Schools on hold – how simple measures can help improving the indoor environment in schools

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ABSTRACT

This work presents the lessons-learned from a Norwegian project called "Skoler på vent" – "Schools on hold" – which is aiming at finding simple and effective measures for improving the indoor climate in schools that have been put on hold. Schools on hold often suffer from dissatisfying indoor thermal comfort which also extents to affecting people`s health, well-being and learning. Measurement data (temperature, CO_2-level and relative humidity) have been collected from several rooms in three schools in the municipality of Trondheim, Norway, during two measurement campaigns. Furthermore, interviews with school employees as well as surveys among the students have been carried out during the same periods to gain insights in the perceived indoor environment. Results show that simple measures such as i) removing the lowering of heating set points during the night, ii) checking the radiator valve position at the end of a school day, iii) introducing routines for natural ventilation during breaks and iv) improving the room cleaning routines can improve the perceived indoor environment notably. Furthermore, the applied methodology is discussed and improvements suggested.

INTRODUCTION

Schools on hold

Schools on hold are schools that are to be rehabilitated or demolished and replaced with new buildings, or where it is uncertain whether the business will be continued at all. These schools are still in ordinary use, but usually only very limited funds are set aside for upgrades. Only the most-needed maintenance is carried out, and these maintenance measures are first and foremost mitigation measures.

Three schools (names are anonymized here) in the municipality of Trondheim, Norway, joined this project:

i) *School A*, a secondary school that has been on the verge of either being renovated or built new for years. This school suffers from ventilation issues.
ii) *School B,* a primary school that has an insufficient indoor environment, especially with regards to acoustics in the newer parts of the school.
iii) *School C,* a combined primary and secondary school that has reached its maximum number of students and with maintenance for the heating and ventilation system being on hold.

Indoor thermal environment vs. health issues

An acceptable indoor environment is evident for good health, well-being and productivity of students and school employees. In Norwegian schools, teaching blocks have increased from 45 minutes to up to two hours. Unfortunately, schools on hold often suffer dissatisfying indoor thermal comfort (Arbeidstilsynet, 2013; Becher, Bjerke, Martinsen, & Øvrevik, 2016). Poor indoor climate can lead to respiratory infections, worsening of asthma, headaches, abnormal fatigue, dry skin, eyes, noses or throats.

Historically, building regulations have set more and more strict requirements for the technical system of the building, especially with regards to the ventilation system. However, natural ventilation and exhaust ventilation are still predominant solutions in Norwegian schools, often leading to a rather poor indoor climate. Studies in Norway (Gustavsen, 2013a, 2013b), Denmark (Wargocki & Da Silva, 2015), Greece (Santamouris et al., 2008) and the Netherlands (Health Council of the Netherlands, 2010; Rosbach et al., 2013) show that schools often suffer from insufficient ventilation and thus have maximum CO_2 concentration levels that exceed recommended levels. Gustavsen (Gustavsen, 2016) found that over 30 % of the students report health problems that can be related to insufficient indoor climate, such as headaches, fatigue and concentration problems. It is challenging to compare schools from different countries due to different climates and building regulations, but a common denominator is the fact that many buildings and their technical installations do not function in an optimal way due to a lack of maintenance or faulty operation.

The Norwegian project "Skoler på vent" – "Schools on hold" aims at finding simple and effective measures for improving the indoor climate in schools that are put on hold and this work presents the lessons-learned from the project.

METHODS

The project has two dedicated experimental campaigns at which both, qualitative and quantitative methods are employed to identify and measure indoor climate and health issues in all three schools. A flow chart of the conduction of the project and its associated simplified timeline are presented in Figure 1.

Measurements

Measurements are carried out in at least four rooms in each of the three schools. The rooms are chosen in dialogue with the school and Trondheim Municipality.

Technical specifications of the sensors

"Air climate sensors" ELMA DT and CA are used to measure the room air temperature [°C], CO_2 level [ppm] and relative humidity (RH) [%]. ELMA sensors are used in School A and School B, whereas CA sensors are used in School C. Technical specifications of the used sensors are presented in Table 1. Measurements are registered with 2 min resolution. Sensors were validated against reference conditions in the climate chamber of the SINTEF laboratories before the first campaign. Most sensors were validated again before the second campaign. Since not all sensors were available for calibration then, less emphasis will be given to the *absolute value* of a measured parameter in the interpretation of the results. Sensors are placed at the same positions in the two campaigns to ensure a more meaningful comparability of the measurement data. The "air climate sensors" are placed rather central in each of the investigated rooms.

