Lüften in Schulen.

Bessere Lernbedingungen für junge Menschen.

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A compact guide to energy research

BINE
Information Service

Ventilation in schools

Better learning conditions for young people

A service from FIZ Karlsruhe GmbH

Straight to the point

In Germany, the shortened overall length of secondary education and increasingly frequent all-day teaching mean that children, adolescents and teachers these days spend more hours of the week in school buildings than previous generations. Modern school buildings need to be able to offer a diverse education and facilitate the use of schools as a learning and living environment. In addition to the socially widely discussed educational approaches, an essential aspect of state-of-the-art schools also includes the provision of buildings with a higher user quality. Given the drop in pupil numbers, this is mainly concerned with the structural and energy-efficient retrofitting of existing buildings rather than with new-buildings. One aspect is architectural design that focuses more on the needs of children and adolescents. However, schools will only be able to offer an environment that fosters learning with modern energy technology that provides, for example, demand-based heating and consistently good air quality. The utmost attention should therefore be paid to the issue of ventilation with all new-build schools or schools subject to retrofitting.

Ventilation strategies usually form a key component as part of a broader energy concept. Such concepts are aimed at retrofitting the building and the technology used, i.e. enabling a building operation that is optimally adapted to the variable conditions at the school. This therefore creates good external conditions for successful learning and for reducing the costs for operating and maintaining buildings. For years, the www.enob.info and www.eneff-schule.de web portals have been monitoring research projects on energy-optimised schools and presenting successful examples and methods.

In recent years, numerous school buildings have been refurbished and some new ones built within the framework of the energy research, the German government's Economic Stimulus Package II and related measures. The implemented measures almost always include ventilation concepts. This BINE Themeninfo brochure has therefore compiled the most important information on ventilation in schools.

The BINE Editorial Team wishes you an enjoyable read

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Requirements made from all sides

A well-planned and suitably adjusted building services technology is required in order to equally ensure energy efficiency, a good indoor environment including a good air quality and an attractive learning environment in schools. Many different requirements need to be taken into account.

School buildings differ significantly from other non-residential facilities. They are densely occupied and used intermittently. Teaching takes place for about 20 to 25 % of the hours per annum and only some of the rooms are also needed for afternoon classes or evening events. As a rule of thumb, many school construction guidelines specify an area of 2 m² and a room volume of 6 m³ per student. Tables and chairs are positioned close to radiators and windows, which exacerbates heating and ventilation. In order to achieve a sufficient air quality in classrooms by just using windows to ventilate requires that a ventilation pause is made every 20 minutes. However, this rarely occurs in everyday situations.

Classrooms need to meet different requirements: in addition to energy-efficient heating and a high air quality, good visual and auditory conditions are also needed. These include the prevention of glare from incident sunlight, energy efficient lighting systems, protection against noise emitted by the outside world, neighbouring classes and ventilation systems, as well as short reverberation times for good speech intelligibility. It should also be possible for users to exercise control over building service systems in the classroom.

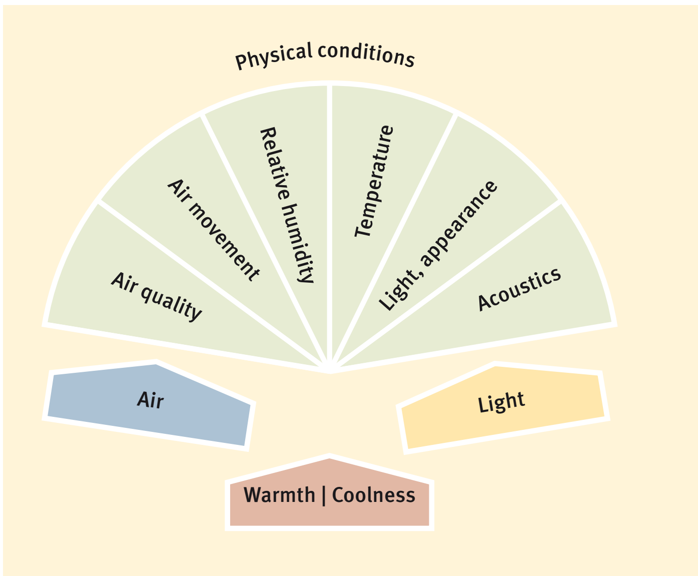
A class of 30 students produces between 2.3 and 2.7 kWh of heat per hour and 500 litres of CO_2. These indoor loads need to be removed to prevent excess heating and for hygiene reasons. CO_2 is the key indicator for indoor air quality. If its value is high, this usually indicates a high odour load. A class therefore needs between 500 and 900 m³ of fresh air per hour.

Ventilation concepts need to be compatible with this context. If it is decided to opt for a mechanical ventilation system, new-build schools offer other ways to structurally integrate the ventilation technology into the building structure than building retrofittings. There are, however, always similar issues with regard to ventilation that need to be clarified such as:

- Which is the most suitable ventilation system for our school?
- Which is a suitable façade for our school?
- How much building automation is envisaged?
- To what extent should the users, i.e. the teachers and pupils, be able to exercise control?

This BINE Themeninfo brochure begins by examining the requirements for a good indoor environment and the design of systems that enable flexible usage times for individual rooms. Another focus is on the different ventilation systems, their control and demand-controlled ventilation. This is followed by the acoustic requirements and experience reports. The topic is rounded off with a look at the energy balance provided by different ventilation concepts.

Fig. 1 *These factors affect a comfortable indoor environment. The air quality, humidity and temperature can be influenced using building services systems.*
Source: Fraunhofer IBP/BINE Information Service



Air quality in daily school life

The previously common, largely inadequate ventilation practices in schools are not without reason. A lot of experience has been gained on this from research projects. Which requirements for a good indoor environment and a high indoor air quality have to be considered? How are internal heat loads and occupancy hours incorporated in the calculations?

Around 50 schools in Germany have so far been energy efficiently modernised as part of projects publicly funded via various donors. Evaluations of such retrofitting projects, which for example have been carried out as part of the German government's Economic Stimulus Package II, show that both the knowledge about ventilation systems as well as the implementation of ventilation concepts have not yet sufficiently arrived in practice. A survey conducted by Augsburg University of Applied Sciences [1] in a southern German government district revealed that of 96 energy-efficiently retrofitted schools, in 60 % ventilation concept was developed. Hereby, in 40 % mechanical ventilation systems were installed and 20 % of the schools envisaged using a ventilation schedule.

By means of surveys, the social scientific support research conducted as part of the Energy Efficient School (EnEff: Schule) research programme has determined, for example, that almost 60 % of students and 50 % of teachers rarely ventilate in the classroom. During break times, this proportion still amounted to at least 40 % among the students and 10 % among teachers. Numerous measurements of the carbon dioxide concentration in classrooms in existing schools verify the poor air quality there (Fig. 3).

Why do people ventilate so little?

The indoor environment comprises the thermo-hygric, acoustic and visual indoor environment as well as the indoor air quality. While humans can perceive thermal, acoustic and visual stimuli very well, they have no sensorium for air quality and humidity.

Humans can adapt within 10 to 15 minutes to odour emissions from people. Humans can assess the air quality when entering a room but lose their ability to judge it a very short time later due to olfactory adaptation. For this reason, persons who stay for long periods in a room no longer perceive the deterioration in air quality and therefore see no reason to ventilate. In contrast, we close windows very quickly if the temperature drops too much or if it is too loud outside.

Which requirements apply to the indoor environment?

Demands on the indoor environment and hygiene in classrooms are laid down in German and international standards as well as guidelines: EN 15251; EN ISO 7730; DIN 18041; DIN 4109; VDI 6022 and Umweltbundesamt 2008 [2]. In terms of ventilation systems, these relate to the overall thermal comfort, the prevention of draughts, air quality and noise emissions. The German Energy Saving Ordinance (EnEV) stipulates the energy requirements.The associated DIN V 18599 series of standards specifies the calculation rules. Using a reference building that is equipped with reference technology in accordance with EnEV and which should correspond to an average situation, the requirement level is specified and

Fig. 2 *Airflow rates for new and existing buildings in accordance with EN 15251 for 30 students including teachers in a 60-m² classroom*

Classification according to EN 15251	Airflow rate for loads per person $m^3/(h\cdot person)$	Airflow rate for low-emission buildings $m^3/(h\cdot m^2)$	Airflow rate in total per classroom m^3/h	Airflow rate in total per person $m^3/(h\cdot person)$
Category II, New buildings	25	2.5	900	30
Category III, Exist. buildings	14	1.4	500	17

the effective, final and primary energy requirement of the building determined in accordance with DIN V 18599. Here a special usage profile is specified for classrooms.

What is thermal comfort?

A person's perception of temperature (thermal sensation) is determined by physical environmental parameters such as the air temperature, surface temperature of the enclosing surfaces and the air velocity in conjunction with the person's activity (internal heat production, moisture released through breathing and skin surfaces) and their clothing. Thermal comfort exists when a person's temperature perception corresponds to their expectations in regards to the thermal environment. This is influenced by the context, for example by the prevailing weather conditions during the last few days or the purpose for which the space is used.

People release heat to their surrounding mainly through convection, radiation and evaporation. The heat dissipated by convection is influenced by the air temperature and air movement in the room. Heat emission by long-wave radiation is caused by the temperature difference between the skin or clothing surface and the surface of all walls and windows in the room as well as the floor and ceiling. The air temperature and surface temperature of the surrounding surfaces ("radiant temperature") are therefore the main variables influencing the thermal comfort in a room In a temperate climate. The two variables are combined to form the operative temperature. It is the most commonly used variable in Germany for describing the thermal environment. With low air speeds below 0.2 m/s, the operative temperature is the average of the air temperature and the mean radiant temperature of the surrounding surfaces.

Draughts can be perceived when the air velocities in rooms with mechanical ventilation systems are too high as well as with window ventilation. In the latter case, users can generally eliminate draughts themselves. Parameters influencing the perception of draughts are the temperature of the air itself, its mean air velocity and the standard deviation of this air velocity as a measure for the occurring maximum values. For example, with an air temperature of 22 °C, an average air velocity of 0.18 m/s with mixing ventilation and 0.22 m/s with displacement ventilation would be permissible. With summer ambient temperatures, increased air velocity can also improve the thermal comfort, since the heat produced by the body can be better released.

What is good indoor air quality?

Air quality is nowadays assessed in terms of health and sensory aspects. As part of the health assessment it is ensured that there are no impermissible concentrations of contaminants in the air that could impair health. As part of the sensory evaluation of the air quality, the air is assessed in terms of odours. Although odorous air constituents are not necessarily harmful to health, odours are often deemed to be unpleasant and often lead to anxiety if people fear that they could be harmful to health.

