Best practice for lighting in Frankfurt schools also standard in the directive with 2W/(m^2 100lx)

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Abstract

In the last years the producers have made remarkable progress with the efficiency of lighting. There are to notice conspicuous longer life time, better efficiency, changeable light distribution and therefore at all better planning factors. But those increase in efficiency needs more reinforce consideration, both, in standards and guidelines as well as in the concrete planning.
Measurements of the illuminance in modernised schools of the city of Frankfurt show partly substantial exceeding towards planned data and the demanded valuing in the standards. Those exceeding cause relevant higher costs for investment and maintenance and can also lead to loss of comfort with screen-handling.
Therefore new lighting-programs were controlled and tested in an pilot-project at the school “Helmholtzschule”. The experience was considered by the construction office in revised guidelines of the city. New lighting modernisation in schools of the city Frankfurt furthermore approve this substantial potentials of saving towards the precept in the newest standards. Different to the characteristic values in the DIN V 18599 with 5 to 10W/(m² 100lx) and DIN EN 12464, the guidelines for economical building (Leitlinien FFM) of the city of Frankfurt give lower specific values with 2 to 2,5 W/(m² 100lx), according to SIA 380/4 (switzerland) and LEE 1996. The guidelines for the German Association of Cities and Towns therefore give 2,5 to 3 W/(m² 100lx).

These values and the resulting low costs are proven for example in the following buildings:
In the new built primary school at Riedberg in Passivhouse-quality (Qp = 59 kWh/m²a) the classrooms with demand of 300lx attain a specific wattage for lighting of 5,6 W/m², the specific value is 1,9 W/(m² 100lx), over 400 lx are measured. In the comprehensive school “Schule am Ried”, after modernisation. the illuminance Em was calculated with an average illuminance of 368 lx with a specific value also under 6 W/ m². Despite of this optimised planning a average illuminance Em of 443 lx was measured after modernisation. Therefore the postulation of an maintenance-factor lower than 0,8 an (DIN EN 12464) is not necessary for optimised planning with lighting programs.
Another example is the lighting reorganisation of two gymnasia. In spite of their relevant height the specific values almost keep nearly at the guideline values.
Therefore the Departement of Energy-management starts a program of new lighting for further eight schools. With an optimised planning the lower costs for invest and maintenance results in a pay back time of only 5 to 10 years.

Introduction

A reduced power-consumption with standard lighting-quality is set objektive by the EU (Directive on Energy performance of Buildings - EPBD or EC-guideline 2202/91/EG). The potential is larger than estimated in standards and computation rules.

In the new Standard DIN 18599 part 4 you can find empirically established values about the lighting-efficiency for non residential houses. Comparing these values with the empirically established values for good lighting in the guide for electric energy of the country Hessen 1996 (LEE 1996) or weakend in SIA 380/4/LEE 2000, a substantial saving potential for power consumption and partly invest from 50 to 80% is to recognize.

The city of Frankfurt has already verified this potential since 2002 in a pilot-project and further projects. The results shall point out the economical potential during the restoration. The city of Frankfurt has therefore postulated the standard of the LEE 1996 in its guidelines for economic building and has put them into the further practice. It was shown, that software and spreadsheet calculation according to standards are not suitable for an optimised planning. Also became considered the experience, that illuminance is not decisive for the positive evaluation of the illumination-quality alone.

Standard values

In table 1 of DIN 18599 part 4 the following specific values for Efficiency of lighting from evaluation of stock of buildings are given:

Light distribution	Relative light output downwards φ_u	specific wattage with electronic ballast
	[-]	[W/m² 100 lx]
direct	> = 0,9	5
direct/indirect	0,1 <= . . .< 0,9	6
indirect	0,1	10

