Good indoor climate in pre-school and school

– A guideline for light, acoustics and air

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We spend on average 90% of our time indoors, and the quality of the indoor climate is extremely important for both our health and our productivity. This applies in all areas, and particularly in schools and preschools. Smart students demand a smart school environment!

At the same time, creating a good indoor climate that is energy efficient at the same time is a complex issue. The purpose of this guide is therefore to provide assistance in the day-to-day work of building managers and planners in their planning, procurement and follow-up of projects.

The EU project EFFECT4buildings has worked alongside other countries around the Baltic Sea to jointly develop tools and methods that will lead to increased energy efficiency in buildings. Tools are available for nine areas: profitability calculations, packaging, financing, decision-making, EPC contracts, MSC contracts and Green Lease contracts. In addition, the project has distributed knowledge about various technical solutions. More information about the project can be found at www.effect4buildings.se

Multi Service Contracts (MSC) refer to new construction and refurbishment projects that aim to achieve more than just energy efficiency, and where an improved indoor climate is a key element. This guide is one of the tools that have been developed in this area.

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The value of a good indoor climate

Through educational activities, social security and high-quality physical environments, schools lay the foundation for good public health.

Good conditions in early life and a good working environment are two of main objectives of the public health policy (1). The focus is on implementing measures for equal health that support and strengthen a good start in life and equal conditions for growing up. Equivalent education and good learning environments are key aspects of good and equal health.

A good environment in pre-school and school is an important prerequisite for children's and young people's school performance (1). Children and young people who do not have school-leaving certificates from primary or secondary school have fewer opportunities in working life and are more likely to experience social exclusion in the future. Early exclusion and absence can result in significant costs for society in the form of subsequent interventions for education, care, etc. On the other hand, a good school environment provides the conditions for good health and social inclusion later in life, thereby justifying preventive efforts in the school environment.

WHAT IS A GOOD INDOOR CLIMATE?

There are a great many factors in the indoor climate that have an impact on human health, both directly and indirectly. We now spend the majority of our time indoors, on average more than 21 of the 24 hours in a day (3). The indoor climate is therefore probably more important for our health and wellbeing now than ever before.

When it comes to a good indoor climate in school buildings, it is particularly important to understand the complexity of the structure of the environment. The location of the building, its proportions, scale, storey and room heights, finishes and choices of materials all have a considerable impact on our experience of rooms and how well we work in them. It is therefore best to design the environments in interdisciplinary teams, which embody a holistic approach to the design and quality of the environments.

Natural light, sound levels and air quality are some of the most important factors for achieving a good working environment (4) and therefore constitute the focus of this guide.

The school of the future

The demands placed on the indoor climate are largely governed by the conditions and requirements of the activities being conducted. Existing schools and the schools of the future require varied learning environments, flexible room usage and long-term sustainability.

The traditional classroom is often put forward as an example when discussing school premises. However, the fact is that the classroom – or basic room, as it is sometimes called – is only one of many room functions required in order to conduct modern educational activities. Today, many schools work with problem-solving and collaborative pedagogy, and teachers tend to work more often with a team-based approach. The collaborative approach employed by students and teachers creates the need for a greater variety of rooms, at the same time as placing different demands on existing classrooms, in particular with regard to acoustic conditions.

Informal learning environments

Having different rooms for different uses provides greater flexibility in terms of teaching, and better meets the varied needs of today's student groups. Examples of this include informal learning environments, which are required to complement group and classrooms. Informal environments should support independent work, individually or in groups, where students can find relevant information and discuss solutions with each other. Informal environments are often located adjacent to formal environments such as classrooms or group rooms, potentially in the form of large open spaces or widened corridors. Open environments are more difficult to plan, since they need to be able to accommodate several different activities – focus work, small group reviews and high flows of people through the same space. This places higher demands when it comes to the planning of quality aspects for lighting, acoustics and air.

CO-USAGE AND FLEXIBILITY

Building a new school entails a major investment, which is why increased demands for space efficiency and flexibility are incorporated in directives ahead of refurbishment and new construction. One way of creating space-efficient solutions and simultaneous social benefits is for school buildings to be made available to other parties in addition to just school activities. Co-usage can be achieved by the school being available to e.g. clubs, libraries, sports and culture, etc. This places new demands on schools' indoor climates as regards reconfigurability, both on a day-to-day basis and over time, i.e. new requirements for flexibility.

The desire to create flexible schools gives rise to the pursuit of general room solutions, where the environments can accommodate different operations and activities. A classroom can function both as a daytime teaching space and as a leisure area after school. Canteens are now often located in open entrance areas, where they can also serve as meeting places in the evening or as the school hall. This form of room planning places high demands as regards foresight in terms of flows, interior design and equipment, as well as the basic robustness of structural engineering systems.

A HEALTHY SCHOOL

A sustainable and healthy lifestyle goes hand-in-hand with the school's lifelong learning mission, and sustainability should be evident and clearly visible in the building. Playgrounds and indoor climates should encourage movement and activity, as well as offering calm and secure environments for mental focus and recovery. The environments should be non-toxic, as growing children are particularly susceptible to toxins and endocrine disruptors.

Energy and climate goals are now fundamental in new buildings, and are manifested in a range of certification systems. The requirements will need to be further tightened up in order to achieve environments that are sustainable from a climate perspective, at the same time as promoting health and being free from toxins.

We now have a need for varied spaces in school environme-nts. It is common to have more or less open areas in close proximity to formal class and group rooms. These open environments are designed for individual focus work and/or working in groups. Classrooms are equipped to a greater extent with a variety of furnishings to suit different learning styles.

BILLING SCHOOL, SKÖVDE. © WHITE ARKITEKTER, PHOTOGRAPHER IVAN BRODEY

ÖSTERMALM GRAMMAR SCHOOL, 1910. STOCKHOLM CITY MUSEUM
PHOTO NUMBER C 1893; PHOTO NUMBER FA 33742

PHOTOGRAPHER: PETERSENS, LENNART AF, STOCKHOLM
CITY MUSEUM, PHOTO NUMBER F 42132 (1913–2004)

TEGELHAGEN SCHOOL, SOLLENTUNA © WHITE ARKITEKTER
PHOTOGRAPHER ANDERS BOBERT

BRUNN SCHOOL © WHITE ARKITEKTER

School premises through the ages in Sweden

The potential to create good light, acoustic and air conditions is affected by the age of the building.

BEFORE 1930

Buildings from the early part of the 20th century were constructed from robust materials and are often perceived as grand. From a structural engineering perspective, they are characterised by high storeys and authentic materials, such as brick, stone and wood.

Daylight was the primary light source, and the buildings were therefore designed with tall, generous window openings to bring light a long way into the premises.

Schools from this period have poor acoustic properties, in part because they were not provided with soundproofing, but also because they were not planned according to current collaborative educational ideals.

The high ceiling heights contributed to good air conditions. The schools were often heated with calorifier systems; these entailed heating the air, which was then brought into classrooms via ducts built into the walls. The air was removed via natural ventilation ducts, which were also built into the walls. It was not uncommon for these supply air systems to be removed when the buildings were supplemented with radiator systems in the 1940s.

1940S–1960S

During the middle of the 20th century, many school buildings were built according to type models developed by the National Swedish Board of Education. The buildings are characterised by democratic values, a "people's home" approach and good prevailing socioeconomic conditions. The previous grandeur was toned down and replaced by a more muted, yet clear and high-quality design.

The interiors of these buildings are characterised by classrooms laid out in rows along long corridors, with large, south-facing windows. This arrangement does not tally with today's educational ideals, as there is a complete lack of group rooms and informal environments. In the 1940s, the schools were often ventilated with natural ventilation systems, which were also based on airing during breaks. Fan operation became increasingly common in later years.

1960S–1990S

During this period, construction methods and educational activities changed radically compared to the previous conditions. The schools were built using prefabricated elements in order to reduce costs and increase energy performance. Window sizes and storey heights decreased, as did layouts and flows. The approach worked on the assumption that each class had its own "home classrooms", with lockers for each student being placed in the long corridors. School buildings from this period are often low, with central corridors lined with long rows of classrooms and group rooms. The buildings are often dilapidated today, due to the lower quality of the original materials, but they work relatively well in combination with contemporary educational collaborative ideals.

Around the end of the 1970s, the ventilation systems started to employ heat recovery. The ventilation systems remained fairly similar throughout the period from the 1970s to the 1990s, with the exception of some modern natural ventilation schools that were built in the early 1990s.

2000S

The educational changes implemented in recent years have driven the development of new school typologies. Previous communication areas, such as corridors, are now often reconfigured to accommodate informal environments. Common areas are highly valued, and the staff also tend to work more in teams adopting a flexible approach. This allows a more efficient use of the premises than before. From a structural engineering perspective, there has been a return to more generous storey heights and larger glazed areas in the window openings.

Schools from this period boast a relatively high level of structural engineering quality in terms of energy efficiency. In recent years, many of the ventilation systems have been equipped with advanced demand-control systems. However, many open areas impose higher demands on the planning of the acoustic environments.

LIGHTFIELD STUDIOS, ADOBE STOCK

Light

The value of light quality

Light affects our health and wellbeing, both from a biological and a psychological perspective. Varied and well-planned lighting is a powerful tool for the creation of inspirational, healthy and energy-efficient environments where people are happy.

We are spending less time outdoors than ever, being inside for more than 90% of our time. Our wellbeing is closely linked to our light intake, and our new lifestyle means that we are spending more time in electric light than in daylight, which has been proven to have a negative impact on health (1).

