of employees.

Immediate state. At the time of completing the questionnaire, only 37 % of the respondents felt well, the remaining 63 % were either stressed or tired. An immediate perceived temperature at the time of filling in the questionnaire shows certain differences within the 3rd floor (Figure 2).

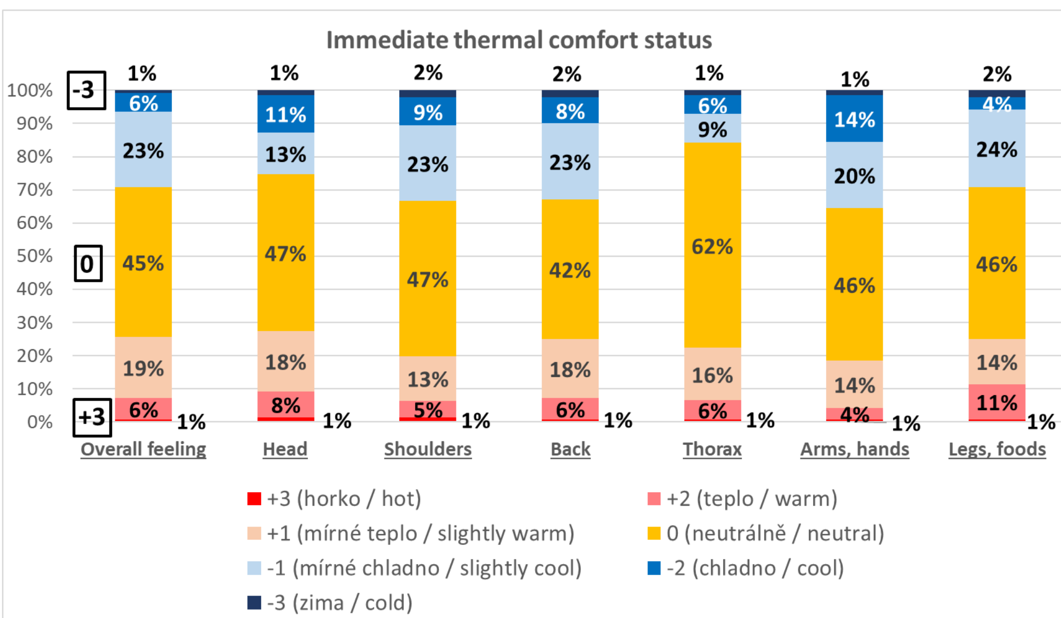

Figure 2 Immediate thermal comfort status, 3rd floor

30 % of respondents perceive feelings (on a seven-point scale, -3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, + 1 = slightly warm, + 2 = warm, + 3 = hot) on the cold side and 25 % on the heat side, while from the graph of partial immediate comfort of 3rd floor respondents it can be concluded that there are vertical temperature differences, both on the side of perceived cold (16-36 %) as well as heat (19-27 %). 36 % of the respondents are dissatisfied, of which 55 % with the requirement of a warmer environment and 39 % with the requirement of a colder environment, 6 % without preferences.

47 % of respondents are dissatisfied with air humidity, 54 % with air quality, and 58 % with air flow, whereas 50 % of respondents perceive the air flow and 50 % respondents do not perceive it, and 94 % of respondents are disturbed by sounds. The answers show that this dissatisfaction is caused by the perceived stuffy air in 43 % of responses, air flow caused by HVAC in 58 % of responses, the perceived noise from colleagues (because of open space) in 68 % of responses and noise of HVAC in 20 %.

Seasonal comfort and workplace. If we look at seasonal dissatisfaction, it can be stated that more than 55 % of respondents are dissatisfied in all 4 areas surveyed (air quality, air flow, temperature, and humidity) both in the winter season and in the summer season, Figure 3. The dissatisfaction of respondents in winter is slightly higher; the greatest dissatisfaction is with air quality (84 %) and air flow (80 %), followed by temperature (60 %) and the least dissatisfaction is with air humidity (58 %). In summer, the greatest dissatisfaction is with air flow (76 %) and its quality (72 %), followed by temperature (71 %) and humidity (56 %).

