



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

# Perceived and measured indoor environment in Norwegian schools

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# Background

1. Good indoor climate in schools plays crucial role in promoting health, well-being, and effective learning among students.
2. Many schools in Norway face indoor environment problems primarily due to inadequate maintenance.
3. Maintaining optimal thermal environment is important to create a comfortable atmosphere for both students and teachers.
4. Sufficient ventilation airflow rate should be supplied to ensure adequate indoor air quality to reduce adverse health effects.
5. It is a great challenge to integrate both perceived (subjective experiences reported by individuals) and measured (objective data collected through sensors or instruments) indoor environment data.

# Outlines

- Measurement and survey results in 2017
  - Three middle schools in Trondheim
- School on hold (Skole på vent) project 2018-2020
  - Three schools in Trøndelag including primary and secondary schools
- Machine learning results in 2020 (two schools in Oslo)

# Indoor environment in schools – 2017



*Hoeggen School (1982)*



*Rosenborg School (2009)*



*Markaplassen School (2001)*

# Selected classrooms

School	Room	Floor	Area [m <sup>2</sup> ]	Number of pupils	Solar shading in addition to curtains	Special
<b>Rosenborg</b>	1	First	123	25	Exterior	
	2	First	58	25		Aula, no windows
	3	First	127	25		
	4	Second	71	25	Exterior	
	5	Second	48	20	Exterior	
<b>Markaplassen</b>	1	Second	72.6	30	Exterior	
	2	Second	56.8	26	Exterior	
	3	Third	72.7	28	Exterior	
	4	Third	82.5	30	Exterior	No local exhaust
	5	Third	72.2	29	Exterior	
<b>Hoeggen</b>	1	Second	53.7	25		Sloped ceiling
	2	Second	98.2	25		Sloped ceiling
	3	Second	59.6	25		Sloped ceiling
	4	Second	75.0	25		Flat ceiling, no exhaust
	5	Second	70.7	25		Flat ceiling

# Measurement schedule

Rosenborg and Markaplassen		Hoeggen		
			Monday, Tuesday, Wednesday and Friday	Thursday
Period	Time	Period	Time	Time
1 <sup>st</sup>	08:30-09:25	1 <sup>st</sup> + 2 <sup>nd</sup>	08:15-10:00	08:15-09:45
2 <sup>nd</sup>	09:35-10:30	Break	10:00-10:15	09:45-10:00
Break	10:30-10:40	3 <sup>rd</sup> + 4 <sup>th</sup>	10:15-11:45	10:00-11:30
3 <sup>rd</sup>	10:40-11:35	Break/Lunch	11:45-12:45	11:30-12:00
Break/Lunch	11:35-12:25	5 <sup>th</sup> + 6 <sup>th</sup>	12:45-14:15	12:00-13:30
4 <sup>th</sup>	12:25-13:20	(7 <sup>th</sup> )	(14:15-15:00)	
5 <sup>th</sup>	13:30-14:25			

# Measurement instruments 2017



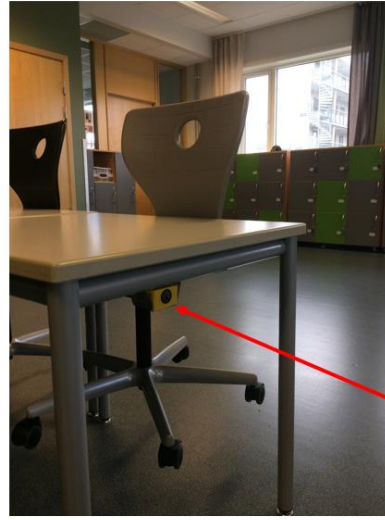
*Figure 1: The measurement equipment; Vaisala, Dustrak, AeroTrak, Pegasor and Tinytag (Photo: Katrine Ekeland)*



# Measurements in classrooms



Normal classroom at Rosenberg  
(Photo: Katrine Ekeland)

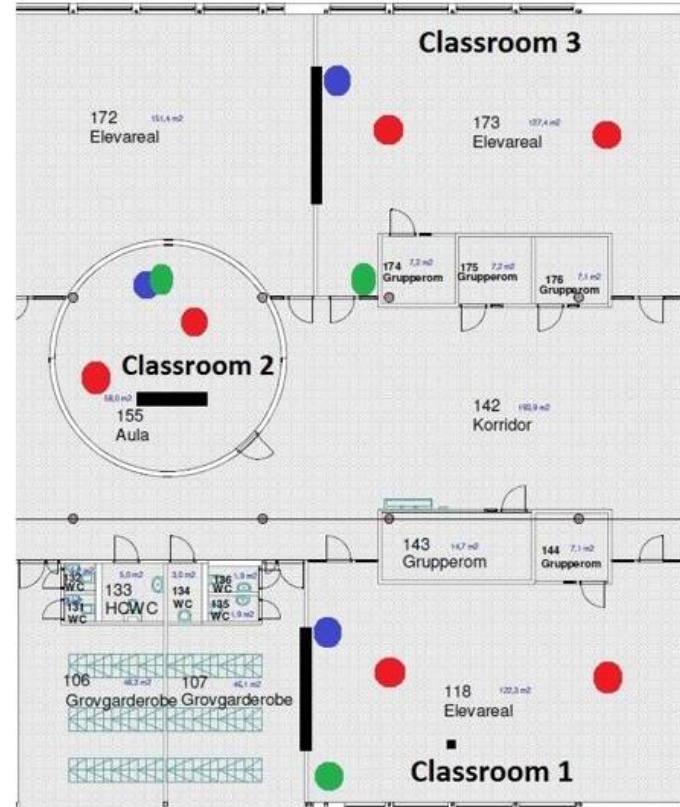
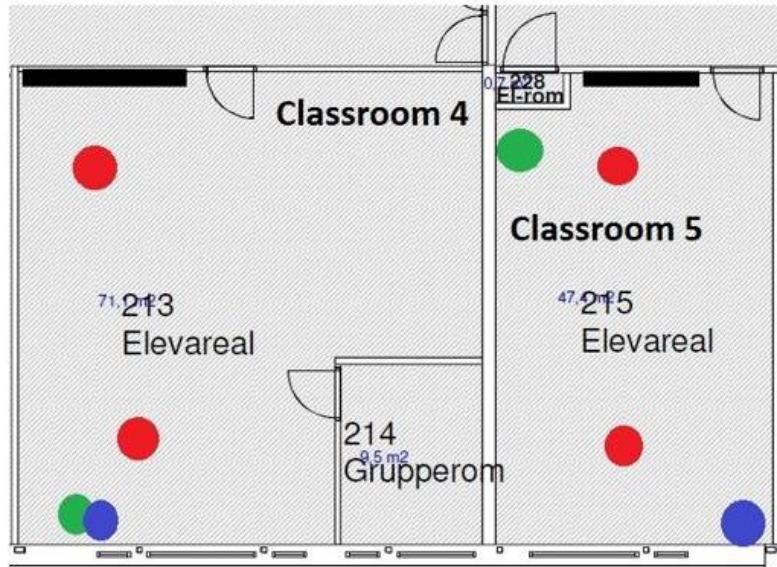