Light contributes to our vision as well as synchronising the biological clock that controls our sleeping and waking cycles. High daylight intake improves our sleep, performance and mood, as well as reducing daytime sleepiness. Daylight and its shadow effect also contribute actively to the way we experience the built environment, the natural character of a room and shifts in colour and shape. The Nordic region's northerly latitudes provide less natural daylight and global solar radiation during the autumn and winter months, with the result that electric lighting alternatives are needed during the daytime as well (2).

LACK OF LIGHT IN SCHOOL

In schools, it is not uncommon for luminaires to be incorrectly positioned and for people to experience flicker and glare from lighting, which have been shown to have negative effects on health and learning. It is common for classrooms to be illuminated with a completely uniform lighting distribution, creating monotonous rooms that hamper spatial perception. The way in which daylight and lighting are designed in relation to people's needs is therefore of crucial importance in the creation of good learning environments.

Light and health in school

Research shows that children who attend schools that prioritise spending time outdoors tend to move about more, have a lower Body Mass Index (BMI) and sleep for longer at night than other children (3).

In the indoor climate, high levels of natural light, through large windows with a large glazed area and high light transmittance, have a positive impact on the performance of students and staff, both in the short and the long term (4). Positive effects on learning speed are also seen in classrooms that are supplied with plenty of daylight (5).

Views of vegetation also have a positive impact on learning and study results.

Lighting that makes it easy to read the teacher's and students' facial expressions makes communication in the classroom easier and provides the conditions for conversation, while more muted light can heighten listening (6).

The perceived value of an indoor climate that has been designed using daylight can be considerable. The constant variations in daylight, combined with carefully selected colours, materials and surface finishes, can contribute to added value in the design of school rooms and the way rooms are perceived. The design of the outdoor environment has a significant impact on the availability of light on the site and on how much of the light finds its way into the buildings.

ENERGY EFFICIENCY

Fluorescent lamps made great strides on the market as a substitute for daylight during the energy crisis in the 1970s. This led to a significant reduction in both window sizes and light quality in school environments. Energy-efficient solutions can now be created by means of good lighting design, without sacrificing increased wellbeing. This is achieved by prioritising good access to daylight alongside well thought-out lighting, aided by adequate control systems.

How is a good lighting environment achieved? Technical aspects

Working methods covering the qualitative and quantitative values of light in early design stages, where daylight and lighting are utilised and planned optimally, create synergies for both wellbeing and energy consumption. This section describes the fundamental prerequisites for achieving good lighting environments as well as explanations of technical concepts and aspects.

NEW CONSTRUCTION

In the case of new construction, there are good opportunities to secure good access to daylight where it is needed. The potential to create a well-designed daylight environment exists when constructing new buildings, with the development of daylight concepts specifically for the project in question. With knowledge of which factors affect the availability of daylight and outlooks from a building, it is possible to optimise daylight when designing the building.

In most school projects, initial daylight calculations are performed as early as the preliminary study and developed design stage, to ensure optimum placement and programming of a building on a selected plot. However, this can be carried out at the detailed planning stage. The calculations ensure the building's supply of daylight and its preliminary compliance with regulatory requirements regarding e.g. daylight factor. These simulations are particularly important in urban areas, where the conditions for supplying good daylight can be tricky.

A more detailed daylight calculation is usually performed in the technical design stage, analysing the amount of light that enters the proposed building at room level. The calculation often forms the basis for the planning application, and may be required in order to get the go-ahead for construction. The calculations are used by the project to provide input regarding how well daylight reaches rooms that are intended to be permanently occupied. If insufficient daylight levels are achieved, it will be necessary to redesign the façade, window placement, floor plan, any balconies, etc., in order to achieve a better result. This is iterative work that is conducted in the design process jointly by an architect and a daylight specialist.

In the specialist design stage, a verification calculation is performed using the final design and to ensure that good daylight and design have been achieved, and that regulatory requirements are met. This calculation is often used as a report during the environmental certification of buildings. The work on the lighting is based on the conditions observed in the daylight studies, but also on the building and room design as well as the interior architecture and the functionality of the rooms. The information is analysed with the aim of creating a lighting design concept that satisfies both qualitative and quantitative aspects of lighting.

In the programme stage, lighting principles for various room types are described through illustrations, text and reference images, types of luminaires with technical descriptions, as well as control principles.

The lighting design concept is further developed in the technical design stage, including the placement of luminaires, light calculations and a list of luminaires. At the same stage, any test lighting is carried out in close cooperation with architects, interior designers and daylight specialists, as well as with building owners, managers and users in certain cases. Test lighting is a crucial step in the process, where several different lighting proposals can be evaluated on the basis of qualitative and quantitative effects.

During the specialist design stage, the lighting design concept is developed in greater detail and coordinated with the various consultants to ensure that it can be built as intended. Lighting plans, lists of luminaires and control principles are subject to further design work by an electrical consultant for the planning of electrical installations. Following-up during the construction period is important, as many details are decided on site.

The involvement of lighting designers throughout the construction process, including when the system is being evaluated, is crucial for the planning and building of a good lighting environment, but also to ensure cost management.

The lighting scenarios are programmed before the tenants move in, and should be adapted continually over time following occupation to enable adjustments according to evaluation by the users.

Flexibility is an important element when planning lighting in new buildings. Ensuring that luminaires can be replaced, moved and regulated in the future without major changes is also dependent on having a system where electricity and control are planned with room for change. Specifying luminaires that are future-proof from a maintenance perspective, but also to preserve the light's properties over time, is important in terms of both quality and cost.

REFURBISHMENT

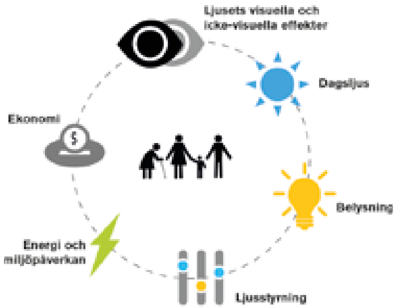
Improving natural light levels during small-scale refurbishment projects in existing schools can be difficult, as the windows are already in position. However, through proposals for new floor plans, the treatment of surface layers in respect of structure, material and colour, as well as new planning as regards furnishings, architects and interior designers can optimise the positive effects of existing natural light in older buildings.

The preconditions for natural light are difficult to regulate during refurbishment work, but this is not the case when it comes to lighting. For example, lighting can be used to recreate light that is as natural as possible (12). However, it can also be employed to improve the existing illumination of a school environment. Restrictions as regards lighting during refurbishment work mainly relate to the potential placement of luminaires.

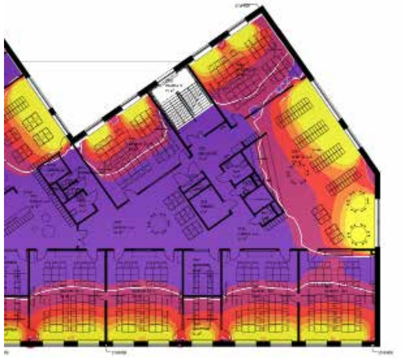
PLANNING AND CALCULATION

Calculations and simulations

Daylight calculations and simulations are becoming increasingly common in projects in order to show that requirements and regulations are being fulfilled. The important thing is to identify a good process that follows the building and design process. Budgets are often smaller in the early stages, and it is therefore important to adapt the calculation level accordingly so that we can still steer the design work in the right direction in order that the conditions for satisfying stringent requirements are not lost.



Factors affecting a good lighting environment



Internal daylight calculation in a school

Calculation image of illuminance (lux)

Daylight calculations

The most common way of calculating daylight is through the quantitative concept of daylight factor. This is calculated as the ratio between illuminance (measured in lux) inside and outside, and is given as a percentage. The daylight factor is defined for a completely cloudy day, i.e. only diffuse light is included, which means that the measurement is not dependent on weather conditions. The daylight factor can be simulated with computer programs and is measured either at a specific point in the room, as an average or as a median.

Another way of calculating daylight is with the aid of a more advanced simulation that takes into account both diffuse light and direct sunlight at the project site. This is known as daylight autonomy. It is a measure of how many hours during the annual working time a building reaches sufficiently high lux levels without the use of electric light. This measure is consequently geared more towards saving energy as well.

In the early stages on an urban development scale, two other methods for calculating daylight can be mentioned. These are VSC (Vertical Sky Component), which measures the availability of daylight at the façade, as well as VDF (Vertical Daylight Factor), which is a slightly more advanced version of VSC and requires more information as it e.g. takes reflected light into account.

Calculation of lighting

Nowadays, lighting is mostly calculated digitally using software. This software is useful for calculating e.g. illuminance, luminance, uniformity of illuminance, glare and energy consumption, as well as to visualise how light will be distributed in a room. The calculations are used to ensure the fulfilment of quantitative requirements, but can only measure qualitative requirements to a certain extent. In order to safeguard qualitative aspects such as glare, colour reproduction and flicker, the execution of a visual assessment and measurement is recommended.

GENERAL FACTS ABOUT LIGHT

Illuminance (lux) & luminance (cd/m2)

Illuminance measures luminous flux in the unit lux, and describes the light that falls onto and illuminates a surface. Illuminance is a quantitative concept that is easy to measure digitally and with a lux meter, but which is often overestimated in lighting design.

Luminance measures how much light is reflected from a surface in a particular direction, in the unit cd/m2. Light-coloured and shiny surfaces reflect more light than dark and matte surfaces, which will affect the luminous distribution. Luminance can be measured both digitally and with a luminance meter.

