Non-visual effects: Myth or Truth

Billd: www.giga.de

Content

1. Background of German Engagement for the LED
2. Practical using – two point of views
3. DIN SPEC 67600
4. Project NiviL on the University of Technology Berlin
5. Consequences and Outlook

Content

1. Background of German Engagement for the LED

1. German Engagement for the LED

LED = One of the leading markets for Germany

Research budget (2008 – 2015): 40 € million for technology and pilot projects
plus 50 Mio € for promotion of projects in the municipalities

Reasons

1. LED technology is ready for using – no reasons to wait longer!
2. permits energy savings between 50 - 90 %
3. improvement in lighting

Editorial

Since launching its LED Lead Market Initiative at the end of 2008, Germany's Federal Ministry of Education and Research has put up more than €40 million for technology and municipal pilot projects. With the public lighting competition "Kommunen in neuem Licht" and the two sectoral projects "UNILED" and "Performance Quality Label" (PQL), it has shown that LED technology

- *is usable within the existing infrastructure without major additional investment*
- *permits energy savings between 50 and 90 percent*
- *is felt by users and residents to bring an improvement in lighting.*

In the light of these project findings, the Federal Government has driven forward the implementation of the new lighting technology. Under the municipal directive for energy efficiency, the Federal Environment Ministry has supported hundreds of LED projects. In a decree issued in 2013, the Federal Ministry of Transport made LED the lighting solution of choice for federal buildings. The federal states (Baden-Württemberg and shortly NRW) have started to follow suit. The LED Lead Market Initiative has thus achieved its objective. By international standards too, Germany is a lead market for LED technology – not only in terms of international high-profile flagship projects in Freiburg, Munich, Trier and elsewhere but also in terms of euros and cents for the large number of mostly small and medium-sized enterprises.

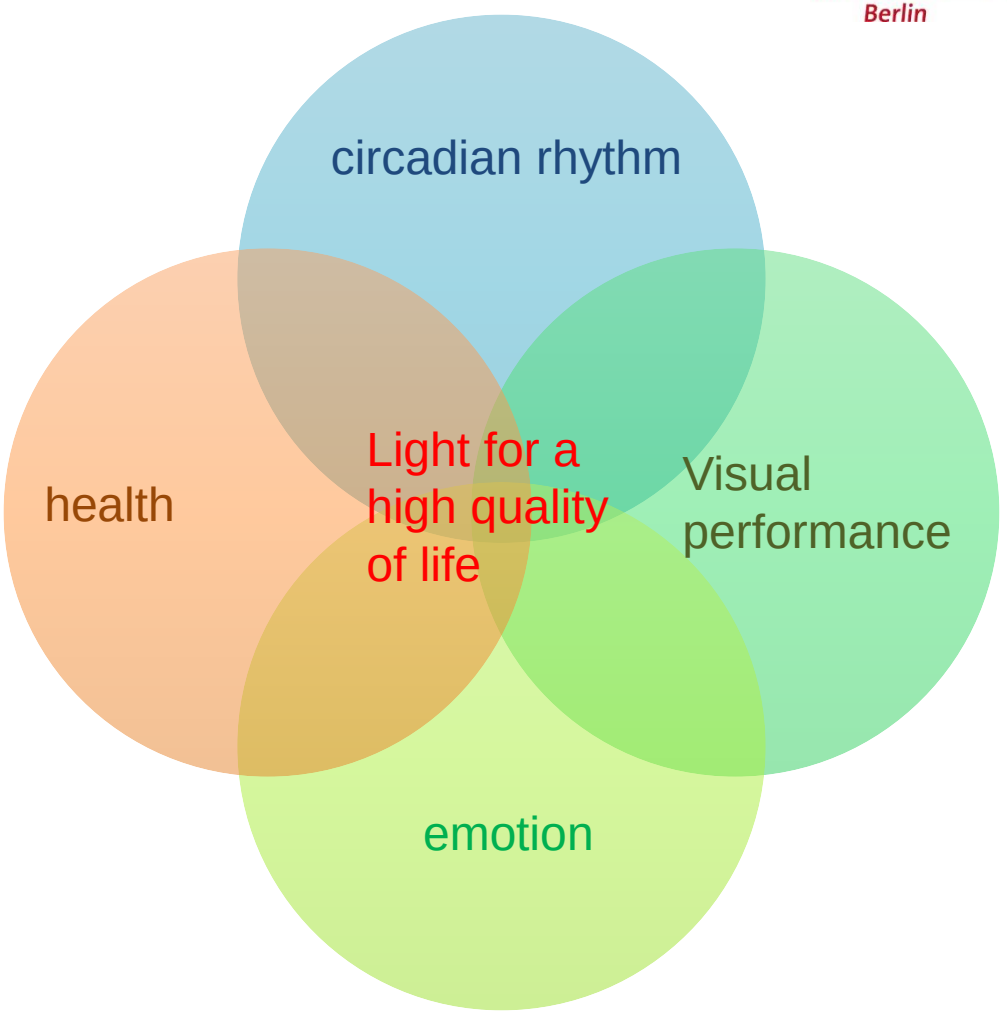
One of the issues closely connected with LED technology is the impact of light on human beings. Modern testing and measurement methods enable the physiological, psychological and social effects of light to be investigated much more thoroughly than in the past. And with the new scope for colour control and colour rendering that LED technology offers, the findings are much easier to harness than with conventional lighting technology. When public utility companies marketed the new municipal gaslight in the early decades of the 20th century, brightness – measured in "candlepower" – was pretty much the only yardstick used. As the century progressed, luminance, illuminance, contrast rendition and glare were added as quality criteria. Today, light colour, colour temperature and the interplay between light, illuminated surfaces and human perception are starting to play a central role.

In 2013, the Federal Ministry of Education and Research called for "intelligent lighting". sending out an invitation for basic research to be conducted in these areas. The projects selected will be launched shortly. With the new technology, research is again an important issue for the lighting industry. I look forward to the new lighting solutions signalled by numerous examples in this booklet.

2. Value added of the LED

- Visual effects
- emotional effects
- non-visual effects

= Human centric lighting (HCL)



Remark:
Non-visual effects – only one aspect of HCL!

Content

1. Background of German Engagement for the LED – LED Leading market
2. Practical using
    a. Industry
    b. Office
    c. Schools
    d. Nursery homes and hospitals
    e. Residential and hotels

– two point of views

Content

1. Background of German Engagement for the LED – LED Leading market
2. Practical using – two point of views

What can we believe?

One side:
Industrie:

- want to create new Products with added value
- Have to invest in knowledge, new processes

Other side:
Custemer:

- Doubtfull
- Experience: Not every product fulfills this promise!

http://www.lightingeurope.org/uploads/files/Quantified_Benefits_of_Human_Centric_Lighting_April_2015.pdf

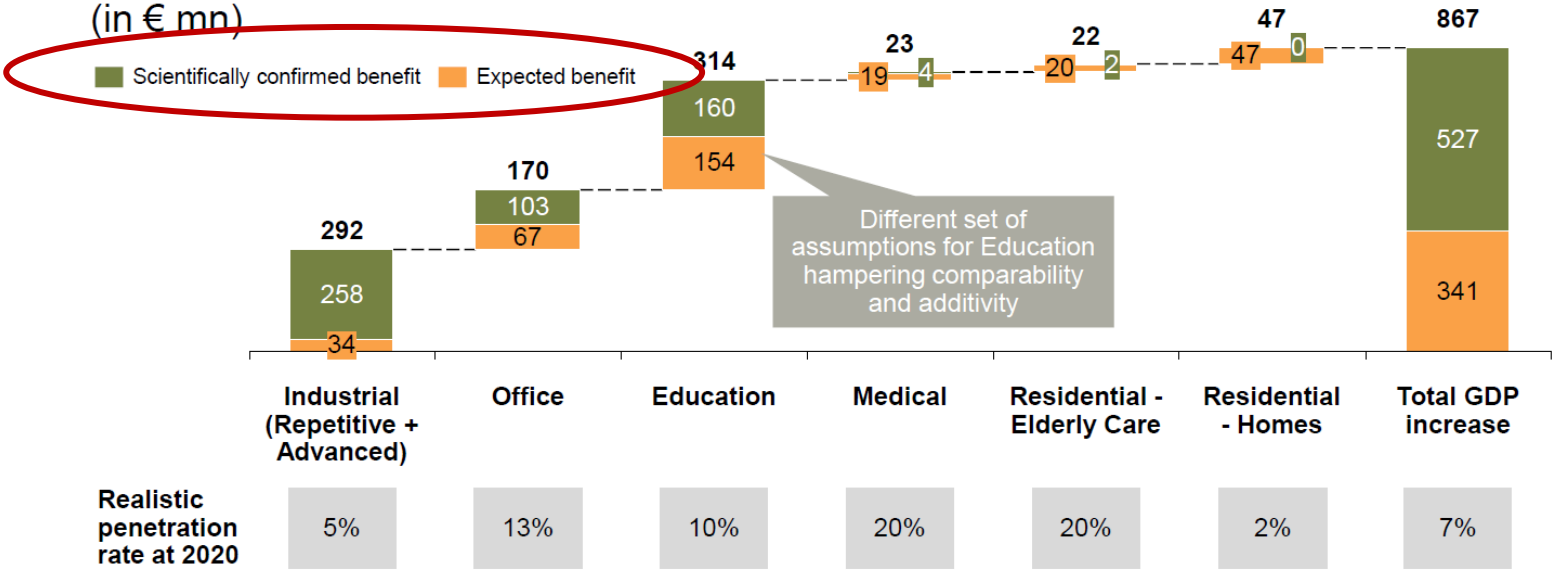
Market study from ZVEI/ ATKearney

ATKearney

At realistic market penetration macro simulations yield Human Centric Lighting effects up to € 0.87 bn in 2020 in Europe

Macro level effects of Human Centric Lighting in 2020
(in € mn)

Highly sensitive to assumptions[1]



Macro level effects of Human Centric Lighting require further justification from scientific long-term studies to confirm the benefits

1. Benefits are highly sensitive to the underlying assumptions, especially effects of Human Centric Lighting, which mostly needs further research
Source: A.T. Kearney simulation model incl. detailed source references

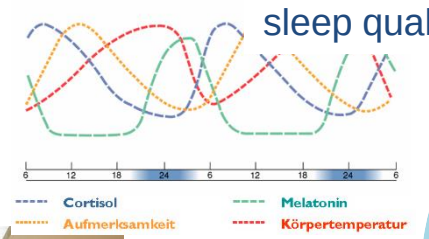
A.T. Kearney 10/12.2012/44194d 19

Highly sensitive to Assumptions

Needs further research!

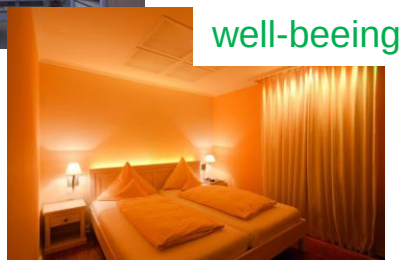
Non-visual effects:

Technische Universität Berlin



retirement home

hospital



well-beeing

office

school

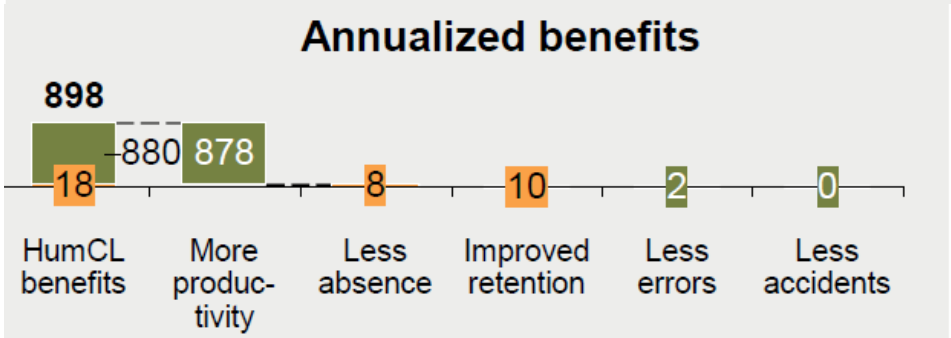
Lichttechnik

For repetitive tasks in industrial settings, effects from Human Centric Lighting are dominated by productivity increases

Industrial (Repetitive) – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)

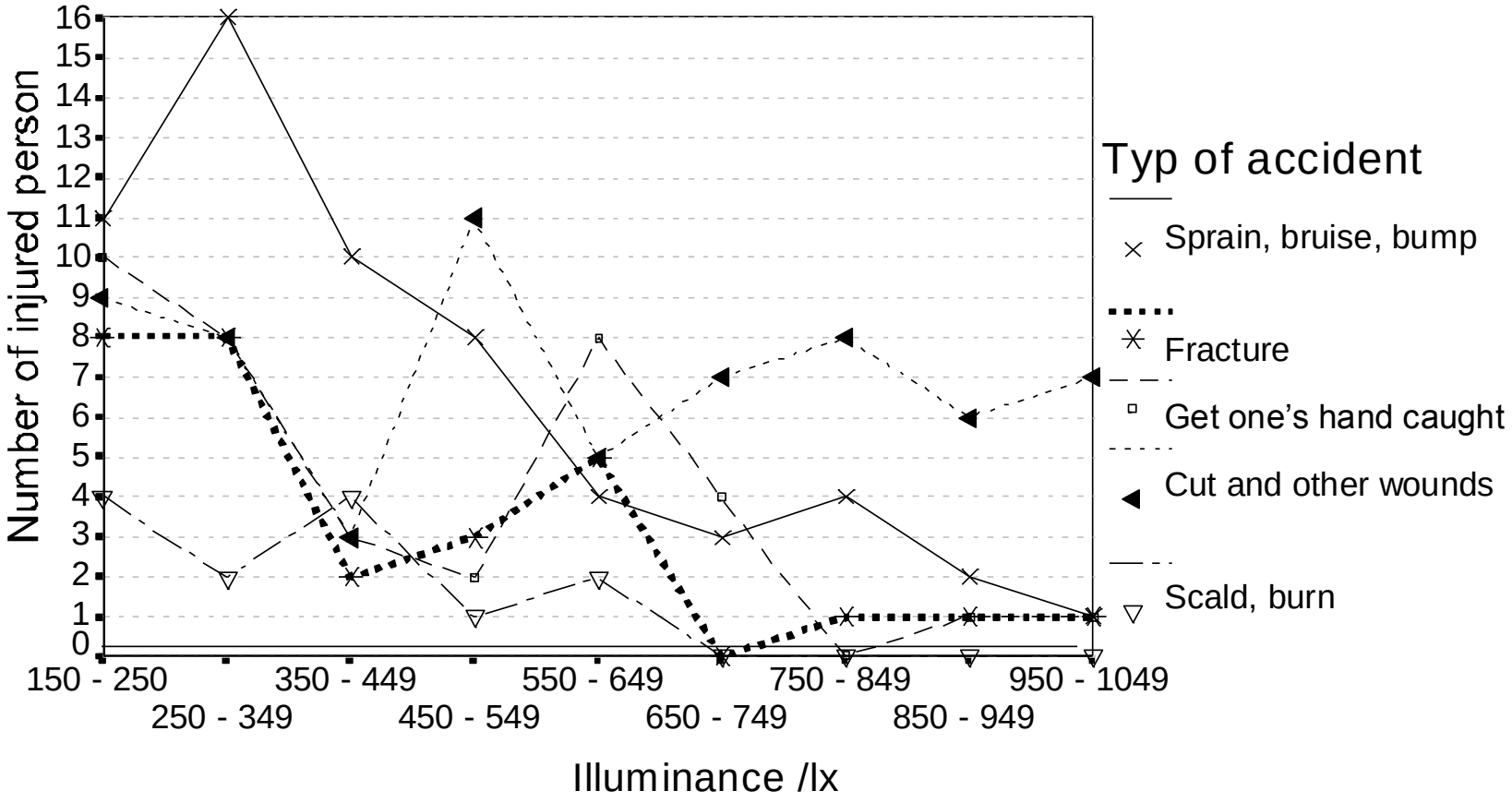


Reasoning for benefits

- More productivity (4.5% vs. LED lighting), less errors (1%) and less accidents (1%) due to increased alertness and energizing effect
- 1% less sick days and 1 year improved retention due to higher physical robustness (mid- to long-term effect)

