BUILDING BETTER SCHOOLS

SIX WAYS TO HELP OUR CHILDREN LEARN

VELUX®
Modular Skylights

More than

64M

European school children and

4.5M

teachers spend around

200

days in school per year

Children spend around

70%

of their time indoors corresponding to almost

1

year indoor throughout primary school years

... and many studies show that a well-designed indoor school environment will promote improved knowledge and learning, as well as children's health and well-being.

INTRODUCTION

Have you ever thought about how 64 million European children spend more time at school than anywhere else other than their own home? In total, they attend approximately 200 school days each year, which corresponds to almost one full year inside a classroom throughout their primary school years[1]. So how do we go about designing those classrooms to be healthier and more supportive of great learning outcomes?

This is a question that is perhaps more important than ever, as Europe and the UK are soon to see a boom in the construction and renovation of schools not experienced since the 1970s. What a tremendous opportunity this is for both architects and educators to rethink what an educational facility should be and how the physical environment can be designed to have a positive impact on learning.

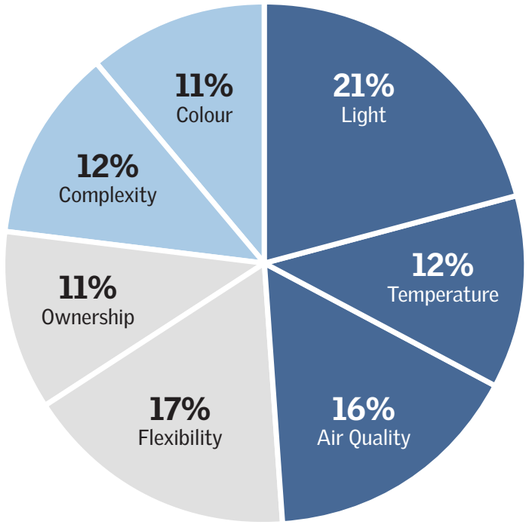
1 SINPHONIE final report LINK

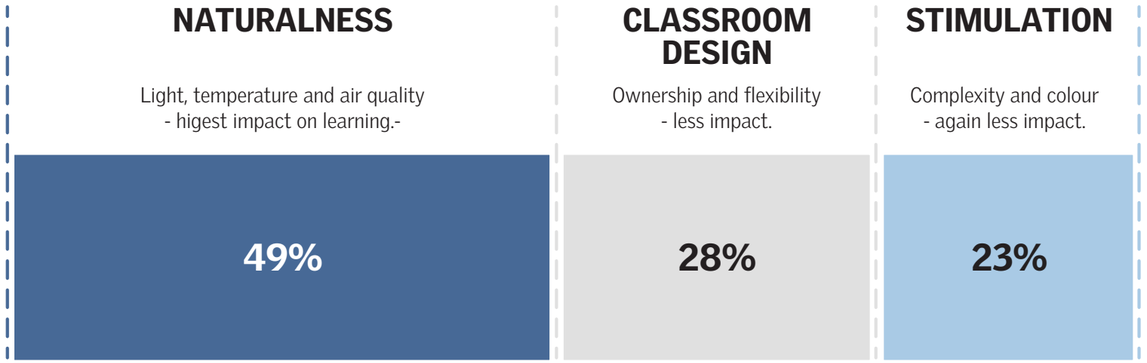
This guide, and the HEAD study on which it is largely based, assesses three primary physical characteristics of school design which have been found to be particularly influential to learning:

- Naturalness: Light, temperature and air quality. These elements together account for half the learning impact of a school design
- Classroom design*: Ownership and flexibility, accounting for a quarter of the learning impact
- Stimulation: Complexity and colour, also accounting for a quarter of the learning impact

*In the HEAD Study, Classroom design is referred to as "individualisation".

Additionally, we look at acoustics, which the HEAD study acknowledges as a "secondary factor" to naturalness. This means that it is evidently an important factor in learning, but that it "was competed out in importance by other factors".





Note: "Classroom design" is "Individualisation".

New research

Recent research conducted by Professor Peter Barrett and his team of school design experts at the University of Salford, UK, showed clear evidence that well-designed primary schools can substantially boost children's academic performance in reading, writing and maths.

Their ground-breaking study, the HEAD Project (Holistic Evidence and Design)[1], concluded that differences in the physical characteristics of classrooms explained 16% of the variation in learning progress over a year for the 3766 students included in the study. Put simply, the better designed the classroom, the better children do academically.

The vital design elements

The findings outlined in the HEAD study reveal that certain design elements are intrinsic to improving learning in the classroom. These are:

- Daylight
- Indoor air quality
- Acoustic environment
- Temperature
- Classroom design
- Stimulation

This is the first time that clear evidence of the effect on users of the overall design of the physical learning space has been isolated in real life situations. In the past, specific aspects such as air quality have been studied, but how it all comes together for real people in real spaces has, until now, been based on gut-feeling and wishful thinking.

For three years, researchers on the HEAD project carried out detailed surveys of 153 classrooms from 27 diverse schools and collected performance statistics for pupils studying in those spaces.

The importance of sensory factors

The study considered a wide range of sensory factors and used multilevel statistical modelling to isolate the effects of classroom design from other factors, such as the pupils themselves and their teachers.

As noted by researchers in the report, "Surprisingly, whole-school factors (e.g. size, navigation routes, specialist facilities, play facilities) do not seem to be anywhere near as important as the design of the individual classrooms. The message is that, first and foremost, each classroom has to be well designed."

Below you will find practical guidelines on how to implement the HEAD findings in your next educational facility project.

Whilst reading these guidelines, why not consider how these design principles (for optimal learning outcomes) could also be applied to other types of buildings - creating better healthcare facilities, better work spaces and better living places etc.

2 Clever Classrooms – Summary Report of the HEAD Project LINK

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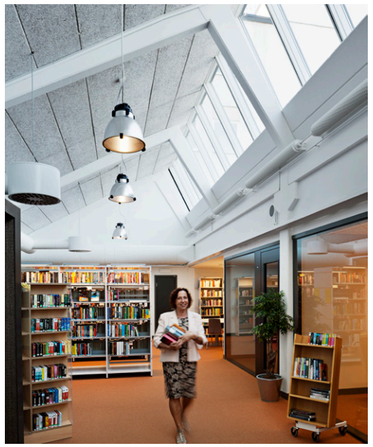
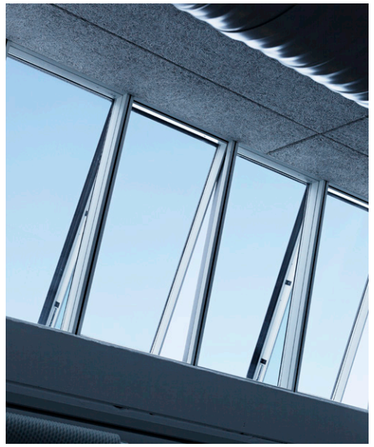
DAYLIGHT

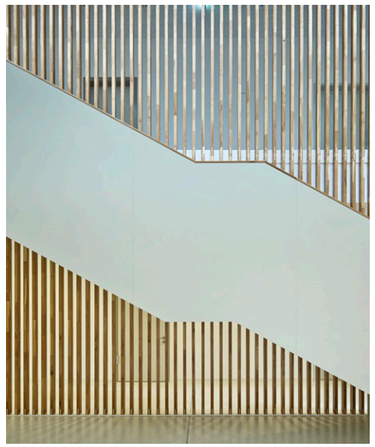


CASE: SÅGBÄCKSGYMNASIET

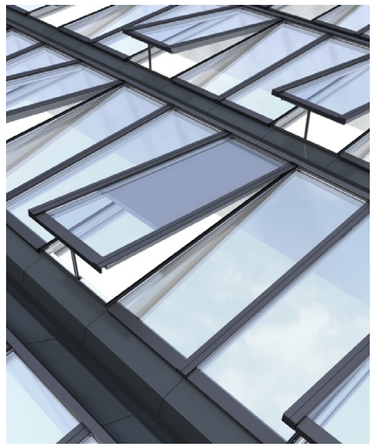


INDOOR AIR QUALITY

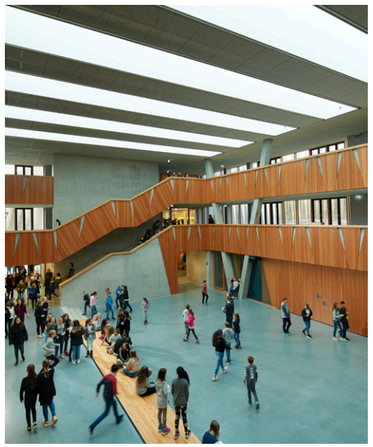
CASE: RYPARKEN LILLE SKOLE



ACOUSTIC ENVIRONMENT



TEMPERATURE



CASE: HESSENWALDSCHULE

CLASSROOM DESIGN

STIMULATION

1 DAYLIGHT

We all know that the best antidote to the 'winter blues' is a break in a warmer, sunnier climate, preferably with white sandy beaches and clear blue waters.

The reinvigorating effect of natural light and warmth can also be felt on a smaller scale, and in a wide range of environments, from homes and offices, to public buildings, schools and universities. It is perhaps no surprise then, that when a recent study [1] looked at how the physical design of educational buildings affects student performance, one of the significant individual parameters was lighting.