Data preparation

Regarding data analysis, the measurement data is divided into two periods for each school: working hours and non-working hours. Respective working hours in the three schools are presented in Table 2. For both periods, i) working hours and ii) non-working hours, two indicators are used to assess how/whether the proposed simple measures lead to improved indoor environment in the rooms/schools, based on the quantitative data:

1. *"Time-averaged values"* for CO_2, temperature and RH,
2. *"Percentage of time that a parameter (CO_2, Temperature, RH) is outside a pre-defined boundary"*, with the following boundary values:
   - CO_2 > 1000 ppm (Folkehelseinstituttet, 2015),
   - T < 19 °C (NorskStandard, 2019),
   - T > 22 °C (DiBk, 2017),
   - RH < 20 % (Sintef Byggforsk, 2016).

It is here pointed out, that CO_2 values higher than 2000 ppm are not considered in the calculation of the time-averaged value due to the strong probability that the registered measurement values come from persons blowing right into the sensors.

Table 1. Technical specifications of the used indoor climate sensors.

Parameter	Measuring range	Accuracy at 23 °C ± 5 °C	Resolution
ELMA DT-802D (elma instruments, 2020b)			
Temperature	-5 °C to 50 °C	± 1 °C	0.1 °C
Carbon dioxide	0 ppm to 9999 ppm	±100 ppm ±5 % of measured value	0.1 %
Relative humidity	<90 % RH	± 5 % RH	0.1 % RH
CA 1510 (elma instruments, 2020a)			
Temperature	-10°C to 60°C	± 0.5 °C	0.1 °C
Carbon dioxide	0 ppm to 5000 ppm	±50 ppm ±3 % of measured value	1 ppm
Relative humidity	5 % to 95 % RH	± 2 % RH	0.1 % RH

Table 2. Overview over working hours of the investigated rooms in all three schools.

School and room	Working hours
School A (all rooms)	08.15 – 14.35
School B (all rooms)	08.15 – 13.15
School C	
321A	08.00 – 13.45
Blue room	08.00 – 13.45
Care room	13.00 – 16.30
Teachers room	08.00 – 16.00

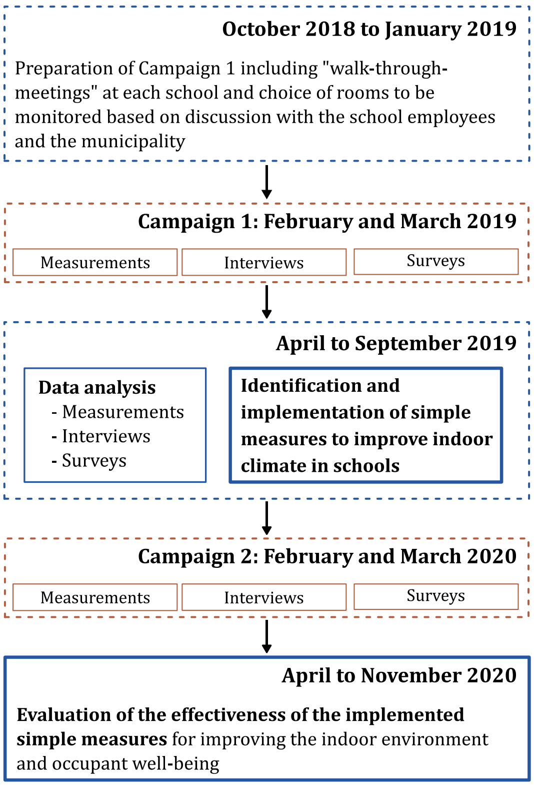


Figure 1. Conduction of the project.

It was found during the analysis of the measurement time series that these situations occur very rarely and if so, only for a very limited time (< 5min), thus suggesting that these peaks are not representative for the rooms CO_2 level.

Interviews

Structured interviews are conducted with the principals, teachers, operating staff and the school nurses to investigate how the users perceive the indoor environment at their respective schools. Interviews are done in both campaigns, before and after the measures are implemented, and the interview questions are slightly adjusted from campaign 1 to campaign 2. The interviews contain text questions, multiple-choice, and number-rating questions. The majority of the interviews is carried out as telephone interviews, while a few informants are interviewed at the school. Each interview lasts for about 30 minutes.

In campaign 1 school employees are asked how they perceive the indoor air quality, temperature, lighting and acoustics, and whether they have experienced discomfort or health problems that could be related to an unhealthy indoor environment. The teachers and the school nurses are also asked whether they experienced the indoor climate to affect the pupils` well-being and health, and their ability to concentrate. Furthermore, the interviews focus on indoor environment issues that can affect the psycho-social work environment.

Regarding campaign 2, the same informants are asked to the extent possible. Additional to the questions asked in the first campaign, the informants are asked whether they know which measures the school has implemented after the first campaign and whether they have noticed any changes on the indoor environment, for better or worse.

