Kampen School - Evaluation of pupils' performance and perceived health and well-being before and after school retrofitting

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SUMMARY
Retrofitting of Kampen School in Norway has been a demonstration project where new concepts for energy efficient ventilation and lighting are integrated.

Before retrofitting, the school had a mechanically balanced ventilation system that provided each classroom with approximately 120 liter/second of fresh air.

After retrofitting, the school has demand controlled displacement ventilation controlled by a combined CO_2- and temperature sensor and energy efficient lighting system that utilize daylight.

To examine the effects of the energy measures, we followed pupils at Kampen School over three to four years. We also followed pupils at nearby primary school (Lilleborg) over the same period as a control. Each year, performance tests, health and well-being questionnaires and technical measurements were carried out.

We found that pupils at Kampen School in total had significant improvement of the concentration test scores and health and well-being questionnaires compared to Lilleborg.

KEYWORDS
IEQ, Ventilation rates, Displacement ventilation, Field studies, Case-control design

1 INTRODUCTION

Several studies have shown that improved thermal comfort and supply air rates improves health and productivity (Wyon, 1975, Wargocki et al. 2000). However, there are few field studies that demonstrate these improvements. Especially studies that links Indoor Environment Quality (IEQ) and performance in classrooms are limited (Mendell and Heath, 2005). One exception is Haverinen-Shaughnessy who demonstrated an association between students' academic achievements and ventilation rates (Haverinen-Shaughnessy et al. 2011).

Retrofitting of Schools are often postponed due to economical reasons and there are at times discussions in Norway about whether this influence pupils' performance or not. On this basis it was decided to use Kampen Primary School as a demonstration project to evaluate the connection between indoor climate and pupils' performance.

The school was retrofitted with fan assisted natural ventilation, or hybrid ventilation. The ventilation solution was based on the original building integrated ventilation solution from

1888. The air pass through a filter and a run-around heat recovery battery with low pressure drop, then pass via a concrete duct, under the building, finally towards separate vertical shafts to each classroom. The thermal mass in the intake tower, concrete duct and vertical shafts will provide a considerable amount of cooling on hot days because they are cooled down at night by means of night-ventilation.

Each classroom has traditional displacement ventilation controlled by a combined CO_2- and temperature sensor, placed in breathing height on an inner wall. The ventilation system is designed to provide the classroom with approximately 250 liter/second when the classroom capacity of approximately 28 pupils is utilized. In addition, the school is retrofitted with improved glare control and increased utilization of natural daylight. Retrofitting of Kampen School was a case study in IEA ECBCS Annex 36 (2003).

2 MATERIALS/METHODS

This is a case-control design. Two classes from Kampen and one class from a nearby comparable school, Lilleborg Primary School, were followed up before and after retrofitting (Table 1). The youngest test pupils were in third grade in June 2001, meaning that they are about 9 years old. A test procedure was written in detail before start and not changed during the project.

Table 1. Time schedule for the tests for each class. Kampen Primary School was retrofitted between June 2002 and June 2003.

Parameter	June 2001	June 2002	June 2003	Sept 2003	June 2004
Kampen 1	4b	5b		7b	7b
Kampen 2	5b	6b	7b		
Lilleborg	3a	4a	5a	6a	6a

Physical parameters like temperature, carbon dioxide-level, lux-level and relative humidity were measured. All measurements were done with calibrated equipment. CO_2- was measured in breathing height, app. 1 meter above floor. Other measurements were done at desk level, app. 0.8 meter above floor. In addition, the number of persons present, positions of the curtains and outdoor conditions were recorded.

At the same time the performance tests were carried out, perceived health and well-being were measured with a questionnaire consisting of 45 simple yes and no questions (Jerkoe et al. 2006). The pupils filled in the questionnaire three times during two weeks. The questionnaire is based on the Ørebro questionnaire (Andersson et al. 1988, Andersson, 1993), but all questions are related to the present moment and not for a period of three months. This makes the test suitable for primary school pupils. The questionnaires were filled in at the end of schooldays with normal school activity, except Mondays.