Measurement setup in room 1 at Rosenberg





# Measurement points distribution



# Questionnaire design

## Hvordan opplever du inneklimaet på skolen din?

Vi ønsker å ha et godt inneklima på skolen vår. Inneklimaet er viktig for helse, trivsel og læring. Vi vil gjerne vite hva du synes, og håper du vil svare på noen spørsmål. Du skal ikke oppgi navn, og ingen får vite hva du har svart. Når elevene har svart på undersøkelsen, lages det en rapport som skolen kan bruke for å opprettholde et godt inneklima eller forbedre inneklimaet ved skolen din.

Takk for at du hjelper til!

### Bakgrunnsspørsmål

#### Klassetrinn

Drop down liste – klassetrinn: 4, 5, 6, 7,8,9,10,VDG1, VDG2, VDG3

#### I hvilken skolebygning er du mest?

Listen er basert på de navnene på bygningene som rektor har satt opp. Du kan bare velge ett bygg

- Bygning 1
- Bygning 2
- Bygning 3

#### Kjønn

- Jente
- Gutt

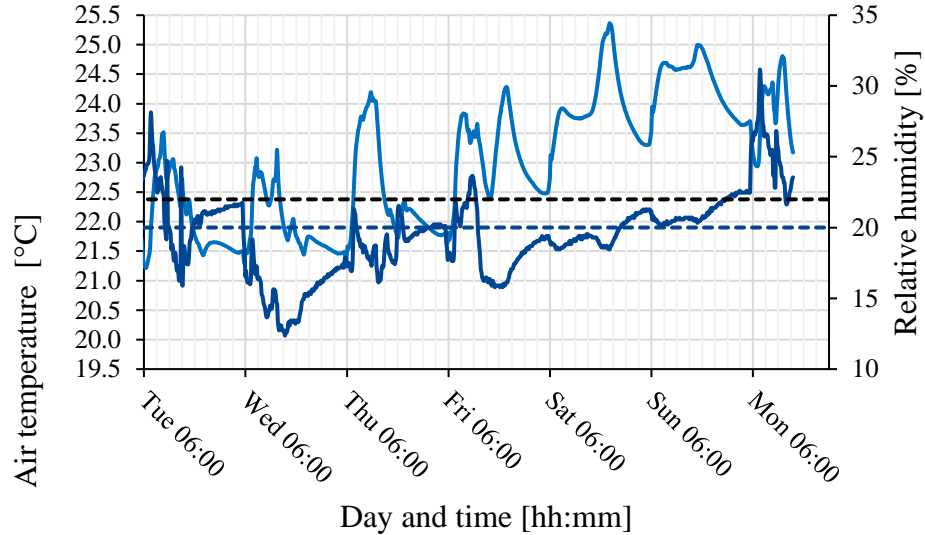
Hvordan synes du luften, støyen, temperaturen og lyset har vært på skolen din de siste 3 månedene?

Har du i skoletiden vært plaget av:

Har du i skoletiden vært plaget av:

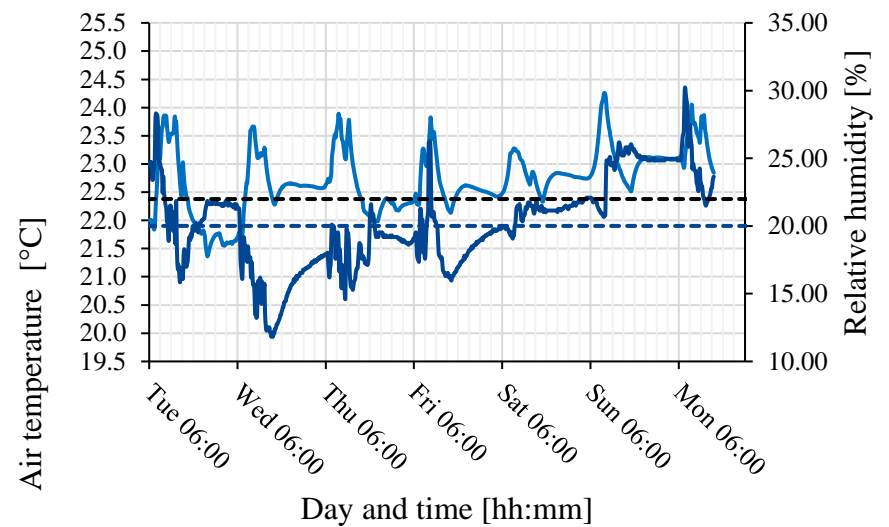
	Ja, ofte (hver uke)	Ja, iblant	Nei, aldri	Vet ikke
Trekk av kald luft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
For høy romtemperatur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Varierende romtemperatur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
For lav romtemperatur	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Innestengt (dårlig) luft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tørr luft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Ubehagelig/vond lukt	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Statisk elektrisitet som gjør at du får støt	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Støy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Støv og skitt	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
For svak belysning fra taklampene	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
For skarp belysning fra taklampene	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Skarpt lys fra solen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

# Measurement results - Rosenborg School



- Air temperature
- ..... Recommended minimum RH
- RH
- Recommended max temperature