Industry (1)

Light and accidents

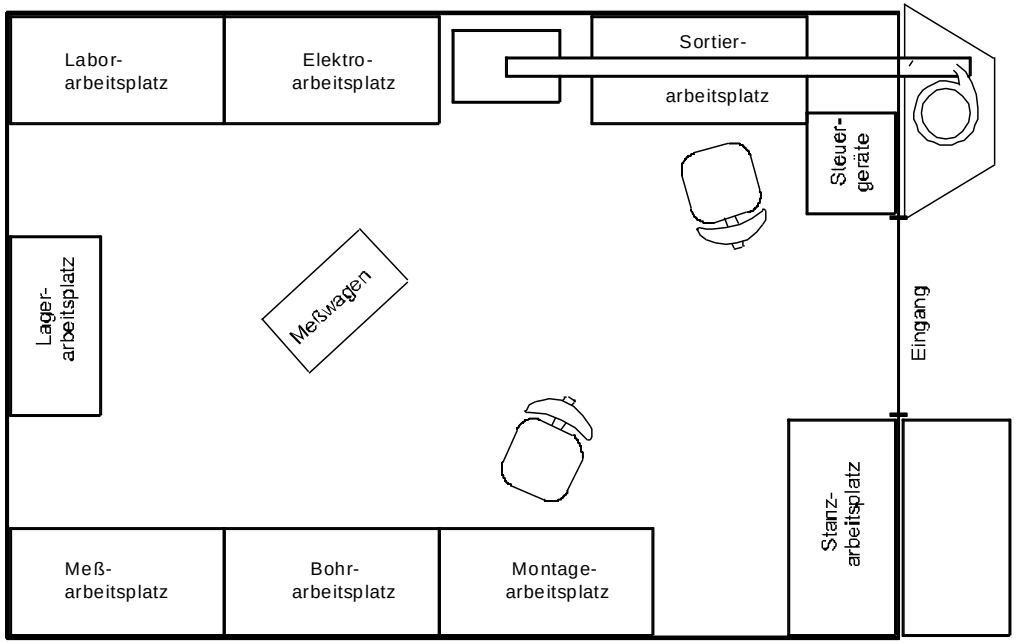


Voelker, S. Dissertation, Ilmenau 1999

Industry (2)

Voelker, S.; Dissertation 1999

- Dependent variables: performance, errors, acceptance (questionnaire), alertness (highest hear and flicker frequency)
- Independent variable: illuminance (30, 100, 200, 600 lx)
- Test design: short-term lab tests, 8 work places a 10 min (in sum 2 h) N = 40, long- term lab test 8 h, N = 12
- Field test, 130 workplaces in Metal- and Electro-Industry



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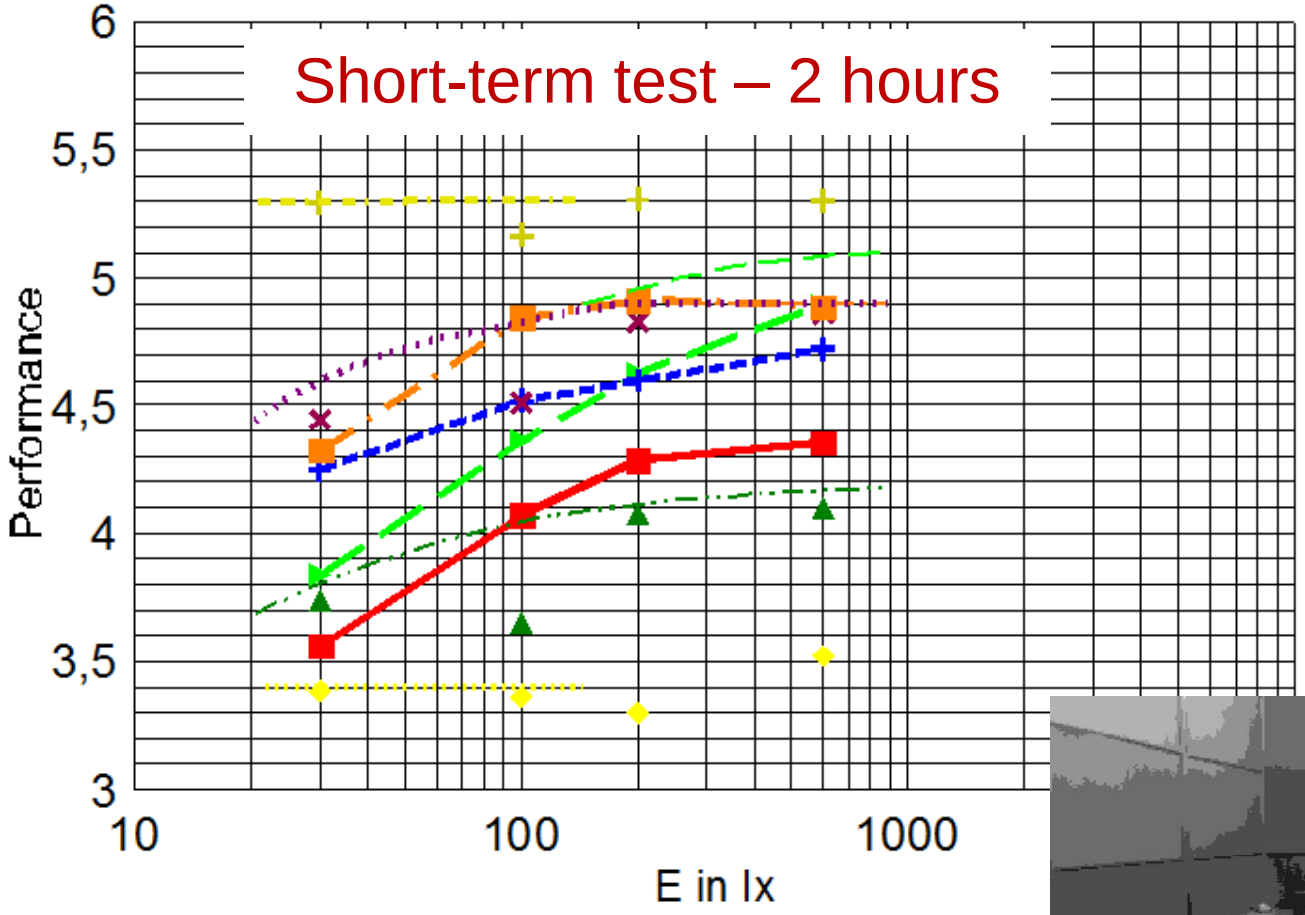

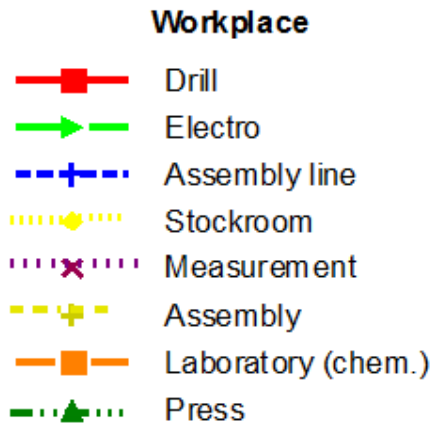

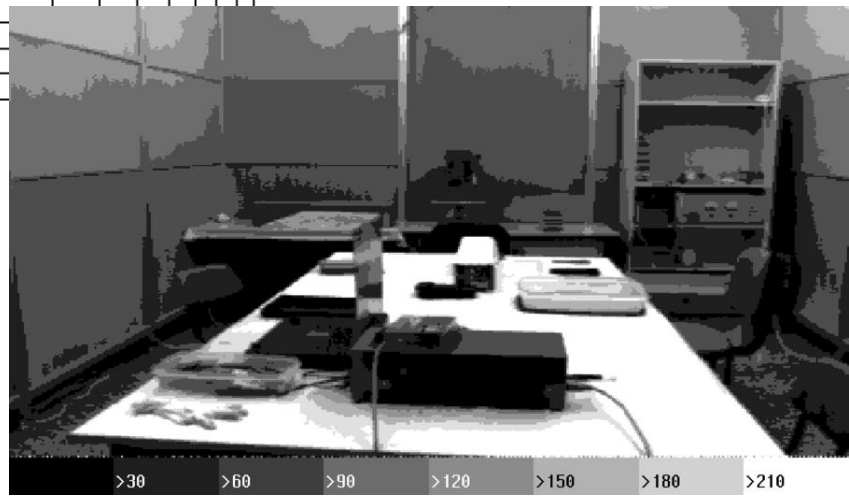

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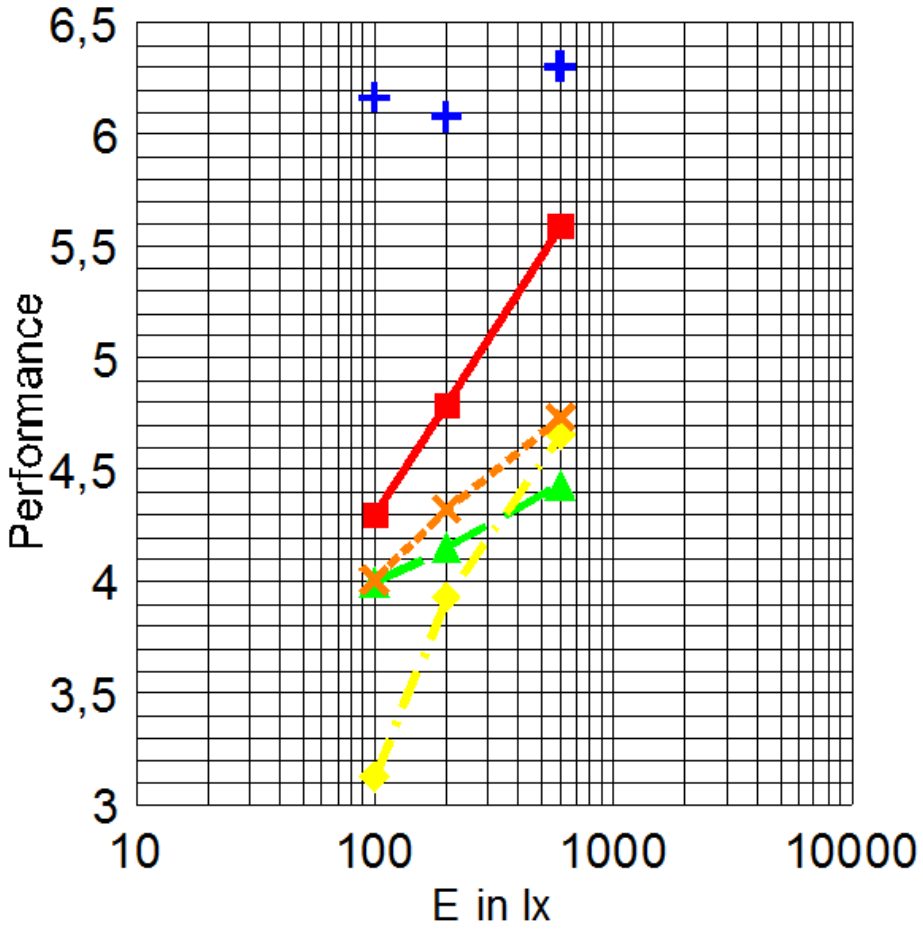
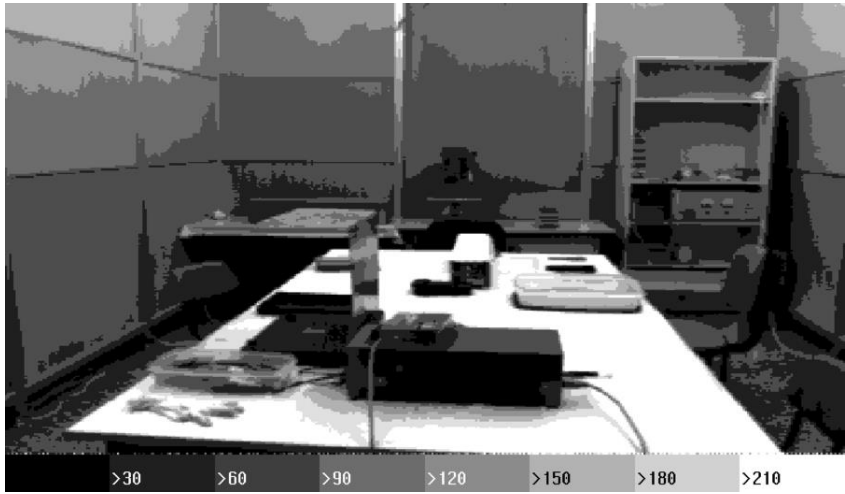


Long-term test – 8 hours

Workplace

- Drill
- Electro
- Press
- Textil
- Saw



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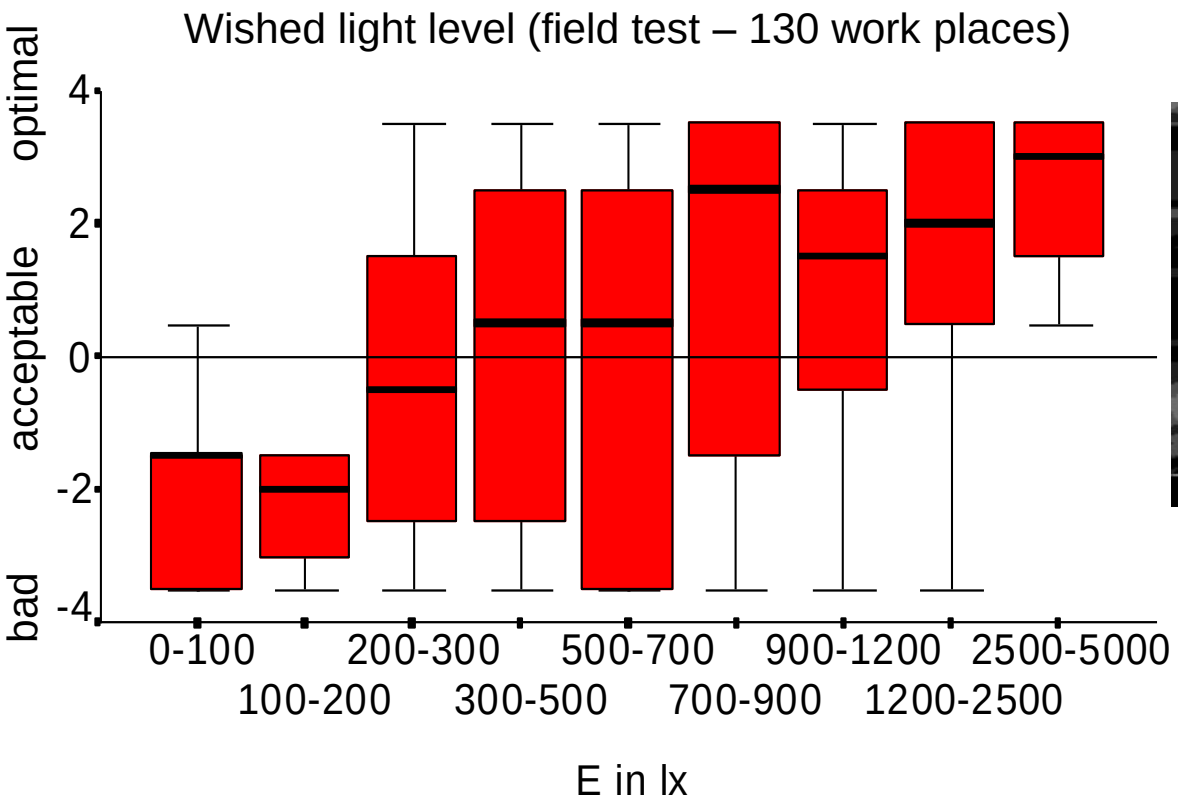
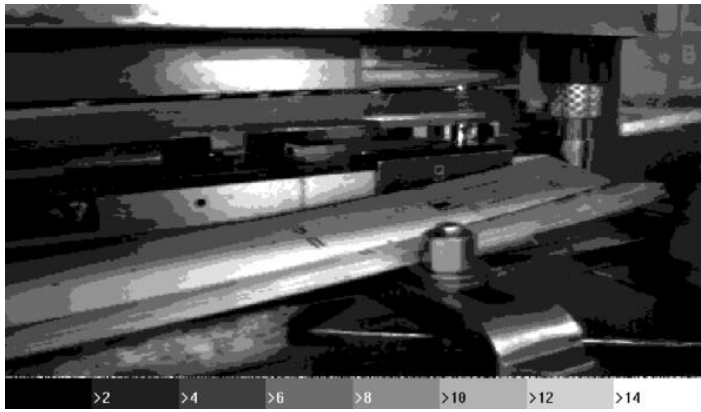




Voelker, S. Dissertation, Ilmenau 1999

- Light level between 300 - 500 lx: acceptable
- Optimal light level: 700 – 1500 lx
- Similar results of Halonen, Tenner, et al.

