**Zumtobel Research**

# General refurbishment of Sonthofen Secondary School

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Sonthofen Grammar School

# Abstract

The Sonthofen Grammar School was built in the 1970‘s based on a reinforced concrete frame construction according to the Kassel model. At that time, the operating costs of a building only played a subordinate role. Also, due to a very negative energy balance, many buildings of this type in Germany today are in need of rehabilitation. Partial refurbishment attempts or projects mainly oriented to façade insulation have lead to unsatisfactory energetic results. An adequate primary energy limit was achieved with the Sonthofen Grammar School using a holistic planning approach oriented towards passive house standards. In particular the electrical consumers such as lighting influence the primary energy factor to a very high level with a factor of 2.7. Starting points in this project were therefore also efficient luminaires, use of daylight with optimum solar protection systems and a bus system with decentralised control of lighting. The useful area was extended by a further storey in the specialised classroom section from 7,800 $m^2$ to 8,800 $m^2$. At the same time, primary energy requirements could be reduced from 37.1 $kWh/m^2a$ to 17.6 $kWh/m^2a$ and end energy requirements from 13.7 $kWh/m^2a$ to 6.5 $kWh/m^2a$.

# Short Summary

According to the decision of the Municipality of Sonthofen, the main aim of the general refurbishment of the grammar school should be as low an energy level as possible if technically feasible and financially viable: at passive house level.

The target value for heating energy requirements was thus set at around 15 kWh/m$^2$. Comparable universal (passive house) limits for electrical energy consumption are currently not yet available, as with non-residential buildings the reference building approach leads to differing, building-specific values. However, in the recent past building concepts have been developed that managed to combine a high level of user comfort with minimum primary energy requirements and with moderate investment and significantly reduced operating costs, e.g. EnOB or solar construction projects. For these buildings, primary energy requirements of max. 100 kWh/m$^2$a were set and were achieved in the majority of cases. This includes the energy demand for heating, cooling, ventilation, hot water and lighting. With a uniform distribution of the targeted limit, 15–20 kWh/m$^2$ remain for the specific consumption areas. This also applies to the lighting.

With the primary energy factor of 2.7 for electricity, this gives an end energy requirement of **max. approx. 7.5 kWh/m$^2$a** for room lighting in order to achieve the target value of 20 kWh/m$^2$a. This appears to be impossible with conventional system solutions.

What resulted from these target specifications was a multidimensional planning approach consisting of the following individual tasks:

**Measurands, evaluated parameters**

| | |
|---|---|
| 1. Room lighting: | Design of lighting system in compliance with relevant standards |
| | Observance of photometric quality criteria |
| | Selection of highly efficient products |
| | Optimisation of system efficiency |
| 2. Solar protection: | Optimisation of solar/anti-glare protection and light ingress (direction of light) |
| | Consideration of maintenance costs and protection against destruction |
| | Comparison of various slat systems |
| 3. Control: | Definition of control strategy for room lighting |
| | Definition of control strategy for solar protection |
| | Presence-based control for classrooms and ancillary rooms |

However, the process of optimisation is not finished with the end of planning. The most important step is with commissioning of the complete system. This is carried out over a period of three years (fine-tuning step by step) as part of monitoring accompanying the construction implementation. At the current time (March 2012), real consumption values are not yet available. Construction work has not been completed yet.

## 1 Problem definition

## 2 State of science

## 3 Research hypotheses

### Problem definition

Refurbishment today is always connected with measures for improving energy efficiency. This often results in subsidy grants based on energy performance certificates. In order to achieve ambitious aims or defined specifications, a holistic planning approach has to be chosen that ensures the interplay of innovative artificial lighting and daylight-based technologies via a lighting management system. In addition, these parameters are connected to a large extent with user acceptance and human well-being. Energy-efficient measures in lighting concepts often entail limitations of working or living environments, e.g. illuminance levels that are too low or a monotonous lighting concept resulting from restrictive lighting design.