1 Impact of Lighting on School Performance in European Classrooms (2016) C. Maesano and I. Annesi-Maesano, CLIMA 2016, 12th REHVA World Congress 2016, Aalborg LINK

DAYLIGHT IN SCHOOLS

MORE DAYLIGHT IMPROVES LEARNING

Students with the most daylight in their classrooms progressed:

20%
faster on math tests

26%
faster on reading tests

Students that had a well-designed skylight in their room improved:

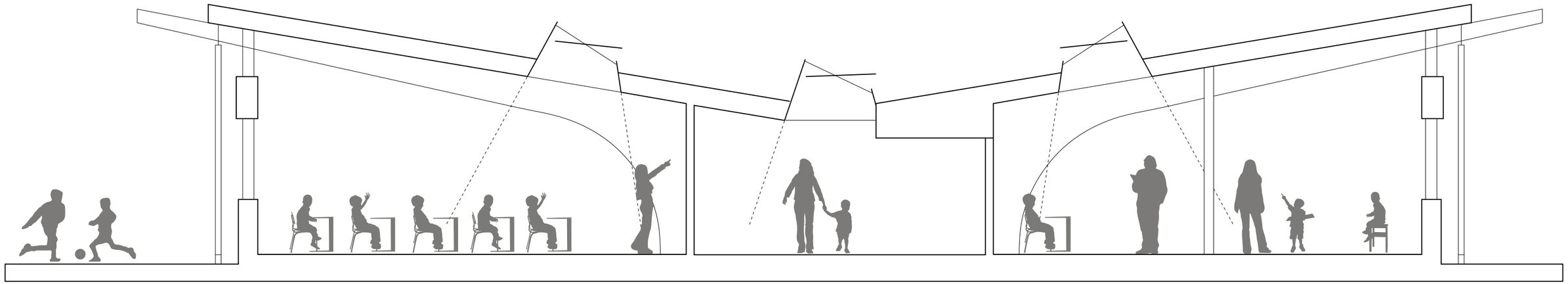
19–20%
faster than those without a skylight

Students in classrooms where windows could be opened were found to progress:

7–8%
faster than those with fixed windows

1999 by George Loisos for The California Board for Energy Efficiency Program. Submitted by HESCHONG MAHONE GROUP

Test score results for over 21,000 students in 2000 classrooms from districts, located in Orange County, California, Seattle, Washington, and Fort Collins, Colorado



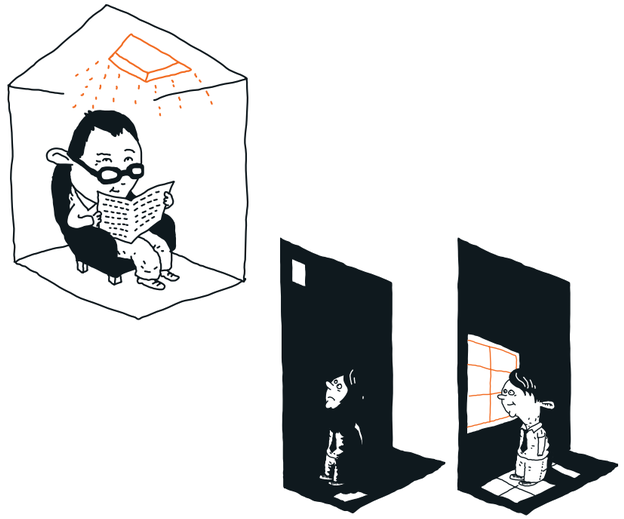
4 ways to improve the daylight condition in classrooms

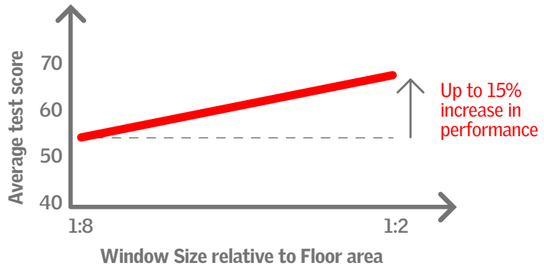
1. Ensure that daylight is the superior light source for most of the daylit hours during the year, when designing schools and classrooms

2. Select solar shading systems that can ensure a high level of daylight quality and maintain view to the outside.

3. Concentrate on the schools most utilized spaces – invest in daylight solutions where the students are – and allow slightly darker areas within the room, if needed.

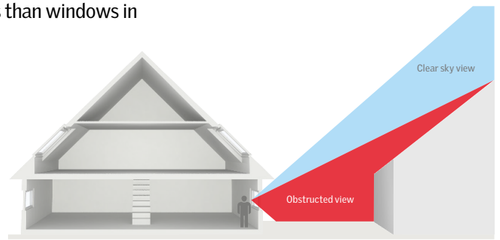
4. Integrate successful architectural daylight solutions in the overall school design, that combines the advantages of windows both in the façade and in the roof.

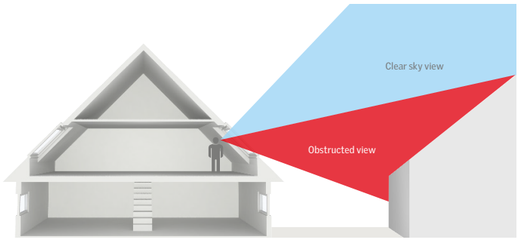




More daylight improves learning
Pupils working in classrooms with larger windows performed up to 15% better in both mathematical and logic tests, compared to classrooms with small windows.

Roof windows and skylights are generally less affected by outside obstructions than windows in the façade.





Why daylight?

Several studies have shown that daylight is not only good for children's overall health and wellbeing, but that it can also significantly improve academic performance.

One such study [1] was conducted by the Sorbonne University using SINPHONIE Study data, covering 13 European countries with a total of 2,387 children participating. It concluded that academic performance can increase by up to 15% when students work in classrooms with larger windows – due both to increased daylight, and a better view to the outside world.

The Clever Classrooms study [2] conducted by the University of Salford, UK, concluded that good daylight helps to create a sense of physical and mental comfort, its benefits more far-reaching than merely an aid to sight.

How to design with daylight

While daylight does occasionally need to be supplemented by ample, high quality artificial lighting when outside light levels are too low, where possible we should aim to make daylight the main source of lighting in schools. If it is properly controlled, sunlight is generally welcomed as a source of lighting in buildings throughout Europe.

When windows or skylights face North, the daylight entering a space tends to be softer and more diffused, with subtle changes in light levels and colour texture throughout the day. With other orientations, sunlight enhances the overall brightness of interiors, with specific areas of concentrated light.

The challenge of designing with daylight is particularly evident in deep classrooms, where there is a considerable distance between windows and the back of the room. Here there is often a disparity in light levels – bright near the windows and darker further back. In situations where the shape or size of classrooms does not allow for adequate light levels throughout, and/or where the possibility of window space is limited, skylights are often the optimum solution. Where there is no direct access to the sky due to constructed floors above, light shafts can be an effective alternative.

One of the collateral benefits of creating openings for daylight is that they also provide us a connection to the outdoors, allowing us to follow changes in the weather, the time of the day and year.

There are many factors to take into account when considering how much daylight will be gained from windows or skylights. These include glazing transmittance, wall thickness, external obstructions, extensions above (e.g. overhangs, balconies) and to the sides (e.g. extension of the building itself), depth of the room, etc. When taking all these factors into account, a skylight typically provides more than twice the amount of daylight than a facade window of equal size.

Controlling excessive glare

Glare is created when areas that are too bright are located within the field of view, or when the contrast ratio is high. Nevertheless, glare caused by daylight differs from glare caused by electric light sources in terms of the size, complex luminance distribution and acceptance of the users (e.g. people tend to be more tolerant of glare in a daylit environment) [4v]. While high levels of daylight in a classroom provided via large windows and skylights are optimum, they still need to be controlled to avoid the excessive glare that can come from direct sunlight. This issue becomes increasingly acute with today's widespread use of interactive whiteboards and projectors in classrooms.

One important aspect to consider when controlling glare and contrast is the orientation of the windows. Larger expanses of glazing should ideally be facing north, in order to allow diffused daylight to penetrate as much as possible throughout the day/year.

1 Impact of Lighting on School Performance in European Classrooms (2016) C. Maesano and I. Annesi-Maesano, CLIMA 2016, 12th REHVA World Congress 2016, Aalborg LINK
2 Clever Classrooms (2015), Summary report of the HEAD project, University of Salford, Manchester LINK

Building standards and light levels

Daylight performance in an interior space depends largely on the availability and properties of daylight at the building's location (i.e. the prevailing climatic conditions). The proposed European Daylight Standard (FprEN 17037) suggests changing the basis of daylight evaluations to 'daylight factor targets' based on the occurrence of outdoor illuminance levels from recorded climatic data. The 'climate connectivity' of the proposal states that a space should achieve a target daylight level at work-plane height across a specified percentage of the relevant floor area for half of the daylight hours in the year. The target daylight level is based on the provision of an interior illuminance higher or equal to 300 lux, corresponding to the requirement for lighting at work places (see below). The target daylight level needs to be achieved for 50% of the relevant floor area in a space with windows in the façade or in an inclined roof. In addition, a minimum target daylight level based on the provision of an interior illuminance higher or equal to 100 lux is required over 95% of the work plane. In a space lit only by roof windows in a nearly horizontal roof construction, the target daylight level need to be achieved across 95% of the relevant floor area. The corresponding target daylight factors for each European capital, is available in the standard, but values are higher for countries located in Northern Europe compared to Southern Europe due to the natural decrease in daylight availability.

