Users’ satisfaction of indoor environmental quality conditions in ZEB+ at high latitudes

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Abstract. Energy efficiency policy forces architects to design buildings with increasingly well-sealed building skin. With the minimized outdoor connection, the indoor environment factors depend strongly on technical systems and control. In these scenarios, occupant dissatisfaction indicates a need for improvements of indoor environment and the way it is controlled. The aim of the article is to contribute to the discussion about the user perspective of indoor environmental quality in ZEB in the Nordic region. The focus on daylight as a factor for visual comfort, and on low outside temperature as an aspect of thermal comfort was dictated by this choice. An experimental study was conducted with 75 participants, in which the thermal, acoustic and visual conditions (controlled factors) together with a view out, humidity and CO2 level (monitored factors) were assessed by them and quantified via sensors. In most studied settings, the thermal comfort was the most determinant factor, followed by the acoustic and visual comfort. Other significant factors were mean illuminance in the room, mean temperature at the participants’ desks and a mode value of the noise level. The daylight levels much lower than recommended in regulations were accepted by participants as comfortable if they were sitting by the window. Also, participants preferred a higher indoor temperature than the recommended in Norway.

1. Introduction
Humans are extremely adaptive to the environment, which allows us to survive as a species. But the repetitive adaptation to uncomfortable conditions is difficult to combine with health maintenance and a high level of performance expected nowadays e.g. from office workers. Also, the opportunities to individually adjust the indoor conditions are limited in most new office buildings today. Windows cannot be open for natural ventilation. Automatically operated sun-shading devices cannot be individually adjusted for optimal daylighting. Similar restrictions apply to ventilation, heating and electric light systems. Fixed working days and fixed workstations reduce temporal and spatial adaptive opportunities, meaning that employees are not able to change their working place and hours. In addition, office occupants rarely change their clothes during the working day to adapt to internal environmental conditions [1]. As the automated control of the indoor environment quality (IEQ) parameters becomes
a standard, more knowledge is necessary to optimize it, especially deeper knowledge of occupants’ comfort/discomfort experience is very much needed. In this regard, comfort can be defined as the subjective sensation of an indoor environment, including physical comfort (e.g. temperature, illumination etc.), functional comfort (e.g. disturbances, interruptions from work) and psychological comfort (e.g. privacy and territoriality) [2]. The scope of the present paper focuses on the physical comfort of the users. More specifically, on the thermal, acoustic and visual conditions at high latitudes.

Regarding thermal comfort, in a study comparing office layouts with high level of thermal control (traditional cellular office) and low level of thermal control (open plan office) found that individual thermal control resulted in 35% higher user satisfaction and 20% higher user comfort compared to open plan offices. At the same time, individual thermal comfort significantly increased the energy consumption of these offices. Researchers suggested, that individual user control over both temperature and ventilation, instead of using a centrally controlled air conditioning for fresh air and user control of radiator for temperature control, can help to reduce the energy use [3].

Regarding acoustic comfort, and considering that an office work requires high concentration, good acoustic conditions are needed. Speech, noise from ventilation systems, office machines and from the outside may cause annoyance and reduce the productivity of the occupants. Interestingly, high noise levels contribute to thermal discomfort and a temperature change of 1°C may have the same effect on productivity as a change in the noise of 2.6 – 2.9 dB [4]. Frequently experienced noise at work (e.g. loud air conditioning, internal machines such as fax machines and telephones) can produce annoyance that may result in significantly higher stress levels, and thus overall environmental discomfort.

Regarding visual conditions, it is well-known that vision cannot operate without light. Daylight is the natural and the most appropriate light for humans. It enables perfect colour rendering, natural directionality and supports our circadian rhythms [5]. Therefore, the daylight temporal availability and the daylight level are the most important aspects of providing a healthy and comfortable visual environment [6;7]. Previous studies showed also that office occupants strongly prefer daylight over artificial lighting [8]. Other factors as glare, light uniformity and colour rendering are frequently associated with visual and overall comfort [9]. Nevertheless, the light level remains the most relevant factor affecting visual comfort. In the Nordic region, with short daytime during the winter, it may become even more critical to provide the required amount of natural illumination supporting employees’ physical and mental health and productivity. A too low light level that is a rather usual case in the Nordic region, may cause visual discomfort, as it won’t provide an adequate amount of light required for visual task accomplishment.