### State of science

Lighting technology in professional building illumination offers innovative options for maximum user acceptance and maximum energy efficiency. This is possible for example via efficient light distribution and glare limitation. Daylight has maximum acceptance, and is available at high intensity over many hours of the day for free, but on the other hand may cause glare and high room temperatures. This is why for the achievement of energy performance indicators for lighting, a clever interplay of daylight and artificial lighting is implemented. Maximum utilisation of daylight combined with optimum solar protection systems offer very good energy balances with high user comfort. An excellent level of coordination is achieved via lighting management.

### Research hypotheses

The study aims to respond to the following question: can strictly defined energy performance indicators be achieved via a well thought-out holistic approach involving the interplay of daylight, artificial lighting and structural situations without having to restrict user comfort?

# 4 Research methods

## 4.1 Selection of methods

The energy values for the Sonthofen Grammar School were analysed and optimised using artificial lighting and daylight calculation programmes, simulation and visualisation for various slat systems and measurements in sample rooms. Further optimisation was carried out after finishing the construction via accompanying activities and measurements during operation.

## 4.2 Test setup

Following the analysis and decision phase for the lighting, lighting control and slat systems, the energy requirement for room lighting was calculated and evaluated according to three calculation methods:

- Energy requirement according to DIN V 18599
- Energy requirement according to MINERGIE®
- Energy requirement according to a user profile drawn up by the project team

The actual energy consumption for the lighting system is monitored and optimised following completion of the construction project.

# 4.3 Test procedure

## 4.3.1 Room lighting

Lighting concept for classrooms

Due to the depth of the classrooms of over 8 m, a triple axis luminaire configuration was chosen to achieve homogeneous room illumination. With a standard classroom covering a floor space of around 70 m$^2$, initial calculations (300 lx) resulted in 9 luminaires (pendant luminaires with specular louvre, direct/indirect distribution) with 49 W lamps per luminaire. After discussing the various lighting and luminaire concepts, the decision was made to use a surface-mounted luminaire designed according to the “Mellow Light” concept with high quality of light (no cave effect).
Thanks to the high light output ratio and optimum positioning, the lamps fitted could be reduced from 49 W to 35 W in a second step (classroom with 70 m$^2$ and 300 lx).

Several calculations were also made for the blackboard lighting. Finally, a double-length surface-mounted luminaire with asymmetric light distribution and a flat aluminium housing (2 x 1 x 54 W, 500 lx vertical for the blackboard area) was chosen.

Measurement in a sample classroom gave a new illuminance value of around 460 lx with uniformity of 0.56 ($g1 = E_{min}/E_{mean}$). The measurement confirmed the photometric values calculated (Em = 440 lx, g1 = 0.52).

For the corridor areas a wall luminaire was used consisting of a batten luminaire (1 x 35 W) and an attachment optic of white perforated sheet.

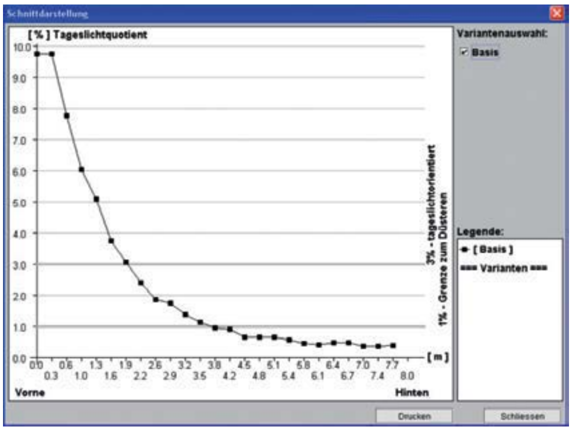
After carrying out the complete detailed planning, the following comparative values between existing and new system were determined.

**Comparative values between existing and new system**

| | Useful area dimmed m$^2$ | Number of luminaires Qty | Electrical installed load kW | Specific connected load W/m$^2$ | Energy requirements end energy kW/m$^2$a | Energy requirements 3,000 K kW/m$^2$a |
|---|---|---|---|---|---|---|
| Existing building | 7,800 | 1,410 | 128 | 16.4 | 13.7 | 37.1 |
| Building after refurbishment | 8,800 | 1,380 | 67 | 7.6 | 6.5 | 17.6 |

A second storey is added to the specialised classroom section.