The absolute light levels that are needed for a particular visual task will depend on the character of the task and the visual environment where it is performed. A European Standard, EN 12464-1: Light and lighting — Lighting of work places — Part 1: Indoor work places, provides information on the indoor light levels applicable for a school environment. Generally, the following interior light levels are recommended:

Lux level	Visual task level	Building spaces
100	Limited to movement and casual perception	Circulation areas, corridors
300	Fairly simple	Classrooms (minimum lux level for all areas of a classroom), tutorial rooms, computer practice rooms
500	Moderately difficult	Auditoriums, lecture halls, practical rooms and laboratories, libraries (reading areas), blackboard/whiteboard in classrooms
750-1000	Very difficult	

Another effective solution for glare control is the installation of easily operable opaque blinds to control daylight levels. An alternative to blinds is permanent external shading, but this may still require the use of additional shading devices, depending on individual circumstances and requirements. Other solar protection devices such as curtains, roller blinds etc., made in textile, film or perforated opaque materials can be used. These will all reduce the occurrence of glare to differing degrees, depending on: optical properties of the material; orientation of the window; geographical location and annual sunshine hours; glazing area and transmittance of the pane and the distance of the user from the light source. The material properties and levels of glare protection for these type of solar protection devices are defined in European Standard EN 14501 Blinds and shutters, and the draft European Standard FprEN 17037 Daylight in Buildings.

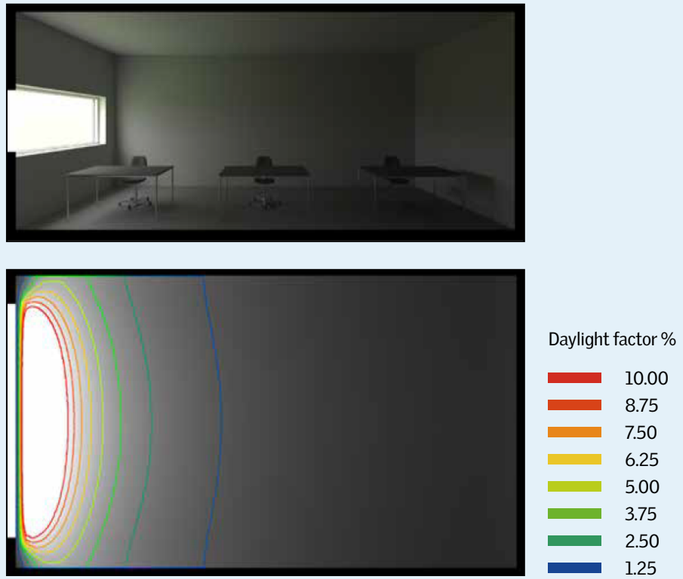
Equally important is the issue of contrast. When considering both glare and contrast, the difference between absolute brightness and relative brightness is critical. Consider how high-beam headlights can be blinding at night, while hardly noticeable during the day. Similarly, a strong source of light will cause much less glare and contrast in a generally brightly-lit room compared to, say, a single large window with direct sunlight in an otherwise dimly-lit room. The recommendation between visual task and near surroundings is a 1:10 "luminance ratio" within the field of view. This luminance ratio is an expression of the ratio between the luminance within the central vision and the peripheral vision of the surroundings [3].

Windows vs. skylights

Good daylight distribution across a room is often best achieved by using several different sources of daylight, such as a combination of skylights and windows, and this can also ensure reduced levels of glare and contrast. However, let's not forget the importance of a view: "When we are sitting next to a window, we would rather tolerate a high amount of daylight and enjoy the view outside than draw the blinds down and use artificial lighting."[4]

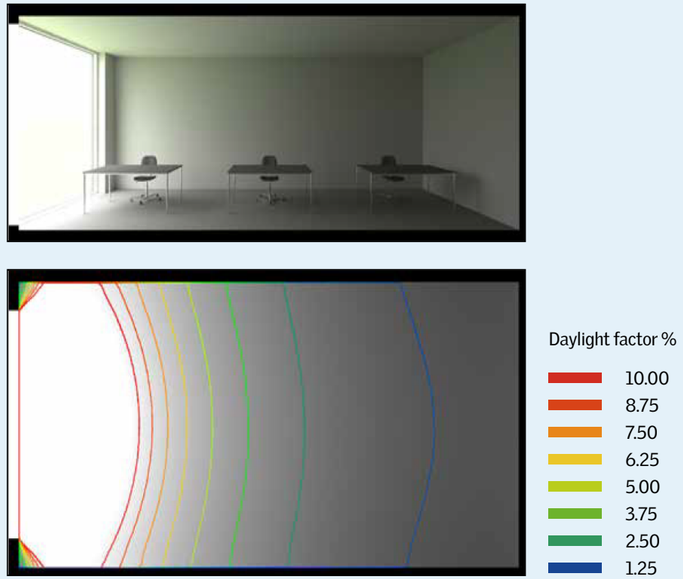
For spaces where even large areas of window glazing will not allow enough daylight to penetrate, or where their installation is simply not possible – such as very large classrooms, lecture theatres or indoor common areas in the centre of a building – skylights are a great option to consider. Operable skylights strategically located in the overall building design allow plenty of daylight to penetrate in the dark winter months, while also providing fresh air throughout the year, improving indoor air quality and helping regulate temperature.

3 CLEAR Luminance Ratios, LINK
4 "Design Innovations for Contemporary Interiors and Civic Art", Luciano Crespi, 2016



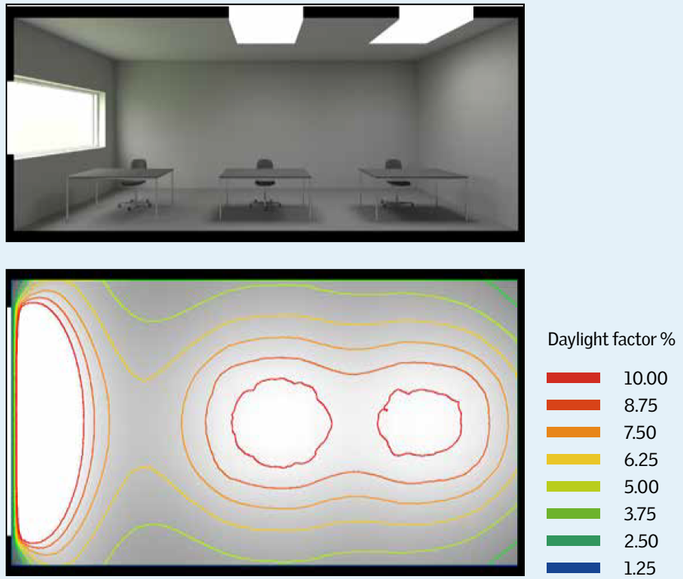
Small facade window
(10% glazing to floor area ratio)

- a DF of 2%, only a few metres from the facade
- low daylight levels at the back of the room
- only workplaces close to window can be considered daylit.



Large facade window
(30% glazing to floor area ratio)

- a DF of 2% approximately 4.5 metres from the facade
- daylight levels very high near window and low values at the back
- the first two workplaces can be considered daylit.



Small facade window + roof windows
20% glazing to floor area ratio (11% facade window + 9% roof windows)

- a combination of facade and roof windows provides generous and useful DF levels over the entire work plane
- use of roof windows means better daylighting performance and visual comfort
- all of the three workplaces can be considered well daylit.

CASE 1

SÅGBÄCKS-GYMNASIET

Rebuilding a school's character with plenty of daylight

In 2012 local authorities ended more than 10 years of talks by adopting a plan to refurbish the old vocational school in Huddinge, Sweden. The school, originally built in 1961, represented classic 60s architecture and was of good quality. Still, fifty years of wear had left its mark, and when the refurbishment plans were agreed upon they included the replacement of more than a 100 old skylights.


The full length of the installation is visible from the assembly area even across the classroom dividers. Daylight is directed into the classrooms from above.

An iconic industrial style perfect for skylights

One of the defining characteristics of Sågbäcksgymnasiet is its sawtooth roof. The classic feature of the industrial age quickly became a focal point for the project leaders at Origo Arkitekter, the leading architect firm. Åsa Machado explains: "The sawtooth ceiling and the possibility of skylights were central to our plans; we realised this very early on. We decided to give the entire school access to what we believe was the premises' best side."

The sawtooth roof allows four bands of north-faced skylights to illuminate the interior. While the old skylights had frosted glass with dimming effect and extremely poor energy performance, the new ones will be able to support and nourish the new assembly area with plenty of daylight, ventilation and energy control.