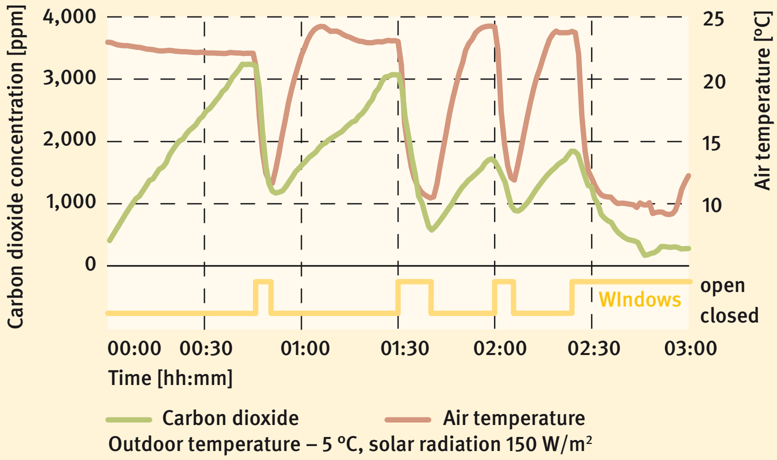


Fig. 3 *Carbon dioxide concentration with intermittent ventilation in a test classroom occupied by 24 CO_2 emitting dummies. Source: Steiger, Hellwig*

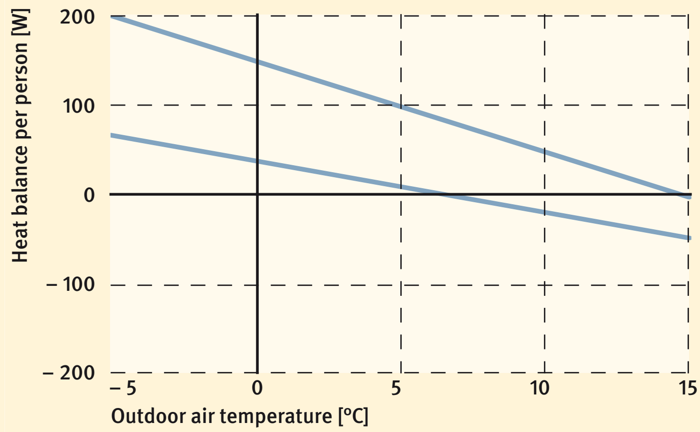


Fig. 4 *Heat balance range derived from the sensible heat emission per person and the ventilation heat losses resulting from the airflow rate per person (without heat recovery) spanning from 75 W/person to 90 W/person and from 17 m³/(h·person) to 30 m³/(h·person). Source: Hellwig*

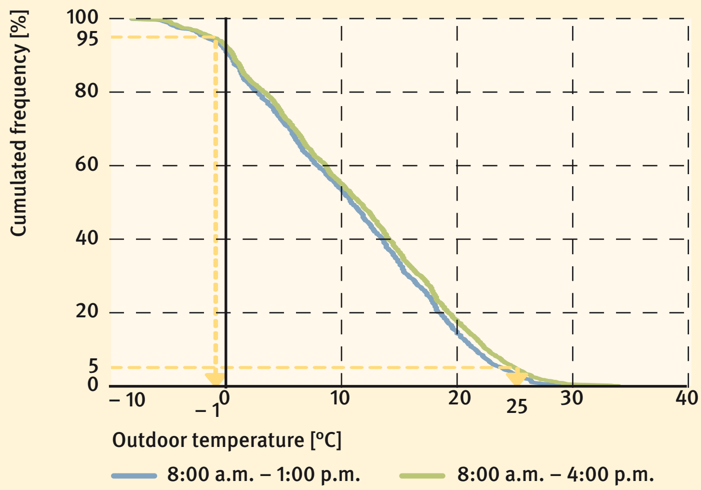


Fig. 5 *Outdoor temperatures during occupancy, average climate for Germany, TRY 04, 2010, average urban area, 50,000 residents, school holidays in Bavaria in 2010. Source: Hellwig*

German Federal Environment Agency's guidelines for the indoor air quality of school buildings

The CO_2 concentration is measured in accordance with the percentage by volume (vol%) or parts per million (ppm): 1,000 ppm = 0.1 vol%. The high occupancy levels in classrooms means that people provide the main source of contamination for indoor air. Through breathing and the vapours formed, people release odours into the room and at the same time breathe out CO_2. The odour intensity correlates with the increase in the carbon dioxide concentration in the room. Since the mid-19th century, this has served as a key parameter for assessing the air quality. The guideline values provided by the German Federal Environment Agency's Indoor Air Hygiene Commission for carbon dioxide in ambient air represent practical recommendations for action and are not toxicologically based benchmarks. Fig. 6 shows the values and the associated recommendations for action.

Fig. 6 *Guideline values for carbon dioxide and recommendations for action. Source: German Federal Environment Agency*

CO_2 concentration [ppm]	Hygienic assessment	Recommendations
< 1,000	Hygienically inoffensive	No other measures
1,000 – 2,000	Hygienically elevated	Ventilation measures (Increase outdoor airflow rate or air change) Check and improve ventilation behaviour
> 2,000	Hygienically unacceptable	Check potential to ventilate the room If required, investigate further measures

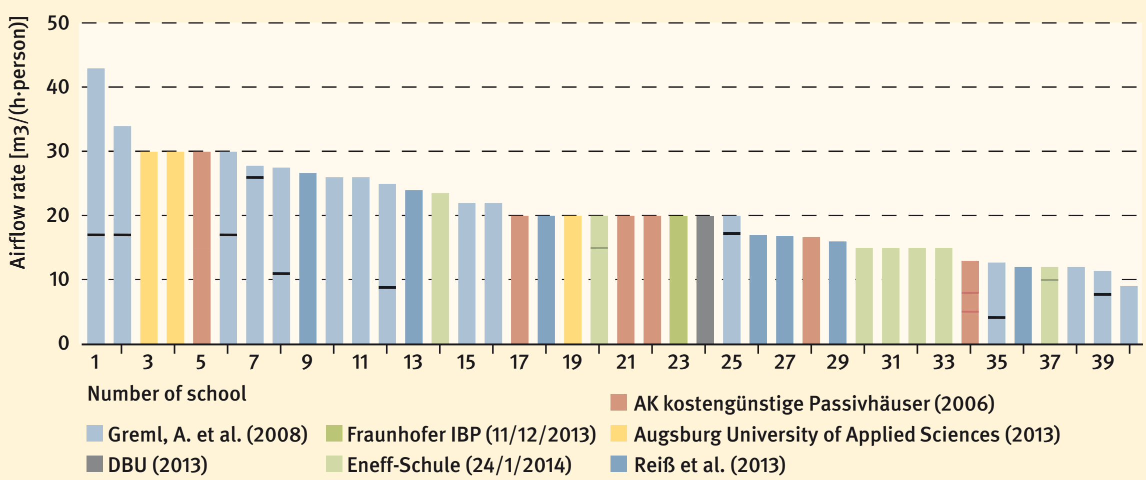
Sources of odours and other substances in the air include people in the room and emissions from furnishing and cladding materials and furniture. Volatile organic compounds (VOCs) play a substantial role in assessing the air quality in health terms. They can only be prevented by using low-emission products. Only the odour emitted by people correlates with the increase in the carbon dioxide concentration in the room, which is relatively easy to measure.

Air flow rate requirements and practical examples

Because the air quality in classrooms is largely influenced by the number of people present, the amount of air required can be calculated based on the desired maximum CO_2 concentration. EN 15251 recommends adding an additional airflow rate for the room floor area, which is aimed at removing the emissions from the furnishing and cladding materials. In Germany, a low-emission rate from furniture and cladding materials is usually assumed. The resulting airflow rates are shown in Fig. 2 for new buildings and existing building stock.

Fig. 7 shows the airflow rates in classrooms implemented using mechanical ventilation systems as part of 40 demonstration and practical projects. 60 % of the projects have implemented airflow rates between 15 and 25 m³/(h·person). One quarter of the airflow rates are

Fig. 7 *Air flow rates implemented in buildings with mechanical ventilation systems in demonstration and practical projects in Germany and Austria. Sources: Hackl, Hellwig*



higher than 25 m³/(h·person). Seven projects implemented airflow rates less than 15 m³/(h·person).

Internal thermal loads and occupancy

The large number of persons in classrooms also leads to high internal heat loads. An adult with sedentary activities releases 75 W to 90 W of sensible heat. Although children are smaller they are mostly more active than adults – including in lessons. The heat dissipated by them is therefore the same as for adults when taken as a whole. For instance, already at an outdoor temperature of about 5 °C and a fresh airflow rate of 17 m³/(h·person), a person with a sensible heat emission of 90 W releases more heat into the room than is transported by the ventilation to the outside (Fig. 4). The ventilation in classrooms is therefore used also to remove internal heat loads at relatively low outdoor temperatures.

Primary schools in Germany are typically used between 8.00 a.m. and 1.00 p.m. The days are longer at secondary schools and all-day schools: 8.00 a.m. to 4.00 p.m. The lengths of the individual lessons vary widely from 45 minutes for a single lesson to 60 minutes and even 90 minutes for a double lesson. Teaching takes place on 190 to 200 days a year. Based on occupancy between 8.00 a.m. and 1.00 p.m. or between 8.00 a.m. and 4.00 p.m., this results in the cumulative frequency distribution for the outdoor temperature during school occupancy shown in Fig. 5. In the average German climate, 90 % of the lessons take place at times when the outdoor temperature lies between – 1 °C and 25 °C. Lower outdoor temperatures prevail during the phase in which the classrooms are heated before the lessons start.

Room design and space requirements

Most school construction guidelines in Germany specify a minimum of 2 m² per student with a ceiling height of at least 3 metres. Flexibly furnishing the classrooms enables the entire surface area of the classrooms to be used as an occupied zone. That needs to be taken into account when designing the ventilation systems.

[1] Hackl, M. ; Hellwig, R.T.: Energetic retrofitting and indoor climate improvement of schools in the administrative district Swabia in Bavaria, Germany. In: Ziemann, O.; Mottock, J.; Pforr, J. (Eds.): Applied Research conference – ARC 2014, Ingolstadt, 5th July 2014. Aachen: Shaker Verl., 2014., p 190-195.

[2] EN 15251; EN ISO 7730; DIN 18041; DIN 4109; VDI 6022; Umweltbundesamt 2008

In practice

Automation assisted window ventilation

The Fraunhofer Institute for Building Physics in Holzkirchen has explored the potential of automation assisted window ventilation in a test-bed. The aim was to suitably position operable windows within the facade and to develop a control concept.

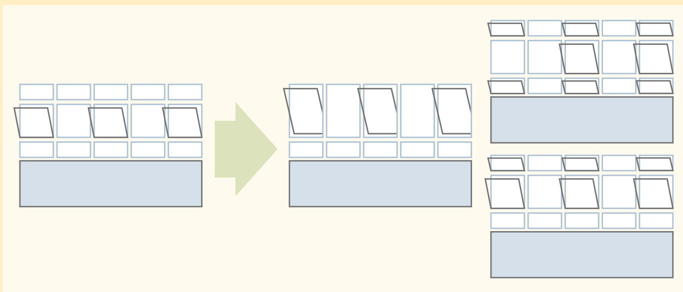
Pivot and bottom-hung windows arranged in double rows proved to be highly suitable for combining with a closed-loop control system. Two separate windows for supply and extract air induce a stable airflow rate in the room, which can be controlled through the opening width. With standard bottom-hung windows arranged in a single row, the airflow rate fluctuates too much with the outdoor weather conditions. In summer, the facade should allow the generous opening of windows.

The closed-loop control system includes both the air quality and air temperature, since both are influenced by the window opening. The weather conditions are additional disturbance parameters. The principle of a fuzzy control system was tested. Both the CO_2 concentration of the indoor air and the room temperature were adequately controlled by the fuzzy controller.

The controller provides a stable control and the opening width of the window adapts very quickly to a rise or fall in the internal heat load caused by persons. A heating control can be integrated into the fuzzy controller or can be operated independently. Tests with actual school pupils have shown that there is general satisfaction with the automation assisted window ventilation. It is certainly important that users can also manually control the ventilation, and this can be easily implemented.