## 4.3.2 Solar protection



Course of daylight quotient from the window axis to inner wall (approx. 8 m). The daylight quotient is the ratio of illuminance at a single point in the interior to external illuminance.

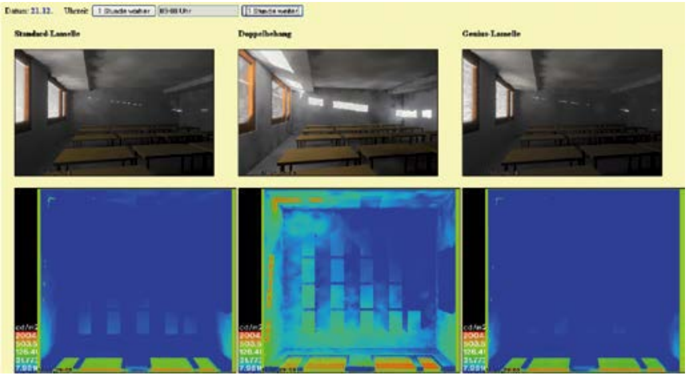
Sunlight can make a significant contribution to reduction of the energy requirements with artificial lighting, although 42 % of solar radiation is in the IR range and, thus, also heat radiation. This is why well-functioning solar protection (heat protection) is usually unavoidable. In contrast to façade design, not much can be changed on the building‘s geometry and room layout during refurbishment. At around 8.2 m, the room depth of most classrooms of the Sonthofen Grammar School is so large that sufficient supply of the rooms with daylight is not possible. By taking away the protruding balcony elements and modifying the façade to a generously glazed band façade, a relatively good supply of daylight to the room half near the windows was achieved. The daylight quota, however, sinks from around 10% near the windows to a value of about 1 % in the room centre, so that the inner room half only gets insufficient daylight.

In order to be able to distribute the daylight somewhat more uniformly in the room, solar protection providing direction of light should therefore be implemented. The primary evaluation criteria of a solar and anti-glare protection system with direction of light are:

- Reduction of heat ingress
- Protection from excessive luminance levels (anti-glare protection)
- Guiding of the daylight deeper into the room
- Ensuring a view of the outside (see through)
- Energetic optimisation of the room lighting
- Operating and maintenance costs
- Protection from mechanical destruction

Before further testing, the integration of the slat system into a composite window was decided upon. This should firstly reduce maintenance and operating costs (protection from the external climate) and secondly avoid the danger of mechanical destruction (vandalism with use indoors).

In order to select a suitable slat system and for the energetic evaluation of its functions, a professional simulation with various slat systems from the Braunschweig-based ALware company was carried out.



Simulation of various slat systems

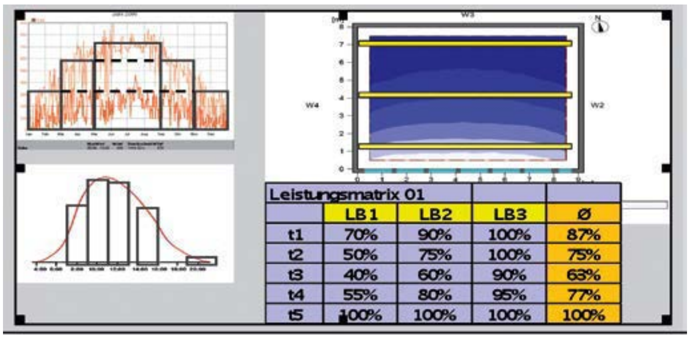
The visual and photometric comparison of the three selected slat systems during the course of a day showed that the concave specular slats most optimally met the requirements as a whole. These were specifically:

- Reduction of the solar ingress of heat
  (total energy transmission factor)
- Reduction of window luminance levels (glare limitation)
- Redirection of light for better room illumination (energy efficiency)

