ABSTRACT

Within the FP7 project “3ENCULT – Efficient Energy for EU Cultural Heritage”, the school building “Höttinger Hauptschule” in Innsbruck (Austria) is one of the 8 case studies for demonstration and verification of energy efficient solutions. Besides the reduction of thermal losses, a special focus will be on the optimisation of daylighting and energy efficient artificial lighting with high priority of conservation-compatibility for all of the interventions. New software for visualization (VIVALDI by Zumtobel) is used. The principle behind it is to evaluate the luminance of interesting areas of calibrated HDR (High Dynamic Range Image) photos taken of rooms with prototypically installed systems. As the electric consumption of the artificial light is well known, the saving potentials of different lighting solutions can be evaluated.

KEYWORDS

Artificial light, day light, energy efficiency, simulation software, visualisation tools, school building, cultural heritage.

DESCRIPTION OF THE CASE STUDY

The Secondary School Hötting (Fürstenweg, Innsbruck, Austria) is one of the 8 case studies for demonstration and verification of energy efficient solutions within the European research project 3ENCULT (Efficient Energy for EU Cultural Heritage). It is listed as one of the most important examples of early modern architecture in Tyrol.

In connection with the reformation of the school system and the introduction of the “Hauptschule” at the end of the 1920’s, new types of schools started to be planned. These new types of school were planned to meet modern criteria such as ventilation, illumination and sun light influx. For the new school at Hötting, a public tender was held and won by a group of architects around Franz Baumann and Theodor Prachensky at the end of 1928. They were assigned the contract to do the planning which started in fall 1930. Construction itself was undertaken by Retter, a construction contractor and the school opened on the 25th of October in 1931. The Hauptschule Hötting is a perfect example for the general development of architectural culture under the principles of the “New Objectivity” [1]. The building is still in use as a “Hauptschule” and has recently become a “Neue Mittelschule”.

Optimisation of daylight and artificial light in cultural heritage
Hauptschule Hötting in Innsbruck, Austria (3ENCULT Case Study 5)

Rainer Pfluger, Matthias Werner, Wolfgang Feist
Faculty of Civil Engineering, Unit Energy Efficient Buildings
University of Innsbruck
e-mail: rainer.pfluger@uibk.ac.at
The development plan (see Figure 1) shows an urban clearing character to the south, however new buildings are planned in the southeast of the area between school yard and the river Inn.

The high heating energy demand (more than 200 kWh/(m²a)), severe overheating problems, low quality of daylight and artificial light as well as air quality problems and low thermal comfort (draft risk and low surface temperatures in winter) are the main reasons for the need of modernisation of the building. Additionally problems from building physics point of view and have to be solved (e.g. moisture problems, fire protection).

The local team for research, and planning of interventions consists of UIBK (scientific guidance), Innsbrucker Immobilien GMBH&CO KG (building owner), Bundesdenkmalamt, Landeskonservatorat für Tirol (preservation of monuments) and Architekt DI Gerald Gaigg (architectural team).

Most of the building (including some of the windows) are in the original condition. The first and second floor of the east part of the building was added later. The extension can be seen on the right foto of Figure 2, which shows the north-west facade of the building.
Figure 3. Floor plan: groundfloor (left), upperfloor (right)

Figure 4 shows an original freehand sketch of the main entrance drawn by Franz Baumann and a photo of the status quo (2011). The stairs, bent around the concierge room, connects the niveau auf the street with the 2.7 m elevated groundfloor level. The roofing of the entrance looks like a massive concrete slab, in fact it is constructed by girders covered with thin concrete panels. The concrete profiles at the right side of the entrance was originally planned to house indirect lighting.

Figure 4. Sketch by Franz Baumann (left) and photo (right) of the main entrance

The architects Baumann and Prachensky also designed the interior details from the furnitures to the clothing hook in the wardrobe. The latter is still preserved as shown in

Figure 5. Sketch by Franz Baumann (left) and photo (right) of the main entrance
Figure 6. View from S-E (Photo 1/2011, Pfluger)

The gymnasium, adjoining the main building as shown already on one of the first sketches for the architecture competition, has the dimensions of 12 m by 25 m. At the construction date, the gymnasium was the largest throughout Tyrol.

Figure 7. View from N-W, main building and gymnasium (left: original sketch for the architecture competition, right: photos 1/2011, Pfluger)

ENERGY EFFICIENT LIGHTING IN HISTORIC SCHOOL BUILDINGS

High quality of visual environment is important for the performances of students in school buildings. In new school buildings, one important goal of the planning process is to optimize the daylight access by the design of classrooms. On the other hand, energy use by electric lighting should be minimized. In principle, the same holds for refurbishing of historic school buildings, but with certain restrictions of conservation-compatibility for all of the interventions. In this
paper, research within the EU-project 3ENCULT about optimisation of lighting is shown for a class room and a lecture room for physics of the case study “Hauptschule Hötting”.

