Indoor climate in a renovated Danish school: Measurements of electric light, indoor temperature and air quality (CO_2)

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Abstract

Endrup school is located north of Copenhagen in Denmark and renovated recently. The purpose of the renovation was to improve the indoor air quality (benchmarked by perceived freshness and CO_2 levels) daylight levels and daylight distribution. To achieve the renovation targets, additional windows were installed and demand-controlled natural ventilation was applied (based on CO_2).

Simulations of Daylight Factor were used to optimise daylight distribution and location of the added roof windows. The measurements of the classroom's indoor environment, such as temperatures, noise and CO_2 levels, was done using Netatmo sensor stations. Switching patterns of electrical lighting use in each classrooms has been monitored by installing HOBO Data Loggers mounted inside the luminaires to record when the light is on or off. All the measurements have been logged with sub-hourly values since end of January 2015 until middle of December 2015, except the electric lighting use (e.g. until beginning of June 2015). In total, four classrooms were included in the evaluation; two renovated and two non-renovated. In addition, two teachers replied to a questionnaire to explore variation between the classrooms. The replies provide insight to what the teachers think of the classroom and the interior environment.

Keywords School; Natural Ventilation; Indoor Air Quality; Daylight; Thermal Comfort; Electric Lighting Use

1. Introduction

Good indoor climate should be a key component of school modernization projects to achieve significant energy savings, be environmentally responsible, and eventually have an influence on student attendance, impact on learnings, and better overall facilities for students to learn and educators to work.

Studies show that daylit environments lead to more effective learning. It was found that students in classrooms with the most window area or daylighting produced 7% to 18% higher scores on the standardised tests than those with the least window area or daylight [1]. Also, investigations on the mental performance in school buildings have shown that poor air quality reduces mental performance, while good air quality improves it [2].

This paper investigate the impact of renovation in two classrooms at Endrup School (see fig. 1), located north of Copenhagen in Denmark. The purpose was to improve the indoor environment and daylight condition to adapt the classrooms to future demands on education. The initiatives, at Endrup School, were to improve daylight condition and indoor environment in two preschool classrooms, by installing roof windows equipped with demand-controlled ventilation.

Fig. 1 Interior photo of Endrup School. The two pictures show Endrup School before and after (Photo by Torben Eskerod).

The aim of this paper is; to examine the relationship between improved daylight conditions and if this change switching pattern of perceived need for electric lighting; and added demand sensor controlled operation of windows in relation to existing non-renovated classrooms to examine the indoor environment. Subsequently, active use of daylight and fresh air not only ensures a comfortable classroom, it also has a number of welldocumented positive effects on our senses and concentration. A classroom is an environment that should support learning and creativity. To fulfil this goal, a pleasant and comfortable indoor climate is necessary.

2. Methods and approach applied

Measurements of classrooms indoor environment where handled by the Netatmo weather station (see fig. 2). In each of the four classrooms, the indoor station where located near the teachers desk to ensure power supply. The outdoor module where located below an overhang to be protected from direct sun and rain. Each weather sensor where connected to a 3G Wi-Fi router, so that our measurements were accessible. The specifications of the weather stations sensor and measurements are shown in Table 1. Switching patterns of electrical lighting use in each classrooms has been monitored by installing HOBO U12-012 Data Loggers mounted inside the electric lighting luminaires to record when the light is on or off (e.g. measure light intensity).

Table 1. Specification of the Netatmo weather stations sensor and measurements.

	Range	Accuracy
Temperature (indoor), C°	0°C to 50°C	± 0.3°C
Temperature (outdoor), C°	-40°C to 65°C	± 0.3°C
Humidity (indoor and outdoor), %	0 to 100%	± 3%
CO_2 meter (indoor), ppm	0 to 5000 ppm	± 50 ppm / ± 5%
Sound meter, dB	35 dB to 120 dB	-
Light intensity	1 to 3000 fc (~10-30000 lx)	-