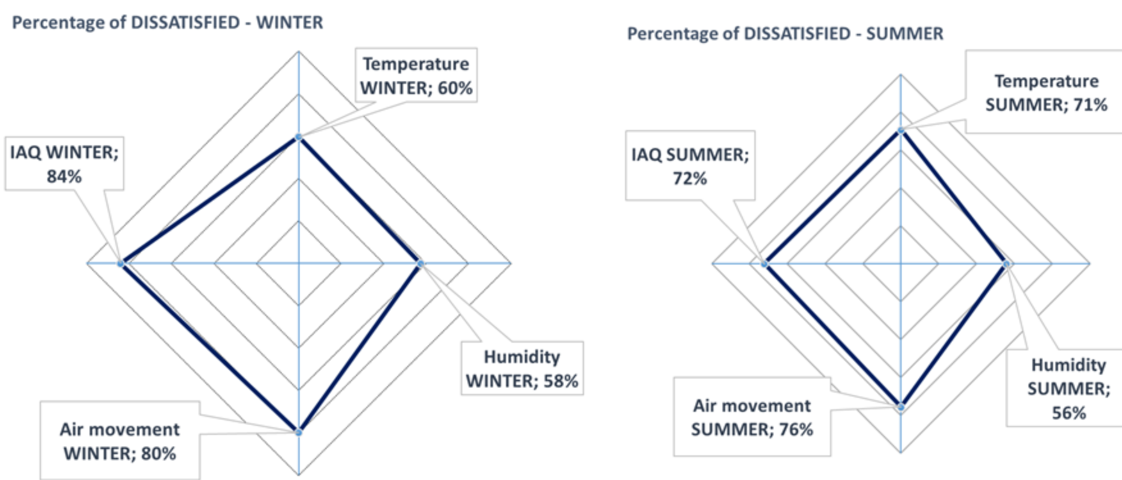

Figure 3 Seasonal dissatisfaction – 3rd floor

In the winter season, the most annoying for 70 % of respondents is stuffy air, an unpleasant draft caused by HVAC for 51 % of respondents, and perceived dry air. In summer season, the most annoying is stuffy air for 61 % of respondents, feelings of heat to hot in 52 % (with a third of respondents bothered by cool to cold), draft from HVAC in 49 %, feelings of dry air in 44 % and no air movement in 43 %.

More than 50 % of respondents are dissatisfied with the equipment and facilities of the workplace and with the placement of furniture. The greatest dissatisfaction in the workplace is caused by sounds in the workplace in 90 % and lack of privacy in 82 %. 69 % of respondents are dissatisfied with amount and quality of daylight, 63 % of them with intensity, and 60 % with the color of artificial lighting.

The opportunity to actively participate in modifying the quality of the indoor environment. The answers to the possibility to participate in adjusting the quality of the indoor environment show that 68-73 % would like to be able to regulate the temperature and air flow in the workplace, more than 50 % of respondents would like to be able to open a window and 34 % / 42 % regulate daily / artificial light.

