Noise measurements during focus-based classroom activities as an indication of student's learning with ambient and focused artificial light distribution

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Summary

Students' learning is of utmost importance in classrooms. The environmental conditions in classrooms have been found to impact students' ability to learn. This study investigated how artificial light distribution impacts students' learning during focus-based learning activities, e.g., mathematics, reading, and paper-based activities, by measuring the noise level in classrooms. The measurements are carefully designed so that the similar focus-based activities are planned with two different light distributions, one being an ambient artificial light distribution and the other being a focused artificial light distribution. In each light condition, the noise levels from pupils doing similar focus-based activities are compared. Four classrooms covering from elementary school year 1 to 6 (aged from 6 to 11) are measured, ending up with 20 comparable pairs in terms of the activity and the pupil's number with help of video footage analysis. It is found that the noise level with the focused lighting is reduced in 14 out of 20 cases. The average reduction of the noise level with the focused light distribution is found to be 1.7 dB.

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1. Introduction

Over the years, a significant body of evidence has been accumulated that demonstrates our physical built environment influences our ability to act [1]. This has been found particularly true for educational environments, where a range of parameters has been identified that influences our behavior, wellbeing, and ultimately academic performance. Light is one of such influential parameters [2]. For those designing or using educational facilities, it is relevant to understand how lighting conditions may influence our ability to perform curricular activities. A better understanding of the relationship between indoor lighting conditions and human (learning-related) behavior empowers to design more suitable learning environments.

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This research, embedded in the architectural practice at Henning Larsen Architects, explores this relationship specifically in public, primary schools in Denmark, where recently a major educational reform took place [3]. Greater emphasis is now put on stimulating "learning" through physical playfulness, diversity in curricular activities, and addressing individual learning styles instead of applying a generalized approach. As a result, Danish primary schools have implemented a teaching philosophy that promotes for individuality, flexibility, and diversity.

Ideally, the design of spaces where this new learning takes place facilitates these educational principles. This environmental need has also been recognized by the Danish local municipalities, and a significant number of primary schools have been or are currently in the process of being renewed or refurbished. In line with this development, our research ambition became to explore how artificial

lighting can play an active role in creating such supportive new learning environments, and simultaneously grow our knowledge on how artificial lighting influences (learning-related) behavior of pupils in Danish primary schools.
Previous research revealed that conscious design with light and darkness co-defines the appearance of a space [4], which contributes to our experience of atmosphere [5]. This is, amongst others, shaped by the way light is distributed in a space, or spatial contrast. A former field study in eight primary learning environments by Henning Larsen Architects revealed that a low-contrast, or uniform, distribution of artificial light has become the norm [6]. The resulting luminous atmosphere is described as functional, although it is uninspiring and dull. Having also learned that educators try to modify this atmosphere by using local light sources instead of the generic ceiling lighting to promote focus and concentration, they are effectively changing the manifestation of spatial contrast in their environment.
These findings suggest that spatial contrast has the potential to be an instrument for educators to orchestrate a different-than-normal atmosphere in their learning environment, and in their view, increases concentration during certain curricular activities. If this idea could be demonstrated true, then artificial lighting might receive greater attention in learning space design. It was therefore further explored in a design context by hosting workshops with a number of architects at Henning Larsen, which led to the formulation of the following hypothesis:

> "*Focused, local light* leads to high-spatial contrast that constructs an atmosphere that promotes pupil behavior and mood states benefitting their ability to concentrate"

2. Experiments

To validate this hypothesis, this prototype has been implemented in four learning spaces of Frederiksbjerg folkeskole (figure 1), a new public school located in Aarhus, Denmark
This school, inaugurated in August 2016 and co-designed by Henning Larsen, is considered a benchmark example of the new educational ideals translated into supportive learning environments and was therefore thought to be a credible example to evaluate our hypothesis in the context of the new reform.

Figure 1. Frederiksbjerg school.