Table 1: lighting efficiency, DIN 18599/4

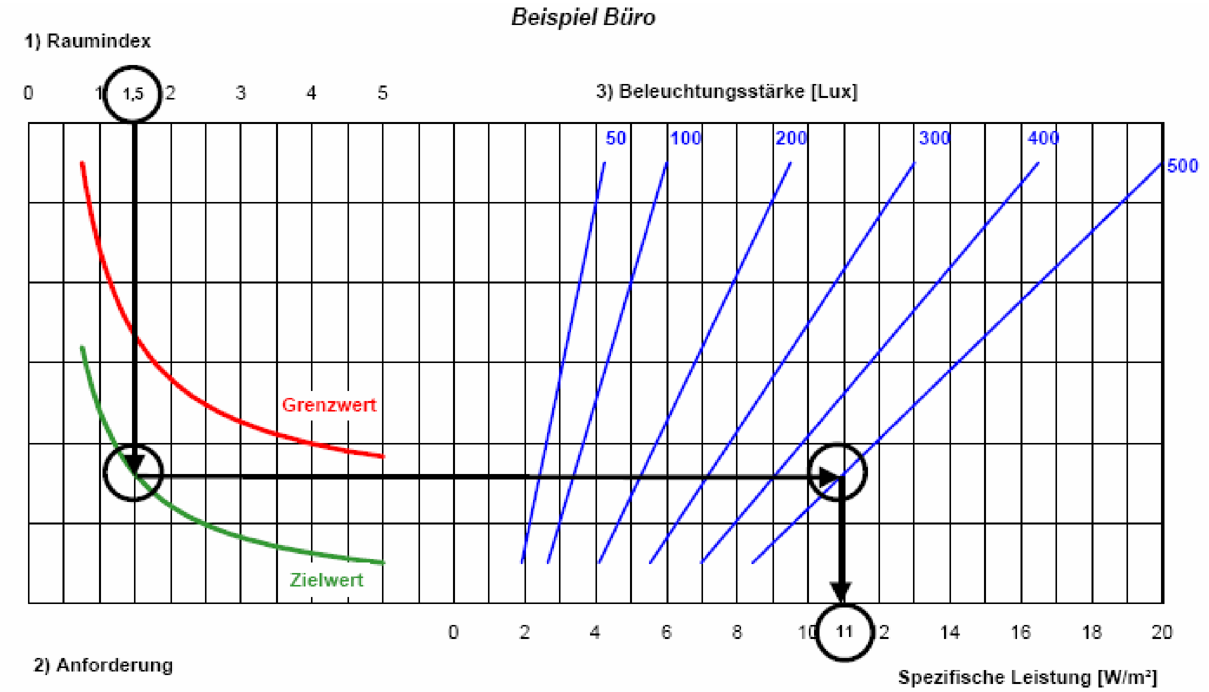


Fig. 1: specific wattage for lighting, lighting efficiency dependent on room index and illuminance, SIA 380/4 in: SIA etool (left: room-index)

The LEE 1996 (guideline electric energy in Buildings), reference on the empirically values after SIA 380/4 and new computations, gives 2,5 W/(m² 100lx) as limit value and 2 W/(m² 100lx) as goal value.