Figure 2 illustrates in a compact manner the specific characteristics which are of interest in the interviews with regards to perceived indoor environment and occurring health issues. It can be seen from Table 3 that fewer interviews are conducted during the second campaign, which is mainly due to the outbreak of Covid-19 and the understandably prioritized tasks that the close-down of schools implicated for school employees. Nevertheless, the feedback from the few informants can give an indication of the effect that the simple measures may have had on the perceived indoor environment.

Surveys

The questionnaire was sent out to all students in each case school. The questionnaire was answered more or less in the same period as the field measurements were conducted in both campaigns. The focus area for the questionnaire was health symptoms and experienced indoor environment problems. The number of respondents is presented in Table 4.

Table 3. Number of interviews conducted at each school during both campaigns.

School	Number of interviews	
	2019	2020
School A	9	7
School B	7	5
School C	5	4

Table 4. Survey response rate [%] for each school.

School	Respondence [% from *absolute number*]	
	2019	2020
School A	**0** from 333	**37** from 333
School B	**90** from 244	**83** from 233
School C	**61** from 300	**83** from 300

In 2019, School A and School C experienced technical issues, which led to no answers at School A and reduced number of respondents at School C.

Evaluation methods

In this paper, main focus is given to the results from the qualitative data collection. Measurement results are used to investigate whether the change of the quantitative results from campaign 1 to campaign 2 supports the qualitative results.

Results from the conducted surveys are presented in the form of a radar chart for perceived indoor environment as well as reported health issues. For each school the charts contain the results for both campaigns in comparison to a reference school. The *reference school* is a Norwegian school which does not have any known issues regarding poor indoor environment or health. The same survey is conducted at the reference school to obtain reference values.

RESULTS

Proposed measures to improve indoor environment

Several simple measures are proposed and implemented based on the findings from the qualitative and quantitative analysis of the first campaign in February and March 2019. These quantitative and qualitative results are summarized in Table 6 to Table 8 (quantitative) as well as Figure 2 to Figure 4 (qualitative) for each school respectively.

Findings from the first campaign are summarized to be able to relate to the proposed measures for improving the indoor environment:

1. It can be seen that especially School A and School C suffer from too high temperature variations throughout a day and poor air quality. There are only few complaints about temperature and quality at School B.
2. Students at School B and School C complain about high noise-levels.

Hence, most of the measures aim at improving temperature-related dissatisfaction and poor air quality. Other proposed measures focus on complaints related to noise. The implemented simple measures to improve the indoor environment and to enhance occupant well-being are summarized in Table 5.

Evaluation of the implemented measures

School A

The results for perceived indoor environment and reported health issues are shown in Figure 2, whereas measurement data from both campaigns is provided in Table 6. Regarding the questionnaires among the students, it can be seen from Figure 2 that School A suffers especially from poor air quality, noise, too high temperature fluctuations as well as dust and dirt (Figure 2a). Health issues reported by the students exceed the results from a reference school by far (Figure 2b). Students especially report tiredness, concentration problems, headache and even dizziness. All these reported health issues can be related to poor air quality.

Comparing the statements from the interviews for both campaigns, the following is reported:

- the temperature level and air quality are more satisfying in 2020,
- but some interviewees found it still too cold in general,
- the temperature fluctuations throughout a day are worse in 2020,
- More headaches and concentration problems in 2020,
- Rearranging student desks lead to student moving the desks back to initial positions as space was too limited.

In general, it can be seen from the measurement data that temperature levels are more satisfying. As mentioned previously, the absolute values of the measurements have to be read with caution, but it can be seen from Table 6 that the average temperature in the monitored rooms has increased from 2019 to 2020.

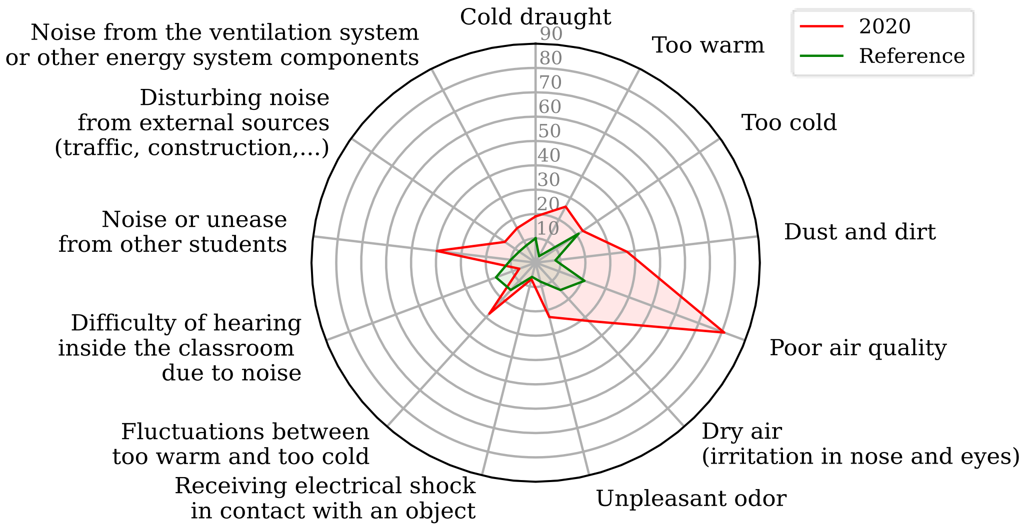
Table 5. Proposed and implemented simple measures to improve the indoor environment.

