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Perception of Indoor Environmental Conditions in a Hungarian Secondary School

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ABSTRACT

In a continental climate during winter the outdoor environment is cold and windows are generally closed in a school building. The mental development of the pupils highly depends on the supplied fresh air amount; therefore the efficiency of ventilation is a main issue. Two different sized same orientated classrooms in a secondary school in Hungary were examined by measuring indoor air temperature, relative humidity, CO_2 concentration and illuminance levels for representative days in February 2020. Pupils' perceptions of indoor environmental conditions were investigated via questionnaires, which targeted their subjective perception on the relevant parameters, rate of satisfaction and habits of natural ventilating. Pupils' sensation votes were found significantly different in the two classrooms in thermal and air quality. The subjective thermal perception was found to be in connection with the objective data. Males' and females' thermal and air quality sensation also differed significantly: males perceive conditions warmer and staler air quality. Occupants whose self-assessment was tired perceived temperature higher, air quality staler, surrounding darker and they are generally less satisfied compared to their non-tired colleagues. The participants voted dominantly for air quality and thermal aspects as suggestions for improvements, which matches their primary reason of operating windows.

Keywords

Indoor air quality, hygro-thermal aspects, natural ventilation, data acquisition with questionnaires, indoor environmental quality

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KURZFASSUNG

In einem kontinentalen Klima ist im Winter die Außentemperatur kalt. In Schulen sind die Fenster generell geschlossen. Die geistige Entwicklung der Schüler hängt auch stark von der Menge der Frischluft ab, so hat die Frischluftzufuhr eine hohe Bedeutung. Zwei Klassenzimmer in einem ungarischen Gymnasium mit unterschiedlicher Größe aber gleicher Ausrichtung wurden diesbezüglich untersucht. An repräsentativen Tagen im Februar 2020 wurden die Innenraumtemperatur, relative Feuchte, CO_2 Konzentration und Lichtstärke gemessen. Das Empfinden der Schüler bezüglich der Raumkonditionen wurde mit Hilfe eines Fragebogens untersucht. Ziel des Fragebogens war es, das subjektive Empfinden der relevanten Parameter abzufragen, die Zufriedenheitsrate zu bestimmen sowie das Verhalten der Schüler zur Fensterlüftung festzustellen. Das momentane subjektive Empfinden der einzelnen Schüler, bezüglich der Raumtemperatur und der CO_2 Konzentration in den zwei Klassenräumen wurde signifikant unterschiedlich empfunden. Die objektiv gemessenen Werte konnten mit dem subjektiven Empfinden sehr gut in Relation gebracht werden. Die Raumtemperatur und die Luftqualität wurde von den männlichen Teilnehmern anders bewertet wie von den weiblichen Teilnehmern: männliche Teilnehmer empfinden die Temperatur generell wärmer und die Luftqualität schlechter. Die Schüler, die sich im Fragebogen als müde beurteilt haben, empfanden die Raumtemperatur höher, die Luftqualität schlechter und die Lichtstärke schwacher als der Rest, welche sich nicht als müde beurteilten. Die hauptsächlichen Vorschläge der Teilnehmer zur Verbesserung des Raumklimas waren der Einfluss auf die Raumtemperatur und Luftqualität. Der Hauptgrund der Fensteröffnung bezieht sich ebenfalls auf die zwei vorgenannten Punkte.

Schlüsselwörter

Innen Luftqualität, hygro-thermische Aspekte, Fensterlüftung, Datenerfassung durch Fragebogen, Innenraumklima

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CONTENTS

1 Introduction 1
1.1 Background 1
1.2 Motivation 6
2 Method 8
2.1 Overview 8
2.1.1 Describing the onsite measurements 10
2.1.2 Surveys 12
2.2 Research questions 15
2.3 Analysis 17
3 Results and discussion 19
3.1 Overview of monitored data 19
3.1.1 Cumulative distributions 19
3.1.2 Psychometric chart and comfort window 25
3.2 Questionnaires targeting instantaneous perception 27
3.2.1 Time range satisfaction 29
3.2.2 Sensation votes in the two classrooms (Q1 and Q2) 30
3.2.3 Perception differences among pupils of different genders (Q3) 35
3.2.4 The effects of tiredness (Q4) 39
3.2.5 Ventilation habits (Q3 and Q4) 44
3.2.6 Perception differences among pupils of different genders and ages (q4) 47
3.2.7 Distance of the seating location from the windows (q3) 50
3.2.8 Suggestions for improvements 52
3.3 Feedback from the second questionnaire 54
3.3.1 Time spent indoors (q1) 55
3.3.2 Intelligibility of not yet tested questions (q2) 56
3.3.3 Outdoor contact 58
4 Conclusion 59
5 INDEX 62

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5.1 Index of figures 62
5.2 List of tables 63
6 References 65
7 Appendix 71
A. Questionnaire 1 71
B. Questionnaire 2 72
C. Satisfaction as a function of gender sorted in ages of pupils 73
D. Calculations 79

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1 INTRODUCTION

1.1 Background

In the future more and more emphasis is going to be laid on energy efficiency of the building sector because of being responsible for a 40 % share in global energy consumption. There is a large gap between residential (200 kWh/m^2/a) and non-residential (295 kWh/m^2/a) buildings' energy consumption (Ascione et al., 2015). To reduce the difference, it is inevitable to have better building envelope, more efficient HVAC systems and cognisant users. But it is also necessary to keep an eye on indoor conditions. This is especially true for educational buildings.

Air permeability, air exchange rates, effectiveness of natural ventilation and indoor pollutant concentration in Italian primary school classrooms were evaluated. Air exchange rates were higher at depressurization tests than at pressurization tests. On average the estimated air exchange rate via infiltration at natural pressure was 5 % of the required values, which implies that solely infiltration will not provide enough fresh air to the spaces, therefore ventilation is necessary (Stabile et al., 2016). There are two types of schools: the ones which are naturally ventilated and the others use a mechanical ventilation system. It is not obvious which one is better. The main decisive question is whether mechanical ventilation is well designed and is able to provide sufficient amount of fresh. Whether this fresh air amount is well distributed in the classrooms and the pollutants are extracted.

In India an attempt to show an unquestionable difference between a naturally ventilated and an air conditioned lecture hall have failed. There was no significant evidence found of one type being better than the other (Mishra and Ramgopal, 2015a). In energy analysis simulation in Portugal different scenarios of mechanical ventilation were examined. The primary problem was not having enough money to spend on the operation of the ventilation device. Reduced air flow but extended schedule of the system is calculated to result in air quality improvement and 4.5 % energy conservation (Bernardo et al., 2017). In Portuguese retrofitted schools the mechanical ventilation system was shut off because of operation costs (Almeida and Freitas, 2014). Spanish naturally ventilated schools' indoor air quality was compared to mechanical ventilation system equipped schools'. The results showed that manually operating the windows and wasting heat through the windows unrecovered is still more economical, than paying the operation costs of the mechanical ventilation system (Gil-Baez et al., 2017). Mechanical ventilation often does not meet acoustical requirements, so it not always provides a complete solution (Mumovic et al., 2009).

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On the other hand, natural ventilation does not always sufficiently provide air change rates. 5, 10, 15 and 20 minutes in an hour of manual ventilations periods were compared in a test-classroom in Italy. The shorter the manual airing period the poorer was the air quality. In case of only 5 minute long periods restriction the teacher decided to open the door of the classroom because the conditions were unbearable. Even with the 20 min/h ventilating scenario the ventilation rate per capita was less than half of the minimum required value (Stabile et al., 2019). The same author found in a previous work that to improve air quality the occupants open rather the door to the corridor, than the external window. And in heating period a 1.2–3.5 times higher CO_2 concentration was measured compared to non-heating period (Stabile et al., 2017). Some studies directly find mechanical ventilation better, than natural ventilation. In mechanically ventilated classrooms in the UK the CO_2 level has not reached 1000 ppm, meanwhile the examined naturally ventilated classrooms often suffered high concentrations of CO_2 and from draughts (Mumovic et al., 2009). A joint probability analysis was performed with indoor and outdoor air temperatures as drivers of manual ventilation in Portuguese schools. If outdoor running temperature is above 19 °C, an effective manual ventilation can be done, between 16 °C and 19 °C the ventilation depends on the indoor temperature, and below 16 °C and generally for the cold period there is only a limited amount of fresh air supply possible through the fenestrations because occupants refrain from opening the windows. Although these findings have limitations, because only temperature is taken into account as driver of window operation (Duarte et al., 2017). In a study conducted in Kuwait (desert climate) increasing the length of the breaks were suggested to tackle poor indoor air quality (Al-Rashidi et al., 2012). In Italian schools short but frequent operation of windows is suggested as the appropriate ventilation mode (Schibuola et al., 2016).

Some researchers use CFD analysis of a specific classroom to gain more insight in the aerodynamics of the space and energy efficiency of the system (Wang et al., 2014). In a Chinese study pupils exposed to such areas, where the ventilation effectiveness was good enough, felt better (Song and Meng, 2015). Other researchers build test classrooms and conduct in situ measurements. Natural ventilation by manual window opening; automated operable windows; automated operable windows combined with exhaust fan; and mechanical ventilation system ventilation system types in a school were compared in Denmark. The lowest ventilation rate (ca. 2-4 L/s/person) was measured in the naturally ventilated classroom and 7.5 L/s/person (highest) in the classroom where mechanical ventilation was built in. Symptoms such as headache, tiredness, dried lips etc. where found to be more common in the mechanically ventilated classrooms, and the least symptoms occurred in spaces with automated windows and exhaust fan. Surprisingly the air quality was assessed to be worst in the mechanically ventilated area, presumably due to airborne pollution in the filters of the air handling unit (Gao et al., 2014). Other researches have

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revealed stratum ventilation to be the most pleasant in an experimental classroom, where the supply inlets were located in front of the pupils and the return outlet was behind them, supply temperature of 28 °C and ACH=10 (Fong et al., 2015). Similar setup was also applied and claimed as one of the best mechanical ventilation solutions existing nowadays (Zhang et al., 2017). Mechanized automatic controlled operation of windows was compared to manual airing in an Italian school. The automated system performed better and provided more comfortable indoor environmental conditions meanwhile keeping temperature level without any consistent drop (Stazi et al., 2017).

Pupils learning performance is affected by the impacts of the surrounding. Mechanically and naturally ventilated schools in Denmark were investigated and pupils' performances examined whether they are influenced by the ventilation method. An increment of 1 L/s/person ventilation rate was found to increase the passing rate of pupils by 3 %. Mechanical balanced ventilation was concluded to be indeed better for pupils. Poor indoor environment has a negative impact on their performance. Poor indoor air quality had bigger effect when pupils had to read or do math exercises. More complex tasks such as foreign language fluency is not comparable because the comprehensive competences may also differ among the pupils (Toftum et al., 2015). A different work found 2 % increment in speed of task solving if temperatures were decreased by 1 °C in Danish classrooms. The researchers concluded the performance of pupils could possibly improve by 30 %, as the conditions would be idealized. Energy efficiency measures should only be considered if the conditions do not worsen (Wargocki and Wyon, 2013). Children's and adult thermal perception was compared in a study in the UK. A 3 K colder indoor temperature was found to be comfortable for children (compared to adult comfort temperature) which implies a huge energy saving potential for schools (Montazami et al., 2017a). In elementary schools in the UK a 2 °C (compared to EN 15251) and 4 °C (compared to PMV model) colder preferred comfort temperature was found. The best matching calculation model was *"Body surface area correction of input activity metabolic rate and resting metabolic rate, both in the 'met' calculation and inside the PMV model".* A huge variance in thermal sensation votes (hereinafter TSV) and actual percentage of dissatisfied (APD) highlighted also non-thermal parameters to play a role in perception, so it also has limitations and does not reflect perfectly the pupils' thermal sensation (Teli et al., 2012). Similarly in a Slovakian special education school the appropriate conditions for children also differed significantly from the PMV and PPD models' predictions (Vilcekova et al., 2017). Lower temperature and higher ventilation rates resulted in better performance in mathematics and reading tests (Haverinen-Shaughnessy et al., 2015). In a Chinese study relation between learning performance and

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temperature were found. Although the ideal performance were provided at 14 °C and by ~1.5 clo average clothing value (Jiang et al., 2018).

In China a lot of schools do not have an HVAC system. Occupants find thermal conditions acceptable with a mean thermal sensation vote (TSV) in a range of -0.48…0.55 (where -3 is cold, and +3 is hot, 0 is neutral). This implies an adaptation to cold conditions (Wang et al., 2017). In Portugal people who are accommodated to warm conditions accept easier warm conditions (Dias Pereira et al., 2014). During peak summer conditions in Indian naturally ventilated classrooms (mean temperature 34.9 °C) surprisingly only 19 % of respondents found thermal conditions uncomfortable (Kumar et al., 2018). Pupils' thermal perception at home and at school is in a strong relationship (Montazami et al., 2017b). Different factors such as clothing, its adjustment, consumption of foods and/or beverages, usage of medical aids and different travelling modes to the university has not been proved to have influence on thermal perception. Rather a significant difference was found in TSVs at 10, 20 and 45 minutes from the start of the classes (Mishra et al., 2017). But there is not only thermal adaptation. One can also adapt to poor air quality. Users suffer poor air quality because their main objective is to have satisfying temperatures (Stazi et al., 2017). A comparison of Spanish and Polish university classrooms pointed out that some spaces in the Polish university had had severe CO_2 concentration over 1000 ppm even before the lecture had started. But Polish students still perceived air quality more satisfactory in the beginning and after 30 minutes, than in the Spanish university classrooms where there was a moderate CO_2 concentration prevalent (Krawczyk et al., 2016).

"Three modes of adaptation are: (1) behavioural adjustments […], (2) physiological […] and (3) psychological […]." (Fang et al., 2018)

Because of the effects of adaptation it is also a question how the PMV-PPD model could be fitted to non-air-conditioned zones, e.g. naturally ventilated spaces. In an Italian study the so-called expectancy factor (correction between TSV and PMV) of 0.9 was found to give a better fit than the original PMV model (d'Ambrosio Alfano et al., 2013).

Air quality is probably the second most important aspect after thermal perception. There are a lot of air pollutants which could affect health and mental well-being. CO_2 and PM levels were monitored in Chinese classrooms; inadequate natural ventilation resulted in CO_2 concentration of 2500 ppm. The calculated ventilation rates were below 1 l/s per person, although ASHRAE recommend 8 l/s per person. Indoor $PM_{2.5}$ concentration was around 60-70 % of the external level (Hou et al., 2015). In a Slovakian special education school PM level was also measured higher than the limits (Vilcekova et al., 2017). In a Serbian non-refurbished school formaldehyde was in all spaces in higher concentration as the maximum allowed limit permits (Jovanović et al., 2014). In refurbished and new school buildings in the

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USA in cold, mild and warm season extremely low non-occupant related pollutants were recorded (Johnson et al., 2018). Settled dust was not found to be significant in absenteeism nor has the settled dust amount correlated to any other monitored parameter in a study in 70 schools in the USA (Haverinen-Shaughnessy et al., 2015). Carbon-dioxide itself is not considered as an air pollutant by the World Health Organisation (WHO) but it is a good proxy in indoor air quality measurements.

"[…] a simultaneous reduction in concentration levels for all the pollutant metrics in classrooms cannot be obtained just relying upon air permeability of the building envelope and manual airing of the classrooms." (Stabile et al., 2017)

In some cases comfort is far away because the building suffers under the so called sick building syndromes like mould growth. This was the case in a Polish kindergarten. After doubling the air change rate a massive reduction of mould was visible but temperature fall by 0.5-1.5 °C (Telejko and Zender-Świercz, 2016). It is also not uncommon, that children live in polluted environments, and it becomes worse in winter (Zhu et al., 2015). These are such factors which affect children's health and mental development negatively.

Visual aspects also play a role in the perception of indoor environment. Daylighting is more pleasant for the human eye than artificial lighting especially for youngsters who have to focus on close (exercise book) and distant (black board) targets throughout the whole day. But direct sunlight on the floor and walls creates visual discomfort and to tackle it in most of the cases drapers are closed and artificial lights are switched on (Secchi et al., 2015). Some researchers combine thermal, visual and acoustical effects in different indexes. With a given weight among these indexes a whole building approach is developed with quantitative parameters (Buratti et al., 2018), (Mihai and Iordache, 2016).

"What is missing from the most of the current studies is the study of occupant psychological and physiological state and their impact on how human body reacts to indoor air quality. This has led to the development of occupant satisfaction questionnaires which are analysed in conjunction with indoor air quality parameters." (Al horr et al., 2016)

This thesis in this manner aims to find relations between pupils' subjective perception and objectively measured physical parameters prevailing in classrooms. Kossuth Lajos Secondary School Mosonmagyaróvár, Hungary is the chosen institute, where the monitoring campaign and the subjective perception of the occupants are inspected via paper-based questionnaires. The research focuses on conditions in two different sized but same orientated classrooms and their occupants' subjective perception with indoor environment. The main issue to be found is, whether the natural ventilation satisfies the pupils' and the teachers' needs for fresh air with the frequency of window operation they apply. Additionally

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it is also of an interest how satisfied they are with the indoor environmental conditions during winter time lessons, when the windows are generally closed. The significance of this work lies in the fact, that researches are mainly focusing on the adult occupants in office buildings and these results cannot directly be translated into teenager's perceptions. Furthermore these kinds of measurements in schools are seldom conducted in Hungary so the results also contribute to the dataset collected in Hungarian schools. This will provide more understanding of teenage occupants' preferences. In order to gain deeper insight of the topic the perception of occupants from two classrooms is compared. Groups of two genders and groups of those, who reported to be tired versus non-tired are considered.

1.2 Motivation

From EU funds a mechanical ventilation system was built in the Lajos Kossuth Secondary School Mosonmagyaróvár in 2012-2013. As soon as it was constructed, the manual ventilation during heating regimes was forbidden in order to conserve energy. The windows had to be kept closed and a purely mechanical ventilation concept was implemented. But after a week, hundreds of complains reported, that there is no effect of this mechanical ventilation system on indoor air quality. It seemed as if the system was not running although the air motion was sensible. So teachers started to operate windows again. The only reason which could have result in these complains is the lack of outlets and inlets for each classroom (1 inlet and 1 outlet belong to a classroom). The concentrated air intake causes discomfort because of its draught risk. As the whole distribution system should be redesigned there is no current action because of financial shortage. The previously applied manual window operation is set back as the accepted form of ventilation, and air handling units are shut off. Asking teachers about their experiences who worked at the school already before the mechanical ventilation system was built; meanwhile it was operating, and now when it is shut down, provided more insight in the background of the system.

There are some problems with the heating system too, which is not a unique issue. Oversized heating systems, positioning of the thermostats in wrong locations and bad management cause overheating and abnormal loads (Arambula Lara et al., 2015), (Ghita and Catalina, 2015). Overheating is a huge problem in this secondary school. Inquiring the possible reasons from the school director, she mentioned some north-eastern ground floor classrooms where there was cool temperature during colder winter days. Based on that a decision was made to run the whole system on an elevated performance and supply temperature in order to tackle the issue of under-heating in 2 or 3 classrooms. Hence the rest of the school suffers from excessive heat and pupils are accustomed to wearing T-shirts even during cold winter-days.

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The above mentioned problems cause poor conditions which were investigated in a monitoring regime from 7th of February to 27th of February 2020 in a classroom based approach. Two same orientated but different sized classrooms were chosen to be examined regarding air temperature, relative humidity, CO_2 concentration. Light intensity on the task area was also measured because of the orientation facing to south-west, which is also far from ideal in an educational building especially during winter time when the sun hits the windows in a lower incident angle. The same orientation was therefore crucial to make the results comparable.

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2 METHOD

2.1 Overview

This case study combines a monitoring investigation of indoor environmental parameters and subjective evaluation of pupils' perception via questionnaires in a Hungarian secondary school. Indoor environment concerning hygro-thermal parameters, air quality with CO_2 concentration and illuminance were measured. The building of interest is the Lajos Kossuth Secondary School Mosonmagyaróvár, Hungary (latitude 47°53'N, longitude 17°16'E, altitude 182 m.), which is a "U" shape representative building among Hungarian schools built in the 1960s. The school is not flanked to high traffic avenues; it is situated in a residential area, where during the working hours relatively few vehicles are driven. This is a great location for an educational building, where acoustical prohibits of operating windows is not an issue. Lower air pollutants exposure and relatively better outdoor air quality are also important properties.

After a renovation in the early 2000s external walls got covered with 8 cm of EPS thermal insulation and a plaster layer, windows have been changed to double glazed ones. In part of a later retrofit in 2012-2013 – which was financed by EU funds – the heat production side of the HVAC systems was upgraded, and mechanical ventilation was installed. Currently heat is produced by a combination of natural gas fuelled high efficiency furnaces and a pellet furnace, the latter was necessary to fulfil the requirements of renewable energy source application. In the same project 4 air handling units and the ventilation systems' air ducts were also constructed.

Officially altogether 606 pupils (F: 374 and M: 232) are divided in 22 classes and 27 classrooms. From these 2 different sized classrooms with the same orientation – avoiding differences caused by different external exposures especially by different solar gains – were chosen. These are investigated with in situ measurements with data loggers, and pupils' perceptions are evaluated via paper based questionnaires.

Figure 1 shows the floorplan of the first floor of conceptual planning of mechanical ventilation. The red framed part on the left is zoomed in a bit on the right side, to have a better view on the objected rooms of interest. The biology storage room is depicted as being not separated from classroom 18 (internal wall and doors are missing), therefore it was necessary to use rectangular shaped objects to emphasize the boundaries of the spaces. The geometrical data of the classrooms and calculated values are depicted in Table 1. The

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average volume-per-person values are calculated based on the average count of pupils in a class which was approximately 18, plus a teacher.

Table 1 The geometrical data of the classrooms (average count of occupants: 19)

	Floor area	Volume	Window-to-wall ratio	Window-to-floor ratio	Average volume per person
	[m^2]	[m^3]	[1]	[1]	[m^3/person]
Classroom 17	58,5	187,2	0,65	0,32	9,85
Classroom 18	78	249,6	0,65	0,32	13,14

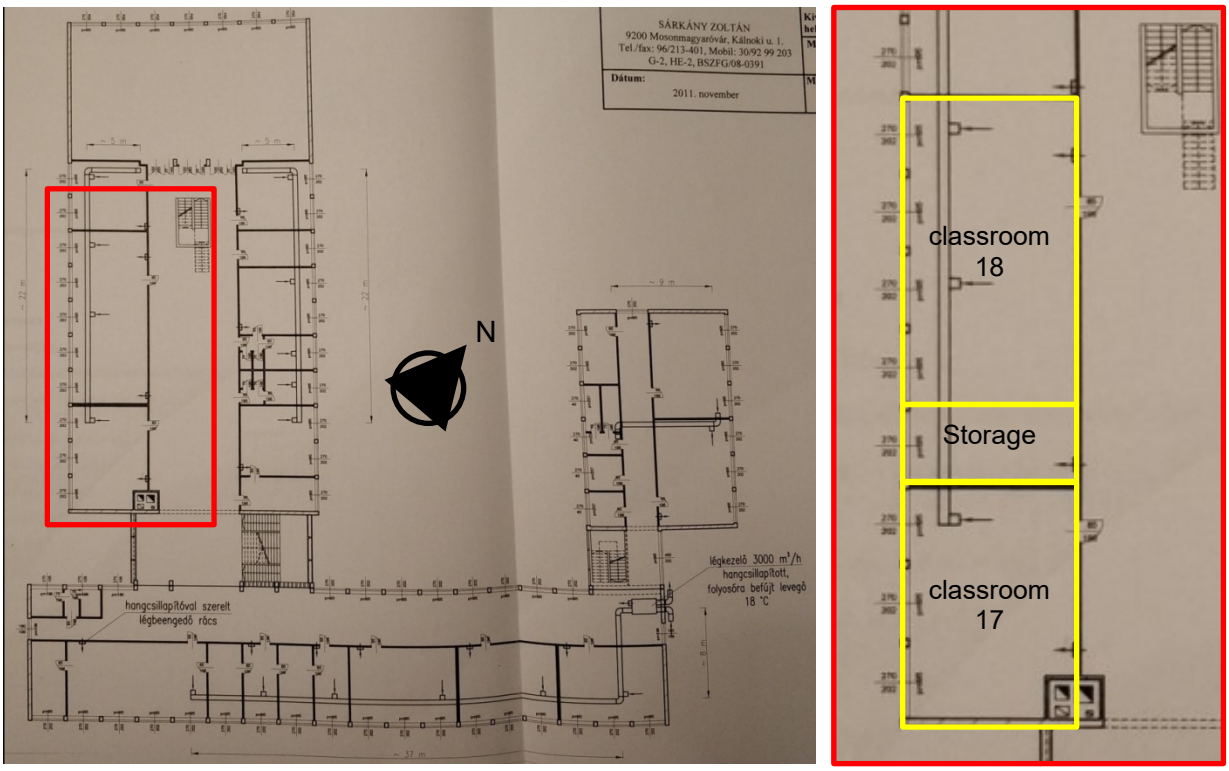

Figure 1 Lajos Kossuth Secondary School Mosonmagyaróvár, Hungary – Site view with the measuring station and floor plan of the first floor with a highlighted area of the monitored rooms

The plan of mechanical ventilation does not reflect the current state. Air ducts are along the corridor (supply and return parallel to each other) and inside the rooms there is no distribution duct at all. There is one air inlet and outlet on the wall to the corridor, which is certainly not enough to provide fresh air for such big spaces. This is why after a few weeks of operation the complaints about the insufficient working of the system forced the director to shut down the system and re-establish manual window operation as the primary ventilation mode. The manual window operation seemed to be more pleasing being “closer to nature” and nonetheless it spares a lot of operation costs (Gil-Baez et al., 2017). In an Italian school the mechanical ventilation system is not used because of the complaints about draughts (Giuli et al., 2012). The same applied also for this secondary school, where a teacher could not stand sitting in the zone where the air grill inlet pointed, and had the air inlet closed.