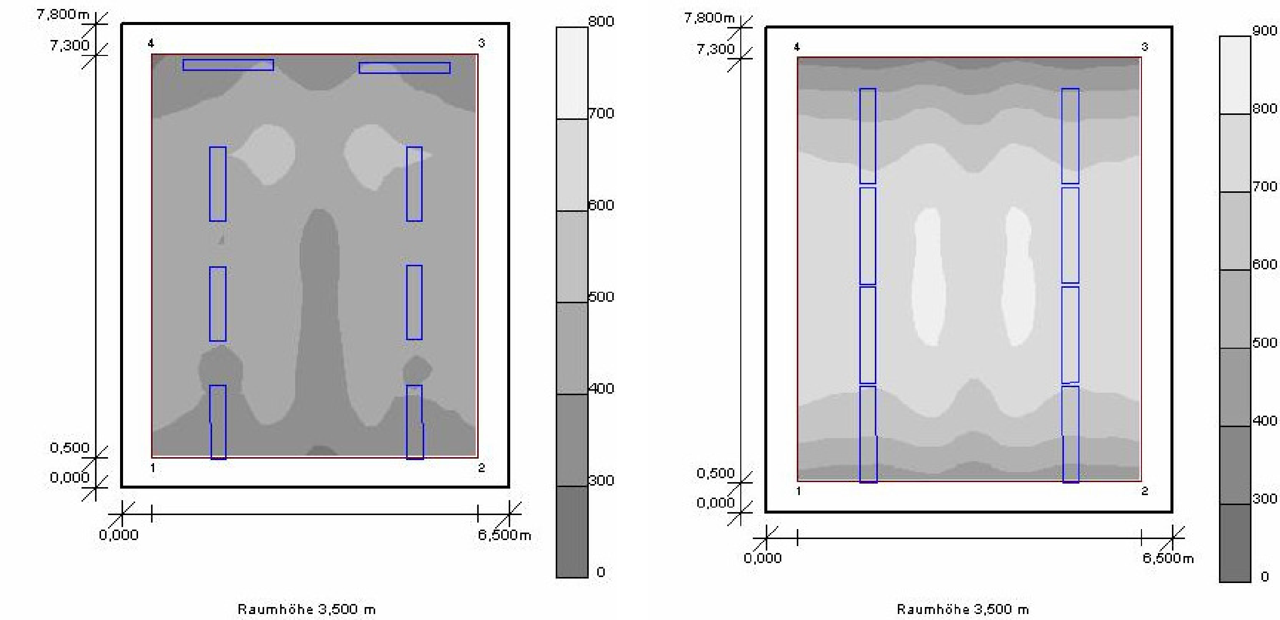
Limit Value	[mW/(m² lx)]	25 * fv fv <= 0,7
goal Value	[mW/(m² lx)]	20 * fv fv <= 0,7

Table 2: Table 2.5 in LEE 1996, fv use factor

Comparing these values with classic planning and the stock values according Fig. 1, the potential for saving (power and therefore power-consumption) is about 50 to 80%. Reduced invest in lighting also is a result (less luminaires).

Pilot project Helmholtzschule

In the project Helmholtzschule the city of Frankfurt has proven the capabilities of an optimised planning for the modernisation of a pilot Classroom with a standard modernisation in the comparison classroom.



Em in lx (*)	Emax in lx (*)	Emin in lx (*)	Emin/Em (*)	Emin/Emax (*)
422	553	295	1:1,4	1:1,9

*)... Nutzebene vermindert um 0,500 m Randzone

Em in lx (*)	Emax in lx (*)	Emin in lx (*)	Emin/Em (*)	Emin/Emax (*)
668	820	349	1:1,9	1:2,4

*)... Nutzebene vermindert um 0,500 m Randzone

Fig. 2: lighting pilot-classroom (left) , optimised with 8x35W T5 luminaires, calculation with DIALUX for demand 300 lx, reflection 70/50/20, maintenance factor 0,8
comparison classroom (right): 8,8 W/m^2, 670 lx

The specific wattage of the lighting in the pilot classroom with eight T5 35W luminaires is 6,1 W/m^2. The standard after AMEV Bel2000, which is much better than the values of DIN 18599, is 8 luminaires with 58 W T8, resulting in a value of 8,8 W/m^2, experienced in the comparison classroom. The old classrooms had about 16 W/m^2 with 12 x 58W T8 luminaires. The default average illuminance of the DIN (300 lx etc.) were kept in both cases (Em 420 lx and 670 lx). The meassured illuminance showed a substantial excess over 20% against the planned values. This was also reported from other software, also in Switzerland. Despite of less illuminance, however the pilot room was evaluated as brighter and friendlier by the users, which confirmed the concept. This showed also, that, apart from the illuminance on utilizable level the choice of the light distribution- broad-radiating- as well as a small indirect portion by a laterally punched raster - can be also decisive (Fig. 3.

Fig. 3: lighting pilot-classroom (left): 6,1 W/m², 420 lx, comparison classroom (right): 8,8 W/m², 670 lx

Compared with a old lighting one can save 33% of invest (4 luminaires) and nearly 70% of power consumption.