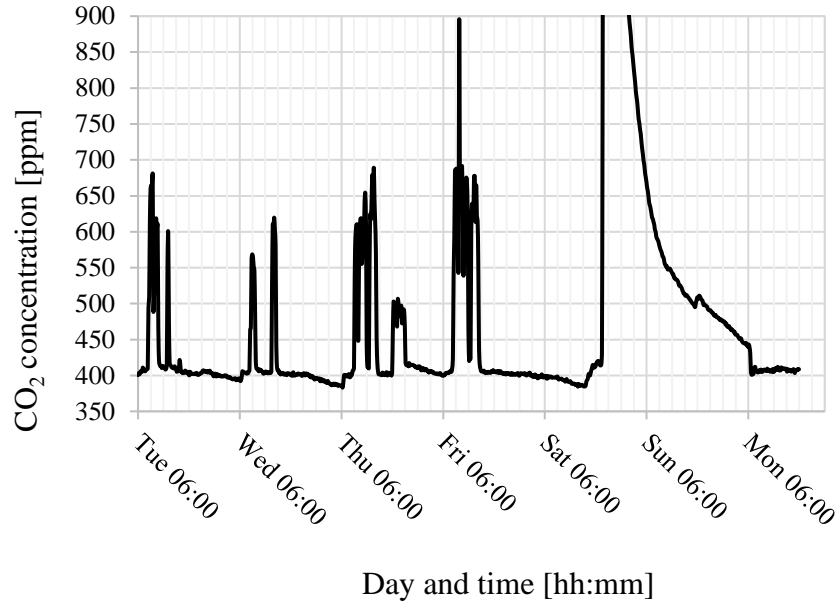
Indoor air temperature and RH, classroom 3



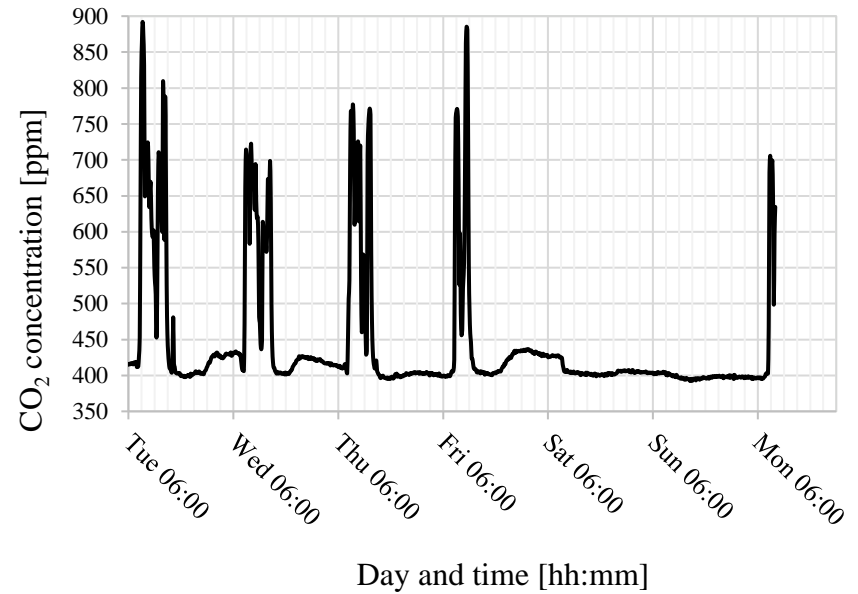
- Air temperature
- RH
- Recommended max temperature
- ..... Recommended minimum RH