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In most of the secondary schools in Hungary it is allowed to operate windows, but in the majority of elementary schools this is not permitted at all. So only the teacher is in charge of window operation and general control of indoor environment, because the pupils are too young (Deme Belafi et al., 2018), (Montazami et al., 2017b). Hence children of elementary schools "passively accept indoor conditions" (Giuli et al., 2012). Teenagers in this secondary school count as individuals who can operate windows as they wish to adjust the conditions to their own needs, so a non-passive behaviour was investigated (only limitation: during lectures first they have to ask the teacher for permission).

2.1.1 Describing the onsite measurements

The in-situ measurements took place during heating regimes from 7th of February (Friday) to 27th of February (Thursday) 2020. Some days were cold enough to prevent windows to be continuously opened and some were spring like mild. Parameters were measured in a one minute sampling frequency and questionnaires were handed out on Thursdays and Fridays (7th, 13th, 14th, 20th, 21st and 27th of February). Personally explained questions and entries of the surveys helped on the pupils' intelligibility and provided a better quality of information to the children about the topic, and also the quality of their responses is presumably better (Dias Pereira et al., 2014), (Vilcekova et al., 2017), even running a small workshop is beneficial (Montazami et al., 2017b).

Air temperature, relative humidity, illuminance and CO_2 concentration were measured in classrooms 17 and 18. Orientation have a huge impact on thermal perception even if there is no direct effect on the parameters itself (Teli et al., 2012) therefore it was crucial choosing spaces exposed to the same cardinals. CO_2 concentration was measured by a Wöhler device which needed continuous power supply therefore more inflexible, than the wireless battery powered portable HOBO loggers. The latter allowed an absolute freedom in placing them in-situ. CO_2 sensor placement is location dependent, but in the majority of cases there is insignificant difference among the measured values of the devices (Pantazaras et al., 2018). In order to measure safely and more importantly not to disturb the lesson, loggers were not allowed to be put on the desks of pupils but only on the teacher's table. CO_2 concentration was not monitored in the corridor, because there was no suitable safe place for it. For more informative details about the measuring devices' technical data see Table *2*, and for their exact locations (coordinates from the rooms' south east corner) see Table *3*, for their physical location see Figure 2.

Outdoor measurements were also conducted. Due to safety reasons the power supply necessitating CO_2 logger was put in a backyard of a residential building approximately 1.5 km away from the school. This ensured a continuous and safe possibility to monitor without

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the device being unplugged by anyone. Air temperature and relative humidity of the outdoor air was measured with a HOBO device in an outdoor sheltered box directly next to the secondary school, which was built for monitoring barometric pressure for another on-going project in which the school takes part in.

Table 2 Specifications of applied measuring devices (*HOBO datasheet; Wöhler datasheet)*

Parameter	Description, manufacture/type	Properties in applied region
θ_i	Indoor air temperature, relative humidity and light intensity loggers HOBO onset / U12-012	0…50 °C ±0.35 °C, outside the range ±0.5°C
RH		10…90 % ±2.5…3.5 %, outside the range ±5 %
E		1…3000 fc ~ 10.8…32292 lx
CO_2	CO_2 Sensor Wöhler / CDL210	0…9999 ppm ±50 ppm ±5 %

Table 3 Location of the measuring devices

Room	Location	Type of device	Relative coordinates from the room's south east corner (x-y-z)
Classroom 17	Lying on the table	HOBO θ_i, RH, E	(7.4 ; 3.1; 0.81) m
	Hanging	HOBO θ_i, RH	(5.1 ; 4.3; 2.35) m
	Lying on the table	Wöhler CO_2	(7.4 ; 3.2; 0.81) m
Classroom 18	Lying on the table	HOBO θ_i, RH, E	(8.2 ; 3.9; 0.92) m
	Hanging	HOBO θ_i, RH	(6.1 ; 3.7; 2.35) m
	Lying on the table	Wöhler CO_2	(8.2 ; 4.0; 0.92) m

Figure 2 Classroom 17 (left), classroom 18 (right)
(Black circles indicate the location of the devices)

The importance of the hung loggers was to have better air movement around the device (not being blocked by one side), thus the device could react to changes faster. There was very

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little to no difference between the values of the hung and the laid devices' recorded data, so in this thesis only the data logged by devices put on the tables was considered.

2.1.2 Surveys

Besides the measured physical parameters, the real emphasis was laid on the pupils' perception of indoor conditions. Their subjective perceptions were gathered via paper based questionnaires (see Appendix A), which consists of the following types of questions:

- Instantaneous 7-scale sensation votes for temperature, humidity and brightness parameters, and a 4-scale sensation vote for air quality perception.
- A retrospective time range satisfaction – targeting the whole 45 minute long lesson – with each of the above listed physical parameter. This was a free entry question expressed in units of minutes. In other words: how long they felt e.g. temperature satisfactory during the lesson.
- A question about whether their self-assessment is tired or not (for the sake of brevity hereinafter simply as "tired" and "non-tired").
- What would they call as an ideal temperature according to their clothing and activity level as a free entry in units of centigrade.
- How long they have not been outdoors.
- In which column of seats are they sitting from the window pane (in both classrooms it was to their left-side).
- The frequency of their window operation in order to adjust conditions to their needs, and what is the main reason of it.
- A 7-scale general satisfaction rate with indoor environment as a whole.
- What their suggestions for improving the conditions are.

In Portuguese kindergartens to express one's perception children had to choose from 3 pictures and colour it, which represented cold, neutral or hot environment (Almeida et al., 2016). Some studies used 13 entry Thermal Sensation Vote (hereinafter also as TSV) scales (Ricciardi and Buratti, 2018), (Buratti et al., 2018) to have a 0.5 value increment among the votes, which they state to be more beneficial, and it gives more options especially around neutral state (Yang et al., 2018), but the vast majority applies the Fanger-type 7-scale votes, because there are enough options to choose from.

Questions dealing with relative humidity are not an easy task. In some previous studies teachers suggested the researchers do not to even list those questions in the survey, because it might cause intelligibility problems (Martinez-Molina et al., 2017). Others also recognise the difficulty of the intelligibility: *"Questions regarding influence of relative humidity*

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should be added in a vivid way to be easily understood by pupils." (Yang et al., 2018). Although water vapour pressure has a higher correlation with perception votes than relative humidity, and it is a better indicator for comfort (Mishra and Ramgopal, 2015b), it might become more misleading for pupils to understand than humidity itself, so in this thesis question about humidity is asked.

To evaluate visual perception occupants in a pre-built experimental office in Hong-Kong (Tang et al., 2020) were provided a similar question with similar options as in this study. Although this thesis's brightness sensation vote has a neutral option too.

Freshness and staleness are not transitioning as warm and cold temperature with an ideal like option in the middle. Either one or the other is perceived; only the intensity of the one could be distinguished. Therefore, asymmetrical indoor air quality scales are used mostly. There are studies, which grade the stale conditions (Vilčeková et al., 2017), and others which use the stale as one extreme and grade the freshness, cleanness (Ghita and Catalina, 2015). In this thesis the "fresh" option is the one extreme, and the stale conditions are represented in 3 options to choose from. Because of some symmetrical scales in the literature (Almeida and Freitas, 2015), (Wang et al., 2017) a question was asked in the feedback questionnaire (Appendix B) – which was handed out after the whole monitoring period has already finished – which of the two scales of indoor air quality sensation vote (asymmetrical or symmetrical) the pupils prefer.

Some asymmetrical comfort and satisfaction scale also exist (Jiang et al., 2018), but symmetrical as well (Giuli et al., 2012), (Mishra and Ramgopal, 2015b). In this questionnaire the symmetrical one is applied. Questions were formulated unambiguously, *"[…] purposely the word "comfort" was never used to avoid misleading answers or interpretations."* (Loreti et al., 2015).

The retrospective time range satisfaction with the parameters could have been grouped into e.g. 5 minutes of options, but first a free entry question was applied, and merging data afterwards was still possible.

For safety reasons it was not possible to have a globe thermometer in the classrooms, the school director did not want to risk damage. For the sake of personal privacy it was neither allowed to gather information how tall and how heavy the pupil were, nor was it permitted to investigate how the pupils were dressed. Accurate clothing values are not gathered in the questionnaires. In some research it is important to have exact values, unless the predictive model could not be created precisely. It helps if the clothing values are same for every occupant so sometimes even the researchers provide uniform clothing to diminish the exposure differences (Tang et al., 2020). The activity level could have been guessed easily that pupils are sitting on their chairs and being rather mentally active than physically. But

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without operative temperature and their body mass and body surface it is for no reason necessary to specify the activity level of the pupils in such accurate way. Instead they were asked to directly write the ideal temperature they would set according to their current clothing level and the kind of activity they pursue.

One question asked how long they have not been outdoors in order to find out, whether pupils leave the school building at all during education time, or they arrive at school in the morning and first exit after 5-8 hours. This might influence their general well-being, freshness, ability to pay attention to their task and being able to focus.

It was also asked in which column – counting from the window – one sits. This was in order to find out one's seat's distance from the window. It might result in difference in general perception of indoor environmental conditions. For the list of distances from the windows in the two classrooms Table *4* is to be seen.

Pupils listened in an open-minded manner as the background of the research was introduced to them and participated freely. Sometimes during the questionnaire phase some smaller groups gathered together, and they have discussed, what to mark on the sheet. This is also common in other researchers' field studies: *"[…] interactions with other classmates can potentially influence the responses from those pupils who tend to align their answers with the general feedback."* (Martinez-Molina et al., 2017).

Table 4 Distances from windows in the two classrooms

Name of the classroom	**1st column**	**2nd column**	**3rd column**	**4th column**	**5th column**	**6th column**
Classroom 17	0.5 m	1.1 m	2.5 m	3.1 m	4.4 m	5.0 m
Classroom 18	1.3 m	1.85 m	2.4 m	3.75 m	4.3 m	4.85 m

This first type of questionnaire (Appendix A) was handed out several times along the measuring period, altogether 822 responses were gathered from the total count of 232 participants. So the same pupils filled it out multiple times (Thursdays and Fridays). This has a disadvantage on one hand that they already were counted to the sample, and thus could distort the general outcome being someone's perception repetitive. But, on the other hand it is advantageous that they already knew for the second or third time what the questions are asking, they already conquered the first uncertainty if there was such. As the external conditions also change continuously which affect indoor conditions their feedback is not doubled, tripled but as unique as a complete different person's perception. In a study in Italian schools the same 68 pupils were surveyed and a total number of 614 responses gathered (Stazi et al., 2017), which implies that on an average 9 questionnaires were filled out by one pupil during the monitoring session.

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As the intelligibility was mentioned above it was crucial for this study to get to know, whether pupils have understood the questions already before they were explained them. That is why another type of questionnaire was also handed out but this time only one per each pupil was taken into consideration (see Appendix B). This questionnaire was only given them after the whole monitoring period, as a last feedback. Questions of it focused on intelligibility of the previous questionnaire's questions and their habit of going out during breaks, sports lessons etc.

Surveys were written in Hungarian; in Appendix A and B they are translated to English. They were handed out always on Thursdays and Fridays in the last five minutes of the classes not to disturb the lessons. Sometimes it was not possible to gather feedback from both of the classrooms because of writing tests or cancelled classes because the teacher was absent. Occasionally teachers allowed entering the classroom but continued on presenting their lecture and this way the class was over and not all of the pupils were willing to stay in for the break to fill out the survey. Sometimes teachers also filled out a questionnaire but not all of them wanted to participate.

2.2 Research questions

This thesis focuses on the subjective perception of the pupils whilst indoor environmental parameters were monitored. The first and the most important research question is:

Q1. Does the subjective perception match the objective measured data?

To find this out the above mentioned questionnaire responses were evaluated. Thermal, humidity, indoor air quality and brightness sensation votes serve as instantaneous perception. Time range satisfaction minutes are considered as someone's satisfaction with the given parameter during the whole lesson. These both (instantaneous and general) sensations could be directly compared to the measured physical parameters.

The same type of apparatus is located in the two classrooms quite similarly. Pupils are asked of their subjective perception with the same questionnaire. But there is a difference between the two classrooms, namely their volume. In the bigger space one has a bigger volume per capita ratio (see Table 1). The results of the monitoring period showed that ex- and infiltration causes an outdoor like CO_2 concentration in the classrooms after a weekday and especially after a whole weekend (non-occupied period). This means there is very low CO_2 concentration in both classrooms in the morning. There is a difference in the size of the classrooms so there is a difference between the volumes of fresh air inside the classrooms. The classes have more or less similar count of occupants (CO_2 sources). Hypothetically this means a longer period of time in case of classroom 18 (the bigger classroom) while the

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occupants could perceive indoor air quality as fresh. This leads to the second research question:

Q2. Is there a significant difference between perceptions of indoor environmental conditions between the two classrooms?

In both of the classrooms there are both males and females, but there are almost twice as many females in this secondary school as males. One could ask whether it distorts the distribution of answers if more female replied than male. Who is a representative occupant? Is he a male, is she a female, is it indifferent? If there is no difference in their perception, it is then not important. So it might be an interesting aspect to find out whether the genders influence perception.

Q3. Is there a significant difference between the male and female perception of indoor environmental conditions in this school visible?

The handed out questionnaire inquires about one's self-assessment of tiredness. This separates the occupants also to two disjoint groups. If somebody voted tired, means the ability to focus on the task is already have started to reduce. In this state one reacts on the same conditions differently. The major causes of tiredness could be high temperature, high CO_2 concentration, dark surroundings, the time of the day and many more. Some of these effects could be changed by a better building management (e.g. reduce indoor air temperature) but some are not related to the indoor environment but to the person (e.g. someone has not slept long enough the day before).

Q4. Is there a significant difference between occupants' perception of indoor environmental conditions whose self-assessment is tired compared to the non-tired colleagues?

Each of the research questions consists of more sub-tests because of the different physical parameters, and the instantaneous plus the time range perception of these. The main objective is to compare the subjective perception and the objective dataset, furthermore to compare different classrooms'; different genders'; and tired and non-tired pupils' (where meaningful):

- sensation votes,
- time range satisfactions,
- general satisfactions,
- ventilation habits.

For example in case of ventilation habits it is not meaningful to compare the difference between the occupants' votes sorted by classrooms. Pupils move to different classrooms for

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each lesson, so their location in the moment of filling the questionnaires is random, it has nothing to do with their ventilation habits.

Some further questions were also of interest, but these do not connect organically to the main part, so these are only briefly investigated not to disorient the reader. These questions are:

q1. Do pupils go out frequently or do they stay the whole day inside the school building?

q2. Do pupils understand the questions formulated? (Not all of the questions were tested in previous literature.)

q3. Does the distance from the window pane influence the perception of indoor environmental conditions significantly?

q4. Is there a difference among perception of indoor environmental conditions among groups of pupils of different ages?

After each subchapter the corresponding number of research question is written in brackets. The main research questions – as written above – are with uppercase “Q” and the minor questions with lower case “q”.

2.3 Analysis

Missing answers for questions were kept blank and were not considered into that result. But handling a complete questionnaire as invalid was not necessary. The questions are independently formulated and if an answer is missing it does not influence any given answer for another question. The three question most frequently left out were the time range satisfaction with thermal sensation, humidity sensation and brightness sensation with around 8.3…8.4 % of missing data. The same time range satisfaction with indoor air quality only resulted in a 2.1 % fraction. The difference was presumably because of a design fault of the appearance of the questionnaire rather than unintelligibility. Presumably the black separating lines between the groups of different parameters were misleading, and if one does not check the numbers of the questions, it is skipped without noting it. The question about time range satisfaction of indoor air quality was filled out with higher percentage, because the sentence of the question was longer than the colourbar of the sensation vote’s question directly above. It only consists of 4 entries compared to the 7 entry of thermal, humidity and brightness sensation votes.

The measured data is logged in a one-minute frequency from 7th (Friday) of February 2020 till 27th (Thursday) of February 2020. For the sake of continuity the missing one or two minutes of records – which occurred at the time of the reading out of data – were manually

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interpolated between the last logged moment of the previous session, and the first record of the new session. This has not changed the dataset dramatically because the actual values would have been somewhere in the interpolated region. At some point the CO_2 loggers were set to a 2 minute logging frequency due to short period of time in logging memory of the device, and preserving data safety is better than having extra accuracy. These periods were for comparability reasons interpolated in between every even minute to have the whole data set universally in a one-minute frequency. The logged data was processed, analysed and plotted with Matlab R2019.

Statistical significance t-test are conducted according to the following formula, which is also called as Welch's t-test or unequal variances t-test:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_s^2}{N_2}}} \qquad \textit{Eq. 1}$$

where	$\bar{X}_1, \bar{X}_2$	the means of sample 1 and 2 respectively
	s_1, s_2	the standard deviations of sample 1 and 2 respectively
	N_1, N_2	the count of sample 1 and 2 respectively.

The null hypothesis in all cases assumes no difference between the two investigated groups' votes' mean values. To a count of 822 questionnaires the critical t-value is ±1.65 at an α cut-off level of 0.05.

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3 RESULTS AND DISCUSSION

3.1 Overview of monitored data

In this subchapter the monitoring data from 7th of February (Friday) to 27th of February (Thursday) 2020 will be introduced. Cumulative distribution plots are going to introduce the general state in the secondary grammar school separated for the two classrooms. After that follows a brief comparison of the two spaces in a psychometric chart. Then the focus is turned to the subjective perception of the pupils. For a better understanding in each subchapter results are combined with the discussion part.

3.1.1 Cumulative distributions

The best way one can introduce the measured conditions is either in a line graph with increasing time on the horizontal axis, or in a cumulative graph. In this sub-chapter the cumulative graphs turned out to be more informative, so the temperature, relative humidity, CO_2 concentration and illuminance values are ordered in an ascending way in Figure 3, in Figure 5, in Figure 6 and in Figure 6 respectively.

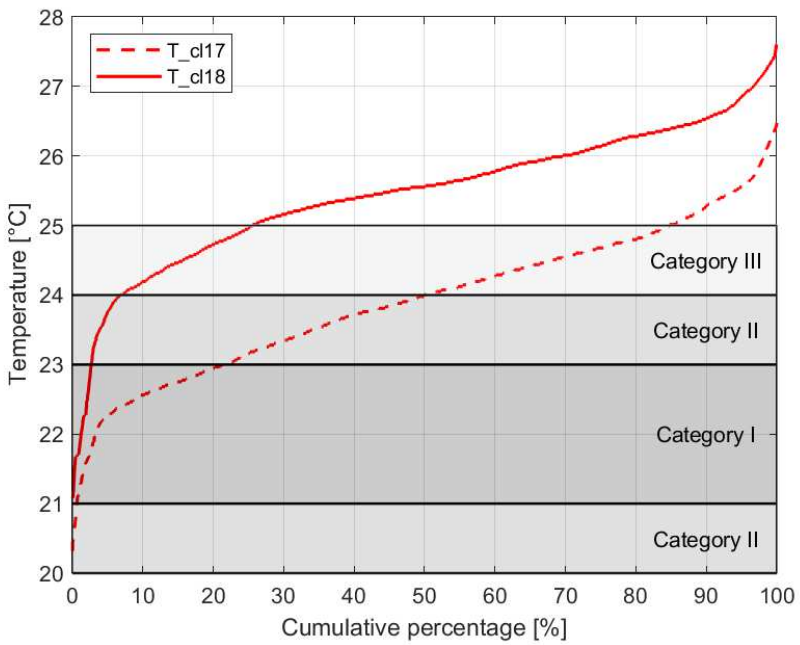

Figure 3 Cumulative temperature in both classrooms and the limits of thermal categories according to (DIN EN 15251:2012-12)

The thermal comfort level stipulated by EN15251 in both classrooms is to be seen in the cumulative graph. The percentages of time belonging to different categories are comparable in Table *5*. The minimum temperature in classroom 18 is slightly higher than in classroom 17.

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Classroom 18 is officially closed with a key after each class to protect the school equipment. Because of this the natural ventilation and the direct contact with the coldest temperatures would occur already during lessons and not during breaks, which is not that tolerated. So the windows are not kept opened for as long as in classroom 17. The ventilation periods are shorter. As classroom 18 is bigger it has more heat emitters, the overheating is also more serious in that classroom than in classroom 17. As the cumulative temperature graph indicates an average 1.5…2 °C temperature difference is between classroom 18 and 17 for the occupied hours, which is already perceivable. Such suggestions for improvement like "controlling of the heating system" and "equalized temperature among classrooms" were mentioned by the pupils (see Figure 27).

Only a negligible amount of time (2.6 %) is in category I according to EN 15251, whereas in classroom 17 this is 21.2 %. In classroom 17 approximately one sixth of the time is outside of Category III, where almost ¾ of the time belongs to this fourth category in classroom 18. A quite obvious difference between the spaces' air temperatures are recorded during the 3 week long monitoring regime.

Table 5 The percentages of time when the classrooms belonged to the thermal categories according to (*DIN EN 15251:2012-12)*

	Classroom 17	Classroom 18
Category I (21 °C ≤ T ≤ 23 °C)	21.17 %	2.64 %
Category II (20 °C ≤ T ≤ 24 °C)	49.90 %	6.77 %
Category III (19 °C ≤ T ≤ 25 °C)	84.76 %	25.57 %
Otherwise (T > 25 °C or T < 19 °C)	15.24 %	74.43 %

Let us consider the relative humidity (see Figure 4 and Table *6*). As a general statement there is dry air in both spaces during the monitoring campaign in February's occupied hours. Suggested lower limit of 30 % of relative humidity is in a long term not met especially in classroom 18, but classroom 17 is also very close to the unacceptable region. A quite narrow span of indoor relative humidity was logged, which is approximately within the range of 25 to 35 %.

The cumulative graph displays an almost universal 2 to 3 % difference between the two classrooms' indoor relative humidity. According to the producer of the HOBO measuring device the accuracy is ±2.5 % which means, the difference is almost negligible. During the half of the occupied hours one has to suffer from dry indoor air in classroom 18, if dryness is considered below 30 % of relative humidity.