Industry (3)

Juslen, H., 2008

Method: Field Studies in the Industrial Environment

1.	Fixed light level: 50 or **1700 lux**	→ higher productivity	3%
		→ lower absenteeism	-17%
2.	Fixed light level: 800 or **1200 lux**	→ higher productivity	3%
3.	Fixed light level: 500 to **1050 lux**	→ higher productivity	5.5%
		→ lower absenteeism	-2.5%
4.	Personal light: **100 – 3000 lux**	→ higher productivity	4.6%
5.	Personal light: 100 – 900 lux, fixed colour temperature 3500 K or **4400 K**	→ higher productivity	5.7%

- a wide range of preferred illuminances
- employees like to have personal lighting control possibilities

Industry (4)

Canazei & Dehoff (2013, Zumtobel Research):

- Dependent variables: performance (processing time per piece)
- Independent variables: Dynamic change in brightness: 1000 – 3000 lx vs. static 1000 lx
- Test design: field test in industrial Company Flexitronics, each 1 week changed, 3x randomized repeated, N=14
- Result: in winter: 4% shorter relative processing time per piece, not in summer, Difficulties to measure productivity

Industry
Summary

	ATKearney	Scientific based
Better task performance	16 % (300 lx -> 2000 lx)	✓ depending on task 5 – 50 %
Reducing of errors	30 %	✓
higher alertness	50 %	? difficult to measure
Less Accidents	50 %	✓ for low light level
higher productivity	15-20%	✓ depending on task 5 – 50 %

Additional results in the literature review from van Bommel, van den Beld & van Ooyen (2002, Philips):

Industry

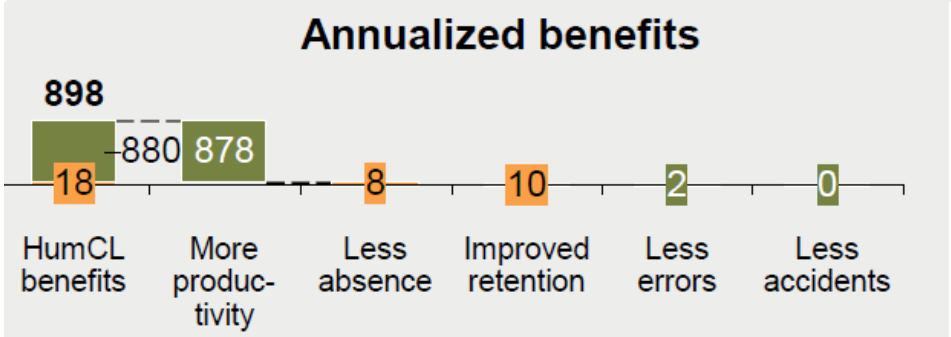
ATKearney

For repetitive tasks in industrial settings, effects from Human Centric Lighting are dominated by productivity increases

Industrial (Repetitive) – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



Reasoning for benefits

- More productivity (4.5% vs. LED lighting), less errors (1%) and less accidents (1%) due to increased alertness and energizing effect
- 1% less sick days and 1 year improved retention due to higher physical robustness (mid- to long-term effect)

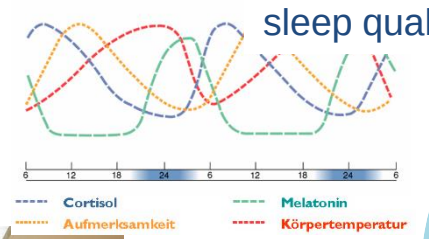
✓ Condition: much more precisely lighting design

? References?

Non-visual effects:

Technische Universität Berlin

sleep quality



retirement home

circadian rhythm

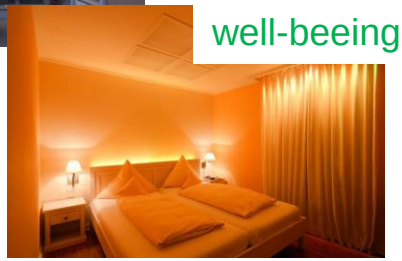
health

quality of life

performance

emotion

well-beeing



school

Lichttechnik

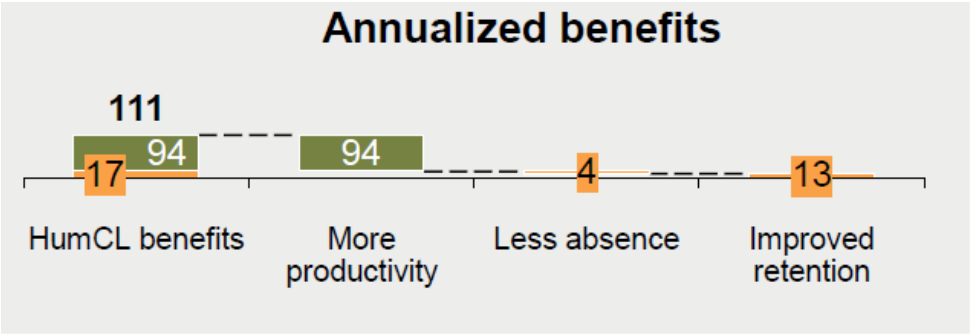
ATKearney

In the office segment, increased productivity can result in significant labor cost savings

Office – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



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Reasoning for benefits

- + 1.15% productivity due to increased alertness and energizing effect (~ extra output worth 2 hours per month) → some research even justifying productivity increases of up to 19%
- - 1% sick days due to better well-being
- + 1 year duration of employees staying

Office (1)

Aries, 2005:

- Dep. variables: Fatigue, sleep quality (questionnaire)
- Indep. variables: vertical Illuminance
- Test design: field study with office workplaces
- Results:
  - Only 20 % of workplaces have more than 1000 lx
  - people who worked under **lower vertical illuminance levels** reported significantly **more fatigue** and **worse sleep quality** than people working under high levels of vertical illuminance, also when adjusted for gender, age, eye correction, seasonal sensitivity and chronotype.“

Office (2)

Mills, Tomkins & Schlangen (2007, J. of Circadian Rhythms)

- Dependent variables: alertness/concentration/sleepiness (self-questionnaires - modified Columbia Jet Lag Scale), performance (item from WHO-HPQ), health (SF-36)
- Independent variables: Color Temperature (2.900 K vs. 17.000 K)
- Test design: 1 floor of a call center gets new 17.000 K (= Intervention), 1 floor stays with 2.900 K (= Baseline), N = 69, questionnaires at beginning, after 7 and 14 weeks during the working hours

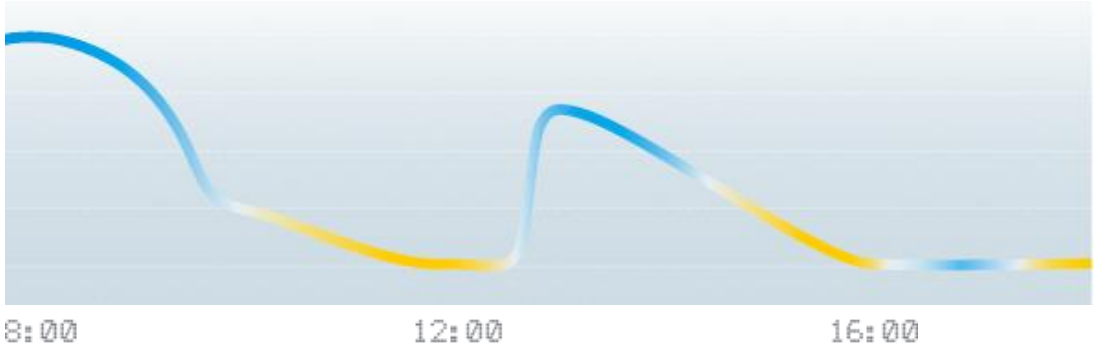
- Result: 26-37% improvement of concentration and alertness from Columbia Scale, 19 % better work performance from WHO-HPQ, 14 % better mental health from SF-12 and good acceptance
- intervention group in contrast to baseline group

- Discussion: uneven numbers of test persons in the groups, seasonal effects possible, visible difference in light colors → people talk

Office (3)

Viola et al. 2008

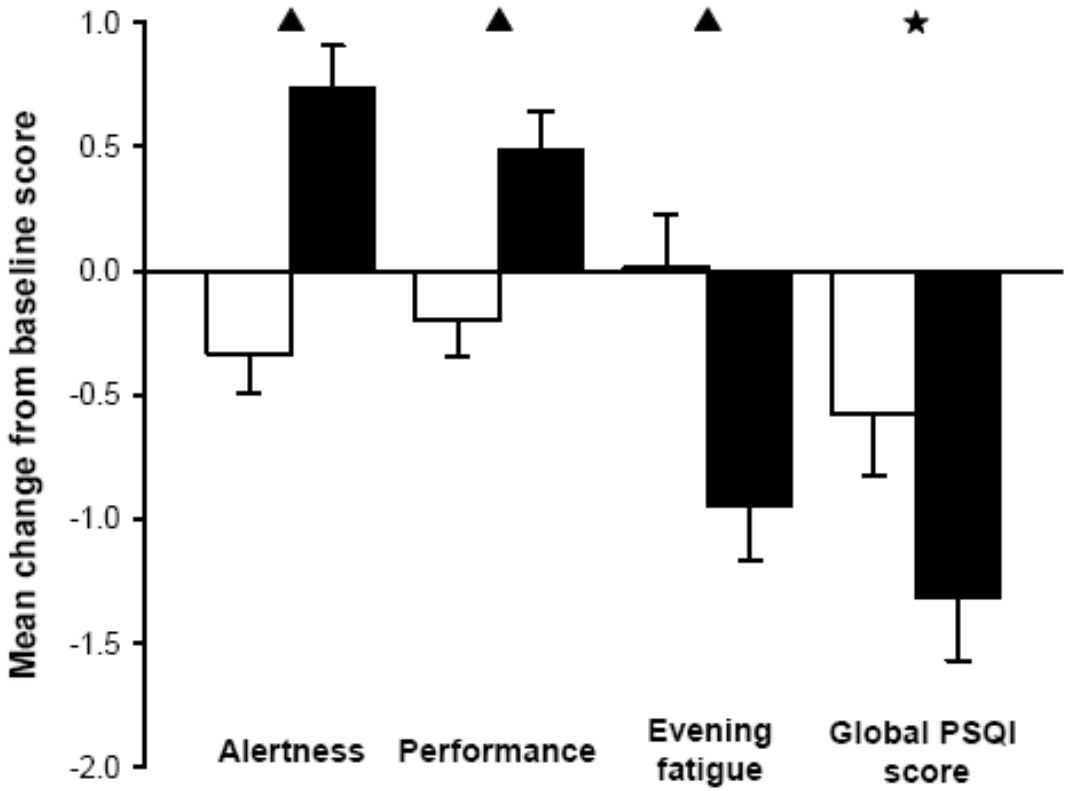
- Dep. variables: Alertness, Performance, evening fatigue, PSQI (questionnaire)
- Indep. variables: T_F 3000 K (yellow) vs. 5000 K (blue) Illuminance 500 – 900 lx (variable)
- Test design: field test



Office (3)

Viola et al. 2008

- Dep. variables: Alertness, Performance, evening fatigue, PSQI (questionnaire)
- Indep. variables: T_F 3000 K (yellow) vs. 5000 K (blue) Illuminance 500 – 900 lx (variable)
- Test design: field test
- Results: Cool white light during the working hours on day improves the subjectiv alertness, performance und increase the fatigue



Office (4)

de Kort, 2009

- Dep. variables: recovery, vitality, sleep quality, mental health, headache and eyestrain, subjective performance
- Indep. variable: Comparison between dynamic lighting (500 – 700 lux, 3000 – 4700 K) and static lighting (500 lux, 3000 K) with the same installation
- Repeated manipulation of the dynamics
- Four parallel groups: 2 long term (change once per year) and 2 short term (change once per month), Monthly measurement (web-based questionnaire) (wk 3)

- Results:
  - No significant differences in workers' need for recovery, vitality, sleep quality, mental health, headache and eyestrain, subjective performance, controlled for relevant personal, job and work related characteristics.
  - Workers in dynamic lighting did report being more satisfied with the lighting condition

Office (5)

Shamsul et al., American J. of Public Health Research, 2013

- Dep. Variables: Performance: visual acuity and contrast (frACT-test, with Landolt rings), Self assessment KSS, Office Lighting Survey
- Indep. variable: Color temperature (WW 3000 K, CW 4000 K, DL 6500 K)
- Test design: randomized sequence of CCTs in an experimental room without daylight, N = 47
- Results: 6500 K best performance
  4000 K most comfortable

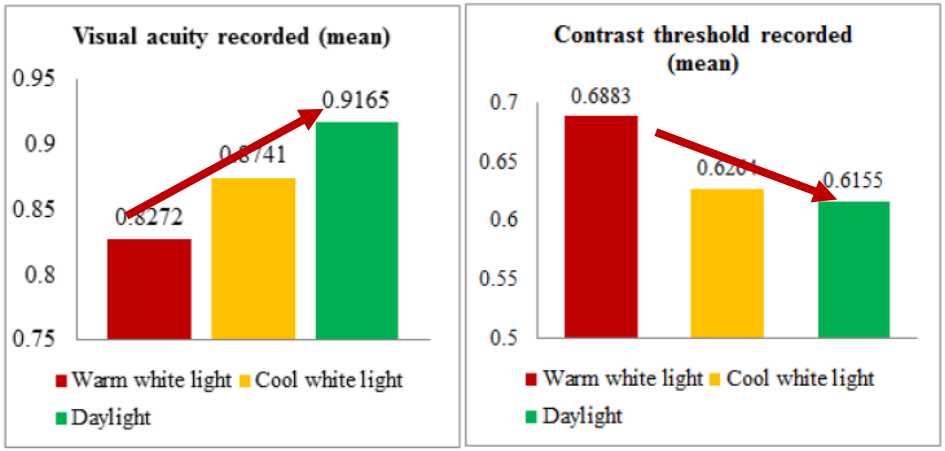


Figure 7. (a): Average results of the acuity test (correct decision per second); and (b): contrast threshold (%) obtained during the computer-based tasks

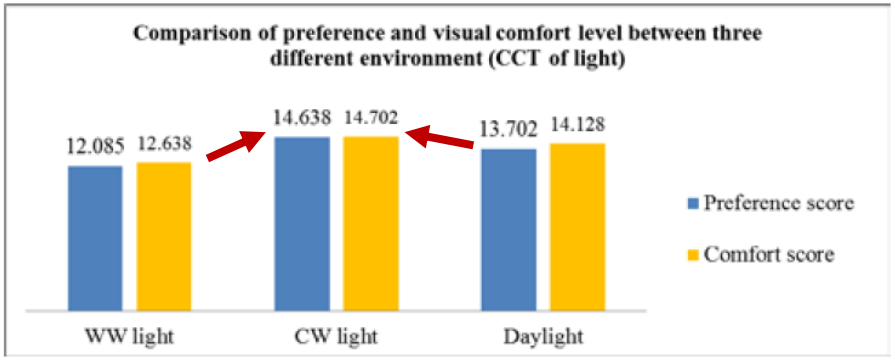


Figure 8. Comparison of subjective preference and comfort level of participants for three different CCT of light

Office (6)

Smolders et al., Journal of Environmental Psychology, 2014

- Dep. variables: attention self assessment, Karolinska Sleepiness Scale (KSS: 1 - 9), auditory concentration task (PVT and Go-NoGo)
- Indep. variable: E_v = 200 & 1000 lx, groups: fatigue vs. control
- Test design: 2x2 within subjects design, same daytime per person, no daylight contribution, N = 28

Baseline		*Antecedent condition*	*Manipulation check*	*Light exposure*		
Instruction, questionnaire & apply electrodes	Self-report, performance tasks & physiological measures	**Fatigue**: Demanding tasks (MATB & modified Stroop task)	Mood questionnaire	**Block 1**: Self-report, performance tasks & physiological measures	**Block 2**: Self-report, performance tasks & physiological measures	Questionnaire
		Control: Relaxing tasks (Watching nature movie & reading magazines) and congruent Stroop task				
200 lx at desk (92 at the eye)				**200 lx or 1000 lx at the eye**		
8 min.	7 min.	29 min.	1 min.	13 min.	13 min.	4 min.