Fig. 8 *Interior of the test-bed facility at Fraunhofer IBP Holzkirchen with dummies that emit both heat and CO_2. Source: Fraunhofer IBP*

Fig. 9 *Facade design in classrooms: A separate supply and extract air opening within the facade is more favourable (right) than a single opening for bothsupply and extract air, such as with only a single row of tilted windows (left). Source: Fraunhofer IBP*



Ventilation and building automation systems

There are three main ways to ventilate schools: natural ventilation, for example using windows, is the most commonly used system. Mechanical ventilation can be implemented as decentralised or centralised systems. Hybrid ventilation combines the benefits of natural and mechanical ventilation. Building automation provides good prerequisites for mechanical ventilation.

Manually operated window ventilation can be organised using a ventilation schedule. To this end a responsible person (teacher or student) is nominated who ensures that the room is aired at regular intervals. In classrooms this is usually every 20 minutes. The airing according to ventilation schedules can be supported using ventilation signals, whereby suitable sensors need to be selected (see CO_2 measurements, p.12).

Mechanical ventilation systems can be divided into central extract ventilation systems (with uncontrolled air supplies via gaps or controlled air supplies via, for example, humidity-controlled air vents) as well as into supply and extract air systems using decentralised or central units. Decentralised ventilation units are named in accordance to where they are installed: under-sill or sill units are positioned below the windows, where outdoor and exhaust air can be routed via sleeves directly through the facade. The units directly feed supply air into the room or remove extract air from it. Vertical units can be freely located in classrooms, since the outdoor and exhaust air can also be routed via short ducts through the facade. Ceiling units are mounted below the ceiling near the facade or anywhere in the room. Outdoor air and exhaust air are fed through the facade. The air can be directly distributed from vertical and ceiling units or can be distributed via an additional network of ducts.

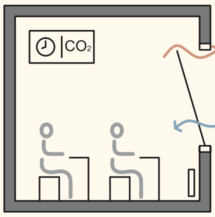
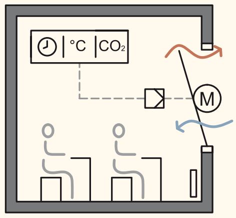
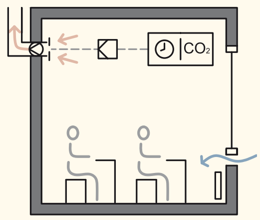
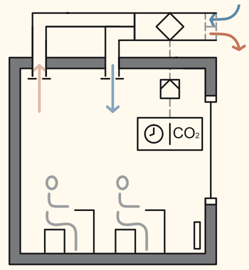
The use of mechanical ventilation systems does not imply that it is possible to dispense with facades that can be sufficiently opened, since natural ventilation can be used for much of the year. Hybrid ventilation systems use natural and mechanical driving forces (Fig. 10). With window ventilation using a schedule, hybrid ventilation and ventilation in summer, the position of the ventilation openings in the facade is also important (see p. 7).

Positioning of supply and extract air opening influences the airflow pattern

Mechanical ventilation systems differ in terms of the supply and exhaust airflow and the resultant indoor airflow pattern. With mixing ventilation, the supply air is injected with high momentum and mixes quickly with the room air. Mixing ventilation can generally be generated with all the aforementioned mechanical ventilation systems and at all the positions possible for decentralised devices. Displacement ventilation stratifies the indoor air quality, whereby fresh air is supplied to the lower occupied zone. To achieve this, the supply air must be fed in near the floor level at a lower temperature than room temperature. The fresh air is then warmed by the students, rises up their bodies and can be inhaled. The stale air accumulates in the upper part of the room and therefore has to be extracted near the ceiling. Because of their positioning in the room ceiling units only allow for mixing ventilation. As a result of their different indoor airflow patterns, mixing and displacement ventilation have different ventilation effectiveness. This describes the ratio of the difference of the concentration of air contaminants in the extract and supply air to the difference in the concentration at a particular spatial position. A value of “1” indicates that the air quality in the specific room position is equal to the exhaust air quality. Values greater than “1” mean that the air quality in the specific room position is better than in the exhaust air. Mixing air systems achieve values around “1”. Displacement ventilation systems can achieve up to “2” in occupied zones.

The airflow rates specified in Fig. 2 are for mixing ventilation systems. Centralised or semi-centralised mechanical ventilation systems can generally implement the outdoor airflow rates required here. Ceiling and vertical units generally have a capacity of 700 m³/h while under-sill and sill devices have capacities between 100 to 250 m³/h per unit. In the latter case several devices are used.

When feeding in the air it needs to be ensured that the supply air reaches all room areas. The manufacturers specify the respective depth of penetration, which refers to how far the supply air flows into the room. However, this can be reduced under certain circumstances by room fixtures such as ceiling lights or beams. A suffi-

Ventilation system	*Natural ventilation*		*Exhaust air systems*	*(Semi-)centralised ventilation systems*
Concept	*Window ventilation with ventilation schedule or ventilation signals*	*Controlled, automation assisted window ventilation*	*Controlled exhaust air system*	*Air handling unit for several rooms*
Device type				*Internal / external device*
Schematic				
Description	*Ventilation via windows; ventilation according to a ventilation schedule or air quality sensors signal poor air quality in the classrooms.*	*Temperature and air quality sensors control the air quality via automatically adjustable windows.*	*Exhaust air systems with automatically adjustable vent openings or overflow valves. Demand control using air quality sensors/ presence detectors/ schedule.*	*An air handling unit ventilates several classrooms with centrally handled outdoor air. Air duct system required. Room-based demand control using air quality sensors/ presence detectors/ schedule.*

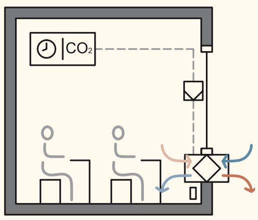
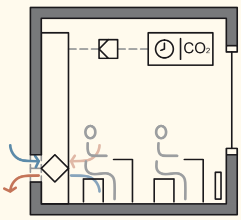
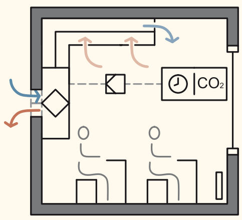
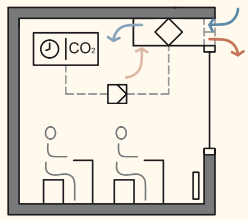
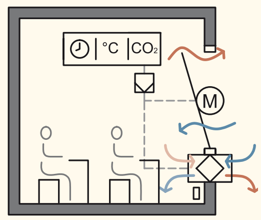
Decentralised, room-based ventilation units *(one ore more ventilation units per room)* *Supply and extract air fan and heat recovery*				***Hybrid ventilation***
Under-sill /Sill unit	*Vertical unit*	*Wall unit*	*Ceiling unit*	*Hybrid ventilation*
				
3 – 5 units ventilate a classroom. Demand control provided by air quality sensors/ presence detectors/ schedule. No ventilation ducts required.	*One unit ventilates a classroom. Demand control provided by air quality sensors/ presence detectors/ schedule. Depending on the installation location, short ducts for outdoor air and exhaust air required. Displacement ventilation possible.*	*One unit ventilates a classroom via a short air duct system. Demand control provided by air quality sensors/ presence detectors/ schedule. Depending on the installation location, short ducts for outdoor air and exhaust air required.*	*One unit ventilates a classroom. Demand control provided by air quality sensors/ presence detectors/ schedule. Air handling, sound absorber and air distribution can be accommodated in a stepped suspended ceiling section. Visible installation possible.*	*Combination of automation-assisted window ventilation and a mechanical ventilation system. Operation mode and demand control are controlled via temperature and air quality sensors/ presence detectors/ schedule.*

Fig. 10 *Overview of possible ventilation systems. The FGK Status Report 22 contains further information. Source: Hellwig/Hackl*

cient depth of penetration is also required when there is a reduced airflow rate, for example with demand-controlled ventilation with partial occupancy.

Heat recovery and heat exchangers

Mechanical ventilation systems provide the opportunity to use a heat recovery. With decentralised units the heat recovery rate ranges between 55 and 90 %, whereby most devices achieve between 80 and 85 %. Recuperative heat exchangers (for example, plate heat exchangers) are generally used for decentralised units. They do not allow moisture recovery. Because of the moisture released by the students through respiration the relative humidity is generally in the normal range. Mixing ventilation systems remove more moisture from the skin (including mucous membranes) than other ventilation systems. If there are complaints about dryness in winter it should first of all be checked whether the indoor air temperature can be reduced, which these days is often over 22 °C. If there are any problems, the mean air velocities and the maximum values of the air velocity should also be checked (see Thermal comfort, p.5).

The heat exchanger should allow a mode of operation aimed at meeting the objectives of comfort and energy efficiency. It should be taken into account that during the transitional seasons and in summer, when the temperature differences between the indoor and outdoor air is small, the power consumption of the fans in primary energy terms may be higher than the amount of energy that can be recycled via the heat recovery system. For this reason, a bypass circuit should be provided. With corresponding outdoor temperatures of about 10 °C or higher, the bypass valve can be partially opened – or even fully opened at higher ambient temperatures. This enables the airflow to bypass the heat exchanger and stops the classrooms from overheating. The bypass control also enables night-time cooling with outdoor air, which is useful when the room has a medium to high storage capacity. Not all ventilation units available on the market have such a bypass valve; some devices provide an automatic external and indoor air temperature control ofr the valve.

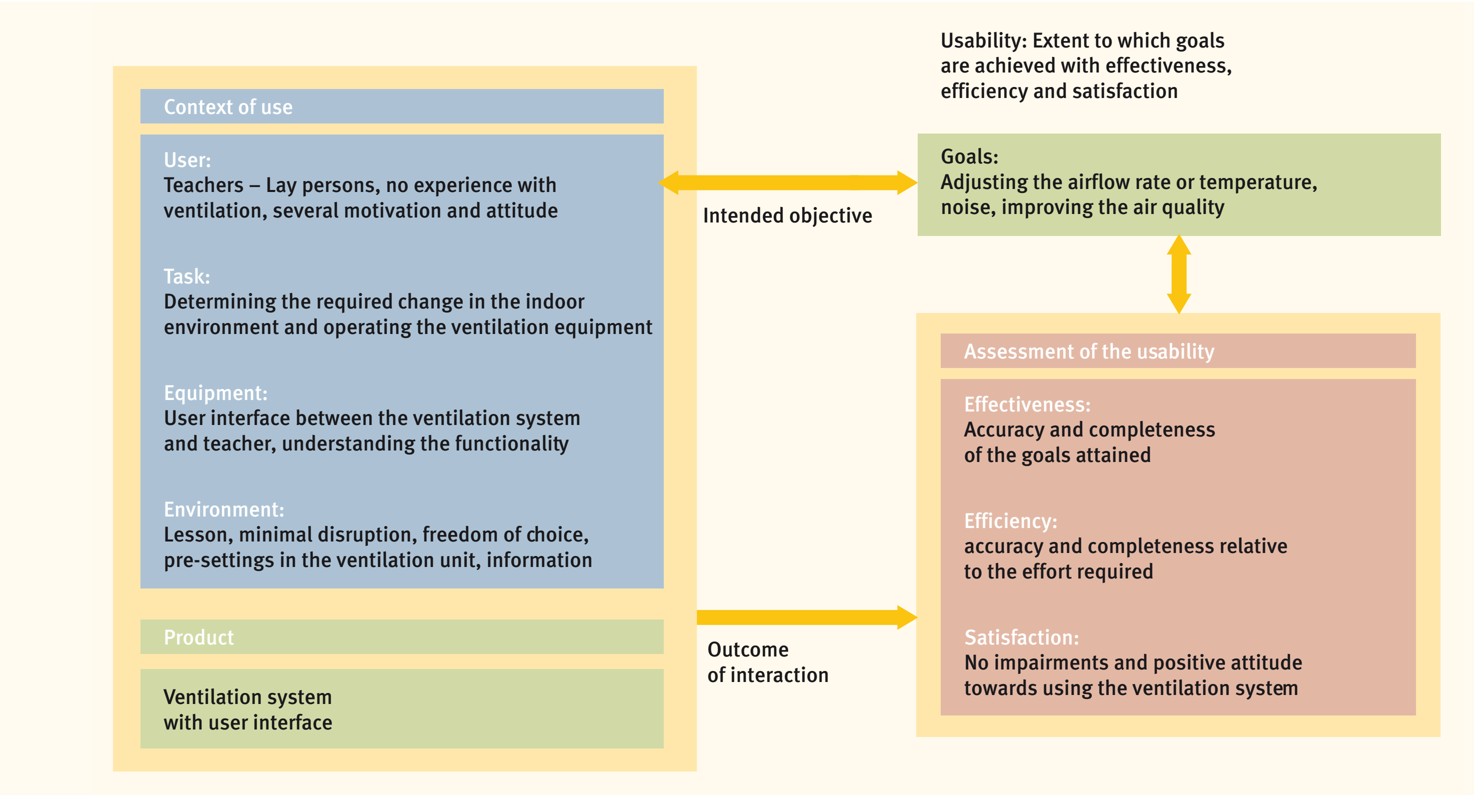
With very low outdoor air temperatures, condensation and icing can occur in the heat exchanger. Therefore before entering the heat exchanger, the temperature of the outdoor air can be raised using an electrically operated pre-heater, a reduced supply airflow rate with a constant exhaust airflow rate, or by using mixed exhaust air. Alternatively the heat exchanger can be bypassed using a bypass valve. Some ventilation units have a supplementary heater. Some devices can cover the entire room heating load; others on the other hand warm the supply air only up to room temperature. A supplementary heater can be operated electrically, using hot water or by mixing in recirculating air.