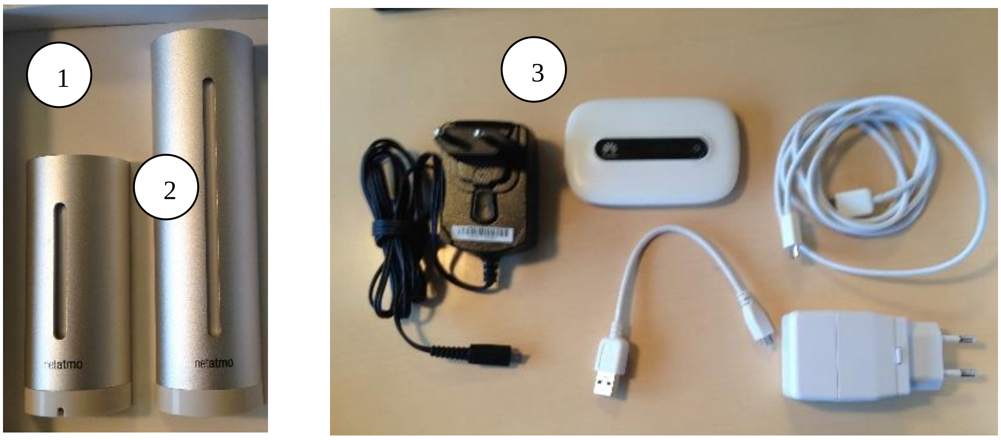


Fig. 2 Netatmo weather station; #1 Outdoor module; #2 Main weather station (possible to add three extra indoor modules) and #3 3G wifi router.

Daylight simulation

The daylighting performance of Endrup School has been specified using the daylight factor (DF) as indicator. The daylight factor is a common measure for the available amount of daylight in a room. It expresses the percentage of daylight available inside (e.g. on a plane 0.85m above floor level), compared to the amount of daylight available outside when the sky is CIE overcast. The higher the DF, the more daylight is available in the room. Rooms with an average DF of 2% or more (average of all point-specific DF) are considered to be daylit. A room will appear strongly daylit when the average DF is above 5% [3]. The daylight factor analysis has been performed using the VELUX Daylight Visualizer, a software tool dedicated to daylighting design and analysis (http://viz.velux.com). Figure 3 show the calculated daylight factor levels in the two preschool classrooms before and after installing roof windows.

Comparisons of the results show the positive effects on the daylight conditions by adding roof windows. The roof windows provide a more even distribution of light in the classrooms. Before the renovation the daylight levels where critically low and need for electrical lighting could be significant.