Varied lighting

Varied lighting, which relates to the preconditions in the location and to the varying needs and activities of the users, provides better and more attractive study and working environments, both in the case of daylight and electric light.

Varied light is used as a term for lighting whose illuminance and colour temperature can be adjusted. The term can also be used in relation to a room where you have access to lighting of different characters, such as a combination of direct and indirect lighting.

A Danish pilot study examined how suspended lighting, in addition to general lighting in a classroom, had a positive impact on the auditory environment (13). The suspended lighting created an illuminated area in the actual workplace and soft lighting between the workplaces. In addition to increased concentration and improved learning capacity on the part of the students, the results demonstrated a reduction in sound levels in the classroom.

From a health perspective and in environments where people spend time where there is poor access to daylight, varied lighting that incorporates circadian lighting principles can help to compensate for the lack of daylight. However, it is important to emphasise that the primary objective must always be to ensure that rooms were people spend long periods of time are provided with natural light.

Colour temperature (Kelvin)

The colour temperature, i.e. the colour of the light, gives an indication of the way the light from the light source is experienced from a colour perspective. The colour of the light may have a warm tint, be neutral white or cold white. The choice of colour temperature is related to psychological aspects, aesthetics and what looks natural. The colour temperature you choose is also linked to the room's colour and interior design, illuminance, area of use and climate (15). The most widely used colour temperatures in indoor climates in Nordic countries range from 2700K - 4000K.

Colour reproduction (Ra)

The colour reproduction of light sources is extremely important when it comes to the quality of light. The higher the colour reproduction, the better the light sources reflect natural colours. In order to grade colour reproduction capacity, the Ra-index is used, which is an average of the deviations of eight defined test colours. The Ra-index can be up to a maximum of 100. Light sources with an Ra < 80 should not be used in environments where people work or spend longer periods of time (14).

Glare (UGR, Luminance)

Glare occurs when the light from a luminaire or surface in the room is noticeably brighter than the room's surroundings. In this case, the eye is exposed to a stronger light than it has adjusted to. Tolerance for glare is probably greater if it comes from daylight and windows than an equivalent electric light (16).

Unified Glare Rating (UGR) is a method for calculating the degree of discomfort from glare in an indoor facility from a user perspective. The calculation is based on the viewer's eye (its position and angle) in relation to the illuminating surface of the luminaire and the ambient light. An important thing to remember is that this is a calculated value of a facility as a whole, not a measure of whether a luminaire is producing glare or not (17). UGR can be measured digitally, although glare can also be evaluated visually and measured using a luminance meter.

Flicker (Hz/s)

Flicker (or light modulation) from light sources and luminaires can cause clear difficulties such as headaches and eye problems. Experts also judge that the invisible flicker affects our nervous system, and may consequently be a contributory factor behind symptoms of stress and electrical hypersensitivity that are more difficult to define. Flicker has no upside, and should definitely be avoided in our lighting environments. Flicker can be measured with a flicker meter (18).

Light emitting diodes (LEDS)

LEDs are now available for colour-changing applications (known as RGB technology), colour temperature-changing and steady white light. Their energy efficiency has now achieved such a high level that they can be used in almost any context. The light quality supplied by LEDs is now good, and solutions with an Ra above 90 are becoming increasingly common. LEDs have many advantages over conventional lighting technology, including high energy efficiency, a long service life, and the fact that they are very robust as well as being easy to control (19).

OHSURIYA, ADOBE STOCK

Variation of colour temperature from warm white (1000K) to cold white light (10000K)

Light regulation (lighting control)

The ability to regulate the light at your workplace increases job satisfaction. This relates both to the ability to switch luminaires on and off, as well as the ability to set a level of illuminance that is adapted to the user's age and work duties.

There are a number of different systems for light regulation of lighting installations, both for controlling individual luminaires and for groups of luminaires (20). Control protocols include DALI, 1-10V, DSI and Bluetooth. Lighting can also be controlled automatically by means of predefined light scenarios, occupancy sensors, absence sensors and daylight sensors, etc.

Circadian light

Circadian light is a way of using lighting to stimulate our circadian rhythm. The idea is to compensate for our insufficient exposure to daylight during the day and the excess of light we are exposed to in the evening from lighting. The effects of stimuli from the light are dependent on the intensity, light distribution, colour temperature and spectral composition of light sources, as well as the location of luminaires in relation to workplaces and the times at which a particular light quality and quantity are provided over the course of the day. Metrics such as Circadian Stimulus (CS) and Equivalent Melanopic Light (EML) are tested as tools to assist in lighting planning to ensure that non-visual lighting requirements are being met.

Specification of requirements during procurements

TASK AND PROJECT DESCRIPTION

In the project description, it is important to formulate requirements regarding daylight and lighting, as well as to describe the project's significant challenges, limitations, any environmental certifications and overall goal formulations.

LIGHTING EXPERTISE

The procurement process should call for consultants who can demonstrate high levels of expertise and experience of working with daylight and lighting issues from a quality perspective, and who can demonstrate an understanding of the complexity of complicated environments like school buildings. Reference assignments to confirm this should be submitted.

The consultants' CVs should be able to demonstrate relevant higher education or well-documented experience in the field of lighting design and daylight calculation. The individuals must also be able to demonstrate a good knowledge of research, legislation and practices in the field.

ADVICE IN THE EVENT OF NEW CONSTRUCTION

- Carry out daylight calculations early in the project to facilitate optimum volume management and building planning on the site in question.
- Maximise daylight in classrooms as much as possible and treat daylight as part of the lighting system.
- Prioritise positioning workplaces where people spend long periods of time in those areas with the best access to daylight.
- Prioritise window glass with high light transmission for maximum natural light. This affects the window's properties for shutting out sunlight, which is balanced with a carefully thought-out choice of sun shielding.
- Avoid deep balconies or projecting sections just above windows where good natural light levels are desired.
- Develop a lighting programme for each room in the building with the aid of a lighting designer or lighting planner, and bear in mind the whole picture, not just individual luminaires.
- Ensure that lighting control and individual light regulation are used to optimise energy use, flexibility and comfort.
- Be sure to use luminaires with the following technical requirements:
  - *Energy-efficient and high quality LEDs*
  - *Colour reproduction (Ra) over 90*
  - *Even colour temperature over time and at different intensities*
  - *Colour temperatures between 2700K - 4000K*
  - *Flicker-free, both in terms of invisible and visible flicker*
  - *Low glare*
  - *Dimmable, adjustable via lighting control*
  - *Long service life that maintains light quality over time*
- The illuminance in the classroom should be 500 lux in the work area with 60% uniformity. The immediate surroundings

around the workplace should have 300 lux with 40% uniformity. The outer surroundings around the workplace should have 100 lux with 10% uniformity. In other types of rooms, the illuminance should be lower with a minimum value of 100 lux, depending on the tasks to be performed.

- Use indirect light, ambient light, which is reflected from ceilings and walls, in combination with direct light directed down towards the work area.
- In the case of poor access to daylight, implement circadian lighting principles to ensure that non-visual lighting requirements are satisfied.
- Ensure that the specified luminaires and control units are not replaced with products that do not meet the quality requirements due to cost savings when purchasing.
- Follow up installations continually during the construction period, as many details are decided on site
- Perform a visual evaluation of the lighting system in respect of e.g. the visual experience, shadows and reflections, and check the lighting settings in each room
- Evaluate the lighting system by measuring illuminance, flicker, colour reproduction and colour temperature in all rooms after completion.
- Remember that the programming of lighting scenarios should be adapted and adjusted regularly over time.

ADVICE IN THE EVENT OF REFURBISHMENT

In addition to the advice regarding new construction, which can be applied to varying degrees in the case of refurbishment, the following can be highlighted:

- Strive to achieve high light transmission when replacing windows. Balance with sun shielding.
- Light colours indoors on walls and furniture reflect and transmit daylight
- Window trims can be angled from the windows out towards the rooms to reflect in more daylight from outside
- Define physical limitations and challenges that can affect new lighting.
- Take the opportunity to consider the lighting in the rooms to ensure that the lighting as a whole meets the needs of the users, rather than simply replacing the luminaires with the same type but with more energy-efficient bulbs.
- If there are any historical lamps that are part of the building's identity, examine the possibility of replacing the technology in the luminaire with higher quality and more energy-efficient light sources.
- Some lighting control protocols are now wireless, providing greater opportunities to control LED luminaires easily and facilitate installation during refurbishment.

Evaluation and follow-up

FOLLOW-UP PROCEDURES
Lighting installations should be documented and checked in such a way that all the lighting's quantitative and qualitative parameters are met.

MEASURABLE ASPECTS
After completing installation, the consultants' supporting calculations should be followed up and control measurements carried out in respect of installed power, illuminance, glare and flicker. Measurements can be carried out using lux meters, luminance meters, spectrometers and flicker meters. Evaluate the lighting control for each room to ensure that lighting scenarios, sensors and predefined settings are working as intended. The programming of the lighting scenarios should be adapted and adjusted regularly according to the current work tasks and the needs of the users. It is therefore important to ascertain that the operation using the equipment is aware of how it is controlled.

Daylight is generally more difficult to measure. It is possible to measure a daylight factor in a room, but in order to check it against calculations, the daylight must be measured simultaneously inside and outside under conditions with a "perfect" overcast sky. This can be done in theory, but in practice it is difficult to compare with simulation results. This is also a time-consuming process.

NON-MEASURABLE ASPECTS
A visual assessment and evaluation of the light can be performed by going through the building room by room. Regular user surveys can help to evaluate how the light is perceived and how well it works. An open dialogue between users and managers is crucial, in order to take steps immediately in the event of a technical failure or dissatisfaction with the lighting system.