Suggested measures	Implemented at: School A	School B	School C
1. Remove night and weekend setback of the set-point temperature for ventilation and heating	x		x
2. Replace incandescent fixtures with LED			x
3. Installation of additional ventilation aggregate in classrooms			x
4. Troubleshooting of the ventilation system			x
5. Troubleshooting and application of the external shading system (if appropriate)	x	x	x
6. Student should leave rooms during breaks	x		x
7. Establish natural ventilation routines for the breaks		x	x
8. Teachers check radiator valves at the end of each school day	x	x	x
9. Rearranging students desks to avoid local discomfort	x	x	
10. Stronger focus on cleaning routines	x	x	x
11. Installation of noise absorption plates in inner walls.		x	

This can be a result of the removed night setback temperature. The "percentage of time outside the boundary value T < 19 °C" shows clearly that there are noticeable less low-temperature violations in 2020, yet school employees perceive the rooms as too cold. Nevertheless, the difference between the average temperatures in both campaigns is mostly within the measurement error of the sensors.

Table 6. Measurement data from both campaigns for School A (WH – working hours, oWH – outside working hours; malfunctioning sensor in room 104 in 2020, hence no measurement data).

		Average values during working hours						Percentage of time outside recommended boundary values							
		CO_2 [ppm]		T [°C]		RH [%]		CO_2>1000ppm		T<19°C		T>22°C		RH<20%	
Room		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
104	WH	601	-	21.3	-	27	-	0.1	-	0	-	13	-	12	-
	oWH	426	-	19.6	-	26	-	-	-	-	-	-	-	-	-
108	WH	743	663	18.8	20	22	28	0.2	4	63	0.6	0	0	36	5
	oWH	438	540	18.1	19.3	22	28	-	-	-	-	-	-	-	-
203	WH	507	532	21.7	21.6	24	22	0	0	4	0	43	33	8	38
	oWH	418	420	19.8	20	26	23	-	-	-	-	-	-	-	-
207	WH	589	493	18.9	19.5	29	30	36	24	59	10	0	0	2	0
	oWH	436	773	17.8	18.3	30	31	-	-	-	-	-	-	-	-



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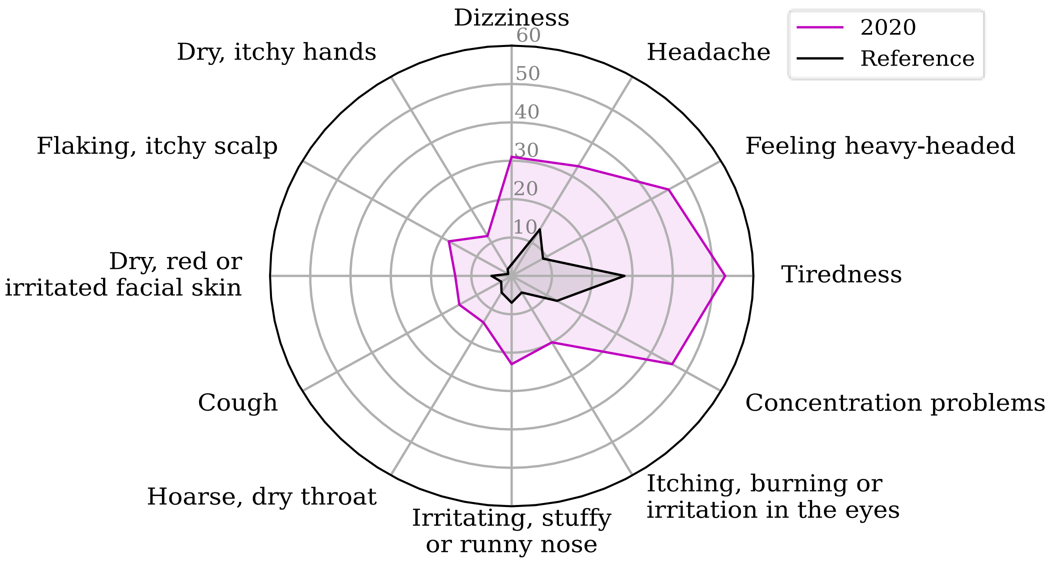


(b)

Figure 2. Perceived indoor environment and health issues based on surveys among students during both campaigns for School A: (a) Indoor environment, (b) Health issues.