🟦 **Library**

🟦 **Café and lounge area**

🟦 **Classrooms**

☐ **Northlight 100 modules**

SEKTION C-C
HUS A OCH C

Leading a vocational school, you need to invest in your students

Principal Hans Almgren describes the school as "a solid building in classic modernist style", and he is glad the refurbishment plan was able to maintain the look and feel of the original architecture: "They have managed to preserve something that is part of the school's soul - the 60s quality", he says.

The principal is especially pleased with the way the new central area with its dominating sawtooth ceiling performs, reinventing the original aesthetics of the building and taking full advantage of the ceiling's potential.

"The skylight was key to the positive change. The architects always strived to open the building up, let in light and create visual depth. We have no dead corners, and no dark corners."

Hans Almgren is well aware of the importance of creating a learning environment that is both inspiring and dignifying. A vocational school is always at risk of being regarded as a second-rate choice, he admits, and that is why the setting is so important.

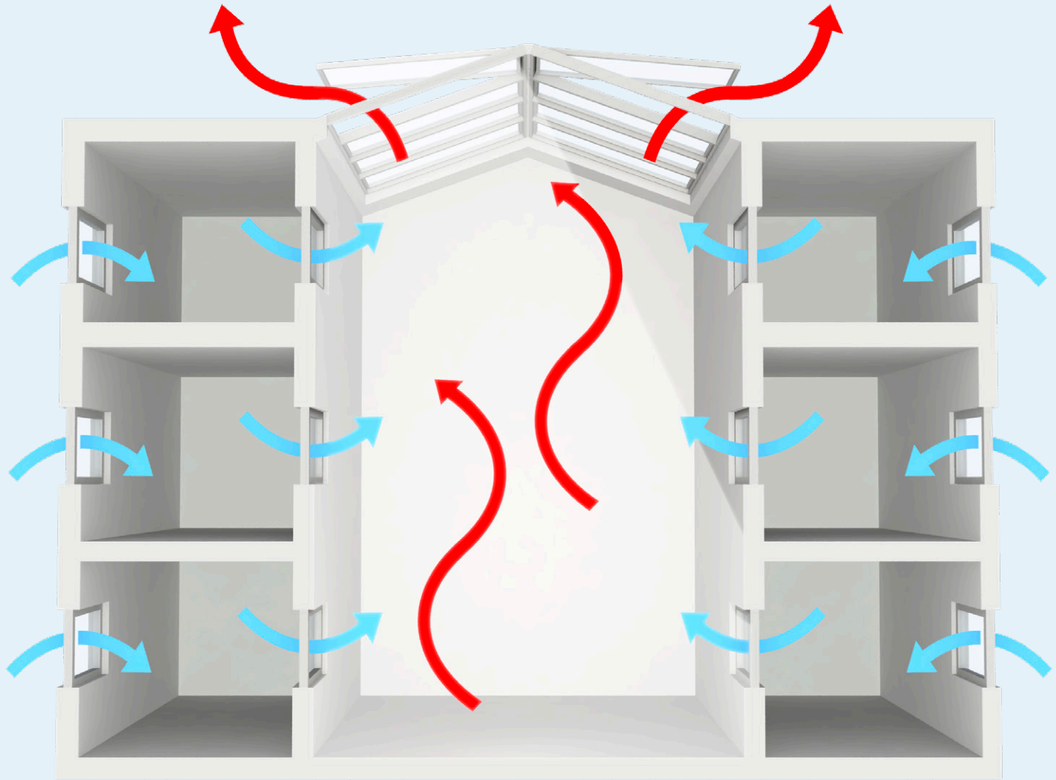
"It is probably true that vocational training is not highly regarded, but we want to be the best in our sector. Our students are important and we want them to enjoy a nice and agreeable environment. This affects their confidence and their willingness to study."

Activity increases in a bright and spacious environment

Inside the building, the change is significant. While the old brown wire glass of the previous skylights left the interior murky at best, the new flow of daylight has transformed the environment entirely, triggering a notable rise in student activity.

Ventilation

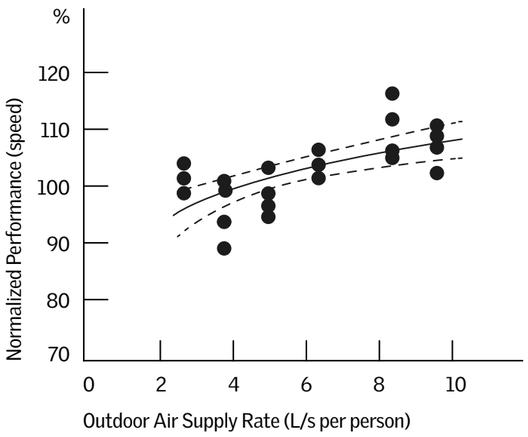
Ventilation in schools can be provided mechanically using fans and/or by natural airflows through open windows and doors.



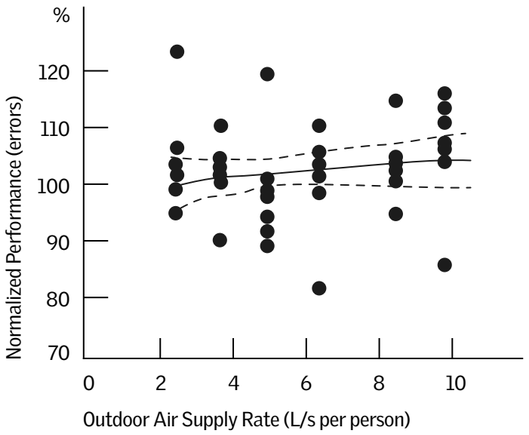
2 INDOOR AIR QUALITY

Poor indoor air quality can not only seriously inhibit students' concentration and overall performance, but can also lead to increased absenteeism due to illness. Adequate ventilation is therefore imperative for healthy classroom design to help students flourish.

Speed



Accuracy



Student performance versus ventilation rate based on a study in Denmark. Performance was based on the speed (left figure) and accuracy (right figure) of completing various school work tasks. The various data points represent results from multiple experiments and multiple types of work tasks.

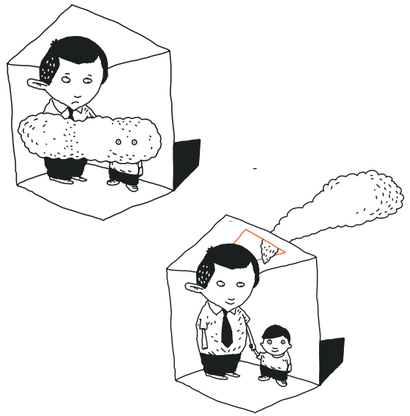
4 ways to improve the indoor air quality in classrooms

1. Open the windows and air out during the lessons. Most schools in Europe have been designed for natural ventilation.

2. Innovative natural ventilation solutions, e.g. demand controlled natural ventilation, can maintain the CO2 level within the recommended range.

3. Mechanical ventilation systems can ensure an optimum level of air quality without compromising thermal comfort in colder months.

4. Hybrid solutions can combine the advantages of both natural and mechanical ventilation.



1 Why Indoor Air Quality is Important to Schools (EPA) LINK
2 Bako-Biro et al: Evaluation of indoor environmental quality conditions in elementary schools classrooms in the United Arab Emirates, 2012
3 Clever Classrooms, Summary report of the HEAD project, University of Salford, Manchester (2015)
4 CEN (2007) EN 15251: Indoor environmental input parameters for design and assessment of energy performance of buildings.

Poor indoor air quality in classrooms doesn't just impact students' ability to concentrate, it can also harm their overall health and wellbeing.

According to the US Environmental Protection Agency (EPA), almost one in 13 children of school age in the US suffers from asthma, the leading cause of school absenteeism due to chronic illness [1].

It's also thought that the developing bodies of children are more susceptible to harmful environmental exposures than those of adults. Children breathe more air, eat more food and drink more liquid in proportion to their body weight than adults do. This alone makes the air quality in schools a matter of concern.

Alarmingly, studies of human exposure to air pollutants, also carried out by the EPA, indicate that indoor levels of pollutants may be two to five times – and on occasion even up to 100 times – higher than outdoor levels.

Inadequate ventilation leads to increased pollution levels, a particular problem in classrooms where children have a lower volume of air per child due to high occupancy density. A significant body of research provides compelling evidence of an association between improved student performance and increased classroom ventilation rates. Typical reported improvements in performance with increased ventilation rates range from a few percent up to as high as 15% [2].

In a recent study, an intervention was made to improve ventilation rates in 16 classrooms. The results of computerised tasks performed by more than 200 pupils showed significantly faster and more accurate responses for choice reaction, colour word vigilance, picture memory and word recognition in the classrooms with higher ventilation rates.

According to the findings of the Clever Classrooms study [3], requirements for good ventilation in classrooms are:

1. Controlled ventilation

Windows and skylights with large opening sizes, ideally with multiple openings, allow users to ventilate classrooms effectively in different circumstances. Top-opening windows and skylights, located high in the room but with mechanisms which are easy to access and operate, allow the hottest and stalest air to escape more efficiently. Roller blinds should not be fitted to these top-opening windows and skylights if they block the air-flow.

2. Room volume

The larger the classroom, the greater the dilution of levels of carbon dioxide and pollutants and the longer good air quality can be maintained. In an average size classroom with a volume of 181 cubic metres, 30 pupils and no ventilation, the air quality becomes poor in just 30 minutes.