MARCEL, ADOBE STOCK

Acoustics

The value of acoustic quality

The acoustic environment in many schools is not adapted to current education, and inspections of the acoustic environment show major shortcomings in planning and construction. A good acoustic environment facilitates learning, creates a better working environment for both teachers and students, and contributes to a more equal school.

We have developed our hearing outdoors for thousands of years, in an environment filled with natural sounds such as chirping birds, babbling streams, gusts of wind in the treetops and human voices. Our hearing is constantly providing us with information about what is causing the sound, where the sound is coming from, whether it is heading towards us or away from us. The conditions in a forest allow our hearing to provide us with valuable information about what is happening around us. This information makes us feel safe. Feeling safe is a prerequisite for learning, and students who feel unsafe find it harder to learn.

The problem is that a high proportion of modern teaching takes place indoors, in an environment with very few natural sounds. This has a major impact on both students and teachers.

Many schools are not up to scratch

A high proportion of the teaching facilities investigated do not meet the Swedish National Board of Housing, Building and Planning's requirements regarding the acoustic environment (1). In an unnatural acoustic environment, it is difficult for students to hear what the teacher is saying. Another effect is that many teachers have problems with their voice. We know that students who are not taught in their mother tongue have a greater need for a good acoustic environment. In many schools, the acoustic environment is so poor that it constitutes an obstacle to achieving an equivalent school.

WHAT IS GOOD ACOUSTIC QUALITY?

In order to succeed in school, it is important for the students to be able to hear, understand and remember what is being said. To achieve this, it is important for the noise level from the ventilation system to be low, for the room's acoustic reflections to not impair speech intelligibility and for the room to have sufficiently good sound insulation. The noise level in the classroom is also influenced by the students – large student groups create higher noise levels while smaller groups produce lower noise levels.

How is good acoustic quality achieved? Technical aspects

The section describes how to create a good acoustic environment and contains explanations of acoustic concepts.

PLANNING THE ACOUSTIC ENVIRONMENT

The Swedish National Board of Housing, Building and Planning places demands on the acoustic environment in school buildings. The demands are taken from SS 25268, a Swedish acoustic classification standard for e.g. teaching premises. With the aid of SS 25268, the client can decide what acoustic quality level the school buildings should meet. The standard consists of 3 different "quality classes" – A, B and C (sound class D is also available, but it is mainly used for temporary buildings).

- Sound class C meets the minimum requirements according to the Swedish National Board of Housing, Building and Planning's building regulations, BBR.
- Sound class B provides a better acoustic environment than sound class C and is suitable if the school has multilingual students who are being taught in their second language.
- Sound class A provides a better acoustic environment than sound class B and is suitable if the school has students with hearing impairments, vision impairments or learning difficulties.

SS 25268 stipulates requirements regarding 5 functional requirements:

1. Airborne sound insulation
2. Impact sound level
3. Room acoustics
4. Sound from installations
5. Sound from traffic and other noises outside the building

The requirements vary in the different sound classes. In the case of airborne sound insulation, for example, the requirements are set depending on the activities conducted in the various rooms, and people's need to concentrate. The requirement for sound insulation in acoustic class B between two classrooms is set at 44 dB. Meanwhile, the requirement between a classroom and a corridor is 40 dB.

Since all classrooms at some point will have a student who is multilingual, they should meet the requirements for sound class B.

The 5 functional requirements are described below:

1. Airborne sound insulation – preventing airborne sound from being propagated in the building

Airborne sound insulation relates to preventing airborne sounds such as voices passing through walls and joists, so that people in adjacent rooms are not disturbed. The need for sound insulation depends on the sources of noise that are present in adjacent rooms and the need to concentrate. Table 1 shows the relationship between the sound from an activity, the sound insulation in the building and the degree of disturbance. The table illustrates that a loud call will not be heard if the sound insulation is 48 dB. If the sound insulation is 35 dB, a normal conversation will be heard. The airborne sound insulation requirements are “field values” and are designated R’w or D nT,w. The field value is measured in the finished building and must not be confused with the laboratory value. The sound insulation of walls is often reported with an Rw value. Rw is a laboratory value that shows the sound insulation of the wall when the wall is measured in an acoustic laboratory.

Figure 1 shows the sound insulation measurement of a wall in a laboratory. The framework of the lab is “soundproof”, so that no sound can pass the wall via the framework. Rw only reports how much sound passes through the wall.

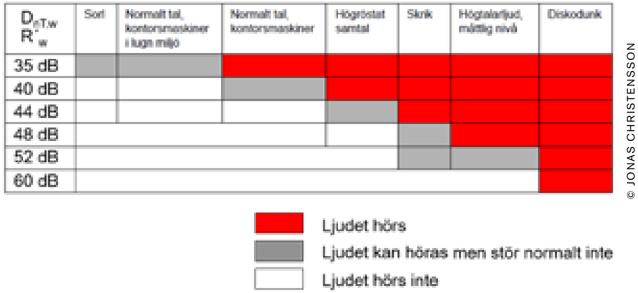
Figure 2 shows a field measurement. The field value is designated R’w and, in addition to the wall’s sound insulation, is also affected by all the “flank transmissions”. The requirements set out in SS 25268 are field values.

2. Impact sound level – preventing sound that occurs when walking on a floor from being propagated in the building

When a person walks on a hard floor, a sound is made. If you are in an adjacent room and can hear someone walking on the floor, this sound is known as impact sound. A standardised hammer device is used when measuring the impact sound level in a building. The hammer device has 5 metal pistons that strike the floor to mimic the effect of a person walking on the floor. The hammer device is placed on the floor of the room from which the sound is being transmitted, and the sound level is then measured in the adjacent rooms. Impact sound can be propagated both vertically and horizontally.

Figure 3 on the previous page shows how impact sound can be propagated in a building. If a low impact sound level is measured in the rooms, the joists have high impact sound insulation. The requirements as regards impact sound level are a field value and are designated L’nT,w.

Different impact sound level requirements are stipulated depending on the selected sound class. Sound class C places demands on the impact sound level down to 100 Hz. Sound classes B and A place demands on the impact sound level down to 50 Hz. Low-frequency sounds are disruptive, so it is therefore better to choose sound class B or A. The need for impact sound



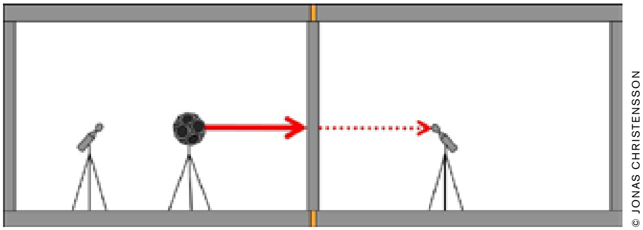


Figure 1: Measurement of sound insulation in an acoustic laboratory.

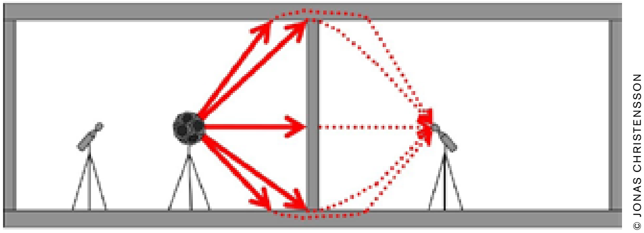


Figure 2: Measurement of sound insulation in a building.

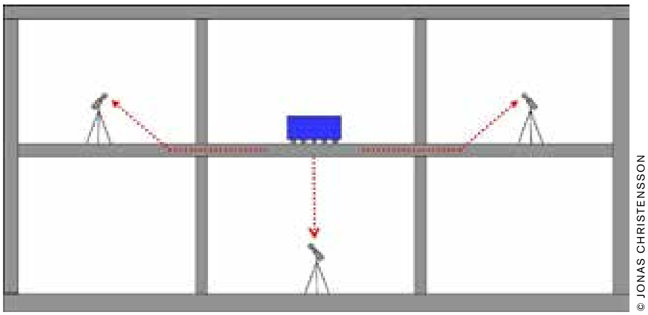


Figure 3: Measurement of impact sound in a building.

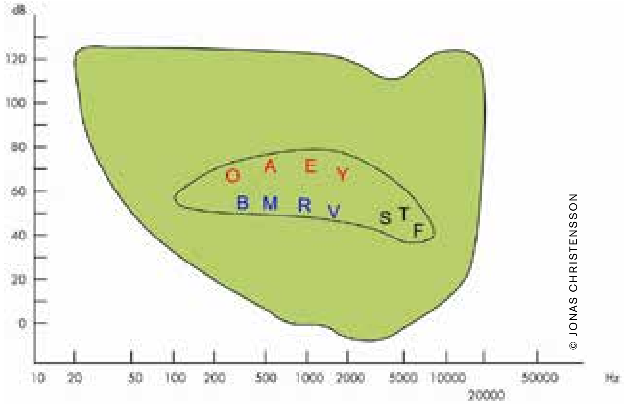


Figure 4: The audibility range of a healthy teenager. The y-axis shows dB and the x-axis shows frequency (Hz).