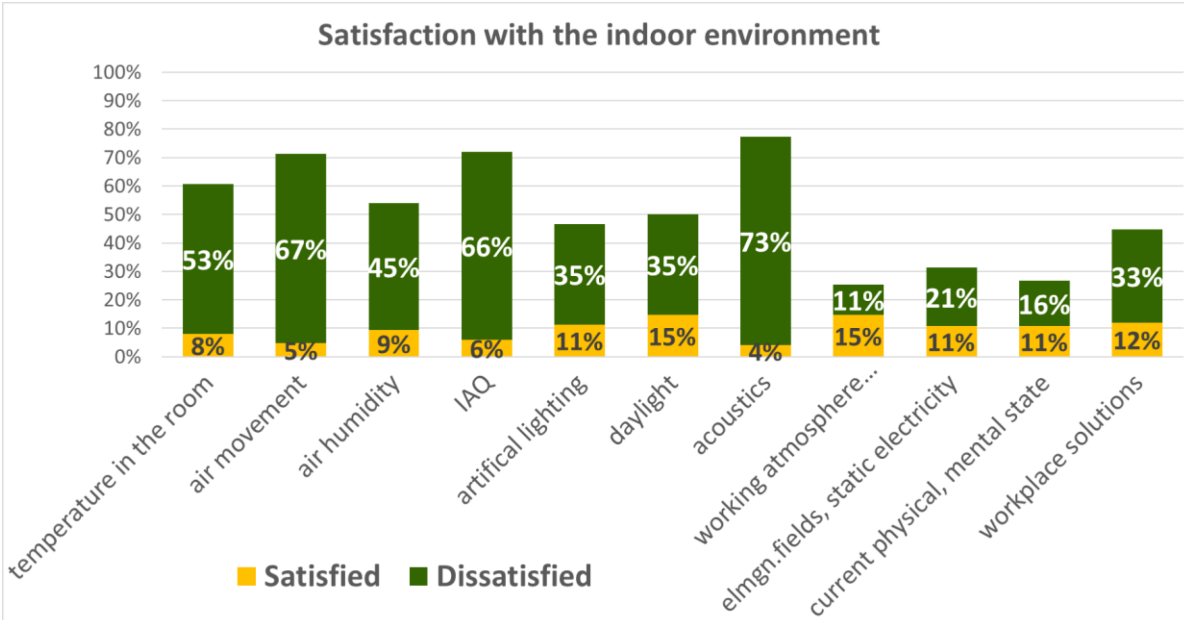

Figure 4 Satisfaction and dissatisfaction with partial parts of IEQ- 3rd floor

Overall satisfaction. The evaluation showed that on the 3rd floor, 51 % of the answers are on the side of overall dissatisfaction with the quality of the indoor environment (on a seven-point scale of -1 to -3), while partial dissatisfaction is evident from Fig 4., where the greatest dissatisfaction is with acoustics in 73 %, air flow and air quality in 67/66 % of responses and room temperature in more than 53 % of responses.

The influence of the internal environment on concentration at work and health and mental state. The current state of the indoor environment in 79 % distracts the concentration of 3rd floor respondents, the biggest influence is noise (70 %), air (51 %), temperature (28 %) and the concentration of people in open space (22 %). Only 7 % of respondents do not perceive any effect of the current state of the internal environment on their health and only 3 % do not perceive any effect on their mental state; rated on a 5-point scale - "not affected at all" to "very affected", see Figure 5). According to the respondents, the greatest influence on the mental state has air quality (35 %), human concentration and noise (32 %), temperature (16 %) and also the quality of light and the inability to open the window.