At the end of the twenties, there was a trend for buildings heading for light, air and sun. The architect, Franz Baumann adapted this modern principle to school buildings. The high quality of daylighting in the entrance hall (see Figure 8) as well as the orientation of all corridors to a window (see Figure 9) gives a good example of this design principle.

**Figure 8. Entrance hall with large glazing area**

**Figure 9. Main Stairway and corridor oriented to day light**

The geometry of the class rooms (depth of 6.6 m, see Figure 10) and the different tasks which must be performed in it makes it a difficult task to light it with daylight. The window area of 16 m² per class room is large enough for good use daylight for 67 m² of floor space. On the other hand, it has to be delt with the risk of glare and overheating. The original drawings (pencil) of the windows and photos of the shading (roller blinds) are shown in Figure 11 and Figure 12. The box-type window gives the chance to integrate shading and daylight deflection elements in the space between the glazings. The advantage to external shanding is the wind protection as well as the protection against staining.
The roller blinds installed at the moment do have the disadvantage of low transmittance (see also measured data for daylight). There is no option for daylight deflection at the moment.

The best way to avoid glare and overheating in summer is by use of overhang. However, as this is not included in the architectural design of the historic building, new ways to solve the problem have to be found. This is part of the research project 3ENCULT (subtask 3, energy efficiency solutions). Box-type windows are a typical detail of many historic buildings, thus the development of window integrated shading and daylight elements with priority of conservation-compatibility has a high potential for transferability to similar projects.
In a first step the luminances and illuminances in the classrooms and the lecture room for physics at daylight and artificial light were measured. From this, different possible design models of classrooms will be drawn up. These designs will be compared to each other by simulation of the light performances with light simulation programs (RELUX, DIALUX, RADIANCE) as well as the program VIVALDY as described in this paper.

Moreover, a primary objective is the improvement of the light conditions in classrooms in respect to energy use and comfort. As a reference, the status quo is measured (light quality, electricity consumption, hours of artificial lighting) as shown in this contribution.

The requirements for the illuminances in schools are given in the European norm EN 12464-1 [2] depending on the tasks of the teacher and the students. As the visual tasks and requirements are quite different, the lighting concept has to be flexible and adjustable to the different activities throughout the day.

<table>
<thead>
<tr>
<th>Task</th>
<th>the teacher</th>
<th>the student</th>
<th>Standard Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Writing on blackboard</td>
<td>Reading on blackboard</td>
<td>500 lux (vertical) 200 lux</td>
</tr>
<tr>
<td>2</td>
<td>Talking to the students</td>
<td>Paying attention to the teacher</td>
<td>300 lux 300 lux</td>
</tr>
<tr>
<td>3</td>
<td>Showing a presentation (slides, powerpoint, television program, etc.)</td>
<td>Looking onto the screen</td>
<td>300/10 lux 10 lux</td>
</tr>
<tr>
<td>4</td>
<td>Paying attention to working students</td>
<td>Writing, reading drawing, etc.</td>
<td>300 lux 300 lux</td>
</tr>
<tr>
<td>5</td>
<td>Coaching computer activities</td>
<td>Looking to the computer screen and the paper</td>
<td>50 lux 300 lux above the computer</td>
</tr>
<tr>
<td>6</td>
<td>Preparing lessons</td>
<td>Not present</td>
<td>300 lux 50 lux</td>
</tr>
</tbody>
</table>

In order to reach a comfortable education and working environment, the luminances must be below 3000 cd/m² and the luminance contrasts in the (wide) visual field must be lower than 1:30.
For evaluation, the classroom has been divided in a blackboard zone (vertical data) and a classroom zone (horizontal data).

![Classroom zone and blackboard zone](image)

**Figure 14. Classroom zone and blackboard zone (left), right: blackboard zone with (A) and without (B) wall-washers [3]**

Wall washers help to light vertical surfaces such as blackboards evenly and without shadows. Moreover, disturbing light reflections can be avoided and good readability from all places of the classroom is guaranteed [3].

Besides the illuminance measurements, pictures of the luminance are calculated from HDR (High Dynamic Range) fotos as described in the next chapter. This pictures can be used to evaluate the glare rating according to the CIE-methode. The maximum value of UGR (Unified Glare Rating according to EN 12464-1) for class rooms is limited to 19.

\[
UGR = 8 \cdot \log_{10} \left( \frac{0.25}{L_b} \sum \frac{L^2 \omega}{p^2} \right)
\]  

\(L_b\) background luminance \([\text{cd/m}^2]\)  
\(L\) mean luminance of each luminous source \([\text{cd/m}^2]\)  
\(\omega\) solid angle of the light emitting area of each luminous source from observer  
\(p\) position index according to Guth

**Measurement equipment and procedure**

For both, illuminance and luminance measurement, MINILUX digital lux-meter was used (measuring range 0 to 199 900 lx, minimum resolution: 1 mlx, DIN class B, max. cos deviation: Class B, <3% ). In case of luminance measurement, a shutter tube with a relation of the diameters d/D and distance L was choosen for a ratio of luminance \([\text{cd/m}^2]\) by illuminance \([\text{lux}]\) of 100. The resulting measuring range for luminance is 0 to 19990 kcd/m².
For luminance pictures, a Canon EOS 400D digital camera (Digital AF / AE SLR, high sensitivity, high resolution CMOS sensor, 10,10 MP Image type: JPEG, RAW 12 bit) was used. HDR (High Dynamic Dange) files were created from five shots with different exposures (under-, normal and overexposed). The HDR-files were calibrated with reference pictures and measurements by direct luminance measured of a surface from the camera position.