Fig. 1. Overview experimental conditions and procedure of one full session.

Office (6)

Smolders et al., Journal of Environmental Psychology, 2014

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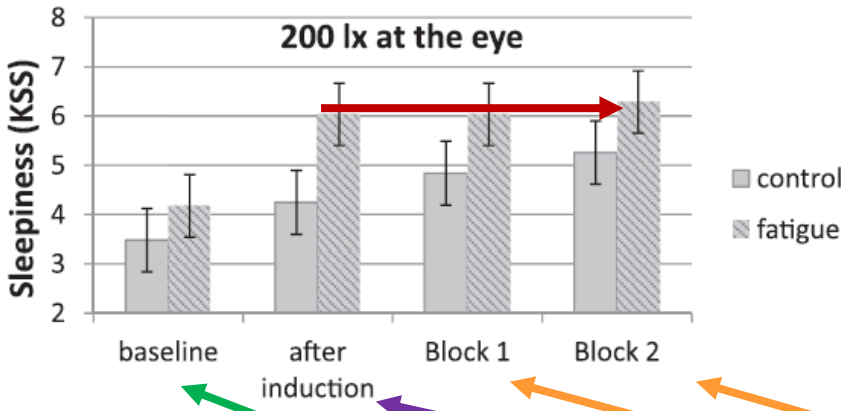
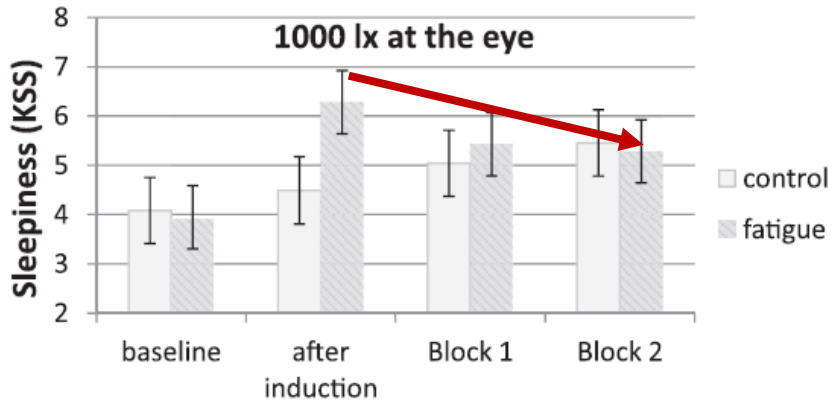
- Indep. variable: illuminance(200 lx vs. 1000 lx), fatigue vs. control
- Test design: 2x2 within subjects design, same daytime per person, no daylight contribution, N = 28
- Results: Improvement of sleepiness and vitality at 1000 lx, especially with tired test persons





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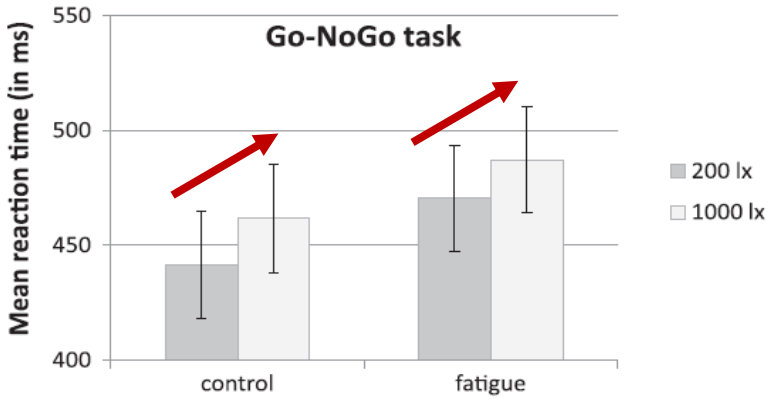
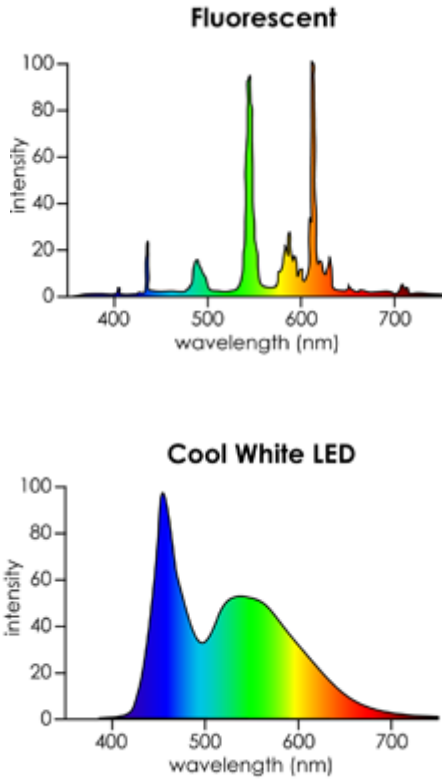
- Test design: 2x2 within subjects design, same daytime per person, no daylight contribution, N = 28
- Results:
  - Improvement of sleepiness and vitality at 1000 lx, especially with tired test persons
  - PVT: 1000 lx positive influence on reaction times, but not significant
  - Go-NoGo: 1000 lx leads to significant slower reaction times → strong task dependence



Office (7)

Möller et al., LICHT 2014:

- Dep. variables: acceptance and well-being (questionnaire), concentration and performance test (KLT-R), sleep quality (heart rate variability)
- Indep. variable: 2 spectra: LED and fluorescent lamp
- Test design: 500 lx @ eye and 4000 K with same experimental procedure (simulated office day)
- Results:
  - LED effects more comfortable
  - Positive effect on sleep quality in following night
  - No differences in performance and well-being



http://www.polyphasicsociety.com/polyphasic-sleep/adaptation/night-lighting/

Light for the office
Summary

	ATKearney	Scientific based
Productivity	1,5 – 19 %	0 – 10 % depending task ✓
Alertness	+	?
Concentration		0 - 30 % can be, by a strong change ✓
Sleepiness		0 - 10 % for the group of tired test subjects, but for a strong increase of illuminance ✓
Satisfy with light		0 – 30 % ✓
Sick days	- 1 %	Possible, but assumption ?
Better well being	+	Probably yes ?
Longer staying	+ 1 year	Possible, but assumption ?

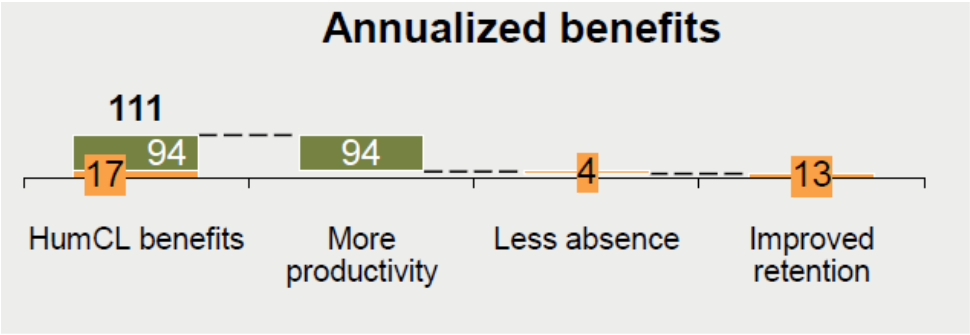
ATKearney

In the office segment, increased productivity can result in significant labor cost savings

Office – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



Reasoning for benefits

- + 1.15% productivity due to increased alertness and energizing effect (~ extra output worth 2 hours per month) → some research even justifying productivity increases of up to 19%
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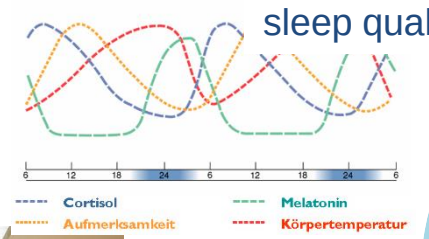
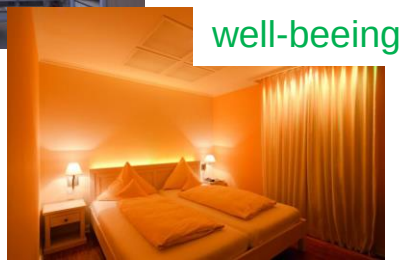


retirement home



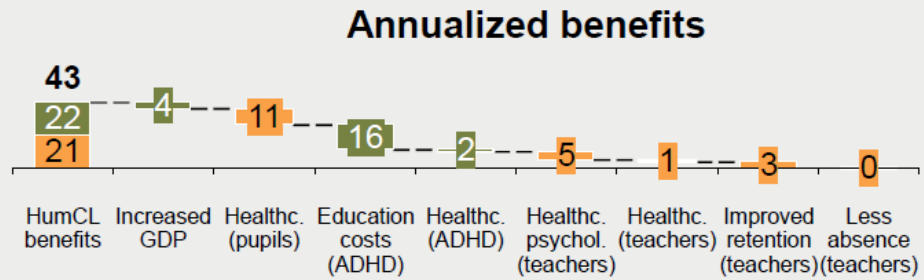
Lichttechnik

In the educational segment, public cost savings for ADHD and healthcare of normal students are the main benefits

Education – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



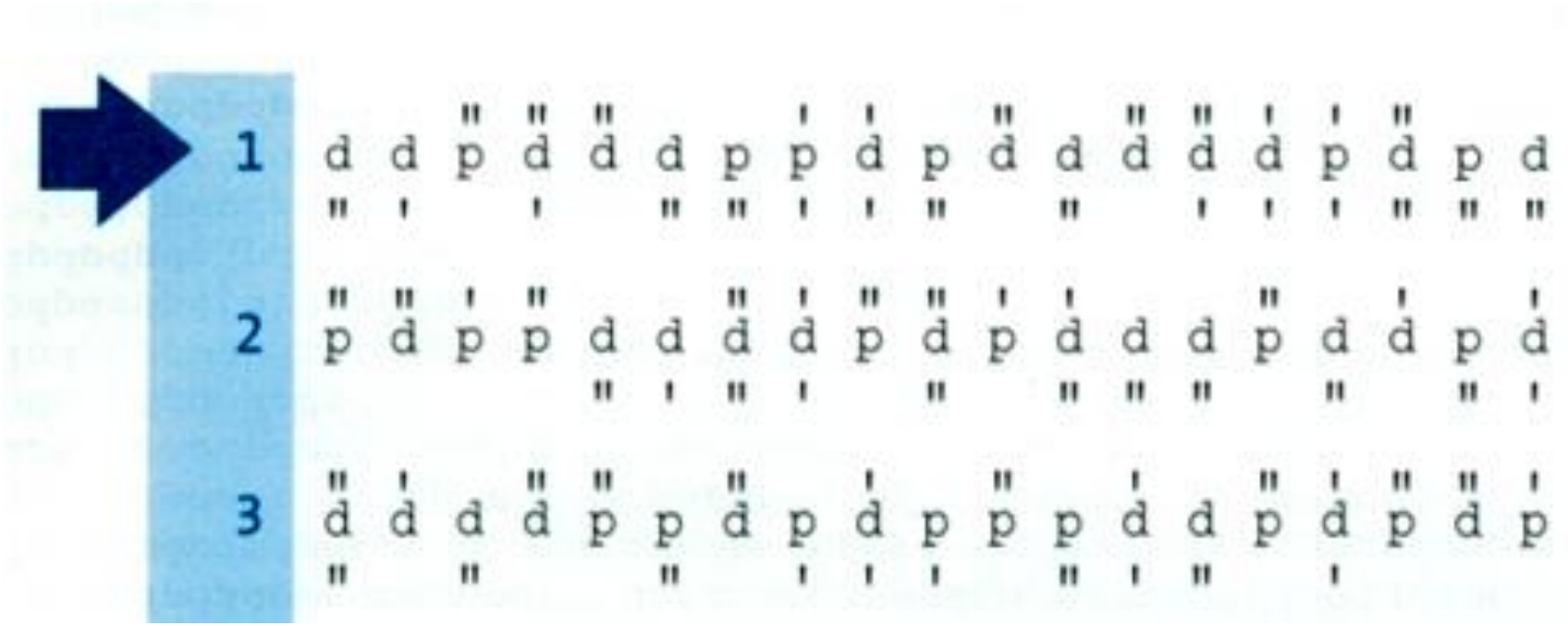
Reasoning for benefits

- GDP increase due to 15% improved cognitive performance of affected pupils[2]
- 10% reduced healthcare and education costs due to less ADHD effects
- 18% improved treatment efficacy for mental disorders
- + 2 years duration of employees staying

Schools (1)

Barkmann et al., Physiology & Behavior, 2012, Hamburg

- Dep. variables: concentration (D2-test), reading speed and comprehension (ELFE 1-6 / LGVT 6-12), attitude to school and subjective evaluation (self questionnaire)



Billd: licht.de

Schools (1)

Barkmann et al., Physiology & Behavior, 2012, Hamburg

- Dep. variables: concentration (D2-test), reading speed and comprehension (ELFE 1-6 / LGVT 6-12), attitude to school and subjective evaluation (self questionnaire)
- Indep. variables: 3 light scene: standard lighting (300 lx, 4000K), light for high concentration (1000 lx & 5800K), variable light (275 lx .. 1000 lx & 3500K .. 11000K)
- Test design: intervention and control classrooms in 2 schools, 45 min test sequence at beginning (both standard lighting) and after 4 weeks (standard vs. concentrate), at beginning and after 9 month questionnaires for long-term effect, N = 116

- Results: no long-term effects, but 70% of students recommend variable lighting

Billd: licht.de

Schools (1)

Barkmann et al., Physiology & Behavior, 2012, Hamburg

- Results: D2-test 20% less errors, 17% improved reading speed

Billd: Barkmann et al. 2012

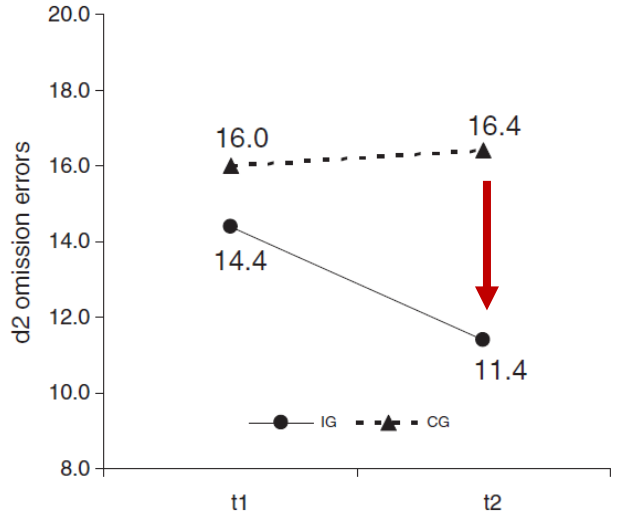


Fig. 2. Mean number of omission errors in the d2 concentration test with VL1 "Standard" lighting for both groups at t1 and VL4 "Concentrate" lighting for the IG at t2 four weeks later.