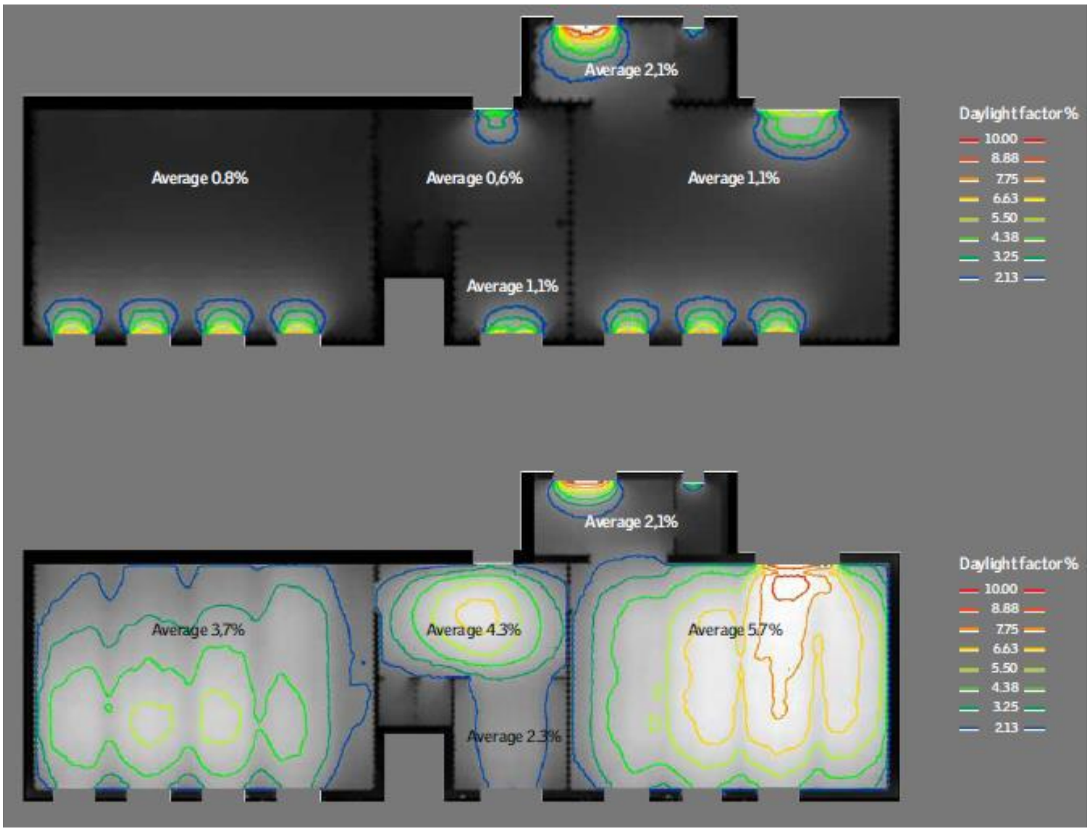


Fig. 3 The daylight factor analysis has been performed using the VELUX Daylight Visualizer, a software tool dedicated to daylighting design and analysis (more informaiton at http://viz.velux.com). The upper part is existing classrooms, while the the lower part show the renovated classrooms and the effects of adding roof windows on the daylight levels and distribution.

3. Results

Measurements of the indoor environment included electric lighting use, thermal conditions, indoor air quality and the student presence by using the noise sensor within the Netatmo weather station. Each classroom is an individual zone in the data measurement system, and each room is analysed individually. Although there are individual differences, these individual differences are insignificant and therefore all data presented is an average of the renovated and the non-renovated classrooms. Data from the weather station is fixed average 30-minute time steps, while the light intensity is 5-minute (average) time steps.

As part of the evaluation, a questionnaire was handed out to the teacher in each classroom, and we received two replies – a renovated and a non-renovated classroom. The intent of the questionnaire is to identify the teachers experience of the indoor environment. The questionnaire comprised of satisfaction/dissatisfaction with indoor climate and air quality, daylight and electric lighting.

The overall purpose of the evaluations is to get indications on the relationship between improved daylight conditions and electric lighting use, and if a demand sensor controlled operation of windows can ensure good indoor climate. By using different methods, both quantitative and qualitative, we can document if there are challenges or problems, and what can be learned and improved.

Data validation

The measured data presented in this paper is only within the time frame when the classrooms where occupied by the pupils; weekdays from 8 in the morning to 15 in the afternoon. Measurements outside this period has been used as a base line to qualify the measured data included in the analysis. For example, weekend measurements of the interior noise level is used as base line to distinguish if the pupils are present or not in the classroom. Another example is the light intensities measured in the weekends. It is used as base line for an intensity when the lights are switched off. Measured light intensities higher than base line is taken as indication that the lights are turned on.

Daylight

The geometry of a building influences its capacity to deliver adequate levels of daylight to the interior. When the building is deep, daylighting solely by facade windows has its limitations and only possible to achieve an adequate daylight distribution (DF > 2%) a few metres from the façade. The effect of adding roof windows in Endrup School roof windows in each of the preschool classrooms results in reach higher average DF levels ranging between 3,7% and 5,7%, (see fig. 3), compared to the average DF levels before (0,8 - 1,1%). Most importantly, the roof windows help to achieve a much better distribution in the individual classrooms to ensure that each student desk receives adequate levels of daylight and reduce the contrast in the daylight levels of the room. From the questionnaires, the reply show that there is general high satisfaction with the daylight in the renovated classrooms. The daylight levels are considered as better compared to the non-renovated, but sometimes experienced to be too high in the renovated classroom. Satisfaction with the electric light is better in the renovated, which is to be expected, since the luminaries are changed to a direct/indirect LED luminaire (e.g. better spatial effect, less risk for glare etc.) compared to a tradition fluorescent direct luminaire.