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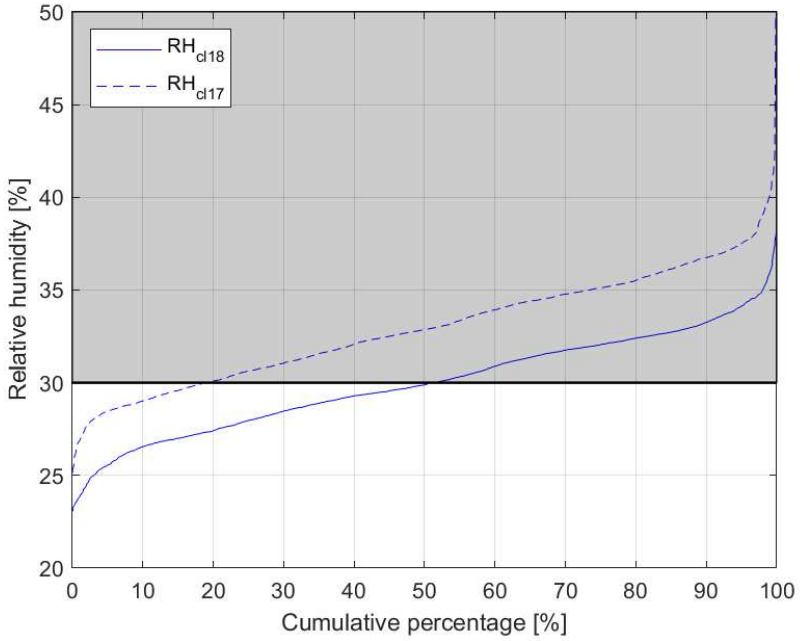

Figure 4 Cumulative relative humidity in both classrooms

In classroom 17 the loggers measured a slightly higher relative humidity than in classroom 18. One possible explanation for the elevated relative humidity values in classroom 17 is the size of the classroom compared to the bigger classroom 18. In a smaller space the same number of occupants produces the same amount of humidity (assumption), but because of the less volume of air which can dilute it, a higher relative humidity will be recorded. Furthermore classroom 18 does not belong to any classes so nobody really pays attention, whether a window remains tilted even for the whole weekend, which means a reasonable amount of energy loss too. But as a statement it could be claimed, that in both classrooms there is dry air. This might be the consequence of the excessive ventilation to fight the high temperatures caused by the overheating. In order to prevent indoor spaces from becoming filled with dry air throughout winter season, a humidifier is necessary to be built into a well-designed mechanical ventilation system. Alternatively a rotating drum heat recovery unit is required which does not solely recover heat but moisture too.

Table 6 The percentages of time during occupied hours when relative humidity was lower than 30 %

	Classroom 17	Classroom 18
RH ≤ 30 %	18.75 %	51.21 %

The cumulative CO_2 concentration graph (Figure 5) does not depict the actual differences of indoor and outdoor CO_2 concentrations, because of the absolute measured concentrations are more commonly applied. The limiting lines of the different air classes are drawn

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considering the mean outdoor concentration level during occupied hours, which is 425 ppm. This way the Category II (425 + 500 = 925 ppm) requirement almost coincides with the Pettenkoffer-criteria (1000 ppm). It is an important remark, because in some cases especially in big megalopolises the background concentration is about 700 ppm (Lei et al., 2017). In such cases already category I conditions can be over the 1000 ppm threshold.

It is a considerable result, that outdoor like concentration values were also measurable indoors, which point out leaky window seals, breaks and cracks where the in- and exfiltration can occur. A tiny difference between the cumulative curves is detectable, namely that in classroom 17 there is a slightly higher concentration level monitored. There is a difference in the usage types of the classrooms, being classroom 18 closed during the breaks in order to keep the equipment in safety. This way it provides fewer opportunities to manually ventilate during the breaks, consequently one expects poorer air quality. But the cumulative graph shows surprisingly the opposite. Presumably the difference between the sizes of the classrooms (being classroom 17 only 3/4 of the size of classroom 18, see Table 1) has a bigger effect. Almost the same count of occupants is inside the classrooms, which means an advantage for classroom 18 because it has a bigger cubature where CO_2 could be diluted. Over 1800 ppm the difference between the cumulative occurrences of the classrooms is negligible. As a general remark in this secondary school indoor air quality is controlled well by the occupants. The frequency of window operations results in a good air quality which becomes moderately poor during the lessons. It was already mentioned above that classroom 18 does not belong to any class and the windows could be left opened for a longer time. In an energy consumption perspective it is a problem and a waste of energy to leave windows partially opened even on mildly cold days (Theodosiou and Ordoumpozanis, 2008), but on the other hand it provides better air quality which is the case in these two classrooms.

Table 7 provides the percentages of time when the classrooms' indoor air quality met the requirements of the EN 15251 standard. 60.79 % and 66.92 % for classroom 17 and 18 are respectively the shares of time from the whole occupied hours, during which the indoor air meets the requirements of air Category II (925 ppm). In comparison 68.27 % and 73.15 % of the time the CO_2 concentration in classroom 17 and 18 respectively are below the Pettenkoffer-limit (1000 ppm).

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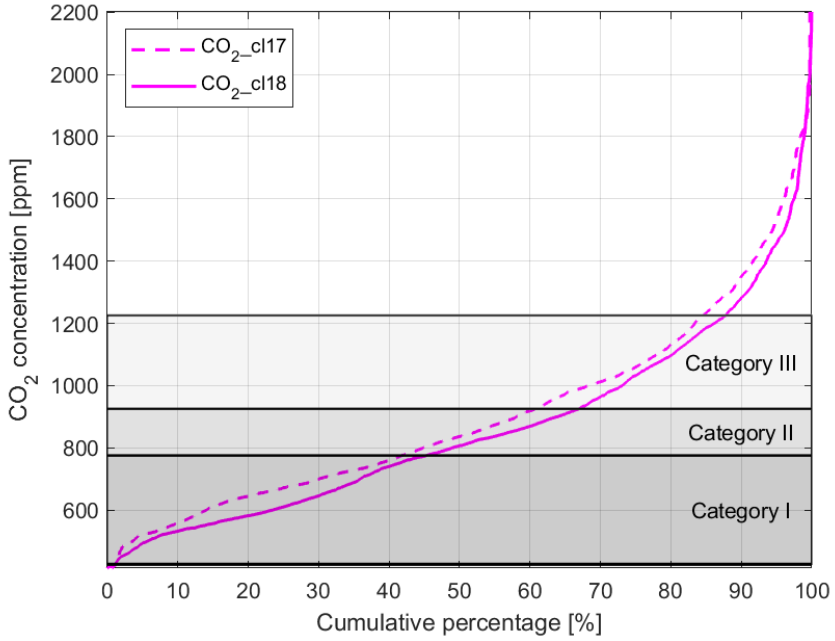

Figure 5 Cumulative CO_2 concentration in both classrooms and the limits of thermal categories according to (DIN EN 15251:2012-12), mean outdoor CO_2 level = 425 ppm

As a comparison in a Serbian school where windows were opened only once per day, the prevalent indoor CO_2 concentration was more than 50 % of time higher than 1000 ppm threshold (Turanjanin et al., 2014). In some cases the occupants do not even open window at all either for the reason, they cannot reach the handle (Martinez-Molina et al., 2017), or because of not taking care of indoor air quality (Ghita and Catalina, 2015). There are such schools where the indoor CO_2 concentration is in range of the health affecting limit of 5000 ppm (Ghita and Catalina, 2015), and in some of them as extreme conditions as 7000 ppm was exceeded on few days of monitoring campaigns (Dias Pereira et al., 2014). In contrast in subarctic Swedish mechanically ventilated schools – where the windows were not allowed to be operated because of the average outdoor temperature in winter was -9.1 °C – 99% of the time the indoor CO_2 concentration was measured below 900 ppm (occupancy in each classroom was about 30 pupils + 2 teachers). Besides mean indoor air temperature was also acceptable 23.1 °C (Yang et al., 2018).

Table 7 The percentages of time when the classrooms belonged to the air quality categories according to (*DIN EN 15251:2012-12)*

	Classroom 17	Classroom 18
Category I ($c < c_{outdoors}$ + 350 ppm)	41.82 %	45.31 %
Category II ($c < c_{outdoors}$ + 500 ppm)	60.79 %	66.92 %
Category III ($c < c_{outdoors}$ + 800 ppm)	84.54 %	87.75 %
Otherwise ($c > c_{outdoors}$ +800 ppm)	15.46 %	12.25 %

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Illuminance measured by the HOBO portable data loggers laid in both classrooms on the teachers' tables is compared in Figure 6. There is a 300 lx threshold for basic education. Table 8 compares the different levels of illuminance in percentages of time.

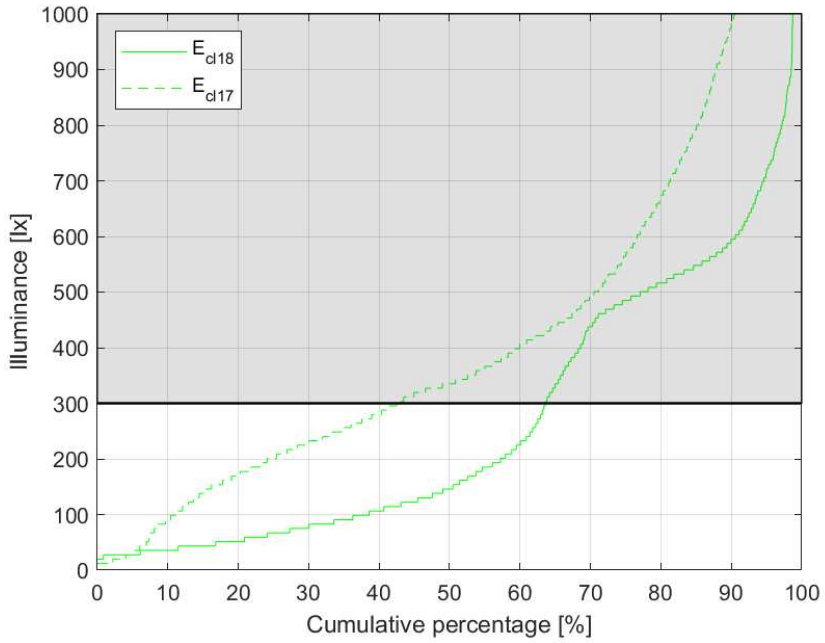

Figure 6 Cumulative illuminance on the task level in both classrooms, and the limits of requirements for normal (300 lx) education according to (DIN EN 15251:2012-12)

Although the orientation and window-to wall ratio is the same for these two classrooms the differently applied curtains could result in a big difference between the cumulative curves. The results indicate a generally brighter state in classroom 17 during the occupied hours almost throughout the whole dataset, meaning that there is a less dim condition. A relatively big difference of the time range of inappropriately lit task areas is to be seen: in classroom 17 approximately 2/5 of the time, while in classroom 18 almost 2/3 part of the time the task area's illuminance was below 300 lx threshold value.

In classroom 17 the curtains were not in a good condition. In classroom 17 the basic education form uses chalk and black board, in classroom 18 there are more often presentations with the beamer, when the drapers are closed. So classroom 17 seemed to be brighter than classroom 18 despite the identical orientation and the more fenestration surface in classroom 18. This random influence of draper operation makes the two classrooms' illuminance values incomparable. Additionally the measured data still has to be handled with caution, because the measuring devices were located at slightly different heights (classroom 17: 0.81 m; classroom 18: 0.92 m) and in different depth of the rooms (classroom 17: 3.1 m; classroom 18: 3.9 m), see Table *3*

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Table 8 The percentages of time when the classrooms task area illuminance met the criteria

	Classroom 17	Classroom 18
E ≥ 300 lx	57.53 %	36.41 %
E < 300 lx	42.47 %	63.59 %

3.1.2 Psychometric chart and comfort window

The equations from which the comfort window is drawn are linked (Szokolay, 2014). They are restricted to metabolic rate = 1 met (sedentary position), and clothing value = 0.67 clo (medium clothing). For more detail see Appendix D.

Neutrality temperature (20.71 °C) is the indoor temperature where most of the occupants feel comfortable, neutral. This is calculated from a monthly outdoor mean temperature. The neutrality temperature's ±2.5 °C tolerance range provides the width of the comfort window. The height of the comfort window is set by fixed limits of 4 g/kg and 12 g/kg absolute humidity values.

Every monitored moment has a temperature and relative humidity value which allows placing them on the psychrometric chart where this comfort window – as an indicator of pleasant conditions – is also drawn (Figure 7).

In comparison to the neutrality temperatures there was a question about what the occupant would call as ideal temperature according to his/her current clothing and activity level. The results of these after averaging of the different aspects' votes are gathered in Table *9*. The minimal voted average ideal temperature according to these groupings is 21.47 °C; the maximal is 22.38 °C. The calculated neutrality temperature is 20.71 °C. The difference between the votes and the calculation is in the range of +0.76…+1.67 °C. Although the acceptability limits for comfortable temperature is ±2.5 °C and covers the range of the idealized temperatures, it is remarkable, that according to the comparison, pupils wished for a warmer temperature than the ASHRAE standard's calculation suggested neutrality temperature.

Each point in the psychometric chart represent a record in a minute in the occupied hours (7:50 – 13:15 on weekdays), and the point-clouds let us compare the general conditions in these classrooms. Points cumulate generally to a somewhat narrow region of the psychrometric chart, but some points are differently scattered. This deviation is during natural ventilation while the outdoor temperature is colder. In this manner the points are somewhat shifted to the left and a bit to the bottom, where the colder outdoor air and its smaller

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absolute humidity dilutes the humidity content of the indoor space besides reducing its temperature.

Table 9 The average „ideal temperatures“ calculated from the votes of the occupants

$T_{cl17} = 22.13\ °C$	The ideal temperature in classroom 17
$T_{cl18} = 21.99\ °C$	The ideal temperature in classroom 18
$T_{male} = 21.47\ °C$	The ideal temperature voted by males
$T_{female} = 22.38\ °C$	The ideal temperature voted by females
$T_{tired} = 21.96\ °C$	The ideal temperature voted by tired occupants
$T_{non-tired} = 22.21\ °C$	The ideal temperature voted by non-tired occupants
$T_{neutrality} = 20.71\ °C$	The neutrality temperature

The generally occurring patches of scatter plots are shifted to the right, which means to the higher temperature region. These point-clouds are also closer to the lower edge of humidity limiting lines. 44.5 % of time in classroom 17 is inside this comfort window, whilst the same comfort window in the almost neighbouring classroom with the same orientation consists of only 6.8 % of the logged data. This massive difference is because of the different usage of the two classrooms, namely there is an obligatory restriction of entering classroom 18 during breaks. So the natural ventilation cannot take place as freely as in classroom 17, and this results in an elevated temperature in the space.

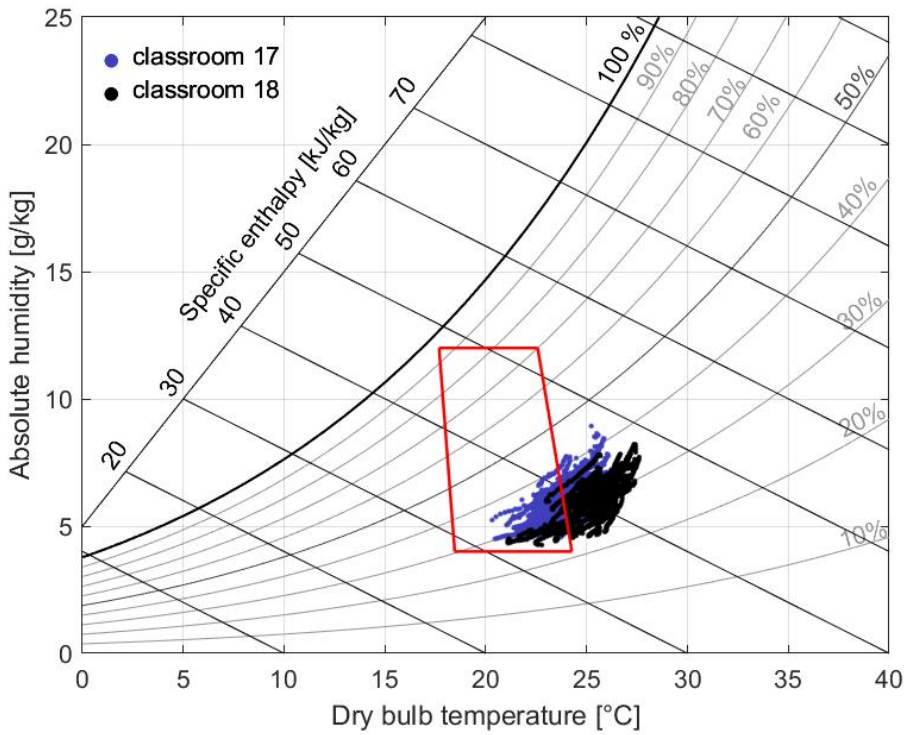

Figure 7 Psychometric chart with comfort window and measured points of the zones

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From Figure 7 the indicated percentages of conditions which were in the comfort window it is immediately visible, that there is a huge difference among the classrooms. First of all these condition representing points build up two separate patches for the two classrooms which are shifted to the right hand side (high temperature) and to the drier side of the comfort window. Due to the imbalanced heating system, some northern oriented classrooms located very far from the heating central are targeted to have the minimum required heat amount. To reduce complains about cold temperatures in these spaces, the other classrooms have to suffer overheating. There are multiple options for the improvement suggestions which mention these problems (see Figure 27): “controlling of the heating system”, “air conditioning”, “colder temperatures”, “equalized temperature among classrooms”, “cooling”, etc. Presumably even the operation of windows during winter time is in connection with the problem of overheating, although the last one is combined with air quality issues.

Classroom 17 is usually occupied by a class of 15 year-old pupils who have their lessons after another in the same classroom. This presence of a “controlling occupant” in the classroom results in 44.5 % of time during the occupied hours to be inside the frames of the comfort window. Classroom 18 is the biology room which is obligatorily closed during the breaks for the sake of security of educational equipment in the room. Only sometimes if the teachers give their key to the pupils, they are allowed to enter the space during the breaks. This phenomenon restricts the entering of “controlling occupants” into the room in comparison to classroom 17. Thus a relatively more extreme condition is deterministic, and only 6.8 % of time is comfortable in classroom 18.

3.2 Questionnaires targeting instantaneous perception

In this subchapter the responses of the pupils are presented. The same dataset is used for the different investigation aspects, research questions. Sensation votes are depicted in bar charts and the statistical data belonging to them is presented in tables.

T-tests are used in this chapter to analyse the datasets, see Eq. 1. The null hypothesis is that there is no difference between the means of the votes of the investigated groups. Numerical data is required for these t-test, so the categories of the different perception votes, ventilation frequencies, and general satisfaction votes are according to Table *10*.

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Table 10 The numerical values attached to the categories

Value	Thermal sensation vote	Humidity sensation vote	Indoor air quality sensation vote	Brightness sensation vote	Ventilation frequency	General satisfaction vote	Value
5					Almost always		5
4					Regularly		4
3	Hot	Very humid		Extreme bright	Sometimes	Very satisfied	3
2	Warm	Humid		Too bright	Almost never	Satisfied	2
1	Slightly warm	Slightly humid		Slightly too bright	Never	Slightly satisfied	1
0	Neutral	Neutral	Fresh	Neutral		Average	0
-1	Slightly cool	Slightly dry	Slightly stale	Slightly dark		Slightly dissatisfied	-1
-2	Cool	Dry	Stale	Dark		Dissatisfied	-2
-3	Cold	Very dry	Very stale	Very dark		Very dissatisfied	-3

According to the choice frequency of “very dry”, and “very humid” options in humidity aspect; “very dark” and “extreme too bright” options in brightness sensation could be taken out from further research questionnaires. They do not represent conditions well, only a negligible amount of votes are in these categories if so.

During winter time the outdoor absolute humidity is low, but probably higher than it would be assessed as “very dry” if it is ventilated into the space. Normally in a school building there is no excessive humidity gain from indoors which can result in very humid perception.

Drapers or shadings are operable to avoid extreme bright conditions. The education takes place during the day, when there is sun reigning outside. Even under overcast, rainy conditions it is too bright outside for the indoor to be perceived as “very dark”, because normally luminaires are turned on before it gets very dark. These marginal extreme conditions could still happen somewhere sometimes just by chance, but under these climatic conditions, with this specific window-to-wall ratio and with this orientation these options were rarely picked.

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3.2.1 Time range satisfaction

There was a question in the survey with the following form: “During the lecture time for how many minutes were you satisfied with the …” and the physical parameter was named (indoor air temperature, relative humidity, indoor air quality and brightness). It enquired about the “long run” perception during the whole lesson and was asked to be filled out by a free entry in minute as unit. There could have been provided some ranges such as “0-9 minutes”, “10-19 minutes”, etc., but a free entry question has a finer distribution. If the questionnaire had been filled out on a computer, the best solution would have been to move a pointer above a bar, where on both ends of the bar there is a statement indicated (Bakó-Biró et al., 2012). Figure 8 depicts the cumulative graph of the time range satisfactions.

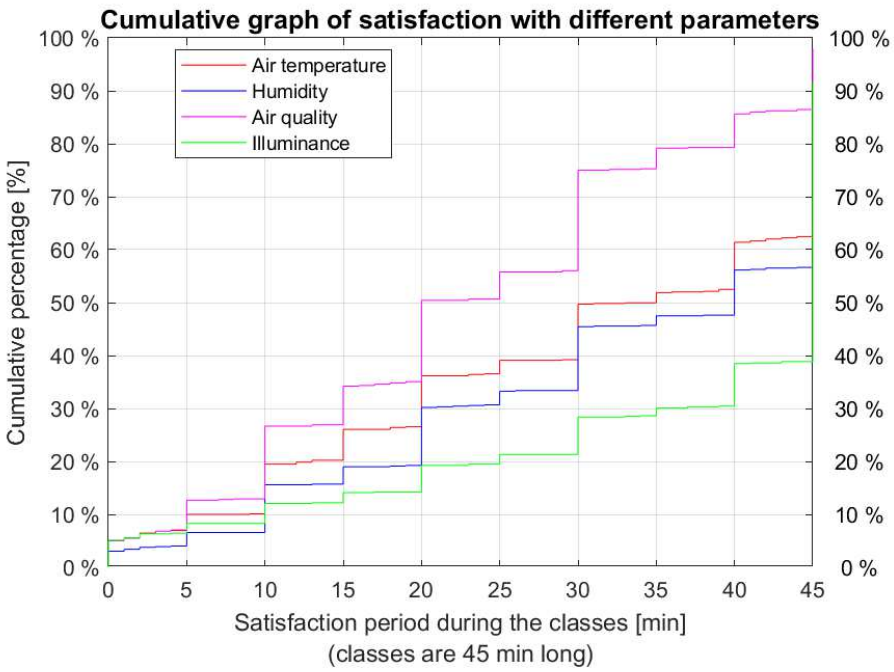

Figure 8 Satisfaction rate as a function of time of a class
Thermal (red), humidity (blue), air quality (purple) and illuminance (green) sensation

Considering 45 minutes as 100 % (the total lesson time) the individual endurance satisfaction rates of the parameters resulted in the following:

- air temperature 63.3 %
- relative humidity 68.6 %
- CO_2 concentration 51.5 %
- Illuminance 78.2 %

The cumulative graph of the free entry question of time range satisfaction resulted in a more or less 5-minute-step line. This means the pupils generally think discrete and do not use the provided possibility to give any other free answer. Therefore in future research it is not necessary to use free entry questions in questions dealing with time ranges, but rather a 5-

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minute-step scale to be chosen from. This would make the digitalization of data also more rapid.

In some schools the quality of both natural and artificial light is poor (Vilcekova et al., 2017), but except this phenomenon usually the most satisfaction is gained by visual aspects (Ricciardi and Buratti, 2018). Although in a whole perception approach the weighting of lighting-index is chosen from smaller part of occupants as the most important factor, compared to acoustical and thermal aspects' indices (Buratti et al., 2018). In this case study in a Hungarian secondary school the visual condition was the most satisfactory resulting in an average satisfaction of 78.2 % of the time (35.2 min), and the least satisfactory condition was the indoor air quality with only an average 51.5 % of the lecture time (23.2 min).

3.2.2 Sensation votes in the two classrooms (Q1 and Q2)

Sensation votes are gathered via the first type questionnaire (see Appendix A) in every last five minutes on the objected lessons in classroom 17 and 18 on Thursdays and Fridays. Four types of different questions – either with a 7-entry symmetric scale (temperature, humidity and brightness) or with a 4-entry asymmetric (air quality) scale – enquired instantaneous perception of the physical parameters.

The distribution of thermal sensation votes, humidity sensation votes, indoor air quality sensation votes, brightness sensation votes and general satisfaction votes separated to the two objected classrooms are depicted in Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13 respectively. Distribution means and standard deviations are in *Table 11*. The calculated t-values compare classroom 17 to classroom 18, so the positive t-values mean higher values of the votes in classroom 17.