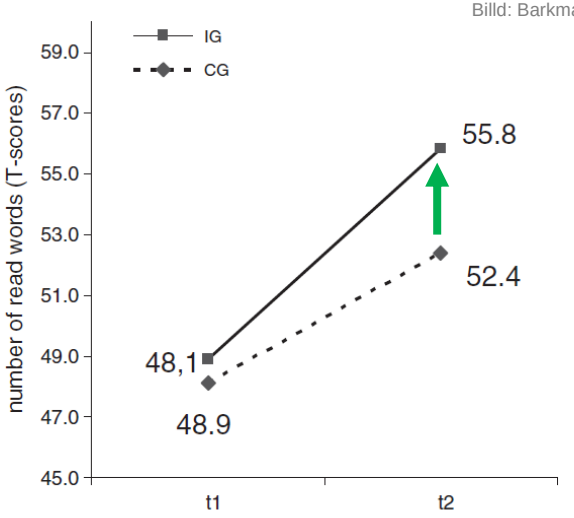


Fig. 3. Means (T-scores) of read words in the ELFE and LGVG reading test with VL1 "Standard" light for both groups at t1 and VL4 "Concentrate" light for IG at t2 four weeks later.

- Do not forget STD:

		IG (n = 48)		CG (n = 46)		F	p	η^2_{part}
		M	SD	M	SD			
Errors of omission	t1	14.4	16.80	16.0	17.28	4.206	.022	.047
	t2	11.4	14.15	16.4	19.74			
Reading speed[1]	t1	48.9	9.78	48.1	8.94	7.272	.004	.076
	t2	55.8	12.80	52.4	8.44			

Schools (2)

Wessolowksi et al., Journal of Environmental Psychology 2014, Hamburg

- Dep. variables: fidgedtiness (Move-it camera: counts varying pixel, long-term: Conners Rating Scales), Aggression (independent experts evaluate video, long-term: aggressiveness of youth self-report)
- Indep. variables: 3 Light scenes: standard lighting (300 lx, 4000K), ‘relax lighting’ (325 lx, 3500K), ‘dynamic lighting’ (275 lx .. 1000 lx, 3500K .. 11000K)
- Same Test design like before

Billd: licht.de

Schools (2)

Wessolowksi et al., Journal of Environmental Psychology 2014, Hamburg

- Results: Fidgetness and aggression decrease with ‚Relax lighting', but no long-term effects

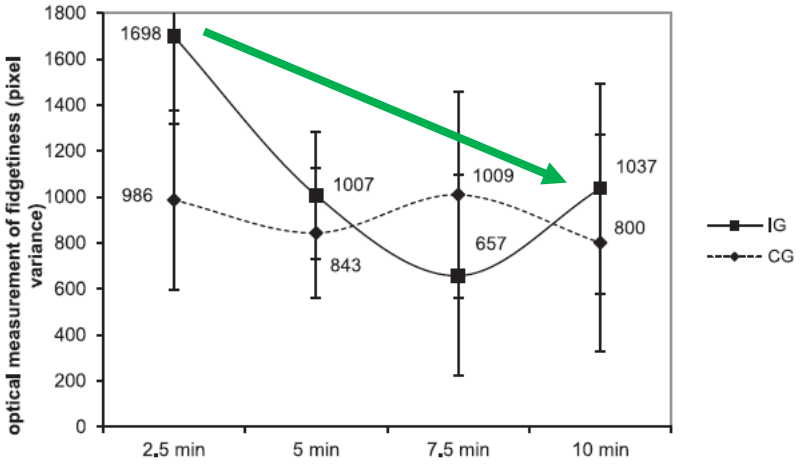


Fig. 1. Measurement of fidgetiness: intervention group with light program "Relax" and control group with standard light. Significant medium sized effect for group × time interaction.

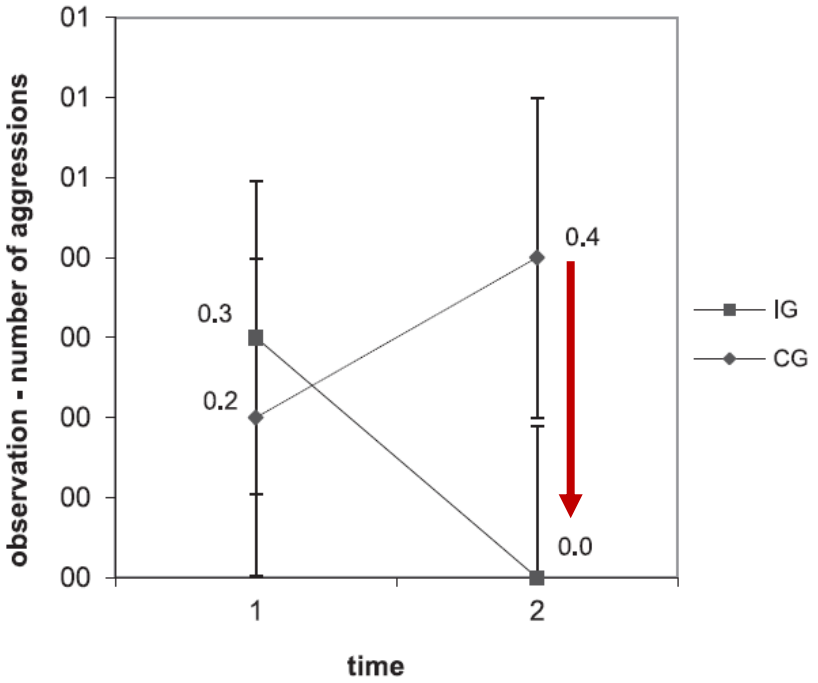


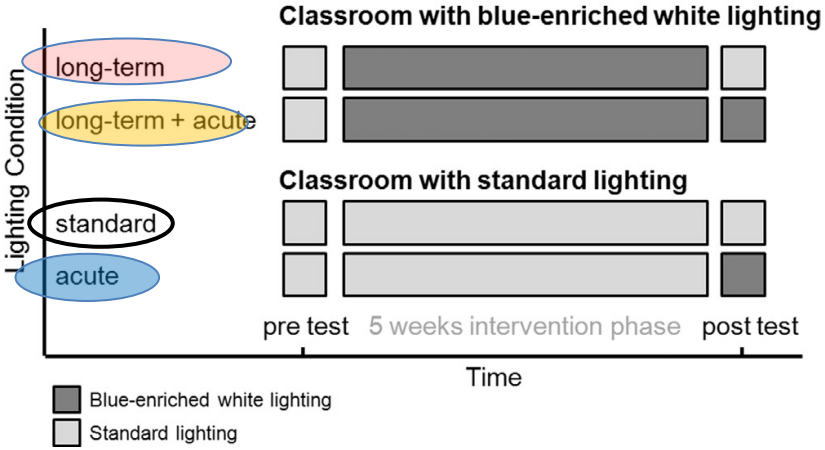
Fig. 2. Presentation of the systematic behavioral observation with regard to aggression, intervention group with light program "Relax" and control group with standard light.

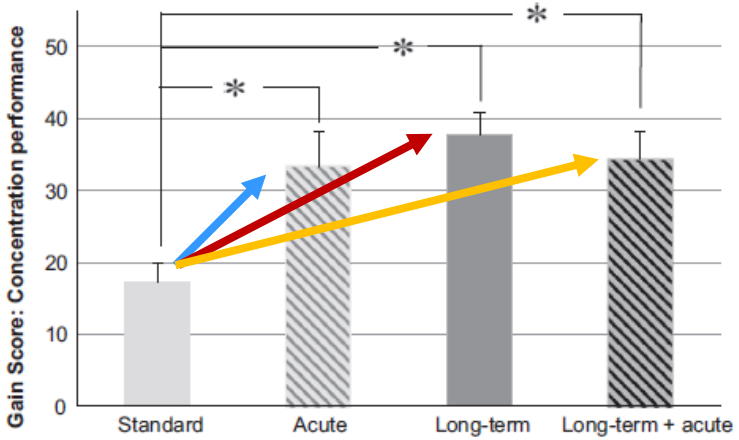
Schools (3)

Keis et al., Trends in Neuroscience and Education, 2014, Ulm

- Dep. variables: concentration (D2-Test, numbers combining test)
- Indep. variables: spectrum and light distribution
- Blue enriched light (LED: 4000K direct, 14.000K indirect) vs. standard light (fluorescent lamps only direct 3000K (school 1) or 4000K (school 2))
- Testdesign: N = 58, 12. grade, 2 school classes in 2 schools, 5 weeks longterm illumination x acute test conditions
- Result:

  significant improvement of concentration with blue enriched light





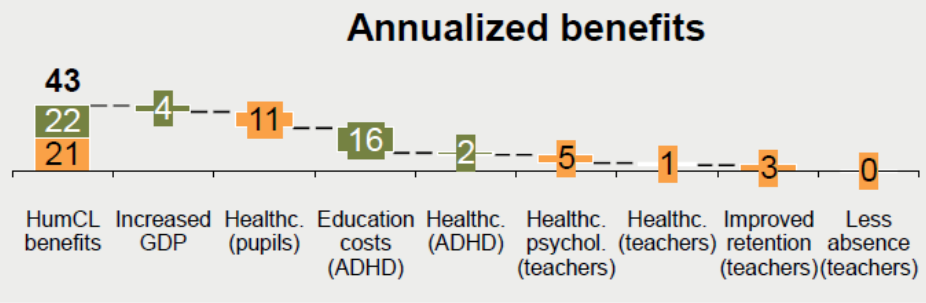
ATKearney

In the educational segment, public cost savings for ADHD and healthcare of normal students are the main benefits

Education – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



Reasoning for benefits

- GDP increase due to 15% improved cognitive performance of affected pupils[2]
- 10% reduced healthcare and education costs due to less ADHD effects
- 18% improved treatment efficacy for mental disorders
- + 2 years duration of employees staying

✓ Cognitive performance improved

Impact on GDP ?

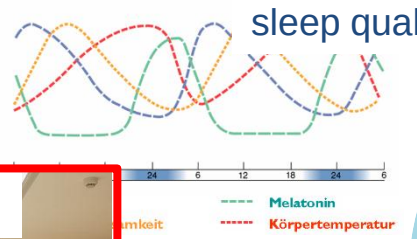
✓

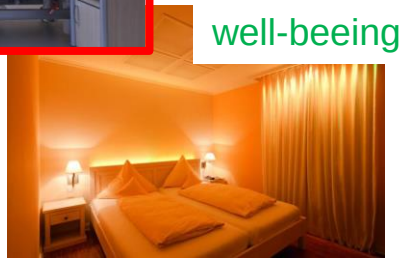
?

?

Non-visual effects:

Technische Universität Berlin





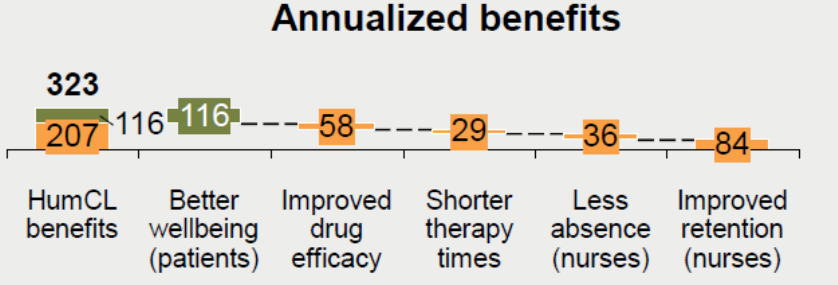
Lichttechnik

In the medical segment, several effects are expected, but are not well researched yet

Medical – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



Reasoning for benefits

- + 0.1% capacity utilization due to better well-being of patients (higher attractiveness for new patients)
- - 0.25% treatment costs due to reduced treatment times
- - 0.25% medication costs due to higher drug efficacy
- - 1% sick days (nurses) due to better well-being
- + 2 years duration of employees staying

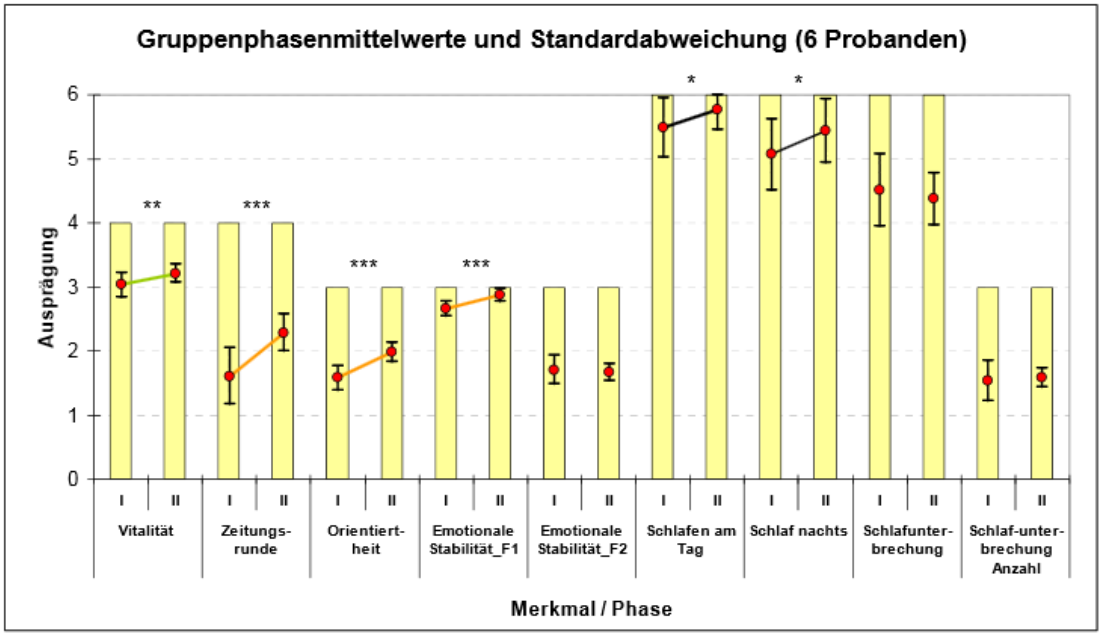
Highly sensitiv to assumptions!