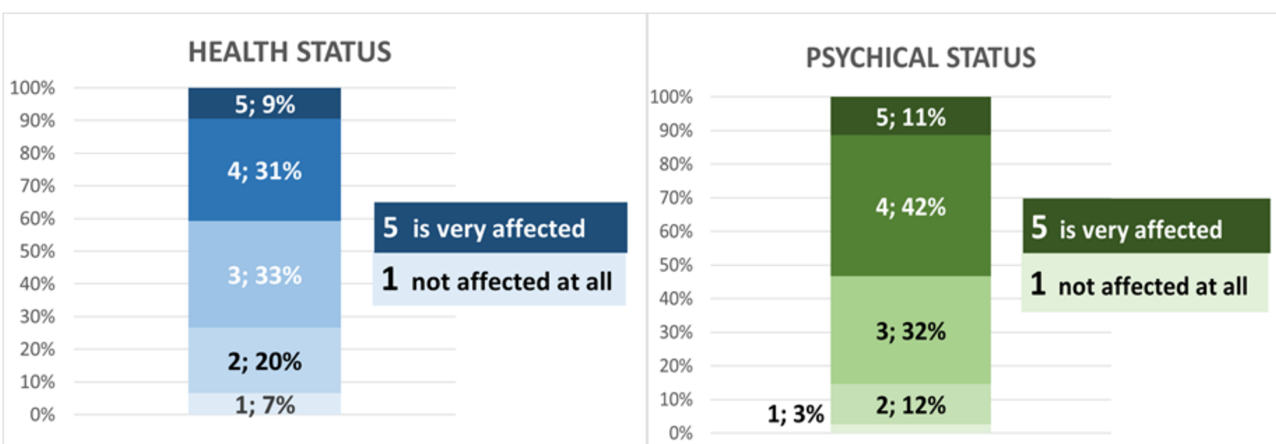

Figure 5 Perceived influence of the current indoor environment quality on the health a psychical status of the respondents - 3rd floor

Questionnaire survey versus measured data

One of the interesting outputs and stimuli for reflection is the graph in Figure 6. where is the correlation between air temperature and subjective evaluation of thermal sensation. On the x-axis are objectively measured values of air temperature in the interior of both solved open spaces in winter and on the y-axis subjective evaluation of 295 users of these spaces at the same time, i.e. at the time of measurement who rated their thermal feeling with a seven-point scale (-3 = cold, -2 = cool, -1 = slightly cool, 0 = neutral, + 1 = slightly warm, + 2 = warm, + 3 = hot). It is clear from the graph that the greatest satisfaction, i.e. the perceived thermal equilibrium, is equal to 24.3 ° C at an air temperature. For lower values, a feeling of slightly cool begins to appear, as shown by the trend in the graph shown in dotted lines. This means that the optimal value of air temperature for most users is 24.3 ° C and if we keep the range of subjective evaluation of the thermal feeling similarly as in the standard ČSN EN 16798-1 −0.5 <PMV <+0.5, then we obtain the range of air temperatures 22.8 - 25.9 ° C. In ČSN EN 16798-1 (formerly ČSN EN 15251) the temperature range for the office for the indoor environment quality category IEQII (Medium level of expectations) for the heating season 20 - 24 ° C is given. This is a range for energy calculations, however the standard states that these are "Initial criteria for the indoor environment", in this case for the thermal environment. The initial design value of the operating temperature in winter for category IEQ II is at least 20 ° C and the assumed thermal feeling PMV −0.5 <PMV <+0.5. The results of our research indicate, for the same range of thermal sensations, air temperature values approximately 2 ° C higher than the standard operating temperature values. This can be caused by low mean radiation temperature (cold surfaces of windows and skylights), lower activity of subjects, thermal resistance of clothing, air flow rate, and other factors, which is the subject of our further research.