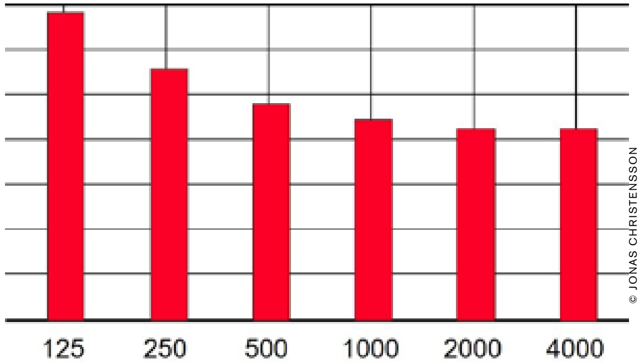


Figure 5: Acoustic reflections in a classroom. The y-axis shows time (seconds) and the x-axis shows frequency (Hz).

insulation varies depending on whether adjacent rooms have a high or low impact sound load. A corridor in a school has a higher impact sound load than a bedroom. Which rooms have high or low impact sound loads should be analysed together with acousticians and users. Some schools are shoe-free zones, but this does not mean that the impact sound load will be low.

If the building's frame is made of wood rather than concrete, particular attention should be paid to problems associated with impact sound, both during the design phase and during construction.

3. Room acoustics – the room's acoustic reflections

When you listen to a person talking in a room, you hear the direct sound (the voice) and all the room's acoustic reflections. A voice contains vowels (A, O, E, Y), voiced consonants (B, M, R, V) and voiceless consonants (S, T, F). The green zone in Figure 4 shows a young person's audibility range. The voice, consisting of vowels and consonants, lies in the middle of the audibility range. Most vowels are high in terms of strength (dB) and low in frequency (Hz). Most consonants are low in strength (dB) and high in frequency (Hz). In the Swedish language it is the consonants that carry the information, which is why it is important for the students to be able to hear the consonants.

Swedish Standard SS 25268 stipulates demands regarding room acoustics, with a measure known as reverberation time. When measuring reverberation time, a loudspeaker is used that creates a sound level in the room (approx. 100 dB). You then turn off the loudspeaker and measure how long it takes for the sound level to drop 60 dB. This time is known as the reverberation time.

Figure 5 with the red bars describes the reverberation time in a typical classroom. Many classrooms have a long reverberation time in the low frequencies. Hard, flat, parallel surfaces cause the sound waves to bounce in the room and create a long reverberation time, especially in the low frequencies. In these rooms, the low-frequency vowels are amplified, making it difficult to make out the information-carrying consonants. In such rooms, speech intelligibility is poor.

Figure 6, with the green bars, shows the reverberation time in a forest. There are no hard, flat, parallel surfaces in a forest. On the other hand, there is an abundance of convex tree trunks, spreading the sound in different directions and creating diffuse acoustic reflections. The dimensions (width) of the tree trunks means that they only reflect high-frequency sounds. Low-frequency sounds have a long wavelength and go around the tree trunks. The tree trunks' high-frequency acoustic reflections mean that consonants are enhanced, which increases speech intelligibility.

In order to generate good speech intelligibility in a classroom, it is important to install absorbers that dampen the low frequencies. It is also important to avoid hard, flat surfaces. Tilting the whiteboard so that sound is guided up into an acoustic ceiling is a good way of avoiding standing longitudinal sound waves. Another way is to use wall absorbers.

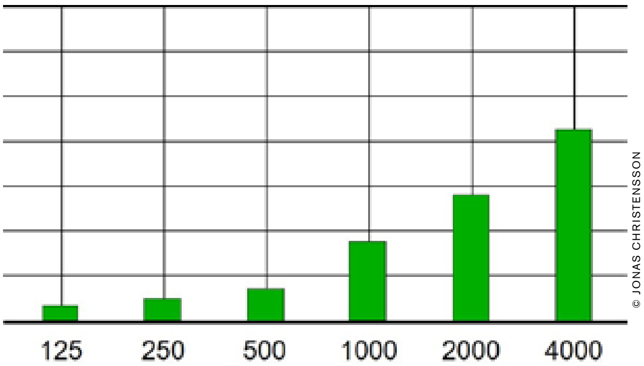
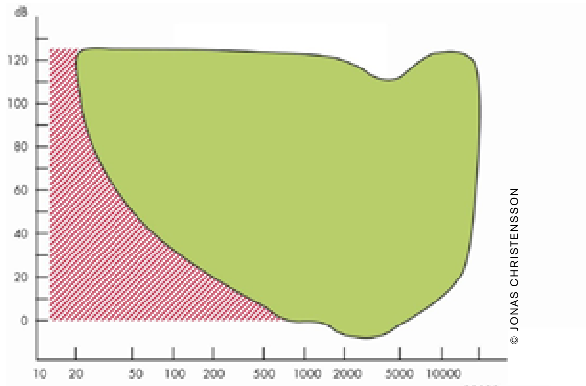


Figure 6: Acoustic reflections in a forest. The y-axis shows time (seconds) and the x-axis shows frequency (Hz).



Sounds below the hearing threshold that are inaudible. The y-axis shows dB and the x-axis shows frequency (Hz).

4. Sound from installations

High sound levels from installations have a negative impact on students and staff. These installation sounds often include very low-frequency sounds that cause us to feel tired. SS 25268 imposes two requirements as regards the sound level from installations, dBA and dBC. When measuring the sound level in dBA, a filter that filters out the low-frequency sounds is used in the sound meter.

In Figure 7, the green zone shows a young person's audibility range. The lower limit of the audibility range is known as the hearing threshold. Sounds that are below the hearing threshold are inaudible to humans, yet they still affect us. High levels of low-frequency sound cause us to feel tired.

A simple explanation is that when you measure the sound level in dBA, the low-frequency sounds are filtered out (the area shaded red). When the sound level is measured in dBC, the low-frequency sounds are not filtered out. A measurement in dBC reveals whether there are any low-frequency sounds in a room. It is therefore important to measure the sound level both in dBA and dBC.

5. Sound from traffic and other noises outside the building

If the school is located close to traffic routes, it is important for the building's façade to have sufficient sound insulation to ensure that outside noise does not disrupt teaching. Windows and supply air diffusers are often the "weak link" in a façade. If the school building is close to streets where diesel-powered trucks and buses often idle, it is important for the building to have a good sound insulation in the façade, especially in the low frequencies.

Active students in a school playground can generate high noise levels, which should also be taken into account when designing the façade's sound insulation. If noise from outside the building enters a classroom, it can disrupt the teaching.

ROOMS REQUIRING SPECIAL ACOUSTIC CONSIDERATION

In large rooms with a large number of students, noise levels can often become high and different groups of students can disturb each other. Creating quiet areas for individual studies in large rooms is an acoustic challenge, placing high demands on the rooms' design and choice of materials. The canteen is another environment that is affected by high noise levels. Noise from cutlery and plates, noise from chairs being dragged across the floor (scraping noises) and noise from students and staff talking generate high sound levels and make it impossible to eat in peace. Sounds from kitchen appliances can also contribute to a high noise level. In order to ensure good room acoustics in more complex environments, it is advisable to engage an acoustician who can help with the choice of surface finishes for floors and walls, as well as with furniture and kitchen appliances.

Specification of requirements during procurements

How should you act as a client when it comes to acoustics? How should you communicate with designers and contractors to ensure that they really understand the demands being placed on the school building?

BRING IN THE RIGHT SKILLS – EARLY

In order to carry out a successful procurement, it is important to select an acoustician who has experience of designing schools. Consultancy businesses often have a number of employees, so check that the person who is responsible for the project possesses the correct skills. This is best done by requesting a personal CV and reference projects from the tenderer.

SET CLEAR DEMANDS – BEFORE ENTERING INTO A CONTRACT

It is important to communicate clearly to the designers, contractors and control officers the acoustic quality that the building is to achieve. By entering 10 crosses in Table 30 in SS 25268, you are giving clear instructions in your capacity as client regarding which acoustic requirements the building is to achieve and how these are to be verified when the building is completed. In order to achieve a good acoustic environment in the classrooms, wall absorbers are almost always required. There is often debate as to whether the wall absorbers are part of the building or part of the interior design. In order to avoid this, the contract must clearly state that the wall absorbers are part of the construction contract. The contract must also set out how the rooms are to be furnished, since the furniture affects the room acoustics. Engage an acoustician to get help quantifying the furniture's absorption level.

If you opt for a turnkey contract, it is particularly important for the acoustic requirements to be clearly stated in the con-

Ljudklassning av verksamheten XX	Ljudklass (A är bäst)				Verifiering	
Funktionskrav	A	B	C	D	Med projekterings- och utförandekontroll	Med mätning
Luftljudsisolering		X			———	
Stegljudsnivå		X			———	
Rumsakustik		X				
Ljudtrycksnivå inomhus från installationer		X			———	
Ljudtrycksnivå från trafikbuller		X				

Example 1. Sound class B has been selected for all functional requirements. Designers and contractors can now see what requirements are to be met in order for the building to satisfy sound class B.

Ljudklassning av verksamheten XX	Ljudklass (A är bäst)				Verifiering	
Funktionskrav	A	B	C	D	Med projekterings- och utförandekontroll	Med mätning
Luftljudsisolering	X				———	
Stegljudsnivå			X		———	
Rumsakustik		X				
Ljudtrycksnivå inomhus från installationer			X		———	
Ljudtrycksnivå från trafikbuller		X				

Example 2. It is also possible to choose different sound classes for different functional requirements.