Researchers of the European project OFFICAIR on indoor environmental quality assessments of modern office buildings in eight European countries found that the highest association with occupants’ overall comfort was for “noise” factor, followed by “air quality”, “light” and “thermal” satisfaction [10]. In a previous study carried out in 26 offices across five countries over North-Central and South Europe, including 4655 respondents, thermal comfort was identified as the most important factor [11]. Another study performed in China examined the IEQ satisfaction in cellular offices with various thermal conditions (18°-32°C), acoustic conditions (45-65 dB) and lighting conditions (100-1300 Lux). Authors found that thermal and acoustic conditions were the most important factors for the overall comfort of the occupants [12].

Although the literature regarding indoor environmental quality can be considered vast, to the authors’ knowledge, there is little research considering daylight, especially daylight at high latitudes, as a factor in IEQ studies. In most of the studies, electrical lighting was used as a factor of visual comfort and glare caused by electrical lighting as a factor of visual discomfort.

The main objective of this study was to investigate IEQ satisfaction through the examination of thermal, acoustic, and visual conditions. The specific aim was to examine IEQ satisfaction during wintertime (November) at the location representing the Nordic region (Trondheim, Norway, latitude 63°43’). Consequently, the visual comfort has been examined for low daylight levels and the thermal comfort in the presence of low outside temperatures. The experiment was carried out in overcast sky conditions (no direct sunlight) which is the dominating weather type most of the year, and especially
during the winter, in the Nordic region. The results will contribute to knowledge about the impact of different factors on IEQ satisfaction in the location and development of control systems that better meet occupants’ comfort needs.

2. Method

The experiment was carried out in the Test Cell Laboratory (SINTEF/NTNU) built according to Zero Emission Buildings (ZEB) standard (see Figure 1a). The cells are 4.35 m × 2.5 m in size; are equipped with a single South-West oriented window (1.10 m x 1.10 m) and a single standard door. Since the cells are identical, both cells were used simultaneously in the same way, which enabled researchers to streamline the experiment time. The cells allowed efficient control of heating and ventilation. The experiment was performed during November.

2.1. Experiment set-up

Two workstations were placed in each cell, they consisted of simple working desks and office chairs. The desks were positioned at the room (and window) axis, the first one (desk I) was placed next to the window, while the second one (desk III) was placed 2.75 m far from the window. One more desk (desk II) was positioned between these two workplaces and was used for a laptop and the acoustic equipment (see Figure 1b). Windows of both rooms are equipped with shading systems controlled from a central server; however, due to the overcast weather conditions, these were not used. Sensors collecting the data were deployed at the walls, at the desks (I and III) and at the wall outside the building. These were sensors for temperature and humidity registration (C1 – C3), inside illuminance registration (D1 – D8), outside illuminance registration (D9), CO2 level registration (E1) and noise registration (F1). The data from these sensors were collected during the whole experiment 24 hours a day, whereas only relevant time periods were analysed.
2.2. Participants
This experiment involved 75 participants. 80% of the participants were 19-29 years old; 13.3% were 30-39 years old; rest of the participants represented other age groups. 50.7% of the participants were males and 49.3% were females. Norwegians accounted for 24.66% of the participants, the rest of the group represented other nationalities. Clothing insulation of the participants varied from 0.31 to 1.34 clo, with an average value equal to 0.78 clo and mode value equal to 0.65 clo. This was registered via questionnaires filled out by the participants (see section 2.5). 53.3% of the participants had normal vision, the rest of them used either glasses (37.3%) or lenses (9.3%). 45.3% of the participant consumed coffee prior to the experiment. 95% of the participants reported that they have good hearing.

2.3. Experimental procedure
Due to the short-day length at high latitudes in November, only one experimental session a day could be carried out i.e. between 09:30 and 13:00. Each session lasted approximately 2.5 hours, including introduction (where procedure, terminology and other details were explained to the participants), and a short lunch pause. Four people participated in the experiment at a time (one pair in each experimental cell) testing the same stimuli combination (SC) and being exposed to eight consecutive SCs arranged in randomized order (see Table 1).