If the ventilation unit contains a cooling coil, this is operated with cold water. Some devices can be optionally supplemented with an adiabatic evaporative cooler installed in the extract air duct. Evaporating water in these coolers lowers the temperature of the extract air before it is fed through the heat exchanger to the outside. The lowered temperature of the extract air cools the incoming fresh outdoor air in the heat exchanger.

Maintenance and hygiene

To ensure that ventilation systems do not themselves become a source of air pollutants, regular maintenance is required. Ventilation systems in non-residential buildings such as schools must undergo regular hygienic inspections in accordance with The Association of German Engineers' guideline VDI 6022. The guideline defines hygiene-relevant requirements for designing, implementing, operating and maintaining ventilation and air conditioning systems. It also stipulates which persons may perform hygiene inspections, whereby it is not sufficient to just use appropriate materials and products. Only professional planning, installation and operation in accordance with the requirements and the implementation of preliminary and repeat hygiene inspections can ensure permanent hygienic operation. The preliminary inspection is used to establish the specific issues that need to be checked during the regular repeat inspections. In systems without air humidification, which is generally the case in schools, repeat inspections should be carried out every three years [1]. VDI 6022 lists the type, scope and time intervals for inspecting the various system components. For example, air filters

Fig. 11 *Usability framework for the usability of ventilation systems in schools on the basis of EN ISO 9241-11. Source: Hellwig*



should undergo visual and olfactory inspections every three months and the differential pressure on the filters should be checked every six months. Stage 1 filters have to be changed every twelve months at the latest, while stage 2 filters need to be changed every 24 months.

Building automation

In public indoor spaces, people often do not feel personally responsible for switching off power consuming devices, such as when leaving rooms. That can be countered using building automation. Outside the occupancy period, it can introduce changes that are effective in energy efficiency or indoor environmental terms. These include, for example, switching off artificial lighting in classrooms at specific times (for example during the breaks), activating ventilation equipment via presence detectors, or providing pre-and post-ventilation and their demand control. Other options include automatically actuating solar shading systems outside the occupancy period when there is high solar irradiance or providing default states that are sensible in energy efficiency and indoor environmental terms but which can be overridden by the occupants (default settings, reduction or support modes or shutting down the heating overnight).

Usability of building automation

If users are able to use a control unit to change the control parameters in a room, this is often viewed critically in terms of the system operation. Nevertheless, this also offers opportunities to increase the user satisfaction (infobox, top right). In general, the usability depends on the context in which a product is deployed (EN ISO 9241-11). The context of usage encompasses the user behaviour, represented by defined user prototypes, the work task, equipment as well as the physical and social environment. The three guiding criteria for the usability of a product are its effectiveness for solving the problem, the efficiency and user satisfaction. The application framework for the usability of ventilation systems in schools is shown in Fig. 11. In addition, the usability of the user interface also needs to be checked. In order to satisfy the guiding criteria, designers should put themselves in the shoes of users who do not have the technical knowledge and understanding of professional experts. The characteristic features of a suitable building automation for schools are summarised in the infobox on page 12.

Demand-controlled ventilation

Demand-controlled ventilation refers to the optimised operation of ventilation systems where the airflow rate is adjusted by means of an open or closed-loop control system to the fresh air demand [2]. This can be done using switched or controlled fans, louvres or diffusers to enable variable airflow rates or by using motorised ventilation elements in the facade.

User control and user satisfaction

Users satisfaction increases if the occupants are able to adjust technical equipment or systems in the room as soon as their own requirements change or the indoor environment changes. Here three aspects are important: the users should be familiar with the opportunities for adjusting the systems. In addition they should also be able to understand the use of the interface intuitively, and the technical system should also respond to their control action. Placebo switches, which have been discussed many times, are entirely unsuitable in this regard. They adversely affect users' confidence in the building, its technical systems and the building operator. The needs and complaints made by users should be taken seriously.

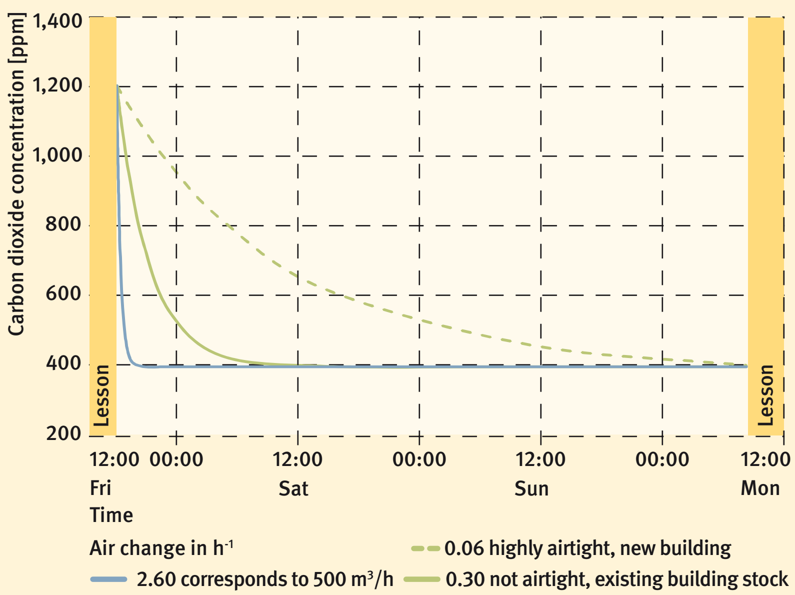
With open-loop controlled systems, the airflow rate is increased or reduced manually, according to people's presence, or using a time programme. With closed-loop controlled ventilation, the need for fresh air is continually measured using air quality sensors (in schools: CO_2 sensors). The outdoor airflow rate supplied to the room is adjusted to meet the identified need using a controller. Basic ventilation in the presence of people can be triggered using a presence detector. The ventilation unit switches on not just when a CO_2 threshold (for example, 1,000 ppm) has been exceeded but as soon as the presence detector detects a person's presence.

Teachers should be able to adjust the operating mode, for example the airflow rate, since this increases the acceptance of the ventilation system. It also enables to respond to the individual needs of different users. Most decentralised devices enable the airflow rate to be adjusted in multiple stages or continuously. Some manufacturers offer pre-programmed operating modes adjusted for use in schools. For example, the temperature and airflow rates can be adjusted using holiday and weekly programmes. In addition, most devices are equipped with a manual mode. This enables users to access the various parameters directly. However, if the ventilation system is to enjoy a high level of acceptance in the classroom, it is essential that the operating module (user interface) is simple and easy to use.

Outside the occupancy period and in periods without ventilation requirements, it should be possible to switch off the ventilation system or reduce the airflow rate to a minimum value. To ensure that the air quality is perceived as pleasant when re-entering the room, the room should be aired just before the occupancy period even if users are absent (interval timer).

Once the classroom is no longer occupied it should be fully ventilated, i.e. the air should be exchanged via a ventilation system until the outdoor air quality is again attained in the space. The airtight construction usual these days, which is aimed at reducing uncontrolled heat losses through infiltration and exfiltration (such as through leakage in joints and wall connections between windows and doors), means that the stale air would otherwise remain in the room until the next morning when school begins. Fig. 12 shows that on Fridays after the last lesson in an air-tight classroom (infiltration and exfiltration air change 0.06 h^{-1}), the CO_2 concentration (the initial value in the example is 1,200 ppm) decreases only very slowly. The outdoor air concentration (400 ppm in the example) is only reached after 65 hours on Monday morning. If the room, however, is additionally ventilated with a ventilation system, the outdoor air concentration is reached again after just one hour and 20 minutes. With a non-airtight construction with old windows, the outdoor air quality is achieved long before the next morning. Such values have already been demonstrated in practice. If the air is only exchanged in the morning (pre-ventilation), odours tend to become fixed in the room.

Fig. 12 *Decrease in the CO_2 concentration in a classroom with different air change rates after lessons on a Friday at 3.00 p.m., initial CO_2 concentration inside: 1.200 ppm, outside: 400 ppm Source: Hellwig*



CO_2 sensors and CO_2 measurement

If carbon dioxide sensors are used for demand-controlled ventilation, these use usually non-dispersive infrared spectroscopy. There are types that work with either one or two infrared sources and with either one or two wavelength ranges for the infrared source. The type of design determines the costs but also the reliability in terms of the measurement accuracy and long-term stability. Sensors with only one infrared source and only one wavelength range for the infrared source require an algorithm that ensures regular comparison: the minimum CO_2 concentration measured in a given period is assumed to be the outdoor air concentration – usually 400 ppm. However, the outdoor air concentration must be regularly achieved for this (usually once every 24 hours). As shown in Fig. 12, this can prove to be difficult. Therefore such sensors are not really suitable for use in very dense or exclusively naturally ventilated rooms with high occupancy. If such sensors are deployed when using mechanical ventilation systems, the room should be immediately purge ventilated after it has been used. It should be regularly checked whether the CO_2 sensors used still measure correctly to avoid unnecessary ventilation.

All sensors generally measure the absolute CO_2 concentration in the room. This is easier to achieve than additionally detecting the outdoor air concentration in order to use the difference between the indoor and outdoor air as a measure of the air quality. In urban areas in Germany, the outdoor concentration can vary within one year by up to 200 ppm. In late winter, the values can reach up to 600 ppm. Overall, a seasonally increased CO_2 concentration in the outdoor air and a measurement error can, when added together, create a classification error amounting to a whole air quality class according to EN 13779. When interpreting CO_2 measurement values, the outdoor air concentration and the CO_2 sensor type should therefore be taken into account.