Elderly (1)

Bieske et al. LuG 2006, N = 6:

- Dep. Variable: vitality, orientation, emotional stability, sleep quality (questionnaire of care staff)
- Indep. Variable: 50 lx E_{eye}, 2800 K → 1800 lx, 6000 K
- Results: Improvement of vitality, orientation, emotional stability, sleep quality

Billd:Philips



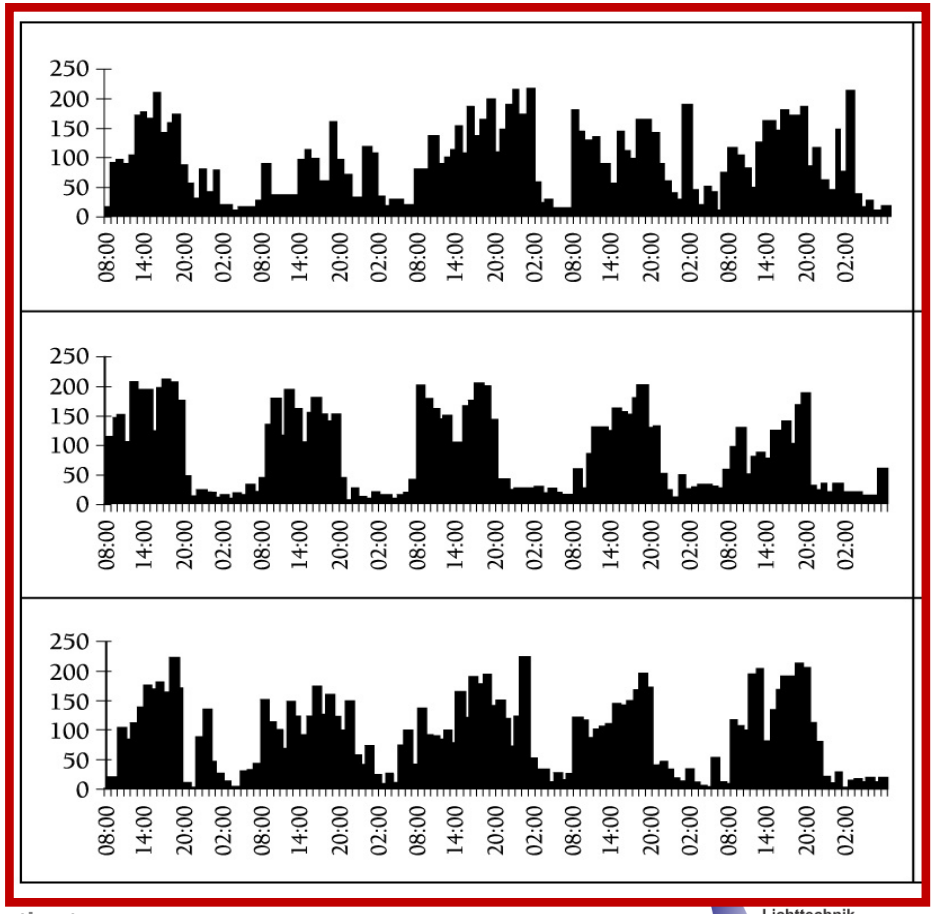
Billd: Bieske et al. 2006

Elderly (2)

Riemersma et al., JAMA, 2008, N = 189:

- Dep. Var.: sleep quality, a.other
- Indep. Vari.: Increased illuminance (300 vs. 1000 lx E_{eye}) by the use of an illuminated ceiling

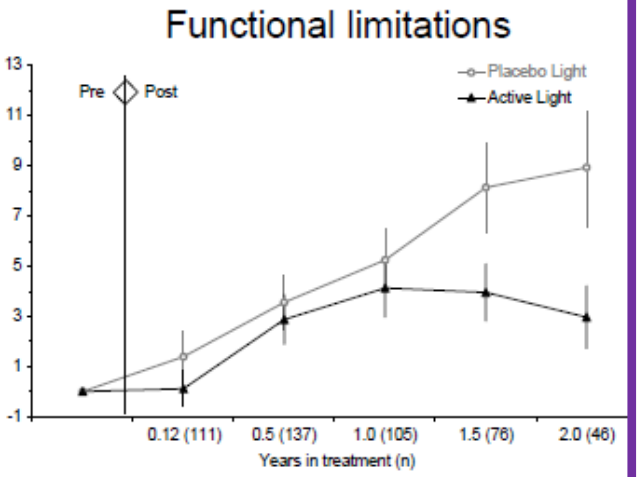
- Results: increased sleep quality (Actigraphy)

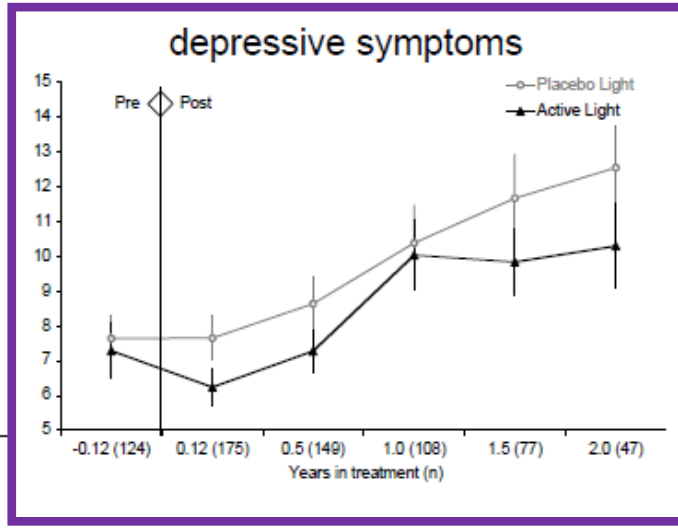


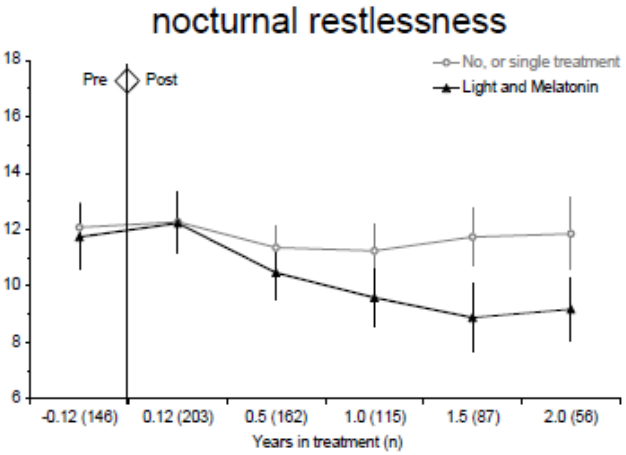
Elderly (2)

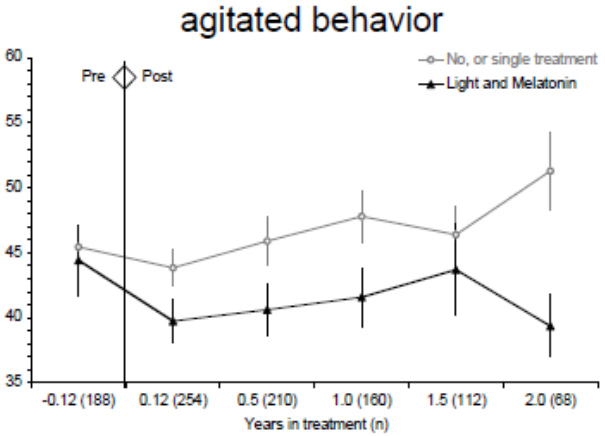
Riemersma et al., JAMA, 2008, N = 189
Results:

- decreased depressive symptoms (Cornell Scale)
- Delayed cognitive deterioration by dementia (Mini-Mental-State),









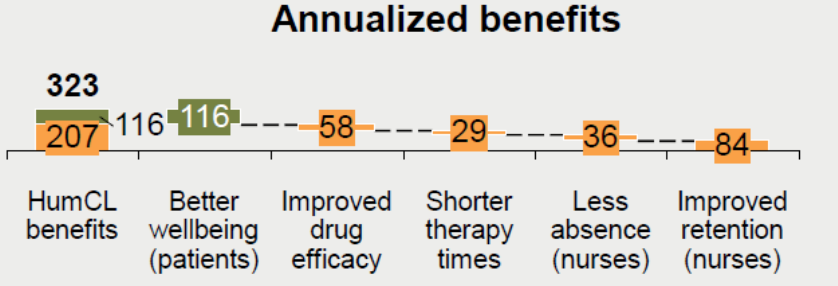
ATKearney

In the medical segment, several effects are expected, but are not well researched yet

Medical – Micro level effect

Highly sensitive to assumptions[1]

Quantified Human Centric Lighting benefits (annualized, in €k)



Reasoning for benefits

- + 0.1% capacity utilization due to better well-being of patients (higher attractiveness for new patients)
- - 0.25% treatment costs due to reduced treatment times
- - 0.25% medication costs due to higher drug efficacy
- - 1% sick days (nurses) due to better well-being
- + 2 years duration of employees staying

Highly sensitiv to assumptions!

✓ Probably yes, but to less studies!

✓ Probably yes, but to less studies!

?

Non-visual effects:

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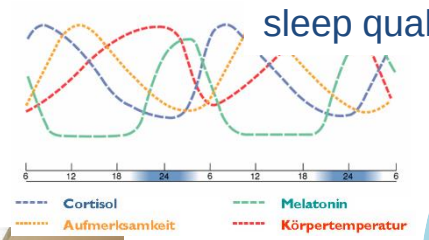
sleep quality



retirement home

Lichttechnik

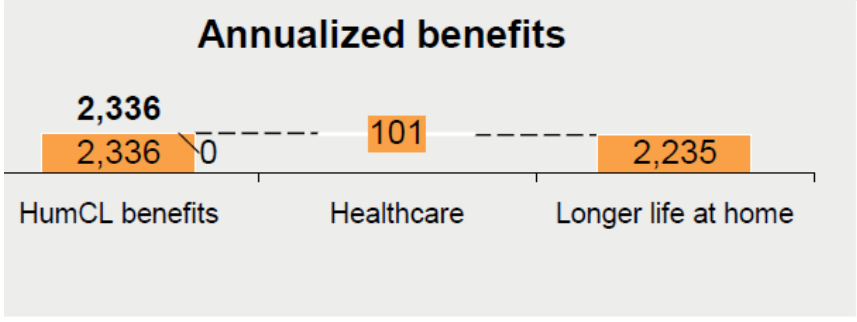
ATKearney

In the residential segment, additional benefits are mainly driven by the deferred need for institutional care

Residential (Homes) – Macro level effect

Highly sensitive to assumptions[1]

Long-term quantified Human Centric Lighting benefits (annually, in € mn)



Highly sensitiv to assumptions!

Reasoning for benefits

- Big benefit for public care costs, because residents can reduce their average time in elderly care from 2 to 1.9 years due to increased physical robustness. Assuming that 40% of affected residents will eventually go into an elderly care facility
- 1% savings on general healthcare costs for affected residents, due to higher physical robustness

Residential (1) – Wellness hotel

Concept

Reference = standard lighting

Interference = chronobiological optimisation

A. Wojtysiak, Osram, Vortrag LICHT 2014, Den Haag, NL

Wojtysiak, A., LICHT 2014:

- Dep. variables: melatonin and cortisol concentration, heart rate variability, Sleepiness (KSS), sleep quality (PSQI, movement sensor, step counter), questionnaires acceptance/ well-being
- Indep. variables: illuminance, spectrum, Timing
- 30-50 lx → 700-2000 lx @ eye
- 1700-2800 K → 4000-6800 K

- Test design: simulated week-end stay, N = 84

Residential (1) – Wellness hotel

- Results: significant improvement of acceptance and sleep quality

	Melatonin	Cortisol	HR LF/HF	EDA	Movement	Self-report		
						Sleepiness	Sleep	Acceptance
Wake up	■	□						
Morning	■	□				■		■
Day	■ ?	□				□		■
Evening	□	□				□		■
Night			□	□	■		■	

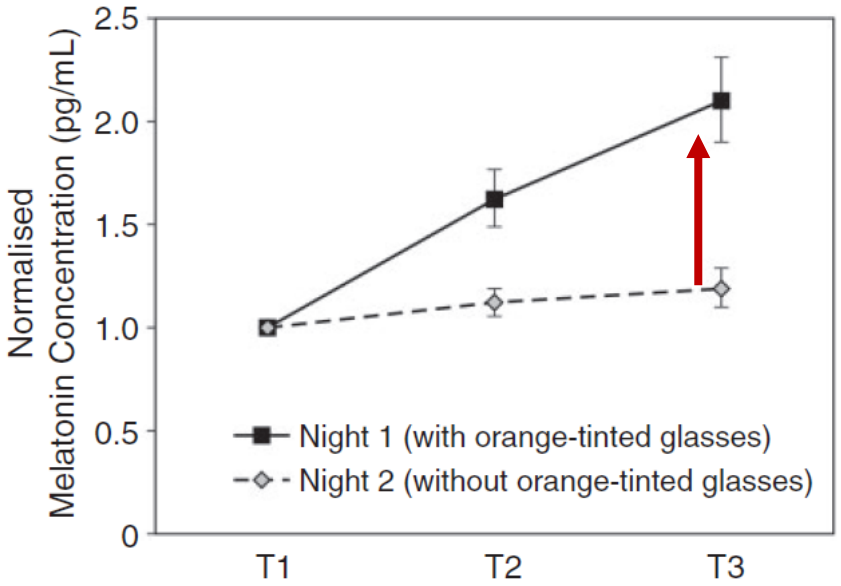
A. Wojtysiak, Osram, Vortrag LICHT 2014, Den Haag, NL

■ signifikant
□ Trend, n.s.
■ signifikant entgegen dem Ziel

Residential (2)

Figueiro u. Overington, Biological research for nursing, 2015

- Dep. variables: melatonin concentration (saliva), Daysimeter
- Indep. variable: spectrum (use of orange glasses or not)
- Test design: usage of self luminous devices (tv, pc, tablet..) 3h before bedtime
- N = 20, adolescents 15-17y
- Result:
  - Using the devices suppressed melatonin about 23%
  - Adolescents are more sensitive (compare Figueiro et al. 2011 with students)



Figueiro u. Overington 2015

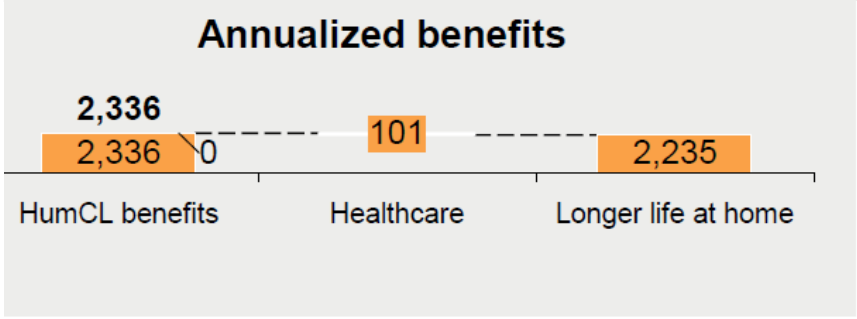
ATKearney

In the residential segment, additional benefits are mainly driven by the deferred need for institutional care

Residential (Homes) – Macro level effect

Highly sensitive to assumptions[1]

Long-term quantified Human Centric Lighting benefits (annually, in € mn)



Highly sensitiv to assumptions!

Reasoning for benefits

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✔ Probably yes, but to less studies!

- 1% savings on general healthcare costs for affected residents, due to higher physical robustness

✔ Probably yes, but to less studies!