Indoor air temperature and RH, classroom 4

# Measurement results - Rosenberg School

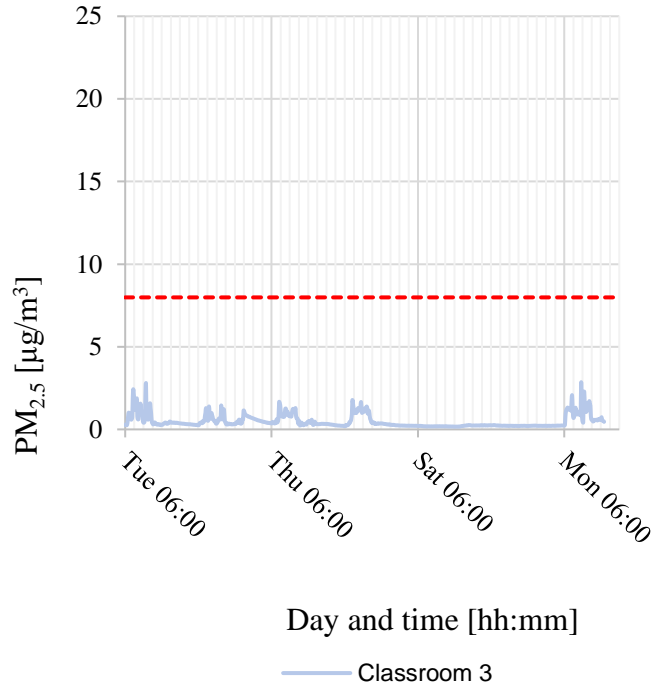


CO<sub>2</sub> concentration, classroom 3

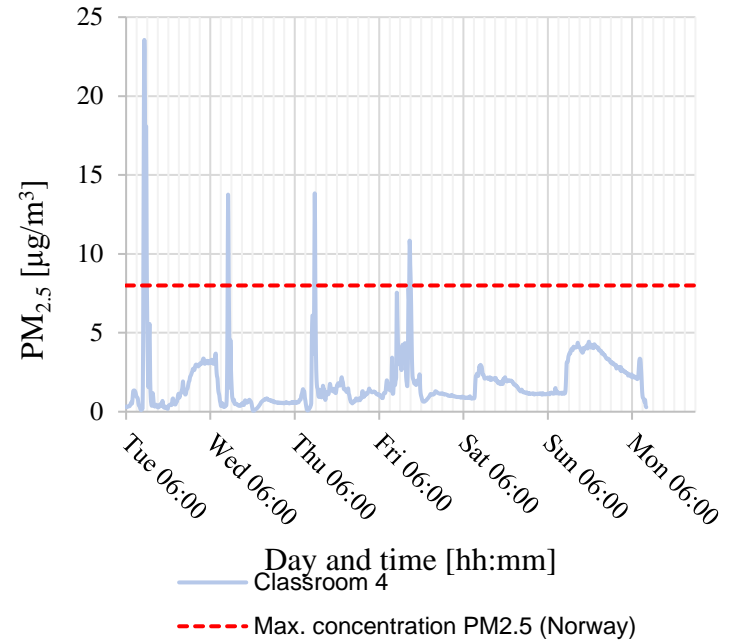


CO<sub>2</sub> concentration, classroom 4

# Measurement results - Rosenberg School

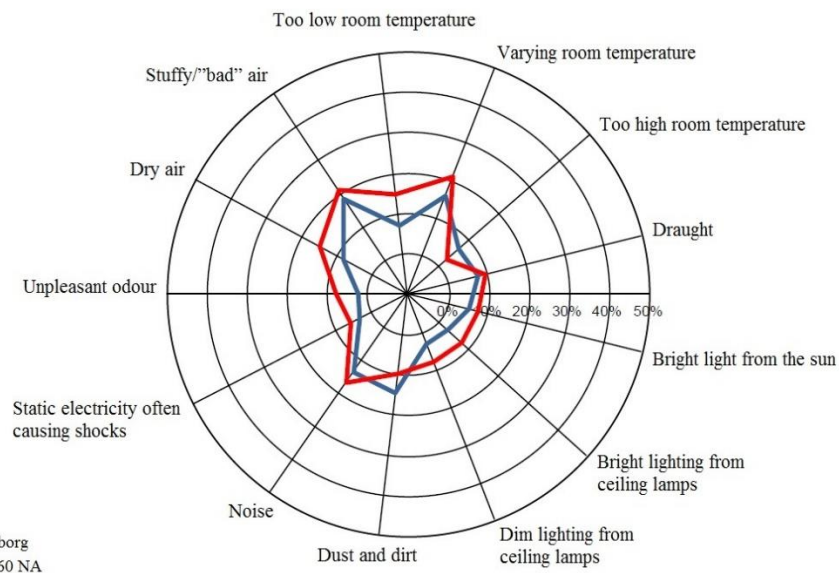


PM<sub>2.5</sub> concentration, classroom 3

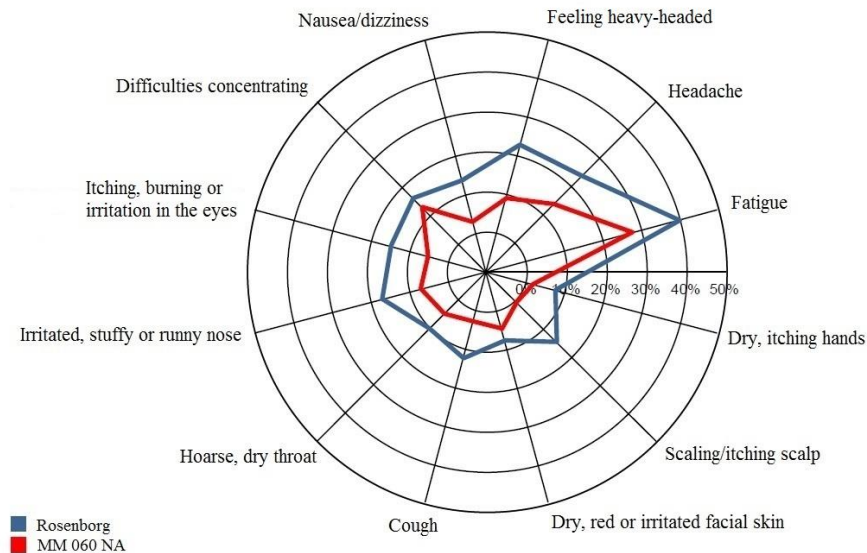


PM<sub>2.5</sub> concentration, classroom 4

# Suvery results - Rosenberg School

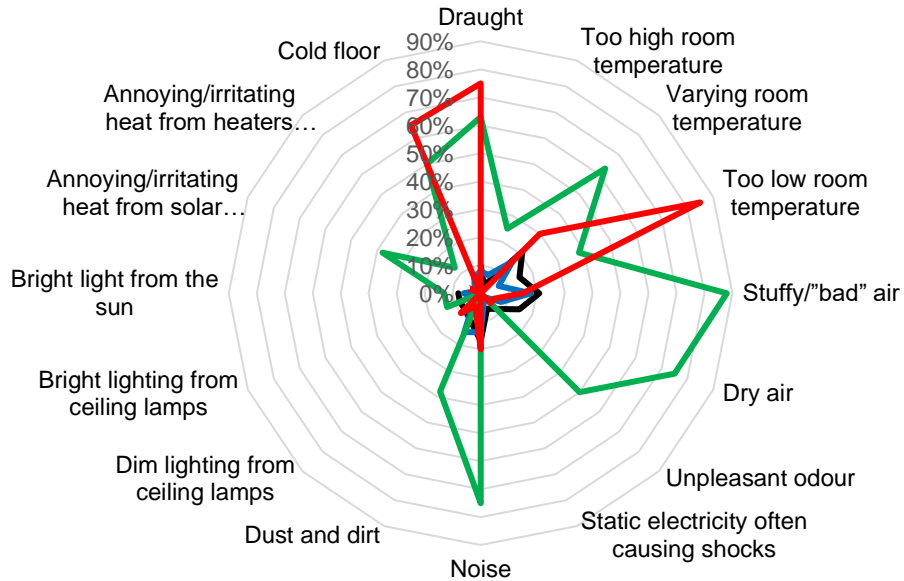


Perceived indoor environment



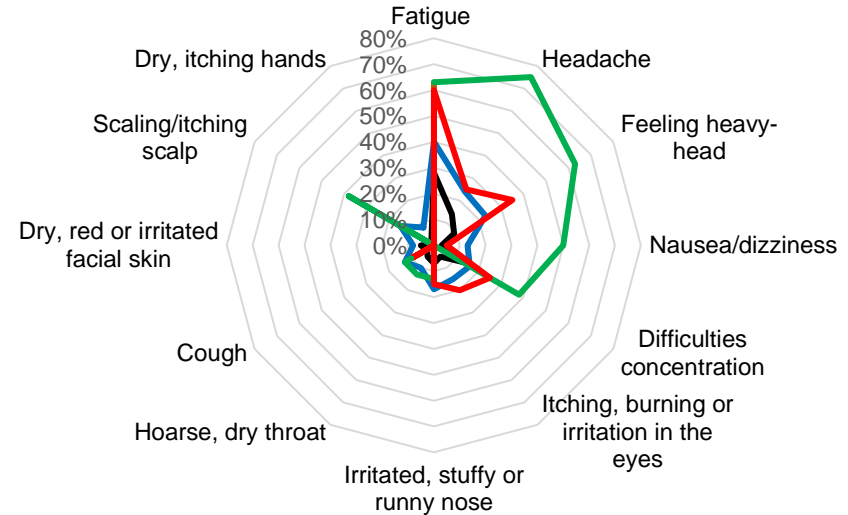
Health complaints/symptoms

# Suvery results 2017 — three schools



— Reference — Rosenberg — Markaplassen — Hoeggen

Perceived indoor environment



— Reference — Rosenberg — Markaplassen — Hoeggen

Health complaints/symptoms



# Remarks

- The measured indoor climate is not always the same as the perceived indoor climate.
- The results from the questionnaire shows that the most common health effects are fatigue, headache and feeling heavy-headed.
- Pupils at Rosenberg school are most satisfied with the indoor climate, which was controlled by advanced HVAC system:
  - Balanced ventilation with a rotary heat exchanger with an efficiency around 80 %.
  - The ventilation rates are controlled with CO<sub>2</sub> and temperature sensors installed in every classrooms.
  - There is three different control strategies for temperature settings; comfort (21°C), pre-comfort (17°C) and economic (16°C).