The test procedure consisted of two different tests measuring cognitive performance. Basic information processing skills were measured with The Digit Symbol subtest from the Norwegian version of the WAIS-R (Wechsler Adult Intelligence Scale – Revised) performance scale. The Digit Symbol test is a timed measure that loads highly on a cognitive speed factor. The Wechsler Adult Intelligence Scale (WAIS) first developed in 1939 (Wechsler, 1939) and further developed with perfomance tests in WAIS III (Ryan and Schnakenberg-Ott, 2003). The second test, OK Tick-Off Test (OK-Tekstkryss) measured sustained performance. The test is a visual detection task designed to assess the ability of individuals to maintain visuo-cognitive alertness for an extended period of time. The test contains meaningless, but readable, words. The task is to tick off as many O and Ks as possible during a 10 minutes work period (Figure 1). The OK Tick-Off Test has shown satisfactory reliability (Fostervold and Nersveen, 2008).

> Hørvir mårkyn map tal jumlag hyk næj lip bav mynervil kingam læpbærrip gøvren pir nighig bår lapråk dar tøtbet dar pinbør liksit hir tartut mør.

Figure 1. Example taken from the OK Tick-Off Test.

3 RESULTS

3.1 Technical measurements and observations

Some of the observations and technical measurements are listed in table 2, 3 and 4. (Mysen and Nersveen, 2004).

Table 2. Technical measurements and observation at Kampen 1 (oldest class).

Date	14th June 01	13th June 02	5th June 03 (After retrofitting)
Timespan	13:30-14:15	13:30-1400	12:30-13:00
Amb. temperature [°C]	18	23	21
Outdoor condition	Sunny/cloudy	Sunny/cloudy	Sunny/cloudy
Persons present	27	28	20
Room temperature [°C]	22.6-24.0	24.5-24.8	24.3-24.9
CO_2-level at end of test	790 ppm	1300 ppm	580 ppm
Average lux-level	596 lux	730 lux	953 lux

Table 3. Technical measurements and observation at Kampen 2 (youngest class).

Date	15th June 01	14th June 02	25th Sept 03 After retrofitting	11th June 04 After retrofitting
Timespan	12:20-13:20	12:30-13:05	13:30-14:15	12:00-12:45
Amb. temperature [°C]	18	23	15	19
Outdoor condition	Sunny/cloudy	Sunny	Cloudy	Sunny
Persons present	23	23	21	23
Room temperature [°C]	22.7-23.7	24.3-24.9	21.7-22.7	23.8-24.2
CO_2-level at end of test	1120 ppm	1040 ppm	440 ppm	350 ppm
Average lux-level	896 lux	516 lux	810 lux	803 lux

Table 4. Technical measurements and observation at Lilleborg.

Date	15th June 01	14th June 02	6th June 03	25th Sept 03	10th June 04
Timespan	12:00-12:48	12:30-13:00	12:45-13:30	12:00-12:45	13:50-14:20
Amb. temperature [°C]	18	22	20	15	24
Outdoor condition	Sunny	Sunny/cloudy	Sunny	Cloudy	Sunny
Persons present	24	23	24	22	17
Room temperature [°C]	21.4-22.0	24.4-24.7	26.4-26.9	21.4-21.7	24.0-24.1
CO_2-level at end of test	760 ppm	970 ppm	980 ppm	990 ppm	780 ppm
Average lux-level	667 lux	481 lux	563 lux	568 lux	503 lux

3.2 Well-being questionnaire

Some symptom prevalences for Kampen 2 before and after retrofitting, are shown in Table 5. Zero (0) indicates that the symptom is not reported, while the number one (1) indicates that the pupil has confirmed the presence of the symptom each time the questionnaire was repeated for each stage. The questionnaire was repeated three times.

Table 5. Average symptom prevalences for Kampen 2 (youngest) before and after retrofitting

	Before retrofitting		**After retrofitting**	
	June 01	**June 02**	**Sept.03**	**June 04**
Are you tired?	0.64	0.53	0.21	0.24
Does your head feel heavy?	0.47	0.30	0.28	0.31
Do you have a headache?	0.38	0.17	0.14	0.10
Do you feel faint or dizzy?	0.42	0.33	0.03	0.10
Do you have problems concentrating?	0.46	0.33	0.24	0.14
Do you have a stuffy or runny nose?	0.28	0.30	0.14	0.17
Is it too warm?	0.44	0.63	0.38	0.31
Is there bothersome warmth because of sunshine?	0.26	0.47	0.28	0.17
Is it too cold?	0.19	0.00	0.07	0.00
Do you feel a draught around your feet or your neck?	0.37	0.33	0.21	0.10
Does the temperature in the room vary?	0.50	0.27	0.03	0.07
Does the air feel heavy?	0.67	0.79	0.31	0.17
Does the air feel dry?	0.63	0.50	0.28	0.21
Is there any unpleasant smell?	0.39	0.30	0.24	0.10
Is it difficult to hear what is said in the class room?	0.22	0.20	0.00	0.03
Is the light good enough?	0.20	0.23	0.00	0.14
Are there bothersome reflections from the board?	0.22	0.20	0.10	0.14