Measurement of day light and artificial light in a class room and a lecture room for physics.

Luminance measurements
Figure 16 shows an example of a luminance false coloure map calculated from a calibrated HDR as described above. It shows the luminance in the class room at a sunny day. The peak values of luminance above 12000 cd/m² illustrate the problem of physiological glare by direct sun. Consequently the roller blinds are closed in those cases. Unfortunately the resulting illuminance is too low for the visual tasks in the classroom without artificial light.
As shown in Figure 17 and Figure 18 the status quo of artificial lighting in the class rooms consists of two rows of fluorescent tubes, which are located asymmetrically (shifted toward the external wall. The light distribution is rather non-uniform throughout the classroom as well as within the blackboard zone, as there are no wall washers installed.
Illuminance measurements

The measured illuminance values at artificial light are too low according to EN 12464-1 standard values (min. 300 lux), especially at the desktops close to the inner wall. The lowest value measured was 249 lux at reading position and 220 lux at the desktop edge.

A detailed measurement (grid 4 x 5) was performed in order to evaluate the uniformity of illuminance according to EN 12464-1 table 1, which is defined as the minimum value divided by the mean value. The result of the measured uniformity is 220 lux / 286 lux = 0.77, which is higher than the threshold value of 0.7.

Figure 18. Luminance values measured at desktop level with sensor FLA603VL4

As shown in Figure 19 and Figure 20, similar problems occur in the lecture room for physics. The reflective surfaces of the desks arise an additional risk of glare in case of direct solar radiation as shown in Figure 20.
New visualisation software for planning of interventions in cultural heritage

Based on the evaluation of calibrated HDR – fotos (or simulation results), the software tool VIVALDI (Virtual & Variable Lighting Design tool for Intelligent ELI/LENI Management, © 2010 Zumtobel) can be used to compose particular situations of lighting from different sources.

With the application of schedules (timeline editor) for dimming of artificial light, the electricity consumption throughout the day (energy chart) can be calculated, if the dimming characteristics of the luminaires are known.

The advantage of this software for planning of interventions in cultural heritage is, that a visualisation of the lighting situation is available for different alternative solutions in advance. It will be applied within the 3ENCULT project for comparison of different energy efficient solutions with priority of conservation-compatibility.
Technical solutions for shading and day light control

As learnt from measurement data, the performance of shading by roller blinds as installed at the moment is not suitable for good visual and thermal comfort in the class rooms. Day light redirecting elements integrated in the box-type windows will help to optimize the daylight autonomy as well as the visual comfort. The problem is, that conventional lamellas can not be hidden completely behind the window frame in ruffled condition. There is still development to be done for products applicable to historic buildings.

The application of surface coats of paint with high reflectance also helps to enhance the daylight redirection.

Energy efficient solutions for artificial light at high visual comfort

In case of a building renovation, a new lighting system will help to reduce operating costs and electric energy demand in future. Most measures are highly economical.

The inventory of the artificial lighting system in the case study showed, that most of the strip lighting fixtures in the class rooms can be switched on only all together. If artificial light is used to compensate for low daylight illuminance, it is useful in terms of energy efficiency to have individual electric circuits for the individual strip lighting fixtures.

Newly developed light sources, like T5 fluorescent lamps, compact fluorescent and LED improve the light output. Electronic ballasts reduce power loss to provide flicker-free light and a better starting of the lamps. Moreover, new reflector materials and designs help to increase the reflector efficiency and to reduce the glare of the lamp.

Presence control automatically switches off the light to save energy if the class room is not in use.

The aesthetics do not suffer in the renovation. For each architecture, there are lamps with matching design and cutting-edge technology. Often, the latest technology can be be mounted into existing lights. Since lamps and ballasts are smaller and smaller, more powerful and energy efficient, safe and bright lighting can be integrated in listed buildings with no visible change.

CONCLUSION

The quality of daylight and artificial light can be measured with the help of a digital lux meter, a shutter tube and a calibrated digital camera (via HDR-imaging) with high accuracy at low cost. New software tools help to optimize and visualize energy efficient lighting strategies. Especially for interventions in historic buildings, the visualisation of planned interventions is a valuable instrument for lighting designers and decision makers.

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