# Skole på vent project (An intervention study) 2018-2020



Stabbursmoen school (1979)



Sørborgen school (1967)



Sunland school (1977)

# Study design

**October 2018 to January 2019**

Preparation of Campaign 1 including "walk-through-meetings" at each school and choice of rooms to be monitored based on discussion with the school employees and the municipality



**Campaign 1: February and March 2019**

Measurements

Interviews

Surveys



**April to September 2019**

**Data analysis**

- Measurements
- Interviews
- Surveys

**Identification and implementation of simple measures to improve indoor climate in schools**



**Campaign 2: February and March 2020**

Measurements

Interviews

Surveys



**April to November 2020**

**Evaluation of the effectiveness of the implemented simple measures** for improving the indoor environment and occupant well-being

# Measurement results - Stabbursmoen school

- Results exceeding the recommended limit within school hours at Stabbursmoen school.

Results: Stabbursmoen Field Study	CO2 > 1000 ppm	Temp. > 22°C	Temp. < 19°C	RH < 20%
Room Blåsal	27.2%	0%	50.2%	3.1%
Room 321A	17.0%	15.0%	9.3%	11.7%
SFO room	16.5%	0%	0%	13.6%
Teacher's lounge	5.5%	51.2%	0%	25.7%

# Measurement results - Sørborgen school

- Results exceeding the recommended limit within school hours at Sørborgen school.

Results: Sørborgen Field Study	CO2 > 1000 ppm	Temp. > 22°C	Temp. < 19°C	RH < 20%
Room 0217	0%	0%	7.3%	30.8%
Room 0222	0%	58.5%	0.2%	17.4%
Room 0273	N/A	N/A	N/A	N/A
Music room	2.8%	11.2%	0%	33.1%
Music room*	4.0%	18.5%	0%	30.4%

# Implemented measures, January 2020

## Stabbursmoen

- Cut of setback of set-point temperature for ventilation and heating system, for night and weekends
- Implementation of external classroom aggregate for the room "Blåsal"
- Control measurements and troubleshooting parts of the ventilation system to detect whether or not fire dampers are closed or other faults.
- Detect if exiting blinds which have not been used for years can be utilized to reduce the radiance from the sun rays
- Establish the possibility to open all the windows associated with a utilized area.

## Sunland

- Cut of setback of set-point temperature for ventilation and heating system, for night and weekends
- Rearrange the placements of pupil's desks to avoid local thermal discomfort (heat from radiators, draught, and similar)
- Actively use blinds to prevent classrooms from overheating during the cooling season

## Sørborgen

- Sørborgen was classified as a school with satisfying indoor environment, hence earlier results.
- Therefore it was decided not to make any improvements for Sørborgen.
- It is developed a poster with five simple measures. The school is encouraged to present it to the teachers and students and apply the measures in their daily routines.

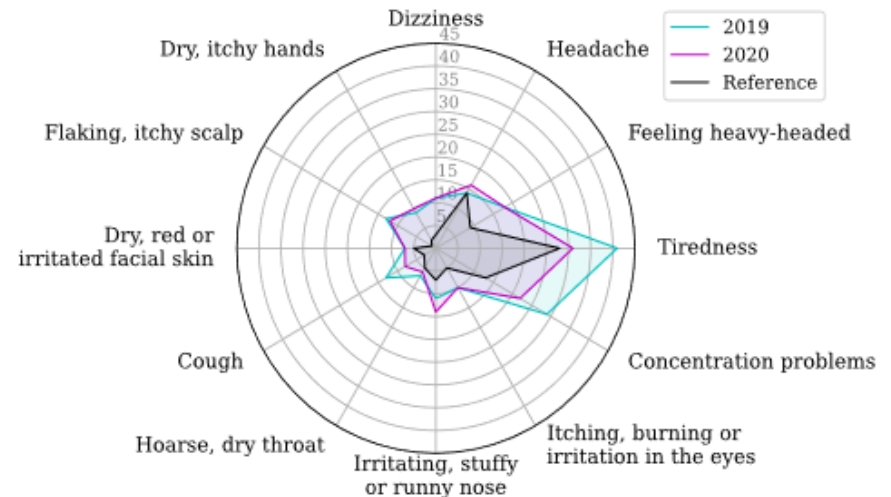
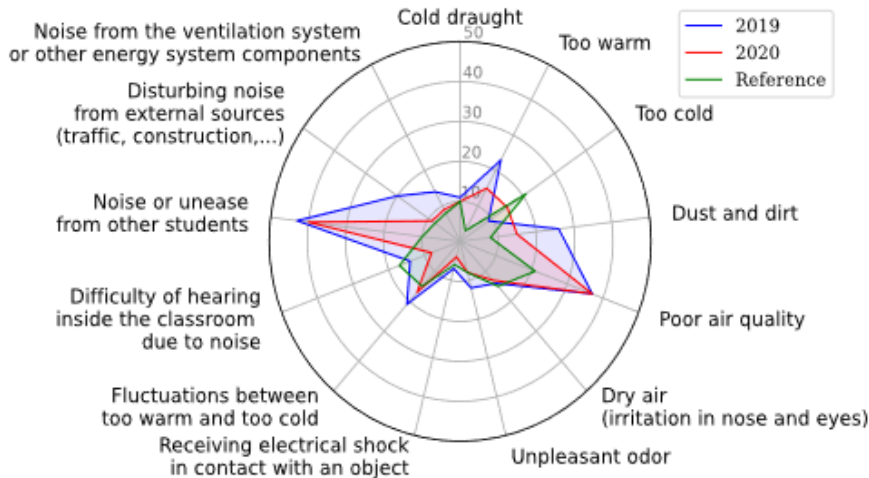
# Measurement results – Stabbursmoen skole

		Average values during working hours						Percentage of time outside recommended boundary values							
		CO <sub>2</sub> [ppm]		T [°C]		RH [%]		CO <sub>2</sub> >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	--	--	--	--	--	--	--	--
Blåsal	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	--	--	--	--	--	--	--	--
SFO	WH	561	-	20.3	-	26	-	9	-	0	-	0	-	9	-
	oWH	431	-	20.2	-	26	-	--	--	--	--	--	--	--	--
Lærerrom	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	--	--	--	--	--	--	--	--



# Survey results – Stabbursmoen skole

- The survey was carried out in 2019 with a response rate of 61%. In 2020, the response rate was a much higher 83%.