3.3 Statistical analysis

We analysed for significant improvements in concentration and well-being after the retrofitting on Kampen School. Let X and Y be the sum of the results for all the students on each of the two concentration tests in an intervention. For each question in the well-being questionnaire the pupils answer zero if something is wrong and one if nothing is wrong. We let Z be the sum of the answers of all the questions for all the students in an intervention. Thus a high value of Z indicates that the students are feeling well. We investigate improvement in

- concentration before and after retrofitting by testing for significant improvement in the total score of the two concentration tests $V = X + Y$
- well-being, testing for significant improvement in Z
- concentration and well-being in total, testing for significant improvement in the total score of the concentration tests and well-being questionnaire $W = X + Y + Z$.

It will only make sense to analyse the sum of X, Y and Z if the variables are on the same scale. Therefore we do a rescaling of X, Y and Z before computing V and W.
In total we do nine tests summed up below.

Table 6. Comparing results from year 2002 against 2003 for the oldest class on Kampen.

	Df	*Tobs*	p-value
Concentration	25	1.792	0.0425*
Well-being	25	2.398	0.0124*
Total	24	2.809	0.0049**

Table 7. Comparing results from year 2002 against 2003 for the youngest class on Kampen.

	df	*Tobs*	p-value
Concentration	20	2.071	0.0257*
Well-being	22	4.432	1.05e -04**
Total	19	3.351	0.0017**

Table 8. Comparing results from years 2001 and 2002 against results for years 2003 and 2004 for the youngest class on Kampen.

	df	*Tobs*	p-value
Concentration	19	0.612	0.274
Well-being	21	5.644	6.66e -06**
Total	18	2.420	0.0132*

*   p-value < 0.05,   **   p-value < 0.01

The results from Lilleborg School are used as control in all our tests. We see that all the tests except for one are significant on a 0.05 significant level. In particular we see that the three tests for improvements in total are significant.

If the pupil's backgrounds are significantly different on Kampen and Lilleborg, this could affect our results. As part of the well-being questionnaire some questions concerned the pupils background, like “Have you eaten breakfast?”, “Do you have carpets that cover the whole floor?”, “Do you have animals at home?” and so on. This questions where not used in the tests above. We used the answers on these questions to compare the three classes in an unbalanced one-way ANOVA. The result is given in the table below.

Table 9. Comparing background information between the classes.

df group	df error	*Fobs*	p-value
2	34	0.067	0.936

The number of observations and such a high p-value, gives strong indications that there are no significant differences between the pupils from the three classes.

4 DISCUSSION

We have shown an improvement in concentration and well-being after the retrofitting, but we are not able to point out which factors that caused the improvements and the different factors might interact. Studies by Wyon tell us that improved thermal comfort might improve mental performance (Wyon, 1975). Increased outdoor air supply rates will improve air quality and decrease CO_2-level in the breathing zone and several studies demonstrate that this can improve performance (Wargocki et al. 2000, Satish et al. 2011, Haverinen-Shaughnessy et al. 2011). Lighting systems and daylight might also contribute (Fostervold and Nersveen, 2008).

In addition to the systematic change in factors due to the retrofitting, we also have randomness in these factors in each intervention which we do not control and which may affect the results. There is also a dependency between the results for the older and the younger class at Kampen since both classes use the same class at Lilleborg as control.

There will always be unaccountable uncertainty in field studies; still it is important to demonstrate that proven relationships in controlled environment have practical impact in a real School environment.

5 CONCLUSIONS

We found that pupils at Kampen School in total had significant improvement of the concentration test scores and health and well-being questionnaires. The main purpose of School facilities is to contribute to an excellent learning environment. This study shows that it is possible to significantly improve the learning environment by upgrading IEQ.

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