The measured results of the electric lighting use and the switching patterns demonstrate that better daylighting performance have an impact on the behavioural switching patterns. Almost five months measurements (late January to the middle of June) show that the two renovated preschool classrooms had the electric lights switch on 98 hours (average) out of a total of approximately 480 hours, corresponding to around 20% of the time, when the pupils are present. The non-renovated classrooms switched the electric lights on 219 hours (average), which is about 45% of the time. This give a saving potential of around 55%. The pattern of lighting use over time is as expected; more electric light is needed in the winter months compared to the summer months.

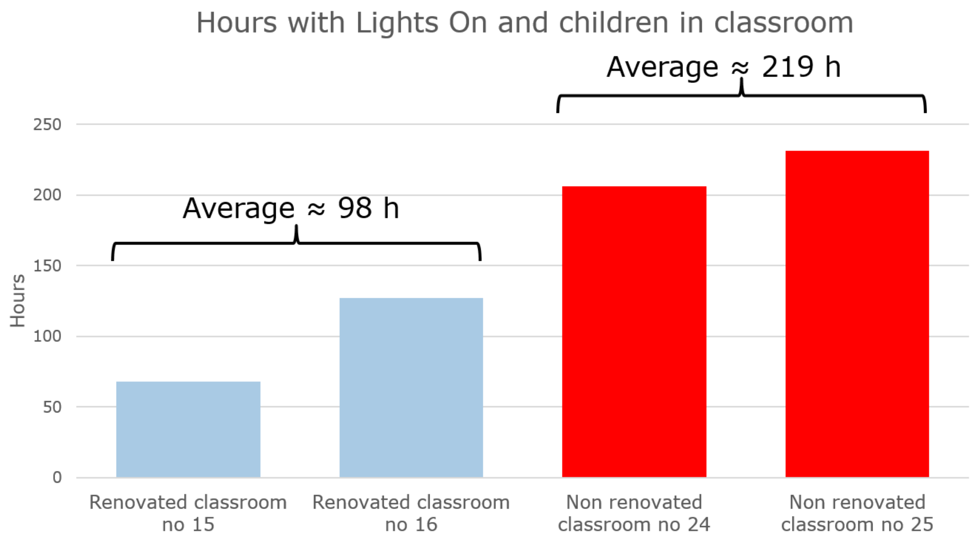


Fig. 4 Measured results of the electric lighting use and the switching patterns demonstrate that better daylighting performance have an impact on the behavioural switching patterns. In the bar graph, the renovated classroom is blue bars (classroom 15 and 16) and non-renovated classrooms is the red bars (classroom 24 and 25).

Ventilation

The indoor air quality and ventilation aspects use CO_2 as indictor of indoor air quality. Demand sensor controlled operation of the roof windows is used to achieve a specific indoor air quality by CO_2 sensor, where after the roof window system attempts to achieve the target. The outdoor CO_2 level is assumed to be 400 ppm.

The indoor CO_2 level for opening the windows is set to ~ 1150 ppm, and the window closes when the CO_2 concentration has been reduced to ~ 900 ppm. The CO_2 sensor where installed in the summer break.

Only classroom hours from 8:00 to 15:00, excluding weekends and school holidays, are shown in Table 2 and fig. 5. Weekends and school holidays have been removed to depict the true classroom performance when the children are actually present in the rooms (see section Data validation). Due to consistent power supply switch-off to the Netatmo weather station, by occupants in the classrooms, this paper report measurements from a renovated (Room 16) and a non-renovated (Room 25). Table 2 show that, for example, an average value of 1000 ppm is met less than 50% on a yearly basis, mainly due to higher concentrations in the winter months when the occupants override the control system, or just not open the windows due to cold outdoor temperatures. Based on autumn measurements, the CO_2 in the renovated classroom is almost 90% of the time below 1500 ppm, when the demand sensor controlled operation of the roof windows was installed. The spring measurement show that this was only achieved around 50% of the time, so the impact of the CO_2 sensor controlled operation of windows, is significant.

Table 2. Distribution of CO_2 concentration in the renovated and non-renovated classrooms.