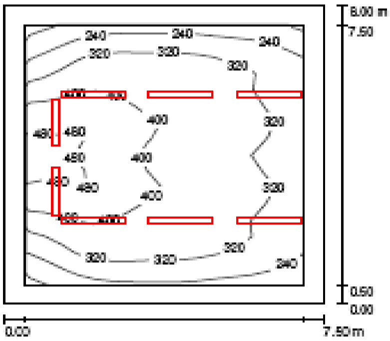
Therefore these defaults of the LEE 1996 were fixed in the technical standards of the building department of city of Frankfurt in 2001/2002. They were used and verified in further projects, for instance in the Passivhouse – primary school at Riedberg and the Comprehensive school “Schule am Ried”.

Further Projects

“Schule am Ried”

For the reorganisation of these Comprehensive school there was placed value on an optimised, economical lighting. From the experience in the pilot-project Helmholtzschule the lighting was calculated with T5 luminaires, and reflection of 70/43/20. For a classroom of 60 m², 8 luminaires with T5 36/39W lamps (3200/3600 lm) are used. The illuminance Em, calculated with maintenance factor 0,95 as 343 lx, was measured with Em = 443 lx (Fig. 4 and 5). Therefore it was shown again, that lighting software shows relative conservative results to give a good warranty for sufficient illuminance. Table procedures in accordance with standards were not suitable for an optimised planning.

Klassenraum / Einblattausgabe



Raumhöhe: 3.000 m, Wartungsfaktor: 0.95 | Werte in Lux, Maßstab 1:101

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g_1
Nutzebene	/	343	139	520	0.40
Boden	20	287	111	465	0.42
Decke	70	48	23	67	0.47
Wände (4)	43	92	26	314	/

Nutzebene:
Höhe: 0.850 m
Raster: 16 x 16 Punkte
Randzone: 0.500 m
Beleuchtungsstärkeverhältnis (nach LG7): Wände / Nutzebene: 0.230, Decke / Nutzebene: 0.139.

Leuchtenanordnungen

Nr.	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	6	TRILUX 5041RSV-L/35 E Raster-Anbauleuchten Baureihe 504··· (1.000)	3600	39
2	2	TRILUX 5081W-RSA/36 E Raster-Anbauleuchten Baureihe 508·· (1.000)	3200	36
		gesamt:	28000	306

Spezifischer Anschlußwert: 5.10 W/m² = 1.49 W/m²/100 lx (Grundfläche: 60.00 m²)

Fig. 4: Schule am Ried, classroom 116, calculated values of illuminance and specific wattage