3. Mechanical ventilation

Where natural ventilation is inadequate or problematic, it can be improved with the introduction of mechanical ventilation.

4. CO_2 sensors

Installing CO_2 svensors in classrooms allows teachers to monitor the indoor air quality and adjust the level of ventilation accordingly. CO_2 concentration is often used as an indicator of indoor air quality. Outdoor air contains a CO_2 concentration of approximately 400 ppm. An indoor CO_2 level of 1150 ppm provides adequate air quality, 1400 ppm will ensure good indoor air quality in most situations, and 1600 ppm indicates poor air quality (CEN, 2007) [4].

There's no doubt that creating a good indoor climate should be a key focus of all school modernisation projects and new school builds. This will provide better overall facilities for students to learn and thrive in and for educators to work effectively. Good ventilation is crucial, as it is the only way to maintain good indoor air quality and pollutants at acceptable levels.

CASE 2

RYPARKEN LILLE SKOLE

From textile factory to teaching facility

Ryparken Lille Skole (literally "Ryparken little school") is situated in a century-old former textile factory in Copenhagen. For years the school and its inhabitants suffered the building's decrepit conditions, until in the early 2010s, the school board decided to start a major renovation project. It would include replacement of the old single-pane skylights, with 85 fixed and 12 vented triple-pane VELUX Modular Skylights

"Our wonderful school needed a loving hand, not only to ensure the longevity of the building itself, but also to make sure that the school is a pleasant place for children and employees alike."

Mette Lisbjerg Jensen, headmaster

Making the most of the circumstances

The old textile factory-turned-school was showing considerable signs of age. The roof was leaking and energy consumption from heating the building had quite literally gone through the roof. Demolition was never an option as it would be too expensive, and in any case, these iconic buildings are listed for preservation. So instead, the school decided on a renovation project to modernize the building while improving the school's indoor climate with more daylight, fresher air and better temperature control.

It didn't take long for the architects to look towards the sky in achieving the school's vision, as the iconic sawtooth roof with its dark-painted northlight glass was a perfect opportunity for striking multiple birds with one stone.

Comfortable temperatures and CO_2 levels throughout the year

In a seasonal climate like Denmark's, securing a comfortable indoor climate can be tricky. Not enough windows and other venting options means temperatures can spike in the summer, while a lack of ventilation can mean elevated CO_2 levels and poor indoor air quality all year round. Too many windows, on the other hand, and the building's users may freeze in the cold winter months. That is, of course, unless the windows are properly insulated. This is one of the challenges for architects working in seasonal climates: how to ensure good indoor climate while providing adequate daylight throughout the year?

Obviously, a key component is to have proper, thermally insulated windows and skylights with double glazing as a minimum. By modern standards, the single-pane glass of the existing windows in Ryparken Lille Skole was a veritable thermal bridge, allowing heat to hemorrhage through the roof. With the highly effective thermal properties of their new triple-paned VELUX Modular Skylights, however, letting in plenty of daylight in winter no longer means plummeting temperatures and sky-high heating bills.

Fresh air through the roof

Insulation is only part of the story. In order to help maintain good CO_2 levels and pleasant summer temperatures you also need access to fresh air – particularly in a building like Ryparken Lille Skole, where facade windows are limited. To ensure effective ventilation of the classrooms, one key goal for the project was to create a large vented area.

VELUX Modular Skylights provide the optimal ventilation solution, with 12 venting modules installed in the project. This allows for significant levels of ventilation, while increasing the comfort, health, wellbeing and performance of pupils.

In fact, it is actually possible to specify VELUX Modular Skylights with up to 50% venting modules, and all modules look identical when closed, so design is not compromised in any way.

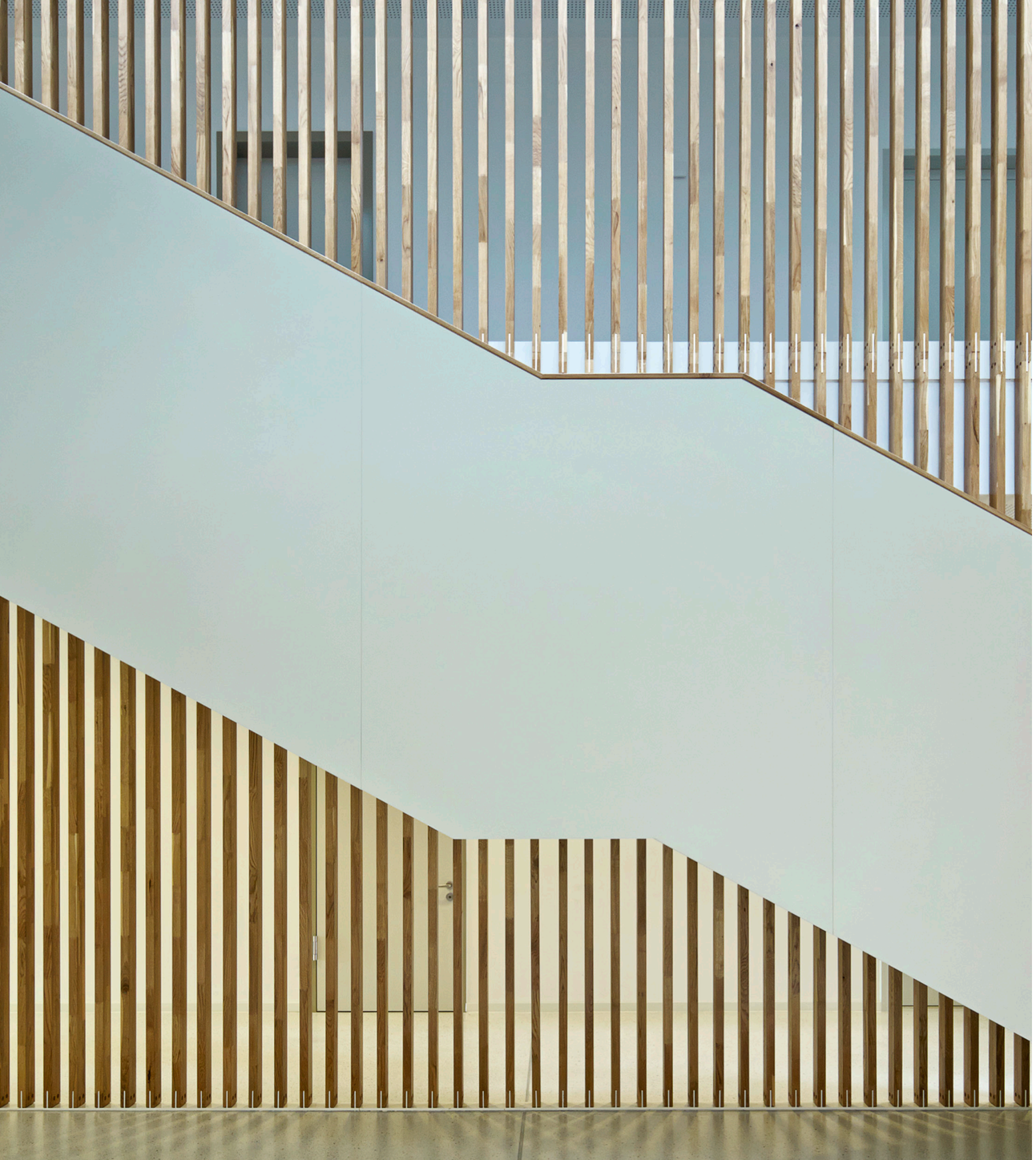
Furthermore, the vented modules can be set to work automatically. These automatic vented modules are particularly beneficial in a school like Ryparken Lille Skole, where classes and breaks run in fixed intervals. This means a ventilation schedule can be set up where the vented modules work together with CO_2 sensors, automatically opening during the breaks if fresh air is needed.

Automatic vented modules also ensure a healthier indoor climate, with less CO_2, less particles in the air and better natural cooling in the warmer summer months.

"We are extremely happy with the result. The school has become a much better work place with a better environment for everybody," says Mette Lisbjerg Jensen, headmaster of Ryparken Lille Skole.

Poor indoor air quality impacts school children's performance

Studies have shown that poor indoor air quality reduces children's academic performance, while good air quality enhances performance in the classroom.