Classroom	Time	Control	CO_2 [%]		
			< 1000	1000-1500	> 1500
Room 16 (renovated)	Aug. - Dec.	CO_2 sensor	44	43	13
	Feb. - June	manual	27	22	51
Room 25	All Year	manual	42	34	24

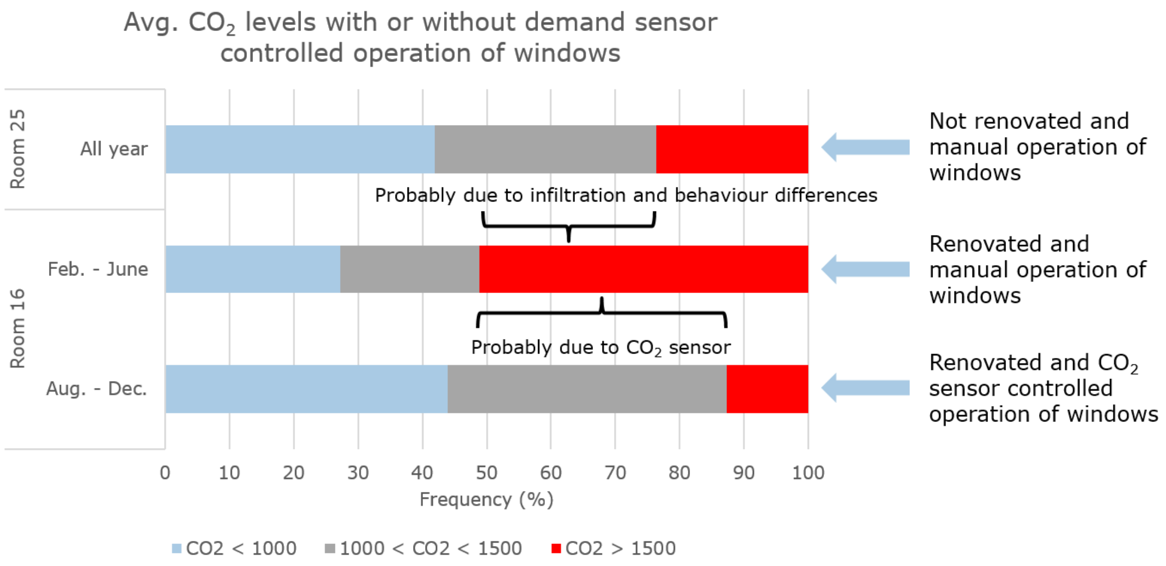
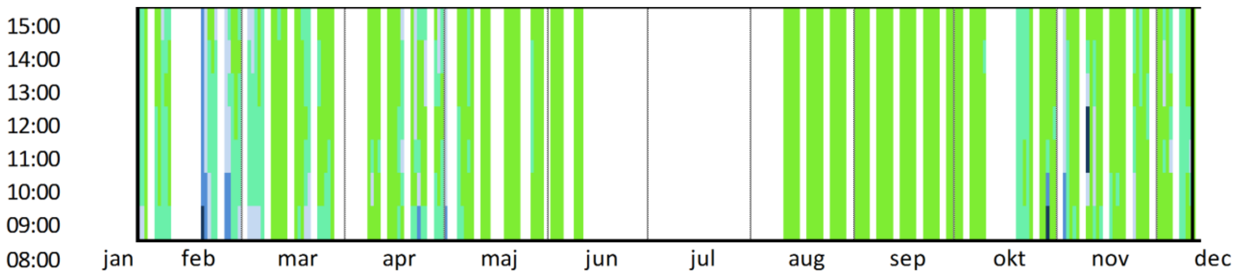


Fig. 5 Distribution of CO_2 concentration in the renovated and non-renovated classrooms. The blue colour show CO_2 distribution below 1000 ppm; the red colour above 1500 ppm; and the grey show concentration betweem 1000 – 1500 ppm.

Among the two teachers, there is greater satisfaction with air quality in the renovated classroom, and they prefer to open the skylights above the facade windows as it provides less noise from the outside (e.g. play ground).