Fig. 5: Schule am Ried, classroom 116, massured values of illuminance

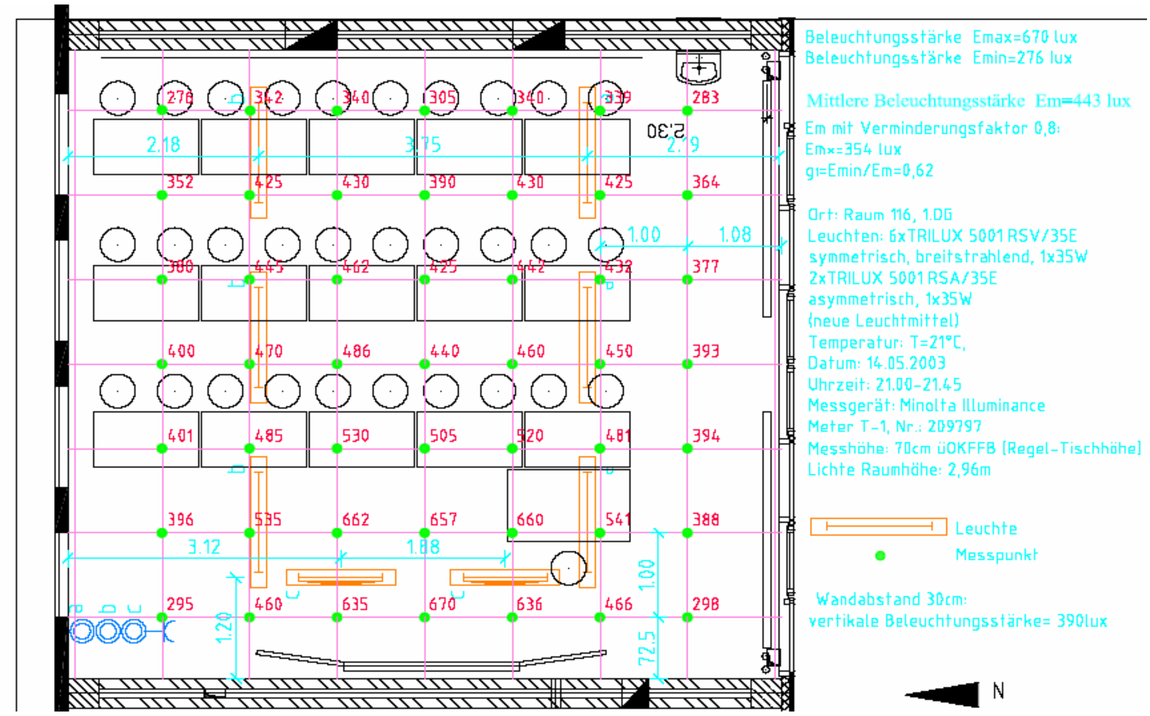


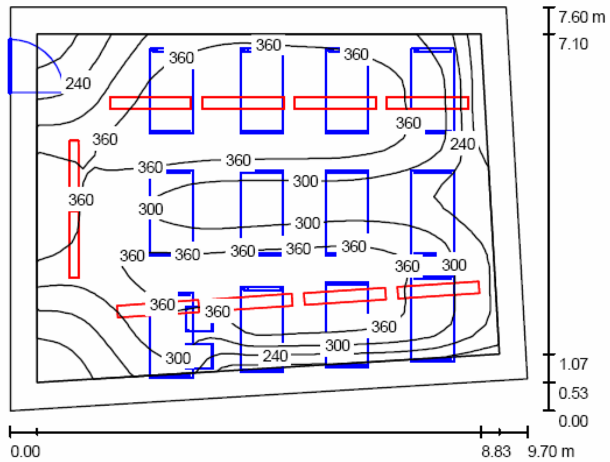
Fig. 6: Schule am Ried, classroom 116

„Heinrich-Kromer-Schule“, Satellite Riedberg

In the primary school at Riedberg the experiences from the preceding examples were considered. The defaults for a Passivhouse school with 120 kWh/(m^2 a) primary energy are very close, therefore also an optimized lighting planning was important. With T5 35 W, mirror raster three-gang luminaires with punched raster it was possible, to get an specific value of 5,6 W/m^2 for an average illuminance of Em 300 lx. Therefore each classroom of 69 m^2 gets 10 luminaires, two of them for the blackbord. The invest per light was typical, 100 € inclusive mounting. Also here the measured illuminance was higher than the calculated, despite the reflection and the maintenance factor were high computed.

Fig. 7: **School at Riedberg, Classroom**

Klassenraum - Einblattausgabe



Raumhöhe: 3.100 m, Montagehöhe: 3.100 m, Wartungsfaktor: 0.80 Werte in Lux, Maßstab 1:100

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g1
Nutzebene	/	327	129	418	0.39
Boden	30	192	50	317	0.26
Decke	90	126	38	2709	0.30
Wände (4)	60	109	26	304	/

Nutzebene:
Höhe: 0.850 m
Raster: 20 x 15 Punkte
Randzone: 0.500 m
Beleuchtungsstärkeverhältnis (nach LG3:2001): Wände / Nutzebene: 0.321, Decke / Nutzebene: 0.384.