2.3.1. Thermal conditions. The city of Trondheim, Norway is located at 63°43’ N, and 10°40’ E. The Köppen Climate Classification subtype for this climate is “Dfc” - Continental Subarctic Climate [13]. This type of climate characterizes by having long, usually very cold winters. Although November is not considered a common winter month for other parts of the world, it is not uncommon to experience winter features during this month in Trondheim. Accordingly, the registered outside temperature conditions during November in Trondheim presented an average of 1° C and 80% humidity. Indeed, the ground was covered by snow during the experiments. The tested temperature levels (21°C as comfortable and 25°C as uncomfortable) were selected following Norwegian recommendations on thermal conditions at working places specifying permissible temperature range from 19 to 26 degrees but recommended to keep it below 22 degrees most of the operational time [14]. The required temperature in the cells was regulated and adjusted via computer; it was done based on temperature levels measured by the globe-thermometer installed in the centre of each cell (see Figure 1c). This computer system regulated the temperature of the air coming into the cell through ventilation, therefore some minor deviations from the set temperature could occur. The temperature was homogeneous across the cells i.e. the temperature at both seating places was equal. To shorten the experiment duration and accelerate room heating (from 21°C to 25°C), a simple electrical heater was used in addition to ventilation. They were positioned at the floor and approximately in the middle of each cell. Heaters were activated during the short break when the participants were sitting in the Meeting room. The heaters did not have any fan, so no additional and unrequired noise was produced.

2.3.2. Acoustic conditions. The noise level equal to 38 dB presented comfortable conditions, and 50 dB presented uncomfortable acoustic conditions. These quantities were chosen based on Norwegian recommendations on the acoustics conditions at the work places with low noise levels, where recommended highest noise levels should not exceed 45 dB during the working hours. These levels were achieved through a play of recorded fan sound via the advanced acoustic system, which enabled precise volume control.

2.3.3. Visual conditions. In the scope of the present research, daylight was the only light source in the study, not including artificial lighting in the experiments. This study was focused on light level, excluding glare as additional factor. Considering that sun angles in the winter months tend to be low and can produce glare, sunlight was thus not present in the experiments, and overcast sky conditions were used. Weather conditions in the Nordic region during the autumn-winter period provide very restricted access to daylight (short daytime length, low outside illuminance levels) with a low frequency
of sunlight. As direct sunlight was not present during the experiment there was no significant risk of glare, and no glare was reported by any participant. The comfortable and uncomfortable visual environment were enabled through the choice of the seating position (short/long distance from the window). The participant sitting at the desk close to the window (desk I) had a higher light level and a rather large view through the window. At the same time, the participant sitting at the desk III had the significantly lower light level and much more limited view out (see Figures 1b and 1c).

Table 1. Eight combinations of indoor environmental conditions tested during the experiment.

| Stimuli combination | Corresponding indoor environmental condition |
|---------------------|---------------------------------------------|
| SC 1                | T_c+A_c+V_c                                |
| SC 2                | T_c+A_u+V_c                                |
| SC 3                | T_c+A_c+V_u                                |
| SC 4                | T_c+A_u+V_u                                |
| SC 5                | T_u+A_c+V_c                                |
| SC 6                | T_u+A_u+V_c                                |
| SC 7                | T_u+A_c+V_u                                |
| SC 8                | T_u+A_u+V_u                                |

* Table notes: Subscript “c” means comfortable conditions, subscript “u” means uncomfortable conditions. Letter T means temperature, Letter A means acoustic conditions, letter V means visual or lighting conditions.

2.4. Data collection
To monitor and register physical indoor environmental conditions, several sets of the sensors were deployed. These sensors included: one external light sensor measuring outdoor illuminance on the window wall every 10 seconds (range 10 to 100 000 Lux), eight indoor light sensors measuring illuminance level at horizontal and vertical surfaces in the room every 5 seconds (range 1 to 40 000 Lux), three sensors measuring temperature (range -40℃ to 125℃) and humidity in the room (range 0% to 100%) every 5 seconds, and one sensor measuring noise level in the room every 5 seconds (range 8 to 80 dB).

2.5. Written questionnaires
The main questionnaire form included sets of questions to be answered on a 5-point Likert-typed scale. These questions included the evaluations on i. overall comfort (evaluation of all three main factors of IEQ), ii. thermal comfort, acoustic comfort and visual comfort separately, iii. satisfaction with the air quality in the room, and iv. quality of the view from their seating positions. Additionally, there were questions of choice for overall comfort among temperature, noise, lighting and other factors including i. choice of the most important factor, and ii. choice of most disturbing factor. Moreover, two preference questions were added: i. preferred changes to the perceived thermal-, acoustic-, and visual conditions (measured in 5-point scale), and ii. preferred change of seat location in the room (to be marked in a drawing). Finally, the participants were also asked to provide demographic (age, gender, country of origin), personal (height and weight, profession/occupation, vision- and hearing ability), and supplementary information (coffee consumption, evaluation of the psychological atmosphere at home and work/school, and clothing). This information could be important for their subjective evaluation of environmental comfort [15], e.g. caffeine can potentially affect the cognitive performance of the participants at the experiment, and thus was used for statistical analysis.