Content

1. Background of German Engagement for the LED – LED Leading market
2. Practical using – two point of views
    a. Office and Industry
    b. Schools
    c. Nursery homes and hospitals
    d. Residential and hotels
    e. Airplanes
3. DIN SPEC 67600
4. Project NiviL on the University of Technology Berlin
5. Consequences and Outlook

DIN Spec 67600:2013-04

Expected positive effects:

- Stabilization of individual circadian rhythm
- Support the amplitude of biological clock
- Activation and improvement of concentration
- Stabilization of motivation and decrease of sleepiness
- Enable and promote regeneration
- Improvement of mood, well-being (e.g. avoid depression)

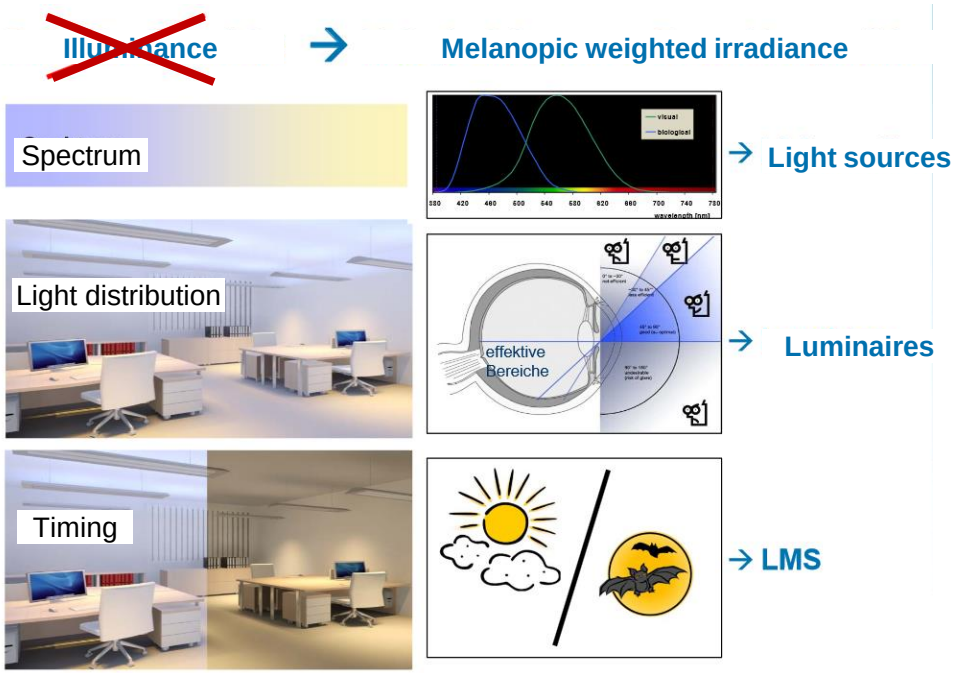
DIN Spec 67600:2013-04

Parameters which influence the biological effects:

- Irradiance
- Duration
- Spectrum (blue part)
- Light distribution
- Dynamic changes
- Light history
- Daytime

Recommendation for biological active light:
E_v at the eye ≥ 250 lx, CCT= 8000K
E_v at the eye ≥ 290 lx, CCT= 6500K

Billd: © “Biologisch wirksame Beleuchtung - Planungsempfehlungen” – Wojtysiak, Fassian, Greiner Mai, Scharpenberg – Biowi 2013



DIN Spec 67600:2013-04

1. Intended biological effects refer to daylight, artificial light or a mixture of both
2. Planning recommendations additional to visual requirements of other standards (DIN EN 12464-1, ASR A3.4)
3. Voluntary

Planning recommendations

- Educational institutions and schools ✓
- Offices ✓
- Control rooms ✓
- Retirement homes ✓
- Medical facilities ✓
- Residential places ✓
- Hotel rooms ✓
- Shift work ?

DIN Spec 67600:2013-04

1. Intended biological effects refer to daylight, artificial light or a mixture of both
2. Planning recommendations additional to visual requirements of other standards (DIN EN 12464-1, ASR A3.4)
3. Voluntary

Planning recommendations

- Educational institutions and schools
- Offices
- Control rooms
- Retirement homes
- Medical facilities
- Residential places
- Hotel rooms
- Shift work

DIN Spec 67600:2013-04

Planning recommendations for specific applications as tables:

+++ Use of biological active light is recommended

++ Use usually recommended; exceptions possible e.g. not constantly occupied workplaces

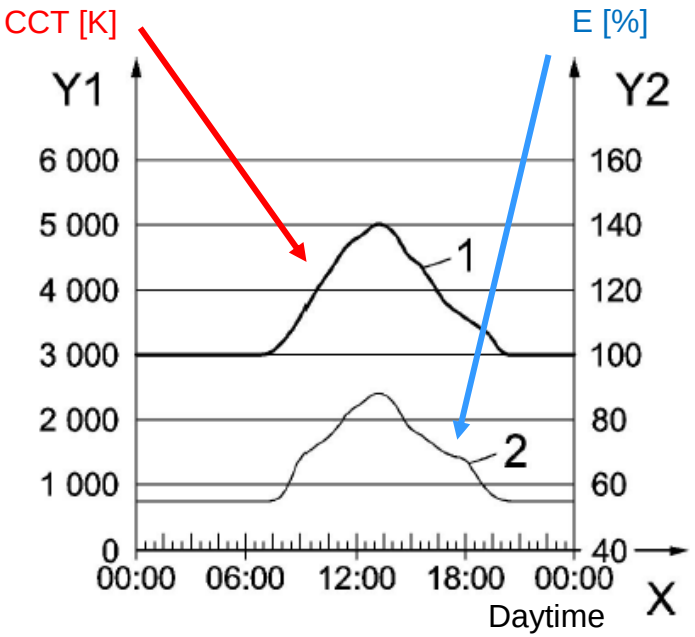
+ Use generally not required

Tabelle A.36 — Ausbildungseinrichtungen — Ausbildungsstätten

Ref. Nr.	Type of the room, the task or the area of task	Relevance for design	Specific conditions
5.36.1	Class rooms, seminar rooms	+++	
5.36.2	Class room for evening classes and adults	+++	
5.36.3	Lecture halls	+++	Dynamic light adapted on the course of day
5.36.4	Blackboards, whiteboards	+	
5.36.5	Demonstration table	+	
5.36.6	Art room	+++	

DIN Spec 67600:2013-04

I. Dynamic lighting for schools

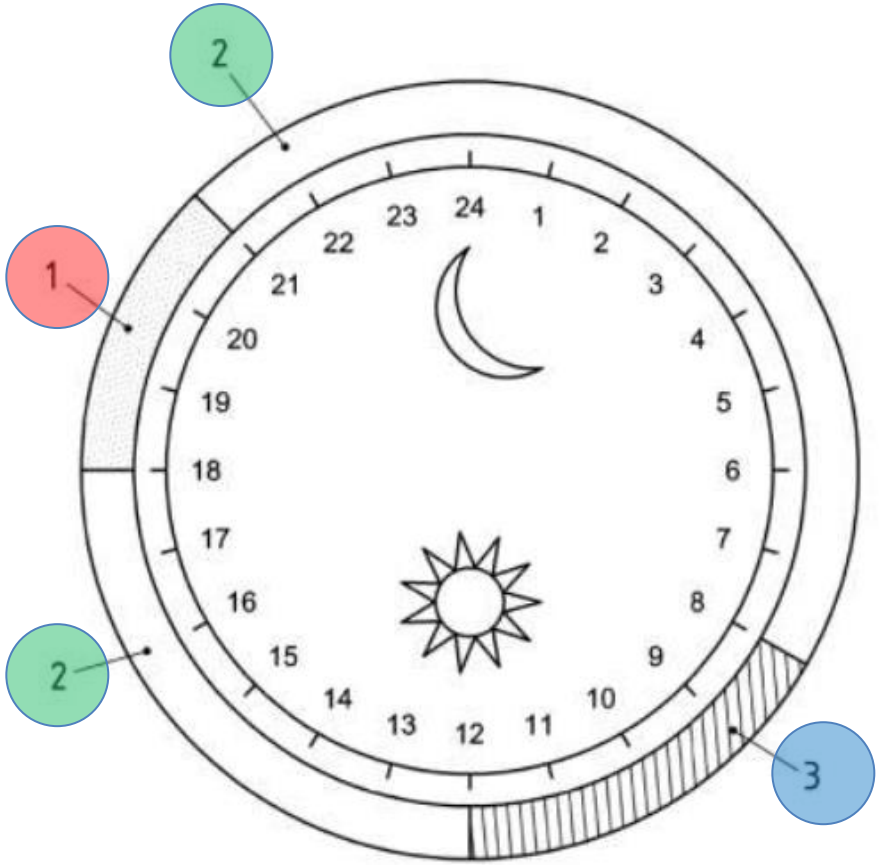


a) Dynamic like natural Daylight

→ Useful dynamics, but every situation needs individual planning

DIN Spec 67600:2013-04

II. Dynamic lighting in retirement homes:



Vertical illuminances:

1. 200 lx and 3 000 K
2. Illuminance level depending on the viewing task
3. 250 lx and 8 000 K

DIN SPEC 5031-100:2015-08

Definition: Melanopic effect of light

Calculation of melanopic radiant quantity
Tables for s_{mel} (λ) based on Lucas, 2014

$$X_{mel,v} = \int_{\lambda=380nm}^{830nm} X_{e\lambda} \cdot s_{mel}(\lambda)\, d\lambda$$

$$a_{mel,v} = \frac{\int_{\lambda=380nm}^{830nm} \Phi_{e\lambda} \cdot s_{mel}(\lambda)\, d\lambda}{\int_{\lambda=380nm}^{830nm} \Phi_{e\lambda} \cdot V(\lambda)\, d\lambda}$$

[24] R. J. Lucas, S. Peirson, D. Berson, T. Brown, H. Cooper, C. A. Czeisler, M. G. Figueiro, P. D. Gamlin, S. W. Lockley, J. B. O'Hagan, L. L. A. Price, I. Provencio, D. J. Skene, G. Brainard. Measuring and using light in the melanopsin age. *Trends Neurosci. 2014 Jan;37(1):1-9. doi: 10.1016/j.tins.2013.10.004. Epub 2013 Nov 25.*

DIN SPEC 5031-100:2015-08

Definition: Melanopic effect of light

Calculation of melanopic radiant quantity
Tables for s_{mel} (λ) based on Lucas, 2014

$$X_{mel,v} = \int_{\lambda=380nm}^{830nm} X_{e\lambda} \cdot s_{mel}(\lambda)\, d\lambda \qquad a_{mel,v} = \frac{\int_{\lambda=380nm}^{830nm} \Phi_{e\lambda} \cdot s_{mel}(\lambda)\, d\lambda}{\int_{\lambda=380nm}^{830nm} \Phi_{e\lambda} \cdot V(\lambda)\, d\lambda}$$

Attention: mel-lm or mel-lx is not allowed!

$$X_{v,\,mel,\,D65} = \frac{K_{mel,\,D65}}{K_m} \cdot a_{mel,\,v} \cdot X_v = 1{,}103\ 57 \cdot a_{mel,\,v} \cdot X_v$$

DIN SPEC 5031-100:2015-08

With Correction factors:

Tabelle 4 — Melanopische Lichtwirkungen

	melanopische Lichtwirkung	
1.	Suppression von Melatonin in der Nacht	siehe 4.1.2
2.	Verschiebung der circadianen Phase	siehe 4.1.3
3.	Änderung der circadianen Amplitude	siehe 4.1.4
4.	Aktivierung mit Licht	siehe 4.1.5
5.	Steuerung des Pupillenreflexes	siehe 4.1.6
6.	Behandlung saisonal abhängiger Depressionen (SAD)	siehe 4.1.7

→ Demands on lighting design describtions of light exposure

Content

1. Background of German Engagement for the LED – LED Leading market
2. Value added of the LED
3. Non-Visual Effects one aspect of HCL – background
4. Practical using – two point of views
    a. Office and Industry
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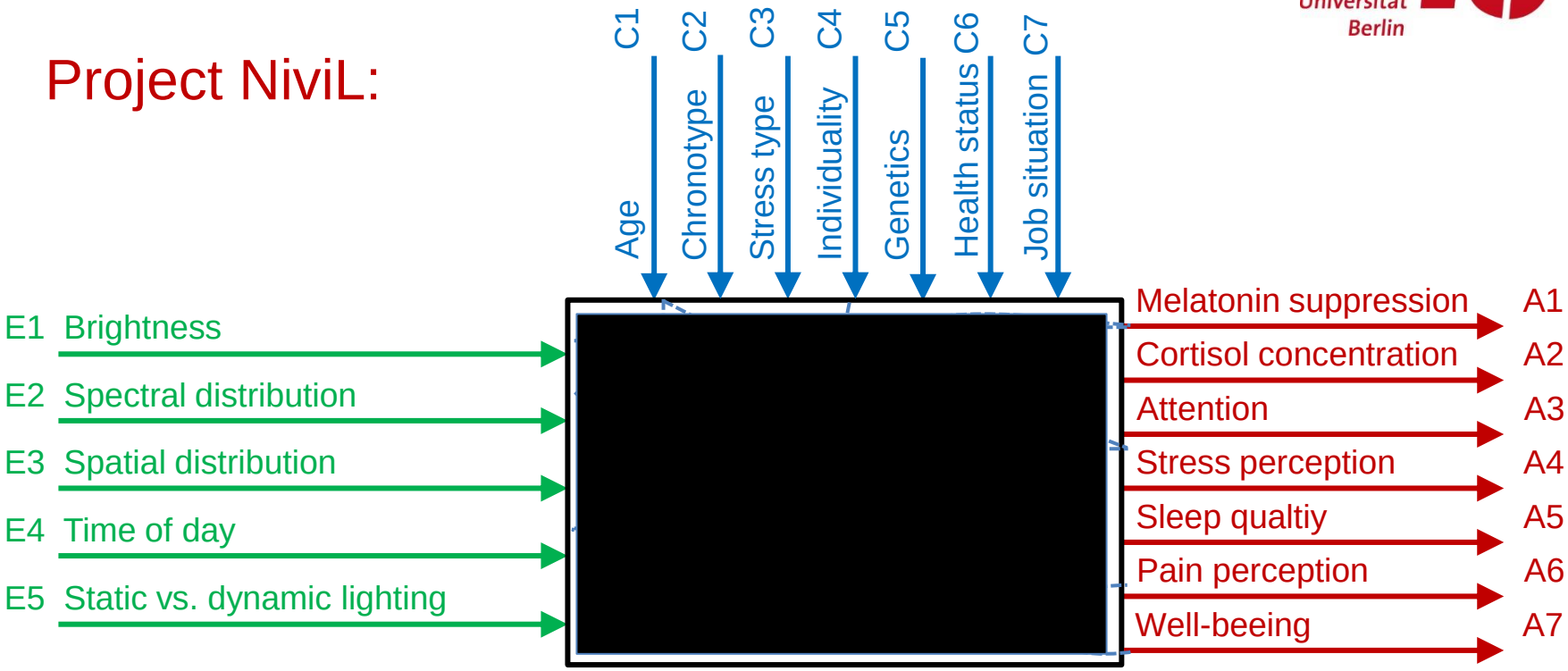
5. DIN SPEC 67600
6. Project NiviL on the University of Technology Berlin

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Technische Universität Berlin

Project NiviL:



- Project: Build a model, define stimulus, specify thresholds values

Lichttechnik

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Technische Universität Berlin

I. Determination of threshold values

- **Dep. variables:** melatonin, cortisol concentration, sleep quality, Attention (Audio task, D2, KSS),
- **Indep. variables:** Different spectra, age, gender, stressed vs. not stressed, bipolar disorder vs. healthy
- Method: half sphere (evening: 20 – 01 o'clock)