Ljudklassning av verksamheten XX	Ljudklass (A är bäst)				Verifiering	
Funktionskrav	A	B	C	D	Med projekterings- och utförandekontroll	Med mätning
Luftljudsisolering	X				———	X
Stegljudsnivå			X		———	X
Rumsakustik		X			X	
Ljudtrycksnivå inomhus från installationer			X		———	X
Ljudtrycksnivå från trafikbuller		X			X	

Example 3. The ten crosses clearly show the designers, contractors and control officers what sound class the various functional requirements are to satisfy, and how they should be verified.

tract, both as regards sound class and verification method. In turnkey contracts, too, it is important for it to be clear how the rooms are to be furnished

.

GENERAL ACOUSTIC ASPECTS

There are a number of basic acoustic aspects that need to be considered in the event of a new construction, although these largely also apply to refurbishments:

Airborne sound insulation: Heavy, dense walls have good sound insulation. Doors, windows and overhead air diffusers represent a challenge.

Impact sound: Buildings with wooden frames (light frames) are an acoustic challenge when it comes to impact sound. Bear in mind that impact sound can also be propagated horizontally.

The lab value of walls has the designation Rw. The result in the finished building, known as the field value, has the designation R'w. The field value is lower than the lab value.

Room acoustics: To create good speech intelligibility, it is necessary to have a good acoustic ceiling and good wall absorbers.

Sound from installations: Set requirements regarding the sound level from ventilation systems and other installations. Set requirements in dBA and particularly in dBC.

Sound from traffic and other noises outside the building: Bear in mind the noise level from traffic etc. when selecting the location of the building.

ADVICE IN THE EVENT OF NEW CONSTRUCTION

It is possible to influence the conditions for a good indoor acoustic environment right from the planning level. In the case of new construction, careful planning of the building's location, both in the city/surroundings and on the site, can avoid costly structural engineering solutions to combat e.g. traffic noise.

1. Engage an acoustician with experience of school projects

2. Select sound class

Select sound class in SS 25268. The building should satisfy sound class B. SS 25268 stipulates requirements for five functions (Airborne sound insulation, impact sound level, room acoustics, sound from installations, sound from traffic and other noises outside the building).

Tips: In addition to the 5 acoustic requirements in SS 25268, requirements may also be stipulated regarding speech intelligibility. In a teaching room, it is important for the students to be able to make out what the speaker is saying. It is possible to check speech intelligibility by measuring STI (Speech Transmission Index). STI is measured according to a standard (IEC 60268-16). The STI requirement varies depending on who is listening. The standard states that if a student is listening to his/her mother tongue, the STI value should be higher than 0.60. If the student is not listening to his/her mother tongue, the STI value should be higher than 0.68. Requirements regarding STI are not included as a functional requirement in SS 25268.

3. Select verification method

The results can be verified in two ways:

1. With measurement: An acoustician performs acoustic measurements in the finished building. Airborne sound insulation, impact sound level and indoor sound level from installations must be measured. The sound level from installations must be reported in both dBA and dBC. Room acoustics and sound from traffic are verified by means of measurement or by checking the design and the execution.
2. With design and execution checks: An acoustician checks that the building has been built according to the design that has been drawn up. Room acoustics and sound from traffic can be verified by means of measurement or by checking the design and the execution. Select design and execution checks when it comes to room acoustics and sound from traffic.

The standards that apply for verifying the various functional requirements are set out in SS 25268. See point 2, "Normative references".

4. Sound from assistive technology

The sound level is also affected by assistive technology in the rooms, such as data projectors and smartboards. Many electrical machines contain fans that often produce a noise. If you want the sound level from the machine to be low, you have to stipulate requirements regarding the sound power level. The EN ISO 7779 standard evaluates the sound power level from various machines. A low sound power level produces a low sound pressure level.

If the supplier of a projector states that the sound pressure level is low (e.g. 25 dBA), the supplier must also specify the distance from the projector at which the sound pressure level was measured.

A projector that produces a sound pressure level of 40 dBA at a distance of one metre may produce a sound pressure level of 25 dBA at a distance of 10 metres. The sound pressure level from a projector decreases with increasing distance from the projector. The sound power level, on the other hand, is not dependent on the distance between the source of the sound and the sound level meter.

- The A-weighted sound power level is specified in LwA
- The A-weighted sound pressure level is specified in LpA
- Serious suppliers report the sound power level

ADVICE IN THE EVENT OF REFURBISHMENT

SS 25268 states the acoustic requirements that a building must satisfy. In the case of new construction, it is relatively easy to design so that the correct sound class is achieved. When it comes to refurbishment, however, it is necessary to ascertain the quality of the existing building first in order to carry out the design work correctly. It is therefore important to consult an acoustician regarding the building's "acoustic status". Certain measures are more costly than others. Replacing a ventilation system or supplementing a "weak" frame can be very expensive. Improving room acoustics rarely requires major interventions and is therefore not as expensive. Below are a few examples of acoustic challenges when it comes to refurbishment.

In addition to the advice in respect of new construction, the following should be taken into consideration:

1. Engage an acoustician with experience of renovating school buildings

The acoustic standard of the existing building means that certain acoustic requirements may be costly to rectify. You should therefore consult with the acoustician regarding the cost and value of the various measures that may be required.

2. After evaluation by the acoustician – Select the sound class and the verification method

Evaluation and follow-up

VERIFICATION AND MEASUREMENT

The results can be verified in two ways:

1. With measurement: An acoustician performs acoustic measurements in the finished building.
2. With design and execution checks: An acoustician checks that the building has been built according to the design that has been drawn up.

Airborne sound insulation, impact sound level and indoor sound level from installations must be verified by means of measurement.

It is important for the sound level from installations to be reported in both dBA and dBC. Room acoustics and sound from traffic can be verified by means of measurement or by checking the design and the execution.

Depending on the sound class that has been selected, different requirements are stipulated for the five functional requirements. Check that the requirement values are satisfied and that they are have been measured and verified according to the selected verification method.

- Measurement protocols must demonstrate that the airborne sound insulation is sufficiently high.
- Measurement protocols must demonstrate that the impact sound level is sufficiently low.
- Calculations must demonstrate that the requirements regarding reverberation times are met. Both for 125 Hz and the average value for 250-4000 Hz.
- Measurement protocols must demonstrate that the sound level from installations is below the requirements in both dBA and dBC.
- Calculations must demonstrate compliance with the requirements regarding of traffic noise.

Also check that measurements and calculations are carried out in accordance with the standards set out in point 2, SS 25268.

SPEECH INTELLIGIBILITY

If you have stipulated requirements regarding speech intelligibility, the STI requirement must be verified by means of measurement according to (IEC 60268-16). The STI requirement varies depending on who is listening. The standard states that if a student is listening to his/her mother tongue, the STI value should be higher than 0.60. If the student is not listening to his/her mother tongue, the STI value should be higher than 0.68.

Assistive technology

3. Check that the appliances are producing the correct sound power level (LwA)

LALALULULALA, ADOBE STOCK

Air

The value of air quality

Air is important for health and wellbeing. The right temperature, relative humidity and a low particulate level are crucial when it comes to efficiency and the ability to concentrate, as well as in respect of staying healthy. Demand-control is the single best way to achieve a good indoor climate combined with low energy consumption.

When we talk about indoor climate, we often refer to temperature and air quality as two separate parameters, yet research shows that these elements are closely interlinked with each other. In our cold climate, a properly adjusted heating system is just as important for the climate as a well-functioning ventilation system. When it comes to heating and ventilation, school premises are among the most complex environments to deal with. From having empty school premises in the morning, to suddenly having a heat load in the form of students that usually produces more power than the rooms require in terms of heating on the coldest days outside. At the same time, maintaining the same temperature throughout the lesson is of great importance when it comes to how alert the students feel and how much they can take in. The key to maintaining a good indoor climate is the demand-control of heating and ventilation, which also delivers very good results as regards energy consumption.

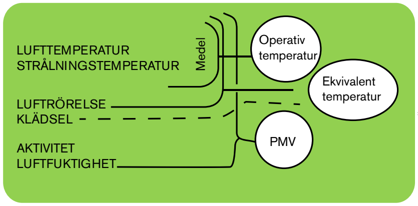
WHAT IS GOOD AIR?

Good air relates primarily to thermal and hygienic factors.

Thermal factors consist of:

- Air temperature (the temperature you read on the thermometer, should be around 21°C in winter for sedentary work such as schoolwork)
- Radiant temperature (surfaces with a temperature other than the room temperature, such as a cold window, affect the perceived temperature; the weighting of air temperature and radiant temperature is known as operating temperature)
- Air movements (the air velocity from diffusers should be max. 0.2 m/s; 0.2 m/s from an air diffuser means that you have to measure a temperature of 22.5°C in order to experience it as 21°C). This can also be used positively in the summer, for example by a table fan having a cooling effect. The term equivalent temperature (perceived temperature) is the weighting of air velocity, radiant temperature and air temperature.
- Relative humidity (should be 40–60%)

The weighting of all four factors gives what is known as PMV (see also below).



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Hygienic factors consist of:

- The air's content of gaseous pollutants
- The air's content of particulate pollutants

RESEARCH / FACTS

There is plenty of research indicating that we need to have a consistent perceived room temperature in order to work well. A consistent room temperature increases our ability to concentrate and our productivity. Another factor that is becoming increasingly evident is the importance of relative humidity combined with the particulate level in classrooms.

How is good air environment achieved? Technical aspects

So how should we proceed to achieve the correct temperature, relative humidity and low particulate level? Since the need for air exchange varies considerably over the course of a year, demand-control is the single best method for achieving a good indoor climate combined with low energy consumption. The air exchange in the summer may need to be 3 times as high as in the winter. If we ventilate with constant flows on the basis of what is required in the summer, the result will be a dry indoor climate in the winter with unnecessarily high energy consumption.