3. Results
3.1. Statistical analysis
A two-level ordinal regression analysis using the software STATA was applied. This statistical approach allowed to analyse the multiple studied factors together with the sensors’ data readings. The analysis was performed for each SC separately and for all the SCs together, resulting in nine analysis blocks. The studied factors of this study are in Tables 2 and 3.
3.2. Results

3.2.1. Overall comfort satisfaction across all stimuli combinations. The results indicate that the participants’ satisfaction with thermal conditions is the strongest factor affecting IEQ satisfaction in this experiment. The more satisfied with the temperature inside the cell, the higher the participant rated the overall comfort in the cell. Other two important factors that almost equally strongly affected the assessment of IEQ are the acoustic comfort and visual comfort. They also affected the perception of indoor environmental comfort in a positive manner, so higher rates of acoustic and visual comfort resulted in higher rates of overall comfort. Other significant factors are found in Table 2.

Table 2. Results of the two-level ordinal regression performed based on combined data of all eight SCs.

| Factors tested                              | Odds Ratio | Standard Error | z    | P>|z| |
|---------------------------------------------|------------|----------------|------|------|
| View satisfaction                           | 1.055      | 0.118          | 0.48 | 0.634|
| Thermal comfort satisfaction                | 2.428      | 0.193          | 11.17| 0.000|
| Acoustic comfort satisfaction               | 1.669      | 0.147          | 5.81 | 0.000|
| Visual comfort satisfaction                 | 1.521      | 0.138          | 4.61 | 0.000|
| Indoor air quality (IAQ) satisfaction       | 1.146      | 0.105          | 1.48 | 0.139|
| Psychological atmosphere at work            | 1.236      | 0.147          | 1.79 | 0.073|
| Illuminance at the desk (E_{desk})          | 0.997      | 0.003          | -1.30| 0.192|
| Illuminance in the room (E_{room})          | 1.099      | 0.004          | 2.48 | 0.013|
| Temperature at the desk (T_{desk})          | 0.605      | 0.152          | -2.00| 0.046|
| Temperature in the room (T_{room})          | 1.544      | 0.412          | 1.63 | 0.103|
| Noise (mode)                                | 0.952      | 0.018          | -2.65| 0.008|
| CO_{2} level (registered)                   | 1.000      | 0.001          | 0.23 | 0.820|
| Humidity in the room (H_{room})             | 0.972      | 0.023          | -1.19| 0.234|
| Level 2 variance                            | 0.901      | 0.288          |      |      |

* Table note: Alpha level 0.05, z = z-value, P>|z| = p-value for z statistic.

3.2.2. Comfort satisfaction for the individual SCs. The separate results for each stimuli combination were analysed based on the descriptive statistics and the two-level ordinal regression analysis. The simplified results are on Table 3. More complete numerical results are available from the authors upon request.

Table 3. Table showing simplified statistical results as significance of each tested factor for each particular SC, where *** means highly significant, ** - moderate significance, * - just significant.

| Factors tested                              | Significance of each factor for particular stimuli combination |
|---------------------------------------------|-----------------------------------------------------------------|
| Thermal comfort satisf.                     | *** SC1 T_{c}+A_{c}+V_{c} *** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Visual satisf.                              | *** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Acoustic satisf.                            | *** SC1 T_{c}+A_{c}+V_{c}** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Noise, mode value                           | ** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Air quality satisf.                         | *** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| M illuminance room                          | * SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Prior coffee consumption                    | * SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| M temp. room                                | ** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| M temp. desk                                | ** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| M_{wall} wall front partic.                 | * SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Ratio[M_{desk} /M_{room}]                    | * SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Psych. comp. work/univ                     | *** SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |
| Clo value                                   | * SC1 T_{c}+A_{c}+V_{c}*** SC2 T_{c}+A_{c}+V_{c} *** SC3 T_{c}+A_{c}+V_{c} *** SC4 T_{c}+A_{c}+V_{c} *** SC5 T_{c}+A_{c}+V_{c} *** SC6 T_{c}+A_{c}+V_{c} *** SC7 T_{c}+A_{c}+V_{c} *** SC8 T_{c}+A_{c}+V_{c} |

* Table notes: M - Mean M_{lux} - Mean illuminance, Clo – clothing.
4. Discussion