School B

Figure 3 shows the results for the perceived indoor environment (a) and reported health issues (b) for School B. It is evident that the biggest issues is noise and unease from fellow students.

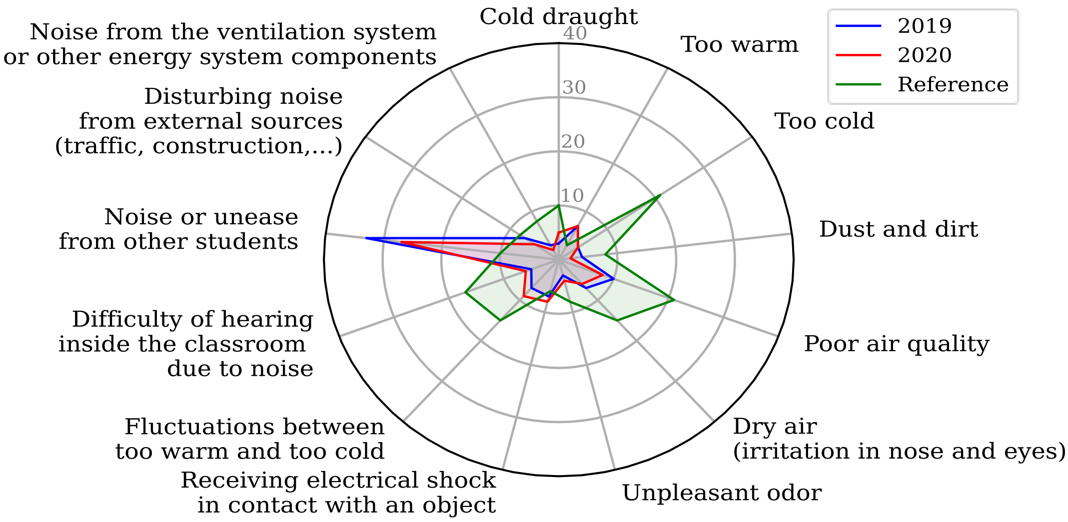
This parameter is not necessarily only related to a poor indoor environment, but an annoyance with other students can also have pedagogical and behavioural reasons. All other parameters are within responses from a reference school. Only 10 % of the students report poor air quality. Regarding health issues, students mainly report headaches (22 %), concentration problems (13 %) and irritation in the eyes (11 %).

School employees mainly report too high temperatures, and irritation in the eyes in the interviews during the second campaign.

Itching and irritation in the eyes can occur when air is too warm and too dry. It can be seen from Table 7 that the average temperatures in the rooms is higher in 2020 compared to 2019. There is a notable increase in the percentage of time that the room air temperature is above 22 °C as well as a decrease in the percentage of time that the RH is below 20 % in the monitored rooms. This confirms the statements from the interviews. This trend can be a result of the removed night setback. CO_2 levels are rather similar for both campaigns.

Table 7. Measurement data from both campaigns for School B (WH – working hours, oWH – outside working hours; malfunctioning sensor in room 273 in 2019, hence no measurement data).

		Average values during working hours						**Percentage of time outside recommended boundary values**							
		CO_2 [ppm]		**T [°C]**		**RH [%]**		**CO_2>1000ppm**		**T<19°C**		**T>22°C**		**RH<20%**	
Room		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
217	WH	432	436	20.4	21.9	24	18	0	0	5	0	1	50	23	55
	oWH	443	459	20.5	22.0	24	19	-	-	-	-	-	-	-	-
222	WH	506	514	22.0	23.8	24	21	0	0	0	0	43	99	13	46
	oWH	418	419	21.6	23.4	24	21	-	-	-	-	-	-	-	-
273	WH	-	493	-	22.1	-	20	-	0	-	0	-	47	-	45
	oWH	-	460	-	22.6	-	20	-	-	-	-	-	-	-	-
Music	WH	516	480	21.6	22.4	22	22	2	0	0	0	8	75.1	23	37
	oWH	556	436	21.1	22.1	25	22	-	-	-	-	-	-	-	-