There is a dominant "neutral" voter group regardless of the classroom, and the votes are shifted to the warmer region rather than to the colder in both spaces. T-value of -4.16 is lower than the negative critical t-value = -1.65 at $\alpha = 0.05$ cut-off level. This means a rejection of the null hypothesis. There is a significant difference between the mean vote of classroom 17 and 18. The data shows a lower mean of sensation votes in classroom 17.

The suspected conjunction between the sensation votes and the measured physical parameter is found. In classroom 18 temperature is much higher (see the cumulative temperature graph in Figure 3) almost a uniform 1.5 °C offset is visible. Classroom 18 tends to be voted warmer than classroom 17. The objective data fit the subjective perception of the pupils.

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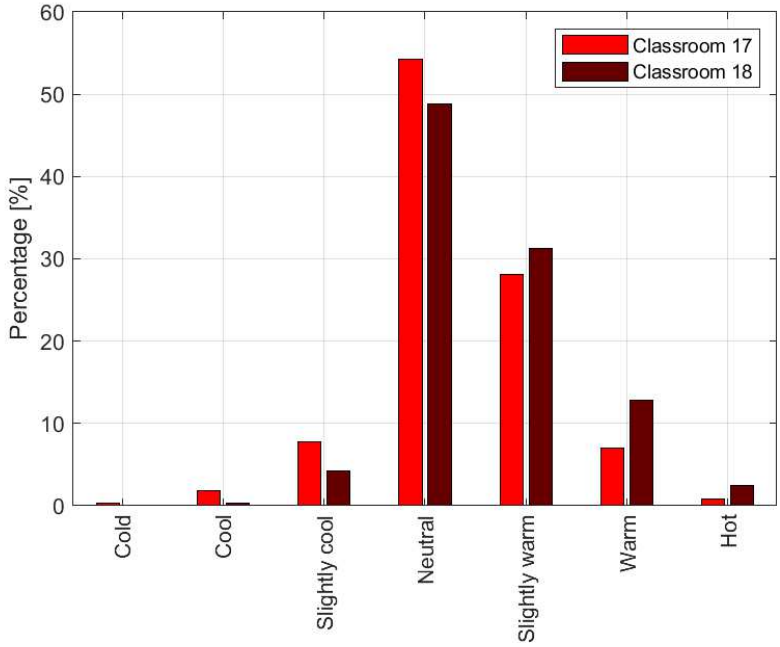

Figure 9 Comparison of the distribution of thermal sensation votes in different classrooms in the last 5 minutes of each lesson

Similarly to thermal sensation votes, the “neutral” state peaks among the humidity sensation votes too. The other options are rather distributed in the drier region than in the humid region. But the difference is not as dominant as the warm vs. cold side in the thermal sensation votes.

A t-value of 0.31 is lower than the positive critical t-value of 1.65, which means the the t-test could not reject the null hypothesis. The pupils seem to find conditions equally humid or dry in both classrooms. This finding is also visible from the slight difference of the range of the measured data. Presumably the similar amount of water vapour from exhaled air during the lessons – when the windows were closed – result in an elevated relative humidity in classroom 17 (the smaller classroom) but was not enough to have a statistical significance.

In mechanically ventilated subarctic Swedish schools the relative humidity ranged from 20 % to 30 % (Yang et al., 2018). In Portuguese classrooms relative humidity was found within adequate limits regardless of being the building refurbished or non-refurbished (Almeida and Freitas, 2015). In this secondary school due to excessive natural ventilation and the in- and exfiltration the dry outdoor air dilutes the indoor moisture content to a low level of relative humidity. 25…42 % of relative humidity is monitored in classroom 17 and 23…38 % in classroom 18.

The temperature and relative humidity can satisfy the pupils, but comfort requirements are not met (Shi et al., 2017). This finding is also applicable to this case study’s secondary school. Thermal sensation votes and humidity sensation votes are in both classrooms

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dominantly voted “neutral”. But in classroom 18 the cumulative temperature graph shows almost no acceptable range of temperatures according to (*DIN EN 15251:2012-12)*, plus the relative humidity is also very low.

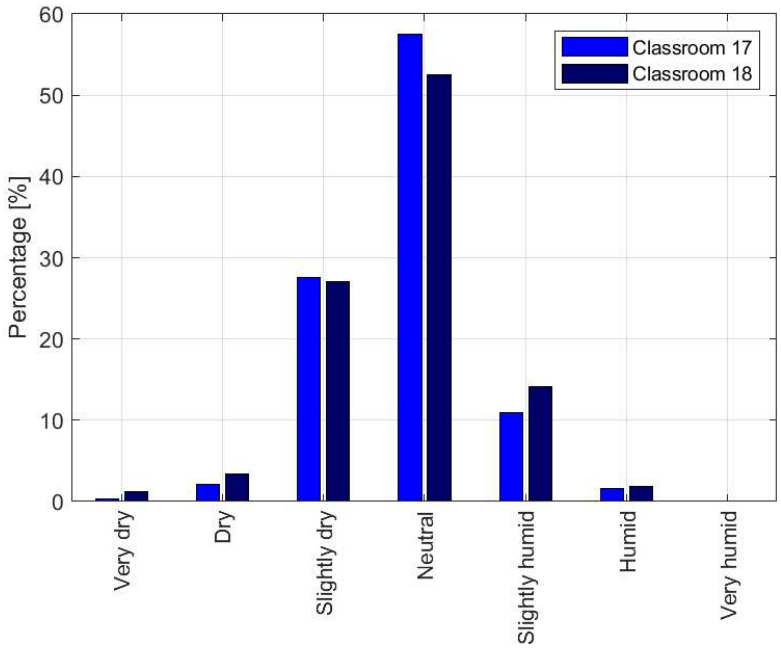

Figure 10 Comparison of the distribution of humidity sensation votes in different classrooms in the last 5 minutes of each lesson

In the indoor air quality perception the dominant vote is “slightly stale” and the second one is “stale” in both classrooms. “Fresh” votes are only 11.3 % and 13 % in classroom 17 and classroom 18 respectively. The questionnaires were filled out in the last 5 minutes of the lessons (after 40 minutes). The “fresh” votes are still not impossible, knowing that on some days there was spring like weather, windows were opened during the lessons and fresh air was supplied.

The t-test resulted in a t-value of 4.41 which is higher than the positive critical value (t_{crit}=±1.65). The null hypothesis is rejected, there is a significant difference between the means of the two groups’ votes. Air quality in classroom 17 tends to be perceived less stale. The cumulative CO_2 concentration graph (see Figure 5) shows a slightly higher concentration level in classroom 17, but generally the CO_2 concentration level in the two classrooms are similar. The objective data is in contrast with the subjective evaluation. There is a smaller cubature where from similar count of occupants use oxygen and produce carbon-dioxide. The air volume per capita is also different (see Table 1). If the windows are closed, there is an earlier stale state achieved (if the effect of in- and exfiltration is neglected during the 45 minutes long lesson). There is a bigger probability of staler sensation of indoor air quality in

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the smaller classroom. The logical consequence should be that pupils of classroom 17 voted air quality staler. The t-test showed a different result.

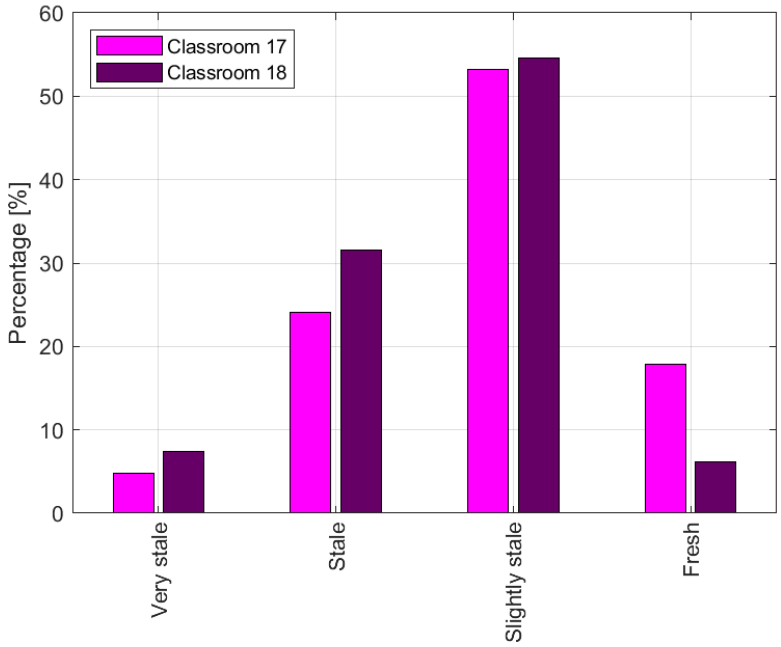

Figure 11 Comparison of the distribution of indoor air quality sensation votes in different classrooms in the last 5 minutes of each lesson

The most “neutral” votes are given in the visual aspect (70.7 % in classroom 17 and 66.7 % in classroom 18). Other votes are distributed mostly in the “slightly dark” and “slightly too bright” options, and “slightly dark” was more often chosen.

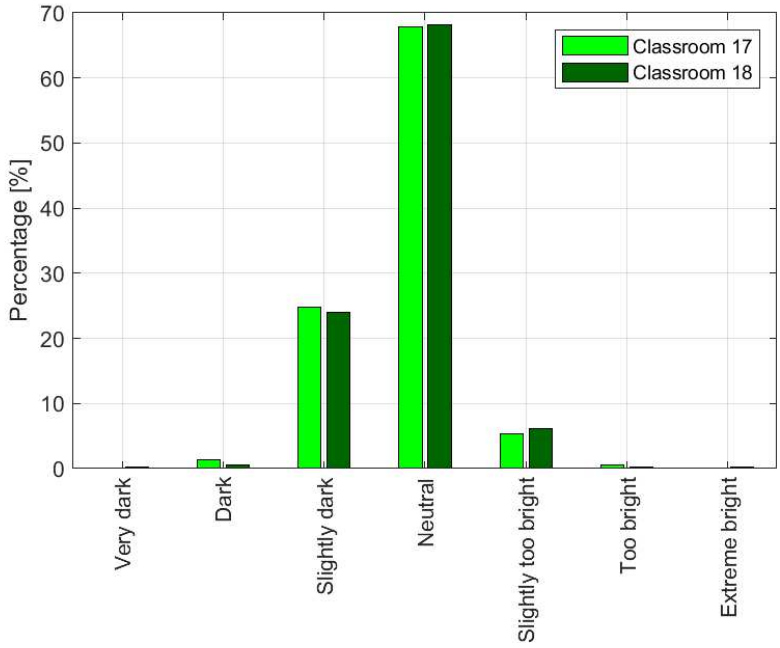

Figure 12 Comparison of the distribution of brightness sensation votes in different classrooms in the last 5 minutes of each lesson

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The calculated t-value of -0.60 is not significant. This means the null hypothesis was not rejected. Pupils assess conditions in both classrooms similarly. The measured cumulative illuminance values (see Figure 6) show a small difference between the general brightness levels of the task areas. The cumulative illuminance curve of classroom 17 was – except for the dimmest values – always over classroom 18's curve. Surprisingly sufficient illumination might reduce perception of poor air quality, although the researchers who found this are also skeptic of this relation (Wang et al., 2015). In this case study in a Hungarian secondary school the air quality was assessed not that stale in classroom 17 as in classroom 18, so the somewhat lighter surrounding might have reduced the perception of poor air quality.

Satisfaction rate with the individual parameters were already asked in either a 7 or a 4 scaled entry question, but generally indoor environment means more than the sum of its elements. The majority of general satisfaction votes are accumulated in the middle option "average". This state means neither definite satisfaction nor dissatisfaction. The amount of votes in satisfied region is bigger than in the dissatisfied region. This means the conditions pleased more pupils.

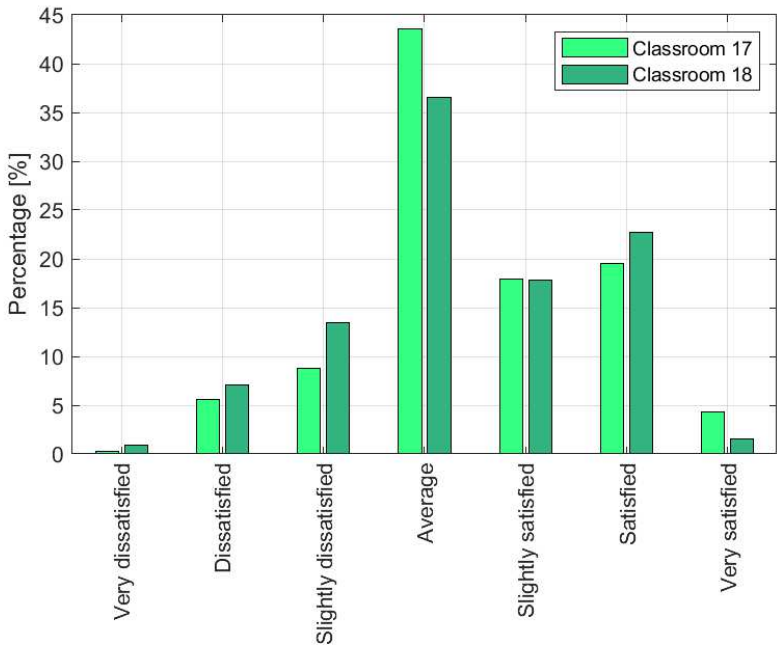

Figure 13 Comparison of the distribution of general satisfaction votes in different classrooms in the last 5 minutes of each lesson

The t-test resulted in a t-value of 1.27, which is just short of the significance level (t_{crit}=±1.65). Statistically the null hypothesis could not be rejected. This dataset does not show a significant difference between the mean values of the two classrooms' occupants' satisfaction rates.

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Table 11 Statistical analysis of the votes separated to the two classrooms. For the numerical values attached to the categories of the votes see Table 10

	Mean ± standard deviation	
	classroom 17	**classroom 18**
Thermal sensation votes	0.322 ± 0.840	0.592 ± 0.868
Humidity sensation votes	-0.184 ± 0.725	-0.203 ± 0.831
Indoor air quality sensation votes	-1.155 ± 0.769	-1.402 ± 0.716
Brightness sensation votes	-0.211 ± 0.577	-0.184 ± 0.600
General satisfaction votes	0.493 ± 1.204	0.374 ± 1.261

3.2.3 Perception differences among pupils of different genders (Q3)

Some researchers find a difference between the perception of males and females (Dias Pereira et al., 2014), but some fails to reject the null hypothesis of being the genders' perception votes same (Giuli et al., 2012). This aspect is also investigated in the current master's thesis.

The distribution of thermal perception votes (see Figure 14), humidity sensation votes (see Figure 15), indoor air quality sensation votes (see Figure 16), brightness sensation votes (see Figure 17) and general sensation votes (see Figure 18) of males and females are depicted and statistical data collected (see Table 12 and Table *13*).

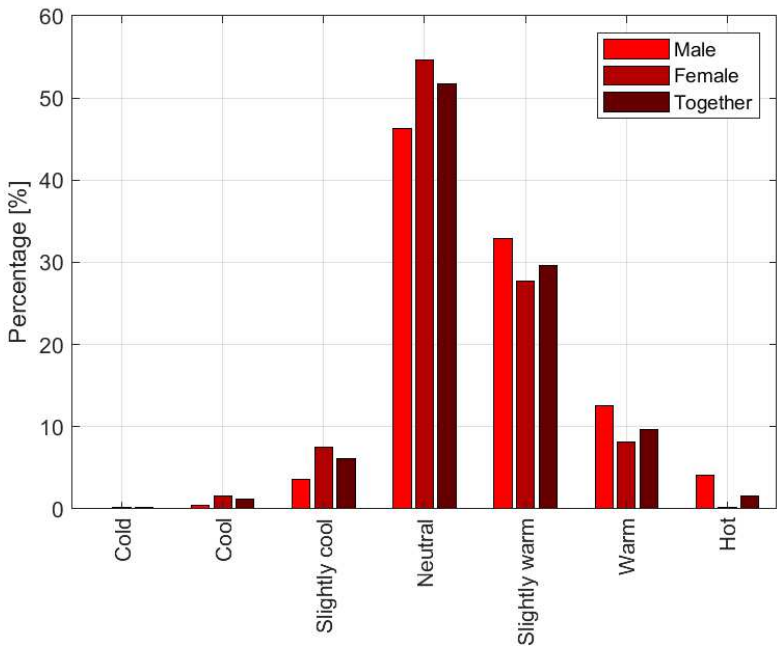

Figure 14 Thermal sensation votes of males and females in the last 5 minutes of each lesson

Males' votes have a higher share in each option of the warm region. In "neutral" and in every cold region option females' votes have a higher share. The t-test resulted in a rejection of the

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null hypothesis, which means it is not true that the females' and males' thermal perception is the same. There is a significant difference found: males tend to feel the same conditions warmer than females.

There is almost the same share of "neutral" voters in both genders' groups in humidity perception. Males have higher share in each humid region option, females voted with higher percentages in each dry region option. The t-test rejects the null hypothesis. There is a significant difference in humidity perception: males tend to feel moisture content of indoor air more humid, less dry than females.

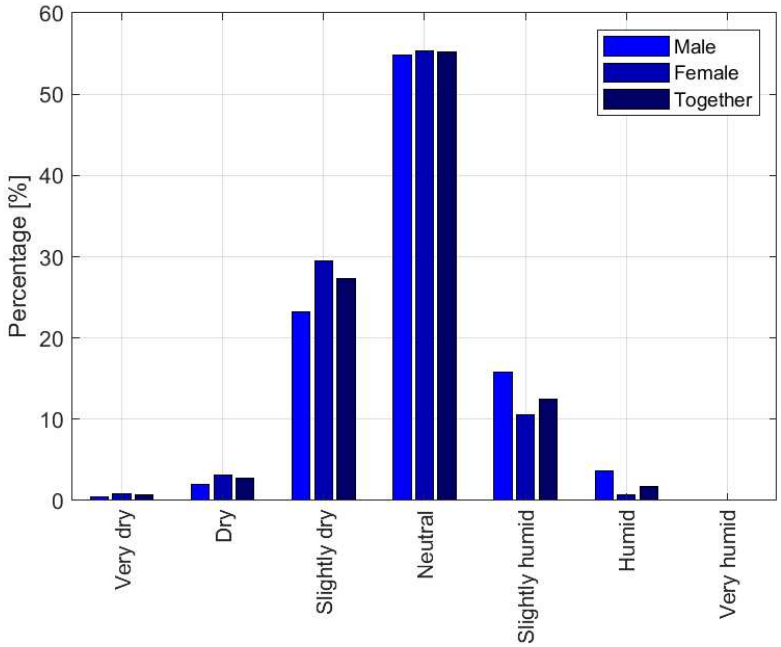

Figure 15 Humidity sensation votes of males and females in the last 5 minutes of each lesson

In indoor air quality aspect males voted in the two best options ("slightly stale" and "fresh") with a lower share and consequently with a higher share in the two worst options ("stale" and "very stale"). The statistical analysis rejected the null hypothesis and resulted in a significant difference between the two genders' votes: males tend to feel indoor air quality poorer, staler.

Due to the high share of "neutral" brightness perception the remaining votes have fewer shares. Males' votes are more common on the too bright side and less common on the darker options' side compared to females' votes. The t-statistics resulted in a t-value of 1.66 which is just over the 1.65 positive critical t-value, so it rejects the null hypothesis. Males tend to perceive conditions brighter, in other words less dark than the females.

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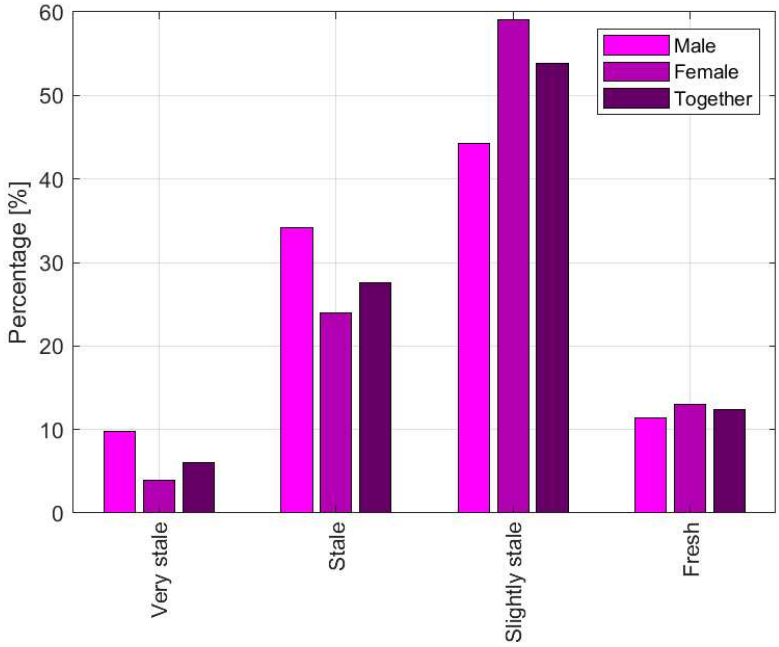

Figure 16 Indoor air quality sensation votes of males and females in the last 5 minutes of each lesson

The general satisfaction votes resulted in a t-value of -1.48 which is just short to reject the null hypothesis. There is no difference found between males' and females' general satisfaction. This may be in connection with the "long run" time range satisfaction votes. Comparing the time range satisfaction votes of the pupils there is no such aspect where a significant difference is found between the votes of male and female pupils. This supports the findings of the general satisfaction votes of the two genders, which showed no statistically significant difference of the votes.

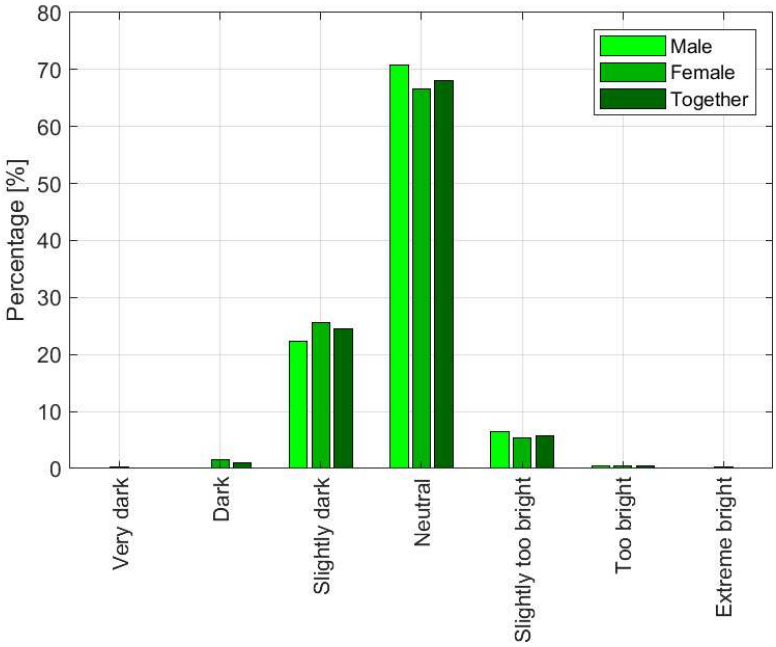

Figure 17 Brightness sensation votes of males and females in the last 5 minutes of each lesson

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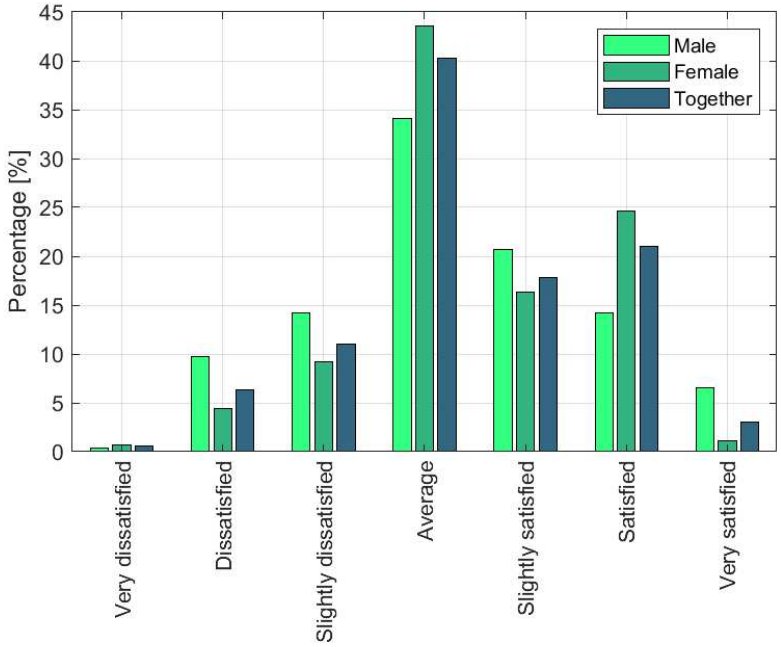

Figure 18 General satisfaction votes of males and females in the last 5 minutes of each lesson

Table 12 Statistical data of the votes of males and females. For the numerical values attached to the categories of the votes see Table 10

	Mean ± standard deviation	
	Males	**Females**
Thermal sensation votes	0.659 ± 0.907	0.335 ± 0.818
Humidity sensation votes	-0.053 ± 0.809	-0.264 ± 0.749
Indoor air quality sensation votes	-1.425 ± 0.820	-1.189 ± 0.703
Brightness sensation votes	-0.150 ± 0.532	-0.224 ± 0.615
General satisfaction votes	0.337 ± 1.351	0.489 ± 1.158

Table 13 Statistical data of the time range satisfaction votes of males and females, the length of a lesson is 45 min.