Leuchtenanordnungen

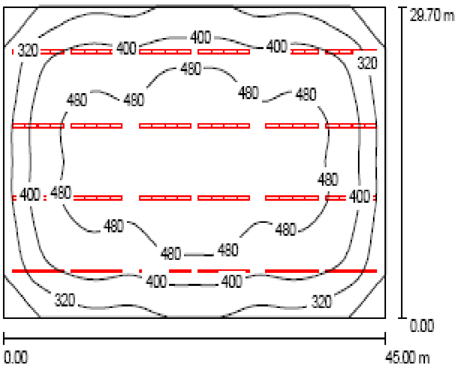
Typ	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	2	TRILUX 5081W-RSA/36 E Raster-Anbauleuchten Baureihe 508··· (1.000)	3200	36
2	8	TRILUX 5261RSV-L/35+05261DG/1500 E Raster-Anbauleuchten u... (1.000)	3300	39
		gesamt:	32800	384

Spezifischer Anschlußwert: 5.53 W/m² = 1.69 W/m²/100 lx (Grundfläche: 69.41 m²)

Fig. 8: School at Riedberg, calculated illuminance and specific efficiency

Gym “Friedrich-Ebert-Schule” and “Wilhelm-Merton-Schule“

Sporthalle Friedrich-Ebert-Schule - Zusammenfassung



Raumhöhe: 7.200 m, Montagehöhe: 7.200 m, Wartungsfaktor: 0.80 Werte in Lux, Maßstab 1:500

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g1
Nutzebene	/	421	169	559	0.40
Boden	55	408	170	544	0.42
Decke	78	180	85	256	0.47
Wände (4)	26	222	97	358	/

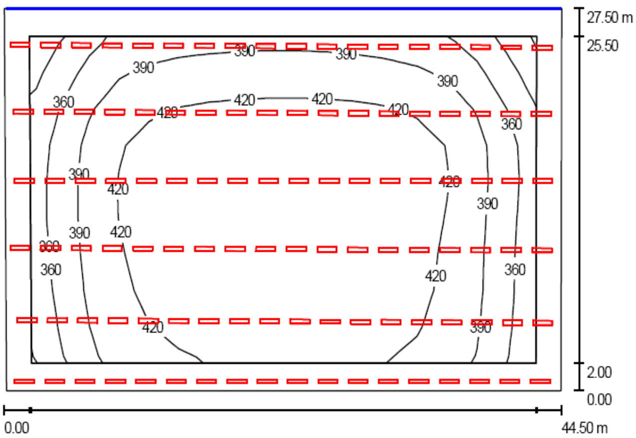
Nutzebene:
Höhe: 0.850 m
Raster: 32 x 16 Punkte
Randzone: 0.000 m
Beleuchtungsstärkeverhältnis (nach LG3:2001): Wände / Nutzebene: 0.524, Decke / Nutzebene: 0.427.

Leuchtenanordnungen

Typ	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	96	Kandem SA 11/2X58 EVG (1.000)	10000	110
		gesamt:	960000	10560

Spezifischer Anschlußwert: 7.90 W/m² = 1.87 W/m²/100 lx (Grundfläche: 1336.50 m²)

Sporthalle Wilhelm-Merton-Schule / Einblattausgabe



Raumhöhe: 9.000 m, Montagehöhe: 7.200 m, Wartungsfaktor: 0.72 Werte in Lux, Maßstab 1:347

Fläche	ρ [%]	E_m [lx]	E_{min} [lx]	E_{max} [lx]	g_1
Nutzebene	/	408	299	444	0.73
Boden	25	372	174	445	0.47
Decke	70	95	58	118	0.61
Wände (4)	51	155	30	698	/

Nutzebene:
Höhe: 1.000 m
Raster: 17 x 9 Punkte
Randzone: 2.000 m
Beleuchtungsstärkeverhältnis (nach LG7): Wände / Nutzebene: 0.389, Decke / Nutzebene: 0.232.