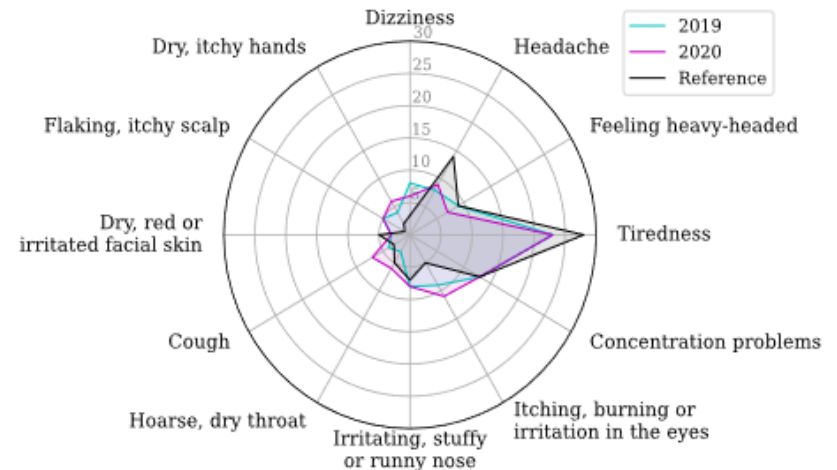
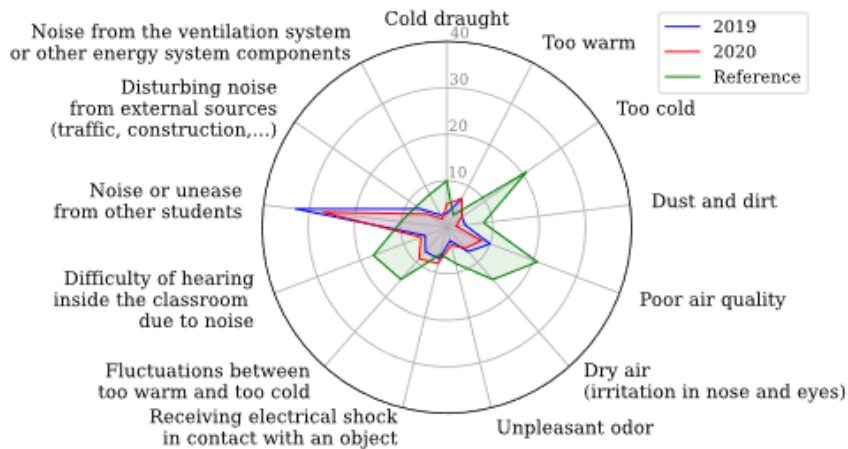


# Measurement results – Sørborggen skole

		Average values during working hours						Percentage of time outside recommended boundary values							
		CO <sub>2</sub> [ppm]		T [°C]		RH [%]		CO <sub>2</sub> >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	-	-	-	-	-	-	-	-

# Survey results – Sørborgen skole

- The survey was carried out in 2019 with a response rate of 90%. In 2020, the response rate was a much higher 83%.



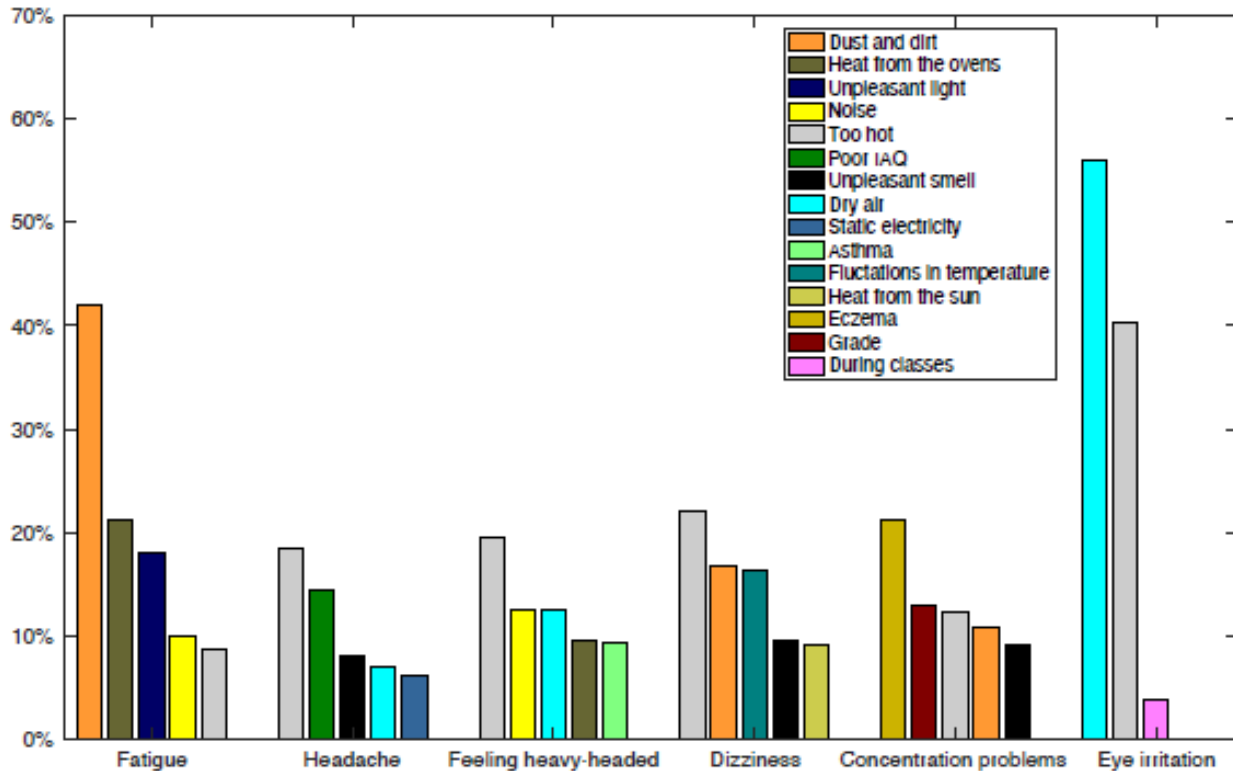
# Remarks

- Measurements and analysis carried out by an independent party are a good tool for school management and the municipality to uncover challenges and implement the right measures.
- The combination of both measurements, interviews and surveys provides good conditions for assessing the indoor climate at schools. Cross-evaluation of the results is important (sometimes differences between quantitative and qualitative methods).
- Information and awareness-raising are important for building a common culture and being able to implement routines that can contribute to schools on hold having a satisfactory indoor environment during the waiting period.