	Mean ± standard deviation	
	Males	**Females**
Time range satisfaction with temperature	28.390 ± 15.909	28.910 ± 15.164
Time range satisfaction with humidity	30.394 ± 15.309	31.703 ± 14.062
Time range satisfaction with indoor air quality	22.706 ± 13.410	23.844 ± 13.173
Time range satisfaction with brightness	36.309 ± 13.675	34.947 ± 14.848

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3.2.4 The effects of tiredness (Q4)

If the temperature rises in indoor spaces it is hard to stay mentally active, the pace of thinking reduces and one starts to become sleepy. Breathing in the relatively dry air dries the throat out, which can lead to coughing, sore throat and draws the attention of pupils off. If there is an elevated concentration of CO_2, mental processes are hindered in comparison to cases where fresh air is provided. Due to the south-western orientation of the school façade where the classrooms are oriented, it was quite often necessary to move the curtains to avoid direct solar rays on someone's desk. Sitting in the darkness but still trying to be focused on the particular lecture takes a big effort which consumes a lot of energy thus tires the pupils rapidly. All of the above mentioned situations accelerate exhaustion. In the survey a question inquired the pupils' state of tiredness. Whether this is caused by one of the physical parameters measured or simply was caused just by the hours of the day.

Sensation votes are separated into two groups according to one's self-assessment, whether someone feels tired or not. For the sake of brevity, they are called as "tired" and "non-tired" pupils. Figure 19 shows the thermal, Figure 20 the humidity, Figure 21 the air quality and Figure 22 the visual aspects; Figure 23 compares their general satisfaction votes. Distribution mean and standard deviation are in Table *15* and Table *16*. The calculated t-values compare tired to non-tired pupils, so the positive t-values mean higher values of the votes from tired people.

Altogether 65.2 % of the questionnaires reported to be tired. Table *14* provides us with proportions of pupils who feel tired during the representative day. For the time of the day a separate distribution of tired and not tired people would not have a direct result, because the distribution of responses is not equalized (depends on the count of occupants per lesson). Additionally to the previous explanation fewer pupils filled out questionnaires in the later hours of the day, because generally younger pupils have 6 lessons a day (till 13:15). So the 7th and 8th lessons of the day have fewer filled-out questionnaires compared to previous lessons' questionnaire amount. Therefore it was better to choose such a version, where the percentages complement to 100 % for each lesson in the table (*Table 14*), hence the written value means which part of the filled-out questionnaires at a given time belongs to the group of the tired or the non-tired population.

There is a relative majority whose self-assessment is tired, this is true for each of the listed times. The highest part of tired people is after the second lesson, then after the third fourth and fifth lessons. The significant difference is shrunk to a modest one after the first, sixth and later lessons. It can be generalized that along the day people accommodate to conditions,

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and start to be more and more active as the amount of tired occupants decrease, but there is the first class, which breaks this purely decreasing trend.

Table 14 Tiredness and the time of the day

	8:35	*9:30*	*10:25*	*11:25*	*12:20*	*13:15*	*later*
TIRED	57.8%	72.1%	68.5%	67.7%	65.3%	58.8%	54.5%
NOT TIRED	42.2%	27.9%	31.5%	32.3%	34.7%	41.2%	45.5%

There is a dominant “neutral” voter group regardless of the tiredness, and the votes are shifted to the warmer region rather than to the colder in both groups. Tired pupils voted in all of the warmer region’s options with higher percentages compared to the non-tired colleagues’ votes. As a result in the colder region and the neutral state the non-tired pupils have a higher accumulation. It is also remarkable, that nobody voted for “hot” conditions from the non-tired group. More than the half of the tired people has not chosen “neutral” option meanwhile the non-tired ones dominated by far in voting so. Additionally the rest who has not voted neutral is biased towards the warmer votes by far, but still the tired ones have a bigger proportion of these people compared to the non-tired colleagues. 87.9 % of the rest (who have not voted neutral) in the tired population votes warmer, this part is for the non-tired occupants 76.8 %.

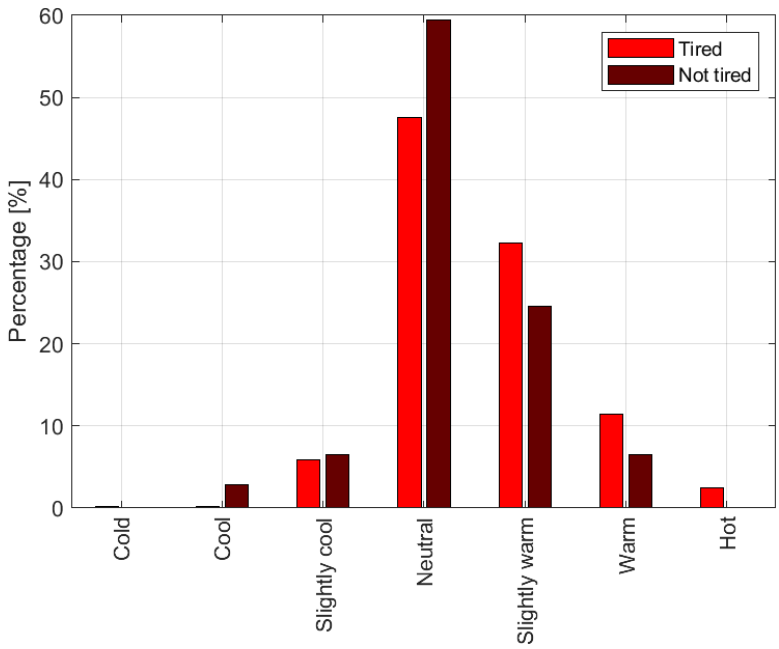

Figure 19 Self-assessed tired and not tired population’s distribution in their thermal sensation votes

The calculated t-value is 4.56, so there is a statistically significant difference between sensation votes of the two groups: tired pupils tend to feel conditions warmer.

In the literature some other researchers applied such graph, where sensation votes are along the vertical axis and actual temperature is depicted on the horizontal axis. Some used this

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type of graph with operative temperature (Ricciardi and Buratti, 2018), (Mishra and Ramgopal, 2015b), but some only measure air temperature and so the horizontal axis is the air temperature (Kumar et al., 2018). In this thesis there were planned to depict actual air temperature, and also a temperature difference between the actual and someone's idealized temperature. This latter was in the literature calculated as comfort temperature difference from the operative and neutrality temperature (Mishra and Ramgopal, 2015b). There was just a huge amount of points without any pattern, the R^2 values of linear regression lines could not reach even 0.15, *"However it may be noted here that for surveys dealing with human behaviour, an R^2 value of 0.40 still indicates a strong correlation"* (Mishra and Ramgopal, 2015b). In this thesis not to interrupt the main focus, these figures are not presented.

In humidity aspects there is a dominant "neutral" voter group regardless of the tiredness; the rest – who have not voted neutral – in both groups tend to appear in the drier region. This part is for the tired pupils about twice as many, for the non-tired ones around three times more votes are in this region than in the humid region. The "very humid" choice was never chosen, and the "very dry" category has also negligible amount of voters.

Due to the fact that in both directions deviating from the neutral state there is a higher share of tired people in the individual options, it means there is no definite direction of voting differently, which is also visible from the t-value=0.29. This implies a similar sample mean of tired and not tired people's votes; the slight difference could be the cause of random variance.

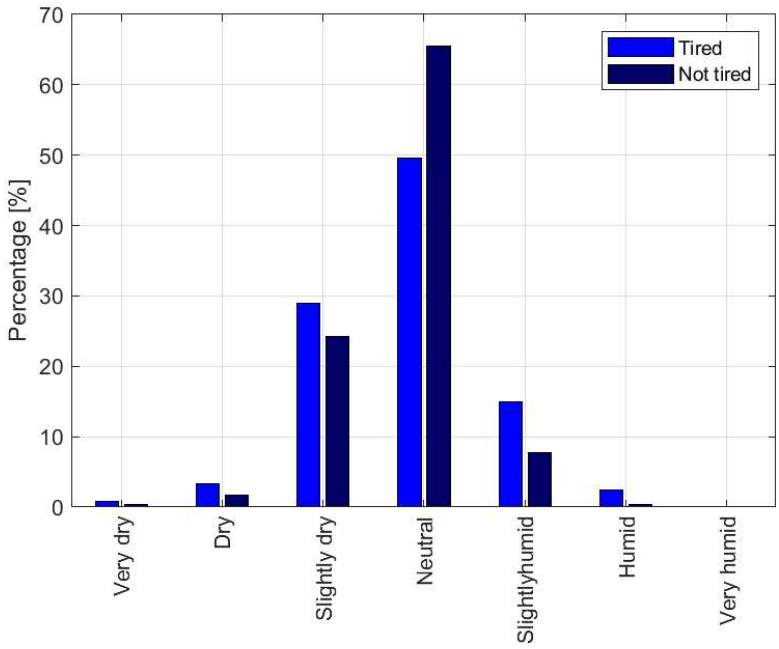

Figure 20 Self-assessed tired and not tired population's distribution in their humidity sensation votes

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In indoor air quality aspects the highest share is in both groups given to the “slightly stale” option. The “ideal” option in the 4 scale entry of indoor air quality is the “fresh”. The non-tired group has a higher share of giving the “most comfortable” answer compared to the tired mates. This conclusion is valid for the “second best” option, for the slightly stale condition too. For the two remaining (“stale” and “very stale”) options the statement is consequently the other way around. If the limit between acceptable and unacceptable air quality would be chosen to be between “slightly stale” and “stale” options, then one could say there is a large difference visible. This is quantitatively also a significant difference, so the t-value of -9.77 provides a rejection of the null hypothesis. From this data tired people tend to vote the air quality staler in their instantaneous sensation votes.

In visual aspects the two most extreme entries are not that frequently chosen; furthermore the middle 3 options (“slightly dark”, “neutral”, “slightly too bright”) happened to have a share over 95 % in both groups, i.e. generally everybody picked these options. The non-tired population still voted more often the “neutral” state than the tired population. Around a four times bigger part of pupils from the rest (who has not assigned to “neutral”) in both tired (3.97x) and not tired (4.40x) groups voted the darker conditions over the too bright ones.

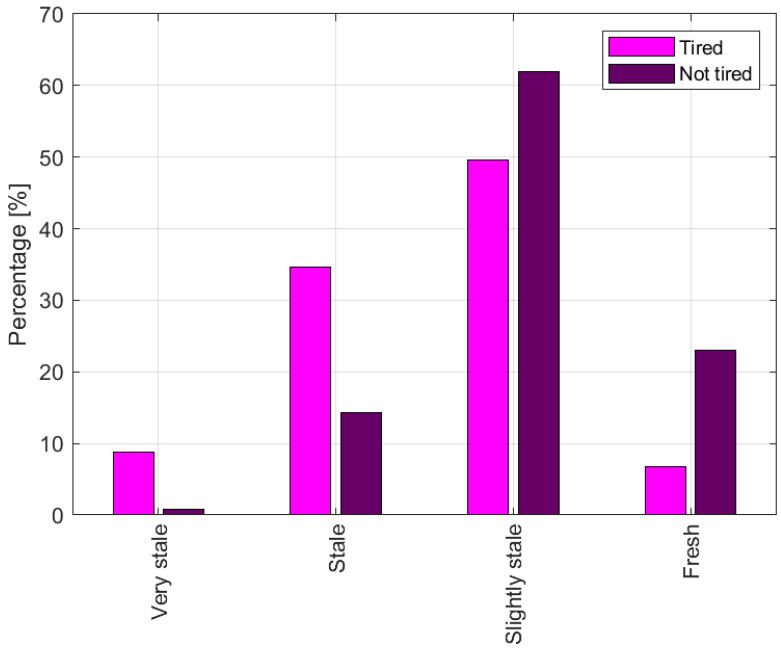

Figure 21 Self-assessed tired and not tired population’s distribution in their air quality sensation votes

Although the higher share of tired people’s votes in “slightly too bright” option, the darker conditions’ votes outweighed these. Tired people with a t-value of -1.77 just being over the limiting critical t-value of ±1.65 set up another rejection of the null-hypothesis. Tired people tend to perceive conditions darker.

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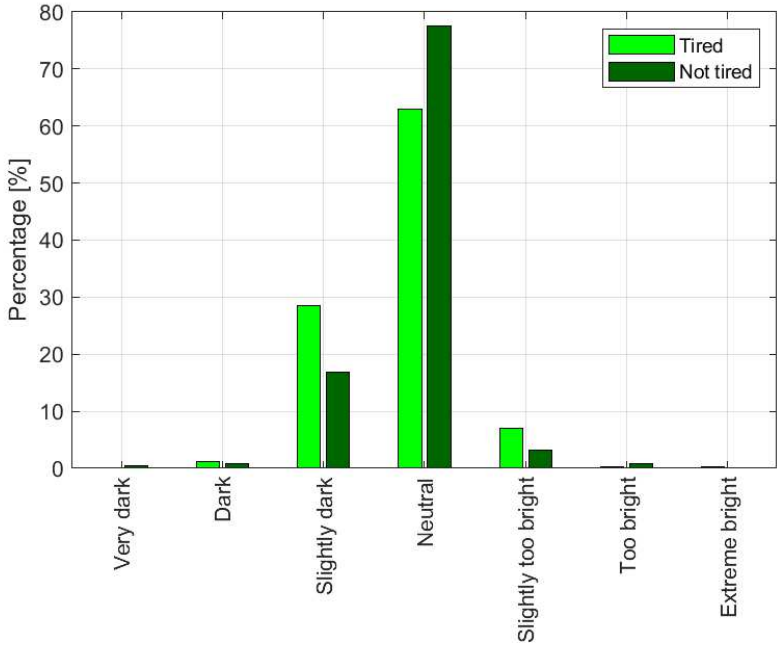

Figure 22 Self-assessed tired and not tired population's distribution in their brightness sensation votes

A slight majority voted for "average" in the general satisfaction vote which is followed by the "satisfied" voters. This jump shows an irregularity and there is not a smooth transition between these two. The general satisfaction rate has also resulted in a significant difference between the tired and the not tired pupils. The mean of the tired people's vote is almost by 0.5 lower on a scaling from -3 (very dissatisfied) to +3 (very satisfied), which implies a more critical perception, and less satisfied state.

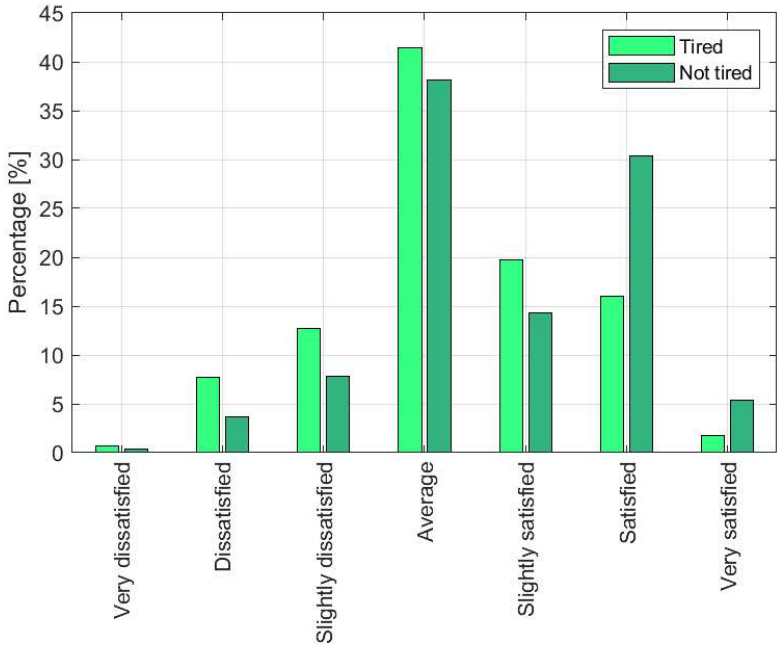

Figure 23 Self-assessed tired and not tired population's distribution in their general satisfaction votes

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Table 15 Statistical data of the votes of tired and not tired pupils. For the numerical values attached to the categories of the votes see Table 10

	Mean ± standard deviation	
	Tired	**Not tired**
Thermal sensation votes	0.553 ± 0.883	0.254 ± 0.792
Humidity sensation votes	-0.184 ± 0.632	-0.201 ± 0.294
Indoor air quality sensation votes	-1.455 ± 0.749	-0.930 ± 0.635
Brightness sensation votes	-0.226 ± 0.614	-0.147 ± 0.532
General satisfaction vote	0.270 ± 1.191	0.746 ± 1.244

Additionally one can compare the time range satisfaction votes of the two groups. In thermal aspects the t-test rejects the null hypothesis. There is a significant difference, namely tired pupils are for a shorter period satisfied with thermal conditions. This difference is almost as big as 6 minutes. Although there is no statistical connection found between tired and not tired instantaneous humidity sensation votes, there is a significant difference between their time range satisfactions. Tired pupils are less satisfied with moisture content of indoor air along the lesson. In indoor air quality aspects tired people were also found to be less satisfied, the difference is more than 7 minutes. And finally in visual aspects the null hypothesis is again rejected. Tired people are for a shorter period of time satisfied with the brightness of the surrounding.

Table 16 Statistical data of the time range satisfaction votes of tired and non-tired pupils. The length of a lesson is 45 min.

	Mean ± standard deviation	
	Tired	**Not tired**
Time range satisfaction with temperature	26.770 ± 15.593	32.385 ± 14.426
Time range satisfaction with humidity	29.406 ± 14.882	34.676 ± 13.160
Time range satisfaction with indoor air quality	20.802 ± 12.879	28.373 ± 12.552
Time range satisfaction with brightness	33.649 ± 15.418	38.746 ± 11.774

3.2.5 Ventilation habits (Q3 and Q4)

The first type questionnaire encompassed a question how often somebody operates the windows. If the response was anything except “never” the primary reason of this was also enquired: whether high temperature, humidity, poor air quality is the motive or this act is

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event based or other reason plays a role. Figure 24 depicts the distribution of the male and female occupants' votes among the frequency options. For the frequency there was no such option to choose as "always" but rather "almost always" because the condition "always" will not be fulfilled if at least once is not, but almost always truly mean what it is intended to mean, i.e. the highest frequency possible.

The vast majority have not picked the two least frequent option but starting from "sometimes" and on. The most common choice among the ventilation frequencies is different for the two genders: Males have chosen the highest frequency "almost always" with circa 39 % share Females chose the moderate option "sometimes" 45.8 %. Males have almost identic shares of votes in options "sometimes" and "regularly" and an increment of accumulation in the most frequent option. In contrast the figure demonstrates a strictly monotonously decrease in females votes in the top 3 options. As the female population is bigger, they outweigh the share of male votes thus the together handled votes show similarly the highest share at "sometimes", and a decrement in the share of voters as the ventilation frequency increases. The numerical values of the categories are according to Table *10*. The t-test rejected the null hypothesis, a significant difference is found. Males ventilate more frequently in this secondary school. Although females also actively take part in the manual airing, 92.3 % of females voted "sometimes" or more frequent.

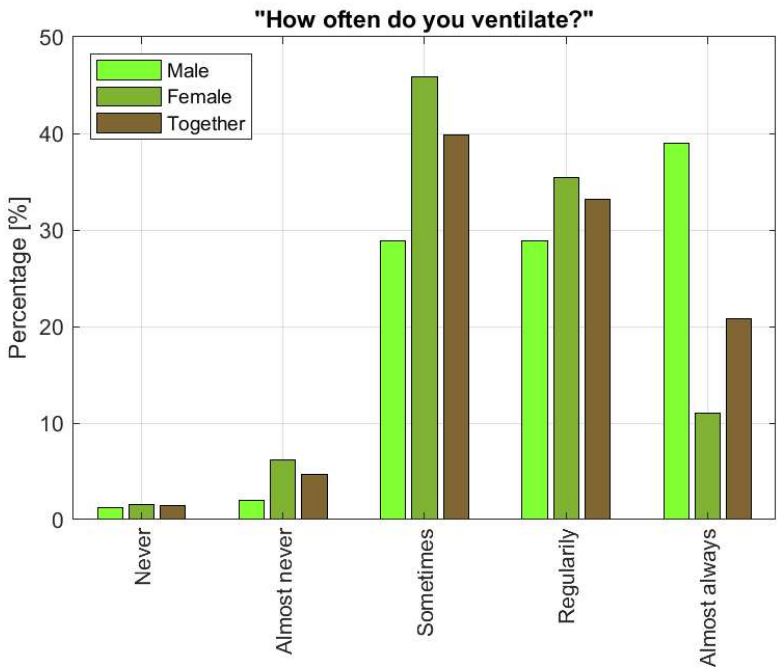

Figure 24 Ventilation frequency distribution of males and females

Table *16*Table *17* compares the mean values and standard deviations of the male and female occupants' ventilation frequencies, and additionally the tired and non-tired pupils' data is also listed. It was already mentioned that male occupants are more active in manual

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operation of windows. The other interesting question was whether the pupils – whose self-assessment is tired – are more active in ventilating, or they passively accept the conditions. If the least frequent option “never” is assigned to 1, and the most frequent option “almost always” assigned to 5 and every other options between accordingly to the corresponding number (see Table *10*), it could be assessed also by the same t-test. The t-test with the given numerical categorization resulted in a significant difference between the tired and non-tired pupils’ window operation frequencies. Tired people tend to be more active in ventilating, so they do not passively accept the conditions, but try to adjust them to their needs.

Table 17 Statistical data of the ventilation frequencies of male and female plus tired and not tired pupils. For the numerical values attached to the categories of the votes see Table 10

	Mean ± standard deviation	
	Male	Female
Ventilation frequency	4.024 ± 0.934	3.482 ± 0.829
	Tired	Not tired
Ventilation frequency	3.754 ± 0.870	3.521 ± 0.949

Figure 25 gives insight in the background motive of window operation of the occupants. The possible options to choose from were related to temperature, humidity, air quality, behaviour, or other influences. Those who have chosen the “other” option had to specify what it was, and the outweighing majority mentioned that they were asked to do so. Presumably, they sit next to the windows during the lessons when teachers want to ventilate.

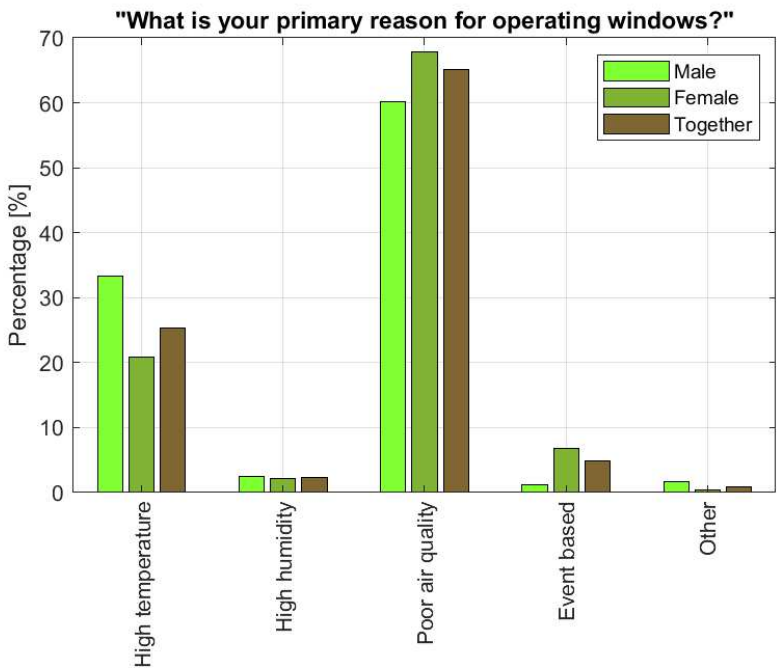

Figure 25 Why the pupils open windows

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The primary reason for opening the windows was undoubtedly dominant: “poor air quality”; 60.2 %, 67.8 % and 65.1 % by male, female and together handled votes respectively. The second most common choice was “high temperature”: 33.3 %, 20.9 % and 25.3 % among males, females and both categories handled together respectively. This already implies the two major problems: air quality, and overheating. Undoubtedly the dominant reason is air quality. This is in line with the least satisfaction minutes given for air quality in the time range satisfaction aspect (see Figure 8).