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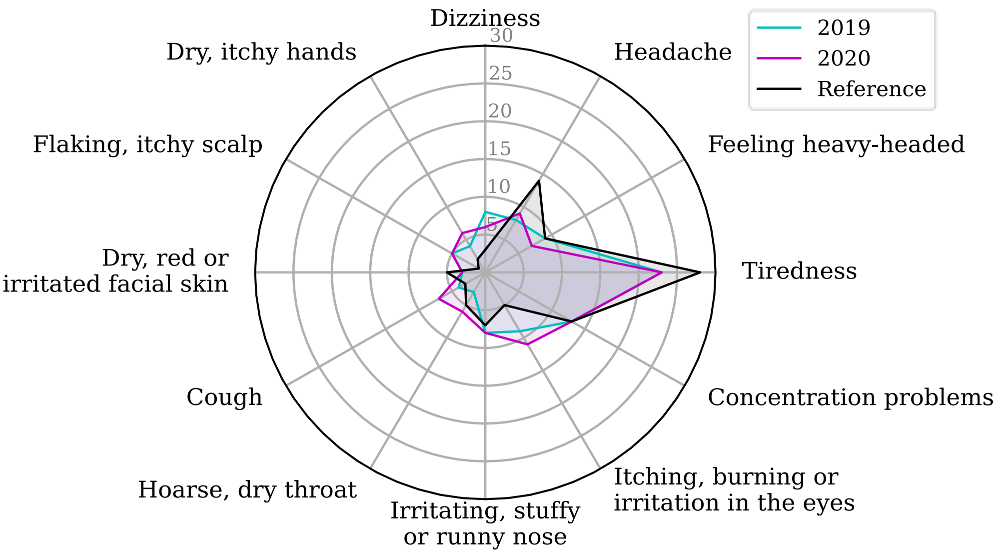


(b)

Figure 3. Perceived indoor environment and health issues based on surveys among students during both campaigns for School B: (a) Indoor environment, (b) Health issues.

School C

The results for perceived indoor environment and reported health issues are shown in Figure 4, whereas measurement data from both campaigns is provided in Table 8.

Regarding the indoor environment, students report a poor air quality (35 %), too much noise from fellow students (40 %) and too high temperature fluctuations. This specific school has an open plan with few partition walls and no doors between the corridor and the class rooms. This challenge is difficult to cope with simple measures. All in all, it can be seen from Figure 4(a) that the perceived indoor environment has improved slightly after simple measures have been implemented A lot less "dust and dirt" is reported in 2020, pointing towards improved clearing routines. Furthermore, the students are asked to tidy up their desks so that the cleaning staff gets better access (Ulsund, 2020).

Figure 4(b) shows that similar health issues have been reported in both campaigns, but that especially tiredness and concentration problems have been reduced towards the second campaign. It can be seen that an irritated nose is reported slightly more often in 2020.

School employees report a poorer air quality in 2020 compared to 2019. In general, temperatures seem to be more comfortable in the mornings. Furthermore, they point out that the most important measure was the upgrade of the lighting system to LED lighting. They report fewer headaches, also confirming the impression of the students.

There is positive and negative feedback regarding the additional ventilation unit in the Blue room. On the one hand, the overall air quality seems to be improved. On the other hand, the interviewees report that students try to avoid sitting next to the unit due to local draught in combination with too low temperatures.

Measurement results agree with the findings from the interviews. The average CO_2 levels seems to be a bit higher in 2020, hence a poorer air quality may be reported. Furthermore, the average temperature is slightly higher in 2020, whereas the RH is lower during the second campaign. It can be seen from Table 8 that the percentage of time

- above CO_2 = 1000 ppm is increased in all rooms in 2020,
- below T = 19 °C is decreased,
- above T = 22 °C is increased,
- below RH = 20% is increased.

The higher temperatures in combination with a lower relative humidity may lead to irritation in the eyes, thus agreeing with the reported answers from the survey.

DISCUSSION

The systematic method presented in Figure 1 including interviews, questionnaires and measurements of the perceived indoor environment can be used to improve the indoor environment, not only in *"Schools on hold"*, but also in general in schools that suffer from a poor indoor environment.

A possible improvement of the indoor environment measurement campaigns is the use of sensors that register the total number of persons (here teachers and pupils) in the room. This is important information when evaluating the high-resolution measurement data, such as CO_2-levels and air temperatures.

It is found that it is of outmost importance to involve the school employees, such as the principals, teachers, operating staff and the school nurses from the very beginning of the work, as these are the persons that implement the measures to improve the indoor environment.