Consistent and professional calculation programmes for holistic qualitative evaluation (lighting effect in the room, visual impression) and quantitative evaluation (illuminance and luminance levels, energy efficiency etc.) of artificial lighting systems and solar protection systems are until now unavailable on the market. A specific calculation model was, however, developed in order to still be able to evaluate the influence of the selected slat system on the energy requirements of the artificial lighting:

- Distribution of sunlight in the course of a day and a year in a simplified scheme (time segments)
- Calculation of illuminance levels achieved by daylight within the time segments specified above
- Evaluation of the required supplementary lighting

As a result, the model supplies a dimming value related to the individual luminaire axes (given in %) in the form of a matrix (dimming value per luminaire axis at defined times of the day).



Leistungsmatrix 01

| | LB1 | LB2 | LB3 | Ø |
|---|---|---|---|---|
| t1 | 70% | 90% | 100% | 87% |
| t2 | 50% | 75% | 100% | 75% |
| t3 | 40% | 60% | 90% | 63% |
| t4 | 55% | 80% | 95% | 77% |
| t5 | 100% | 100% | 100% | 100% |

Calculation model for determining the electrical supplementary requirement for artificial lighting

## 4.3.3. Control

In order to achieve relevant savings with artificial lighting, daylight-based control is required. This means that only so much artificial lighting is added as is needed to achieve the illuminance levels required by relevant standards. Basically, a variety of concepts is available. The simplest version is manually switching off individual luminaire rows with sufficient daylight. The advantage of this method is the low costs, and the disadvantage is the discontinuous modification of illuminance levels and the functional dependence on the discipline of the staff. The latter disadvantage can be rectified with automatic, axis-related switching off. However, practice has shown that the step-by-step switching away of individual axes can lead to significant acceptance problems. In contrast, with an automatically controlled lighting system the level set during commissioning ensures that precisely the illuminance level desired or required is achieved in each room. This leads among others to the over-dimensioning of the system due to application of the maintenance factor (new value higher by 25–50 %, depending on maintenance factor) being balanced out. Two different concepts are available for automatic, daylight-based adjustment of illuminance levels:

- Central lighting control
- Local lighting control

With central lighting control, daylight and sky condition are measured at a central location, e.g. on the roof of a building. Based on room-specific correction factors, artificial lighting is added to the daylight available in the room. The benefit of this method is the "disturbance-free" measurement of daylight (celestial sphere). The disadvantage is the "open" control circuit, meaning there is no direct control (feedback) of the lighting situation in the room.

With local lighting control, one or two light sensors are installed in each room to measure the existing "total quantity" of light. In this way each room is a closed control circuit. Actual and set values are constantly compared and the lighting system is adjusted as needed. The benefit of this method is the level of control due to the closed circuit. The disadvantage is the increased system costs and the sensitivity of the "measurement space" recorded by the sensor to changes (moving furniture, colour changes etc.).

Within these concepts, there is a number of electronic system solutions available, ranging from simple, “wired”, room-related minimum solutions to building management concepts. Following extensive discussion, the planning team of the Sonthofen Grammar School opted for installation of a bus system including local lighting control.

The reasons for this decision were:

- Integration of heating/cooling, ventilation ($CO_2$), lighting and presence detection in the control system (consideration of mutual dependencies, e.g. solar protection – heating/cooling).
- Buildings in a very tight building shell (passive houses) heat up much more quickly compared to conventional buildings. This is why they “respond” more sensitively to erroneous behaviour. The best precaution is automatic adaptation of control parameters if extreme disturbances occur (e.g. excessive outside temperatures).
- Continuous control of artificial lighting guarantees disturbance-free school lessons.
- Concentration is not inhibited by abrupt peripheral changes.
- The closed control loop offers the best monitoring of the lighting conditions in the room.
- The specifically designed bus system enables optimisation of the complete system (temperature, $CO_2$, lighting, solar protection) during the planned monitoring phase.
- Energetic optimisation of room lighting can also be most effectively achieved with an integrated control concept including solar protection.