Hallmarks of good room automation on

For the purposes of achieving high usability, well-functioning room automation provides users with predictable and "normal" indoor environmental conditions appropriate to their expectations. These control systems are designed in accordance with the activities that normally take place in the respective room. The default values that determine a user's first impressions upon entering the room should therefore be carefully specified. Good room automation offers possibilities to intervene (exert an influence) because not all the users' wishes are predictable, the wishes of different users differ, or the requirements change depending on the activity. The users should be able to intuitively recognise their possibilities for making changes and be able to clearly assign them. The indoor environment systems should respond promptly to the changed settings in order to provide the users with positive feedback following their intervention. Simplicity, clarity and a limited choice are more useful than an excessive range of complicated options.

[1] Fachinstitut Gebäude-Klima e.V. Bietigheim-Bissingen (Hrsg.): Raumlufttechnische Anlagen. Leitfaden für die Durchführung von Hygiene-Inspektionen nach VDI 6022. Aug. 2003. FGK Status-Report 15

[2] Fachverband Gebäude-Klima e. V., Bietigheim-Bissingen (Hrsg.): Bedarfslüftung im Nichtwohnungsbau. 2014. TGA – Report 2014. Nr. 1

In practice

Olbersdorf school

The selected package of measures for the school in Olbersdorf, comprises vacuum insulation in the base of the building, the use of the ground as a renewable energy source, an acoustic and chilled ceiling (capillary tube mats) and the use of electrochromic glazing as solar shading in highly exposed classrooms. External solar shading was not possible owing to conservation reasons. Light-directing blinds and presence and daylight-dependent lighting control help to ensure a good supply of daylight. The artificial lighting is switched off centrally after the end of the school day or via a presence detector ten minutes after the last impulse.

In order to achieve the best possible integration of demand-controlled ventilation in a listed building, existing ventilation stacks that formed part of a historic stack ventilation system were used and combined with box-type windows with. The supply air is fed through the air space between the two glass panes of the box-type windows and in doing so is preheated. The exhaust air is discharged through CO_2-controlled DC fans in accordance with the demand. The stacks were upgraded with additional shut-off flaps and sound absorbers. The ventilation systems are switched off at night. It is possible and desirable to open the windows since the exhaust systems only provide basic ventilation for the classrooms.

Fig. 13 *Exterior view of Olbersdorf school. Source: Milke, Planungsgesellschaft AIZ*

Fig. 14 *Building summary Olbersdorf school*

	Retrofitting goals
Built in 1927/28	Energy-efficient retrofitting 2009 – 2011
Listed building: Important regional example of functional school construction in the Weimar Republic with hints of Expressionism	Reduction of the energy consumption to become a 3-litre school
Special school for 180 pupils	Indoor environment that fosters learning:
Gross floor area (DIN V 18599): 4,600 m²	- Improvement in the indoor air quality
Final energy before retrofitting: 235 kWh/(m² a)	- Improvement of the room acoustics
Developer: Rural District of Löbau/Zittau, Administrative District Office	- Decreasing summer indoor temperatures
	Robust and user-friendly design suitable for everyday school life
	Low-maintenance technology
	Use of exemplary products under building conditions experienced in practice

En passant

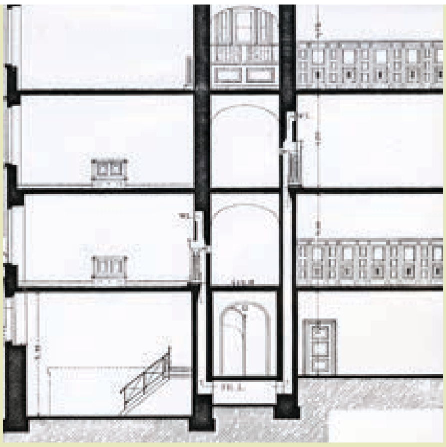


Fig. 15 *Supply air stack with preheating, primary school, Dom-Pedro-Platz 2. Source: City of Munich, Germany*

Stack ventilation

In Germany, stack ventilation systems were widely used from around 100 years ago until into the 1950s. Today, they are no longer in operation and have been partially or completely dismantled. These systems use the principle of thermal buoyancy, whereby rooms are ventilated via ventilation stacks. The heat emission from the pupils in the room drives the ventilation. The high occupancy of classrooms provides good prerequisites for using stack ventilation. Particularly common were systems with supply and exhaust air through separate stacks in each classroom.

A project by the Augsburg University of Applied Sciences examined the potential offered by stack ventilation in today's classrooms in a building dating from 1895. The old supply air stacks were reactivated, provided with adjustable air intake grills and operated without additional preheating for one year. Two classrooms with supply and exhaust air shafts were compared with normal window ventilation. The CO_2 concentration and air temperature were measured in all classrooms. In contrast to window ventilation, for which only 2 m^3/(h·person) were measured, the airflow rates per person in the rooms with stack ventilation achieved around 14 m^3/(h·person) in winter. The stacks provided a pre-heating effect between 0.5 K/m (1st floor) and 0.7 K/m (3rd floor). In winter, 50 % of the CO_2 concentration values measured with stack ventilation were below 1,350 ppm, while with window ventilation the value reached 1,800 ppm. Compared with window ventilation, in summer the rooms with stack ventilation had lower temperatures in the morning and also during class.

Fig. 16 *Historic exhaust air stacks in the attic. Source: Augsburg University of Applied Sciences, E2D, Bauklimatik, 2010*

Good acoustics in classrooms

Good acoustics improves the concentration and is important for students with impaired hearing, non-native speakers and for all language teaching. In many classrooms the acoustic situation is not optimal. The issue of acoustics should therefore also be taken into consideration when designing the ventilation.

Irrespective of whether schools are ventilated using windows or by means of mechanical ventilation systems, good acoustic conditions are required in all classrooms. This applies both to the perception of ambient noise as well as to the noise emitted by technical systems. How the room acoustics are perceived essentially depends on the reverberation time. In addition, the noise situation is also important for communication in the room. For this reason, DIN 18041 [1] defines not only requirements for the reverberation time but also recommendations for the noise level in rooms. Before considering the sound propagation in a room (room acoustics), the noise inputs (building acoustics) need to be first of all minimised so that the room is quiet. The following section presents the relevant requirements for noise in rooms and then briefly describes the room acoustic requirements for the reverberation time.

Noise level in rooms

DIN 18041 defines and uses the ambient sound pressure level for building-related noises as a parameter for noise in rooms. The value of the ambient sound pressure level takes into account the entire sound pressure level in each space being investigated. This includes external noises and noise from neighbouring rooms, building service installations, sanitary installations and permanently installed media technology devices. To predict the value, partial assumptions about the different noise components need to be taken. The external noises as well as noise from neighbouring rooms can only be predicted if an estimate is made of the noise level outside or in the neighbouring rooms as well as of the sound insulation provided by the respective (external) building components. Noises from building services and media technology equipment are easier to predict. In many cases it can be assumed in practice that these two noise components determine the building-related ambient sound pressure level. The external noises as well as noise from neighbouring rooms should be sufficiently low as a result of the sound insulating properties provided by the structural components (ceilings, walls, doors, windows). In measurement terms, the building-related ambient sound pressure level can be determined in empty rooms ready for use.

Fig. 17 shows the classification of the ambient sound pressure level caused by the building-related noises in accordance with the room usage requirements with several comments. In addition to these requirements from DIN 18041 for the total sound level in rooms, there are also other regulations that take into account specific design aspects.

Guideline VDI 2081 [2] lists reference values for the A-weighted sound pressure level for noises from ventilation and air-conditioning systems in ventilated rooms. For classrooms and seminar rooms, it specifies a maximum value of 35 dB(A) with high requirements and

Fig. 17 *Requirements for building-related noises according to DIN 18041. Source: Akustikbüro Oldenburg*

Acoustic requirement for the room usage	***Ambient sound pressure level of the building-related noises***	***Note***
Minimum	$L_{NA, Building} \leq 40$ dB	*Minimum requirement; only suitable for average distances*
Average	$L_{NA, Building} \leq 35$ dB	*Minimum requirement; for people with hearing losses or difficult/ foreign language communication*
High	$L_{NA, Building} \leq 30$ dB	*For people with hearing losses; for difficult or foreign-language communication*

40 dB(A) with low requirements. DIN 4109 [3] also specifies values for the permissible sound pressure level from building services equipment in classrooms. This specifies a value of 35 dB(A) for the maximum sound pressure level.

Reverberation time in rooms

DIN 18041 defines the acoustic quality of a room as follows: “Suitability of a room for specific sound performances, in particular for adequate oral communication and musical performances at the places designated for using the room.”

For rooms with reverberation time requirements (called Group A), the standard defines three types of usage. Examples for the usage types in school buildings include:

Music · Music teaching spaces with active music-making
Language · Meeting spaces, assembly hall
Teaching · Classrooms, seminar rooms, conference rooms

For each of these usage types the standard lists recommendations for the reverberation time in accordance with the room volume (Fig. 18). According to this, a classroom with a room volume of 250 m³ should have a reverberation time of 0.6 seconds at medium frequencies. In addition to specifying the target value for the reverberation time, DIN 18041 also specifies the frequency dependence of the reverberation time. Here it differentiates between the usage types Music and Language/Teaching (see recommendations in Fig. 19). In this case at medium frequencies the reverberation time may not deviate from the recommended nominal value by more than +/- 20 % for the corresponding volume. For the aforementioned classroom, this is therefore 0.48 to 0.72 seconds. This tolerance range is sensible because there is always a certain amount of impreciseness in the planning and people can also hardly perceive small differences. The room acoustics should generally always be designed in accordance with the frequency.

The standard also lists other spaces in school buildings such as foyers, hallways and offices, etc. (called Group B) where the noise needs to be minimised in order “to allow oral communication over short distances in accordance with the purpose”.

The revision of DIN 18041 begun in October 2013 was necessary in order to take into account trends in modern architecture and to codify requirements regarding the room acoustics for implementing inclusive education. Thermally efficient buildings require other room acoustic measures instead of providing standard absorbers on the ceilings because the ceilings sometimes provide a thermal storage function.

DIN 18041 from 2004 is widely accepted as the “acknowledged rule of technology” in the field of room acoustics. No major changes in the specifications and recommendations are to be expected in the current revision.

Lombard effect

If a speaker increases his or her speech volume and sometimes the tone level when there is a noisy background environment, this is known as the Lombard effect. Loud background noise levels can be triggered by noise inputs or too little damping (prolonged reverberation) in a room. Whenever many people communicate with one another in a room (for example in schools and canteens), the Lombard effect creates a mutual „build up“ and a significant increase in the overall sound level. Conversely, a low noise level and an appropriate reverberation time leads to a decrease in the overall sound level. This is known as the inverse Lombard effect or the coffee house effect.