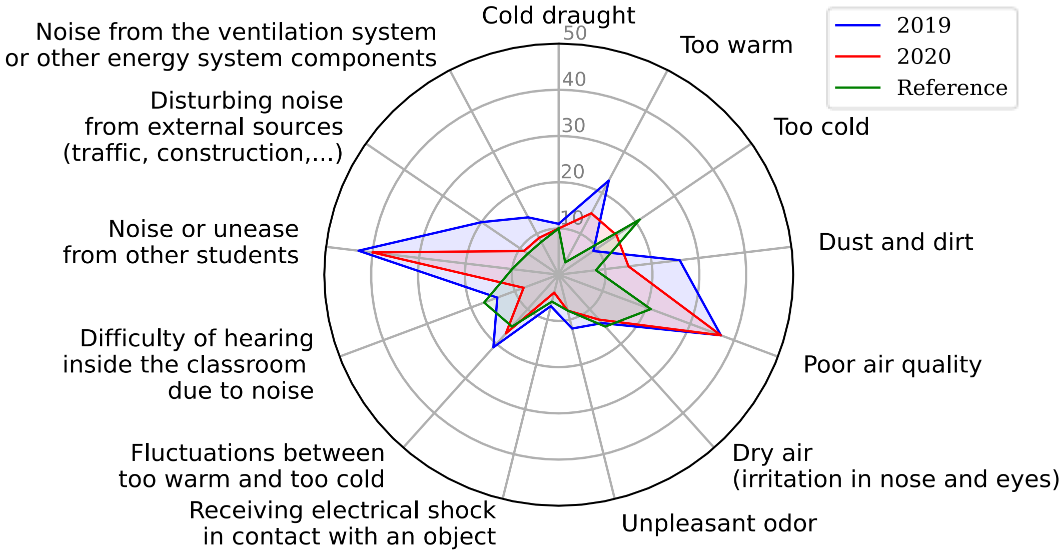
The uncertainties and shortcomings of the two conducted campaigns are discussed in the following.

Regarding the measurements, there are two major issues: i) procedure of the sensor validation before the second campaign and ii) uncertainty about the occupancy rate of the rooms during campaign 2.

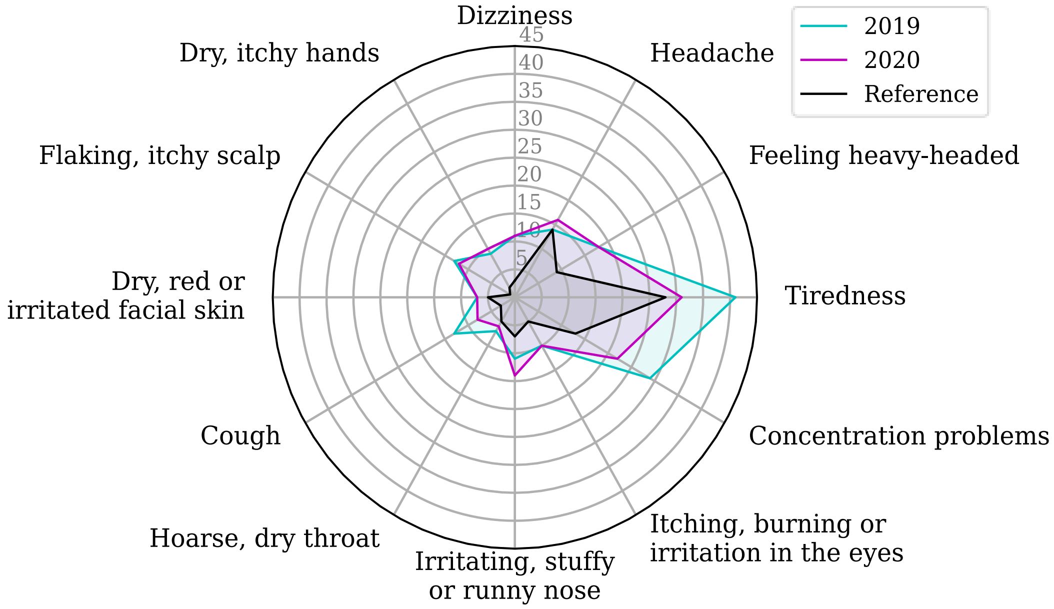
The air quality sensors used at School C have not been validated before the second campaign as they were not available at that point.

Table 8. Measurement data from both campaigns for School C (WH – working hours, oWH – outside working hours; malfunctioning sensor in the care room in 2020, hence no measurement data).