Optimum energetic room conditioning is best achieved with this control concept based on a flexible bus system that has a clearly comprehensible technical complexity.

# 5 Results

Several partly modified calculation methods were used to calculate the energy requirements for artificial lighting: firstly, a somewhat reduced process according to DIN V 18599 Part 4, then a simplified method of calculation based on the Swiss Minergie concept, and a third requirement calculation based on a user profile drawn up together with the school. The different values achieved in determining the energy requirements result from the specifically used calculation paths and from the corresponding definition of the effective operating time per year.

The requirement calculation in compliance with DIN V 18599 is based on user profiles according to Part 10, considering relative absences and planned presence detection. Daylight-based lighting control was not taken into account. The reason for this is the complexity of the calculation method on the one hand, and excessively coarse screening with respect to the basic units for the various types of room and use on the other hand.

The excellent documentation of many Swiss Minergie projects today delivers an extensive array of figures for school lighting. The data covers geometric specifications, specific connected loads and consumption data as well as user profiles. These were used as a basis for the second requirement determination in a slightly adapted form.

A user profile was drawn up together with the school administration for the third calculation that considers both the free days and holidays and the various types of room occupancy.

| Building area | m$^2$ | Q (18599) | Q (MINERGIE®) | Q (user prof.) | W/m$^2$ | W |
|---|---|---|---|---|---|---|
| Ground floor class section | 2,157.16 | 21,904.70<br>10.15<br>kWh/m$^2$a | 19,148.80<br>8.88<br>kWh/m$^2$a | 14,469.11<br>6.71<br>kWh/m$^2$a | 8.06 | 17,386.00 |
| Ground floor specialised class section | 1,393.20 | 10,102.16<br>7.25<br>kWh/m$^2$a | 8,706.00<br>6.25<br>kWh/m$^2$a | 7,473.57<br>5.36<br>kWh/m$^2$a | 6.17 | 8,596.00 |
| 1st floor class section | 2,046.71 | 22,583.94<br>11.03<br>kWh/m$^2$a | 20,896.25<br>10.21<br>kWh/m$^2$a | 14,378.78<br>7.03<br>kWh/m$^2$a | 8.04 | 16,447.00 |
| 1st floor specialised class section | 1,402.69 | 17,816.88<br>12.70<br>kWh/m$^2$a | 16,449.70<br>11.73<br>kWh/m$^2$a | 11,125.19<br>7.93<br>kWh/m$^2$a | 12.02 | 16,865.00 |
| 2nd floor class section | 2,042.40 | 13,492.31<br>6.61<br>kWh/m$^2$a | 14,305.90<br>7.10<br>kWh/m$^2$a | 11,573.36<br>5.67<br>kWh/m$^2$a | 6.82 | 13,933.00 |
| Total values | **9,042.16** | **85,599.98**<br>**9.50**<br>kWh/m$^2$a | **79,704.65**<br>**8.81**<br>kWh/m$^2$a | **59,020.02**<br>**6.53**<br>kWh/m$^2$a | | **73,227.00** |

Specific energetic parameters of the three calculation methods

The lowest requirement value was achieved with the calculation based on the user profile drawn up by the project team. According to this calculation, the energy requirement for artificial lighting is 6.5 kWh/m$^2$a.

# 6 Best practise

The fact that these values can be achieved at the Sonthofen Grammar School is confirmed by the consumption figures from Switzerland, some of them being in the range of 4.5 and 6.5 kWh/m$^2$a.