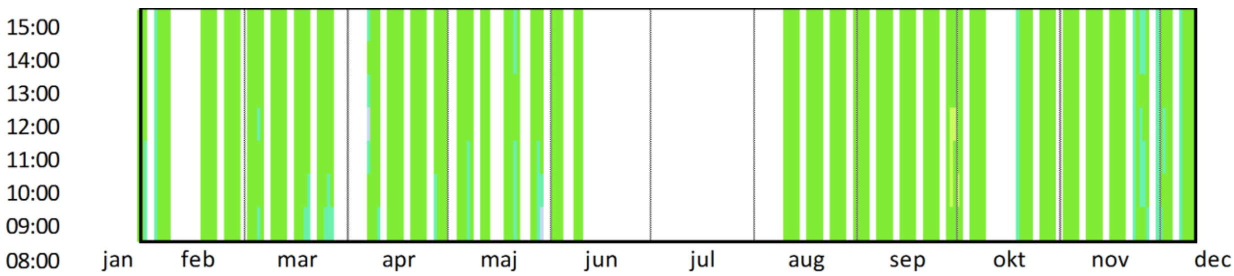
Thermal comfort

The focus in the analyses of thermal comfort is on overheating and undercooling. It is investigated if the control systems are able to provide good thermal comfort and specifically how windows contribute to the performance.



	Hours	Percentage
Too High	0	0.0%
4 high	0	0.0%
3 high	0	0.0%
2 high	0	0.0%
1	844	73.5%
2 low	220	19.2%
3 low	63	5.5%
4 low	17	1.5%
Too low	4	0.3%

Fig. 6 In the renovated preschool classroom, the comfort category of each hour of the year is plotted as a temporal map. The white area is due to weekends and school holidays.



	Hours	Percentage
Too High	0	0.0%
4 high	0	0.0%
3 high	0	0.0%
2 high	5	0.4%
1	1063	92.6%
2 low	78	6.8%
3 low	2	0.2%
4 low	0	0.0%
Too low	0	0.0%

Fig. 7 In the existing non-renovated classroom, the comfort category of each hour of the year is plotted as a temporal map. The white area is due to weekends and school holidays.

Figure 6 and 7 show, respectively for the renovated and the non-renovated classroom, the indoor temperature at each hour of the year within the school hours (between 8 and 15) as comfort categories from EN 15251, where 1 is best. The figures clearly shows that most of the school hours, the temperature category 1. There are a few days, in winter time, where the renovated preschool experience the temperature falls below category 1 for some hours. Window opening has not been logged and an obvious explanation could be manually opened windows. Moreover, the heating system could have had malfunction or the setpoint of the thermostat could be different. The small table, as part of the figure also shows that as a percentage of the total, the number of hours with temperatures above category 1 are so few, that they are rounded off to 0% (no overheating). The smal table do show that for all hours of the year, 7% of the hours are below category 2 (i.e. below 20°C), and 19% in category 2.

There is higher satisfaction with the temperature conditions in the renovated classroom than the non-renovated. The ability to regulate the indoor climate is experienced as better in the renovated classrooms

4. Summary

Daylight and ventilation by windows are inseparably connected to indoor climate. Indoor climate encompasses all the elements: temperature, humidity, lighting, air quality, ventilation and noise levels in the habitable structure. We spend most of our time indoors. The focus on energy savings is an increasing challenge to existing building stock as well as new and future buildings, as energy consumption is believed to result in climate changes. It is, however, important to remember that all energy in buildings is used to serve people's needs, comfort and well-being.

Both the quantitative and qualitative measures of daylight and the indoor environment, show that the renovated classrooms at Endrup school provide solution which can adapt school classrooms to future demands on education. The improved daylight distribution and higher daylight levels make the perceived need for electric lighting within school hours less required and thereby provide a significant saving potential, when we consider initiatives to refurnish future schools. The results clearly show a correlation between high daylight levels and that it affects the way the occupant switch on the electric lighting; less overall needs to switch the electric lights on. The CO_2-sensorbased automatically controlled natural ventilation of the roof windows is a simple solution that often provides adequate air quality in many poorly ventilated schools, either because they are manually operated, or the mechanical ventilation systems is poorly maintained.

Based on the above-mentioned considerations, it is obvious that indoor air quality, appropriate thermal comfort and sufficient daylight play a major role in today's school buildings and for the occupants' staying inside. The results in this paper highlight the importance of having appropriate requirements for daylight and indoor climate measures, ensuring that the indoor environment are being treated with the same level of importance as energy efficiency in future policy development (local and national) relevant for schools and learning environments.

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