The high temperature causing discomfort was a bigger deal among the males, almost 1/3 of them voted this to be the primer causation of their window operation, and meanwhile only 1/5 of the females’ votes are in this category. The thermal perception of the two genders is quite suspiciously different already from this vote, for further details see subchapter 3.2.3 Perception differences among pupils of different genders (Q3). Some males operate windows irrespective to others’ perception, although they might not intend to disturb others’ comfort. Females are relatively more prudent in this aspect. Because of direct body exposure to the transient draught, some females – who might feel colder in comparison to their male mates – refrain from opening windows.

The option “Event based” has not gained a big amount of votes as an outcome. In some schools there is no other parameter with which the window operation could be connected other than leaving or entering of the space, or the occasion provided by the breaks (Deme Belafi et al., 2018). Findings in German flats show (Calì et al., 2016) the major reasoning to open a window was the time of the day, and only after that in second and third place came CO_2 concentration and indoor air temperature. In this case study “event based” option was hardly ever chosen. Probably this deviation is due to the fact that stale air quality is already disturbing and nobody thinks of their window operation as an event based act when entering a classroom, but to get rid of stale air. Conclusively they do not associate it with the entering of the space. Or this difference could stem from the different types of usage between educational and residential buildings. Pupils already have some complains about the indoor environment, and the window operation is a reflection on that perception rather than a scheduled act

3.2.6 Perception differences among pupils of different genders and ages (q4)

Effects of aging were visible in a 2-year long study in Sweden. The same pupils perceived the almost same air quality less tolerable (Wang et al., 2015). Additional insight can be gained if we further divide the genders according to pupils’ ages. For the sake of brevity the findings of this subdivision is only listed in bullet-points. These results are not depicted in the

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main text due to its amount of graphics and area which they would occupy, so the reader is redirected to Appendix C.1Appendix C.6.

There is an assumption that indoor conditions in the secondary school are negligibly different along the measuring period, so all of the votes could be handled as assessing the same condition. This might not be exactly true, but approximately fine as the cumulative graphs have already pointed out a narrow range of altering (temperature, humidity and illuminance). Air quality of the indoor air was assessed also always at the end of the lessons, which might result in a similar staleness of air. But one has to consider, that different window operation could influence conditions a lot. Brightness perception is really dependent on the seat position, thus generally comparing the dataset will probably reflect only to the blessings and curses of the orientation, and the use of shading curtains locally. When the questionnaires were delivered to the classes, curtains were apparently pulled in for all windows, there were some tiny holes where the direct sunlight could penetrate in and hit someone's task area. The group of 14-year old males (4 votes), 19-year old males (7 votes) and 19-year old females (9 votes) is not considered because of their little population count. With this huge amount of data there is a long analysis possible but for the sake of brevity, only some bullet points are listed.

Thermal aspects:

- There is a negligible amount of people voting "cold" and it happened only for the adolescent females (17-, 18-year olds).
- The "slightly cool" vote among females was almost universally picked by 6…8 %.
- "Neutral" female votes have an overwhelming half of the share of votes regardless of their age.
- Only the adolescent females (17- and 18-year olds) voted "hot" conditions.
- Among the males neither "cold" nor "cool" conditions were picked by anyone.
- "Neutral" is in contrast to the female voters definitely less than half of the population for the 17-, 18- year old males.
- "Warm" and "hot" conditions are without a pattern chosen by the males. "Warm" was about 3 or 4 times more commonly picked than "hot", and altogether they outweigh the female votes by far.
- The biggest difference between the thermal perception votes was visible in the group of 18-year old pupils (C: cold region, N: neutral and W: warm region). Females have C: 5 %, N: 84 %, W: 11 %; males: C: 0 %, N: 61 % W: 39 %.

Humidity aspects:

- "Very dry" option is only voted from females but in a negligible amount.

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- “Very humid” option is not picked by anyone.
- Majority found humidity “neutral”, 42.5…63.2 % among the females and 38.5…65.2 % among the males.
- The ratio between the dry region voters and the humid region voters for the females is 1.00…3.14. The same ratio for the males is 1.23…2.43. This means there is at least as many dry voters as humid voters for every age and gender. So the conditions were found rather dry than humid.
- Handling “slightly dry” and “slightly humid” votes as still comfortable, there is the vast majority in comfortable region: 92.3…100 %.

Indoor air quality:

- “Very stale” conditions were not reported by the 16-year old females and males, i.e. they were not exposed to such a lesson, because of e.g. tilted windows in the classroom.
- “Very stale” conditions occurred in all other groups: 3.3…9.3 % of female votes and 10.3…13.0 % of male votes.
- The most commonly picked grader was “slightly stale” for both genders: among the females with 49.5…86.7 %; while among the males with 34.8…68.1 % (except for the adolescent 18-year old males, they voted 43.5 % for “stale” and only 34.8 % for “slightly stale”).
- “Fresh” votes are strictly decreasing among females as the age increases (except for the 14-year old females). This decrement is also visible for males, but it is not a strictly decreasing sequence.
- The ratio of stale and fresh conditions (where possible) is calculated to be 4.6…23.3 for females and 5.9…38.1 for males. This implies a bigger dissatisfaction on the males’ side, as also found in the previous subchapters.
- If the most commonly chosen “slightly stale” condition is considered as still comfortable (only “very stale” and “stale” votes are considered uncomfortable), then the above written ratios will change drastically, there will be more “comfortable” voters than “uncomfortable” voters. This ratio is for females 0.2…0.8; while for males the ratio of uncomfortable and comfortable will be 0.3…1.3. But the 18-year old males voted more “stale” and “very stale” than “slightly stale” and “fresh”. For the second time the 18-year old males seem to be more critical with air quality.
- There is no statistical significance whether one’s age would influence his/her perception.

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Brightness perception:

- The most commonly chosen grader was without exceptions the “neutral”. For females 53.3…74.0 %; for males 64.1…82.6 %.
- There were way more darkness complaints than too bright votes. For females the ratio between dark region and too bright region is 4.1…11.1; while for males this ratio is around 2.5 in all age groups (where possible).
- If the “slightly dark” and “slightly too bright” conditions still count as comfortable conditions, then this category will dominate the votes. For females it would mean 92.8…99.2 %; while for males 97.5…100.0 %.

The analysis for finding differences among different age pupils’ perception does not found any rule which can be established. The pupils are more influenced in their perception by their gender than by their age. At some point it was a slight link to the fact the younger ones are the less observant of the conditions i.e. they voted more “neutral” or the closer to “neutral” option, but at some point it was just the contrary, and adolescents voted so.

3.2.7 Distance of the seating location from the windows (q3)

Windows are in both classrooms to the left hand-side of the seating of pupils. With the windows orientated to south-west there is a massive solar heat gain as the sunrays hit the windowpane at around 10 o’clock and afterwards. Because of this, curtains are closed almost the whole day to prevent disturbing patches of light on the black board and on task areas. Heat distribution asymmetry – besides the solar gains also because of the single sided placement of heat emitting radiators – might alter microclimatic conditions of pupils in both classrooms (Theodosiou and Ordoumpozanis, 2008). Increased draught risk adjacent to the windows is not unusual, but this effect did not extend much beyond the first meter (Mumovic et al., 2009).

Another aspect to be examined was whether the distance from the window pane would make any difference in the perception responses. There were two types of perception asked in the questionnaire. The first question targeted the “right now” sensation on a 7- (for temperature, humidity, brightness) or 4- (for air quality) entry scale. The second question was about the time range satisfaction with the parameters along the lesson as a free entry in minutes (knowing that a class lasts for 45 minutes). For the instantaneous sensation only the actual sensation would have been compared, and in this minor research question it was not important. On the other hand time range satisfaction represents someone’s long run perception, therefore it is more applicable for comparing the differences (see Figure 26).

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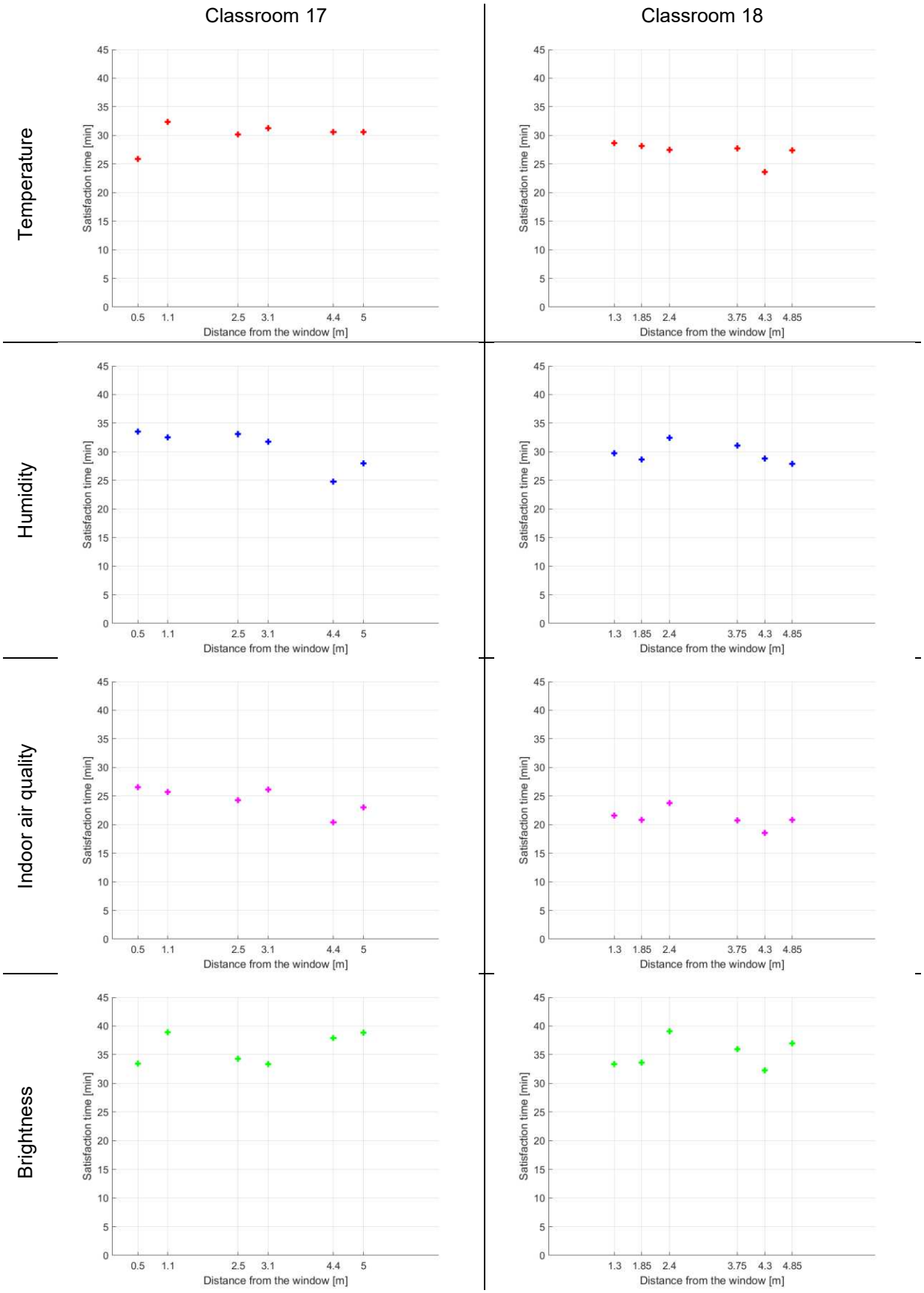

Figure 26 Average satisfaction time with the different parameters as a function of distance from the window pane in classroom 17 (left) and classroom 18 (right)

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In thermal aspects there is not a perceptible influence of the distance from the windows in any of the classrooms visible. In classroom 17 the mean value of the voted minutes fluctuates as the distance increases. In classroom 18 the mean of the voted minutes seem to be balanced and uniform.

As humidity is concerned in classroom 17 the two deepest positions of the room (4.4 m and 5.0 m) have lower mean votes. It seems the closer one's position to the window is, the more satisfactory it is in terms of humidity. In classroom 18 the middle of the room achieved higher mean values. This does not support the finding in classroom 17. With regard to humidity there is also no direct influence of the distance from the windows found.

In air quality aspects the mean values of the time range satisfaction votes of different distances have a decreasing trend as the distance increases. In classroom 18 the mean values of votes in different distances are somewhat lower than in classroom 17. There is a fluctuation of means perceivable in classroom 18's positions, so it does not support the previously found decreasing trend of means as the distance of the windows increases in classroom 17. So there is no direct influence of the distance from the windows found.
Brightness perception in both spaces showed a surprising result. The deepest positions are not affected by the distance from the window. Pupils perceive brightness even in the farthest positions from the windows satisfactory. This is possible, if the drapers are closed and artificial lights provide almost uniform brightness. This was the case most of the time during the monitoring regime. The long satisfaction periods of the pupils show no direct influence of the distance of one's seat from the windows in visual aspects.

It should be considered that pupils were not equally spread in the classrooms, but tended to accumulate closer to the windows. In order to have a more detailed understanding of the phenomena, multiple loggers would be necessary inside the same objected classroom (Shi et al., 2017), so the microclimate of the individual pupils – or pairs who share the same desk – could be analysed more in depth. The distance of pupils' seat from the window pane had not shown any effect on their votes in any aspects.

3.2.8 Suggestions for improvements

Figure 27 shows the list of suggestions how the pupils thought the indoor environment could be improved. This question of the first survey had no options to choose from, but everyone could write their thoughts freely. The categorisation was only later created after reading some already written improvement suggestions. This question was only a week later given to the survey, thus fewer answers were collected, plus still a lot of pupils neglected to write any

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suggestions. The categorization will be shown on the following example: pupil's answer: *"less heating"* (→ "controlling of heating system" + "colder temperatures").

More Frequent Ventilation	30.0 %
Controlling Of The Heating System	10.8 %
Air Conditioning	7.7 %
Plants	7.3 %
Colder Temperature	5.7 %
Fresh Air	4.6 %
Improving The Ventilation System	3.5 %
Bigger Windows	2.4 %
Cleaning	2.2 %
Obligatory Ventilation During Breaks	2.2 %
Air Freshener	2.0 %
Improving The Heating System	2.0 %
More Space	1.8 %
Not To Leave The Windows Open For So Long	1.8 %
Other suggestions	16.1 %

Figure 27 Suggestion for improvements

The topmost votes belong to either air quality (e.g. "more frequent ventilation") or thermal conditions (e.g. "controlling of the heating system"). This is in conscience with their responses of reasoning the operation of windows, where also air quality and temperature issues are chosen dominantly (see Figure 25). Lighting and equipment-based votes are not present among the suggestions to a bigger extend.

Some responses mentioned "shorter lessons", thus exhaustion might be a reasonable issue too. It is not a surprise after knowing that the self-assessment of approximately 2/3 of them is tired. Schools are buildings with high crowding index, so it is not a surprise that a few of the suggestions for improvement mention more space (1.7 %) and fewer occupants (1.5 %).

"Ventilating during lessons" was among the suggestions; this is a primary measure to mend the elevated CO_2 level (Vilčeková et al., 2017). Two of the responses suggested CO_2 indicators in all classrooms, which is also a direct link to suggested measures of other researchers (Bakó-Biró et al., 2012), (Vilčeková et al., 2017), (Schibuola et al., 2016).

"Drawing the curtains apart" obtained a 1.3 % share. Due to the south-western orientation of the façade solar rays penetrate the classrooms already from around 10 o'clock. In the classrooms there is an on-off switch control of artificial lighting. Lights are most of the time set on to tackle under-lighting while the curtains are pulled to prevent over-lighting. In Greek schools, similarly to this case, the highest energy bills were found to be in such schools where there was a good access to natural lighting, because curtains where used to prevent glare (Theodosiou and Ordoumpozanis, 2008). "New curtains" were also mentioned.

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Sometimes patches of light appear on task areas. If there is a mixed sky that day, due to cloud motion these phenomena repeat themselves irregularly a couple of times which disturbs the occupant. The quality of the curtains is not optimal, they have to be changed, or shades should be added.

Ventilation cannot last until the indoor CO_2 concentration is diluted to the level of outdoor concentration because of the thermal property of the entering outdoor air. 1.8 % of respondents mentioned windows being opened for too long as a problem; these are all votes of females.

"Just designing a potentially comfortable building is not enough. One also needs to monitor building and occupant performance during its operation." (Al horr et al., 2016)

Because the average user does not see a whole building approach, none of them mentioned improvements such as using more renewable energy sources or more efficient devices, although installation of LED and PV system in secondary schools provide high energy savings (Mora et al., 2017). Probably they are in an early age, or they were not taught such knowledge yet, and lack of the energy efficiency awareness, which is one of the four base pillars of "User Perception of Energy Efficiency in School building's Design (UPEESD)" (Salleh et al., 2016). Malaysian students were found to possess a high level of awareness regarding the climate change as the surveys were filled out (Puteh et al., 2012). Functionality and layout of educational buildings are significantly important and sensation of "cosy-pleasant" according to a study conducted in a university in Spain (Castilla et al., 2017).

3.3 Feedback from the second questionnaire

The easiest way to get an overview on the responses if we parse all of the given answers in a figure (see Figure 28). The feedback questionnaire was only filled in once per each pupil who already filled a previous type survey.

Questionnaire 1 encompasses 16 questions (not counting the general data like gender, age…), Questionnaire 2 consists of 13. The vast majority found the size of the questionnaires ideal (84.9 %) but it was already tending to be a somewhat longer rather than shorter survey. In some cases the missed answers for the time range satisfaction with the parameters could also be connected to the dense paper layout because of the many questions and the somewhat misleading grouping lines between questions about the physical parameters. Future research questionnaires should not consist of more than 10 short questions on an A4 size sheet in order the have a perfectly clear outlook of the survey.

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QUESTIONNAIRE about the indoor environment 2

Male	Female
36.2%	63.8%

Age	
14	3.4%
15	32.8%
16	15.9%
17	19.4%
18	25.4%
19	2.2%

Mark your answers!

Questions/statements	Please, choose only one answer per question/statement!				
1. Size of the questionnaire			*Long* 12.5%	*Ideal* 84.9%	*Short* 2.6%
2. Without explanation how did you find the question: *"Approximately how long haven't you been outdoors?"*			*Easy* 89.7%	*Difficult but intelligible* 9.5%	*Unintelligible* 0.9%
3. Without explanation how did you find the question: *"According to your current clothing and activity level (e.g. seated) what would you call as an ideal indoor temperature?"*			*Easy* 81.9%	*Difficult but intelligible* 15.5%	*Unintelligible* 2.6%
4. Without explanation how did you find the question type: *"How do you find … right now?"* E.g.: Cold ☐ Cool ☐ Slightly cool ☐ Neutral ☐ Slightly warm ☐ Warm ☐ Hot ☐			*Easy* 95.3%	*Difficult but intelligible* 4.7%	*Unintelligible* 0.0%
5. Without explanation how did you find the question type: *"During the lecture time for how many minutes were you satisfied with … ?"*			*Easy* 81.9%	*Difficult but intelligible* 16.4%	*Unintelligible* 1.7%
6. Which scaling do you find more logical?	*This →* 56.9%	Very stale ☐ Stale ☐ Slightly stale ☐ Fresh ☐			
	This → 43.1%	Very stale ☐ Stale ☐ Slightly stale ☐ Neutral ☐ Slightly fresh ☐ Fresh ☐ Very fresh ☐			
7. „I love when a sports class is outdoors!"		*Always* 15.1%	*Yes, but not in cold* 53.9%	*Yes, but not in hot* 8.2%	*No* 22.0%
8. „I feel better after sports classes!"	*Always* 16.4%	*If we were outdoors* 15.9%	*If we were indoors* 6.5%	*No change* 34.5%	*It is worse* 25.9%
9. „It would be great to ventilate on the corridors too!"	*Always* 53.0%	*If outside is not hot* 9.5%	*If outside is not cold* 15.9%	*No* 2.2%	*Indifferent* 19.0%
10. „It would be better to have a longer break to go out!" (the ending of the day would be also later)			*Yes* 32.3%	*No* 47.0%	*Indifferent* 20.3%
11. Do you go out more if the weather is fine?				*Yes* 64.2%	*No* 35.8%
12. Would you go out more frequently if there were a landscaped courtyard?			*Yes* 56.9%	*In nice weather* 34.5%	*No* 8.2%
13. Did the questionnaires appeal to you?		*Yes both* 87.9%	*Only the first one* 3.4%	*Only this one* 4.3%	*No* 4.3%

Figure 28 The responses for the second questionnaire (feedback-questionnaire Appendix B)

3.3.1 Time spent indoors (q1)

After the mechanical ventilation system was built a few years later a handball hall was erected in the back side of the school building. This cut the school's previous courtyard to its half or even less area was remaining. Realising that the children might not even go outside during a whole day was the triggering idea to include a question in the first type questionnaire which asks them for how long they have not been outdoors (see Figure 29).

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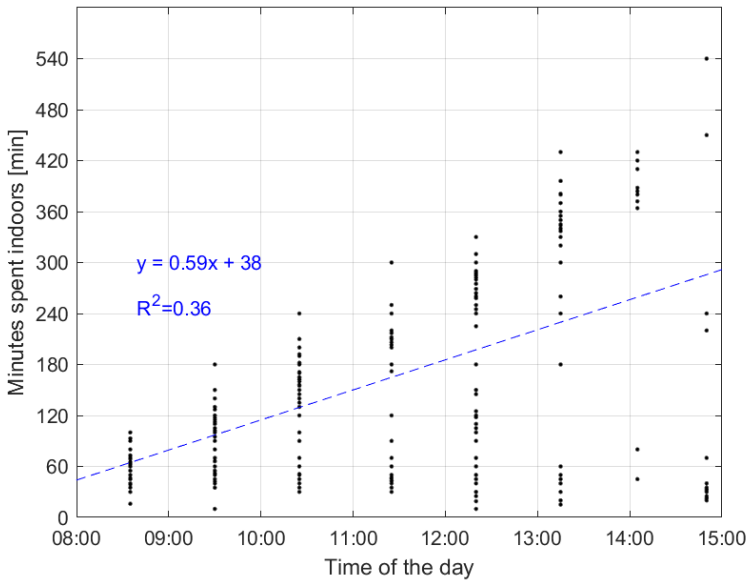

Figure 29 How long the pupils have not been outdoors

This question asked them to estimate their time spent indoors in minutes. The most common answers after each lesson are mostly around the increasing time counted from the official start of the education in the morning 7:50. These are the ones who have not been outdoors since they have arrived at school in the morning. In the later lessons this effect is not that visible, because pupils sometimes go for lunch or spend a few hours elsewhere (e.g. café, buffet, etc.) if they have free time between lessons. Regression analysis gives an equation of y=0.59*x+38, where y is the time spent indoors, x is the time of the day. R^2=0.36 is a relatively low measure of goodness. The effect of the different behaviour of pupils in later lessons distorts the results. Additionally this effects the slope of the variables, where ideally a y=x equation was awaited, and the constant in the equation clearly distorts the equation almost by a whole lesson.

3.3.2 Intelligibility of not yet tested questions (q2)

Reflecting on the previous questionnaire's questions revealed that the pupils generally understood the questions, what they read but with differences among them. The easiest question was the "right now" sensation vote (95.3 %), where they only were asked to tick one entry. Still the remaining 4.7 % of them found it difficult, but intelligible. This small ratio is presumably confused about assessing the humidity, which was undoubtedly hard to perceive. This question type is well tested in the literature, so it serves as a reference in this comparison.