Buildings with planning according to SIA 380/4

**School and sports building overview**

| Building | Area m$^2$ | Energy MWh | Consumpt. kW | Consumpt. W/m$^2$ | EKZ kW/m$^2$ | Construction completion | Q-control | TL-measurement |
|---|---|---|---|---|---|---|---|---|
| *Albisriederplatz* | 6180 | 40 | 39 | 6.3 | 6.4 | Aug 08 | | |
| *Allenmoos I* | 2437 | 21 | 19 | 8 | 8.6 | Jan 04 | | |
| *Allenmoos II (HPS)* | 4608 | 30 | 43 | 9.4 | 6.5 | Dec 06 | | |
| *Am Wasser* | 1894 | 17 | 21 | 11.1 | 9 | Aug 00 | | |
| *Apfelbaum Section A* | 2586 | 4 | 16 | 6.3 | 5 | Aug 03 | 25.5.05 | |
| *Apfelbaum Section B+C* | 1412 | 7 | 9 | 6.4 | 5.2 | Aug 04 | 31.1.07 | x |
| *Apfelbaum Section D incl. gymn.* | 3242 | 29 | 24 | 7.4 | 8.9 | Aug 03 | 25.5.07 | x |
| *Balgrist sports hall* | 599 | 3 | 6 | 9.5 | 4.2 | Nov 05 | | |
| *Buchwiesen* | 5585 | 40 | 44 | 7.9 | 7.1 | Aug 03 | 12.4.05 | |
| *Buchwiesen pavilion 1+2* | 581 | 4 | 6 | 10 | 7.2 | Aug 04 | 12.4.05 | |
| *Buchwiesen Section A* | 1416 | 6 | 9 | 6.3 | 4.4 | Oct 04 | 12.4.05 | |
| *Bühl C* | 1741 | 13 | 13 | 7.7 | 7.3 | Nov 03 | 1.12.03 | |
| *Döltschi* | 5761 | 50 | 50 | 8.7 | 8.6 | Aug 09 | | |
| *Fallet extension* | 4954 | 74 | 54 | 10.9 | 14.9 | Oct 06 | | |
| *Fluntern* | 4003 | 20 | 27 | 6.7 | 5 | Dec 05 | 23.1.06 | x |
| *Gotthelfstrasse (HPS)* | 2293 | 14 | 15 | 6.7 | 5.9 | | | |
| *Hardau (sports hall)* | 5627 | 62 | 37 | 6.5 | 11 | Aug 07 | | |
| *Hardau BWS* | 2051 | 16 | 19 | 9.2 | 7.7 | Aug 05 | 9.2.06 | x |
| *Hardau Primary School* | 2074 | 13 | 17 | 8.3 | 6 | Aug 05 | 9.2.06 | x |
| *Hirzenbach new hall* | 2392 | 10 | 19 | 7.9 | 4.4 | May 07 | | |
| *Hirzenbach new kindergarten* | 1486 | 9 | 11 | 7.5 | 6.2 | Dec 06 | | |

# 7 Discussion and outlook

The three calculated and thus theoretical values demonstrated will have a corresponding deviation to the real consumption data. Diverse other tested and documented projects show that such deviations can be significant and are highly dependent on user behaviour. This can only be eliminated by a self-sufficient system control, the behaviour of which cannot be influenced. But that should not and can never be a fundamental planning aim. Users should always be able to influence the lighting control system to be able to individually adjust the values and settings defined by the system according to their needs.

The acceptance and the energy values of the system can be recorded via simultaneous monitoring initiated following completion of the building construction. Deviations from the calculated and actual consumption can then be determined to supply highly useful contributions for other buildings.

We assume that the determined values can be achieved, at least after commissioning and after an obviously necessary information, training and accustomisation process.

Major challenges are seen in the determination of the real ratio of lighting to the complete consumption of energy, and this task should be solved with the support of further project partners (universities).

# 8 Literature

MINERGIE® Switzerland
www.minergie.ch

Deutsche Gesellschaft für Nachhaltiges Bauen e.V.
www.dgnb.de

Greenbuilding
www.greenbuilding.com

# 9 Brief portraits of the partners

Ratec Licht
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Ratec Licht, Hans-Christian Winter, has developed a highly efficient, holistic building concept involving the interplay of daylight, artificial lighting and lighting management in a decentralised lighting control system and its integration into a bus system. The specific energy requirements were determined based on three calculation methods. The project continues to be monitored by Ratec Licht.

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