The four spaces selected are located in close proximity and have relatively similar natural light and spatial layout characteristics. Two spaces are used each by one group of the 1st to the 3rd grade pupils (aged 6-8 years), and host a varied palette of curricular activities. The other two spaces are used by eight rotating groups of the 4th to the 6th grade pupils (aged 9-11 years) for 90-minute mathematics lessons. Both demographic and curricular settings were thought to benefit from improved pupil concentration.
The **prototype design** has been implemented in addition to the existing **default design** in these four spaces. The **default lighting design** consists of six evenly spread ceiling luminaires. Users may choose to either switch all six luminaires: ON (option A, figures 2a+2b) with an option to increase or decrease the overall light level. The default ON state causes a low-contrast distribution of light, and complies with the current Danish building regulations to provide an average working area illumination level of 300 lux with a uniformity ratio of 0.6 during all hours of use [7]. The **prototype lighting design** consists of the default system complemented by six additional suspended pendants above typical work surfaces (working desks) permitting for local, focused light at eye-level. User may

choose to activate both the default and new pendant system simultaneously (option B, figure 3a+3b) or the pendant system only (option C, figures 4a +4b). Both result in high or very high-contrast distributions of light.
To evaluate the validity of the hypothesis, the influence of the high-contrast prototype lighting design on pupil behavior and their mood, is compared to that presented under influence of the low-contrast default lighting design.
Particularly, we looked at two specific behavioral measures of pupils: their **noise levels** and their **physical activity** during a curricular session. A correlation is thought to exist between the level of noise pupils are exposed to (including their own noise), and their ability to concentrate [8]. In addition, the physical activity, specifically the length of time seated at one place, and noise level will be compared. For our hypothesis to be considered valid, the prototype design should lead to lower average student noise and longer average time seated at the working place. In addition, we also assessed variances in pupil's feelings towards their learning environment, anticipating greater satisfaction to positively influence mood and motivation. To exclude as many intervening variables as possible, a range of other (environmental) factors have been measured as well.

The classroom activities compared are always paper-based works in small groups. There are two age groups for test conditions, key stage 1 (age from 6 to 8) and key stage 2, from 9 to 11 years old. In the key stage 2 classrooms, the activities are always mathematics exercises in their paper books. In the key stage 1 classrooms, the activities are always paper-based and most often concern the pupils work in their activity books, from which they do small exercises. So, the time slots compared are always for focus-based learning activities. Therefore, there are no teachers' instructions and the pupils are supposed to work in small groups quietly.

We installed a B&K 2250 sound level meter to log the noise data every 100 ms in each activity. The sound level meter was hung from the ceiling, turned on before the class start and off after the normal school day. By analyzing the video clips recorded, we have selected comparable class sessions and compared the noise levels during the activities.

3. Noise Results

By carefully considering the number of pupils and the type of activity, we have selected 20 scenarios to compare. So far, we have compared the A-weighted equivalent sound pressure level for the relevant class time. The initial idea was to make a distribution to separate the noise form the pupils from the teachers voice by making a noise level distribution as attempted in [9-11].
By setting 1 dB as a just noticeable difference (JND) [12], we found 14 improved noise conditions with the new high-contrast lighting, 4 cases within the JND, and 2 cases getting nosier than original as shown in Figure 5.
Of the 14 improved conditions, 11 cases show an audible improvement between 1 and 3 dB, and we found 4 cases with more than 3 dB, which is regarded as a significant improvement.
The sequence of the light distribution tested could influence the results. With the original lighting tested first followed by the new lighting, there are 3 improved noise case (42%), 2 neither better nor worse (29%), and 2 worsened cases (29%). With the new lighting first and distributed lighting later, the improvement was much more significant: 9 out of 10 cases were improved, 1 case unchanged. Therefore, it should be concluded that the order of lighting exposure could affect the performance as well.
For the key stage 1 activities, the average reduction in noise level becomes 2.2 dB, whereas the key stage 2 activities have a slightly lower reduction of 1.4 dB, although the difference between 1.4 and 2.2 dB should not be said to be significant. The arithmetic average noise reduction across the 20 cases including the worsened conditions is found to be 1.7 dB, which seems to be significant enough in an overall sense.

4. Conclusions

The noise levels during focus-based activities were measured in a Danish primary school with different lighting conditions. Comparing 20 fair conditions in terms of activity type and number of students, we found that the noise levels of the 70% of the measured cases get lowered, which potentially implies that the students can focus on the class better, and accordingly the students learning could be higher. The average improvement in the noise level was not huge, but clearly above the perceptual noticeable difference.