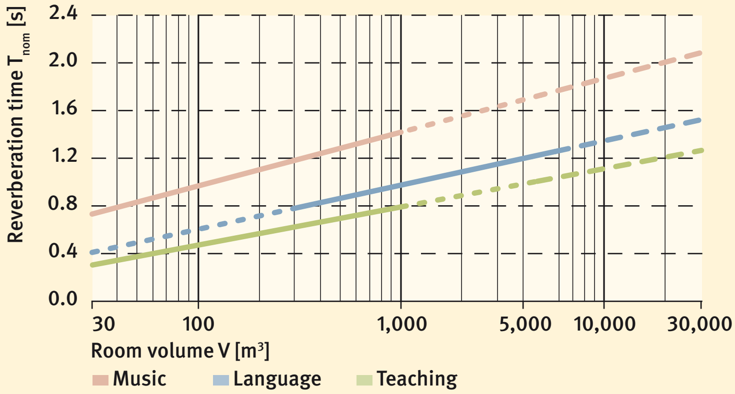


Fig. 18 *Values for the reverberation time T_{nom} according to the room usage and volume according to DIN 18041. Source: Akustikbüro Oldenburg*

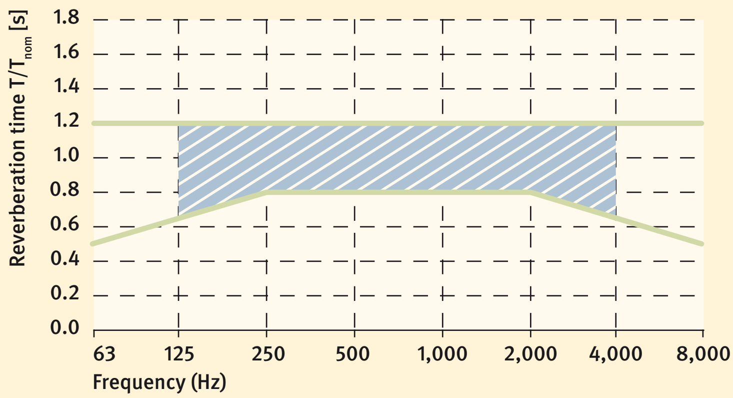


Fig. 19 *Frequency dependence of the reverberation time based on T_{nom} for the Language and Teaching categories. Source: Akustikbüro Oldenburg*

[1] DIN 18041 – Acoustic quality in small to medium-sized rooms, Berlin: Beuth, May 2004 (currently being revised)

[2] VDI 2081 Part 1: Noise generation and noise reduction in air-conditioning systems. Berlin: Beuth, July 2001

[3] DIN 4109 - Sound insulation in buildings; requirements and testing. Berlin: Beuth, November 1989

Experiences and communication

If a retrofitted school building is equipped with ventilation, the user expectations are high. As part of the necessary optimisation of systems during operation, much depends on the chosen communication strategy. The „Soft Landings“ process developed in the UK offers an interesting approach in this regard.

Surveys in schools to be retrofitted or which have already undergone retrofitting show that there are very high expectations regarding the building fabric and the new ventilation technology [1, 2]. The user's expectations are always based on past experiences with the old building. For example, the expectations tend to focus on aspects deemed not so good in the old building. In addition, the expectations also reflect the societal state of knowledge and the benchmarks set prior to the planning (Fig. 21). All retrofittings and new buildings are then judged by these benchmarks. It is therefore important to raise realistic expectations.

Mechanical ventilation systems have been investigated in Austria [2]. Although 40 % of the 270 students surveyed rated the systems with 1 or 2 (excellent or good) on a 5-point marking scale, a quarter rated them with 4 and 5 (just passed or fail). 56 % of the approximately 130 teachers surveyed, on the other hand, were either rather or very satisfied. Half of the teachers rated the ventilation systems as user-friendly. The reasons for the not consistently positive assessment are shown in Fig. 21. The most common issues mentioned were air quality problems, overheating or insufficient heat supply.

Potential for improvement can be derived from the two aforementioned investigations in Austria and Germany. Although the measurements of the CO_2 concentrations show a significant improvement in the air quality in comparison with the existing buildings, the air quality is perceived as insufficient in some schools with ventilation technology. The measurement results show that the temperature in winter is quite high in some classrooms. The air is generally considered to be less fresh when at a higher temperature. Steps for lowering the temperature in these rooms have already been made. In addition, the rooms should be consistently (purge) ventilated after occupancy to remove odours immediately (Fig. 12, p. 12). Additional pre-ventilation during the morning at temperatures at the lower end of the comfort range helps users to perceive the air as being fresh upon entering the room.

In Austria, only about one-third of the teachers were able to control the ventilation system's airflow rate. The temperature could not be adjusted. The ability to use technology to control the indoor environment is, however, desired (see infobox, page 11), whereby user-friendliness is expected (Fig. 11). An interesting finding of the social scientific support research conducted as part of the EnEff:Schule initiative is that a high degree of automation at schools counters the energy-conscious behaviour of the pupils.

Communications strategy

New technology that has not yet become customary in schools must first of all find its way into everyday use. Important for the technology's acceptance is comprehensive knowledge of how it functions among users. From the start of planning to beyond the commissioning, teachers, pupils and caretakers must be involved in the decision-making processes as part of an intensive communication strategy (see, for example, Lindau, p. 19). This avoids misunderstandings, minimises misconceptions and enables genuine participation.

If it is intended to implement ventilation systems and building automation at a school, this requires regular care, maintenance and monitoring of the automated functions. This presents the traditional “caretakers” in schools with a new challenge. Already before its introduction it should therefore be clarified as to which people will be responsible for the operation and whether they are adequately trained to take care of the building automation and ventilation equipment.

Teachers require information about the correct ventilation behaviour and how to deal with problems when operating the ventilation system. Each new teacher should be briefed about the system when commencing work. Ideally caretakers should be briefed about the new technology and its operation in person. To achieve this, the school must also have appropriate information material, e. g. operating instructions for the ventilation system.

A lack of information and communication causes problems with the acceptance and – particularly when there are system malfunctions during the implementation phase – these lead to wrong responses and unsettle people. One of the consequences are dissatisfied users. If teachers and, in particular, students are involved early on, this enables them to more easily embrace the school as "their" school.

Soft Landings for schools

In the UK, a process has been developed called "Soft Landings" in order to help implement structural and technical measures for sustainable buildings, in particular in regard to new or retrofitted schools (Fig. 22). The primary objective of the "Soft Landings" process is to instigate a cultural change in the planning, creation, delivery and operation of buildings. This is intended to increase the long-term efficiency of buildings and the user satisfaction. In addition, the process encourages a greater sense of responsibility among the designers and technicians in terms of ensuring an orderly commissioning and handover to the users. The experience garnered in schools in this British project confirms the findings achieved as part of the German "SolarBau:Monitor" research programme on demonstration projects relating to office buildings.

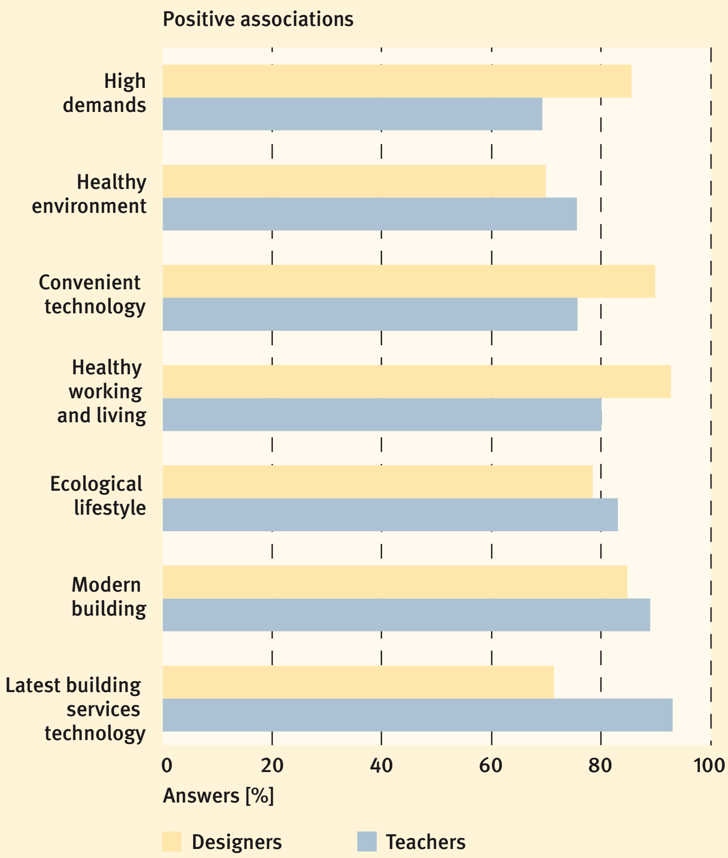


Fig. 20 *Associations made by teachers (128) as well as designers and client representatives (31) with mechanical ventilation systems in Austria. Source: Greml et al. [2]*

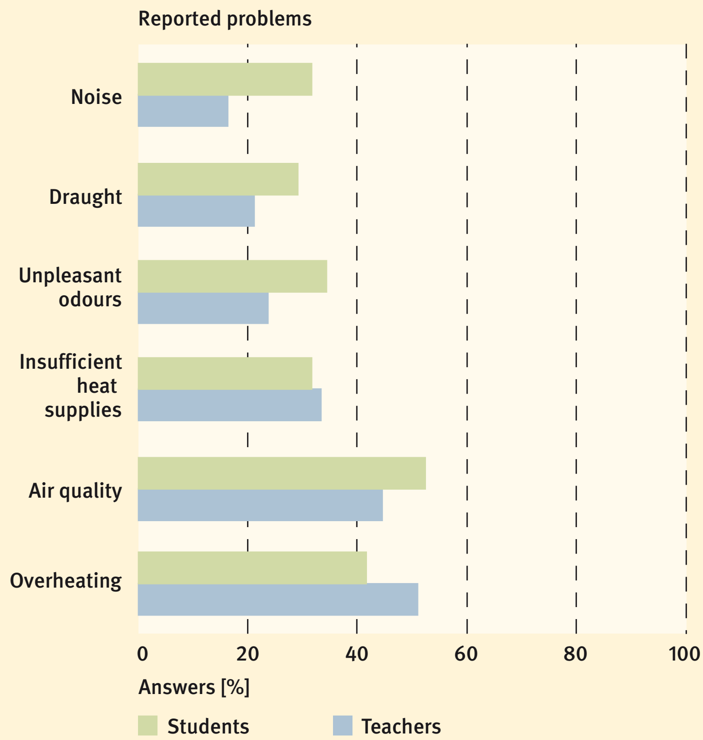


Fig. 21 *Problems reported by students (268) and teachers (128) in regard to the use of mechanical ventilation systems (16) (Austria). Source: Greml et al. [2]*

[1] Reiß, J.; Erhorn, H.; Geiger, M. u. a.: Energieeffiziente Schulen – EnEff Schule. Stuttgart: Fraunhofer IRB Verl., 2013. 358 S, ISBN 978-3-8167-9034-1

[2] Greml, A.; Blümel, E.; Gössler, A. u. a.: Evaluierung von mechanischen Klassenzimmerlüftungen in Österreich und Erstellung eines Planungsleitfadens. Bundesministerium für Verkehr, Innovation und Technologie, Wien (Österreich) (Hrsg.). 2008. Berichte aus Energie- und Umweltforschung. 14/2008

Soft Landings – Five steps for a soft landing

Phase 1: Inception and briefing	• *Explain process and brief responsible operators* • *Involve parties that are not in direct contact with the designers such as teachers, those responsible for the building operation, maintenance and servicing, the caretaker* • *Detail handover and commissioning process*
Phase 2: Design development and review	• *Review previous user experiences and user priorities* • *Take into consideration the technical experience of the users* • *Agree on design goals and features as well as target characteristics (ventilation, energy)* • *Raise realistic expectations among users* • *Check the expected operational behaviour and user friendliness of the technical equipment* • *Discuss experiences from previous projects with the users* • *Check tender results in terms of the requirements specified with the users*
Phase 3: Pre-handover	• *Prepare the start of building operations with the support of designers and operators managing implementation* • *Check that implementation is in accordance with goals* • *Prepare user documentation and information* • *Building operation, maintenance and servicing managers and caretaker familiarise themselves with the technical systems* • *Information, information material and demonstration of the user interface (building operators, teachers) contribute to successful user involvement*
Phase 4: Initial aftercare	• *Serves as an extended handover process* • *Obtain feedback from users and respond accordingly* • *More user training where necessary* • *Respond to user requirements, e.g. adjust nominal values, operating functions* • *Prepare on-site room for commissioning team* • *Ensure that the commissioning team is visible and can be contacted*
Phase 5: Extended aftercare and post occupancy evaluation	• *Professional aftercare for troubleshooting, fine tuning, improved building operations and reducing consumption* • *Compare building performance with design goals* • *User feedback should be reported back to designers and managers* • *Aftercare lasts for 1 to 3 years* • *Professional user survey*

Fig. 22 *The five steps of the British concept.*
Source: „The Soft Landings Framework“, www.softlandings.org.uk

In practice

Lindau secondary school

During the construction of the new Lindau secondary school in 2008, the originally planned ventilation system in the classrooms was waived with the exception of specialist rooms. After problems with the air quality and the room temperature in summer, the school board commissioned an engineering firm in Lindau to retroactively integrate a ventilation system in the finished building.