Regression analysis of the results of all stimuli combination showed objective results. It is important to note that in the tested situations with moderate discomfort conditions that frequently exist in real offices the thermal comfort was the determinant factor for overall comfort satisfaction. The visual and acoustic comfort satisfaction were other two statistically significant factors. Mean illuminance of the room (rather than illuminance on the desk), mean temperature at the participants’ desks (rather than in the room) and noise mode were factors that were of importance according to analysis. However, it is interesting that thermal conditions that were expected to be uncomfortable (25° C), were, in fact, more preferred by participants than conditions with 21 degrees that were considered to be comfortable. The factor that could have affected temperature preferences was the outside weather conditions (around 1° C, snow). The participants exposed to the cold air on the way to the Test Cell Lab appreciated warmer conditions indoors more than could be expected.

These results seem to be in accordance with research stating that cold climatic conditions, such as the ones existing in Nordic regions, have been found to be an important factor that influences the need to count with higher temperature levels indoors [16;17]. Thus, within SC1 (air temperature 21°) 56% responded that air temperature in the room was either comfortable or somewhat comfortable. But, within SC5 (air temperature was 25°) 65% of respondents positively evaluated the air temperature in the room. As it was noted earlier, the temperature range in Norwegian offices may vary from 19 to 26 degrees, but it is recommended to not exceed 22 degrees. Thereafter, even though this is dictated by energy saving, the recommended level is not always comfortable, as our results show.

Interestingly, even though the average illuminance at the working place situated by the window was low (oscillated around 100 lux), it has been perceived as comfortable by most participants This testifies about the easiness of visual adaptation of young people, but also that they enjoy low light levels in the vicinity of the window where they may perceive low light level outdoors.

From the numerical results and comparing SC6 (Tu+Au+Vc), SC7 (Tu+Ac+Vu) and SC8 (Tu+Au+Vu) we may observe that significant dissatisfaction with sound in SC6 or light in SC7 alone does not result with a large number of subjects dissatisfied with IEQ. If the uncomfortable conditions occur for both sound and light simultaneously, as in SC8, the number of subjects dissatisfied with IEQ (14%) is higher than the sum of dissatisfied with IEQ because of sound (3%) and dissatisfied with IEQ because of light (4%).

5. Conclusions

In this study, the overall comfort of occupants in small offices built according to Zero-emission building principles was examined. Three major components of indoor environmental quality (thermal, acoustic and visual conditions) together with the view out, humidity and carbon dioxide level were included into the experiment. These parameters were assessed by experiment participants and monitored via sensors. Participants had no individual adaptive opportunities, i.e. the ability to open the windows, turn on or off the air ventilation, the source of the noise or radiators, change of the clothes. This policy of deprivation of individual control over aspects helping to adapt to IEQ becomes more and more popular in energy efficient buildings widely designed and promoted nowadays, also in Norway. Daylight, a natural and healthy light, was chosen as the only light source for experimental rooms; it is a common knowledge that daylight if used at most during the working hours, contributes to energy saving.

The results showed that in most studied stimuli combinations when the participants experienced moderate discomfort conditions similar to real office conditions, the thermal comfort was the most determinant factor of indoor environmental comfort. Acoustic and visual comfort were the next two factors that influenced participants’ assessments equally strong. Other factors that were statistically significant were: i. mean illuminance in the room, ii. mean temperature at the participants’ desks, and iii. mode value of the measured noise level in the room. Nevertheless, the importance of light should not be overseen. When asked which environmental condition was the most important for the experience of overall comfort, lighting scored considerably higher than noise in all stimuli combinations; temperature scored highest. The results suggest that at office workplaces occupied by young people in
the close vicinity of windows, the lower limit of the average illuminance at the desk may be reduced from 500 lux to 100 lux. This implies a potential for energy saving if applied in the control system for electric lighting.

The study points also that the recommendation for maximum 22 degrees for a thermal comfort in buildings situated in cold climate during winter is too strong, as the temperature of 25 degrees (used as uncomfortable in the study) was appreciated more than 21 degrees (used as comfortable) by the majority of participants.

IEQ is a multilateral concept affected by physical and psychosocial aspects. Being in a small office in a modern energy-efficient building with minimized adaptive opportunity, thermal, visual and acoustic conditions are highly important. Workstations placed by the window may be sufficiently illuminated exclusively by daylight over a longer time than it happens in practice creating good conditions for cognitive work, view out and energy saving. The results of this study shed new light to office design, contributing to discussions about daylighting and temperature effects on users’ satisfaction.

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