Fig 2a. Ceiling lighting only

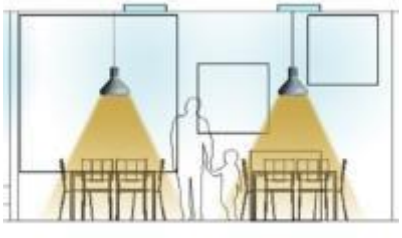

Fig 3a. Ceiling + Pendants

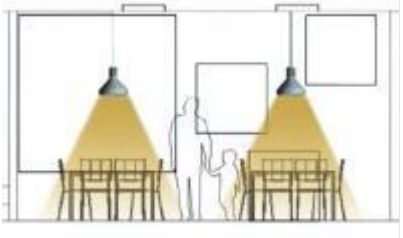

Fig 4a. Pendants only

Fig 2b. Ceiling lighting only

Fig 3b. Ceiling + Pendants

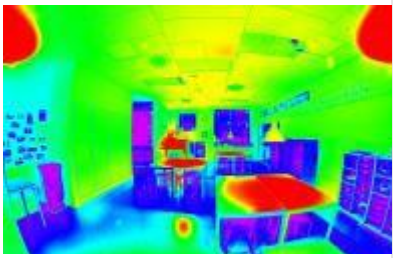

Fig 4b .Pendants only

Fig 2c. Ceiling lighting only

Fig 3c. Ceiling + Pendants

Fig 4c. Pendants only

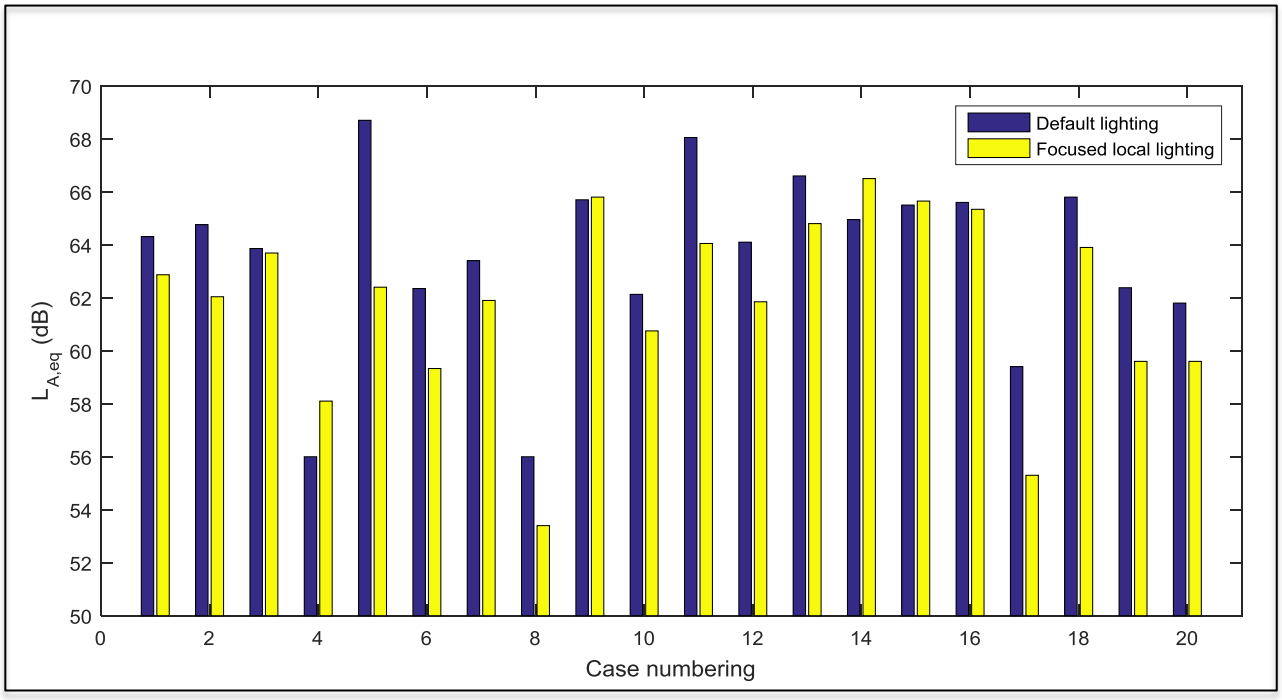

Figure 5. Comparison of measured L_{Aeq}.

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