The designers developed a compromise for the various requirements: a sufficient amount of air, acceptable acoustics also suitable for exams, a limited installation effort and an aesthetic overall impression. A centralised ceiling ventilation unit with heat recovery was chosen with up to 600 m³/h for a maximum of 30 students in each room. Each unit has a demand control based on CO_2 measurements.

The fact that the designers had different devices tested by the teachers and students before choosing a device type is somewhat unusual. The involvement of the users in the selection process is a particularly positive aspect and has largely contributed to the huge acceptance of the ventilation equipment at the school. As part of the tests, surveys and so-called cross-over tests were carried out. In this test, the classes alternated between the rooms with different ventilation units. With the evaluation, the subjective assessment did not always coincide with the measured values. That was shown by the acoustics: the somewhat „louder“ system performed better in the subjective evaluation than would have been expected by its measured values, which were measured in the middle of the classroom.

Fig. 23 *Ceiling unit at Lindau secondary school. Source: Ing. Büro Ruess & Grömmer*

Points of view

“Ventilation systems in schools – Luxury or necessity?”

Professor Dirk Müller
Director of the E.ON Energy Research Centre’s Institute for Energy Efficient Buildings and Indoor Climate (ECB) at RWTH Aachen. Ventilation is one of his focus areas.

At a quiet school site, windows can be opened to ventilate the school classrooms. The outdoor airflow that flows in through the open windows is influenced by the window position, the temperature difference between the indoor and outdoor air as well as by the wind-induced pressure distribution on the building. Constantly supplying the classrooms with outdoor air requires permanent control of the window position that takes into account all the aforementioned influences.
In addition, at very low outdoor temperatures, considerable comfort deficits can occur because of draughts and low temperatures at floor level that prevent concentrated work. The alternative of airing during the breaks is also insufficient for achieving good air quality for an entire lesson because the concentrations of volatile organic compounds quickly increase again following a ventilation phase. It is therefore recommended to use mechanical ventilation in classrooms, which can be supplemented by window ventilation. Integrated heat recovery also increases the energy efficiency.
Of course, students and teachers can also easily get used to the poor air quality. Studies have shown, however, that even when people adapt to the poor air quality it continues to have negative effects on the performance. Therefore ventilation in schools is certainly not a luxury but a necessity!

Johanna Tenge
Special education teacher and vice-principal at the Heinrich Hanselmann school. This all-day school in the Rhein-Sieg municipality teaches students with a focus on mental development.

At our school, a new school building built to the passive house standard supplements an existing „old“ building dating from the late 1990s. The two wings show considerable differences in terms of the indoor environment. The air is very quickly used up in the classrooms in the old building. Opening the windows for ventilation – in summer with lowered blinds – only provides a short-term improvement. Another disadvantage is the higher noise level in the classrooms caused by activities in front of the windows. This makes it difficult for the students to concentrate on their lessons. In addition, the inwardly opening windows restrict movement in the rooms. Wide open windows on the first floor also require particularly attentive supervision of the students. In the new building built to the passive house standard, morning airing helps fresh, cool air to flow into the classrooms. However, this means that when there is warm weather the doors to the school playground have to be kept closed. This is difficult on a daily basis when sunny weather beckons and it is planned to use the outdoor area in front of the classrooms. If this is maintained, however, the classrooms remain at a pleasant temperature and can be used well. It is important that there is additional protection against direct sunlight on the window surfaces (blinds, awnings). In comparison, the ventilation to the passive house standard certainly performs better than in the old building.

Ventilation and energy

The ventilation affects the energy balance of schools to a significant extent. Ventilation systems therefore need to be very carefully integrated into the energy concept of a school. A key aspect is protection from overheating in summer. In order to ensure an efficient use of electricity, the operation of the ventilation and building service systems should be regularly checked.

The basis of any energy-efficient building is provided by the envelope with well-insulated exterior walls, roofs and foundation slabs as well as high quality window systems. Today the challenges lie in integrating the known passive and active technologies in optimally functioning building systems, and in implementing such systems in existing buildings. Furthermore, the equipment has to be operated in an energy-saving manner and users should be able to successfully interact with their building. Many schools now have their own systems for generating solar power. Fig. 24 shows the values for the end and primary energy demand before and after retrofitting for demonstration projects in the EnEff:Schule research programme.

As can be seen from Fig. 29 on page 23, depending on the technical concept for heating and ventilation, the electricity component can dominate the end energy consumption.

Fig. 24 *Energy loads in the EnEff:Schule demonstration projects before and after energy efficient retrofitting. Source: Fraunhofer IBP*

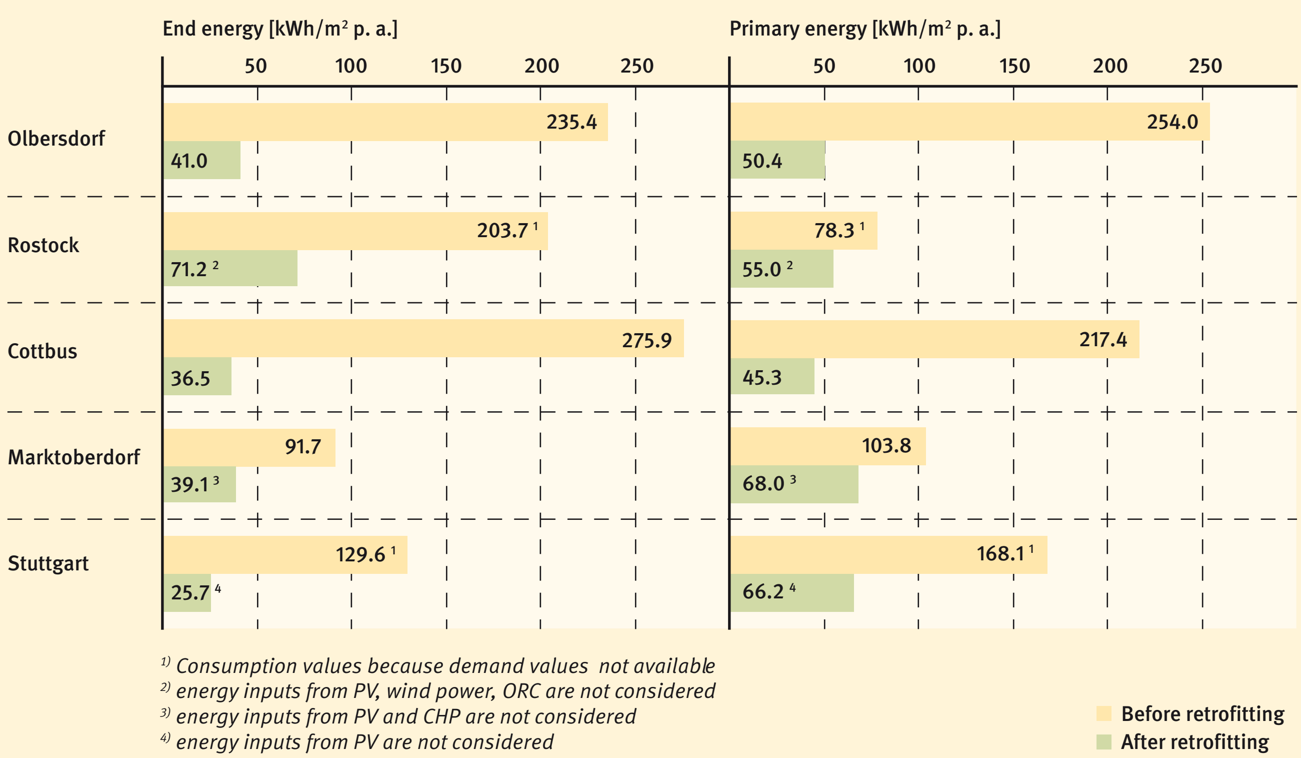


Fig. 25 *Window with external solar shading that can be rear-ventilated. Source: C. Moosmann*

Fig. 26 *Daylight situation in the room with external solar shading: l.) Completely closed solar shading; m.) Lower blind section closed, upper blind section with daylight control; r.) Slats in horizontal position. Source: S. Winterwerber, KIT*

Considerable savings in schools can be achieved by reducing the standby consumption and switching off continuously running systems that are currently not required. An analysis of load profiles [1] in schools shows that there is continuous "base load" consumption in schools (Fig. 28). These loads occur at weekends and during the holidays when, with the exception of just a few administrative spaces, a school does not need to be in operation. They can cause 20 to 50 % of the electricity consumption. Base loads ranging from 10 to 20 W/student have been frequently found, which over the course of a year frequently cumulate to 150 to 300 kWh/student. Continuous loads should generally be identified and the need for their operation checked. Basic loads of less than 5 W/student are possible and desirable. Studies in Austria and Germany show, for example, that ventilation systems are not switched off during the holidays and at weekends. Some systems are continuously operated throughout the year.

For several years, scientists have been optimising the operation at the Gebhard Müller school in Biberach, Germany, which is an energy research demonstration project [2]. Here considerable savings have been achieved during operation. Although an increase in consumption was also noticed in this school during the long-term operation, it was effectively countered by coaching the operating personnel.

Because building automation is these days used in most schools, its possibilities should be used to regularly check all the electricity and heat consumers to enable unnecessary loads to be switched off.

Avoiding overheating in summer

Because of high internal heat loads in classrooms measures to effectively avoid overheating in summer play a major role in schools. A survey conducted by the Augsburg University of Applied Sciences [3] at ninety-six energy efficiently retrofitted schools in a South German government district shows that in almost all cases external solar shading was used to provide protection from the sun. Planning practice has improved significantly here compared with the situation just a few years ago.

Solar shading control

Many studies show that users rarely close the solar shading completely because this blocks views to the outside. This is shown by an example in practice from a school: here the teachers initially found that the solar shading was always completely closed when they entered the east-facing classrooms in the morning (Fig. 26, l.). In order to provide daylight, the teachers raised the solar shading for the rooms. However, the solar shading system also provided the option to create the situation shown in Fig. 26 m., which provides solar shading while redirecting light. Whether this possibility was known in the school is not documented. The solution provided was equivalent to the situation depicted in Fig. 23 r. The school set the slats in the lower section of the venetian blinds to a horizontal position (eastward orientation!). To prevent the teachers from raising the solar shading in the morning, the solar shading was now lowered in a horizontal position.