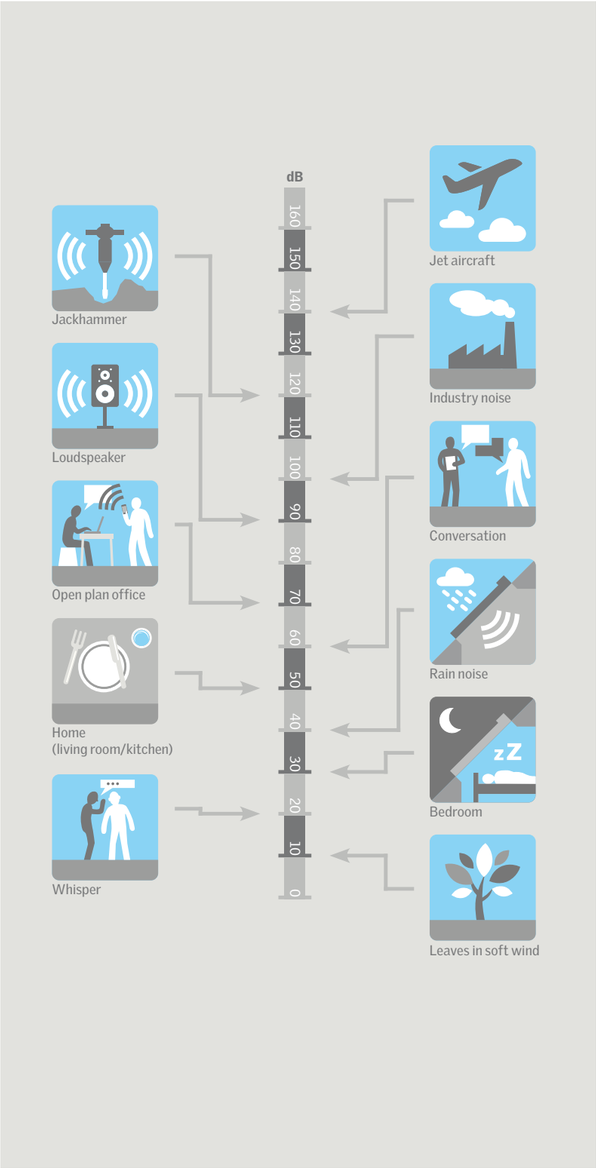


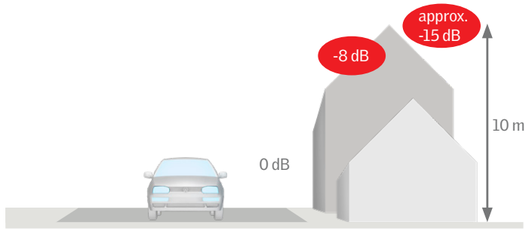
3 ACOUSTIC ENVIRONMENT

One important function of the building envelope is to protect the interior from unwanted outdoor noise. Sound insulation is an important parameter of building components, as outdoor noise can have negative effects on health, mood and learning capabilities. Our perception plays an important role in identifying whether it is sound (positive) or noise that we hear. Unwanted noise is irritating or annoying, and in severe circumstance harmful [1]. Comfortable auditory perception and freedom from intrusive background noise are vital for enabling communication in classrooms and allowing students to concentrate.

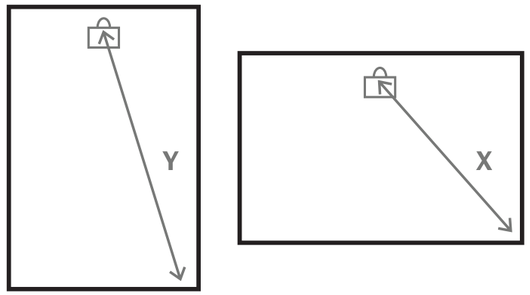
1 https://www.velux.com/deic/acoustics/noise-or-sound LINK

Typical sound levels





A comparison between a façade window and a skylight. Facing the street, the location of a skylight will show 8 dB lower noise levels than the façade window. Moving the skylight towards the back yard can reduce the noise level even more (approx. 15 dB).



If a teacher's table is placed in the middle of the long side, the distance to the corner (X) is shorter than if the table is placed in the middle of the short side (Y).

When designing classrooms, the aim should be to provide optimal conditions for the production and reception of desirable sounds (such as the teacher speaking to students, and vice versa) and the blocking of intrusive sounds (such as playground noise and traffic).

Two studies, by Crandell and Smaldino (2000)[1] and Picard and Bradley (2001)[2], summarised the findings from several previous studies and concluded that the acoustic environment of a classroom is a critical factor in the academic and psychosocial achievement of children. The Clever Classrooms report (2015)[3] also emphasises that this is especially true in the case of children with Special Educational Needs.

Some crucial factors to consider that enhance and improve the acoustic environment of classrooms include:

Controlling external noise

Classrooms situated away from busy areas of a school – such as the playground and reception areas – will be less impacted by external noise. In some cases, external noise interference can be controlled by using areas such as corridors, toilets and store rooms as buffer zones.

Ideally, schools should be sited away from busy roads. However, if the school is located on or near a busy road, traffic noise can be mitigated by placing classrooms as far away from the road as possible on the school site, facing them away from the road, and introducing slopes and embankments covered with plants as buffers. The challenge then becomes controlling noise without sacrificing too much daylight, ventilation and a view of the outside. A favoured solution to this challenge is the use of automatically controlled skylights, which open during breaks, thereby ensuring proper ventilation and temperature control without letting in traffic noise during class.

Windows with a pane construction of 2 layers with different glass thickness (e.g. 4mm and 6 mm) will achieve a better sound insulation than a window with a standard glazing unit. Panes with 3-layer glass units with different distances between glass, and glass thickness, also perform better than the standard solution. Using a different gas filling will also have an effect – krypton gives better sound insulation. And finally, laminations are another way to achieve higher sound insulation of the glazing unit.

Internal noise

In principle, sound generated inside a building can be separated into two sources of transmission – airborne sound and sound transmitted through the building itself. Airborne sound, from human activities in adjacent classrooms or from mechanical noise, travels through air, walls, floors and ceilings. Inside the classroom, unwanted noise can be reduced by using a false ceiling with acoustic tiles, tables and chairs with rubber feet, and the addition of acoustic panels if necessary. Porous materials can also be used to absorb sound, while curtains can improve the acoustics by dampening echoes and reverberation.

Room shape

Seating arrangements within the classroom should ensure that teachers can be readily heard by students, so the closer they are, the better. A rectangular room with a higher length to width ratio most easily allows for this type of seating set-up.

This is not to say that room shape alone can replace proper acoustics. As we will discuss in chapters 5 and 6, flexibility is one of several factors which are very important to classroom design.

A good acoustic environment in classrooms allows teachers to be heard clearly and reduces distraction from external noise. It also allows students to work effectively together in groups when required, while permitting the concentration necessary for solo project work, or when sitting exams.

1 Crandell and Smaldino: Classroom Acoustics for Children With Normal Hearing and With Hearing Impairment, 2000
2 Picard and Bradley: Revisiting speech interference in classrooms. 2001
3 Clever Classrooms, Summary report of the HEAD project, University of Salford, Manchester (2015)

4 TEMPERATURE

Just like the bowls of porridge in the well-known fairytale of Goldilocks and the Three Bears, the temperature in classrooms should be neither too hot, nor too cold, but just right.

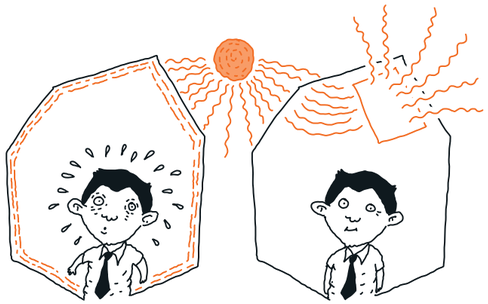
4 ways to improve the indoor temperature condition in classrooms

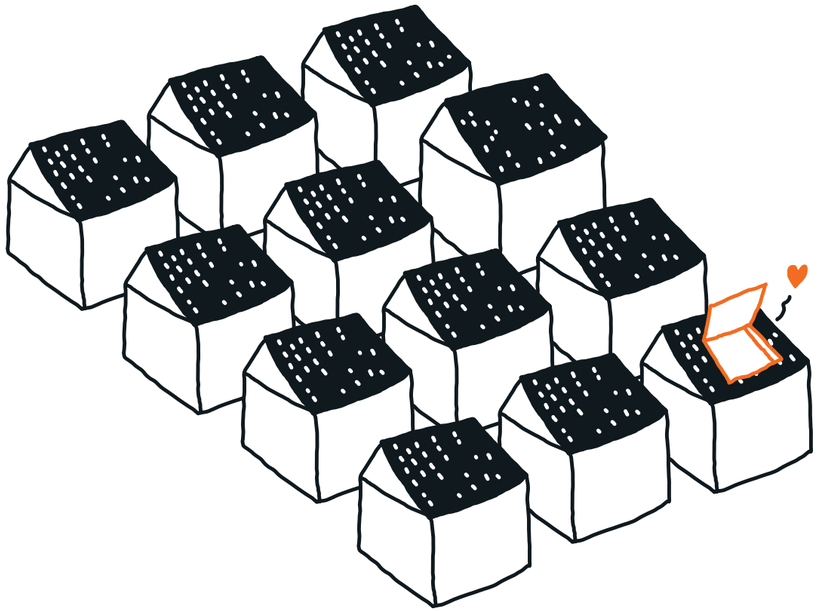
1. Use solar shading and natural ventilation in summer to prevent high indoor temperatures, that would reduce learning capabilities

2. Specify energy-efficient mechanical ventilation with systematically use of natural ventilation, to reach an energy neutral strategy for cooling.

3. Design with windows in the façade and the roof to allow good air flow across the space (e.g. cross ventilation, stack effect).

4. Integrate successful solar shading solutions in the school design by interrelating air quality, air temperature, view and daylight in an iterative approach.





An important consideration in the design of classrooms is the provision of good thermal conditions based on energy-efficient technologies such as natural ventilation, solar shading and intelligent building design (for the warmer months), and efficient, adjustable heating (for the colder months).