The questions about idealized temperature according to the clothing and activity level; and the time range satisfaction with the physical parameters along the lessons resulted in the

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same percentage of “easy” voters (81.9 %, 190 people). The difference appears in the unintelligibility ratio, where 2.6 % found it unintelligible what the idealized temperature question aimed for, and 1.7 % found the satisfactory minutes along the lessons unintelligible. It still might not be that significant (approximately every 40th or 50th pupil). The issue might be that these questions although being understood are difficulty to be answered as almost every 6th pupil voted to this option, 15.5 % and 16.4 % for idealized temperature and time range satisfaction respectively. At some points the satisfaction minutes were not filled out in the previous questionnaires, presumably due to its misleading grouping lines which separated two physical parameters combined with the colour-bars (misleading outlook of questionnaire), hence after picking the sensation vote someone just jumped into the next perception group leaving the time range satisfaction question empty.

The last question from the reflection on the previous questionnaire compares two types of air quality scales, the 4-entry asymmetric one, where there is no option “neutral”, “slightly fresh” and “very fresh”; and the 7-entry symmetrical scale. There is a substantial difference between the meaning of the two kinds of indoor air quality scales, the one provides a neutral zone between fresh and stale conditions, the other does not. Results imply it to be still undecided which to pick in future research, but a slight majority tended to the 4-entry scale. In the literature as already pointed out in sub-chapter “2.1.2 Surveys” there is not a consensus which to choose. Some use symmetrical, some asymmetrical grading staleness, and some use asymmetrical grading freshness. The 4-scale air quality perception vote provided “fresh” and “slightly stale” options which are the excellent and still bearable conditions. This was clear for everybody, and they voted accordingly. So the quality of the answers was not influenced in this manner in this case study. In future researches it would be interesting to investigate on subjective perception of indoor air quality with both scales included in the questionnaire, and for avoiding the aesthetic differences colour-bars should be avoided not to influence the answers.

The question about the time length during the pupils have not been outdoors was found by a negligible amount of pupils as unintelligible (0.9 %), and almost one out of ten of them found it difficult but they understood what the question was asking. Supposedly the difficulty of the question was to calculate back from the current time to the moment when they arrived which is not even remembered by a few of them. This was a complicated task compared to the other questions, especially for those who were filling the questionnaires at the end of a later lesson. Because of the complications some only wrote “I arrived at 7:40” where they clearly emphasized a difficult task of calculating.

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3.3.3 Outdoor contact

From 7th to 12th questions of the feedback questionnaire (Figure 28) the pupils' contact with the outdoor air was inquired. 77.2 % of the filled-out feedback questionnaires prefers outdoor sports lessons but the great majority (53.9 %) restricts it to the not cold outdoor conditions. Surprisingly 38.8 % feels only better after a sports lesson, the rest is either indifferent (34.5 %) or feel worse (25.9 %). The logical reason could be the lack of time for properly having a shower thus the rest of the day is a bit inconvenient in the school.

Question 9 is for special interest because it focuses on the natural ventilation also on the corridors, where some pupils were observed opening windows confidentially. 53 % of the pupils voted to have in all cases – without any constrains – manual opening of windows not just in classrooms but on the corridors too. It is already a majority which approves the need of fresh air supply not only locally inside the classrooms. This supports the suggestions of Greek researchers, namely air renewal needs a whole-building approach and not solely classroom based solutions (Theodosiou and Ordoumpozanis, 2008).

Tackling the issue that pupils do not depart the school building until afternoon, when their education period has ended (see 3.3.1 Time spent indoors (q1)) the 10th question offered an option if there could be a longer break, would they go out at least then? Will they prefer to have some fresh air during the school day, to move around to have some activity? But coins have two sides so on the other hand it means that school time will last longer in the afternoon. Every third pupil would like it this way, every fifth is indifferent and every second is definitely against it. Some social issues are hidden in the background. In our accelerated world teenagers already begin to hurry and get through the necessary obligations but nothing more. So they prefer their own private free-time in the afternoon rather than free-time with their school mates at school in the middle of the day.

Another issue is that due to recent erection of a handball hall close to the school, the backyard of the school is truncated and a parking lot is built. The remaining backyard space is aesthetically not so appealing. It is worthy to consider that 91.4 % would go out more frequently if there was a nice park, or a landscape backyard attached to the school. Half of the population would not prefer a longer break during the day, but with the same schedule the landscaped backyard would be a great opportunity to give more outdoor contact to the pupils during school days.

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4 CONCLUSION

Indoor air temperature, relative humidity, illuminance of task area and CO_2 concentrations were monitored in two different sized but same oriented classrooms of a Hungarian secondary school. Pupils were handed out questionnaires on each lesson on Thursdays and Fridays during the monitoring regime in February 2020. Questions inquired their instantaneous and time range satisfaction along the lessons with the different physical parameters. These were then analysed and conclusions derived following the main and minor research questions. Pupils' subjective perception was compared to the objective data measured in the classrooms. Also a comparison was made between groups of different genders and between those whose self-assessment was tired versus whose was non-tired.

Nowadays there are a lot of refurbishments with the predictions of 15-20 years of payback time on the investment. In a school where a mechanical ventilation system is designed, constructed but shut down because of improper functioning, this payback will never occur. But even if it was designed better it is always important to consider, that calculated values can significantly be different from the real savings. In case of a thermal refurbishment of a secondary school in Poland the calculated 59-71 % of saving was only 33 % in reality (Krawczyk, 2014).

An occupant in a natural ventilated school building plays a crucial role in influencing indoor environmental conditions. They try to fight the debilitating environmental stress via operating windows. As an outcome of this master's thesis manual airing strategy was found to be quite frequently applied and the utmost reason of this act was poor air quality following by high temperature. Derived from the cumulative CO_2 concentration figure (Figure 5) of the two classrooms 61 % and 67 % of time in classroom 17 and 18 respectively met the requirements of indoor air category II according to EN 15251.

In Portuguese non-refurbished schools the average temperature was found marginally higher than in refurbished school buildings (Almeida and Freitas, 2015). In this case study the secondary school's temperature levels are sometimes extreme, although being retrofitted in the early 2000s. Due to the unbalanced heating system some classrooms have to suffer extreme high temperatures. Results of comfort window calculations show an immense difference between comfortable conditions in the two classrooms. 44.5 % and 6.8 % of time when classroom 17 and classroom 18 respectively have comfortable conditions. This achieved low percentage of time inside the comfort window in case of classroom 18 calls for a change. The data-points were shifted to the warmer and drier edge of the comfort window. Although by operating windows in heating period the outside cold air also helps tackling the overheating. This causes an uncontrolled heat loss, and disturbance in others' thermal

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perception. There was a significant difference found between females' and males' thermal and indoor air quality votes it is subsequent and deducible, that males ventilate more frequently to adjust conditions to their own needs. According to the questionnaire responses males are significantly more frequently involved in manual airing compared to females. To mitigate the problem caused by the overheating besides reducing CO_2 concentration, windows are sometimes tilted or left partially opened during lessons too. Some classes are prone to rush out the classroom and leave windows open at the end of the day, thus causing a huge energy loss, because only the cleaning staff might close it 2 or 3 hours later. But wasting energy is not an acceptable solution in our climate crisis. Balancing the heating system is indispensable. Literature presents information on achievable benefits in improvement of mental and physical well-being plus in leaning performance as a result of mending the problem of overheating and providing higher rate of fresh air supply (Toftum et al., 2015), (Wargocki and Wyon, 2013).

Pupils in classroom 18 (bigger classroom) perceive conditions warmer during the occupied hours and the monitored data supports this subjective perception. Classroom 18 is almost by 1.5-2 °C warmer according to the cumulative temperature graph. The humidity perception was not found to be significantly different. In indoor air quality perception pupils from the bigger classroom voted air quality to be staler compared to the smaller classroom. This is probably because of the different usage type of the two classrooms, namely the bigger classroom is officially closed during breaks, hence there is fewer opportunity to ventilate. The brightness perception was also compared but not found to be significantly different.

Due to tiredness pupils' level of attention decreases, their performance is suboptimal. The highest count of pupils whose self-assessment is tired was found after the second lesson, as the day went on this share of tired pupils started to decrease but after each lesson there were more tired people than not tired. Tired perceive thermal conditions warmer, air quality staler, surroundings darker than the non-tired pupils, their general satisfaction is also lower. Additionally in all aspects of the time range satisfaction minutes tired people turned out to be less satisfied. They are more active in natural ventilation, because they try to adjust conditions to their own needs. These findings illuminate an urgent need of an action tackling tiredness causing conditions such as high temperatures, elevated CO_2 levels, dim lighting conditions etc.

According to the dataset collected males compared to females perceive conditions warmer, less dry, staler air quality and less dark surroundings. Although males' general satisfaction votes do not significantly differ from the females' general satisfaction votes. Neither was found a significant difference between the two genders' time range satisfaction minutes.

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Some of these occupants are already in mature state of awareness of environmental impacts. Some suggestions for improvement written to a free-entry question go in tandem with some previous studies suggestions (e.g. application of CO_2 sensor). But still the highest share was outstandingly for “more frequent window operation”. The following top suggestions all dealt with either air quality issues or with the overheating.

The minor research questions targeted children’s outdoor contact; whether they understand not yet in literature tested questions; whether the distance from the window makes any difference of their perception; and whether their age influences their perception. It was found that they do not leave the school building until the end of the day, because there is a too small schoolyard and short breaks. But they would prefer going home earlier in the afternoon than to have a longer break in the middle of the day. They found the questions except the sensation votes more difficult, but still intelligible and only 2 % of them had difficulties understanding the questions. The distance from the windows were not found to be significant in the time range satisfaction aspect. Perception of different ages of pupils sometimes tended to a direction where the younger someone is, the less he cares about the conditions but this had not enough statistical significance, as sometimes being the contrary visible.

Summarizing in this case study the subjective perception of pupils was compared to the objective measurements of indoor environmental conditions. This perception matches with the objective data. In further research classrooms with more data loggers should analyse this more in depth, because the microclimatic condition of different spots in the classroom may differ. Males’ perception is significantly different of females. Those whose self-assessment is tired also perceive conditions significantly different of those whose self-assessment is non-tired. Perception of 14 to 19 year old pupils was found to be independent of their age. In the secondary school there is an unbalanced heating system which needs to be corrected unless the occupants suffer under overheating, and there is a huge waste of energy. The pupils of the secondary school are really active in natural ventilation to adjust conditions to their needs. Poor air quality and high temperature are the two utmost issues which they try to change. The self-assessment of almost 2/3 of them is tired in the school which could also point to air quality and high temperature issues. To diminish ventilation heat losses it is also considerable to redesign the mechanical ventilation system’s distribution ducts, because the single air grill as an inlet and outlet could barely serve 20-30 occupants with fresh air.

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5 INDEX

5.1 Index of figures

Figure 1 Lajos Kossuth Secondary School Mosonmagyaróvár, Hungary – Site view with the measuring station and floor plan of the first floor with a highlighted area of the monitored rooms 9
Figure 2 Classroom 17 (left), classroom 18 (right) (Black circles indicate the location of the devices) 11
Figure 3 Cumulative temperature in both classrooms and the limits of thermal categories according to (DIN EN 15251:2012-12) 19
Figure 4 Cumulative relative humidity in both classrooms 21
Figure 5 Cumulative CO_2 concentration in both classrooms and the limits of thermal categories according to (DIN EN 15251:2012-12), mean outdoor CO_2 level = 425 ppm 23
Figure 6 Cumulative illuminance on the task level in both classrooms, and the limits of requirements for normal (300 lx) education according to (DIN EN 15251:2012-12) 24
Figure 7 Psychometric chart with comfort window and measured points of the zones 26
Figure 8 Satisfaction rate as a function of time of a class Thermal (red), humidity (blue), air quality (purple) and illuminance (green) sensation 29
Figure 9 Comparison of the distribution of thermal sensation votes in different classrooms in the last 5 minutes of each lesson 31
Figure 10 Comparison of the distribution of humidity sensation votes in different classrooms in the last 5 minutes of each lesson 32
Figure 11 Comparison of the distribution of indoor air quality sensation votes in different classrooms in the last 5 minutes of each lesson 33
Figure 12 Comparison of the distribution of brightness sensation votes in different classrooms in the last 5 minutes of each lesson 33
Figure 13 Comparison of the distribution of general satisfaction votes in different classrooms in the last 5 minutes of each lesson 34
Figure 14 Thermal sensation votes of males and females in the last 5 minutes of each lesson 35
Figure 15 Humidity sensation votes of males and females in the last 5 minutes of each lesson 36
Figure 16 Indoor air quality sensation votes of males and females in the last 5 minutes of each lesson 37

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Figure 17 Brightness sensation votes of males and females in the last 5 minutes of each lesson....37
Figure 18 General satisfaction votes of males and females in the last 5 minutes of each lesson....38
Figure 19 Self-assessed tired and not tired population's distribution in their thermal sensation votes....40
Figure 20 Self-assessed tired and not tired population's distribution in their humidity sensation votes....41
Figure 21 Self-assessed tired and not tired population's distribution in their air quality sensation votes....42
Figure 22 Self-assessed tired and not tired population's distribution in their brightness sensation votes....43
Figure 23 Self-assessed tired and not tired population's distribution in their general satisfaction votes....43
Figure 24 Ventilation frequency distribution of males and females....45
Figure 25 Why the pupils open windows....46
Figure 26 Average satisfaction time with the different parameters as a function of distance from the window pane in classroom 17 (left) and classroom 18 (right)....51
Figure 27 Suggestion for improvements....53
Figure 28 The responses for the second questionnaire (feedback-questionnaire Appendix B)....55
Figure 29 How long the pupils have not been outdoors....56

5.2 List of tables

Table 1 The geometrical data of the classrooms (average count of occupants: 19)....9
Table 2 Specifications of applied measuring devices (HOBO datasheet; Wöhler datasheet)....11
Table 3 Location of the measuring devices....11
Table 4 Distances from windows in the two classrooms....14
Table 5 The percentages of time when the classrooms belonged to the thermal categories according to (DIN EN 15251:2012-12)....20
Table 6 The percentages of time during occupied hours ordered to different relative humidity limits....21
Table 7 The percentages of time when the classrooms belonged to the air quality categories according to (DIN EN 15251:2012-12)....23

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Table 8 The percentages of time when the classrooms task area illuminance met the criteria 25
Table 9 The average „ideal temperatures“ calculated from the votes of the occupants.....26
Table 10 The numerical values attached to the categories 28
Table 11 Statistical analysis of the votes separated to the two classrooms. For the numerical values attached to the categories of the votes see Table 10 35
Table 12 Statistical data of the votes of males and females. For the numerical values attached to the categories of the votes see Table 10.....38
Table 13 Statistical data of the time range satisfaction votes of males and females, the length of a lesson is 45 min.....38
Table 14 Tiredness and the time of the day.....40
Table 15 Statistical data of the votes of tired and not tired pupils. For the numerical values attached to the categories of the votes see Table 10.....44
Table 16 Statistical data of the time range satisfaction votes of tired and non-tired pupils. The length of a lesson is 45 min. 44
Table 17 Statistical data of the ventilation frequencies of male and female plus tired and not tired pupils. For the numerical values attached to the categories of the votes see Table 10 .46

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7 APPENDIX

A. Questionnaire 1

QUESTIONNAIRE ABOUT THE INDOOR ENVIRONMENT room number: .....

☐ Male ☐ Female Age: ..... Date and time ..... (y) ..... (m) ..... (d)
..... : ..... (time)

1. Counting from the windows in which column are you sitting? (Count of seats to the left +1) .....
2. Approximately how long haven't you been outdoors? ..... min
3. According to your current clothing and activity level (e.g. seated) what would you call as an ideal indoor temperature? Please, round your answer to one decimal: ..... °C

4. How do you find **indoor air temperature** right now?

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
☐	☐	☐	☐	☐	☐	☐

5. During the lecture time for how many minutes were you satisfied with **indoor air temperature**? ..... min

6. How do you find **indoor air humidity** right now? (It is hard to perceive but try it)

Very dry	Dry	Slightly dry	Neutral	Slightly wet	Wet	Very wet
☐	☐	☐	☐	☐	☐	☐

7. During the lecture time for how many minutes were you satisfied with **indoor air humidity**? ..... min

8. How do you find **indoor air quality** right now?

CO_2 O_2

Very stale	Stale	Slightly stale	Fresh
☐	☐	☐	☐

9. During the lecture time for how many minutes were you satisfied with **indoor air quality**? ..... min
10. Are you feeling tired? ☐ Yes ☐ No

11. How do you find the **brightness** in the classroom?

Very dark	Dark	Slightly dark	Neutral	A bit too bright	Too bright	Extreme bright
☐	☐	☐	☐	☐	☐	☐

12. During the lecture time for how many minutes were you satisfied with **brightness**? ..... min

13. **Do you operate windows at breaks?**

Never	Almost never	Sometimes	Often	Almost always
☐	☐	☐	☐	☐

14. Which is the major cause why do you operate? (You can left it blank, if the previous question was negative).

High temperature	High humidity	Poor air quality	Event based	Other:
☐	☐	☐	☐	.....

15. Are you generally satisfied with the indoor environment?

Very unsatisfied	Unsatisfied	Slightly unsatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
☐	☐	☐	☐	☐	☐	☐

16. How do you suggest the indoor environment could be improved? .....
.....
.....

Appendix A Questionnaire about thermal, humidity, air quality and brightness sensation, ventilation habits and suggestions for improvements

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B. Questionnaire 2

QUESTIONNAIRE ABOUT THE INDOOR ENVIRONMENT 2

☐Male ☐Female Age ……

Mark your answers!

Questions/statements	Please, choose only one answer per question/statement!				
1. Size of the questionnaire			*Long*	*Ideal*	*Short*
2. Without explanation how did you find the question: *"Approximately how long haven't you been outdoors?"*			*Easy*	*Difficult but intelligible*	*Unintelligible*
3. Without explanation how did you find the question: *"According to your current clothing and activity level (e.g. seated) what would you call as an ideal indoor temperature?"*			*Easy*	*Difficult but intelligible*	*Unintelligible*
4. How did you find a question type: *"How do you find … right now?"* E.g.: Cold ☐ Cool ☐ Slightly cool ☐ Neutral ☐ Slightly warm ☐ Warm ☐ Hot ☐			*Easy*	*Difficult but intelligible*	*Unintelligible*
5. How did you find a question type: *"During the lecture time for how many minutes were you satisfied with … ?"*			*Easy*	*Difficult but intelligible*	*Unintelligible*
6. Which scaling do you find more logical?	*This →* Very stale ☐ Stale ☐ Slightly stale ☐ Fresh ☐				
	This → Very stale ☐ Stale ☐ Slightly stale ☐ Neutral ☐ Slightly fresh ☐ Fresh ☐ Very fresh ☐				
7. „I love when a sports class is outdoors!"		*Always*	*Yes, but not in cold*	*Yes, but not in hot*	*No*
8. „I feel better after sports classes!"	*Always*	*If we were outdoors*	*If we were indoors*	*No change*	*It is worse*
9. „It would be great to ventilate on the corridors too!"	*Always*	*If outside is not hot*	*If outside is not cold*	*No*	*Indifferent*
10. „It would be better to have a longer break!" (the ending of the day would be also later)			*Yes*	*No*	*Indifferent*
11. Do you go out more if the weather is fine?				*Yes*	*No*
12. Would you go out more frequently if there were a landscaped courtyard?			*Yes*	*In nice weather*	*No*
13. Did the questionnaires appeal to you?		*Yes both*	*Only the first one*	*Only this one*	*No*

Thank you very much for your help!

Appendix B Questionnaire as a feedback on the difficulty level of the previous questionnaires' comprehensibility and how often and when they would go outdoors

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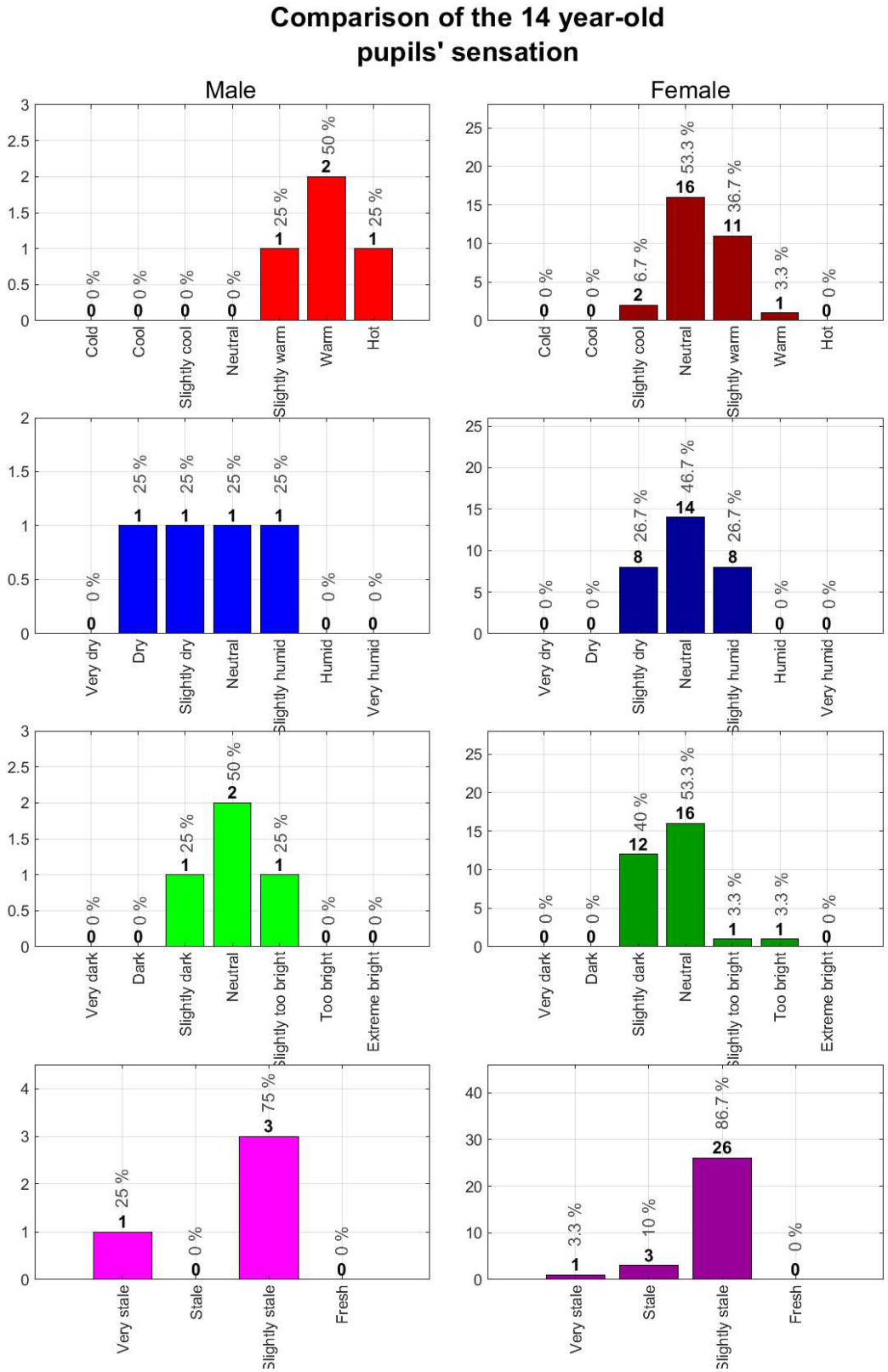
C. Satisfaction as a function of gender sorted in ages of pupils