In order to deal with particles using the ventilation, a minimum filter class of F7 is normally recommended. However, these do not deal with the particles that enter the premises on clothes, cleaning products, furnishings and building materials.

This can be achieved using a recirculation system that better filters particles from both the outdoor air and the existing indoor air. By using a combination of active and passive filters, the indoor air can in practice be almost entirely cleared of free-floating particles. Passive filters capture and store particles, bacteria and viruses. Active filters burn them.

An air-conditioning installation is made up of more than just the technical systems. The design of the premises is at least as important, including factors such as volume, solar radiation, choice of materials, etc. In order to produce really good premises, collaboration is required at an early stage.

HOW TO PROCEED IN PRACTICE?

First and foremost, the Public Health Agency of Sweden's general advice on ventilation, FoHMFS 2014:18, should be followed. This states that the outdoor air flow should not be less than 7 l/s per person. A further at least 0.35 l/s per m2 of floor area should also be supplied, such that consideration can also be given to pollutants from non-human sources. When it comes to heating and ventilation systems, all installations, regardless of the choice of system, must be designed with ventilation that is adapted to demand and the season, where the ventilation flow requirement is regulated in sequence with heat regulation in all rooms. Demand-control can be anything from basic systems where the teacher can air the classroom as the temperature rises, to advanced control systems that measure presence and temperature in all rooms and then heat or ventilate as necessary. The systems must also be able to be adapted according to the season, for example so that pressure control of fans is carried out with different setpoint values depending on the outside temperature.
This can be achieved with various technical solutions in all kinds of ventilation systems: natural ventilation, HRV units or hybrid ventilation. The thing these solutions have in common is

that there is no need to reheat the air, as just about all school premises (especially newly built premises) have a heat surplus in the form of students and teachers. However, care must be taken when supplying cold air (approx. 12°C). Supply air diffusers must be carefully selected in order to be sure to avoid draughts.

New construction

In the case of new constructions, there are plenty of opportunities to design systems for a really good indoor climate.
The most common solution is HRV ventilation, where energy in the exhaust air is used to heat the incoming supply air. In newly built schools, there is basically always excess heat as long as there are students in the classroom. As a result, if you also have a control system to demand-control the air flow in all rooms with the aid of sensors, the air does not need to be heated.
If you have the potential to build an air chamber beneath the building and thereby bring in the air via a ground channel (sometimes known as termite ventilation or hybrid ventilation), you can achieve very even temperatures all year round. The channel to the ground works like a heat exchanger, exchanging the temperature of the air with the ground's even temperature and thereby obtaining heat in winter and cooling in the summer.

Refurbishment

In the case of refurbishment, it is a good idea to go back to see how the building was originally intended to work. Older buildings (late 19th century to the 1920s) often had a calorifier system for heating and ventilation combined with natural ventilation. These old systems can occasionally be removed, although they can frequently be restored and complemented with modern control technology to achieve an energy-efficient installation producing good results as regards the indoor climate.

Specific spatial preconditions

Above, we have mainly described rooms intended for learning (classrooms, group rooms, open study environments, etc.). Other environments may require different measures regarding the indoor climate:

Handicraft/art rooms: if there are machines for woodworking, you should have a sawdust extraction system. Textile craft rooms should be supplied with circulating filters,

The old dampers were motorised when refurbishing the calorifier system 100 years after the school was originally built.

This picture shows an example of how old ventilation windows can be supplemented with a motor.

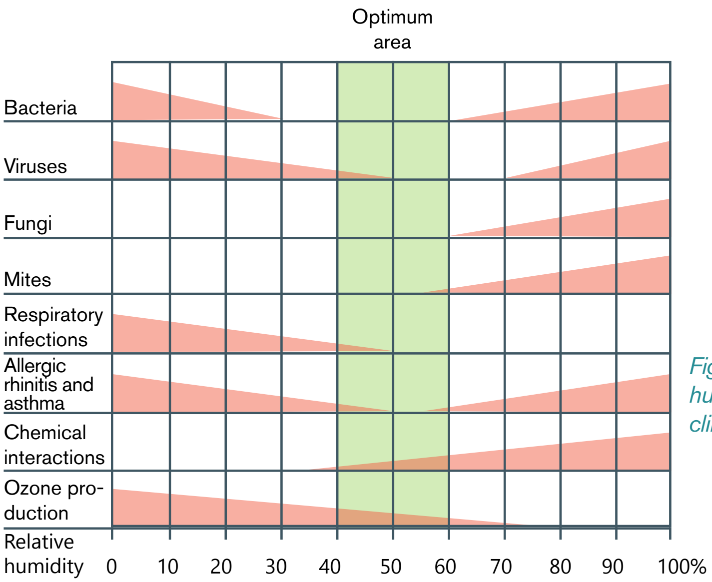

Figure 1. Factors that are affected by relative humidity (RF) and that affect the indoor climate. Scofield-Sterling diagram (7)

as textiles can be associated with extremely large particles. Pottery kilns etc. may also require different ventilation solutions than those required for comfort.

Canteen: The canteen often adjoins the kitchen. If this is the case, it may be appropriate to ventilate the canteen together with the kitchen.

Sports halls: Sports halls often have high ceilings and can therefore be partially ventilated with circulation air, making use of the natural temperature gradient. Changing rooms that include shower rooms should be supplied with a sufficient exhaust air flow from showers and warm supply air.

FACTORS FOR PLANNING AND CALCULATION

Equivalent temperature

When we refer to demand-control, we are talking about controlling according to the temperature we can measure, i.e. air temperature. However, it is the equivalent temperature that is the perceived temperature. It is therefore extremely important for us to plan in relation to radiant heat and air movement.
The choice of diffuser is of very important. Many diffusers are good at maximum air volumes, but do not work as well when the air flows (draughts) are reduced. From experience, we know that we should select a diffuser that produces the same velocity regardless of the flow, or alternatively a stratifier.

Humidity

Humidity not only affects the thermal climate, but also has a direct link to health. There is a reason why there is an increased risk of infection in winter and early spring, when the climate is at its coldest and when it is also at its driest indoors.
When conditions indoors become dry, there is an increase in the electrostatic charge, which results in people attracting charged particles.
Our cilia are also less effective at low relative humidity levels, with the result that we get particles down into our lungs, particles that can also carry viruses and bacteria.

An optimum relative humidity lies in the range 40–60%, which is very difficult to achieve in Sweden in winter as the absolute humidity in the outdoor air is low. The more air we bring in and heat up in the winter, the drier the indoor climate becomes. By reducing the pressure in the winter and increasing it in the summer, at the same time as blowing in colder air in winter, this entails reduced flows in winter and consequently a better relative humidity.

Particles

Our knowledge of the importance of air contaminants has increased and, according to the WHO, they pose a health risk. Fine (< 2.5 µm) and ultrafine (< 100 nm) particles cause an inflammatory response and oxidative stress when they are inhaled.
We now also have the knowledge and methods to measure fine and ultrafine particles. Measurements show that intake filters in ventilation systems do not capture these particles, and that a large proportion of the particles found indoors come in on our clothes and in other ways. We are also witnessing increases in larger particles in our premises, despite the presence of filters. Filters have been added to protect our technical devices, but not us humans. We should therefore focus on circulation purifiers in the rooms in order to deal with the particles that have entered in other ways than via the ventilation system. Heavier particles, such as mineral wool fibres etc., often settle on surfaces, while lighter particles such as microsand and microplastics are present in the air, especially in dry air.

Carbon dioxide

The level of carbon dioxide (CO_2) in the air has been used as an indicator of good ventilation since the 19th century.
The background to the target value of 1,000 ppm of CO_2 dates back to the German professor of hygiene, Max von Pettenkofer, in his paper "*Über de Luftwechsel in Wohngebäuden*". He based his proposal for a hygienic limit of 1,000 ppm of CO_2 on the odour of the individuals who were present in the premises. However, there is also a link between temperature and odour in conjunction with high carbon dioxide levels, which has attracted attention in recent years.

A carbon dioxide level above 1,000 ppm is still considered to be a clear indication that the ventilation is not working sufficiently well to remove contaminants in the air, and that additional controls and measures are required. Portable measuring devices can be used to provide an indication of the air quality. It is now also possible to obtain robust, accurate CO_2 sensors that can be integrated into the ventilation system to demand-control the air flow. As an indicator, the carbon dioxide level works best in large premises such as schools and sports halls holding many people, or in small rooms. The outdoor carbon dioxide level stands at around 400 ppm, while the level indoors is usually in the range 600–800 ppm in well ventilated homes and premises.

TERMS:

1. HRV
Heat recovery and ventilation system.

2. VAV, CAV
VAV (Variable Air Volume) variable flows.
CAV (Constant Air Volume) constant flows.
DCV (Demand-Controlled Ventilation) demand-controlled flows.

3. DEMAND-CONTROL
Controlling heating and ventilation flows according to need, temperature or CO_2.

5. NATURAL VENTILATION
Natural ventilation, i.e. ventilation without fans.

6. TERMITE VENTILATION, HYBRID VENTILATION
The air is conducted through channels in the ground and uses the ground's temperature to heat and cool the air.

Specification of requirements during procurements

TASK AND PROJECT DESCRIPTION

In the project description, it is important to formulate requirements for the indoor climate (thermal and hygienic requirements).
It is important for technical consultants and contractors to understand that it takes more than simply entering an air volume per person to create a good indoor climate. Before a procurement, instead of just going for the lowest price, you should call in the consultants/contractors to ascertain how they have envisioned their system choices and how they intend to meet the stipulated climate requirements. Stipulated climate requirements should focus on a uniform room temperature (20–21°C) and good relative humidity in winter. The requirements must be met until a specified outdoor temperature is reached in spring/summer.
During refurbishment, it is good for the contractors to have experience of similar projects. During the refurbishment of calorifier systems, for example, the contractor should have previous experience of similar systems.