It is increasingly accepted that there is no such thing as a 'natural' comfort temperature. The best results with regards to cooling and heating can be achieved by providing occupants with personal and adaptive options, such as access to personally operable indows, personal control over sun shading, and possibly also desk fans and other such devices. In general terms, buildings should connect people to the outdoors as much as possible and provide shelter from it only as much as is necessary[1].

In Europe, all countries have policies for minimum indoor temperature in school classrooms set out in their legislation or standards. These minimum requirements vary from country to country, as well as by season, but range from 17°C to 20°C. Fewer European countries have standards for maximum indoor air temperature in classrooms, but for those that do, these vary from 22°C to 29°C.

For the past several decades, researchers have been studying the optimal temperature range associated with better learning outcomes. Zeiler and Boxem (2009) [2] carried out a thorough review in order to demonstrate the effects of thermal quality in schools on the learning performance of students. Mendell and Heath (2005) [3], meanwhile, reviewed evidence for the effect of indoor environmental quality on both performance and attendance, and Fisk (2017) [4] did an extensive literature review about ventilation problems in schools, its impact on student performance, health and absence. These studies found that as temperature and humidity increase, students report greater discomfort and their levels of achievement and task performance deteriorate, as a result of decreasing attention spans. High classroom temperatures have also been associated with headaches and eye, ear, nose and throat symptoms, while high humidity levels can lead to increasing incidence of mould, which can in turn cause or exacerbate a range of health problems.

Cooling solutions

Natural ventilative cooling achieved by opening windows and skylights is a fast and direct way to influence the thermal indoor environment. An open window creates increased air motion, and if the outdoor temperature is lower than the indoor temperature, then the indoor temperature will fall.

Even when the outdoor air temperature is slightly higher than indoors, the elevated air speed due to increased airflow will increase cooling of the body.

Natural ventilation for cooling can be done in two ways – day ventilation and night ventilation:

- Ventilation during the day removes excess heat from inside the building by creating high levels of movement in the air.
- Night ventilation (also referred to as night cooling) will cool down a building's thermal mass (walls, floor, furniture, etc.) at night using cool outdoor air. The following day, less cooling energy is needed within the building as the thermal mass has already been cooled.

Orientation of the classroom and shading control also play an important part in creating consistent thermal comfort. Large windows and skylights can be oriented to allow maximum sunlight to penetrate in the winter months, and shaded with moveable shading devices to block out sunlight in the summer months as needed.

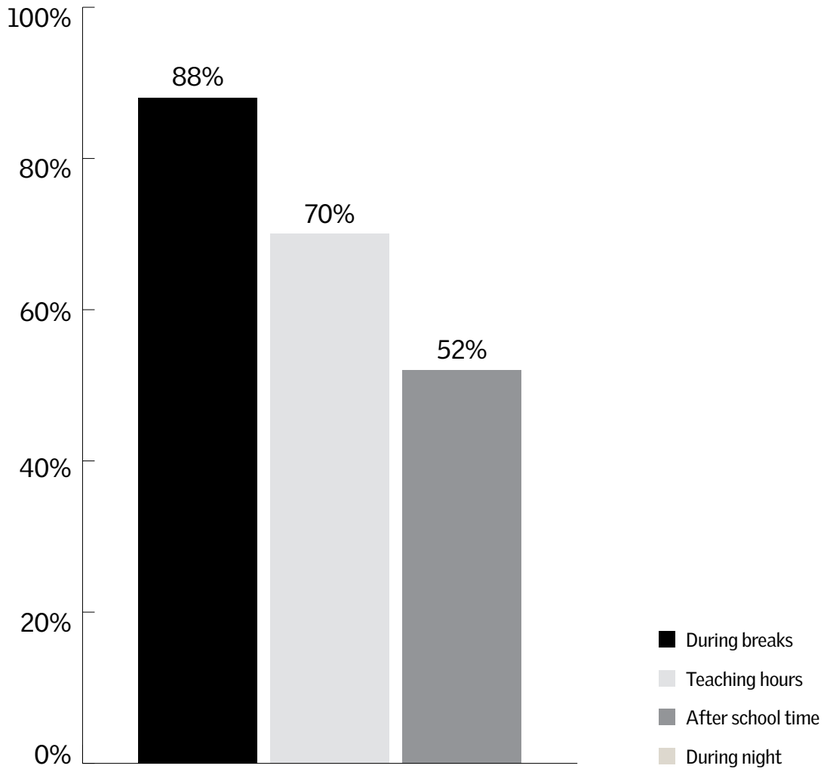
Field studies show that people in

1 https://www.velux.com/article/2016/health-matters LINK

2 Zeiler & Boxem (2009). Effects of thermal activated building systems in schools on thermal comfort in winter. Building and Environment. LINK

3 Mendell and Heath (2005). Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance? A Critical Review of the Literature. Indoor Air

4 Fisk (2017) The ventilation problem in schools: literature review. Indoor Air



This graph from the SINPHONIE study, conducted in 114 schools in 23 European countries, gives a clear indication of the times at which windows are opened during the day. No evidence of the use of night ventilation was reported. https://www.sinphonie.eu

naturally ventilated buildings accept higher temperatures [5]. This effect of the body adapting to its surroundings is referred to as adaptive thermal comfort. A prerequisite for designing with adaptive thermal comfort in mind is that people can freely adapt their clothing and operate windows. The consequence of adaptation is that thermal comfort can be achieved in warm climates without air conditioning, by using natural ventilation, solar shading and intelligent building design. In countries with the hottest summers, ceiling fans or mechanical air-conditioning units may be required in addition to natural ventilation and shading.

Heating solutions

The Clever Classrooms study (2015) [6] found that better temperature control was achieved in winter when rooms were fitted with radiators with thermostatic controls. In contrast, underfloor heating was associated with poor heating control in individual classrooms due to longer response lag times.

The study also recommended that all methods of temperature control in classrooms be easily operable and readily accessible to teachers.

5 de Dear and Brager (1998). Developing an Adaptive Model of Thermal Comfort and Preference. ASHRAE Transactions

6 Clever Classrooms (2015), Summary report of the HEAD project, University of Salford, Manchester LINK

CASE 3

HESSENWALD-SCHULE

A new teaching concept realised through modern architecture

Hessenwald School in Weiterstadt, Germany, is an example of energy-efficient, contemporary architecture that offers a new teaching and pedagogical concept. At the core of both concept and building stands a well-lit and well-ventilated three-storey atrium.

"The best thing that you can do to make people feel healthy is to use materials and lots of light to create good spaces."

Alexander Vohl,
partner at wulf architekten

Modern architecture in rural surroundings

Everybody in the area is talking about Hessenwald School. The professionals, the local community, the pupils, the users and the teachers are all excited about the new school complex. The school has 700 pupils from surrounding towns and villages, but despite its size, Stuttgart-based architectural firm wulf architekten has succeeded in integrating the building into its surroundings by means of a cluster-like pavilion design, whilst at the same time translating the open pedagogical concept into a clear and contemporary architectural language. At the centre is a well-lit and well-ventilated atrium that ties the whole complex together.

The three-storey atrium links the assembly hall, break room, theatre and music room. Six longlight constructions with VELUX Modular Skylights provide optimal daylight conditions. The diffuse, cool brightness that enters the building through the longlights contrasts with the play of light from perforated sunscreens on the façade, thereby creating a balanced atmosphere.

This open architectural design supports an open approach to learning, with a variety of shared spaces that pupils can use independently.

Skylights as the centerpiece

Hessenwald School brings together different levels of schooling, from high, through mid, to lower secondary levels, allowing pupils to switch levels depending on their performance.

The whole school is designed to facilitate an open approach to learning; the centre and focal point for this approach is the atrium. The atrium's cuboid structure is clearly visible from the outside as an independent body, while inside it cuts through three storeys, connecting different learning spaces.

At the top of the atrium are six longlight constructions with VELUX Modular Skylights. They allow diffuse light to penetrate from the outside, creating a balanced atmosphere. The skylights are set back in light wells cut into the expanded metal ceiling, making them look almost like light fittings. However, the bright, natural daylight they provide turns them into a unique feature that gives the atrium its stunning appearance.

Sustainability at the heart of the complex

The VELUX Modular Skylights also support the building's energy concept. In winter, the large glazed areas in the roof contribute energy by warming the air inside the atrium, thus also helping to heat the different pavillions. In summer on the other hand, warm air can escape through venting modules in the longlights to keep temperatures down. The school was designed according to the guidelines for sustainable building in the district of Damburg-Dieburg, and in accordance with the Passive House standard. The solid construction's clear-cut, low cubatures and good storage properties, ensure low maintenance costs through passive measures, while robust construction materials will mean minimal maintenance over time. The heating is provided by a biomass system in a separate building. Overheating in the summer is prevented largely by the use of thermal mass in the exposed concrete ceilings, and by automated night-time cooling through the panels on the facade and VELUX Modular Skylights venting units in the atrium.

This results in what the head of the school, Markus Bürger, describes as an "ideal indoor climate".