Appendix C.1 Sensation votes of 14 year-old pupils

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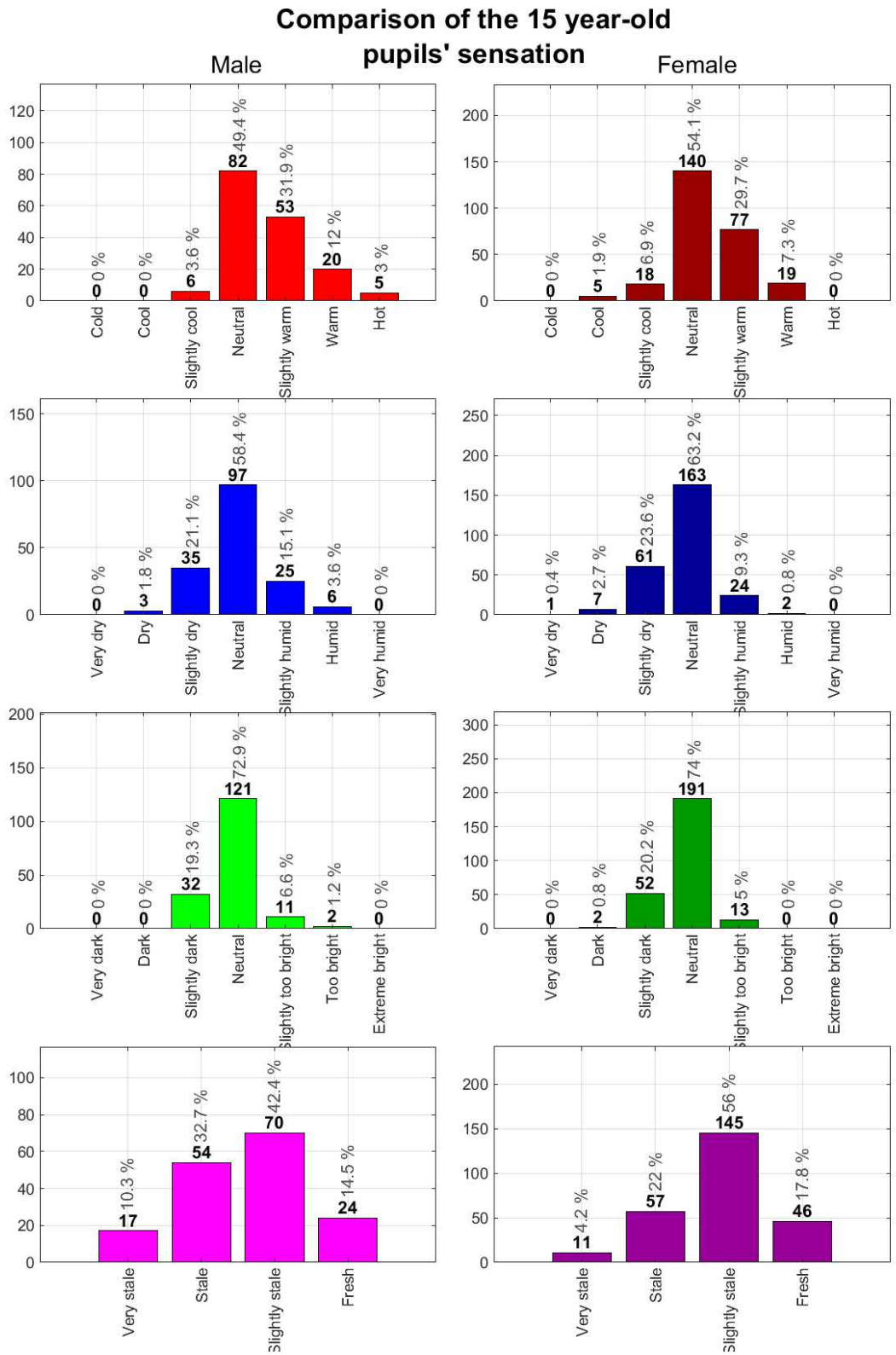

Appendix C.2 Sensation votes of 15 year-old pupils

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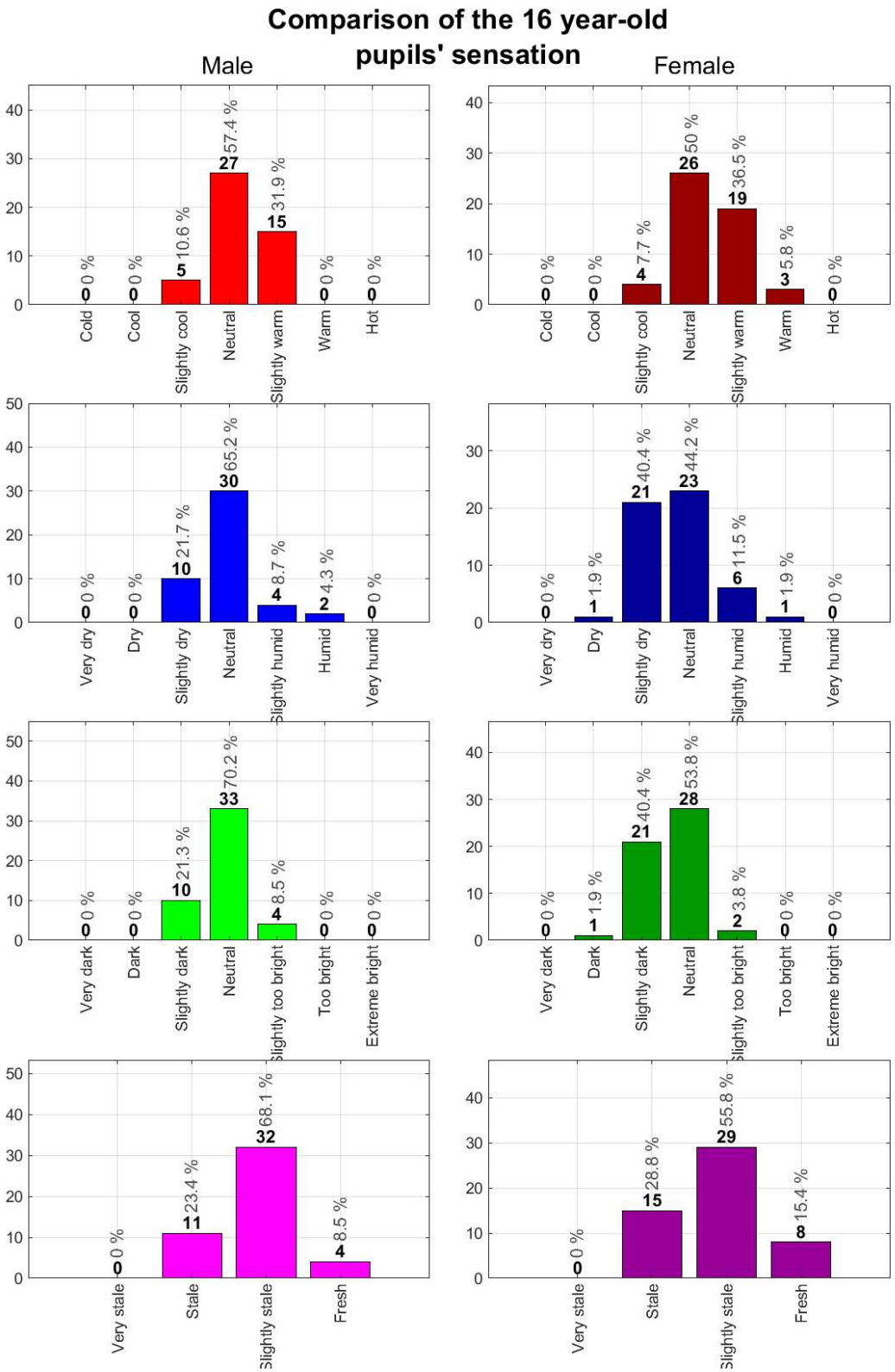

Appendix C.3 Sensation votes of 16 year-old pupils

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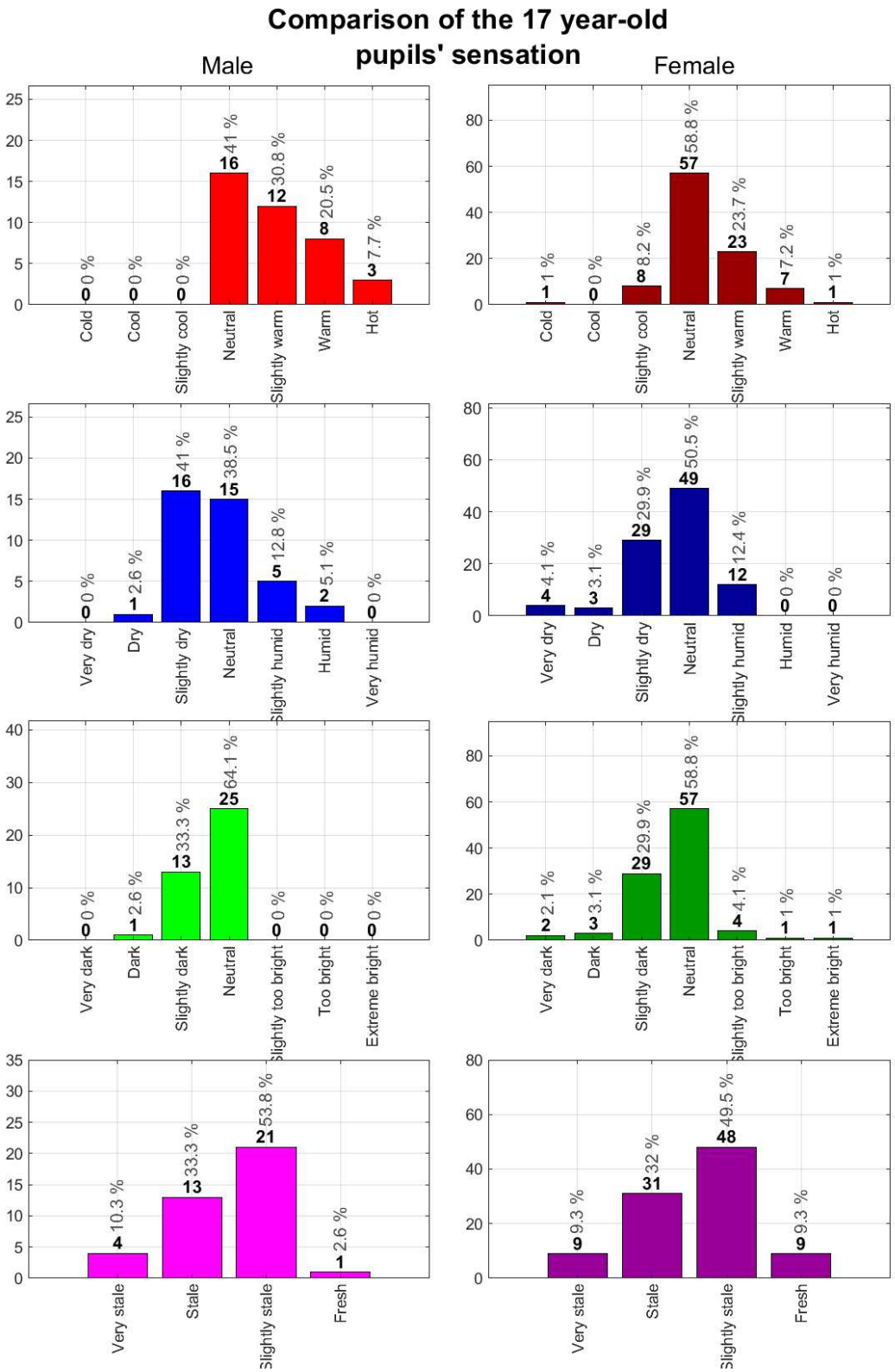

Appendix C.4 Sensation votes of 17 year-old pupils

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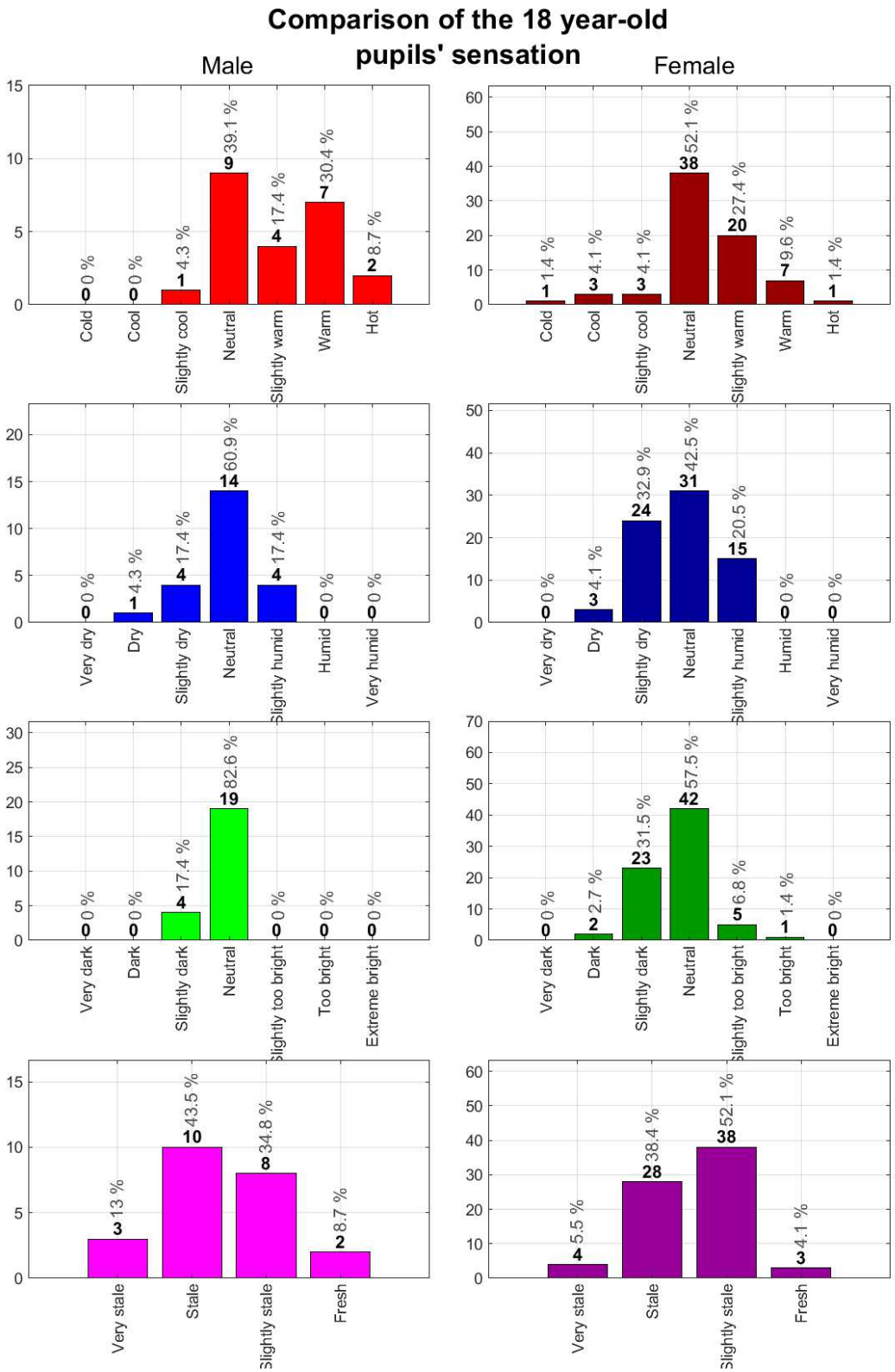

Appendix C.5 Sensation votes of 18 year-old pupils

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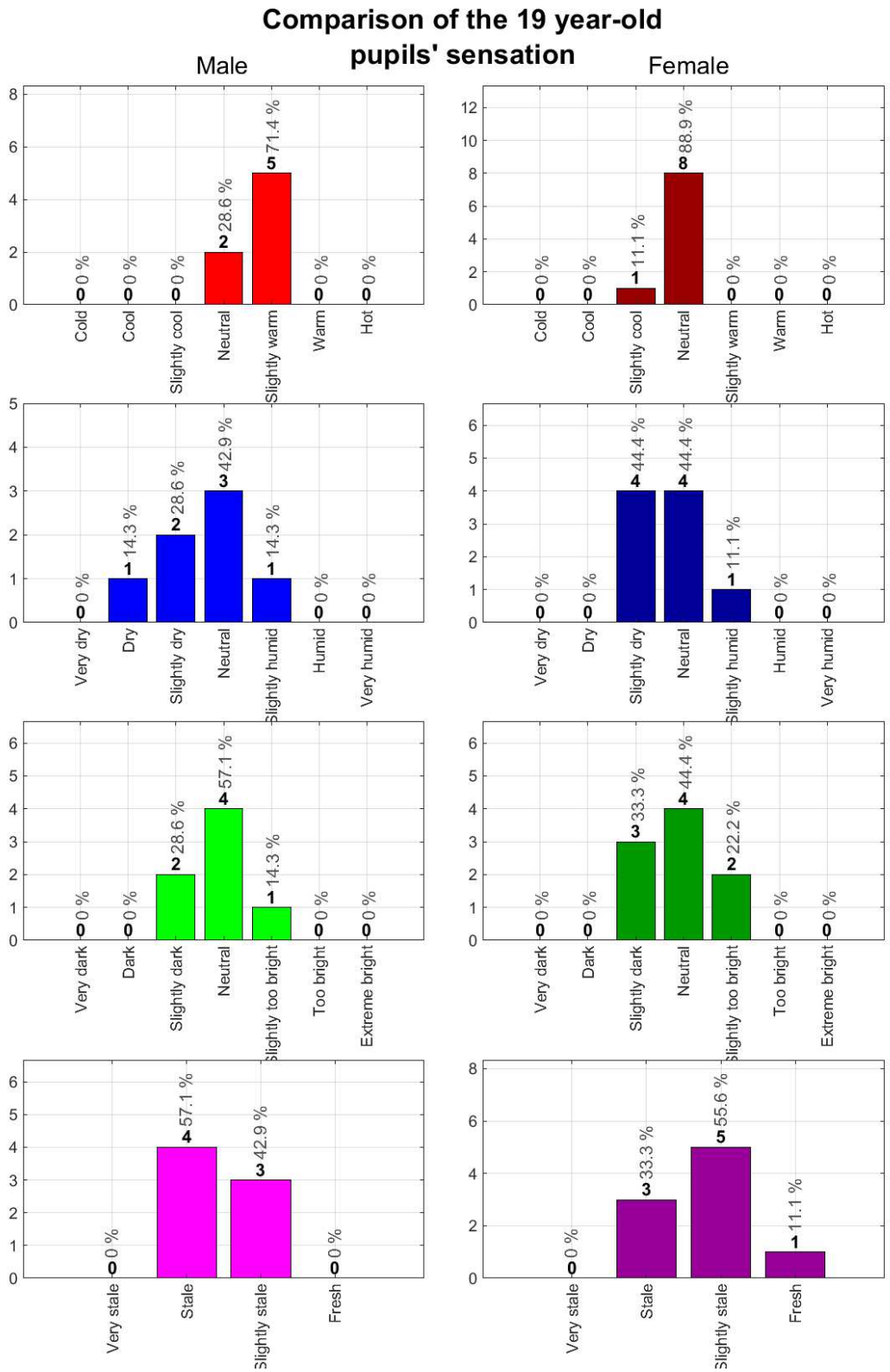

Appendix C.6 Sensation votes of 19 year-old pupils

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D. Calculations

In the following section there will be an introduction how the missing parameters are calculable to have a complete variable set for a psychometric analysis. The atmospheric pressure (p_0) will be handled as a constant for the sake of simplicity: $p_0 = 101\,325\ Pa$.

Defining the saturation water vapour pressure the Buck approximation (*Buck Eq.)* (Eq. 2) is used:

$$p_{sat} = 611.21 \cdot e^{\left(\left(18.678 - \frac{T}{234.6}\right)\cdot\left(\frac{T}{257.14 - T}\right)\right)} \qquad \textit{Eq. 2}$$

where p_{sat} saturation pressure [Pa]

T temperature [°C]

After having the saturation pressure and measured the relative humidity, the actual vapour pressure is just a multiplication:

$$p = p_{sat} \cdot \varphi \qquad \textit{Eq. 3}$$

where p actual vapour pressure [Pa]

φ relative humidity [1].

From the actual vapour pressure absolute humidity could be specified as Eq. 4 shows. This stems from two separate ideal gases, where water vapour and air are two components compared to one another in a fraction.

$$x = \frac{R_a}{R_v} \cdot \frac{p}{p_0 - p} \qquad \textit{Eq. 4}$$

where x absolute humidity $\left[\frac{kg}{kg}\right]$

R_a specific gas constant of dry air = $258.058\ \left[\frac{J}{kg \cdot K}\right]$

R_v specific gas constant of water vapour = $461.5\ \left[\frac{J}{kg \cdot K}\right]$

Dry air and moisture content are handled separately; they make up the sensible part of energy. In order to calculate specific enthalpy (energy content of humid air), additionally a latent heat part of humid air is necessary to be added, which is from the evaporation of the water to water vapour, and make it possible moisture to be mixed to dry air as a gaseous component.

$$h = c_{p,a} \cdot T + x \cdot c_{p,v} \cdot T + x \cdot r_0 = c_{p,a} \cdot T + x \cdot \left(c_{p,v} \cdot T + r_0\right) \qquad \textit{Eq. 5}$$

where h specific enthalpy $\left[\frac{kJ}{kg}\right]$

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$c_{p,a}$ isobar specific heat of dry air $= 1.006 \left[\frac{kJ}{kg \cdot K}\right]$

$c_{p,v}$ isobar specific heat of water vapour $= 1.864 \left[\frac{kJ}{kg \cdot K}\right]$

r_0 latent heat of evaporation of water $= 2500 \left[\frac{kJ}{kg}\right]$

In the following a short introduction of creating a so called "comfort window" will prepare the reader for Figure 7. The equations (Eq. 6…Eq. 10) are restricted to metabolic rate = 1 met (sedentary position), and clothing value = 0.67 clo (medium clothing) and these equations all stem from reference (Szokolay, 2014).

Calculating neutrality temperature, which is the indoor temperature for the given outdoor temperature where the most of the occupants feel comfortable, neutral:

$$T_n = 17.8 + 0.31 \cdot T_{o.av} \; [°C] \qquad \textit{Eq. 6}$$

where T_n neutrality temperature [°C]

$T_{o.av}$ monthly average outdoor temperature [°C].

This is the assumed "ideal" indoor temperature as such for the given monthly average outdoor temperature but to handle it a bit more tolerantly, so not only one temperature fits to the comfortable category, a tolerance range is given. This range in positive and negative direction from this neutrality temperature is symmetrically set for both directions. There is an altogether 5 °C range allowed for this comfort window ±2.5 °C to each direction (Eq. 7, Eq. 8), these are the limits, wherein conditions are still considered as thermally pleasant.

$$T_L = T_n - 2.5 \; [°C] \qquad \textit{Eq. 7}$$

$$T_U = T_n + 2.5 \; [°C] \qquad \textit{Eq. 8}$$

where T_L lower limit of temperature [°C]

T_U upper limit of temperature [°C].

It is not only temperature which makes thermal perception of comfort complete, but humidity too. Due to health reasons (e.g. preventing the drying out of mucous) and avoidance of electrostatic discharges, the lower limit of absolute humidity is 0.004 kg/kg, and the upper limit is 0.012 kg/kg.

The upper and lower temperature limits are on the 50 % relative humidity curve, and from these fix points are the edges of the comfort window drawn. The corresponding sloping SET (Standardized Effective Temperature) lines have an intersection point on the axis of temperature on the psychometric chart by the following temperature values:

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$$T_{xL} = T_L + 0.023 \cdot (T_L - 14) \cdot x_{50}\ [°C] \qquad \textit{Eq. 9}$$

$$T_{xU} = T_U + 0.023 \cdot (T_U - 14) \cdot x_{50}\ [°C] \qquad \textit{Eq. 10}$$

where T_{xL} section point on axis from lower limit temperature [°C]
T_{xU} section point on axis from upper limit temperature [°C]
x_{50} absolute humidity belonging to 50 % rel. humidity $\left[\frac{g}{kg}\right]$

One remark which is important to be considered and it is not a typo: in Eq. 9 and Eq. 10 the absolute humidity values have to be plugged in in grams/kilogram dimension.

There are other types of comfort windows too, but this one suits perfectly. For example a study in Taiwan resulted in a different method of calculating neutrality temperature (Liang et al., 2012), which is:

$$T_n = 12.1 + 0.62 \cdot T_{o.av} \qquad \textit{Eq. 11}$$

where T_n neutrality temperature [°C]
$T_{o.av}$ monthly average outdoor temperature [°C]

In comparison ASHRAE Standard 55 (*ASHRAE 55*, 1981) calculates also as a linear model but with the half of the slope (see Eq. 6). Using the researchers' formula from the Taiwan study the neutrality temperature is $T_n = 17.92\ °C$, and according to ASHRAE Standard 55 formula $T_n = 20.71\ °C$. This might be explained that in Taiwan a hot climate requires other approaches, but in continental climate the ASHRAE formula is more applicable. In this thesis therefore the ASHRAE equations are used.

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