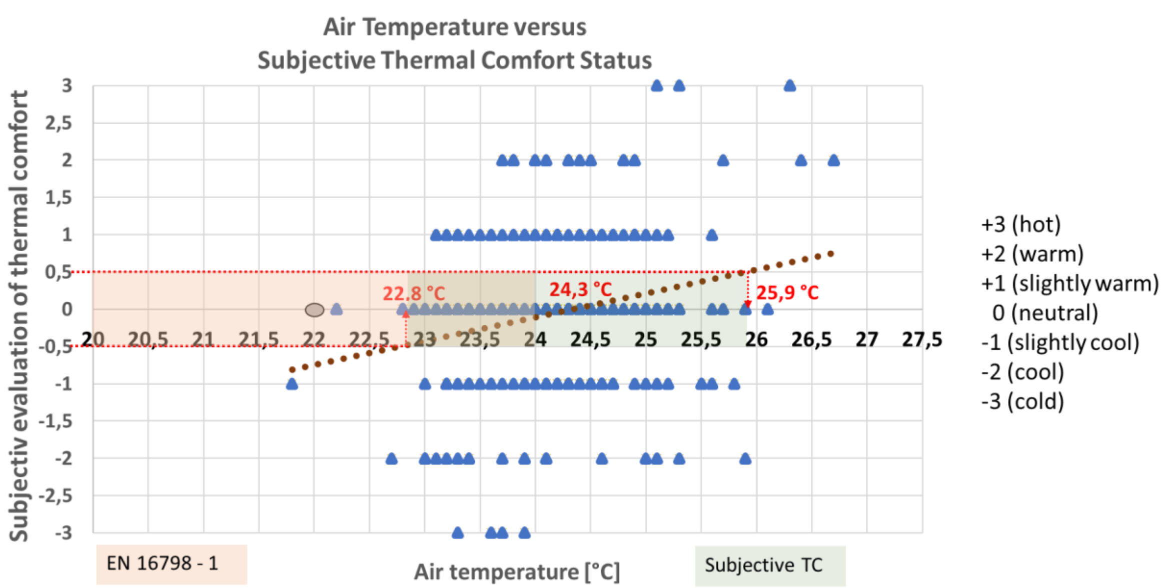

Figure 6 Dependence between the subjective thermal comfort status expressed by a seven-point scale and measured air temperature. The neutral state, i.e. thermal comfort, is achieved at an air temperature of 24.3 ° C. Standard CSN EN 16798-1 assumes a neutral state at operative temperature 22 ° C.

SUMMARY AND RECOMMENDATIONS OF NEXT STEPS

From the performed analysis, resp. from the evaluation of the measured values, it is clear that in the assessed areas the requirements for the indoor environmental quality given by the valid regulations are met for most of the time. The measured values did not show any significant long-term exceedance of the limit values, however, the questionnaire survey indicates the dissatisfaction of a significant group of users. The main reasons given include those typical of large offices. These are noise, lack of privacy, problems with air quality and distribution, air flow (draft/standing air), and temperature conditions, which were subsequently confirmed by short-term measurements. The current HVAC system and control is at its limit and especially in the cooling mode there are local irregularities in the speed and temperature of the supplied air. The objective and subjective methods used to evaluate the indoor environmental quality of open-space spaces clearly show that without modifications to HVAC systems and air distribution, appropriate location and setting of temperature and CO2 concentration sensors, installation of blinds, lighting changes, modifications to the space itself and without enabling the user to participate in the creation of the internal environment, it is not possible to ensure user satisfaction with the quality of the indoor environment. However, this finding would not be possible without a detailed subjective questionnaire and its partial evaluation with a focus on the location of problem areas and their subsequent control measurements.

CONCLUSION

We currently use a simplified model to quantify and evaluate the quality of the indoor environment, describing and evaluating the individual components of the environment separately. However, one perceives the environment as a whole, and so routine evaluation without interrelationships can lead to and often leads to a situation where the monitored parameters of individual components of the internal environment are seemingly fine, yet users complain about the environment. This is, of course, a confirmation of the fact that the environment is perceived by each user individually and it is not possible to create an environment where all users would be satisfied, as Prof. Fanger published in the form of a 5 % dissatisfied rule (Fanger 1970). It is obvious that if we want to evaluate the "well-being of the environment" for humans, it is necessary to evaluate the indoor environment comprehensively using objective and subjective evaluation methods and also considering the building and its parts, evaluated space and technical systems that contribute to environmental quality. In addition, subjective assessment in current buildings often indicates that it would be appropriate to consider whether the existing reference values used for objective assessment of environmental quality should not be updated (especially temperature parameters) and that the links between measured values and subjective perception of the environment are more complex. Dependent on other parameters the case study confirmed the hypothesis that in open space most users would welcome the possibility of individual adjustment of physical parameters of the environment by controlling HVAC systems and noise, IAQ, movement and air temperature are the main causes of dissatisfaction in the workplace. A detailed analysis of the correlation between air temperature and subjective perception of thermal sensation showed that the recommended standard values of operating temperature are low for a given space and users prefer approximately 2 ° C higher air temperature, which is the subject of our further research.

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