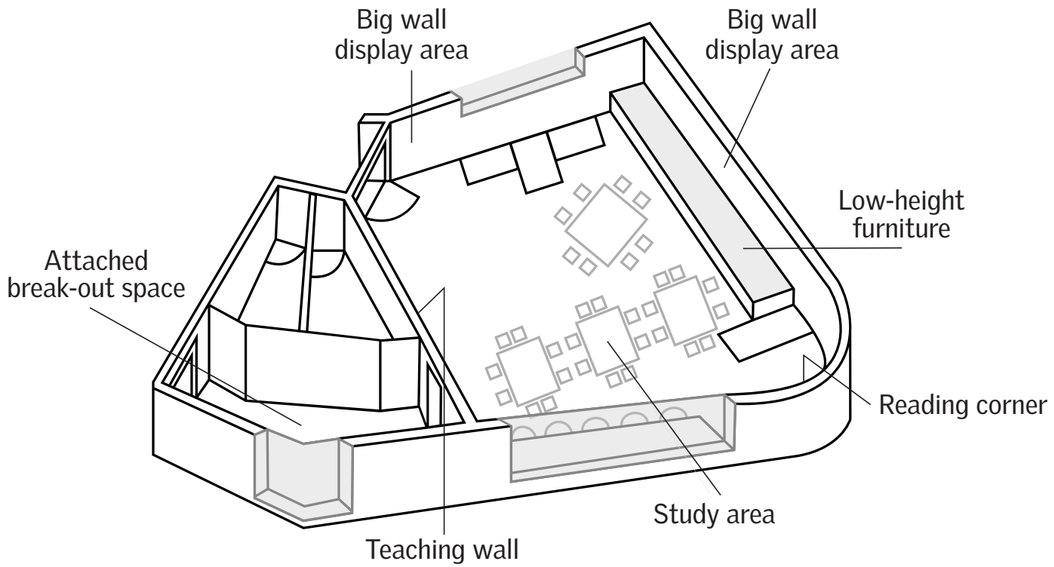
"A climate in which one feels comfortable, shaped by the great architecture, the lighting conditions and the pleasant temperature. For the teachers and pupils to work well together the base - that is, the space - has to be right. What we're talking about here is not just an indoor climate, but a learning climate," says Markus Bürger.

Showered with awards

In 2017 the school received a host of architectural awards, demonstrating that with the Hessenwald School, wulf architekten have succeeded in answering the challenges of new, progressive approaches to teaching and learning with a modern architectural design.

5 CLASSROOM DESIGN

Well-designed classrooms can improve students' learning progress by around 16% in a single year. Ownership and flexibility account for a quarter of this learning impact, so let's take a look at these important factors in terms of classroom design.



This is an illustration of a classroom with several good features of flexibility, inspired by the Clever Classrooms report: It has defined learning zones, an attached breakout space, an optimum shape with a teaching area relatively close to the furthest students as well as big wall areas for varied display options

When children feel ownership of their classroom they feel more responsibility, and this has many positive implications for both the children's learning abilities and the formation of their identities. Classrooms can also support individualisation by offering a variety of opportunities for different modes of learning, meaning flexibility of layout is also key.

Fostering ownership

Physiological and psychological research indicates that personalisation of space is an important factor in the formation of an individual's identity and sense of self-worth. Several studies have found that intimate and personalised spaces are better for absorbing, memorising and recalling information[1]. When children feel ownership of their classroom, it appears to set the stage for cultivating feelings of responsibility[2].

Classrooms that demonstrate the results of students' intellectual engagement – such as projects, displays and models – have also been found to promote greater participation and involvement in the learning process[3].

In the Clever Classrooms study, a range of factors were found to be important in two categories: aspects that helped students identify with "their" classroom; and aspects that are child-sensitive.

Recommendations from the report findings include:

- A classroom should have a distinctive room design or characteristics that make it feel instantly familiar to children.
- It should include plenty of opportunity for pupils' work to be displayed on walls and on dedicated display tables.
- It should include elements personalised for pupils such as named coat pegs, lockers and/or drawers.
- Well-designed furniture should be used to create a learning space that is child-centred. Desks and chairs should be comfortable, interesting and ergonomic according to children's age and size.

Creating flexibility

All classrooms require some degree of flexibility to cater for different modes of learning. Recommendations from the Clever Classrooms study include:

- Classrooms with clearly defined breakout zones or breakout rooms were found to impact positively on learning by providing for one-to-one and small group support in a more private atmosphere. Breakout zones separate from the classroom, however, do not appear to be effective.
- Rooms with varied floor plans provide greater potential for creating different activity areas for younger pupils. For older pupils, squarer and larger rooms work more effectively in facilitating learning opportunities.
- Adequate and accessible storage is important, although too many cupboards can take up useful learning space. A good solution is to place storage such as cupboards and coat pegs within extra-width corridors, as long as circulation is not impeded.
- Large, accessible wall areas provide flexible opportunities for the display of information and students' work.
- Younger children, who spend a lot of time engaged in play-based learning, benefit from a larger number of different learning zones. Care should be paid to allow clear through-routes between the various zones. For older pupils, who spend more time engaged in individual, formal learning or group work, fewer learning zones are necessary.

Paying due attention to children's needs for ownership and flexibility in

1 McMillan: Research in Education: A Conceptual Introduction. 1997
2 DeVries and Zan: Moral Classrooms, Moral Children: Creating a Constructivist Atmosphere in Early Education. 1994
3 Ulrich: A place of their own: children and the physical environment, Human Ecology. 2004

"their" classroom is further enhanced by giving the space links to nature and the outside, such as providing windows with views onto gardens, skylights, and doors that open directly onto play areas.

A modern and less traditional option is to allow flexibility in seating arrangements as well. New schools like the Frederiksbjerg School in Aarhus, Denmark, are experimenting with this as can be seen in the image [to the left], giving teachers an efficient and easy option to break the usual pattern of blackboard/whiteboard-based lectures.

6 STIMULATION

While stimulation, colour and visual complexity are important to creating a vibrant learning environment in classrooms, what is the healthy balance between under-stimulation and over-stimulation?

It can be easy to over-stimulate children with vibrant colours and overly busy displays, but a plain white enclosure is not the answer either. So how do we find the right balance in classroom design?

Theories suggest that diversity, novelty or atypical elements introduce visual complexity, which, in turn, affects stimulation. However, there are differing views on whether more or less stimulation is beneficial in children's learning environments. For example, a recent study cited in the Clever Classrooms report has shown that children in "low visual distraction" conditions spent less time off-task and obtained higher learning scores than children in "high visual distraction" conditions[1]. This study also found that learning scores were higher in sparse classrooms than in highly decorated classrooms. Meanwhile, Read et al (1999) [2]. found that differentiated spaces with varying ceiling heights and wall colours supported cooperative behaviour, although the effect could be counter-productive if the space became too complex.

How much complexity?

The results of the Clever Classrooms study concluded that the effect of complexity is curvilinear, meaning that overly high or low levels of complexity produced poorer learning conditions, whereas an intermediate level of visual complexity was optimal. The study's findings concluded that:

- Visual diversity of floor layout and ceiling is enough to stimulate pupils' attention, while presenting a degree of order. Higher, simpler ceiling forms can "decompress" the space, whereas more complex shapes can add to the complexity, as long as a feeling of clutter and disorder are avoided.
- Visual displays on walls should be well-designed and organised. It is recommended to keep 20-50% of wall space clear.
- Placing display materials on windows should be avoided if possible due to loss of light.

Are bright colours best?

Children are undoubtedly attracted to bright colours. However, a functional approach to colour in the classroom should focus on using colour to achieve positive outcomes such as increased attention span and lower levels of eye fatigue.

For example, Jalil et al (2012)[3] reviewed how different colours influence work performance, cause certain behaviours, create negative or positive perceptions of surroundings and tasks, and influence moods and emotions. Their conclusion: that coloured environments have significant effects on students' learning ability and their well-being.

They state that while colour preference is highly subjective, "red is the most preferred colour among young children and the elderly for an interior environment, while blue is the most preferred colour among young adults, office workers and male students".

For the Clever Classrooms study (2015)[4], colour elements were assessed with low-brightness colours (white/pale) and high-brightness colours (red/orange). The stimulation from the use of colour was found to be curvilinear, i.e. optimally pitched at a mid-level. Other findings concluded:

- For wall areas, the core aspect is curvilinear. Large, brightly coloured areas rated poorly, as did white walls with few colour elements. An intermediate scenario, with light walls in general plus a feature wall in a brighter colour, was found to be the most effective use for optimising learning.
- Against this relatively calm backdrop, additional colour elements played a complementary, stimulating role. As an example, relatively bright colours on the floor, blinds, desks and chairs add extra highlights and splashes of colour.

All in all, the conclusion is that classrooms should never be dull and boring, but careful attention to balance and a sense of order is needed to avoid over-stimulation.

1 Godwin and Fisher: Visual Environment, Attention Allocation, and Learning in Young Children: When Too Much of a Good Thing May Be Bad. 2014
2 Read et al: Impact of Space and Color in the Physical Environment on Preschool Children's Cooperative Behavior, Environment and Behavior. 1999
3 Jalil et al: Environmental Colour Impact upon Human Behaviour: A Review. 2012.
4 Clever Classrooms (2015), Summary report of the HEAD project, University of Salford, Manchester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