# Machine learning tools and indoor environment in schools

- **Prediction of indoor air quality**
  - **RandomForest:** classification, regression and other tasks that operate by constructing a multitude of decision trees at training time and outputting the class that is the mode of the classes (classification) or mean prediction (regression) of the individual trees
  - **AdaBoost:** can be used in conjunction with many other types of learning algorithms to improve performance
- **Prediction of the effect of indoor environmental parameters on health**
  - **XGBoost:** aims to provide a "Scalable, Portable and Distributed Gradient Boosting (GBM, GBRT, GBDT) Library
  - **CatBoost:** a machine learning algorithm that uses gradient boosting on decision trees

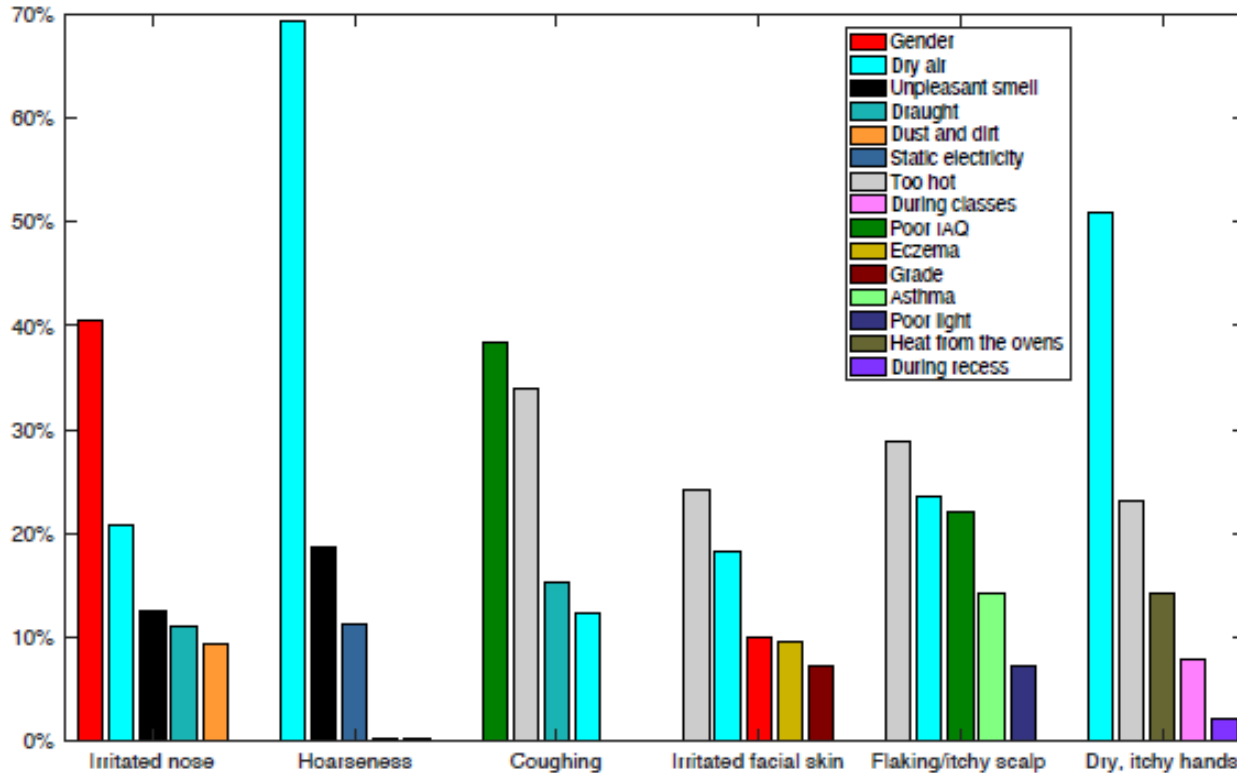
# Machine learning results - Brannfjell school



*The five most important features for the first six health problems at Brannfjell school (lower secondary school)*



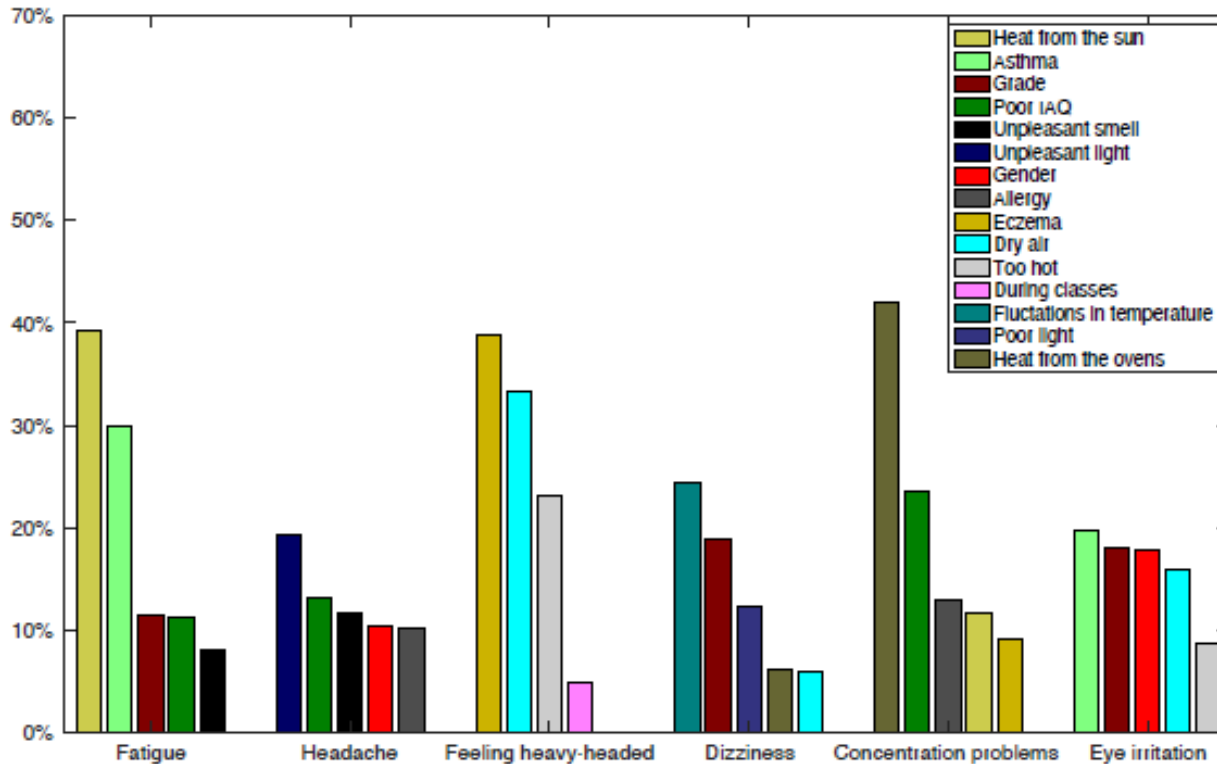
# Machine learning results - Brannfjell school