		Average values during working hours						**Percentage of time outside recommended boundary values**							
		CO_2 [ppm]		**T [°C]**		**RH [%]**		**CO_2>1000ppm**		**T<19°C**		**T>22°C**		**RH<20%**	
Room		2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
321A	WH	637	868	20.1	20.8	28	22	9	39	17	10	8	17	8	11
	oWH	441	442	18.6	18.4	29	20	-	-	-	-	-	-	-	-
Blue room	WH	641	740	18.6	19.5	28	20	18	19	53	32	0	0	2	53
	oWH	430	455	18.3	18.9	28	18	-	-	-	-	-	-	-	-
Care room	WH	561	-	20.3	-	26	-	9	-	0	-	0	-	9	-
	oWH	431	-	20.2	-	26	-	-	-	-	-	-	-	-	-
Teachers room	WH	558	712	20.9	22.0	25	20	4	11	21	0	34	54	17	47
	oWH	478	574	19.4	20.8	28	21	-	-	-	-	-	-	-	-



(a)



(b)

Figure 4. Perceived indoor environment and health issues based on surveys among students during both campaigns for School C: (a) Indoor environment, (b) Health issues.

Hence, the absolute values for the second campaign should be treated with caution, even though the reports from interviews and students about perceived indoor environment with regards to temperature and relative humidity support the change in the measurement results from 2019 to 2020.

Furthermore, there were two malfunctioning air quality sensors during the second campaign and one malfunctioning sensor during the first campaign, thus a comparison of the indoor environment is not possible in the respective rooms.

Besides the technical issues related to the use of the air quality sensors, a second obstacle is the uncertainty of the occupancy rate of the rooms during the second campaign. During the first campaign, the teachers were asked to register the number of persons in a room throughout the school days. This kind of data is missing for the second campaign, thus making it difficult to interpret the absolute values of the CO_2-levels in the rooms. Furthermore, a higher number of persons per room may also lead to increased temperatures as there are higher internal heat gains from occupants.

Additional issues regarding the interpretability of the measurement data are i) the placement of the sensors in the room, ii) interference of students with the sensor setup and iii) the ambient weather conditions. The sensor in room 222 at School B was exposed to direct solar radiation during the afternoon (big windows towards the west), thus leading to higher measured temperatures. Nevertheless, this also sheds lights on the issues of high internal heat gains from solar radiation for rooms without solar shading. In general, the ambient temperature during campaign 1 was considerably lower than during campaign 2. Hence, heat losses through the building envelope are lower during the second campaign, being another characteristic that may lead to higher average room temperatures during the second campaign.

Furthermore, both measurement campaigns are held during wintertime. Measurements during other seasons would complete the results from the interviews and surveys as teachers and students are reporting on the perceived indoor environment based on their experience throughout a whole school year.

Regarding the interviews, the biggest shortcoming is the rather low number of interviewees. A generalization of the statements from the interviewees should therefore be treated with caution. However, a combination of all qualitative and quantitative results can be used to analyse the school`s situations regarding perceived indoor environment. To the extent possible, the same persons were interviewed in both campaigns, implying the risk that not all teachers work in one of the monitored rooms on a daily basis. Therefore, the results from the interviews may differ from the quantitative results. Nevertheless, the statements from the school employees can give a good indication of the overall indoor environment of the respective school.

Regarding the surveys, the most obvious drawback is the lack of data for School A for the first campaign. Among the three schools, this school has the lowest-rated perceived indoor environment and the most reported health issues.

CONCLUSIONS

This work presents the results of a project called "School on hold" aiming at implementing simple measures to improve the perceived indoor thermal environment and reduce reported health issues in schools. Through measurements in monitored rooms, interviews with school employees and surveys among students, it can be verified that simple measures can help to improve the perceived indoor environment notably. Such simple measures can be i) removing the lowering of heating set points during the night, ii) checking the radiator valve position at the end of a school day, iii) introducing routines for natural ventilation during breaks and iv) improving the room cleaning routines. The measures proposed in this project (see Table 5) are not school-specific, but can be implemented in other schools as well. The simplicity of the proposed measures was one of the ideas and pre-requirements of the project.

Regarding School A, the quantitative measurement results indicate that the measures helped to improve the indoor environment marginally. However, the interviewees may not notice an improvement since the indoor air quality is still unsatisfactory. This is also confirmed by the results from the surveys which show that the indoor environment is insufficient even with the implemented measures.

Regarding School B: among the three schools, this school was in the best condition and suffered least from a poor indoor environment. Nevertheless, the school implemented a few of the proposed measures, especially daily routines, and disseminated information towards employees and students.

Regarding School C: it was the school that has implemented the most measures, with special focus on the implementation of daily routines and dissemination among the school employees and students. The actual implementation of the measures, the involvement of and dissemination towards teachers and students may have impacted the perceived indoor environment positively.

This project has shown that simple measures can help improving the perceived indoor environment in schools, and that especially the school principles can make a differences when it comes to establishing daily routines and knowledge transfer towards school employees and students.

ACKNOWLEDGEMENTS

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NOMENCLATURE

CO_2	Carbon dioxide
LED	Light emitting diode
oWH	Outside working hours
ppm	Parts per million
RH	Relative humidity
T	Temperature
WH	Working hours

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