Leuchtenanordnungen

Nr.	Stück	Bezeichnung (Korrekturfaktor)	Φ [lm]	P [W]
1	108	Kandem SA 11/2X58 EVG (1.000)	10000	110
		gesamt:	1080000	11880

Spezifischer Anschlußwert: 9.74 W/m² = 2.39 W/m²/100 lx (Grundfläche: 1220.31 m²)

The old lighting in the Gymnasium of the Friedrich-Ebert-Schule had a specific value of 12W/m^2 but insufficient illuminance. After reorganization with a value of 7,9 W/m^2 a satisfying illumination with more than 400 lx was attained, despite a height of 7,5 m. For 1336,5 m^2, 96 T8 luminaires with-2x58W lamps were used. The measure has a pay-back period within 6 years, calculated with 1750h/a.

In the gymnasium of the “Wilhelm-Merton-Schule” the old lighting had a value of 48 W/m^2. The new lighting with 108 one and two flame T8- 58 W Mirror raster luminaires with EB reach a value of 9,74 W/m^2 with a requirement of 400 lx. This, although the gymnasium has a hight of 9,5 m and a bad reflection because of the wood-walls. The measure has a pay-back period within 3,5 years, calculated with 1000h/a .

Fig. 9 and 10: Gymnasium “Friedrich-Ebert-Schule” and “Wilhelm-Merton-Schule”, calculated illuminance and specific efficiency

All projects

Economy, Reaching of the limit and goal values

The economic conversion of the specific values of the LEE 1996 with a goal value of 2 W/m2 100lx could be proven in the two school projects on adherence to the standard defaults of an average illumination Em = 300 lx.. Even with the two gymnasia with higher lighting requirements (larger height and worse reflection degrees) characteristic values were attainable in the range of the limit value of the LEE 1996 of 2,5 W/(m^2 100lx) with economic measures of reorganisation.

Further efficiency increase

Additional to the optimised planning of lighting also the daylight use and the occupancy dependent light circuit should be optimised. Automatic daylight systems are still not economically for application in schools with measured utilization periods between 400 and 1000h/a.
Therefore a central tracing disconnection was tested and used. It was shown to be as affective as an automatic control. Five minutes after end of the first school hour (approx. 8:30 am) for the first time in all classes the light is centrally and briefly switched of, beside of inner classrooms. Even in the winter at this time it is already sufficiently bright in order to be able to restart the light again if necessary. This is repeated in each break over the day till dawn. Surprisingly in the project there was no negative feedback to this tracing circuit. In relation to an automatic control the light is completely switched of if not necessary. To this the experience confirmed, that a good artificial lighting is no longer particularly noticed and switched of. This leads to the well-known phenomenon of the continuous use of lighting with automatic daylight control.

Further examples

Also newer projects within the office-buildings reach the characteristic values of the LEE 1996. The range of the specific wattage for basically the same task to see is however still astonishing and is from 5,0 to 14 W/m^2, even for ambitious energy savings buildings (Hoffmann/Voss).

Résumé

The goal and limit values of the LEE 1996 and the standard of SIA 380/4 with 2 and 2,5 W/(m^2 100lx) are economically attainable with an optimised lighting. The defaults of the “guidelines for economic building” of the city Frankfurt, 2.5 and/or 2 W/(m2 100lx) as economic optimum were confirmed.
The investment costs for the realised projects are in the context of a good standard and clearly under the costs of a classical installation after standard calculation sheets. With optimised lighting the power (wattage) and current saving alone are 50 % and more in relation to a classical planning. The comparison with the characteristic data of the standard DIN V 18599 for the building stock with 5 to 10 W/(m^2 100lx) proves therefore a realistic saving potential in the existence of over 50% alone for power consumption. Also in relation to a good planning e.g. according to the defaults of the AMEV (BEL 2000) 20-30% can be still saved with an optimised planning. The illuminance of standards was kept in each case, the computed values became exceeded in each case. Safety impacts to the planning computations of the used lighting software are therefore not helpfull. By the selected mirror raster luminaires with EVG, laterally punched raster and high efficient lamps the users are satisfied with the illuminance and quality. Also the tracing circuit was surprisingly accepted. Oversizing of the lighting are not necessary, partly even unacceptable (AMEV BelBild 2002). The pay back period of a modernisation of old lighting in schools is 5 to 10 years, dependent on the useful hours per year..

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