After an inspection with students, the company that installed the blinds was asked why it had chosen precisely this horizontal position. During the conversation it turned out that the ability to move the slats downwards in a 45° position was simply not considered. This would have offered the desired views to the outside. This example shows that all the possibilities provided by the technology must be known when involving specialist building services companies, operators and users. Most people viewing Fig. 26 would also probably spontaneously prefer the solution on the right hand side. However, with more knowledge about the way the system functions, the middle solution could also be acceptable because in this slat position light is directed at the ceiling and from there into the room without heating it by direct solar radiation.

Energy Efficient School research programme – www.eneff-schule.de

The Energy Efficient School (EnEff:Schule) research programme is aimed at collating and presenting all activities in the field of energy efficient school retrofitting. It forms a key component of the Energy Optimised Construction (EnOB) research initiative and is funded by the German Federal Ministry for Economic Affairs and Energy.

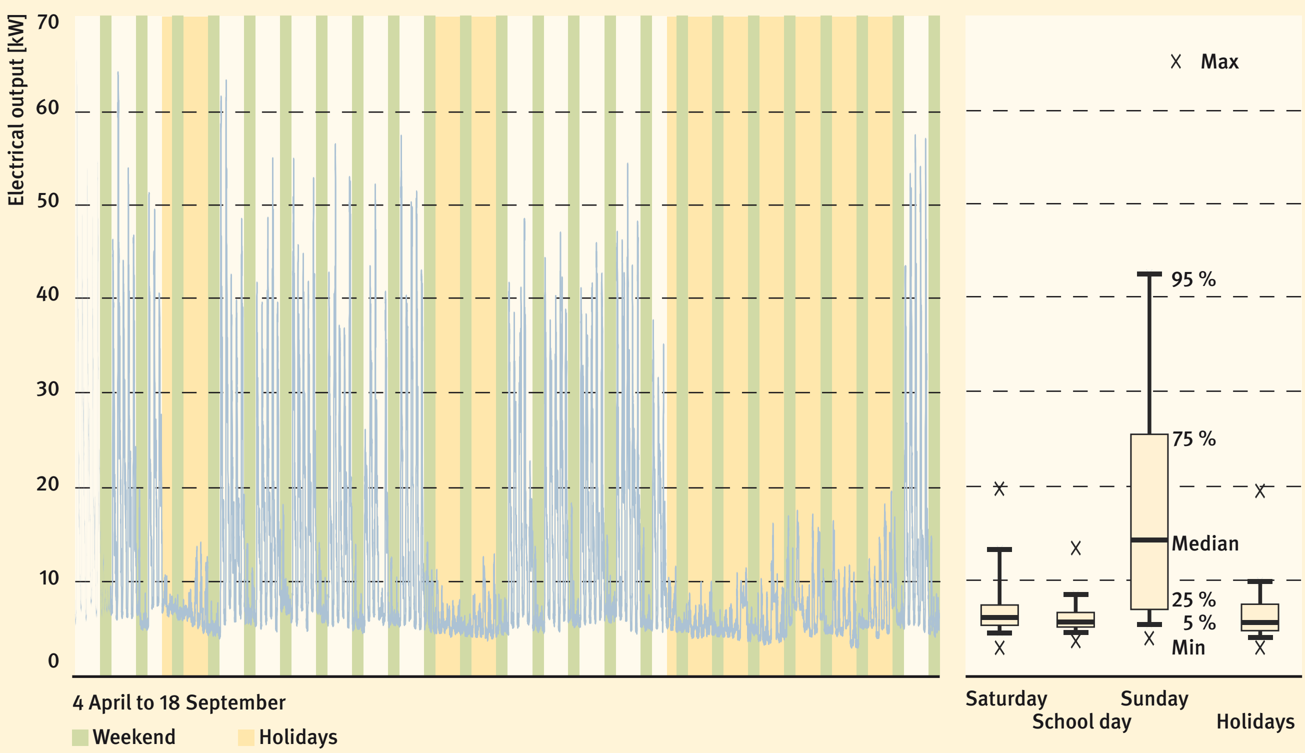
One focus is on scientifically monitoring demonstration projects conducted as part of the EnEff:Schule programme. The projects demonstrate the various possibilities for dramatically reducing the primary energy demand for heating, ventilating, lighting and cooling.

The retrofitted school buildings are intended to achieve different energy efficiency levels. In addition to energy-plus schools, which generate more energy than they consume in the annual energy balance, the research programme also includes 3-litre house schools. In addition, the programme also includes pioneering retrofitting of school buildings, the so-called „best practice examples“.

A special aspect of school retrofittings is the opportunity to engage the school pupils in the retrofitting process. This therefore provides an opportunity to multiply knowledge on an enormous scale. The social scientific support research in the EnEff:Schule programme is aimed at investigating how the school projects affect user behaviour and the attitude of the users – in this case teachers, students, caretakers and parents.

Fig. 27 *Natural and mechanical ventilation is used in the Hohen Neuendorf demonstration project. Source: Ali Moshiri*

Abb. 28 *Left: Example of a load profile at a school with about 1,100 students; identifiable base load between 5 and 7 kW; Right: Distribution of loads with different usage profiles; Weekends, holidays: Base load (minimum value up to 75 %), 3 – 8 kW (2 – 6 W/student) and peak load (95 % up to maximum value), 10 – 20 kW (8 – 15 W/student); School day: Base load (minimum value up to 75 %), 4 – 26 kW (3 – 20 W/student) and peak load (95 % up to maximum value), 43 – 65 kW (35 – 50 W/student) Data: Consiste 2012, Graphic: Hellwig*



A misconception emanating from residential construction is that closed windows in schools prevent overheating in summer. On the contrary: A continuous discharge of the thermal loads produced by 25 to 30 students, which is about 2.3 to 2.7 kW, should also be caused by ventilating in summer, which helps to limit the maximum temperature. With very good external solar shading installed with sufficient spacing in front of the windows, natural ventilation is certainly possible if there is a correspondingly quiet external environment (Fig. 25). In addition, the facade should also enable a generous opening of the windows. In order not to restrict the occupied zones in classrooms, the opening casement windows should not be very wide. For various reasons (security, reduced effort required to ensure that windows are closed), potentially openable windows at many schools are unfortunately permanently closed or can only be tilted.

The heat that has developed during the course of the day should also be removed from the classrooms again. To this end, in summer the rooms should be regularly ventilated overnight. By bypassing the heat exchanger, ventilation systems or devices can also be used for night-time ventilation. Although night-time ventilation concepts utilising natural ventilation through the facade are very desirable and work, these often fail in practice as a result of security and weather protection aspects. In old school buildings with historic stack ventilation systems (see En passant, p. 13), these can be ideally integrated in night-time ventilation concepts as part of an energy efficient retrofitting.

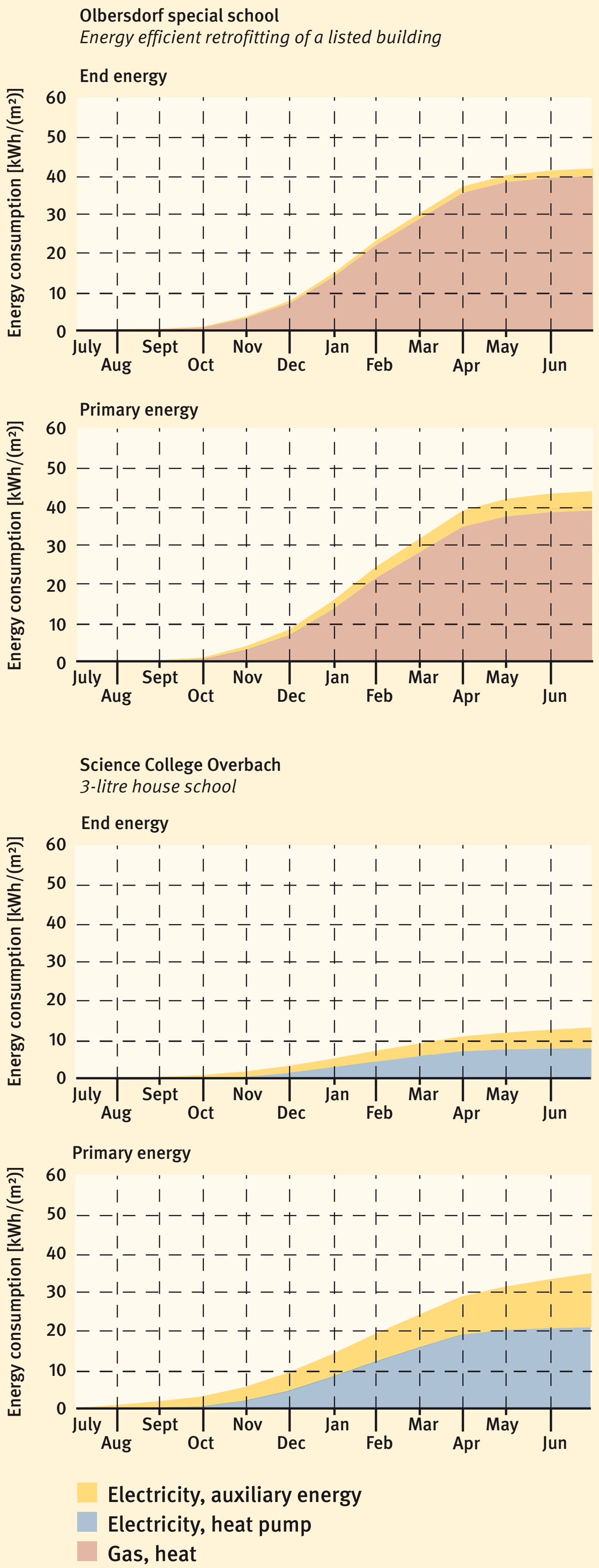


Fig. 29 *Cumulative end and primary energy consumption: Top: Olbersdorf special school; Below: Science College Overbach in 2012/13. Data: www.eneff-schule.de, Fraunhofer IBP; Graphic: Hellwig*

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[3] Hackl und Hellwig 2014

Choosing the right ventilation system

Whether a particular ventilation concept or system is chosen or not depends on many factors. The location determines whether window ventilation is at all suitable, for example if a noisy road runs alongside the school. On-site conditions that cannot be altered mean that not all ventilation concepts can be used in existing school buildings. Of course the investment costs, and occasionally the operating and maintenance costs, also influence the decision for a specific ventilation system. Innovative technologies should be tested to see if they are suitable for a project.

Which ventilation system is suitable for a school depends not only on a purely technical assessment of the situation. If users have reservations about a particular ventilation system it is not advisable to install this merely because of its technical advantages. The users will not use such a system. The early integration of teachers and students in the planning process therefore has a positive effect on the successful implementation of the ventilation technology.

Ventilation systems require continuous operational support, which includes not only maintenance and repair work. Not only should the system parameters be checked and optimised during the commissioning but the users should also be briefed on how to operate the ventilation systems. Regardless whether it is concerned with mechanical or natural ventilation, the users at the school, i.e. the students and teachers, need to understand and know how to operate the ventilation systems and which operating modes achieve the desired effect. This requires an expert person familiar with the systems, who can continuously supervise the systems and who enjoys the users' trust.

Links and literature (in German)

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» Steiger, S.; Hellwig, R. T.: Hybride Lüftungssysteme für Schulen. Abschlussbericht. FKZ 0327387A. 2011
» You can find the extended compilation (including reference sources) for all the literature cited in this Themeninfo brochure at www.bine.info.

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