TECHNICAL INSTRUCTIONS

Formulate which technical instructions are to apply. The requirements should include functional requirements as far as possible, i.e. temperature requirements in each type of premises.

CAV

If you want to have CAV flows in smaller rooms, these rooms must be provided with post-heating. However, one consequence of this is that it is not possible to achieve an equally uniform indoor climate in these rooms.

VAV

All rooms must have VAV control. The air flow may vary over the operating period and be adapted to e.g. temperature or air quality.

This solution often entails a lower investment cost for smaller projects compared to DCV, and often satisfies the requirements for basic projects, such as pre-schools and small schools. VAV often provides good energy savings compared to CAV.

DCV

In the case of more advanced demand-control, air flows and temperature are adapted according to need and the occupancy status of the premises, e.g. with different operating cases. This provides a greater opportunity to adapt comfort according to need, and it is often possible to combine airborne and waterborne products to achieve a complete indoor climate system. DCV is a strong contributory factor to achieving a good classification in various certification programmes, such as BREEAM, WELL and LEED. It provides greater opportunities for energy saving, which is primarily an advantage in buildings with high energy consumption for ventilation and air conditioning.

CO2 is an indicator of how often the air in a room is exchanged. It can be useful to measure CO2 in order to check that the air flow is sufficient in the premises and that 1,000 ppm is only exceeded only for a few hours. It is also a good indicator of odours/contaminants in the air. Ventilation control can be performed on the basis of temperature or CO2. As it produces a range of advantages and disadvantages, the solution needs to be adapted based on each individual type of building.

ADVICE IN THE EVENT OF NEW CONSTRUCTION

▪ Demand and seasonal adaptation of air flows must always form the basis for a good ventilation system. If demand-adapted ventilation becomes too expensive, seasonally adapted air flows should be used as a minimum. Remember that the maximum air flows for the summer season may need to be twice as high as the standard flows to make a good indoor climate possible.
For improved particle purification, request a system that recirculates the air through selectable combinations of active and passive filters.
▪ In winter, the heating system is just as important for the indoor climate as the ventilation system. The heating must be controlled

in sequence with the ventilation and must be properly adjusted.
▪ Close cooperation between client, architect and HVAC consultant ensures that the right choice of system is made for the construction project in question. For example, a large volume is more forgiving for the indoor climate than a low ceiling height.
▪ Work with good choices of materials that can buffer moisture and temperature.
▪ Well thought-out choices of sun shielding and lighting have a major impact on the indoor climate, which is why close cooperation with experts in the field of daylight calculation is preferable.

ADVICE IN THE EVENT OF REFURBISHMENT

In addition to the advice regarding new construction, which can also be applied in the case of refurbishment, the following can be highlighted:
Buildings built before the 1930s
▪ These schools were often built for natural ventilation, with plenty of ducts built into the walls and high room heights. These ducts can still be used for exhaust air.
▪ There were often calorifier systems, i.e. heating via heated supply air in ducts, which can be used for ventilation with a modern control system. These can then be supplemented with modern fans, with the air being preheated via the heat source present in the property (district heating, heat pump, etc.). Existing exhaust ducts are used for passive exhaust air.
▪ The dampers located in the attic to counter draughts in winter can sometimes be motorised. If the dampers are in poor condition, they should be replaced with modern dampers. Dampers must always be present for the exhaust air.
▪ If ventilation and heating are demand-controlled in sequence, which can easily be done in the above types of system, you not only achieve a good indoor climate but also low energy consumption. In fact, consumption is often as low as with systems employing heat recovery and constant air flows.
Buildings built between the 1940s and 1970s
▪ These schools were often built for natural ventilation, exhaust ventilation or separate supply and exhaust air units.
▪ With natural ventilation: The dampers located in the attic to counter draughts in winter can sometimes be motorised. If the dampers are in poor condition, they should be replaced with modern dampers. Dampers must always be present for the exhaust air.
▪ The natural ventilation was sometimes based on airing during breaks. These ventilation windows can be motorised in a modern facility using advanced control systems. The control system measures room temperature, outside temperature, wind direction, wind speed, etc., and controls the degree of opening accordingly.
▪ If you have supply and exhaust air units, the units can be supplemented with modern fans, and you can introduce demand-control in each room. The air should be heated to 10–12°C, and a good choice of diffuser is important (good diffusers for variable flow and significant under-temperatures).
More recent buildings:
▪ More recent buildings often have systems with heat recovery. If constant flow fans are used, these should be supplemented with frequency converters for speed control or be replaced with speed-controlled fans.
▪ Demand-control is introduced in each classroom. The air should be heated to 10–12°C, which for most of the year is in accordance with the heat exchanger, and a good choice of diffuser is important (good diffusers for variable flow and significant under-temperatures).

ENERGY REQUIREMENTS

Requirements should be stipulated on the basis of national energy efficiency requirements. For example, there may be limits regarding maximum permitted energy consumption, which specify the amount of energy per m^2 that a building may consume per year. There may also be requirements regarding thermal insulation, heating systems, ventilation units, efficient electricity consumption and measuring systems for energy consumption. The starting point is that the same requirements apply to refurbishments.
In procurements, in addition to referring only to the Swedish National Board of Housing, Building and Planning's regulations, the client support FEBY18 can also be referred to.

FOLLOWING UP ENERGY CONSUMPTION

A building's energy consumption must be followed up and reported 24 months after the building has been brought into service. In order to ensure that energy performance will actually be achieved, a follow-up system is required.

Evaluation & follow-up

Require that consultants and contractors participate in following up the school. Follow up with measurements and surveys. In the case of refurbishment, carry out surveys before and after the refurbishment in order to see the results of the refurbishment, especially if the reason for the refurbishment is a poor indoor climate.

RIGHT FROM THE START

Compare system selections from the outset with calculations that are subsequently followed up at every stage. Then allow the contractor study these calculations. The consultant must develop procedures for following-up, adjustment and operational optimisation.

FOLLOWING-UP

Adjustment of heating systems

The ideal situation is where requirements can be imposed regarding the performance of a low-flow adjustment (applies if you have district heating, a pellet boiler, or similar). After carrying out pipe work and careful venting, the heating system must be adjusted according to the low-flow method.
The adjustment work also includes the installation of thermostats. In addition, the thermostats must be limited so has not to exceed to the relevant maximum room temperature. The adjustment work includes drawing up preset values, performing rough adjustment, checking adjustment in cold weather and installing thermostats/actuators. When checking adjustment, the premises must be empty, the doors must be closed and the temperature must be measured in each individual room. If you have an advanced control system, it may be possible to log temperatures and relative humidity.

Operational optimisation

After adjustment, operational optimisation of the air-conditioning installation must be carried out. Operational optimisation must be monitored for a year so that all the seasons are covered. During operational optimisation, it is necessary to simulate the presence of students in the premises (i.e. enter the correct heat load) and to adjust all setpoint values accordingly. After a number of years, it may be necessary to repeat operational optimisation.

Energy measurement

Distinguish between measuring energy for property electricity and other electricity as well as heat. This also makes future work on energy declarations easier.

Particles

The measurement must be conducted 24 hours a day for 2 weeks, in order to eliminate random events. Measurement intervals must be sufficiently accurate to illustrate conditions during both short and long lessons. The air indoors is affected to a great extent by the air outside, which is why a parallel measurement and correlation with the outside climate is important. It is recommended to measure both the volume and the number of particles. Experience-based evaluation

Surveys

Surveys must be carried out after a year of operation (in the case of refurbishment, surveys must be conducted before and after the refurbishment work).

MANAGEMENT PROCEDURES AND MAINTENANCE

Cleaning the ventilation systems

If you have ventilation systems fitted with filters, these should be replaced after the pollen season. If there is an intake culvert (ground channel), this acts as a gravity filter and must therefore be cleaned after the pollen season.

PROCEDURES FOR KNOWLEDGE MANAGEMENT

Measurement is important for knowledge management, although user surveys are at least as important. By carrying out user surveys, it is possible to see which parameters are important to control with regard to the indoor climate.

TEGELHAGEN SCHOOL ©WHITE ARKITEKTER PHOTOGRAPHER JOHANNA HALLGREN

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We spend on average 90% of our time indoors, and the quality of the indoor climate is extremely important for both our health and our productivity. This applies in all areas, and particularly in schools and pre-schools. Smart students demand a smart school environment!

At the same time, creating a good indoor climate that is energy efficient at the same time is a complex issue. The purpose of this guide is therefore to provide assistance in the day-to-day work of building managers and planners in their planning, procurement and follow-up of projects.

The EU project EFFECT4buildings has worked alongside other countries around the Baltic Sea to jointly develop tools and methods that will lead to increased energy efficiency in buildings. Tools are available for nine areas: profitability calculations, packaging, financing, decision-making, EPC contracts, MSC contracts and Green Lease contracts. In addition, the project has distributed knowledge about various technical solutions. More information about the project can be found at www.effect4buildings.se

Multi Service Contracts (MSC) refer to new construction and refurbishment projects that aim to achieve more than just energy efficiency, and where an improved indoor climate is a key element. This guide is one of the tools that have been developed in this area.

LÄNSSTYRELSEN DALARNAS LÄN