*The five most important features for the last six health problems at Brannfjell school*



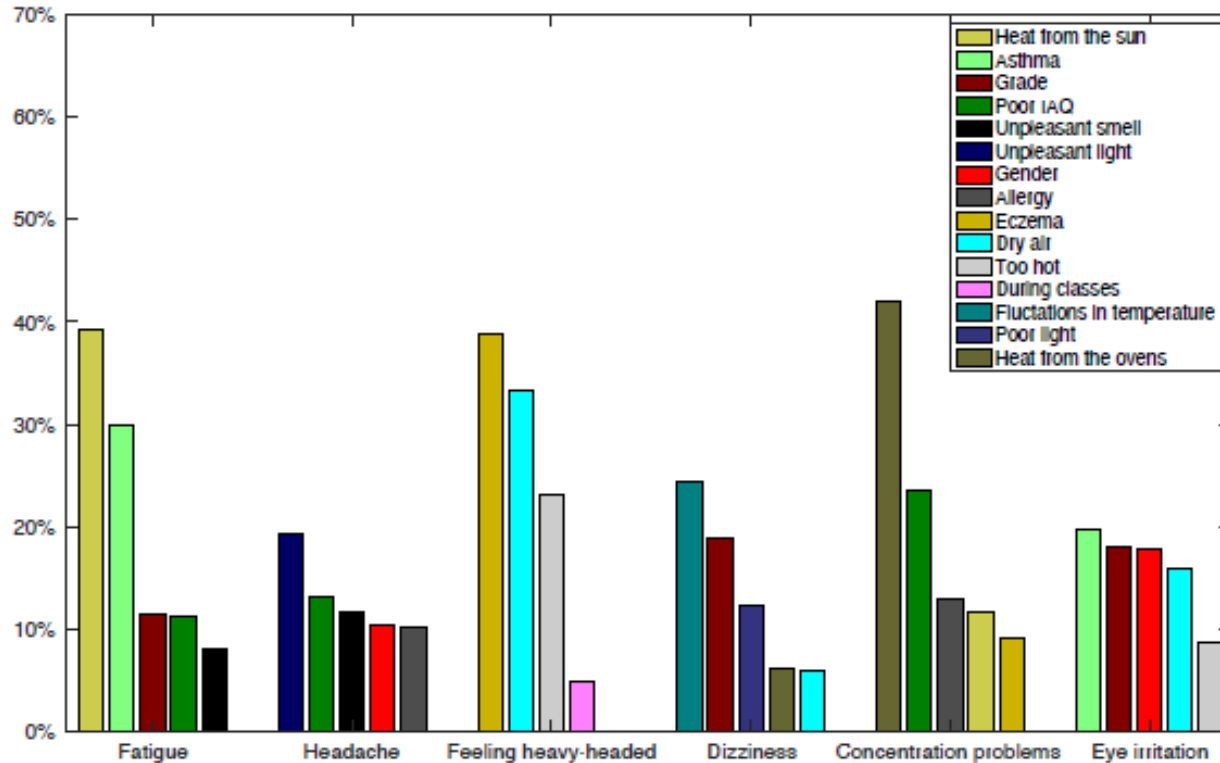
# Machine learning results - Preståsen school



*The five most important features for the first six health problems at Preståsen school (primary school)*



# Machine learning results - Preståsen school



*The five most important features for the last six health problems at Preståsen school*

# Machine learning

Health problems	Raw data	Brannfjell	Preståsen
Fatigue	Grade	Dust and dirt	Heat from the sun
Headache	Poor IAQ	Too hot	Unpleasant light
Feeling heavy-headed	Poor IAQ	Too hot	Eczema
Dizziness	Poor IAQ	Too hot	Fluctuations in temperature
Concentration problems	Poor IAQ	Eczema	Heat from the ovens
Itching, burning or irritation in the eyes	Poor IAQ	Dry air	Asthma
Irritated, stuffy or runny nose	Poor IAQ	Gender	Dry air
Hoarseness/dry throat	Dry air	Dry air	Gender
Coughing	Dry air	Poor IAQ	Gender
Dry, red or irritated facial skin	Static electricity	Too hot	Draught
Flaking/itching of the scalp	Poor IAQ	Too hot	Allergy
Dry, itchy hands (skin)	Dry air	Dry air	Poor IAQ

*The most important feature for the different data*

# Remarks

- The most important three features for whether the pupils experience the different health problems are “Poor IAQ”, “Too hot” and “Dry air”, which may have negative effect on pupils health in Norwegian schools.
- All the schools have classrooms with temperatures above 22°C, which resulted low relative humidity. This should be avoid to reduce negative health effect and learning performance of students.

# Three key take home messages

- The combination of both measurements, interviews and surveys provides good conditions for assessing the indoor climate at schools.
- Pupils at schools, which were controlled by advanced Heating, Ventilation and Air Conditioning system, may be satisfied more with the indoor climate.
- Machine learning can be used to recognize relationships between different indoor environment experience and health problems. Three most importance features, “Poor IAQ”, “Too hot” and “Dry air”, were recognized in Norwegian schools, where negative effect on pupils health have been reported.

# Reference

- Katrine Rasmussen Ekeland, Indoor air quality, ventilation and health effects in Norwegian schools. Master thesis, 2018
- Sigbjørn Voktor Svinvik. Effective ventilation solutions preventing sick building syndrome in Norwegian schools. Master thesis, 2019
- Skole på vent project report 2020
- Anita Ulvestad. Analysis of the effect of indoor environment on human health in various buildings in Norway. Master project work. 2020