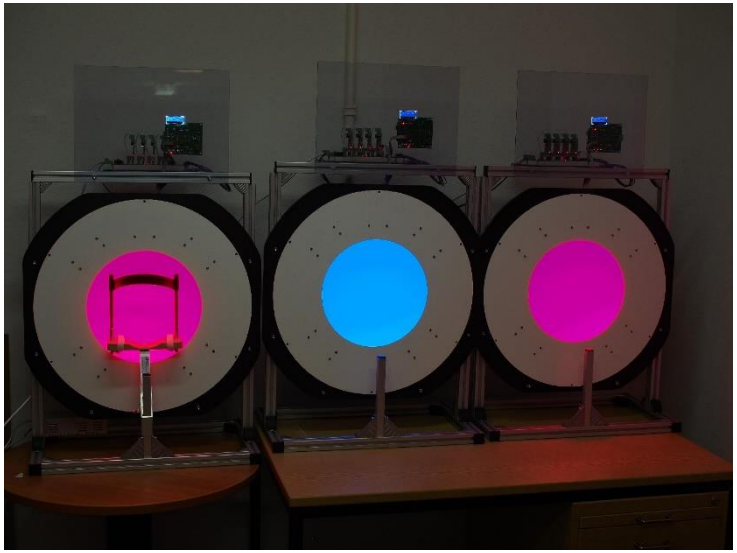


Bild: Kugeln von Falk Wieland

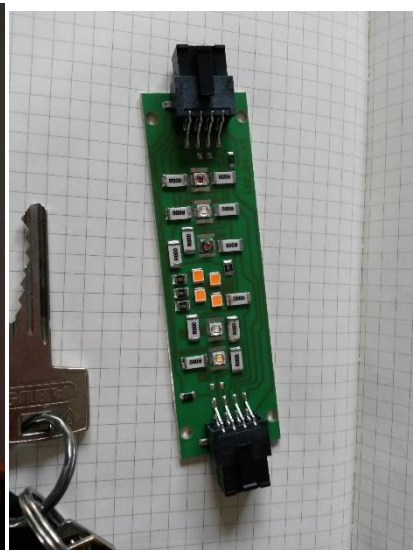


Bild: LED-Platine von Falk Wieland

Used by

TECHNISCHE UNIVERSITÄT DRESDEN

Carl Gustav Carus 1789 – 1869

Technische Universität Berlin

Interdisziplinäres Schlafmedizinisches Zentrum CHARITÉ

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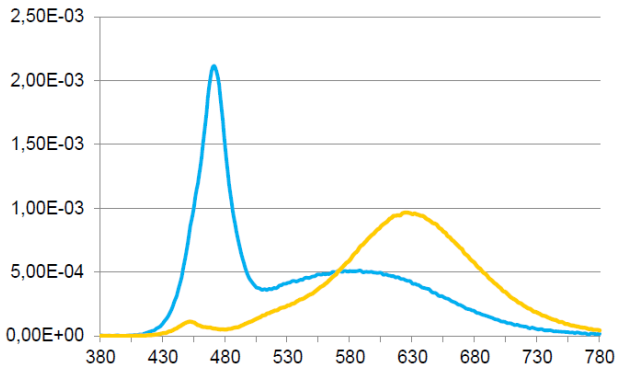
II. Field study in a retirement home

- **Dep. variables:** well-being, quality of life and activity
- **Indep. variables:** Different spectra and illuminances and dynamics
- Method: Fieldstudy, elderly people pre-post comparison, N = 120

Quelle: Ridi



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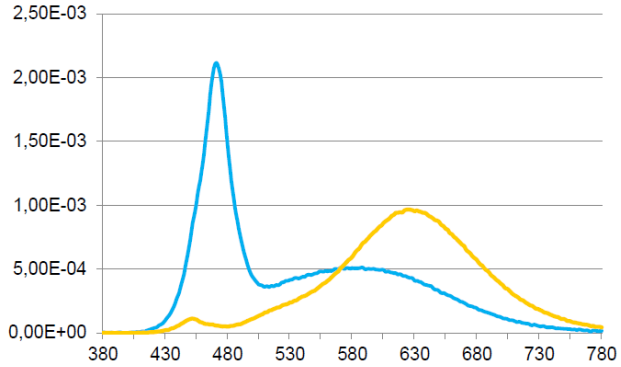
III. Laboratory study (TU Berlin)

- **Dep. variables:** Attention (Audio task, D2, KSS), acceptance of illumination
- **Indep. variables:** Different spectra and illuminances

Quelle: Ridi

Bild: Kugeln von Falk Wieland



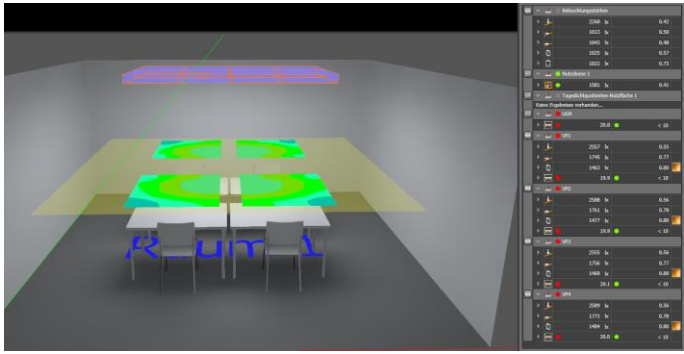


Bild: LED-Platine von Falk Wieland

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IV. Field study in a lecture hall (TU Berlin)

- 90 min lecture under diff. lighting settings
- Attention test D2, self evaluation questionnaire KSS, cortisol
- Lighting: RGBW- fluorescent lamps
- Settings prepared in laboratory → validation in the field

- **Indep. variables:**
  Illuminance @ eye, CCT
- **Dep. Variables:**
  Attention (D2-test, KSS), acceptance, cortisol

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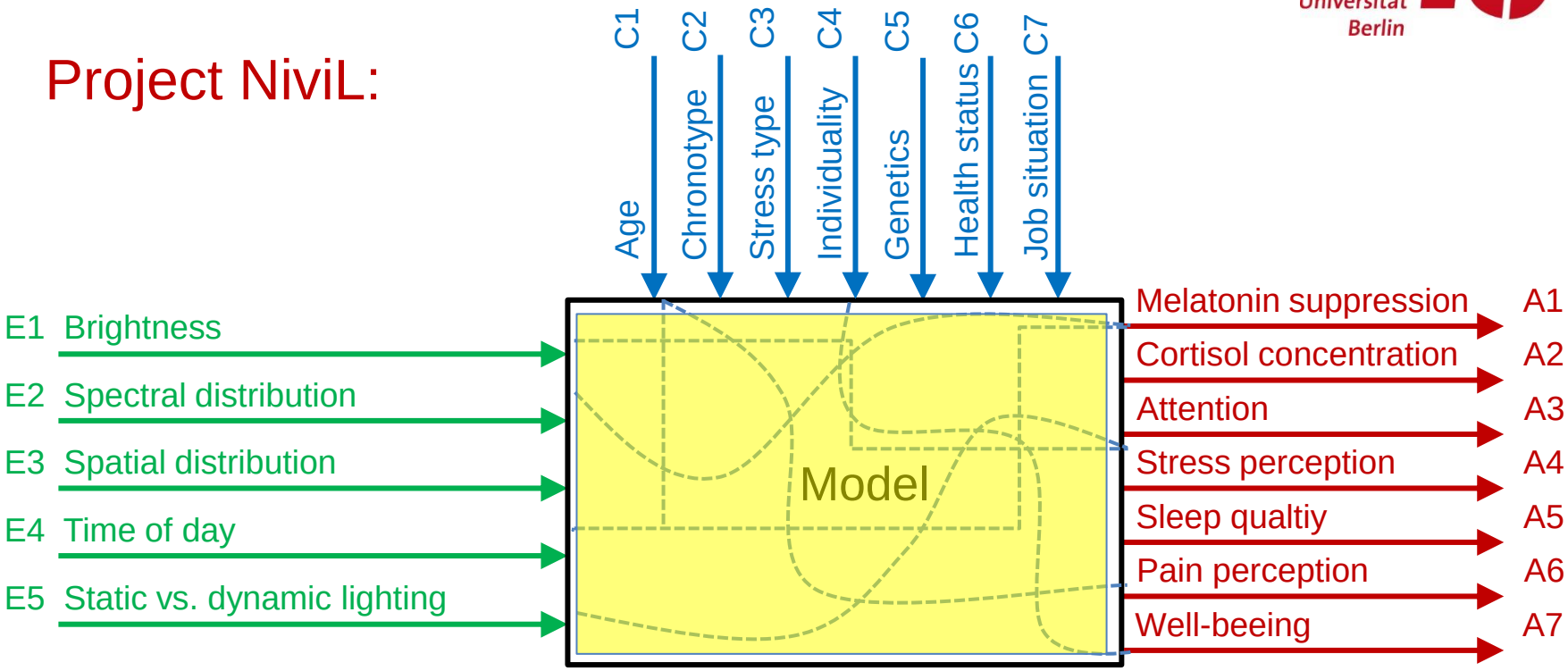
Project NiviL:



- Project: Build a model, define stimulus, specify thresholds values

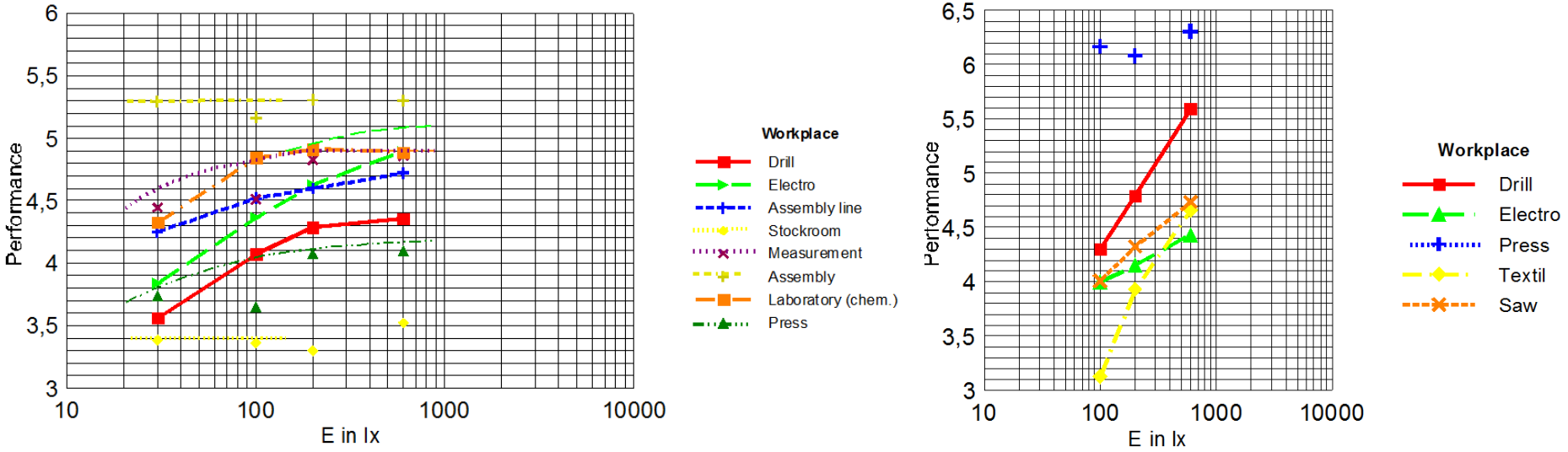
Lichttechnik

Content

1. Background of German Engagement for the LED – LED Leading market
2. Practical using – two point of views
    a. Office and Industry
    b. Schools
    c. Nursery homes and hospitals
    d. Residential and hotels
    e. Airplanes
3. DIN SPEC 67600
4. Project NiviL on the University of Technology Berlin
5. Consequences and Outlook

Conclusion

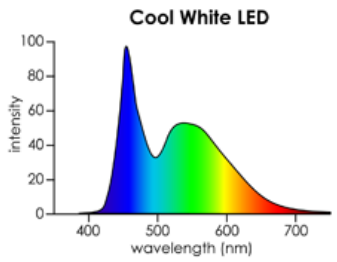
Voelker, S. Dissertation, Ilmenau 1999

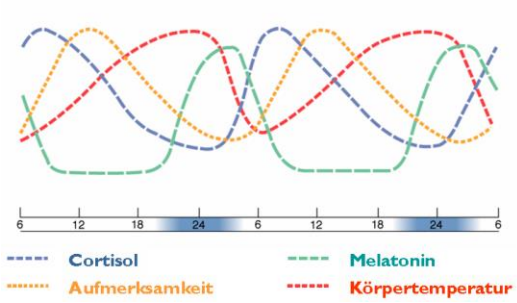


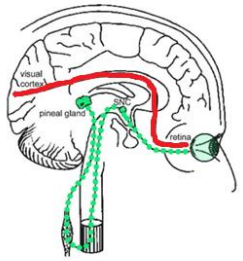
1. Illuminance level has different influence on different task --> different light level will have different effects on different non-visuell effects
2. Time duration of the test has an significant influence on the result! We need long-term experiments with more test subjects in different areas
3. Field experiments show a wide spread (a lot of disturbance variables)

What training is required?

1. Knowlage about light and lighting (correct handling with the terminology)
2. Understanding that a design for non-visual effects has more dimensions than brightness!
    1. Vertical radiation (Illuminance) on the retina <u>combined with</u>
    2. Right spectrum <u>and</u>
    3. Right timing!
3. Individuals are different – where it is possible – use personal control
4. Deal with perception – standards base on old technology – use the possibility to create an adapted lighting design for the specific task

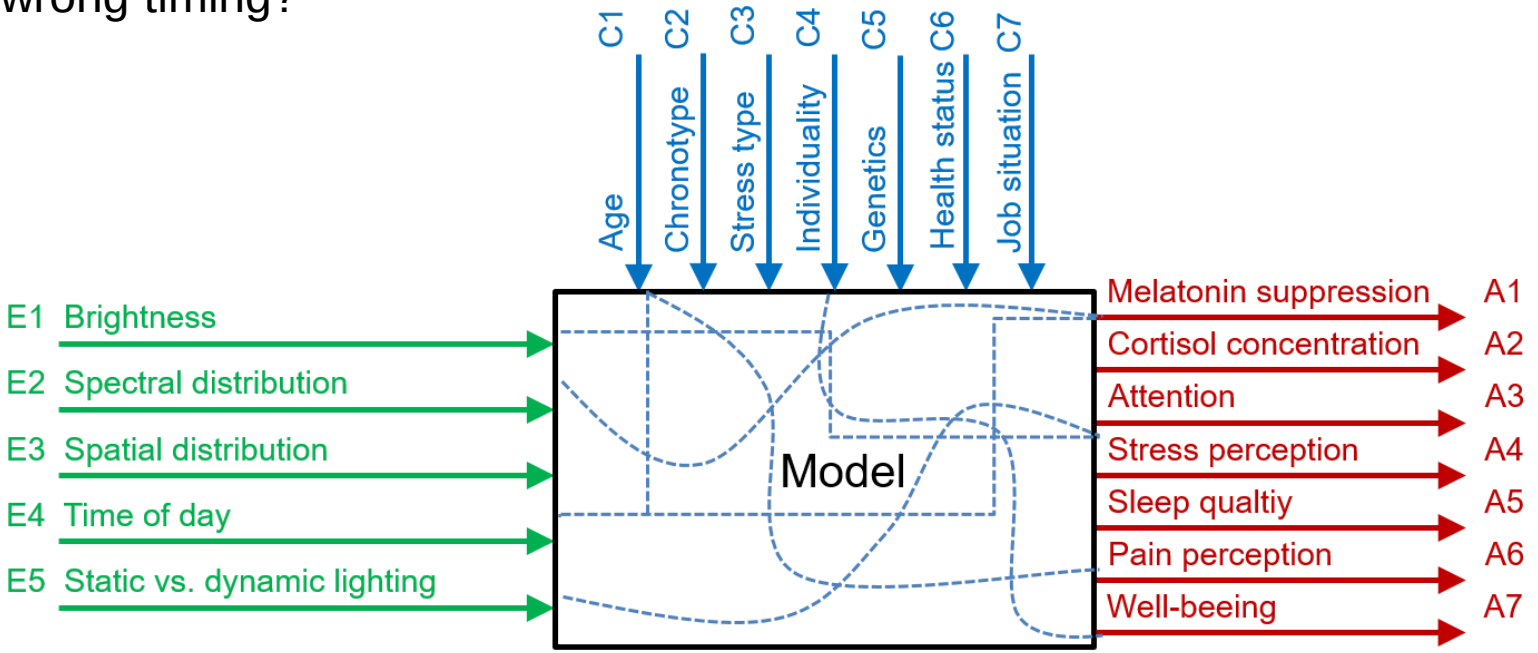






Where do we need more information?

1. Data basis for threshold values (Ex) and limits are thin! – Experiments with larger groups of test subjects are necessary!
2. We need more long-term experiments!
3. Systematic description of the Influence of control variables
4. Which risks do exist for special typs in our population (chronotyp owl) with a wrong timing?

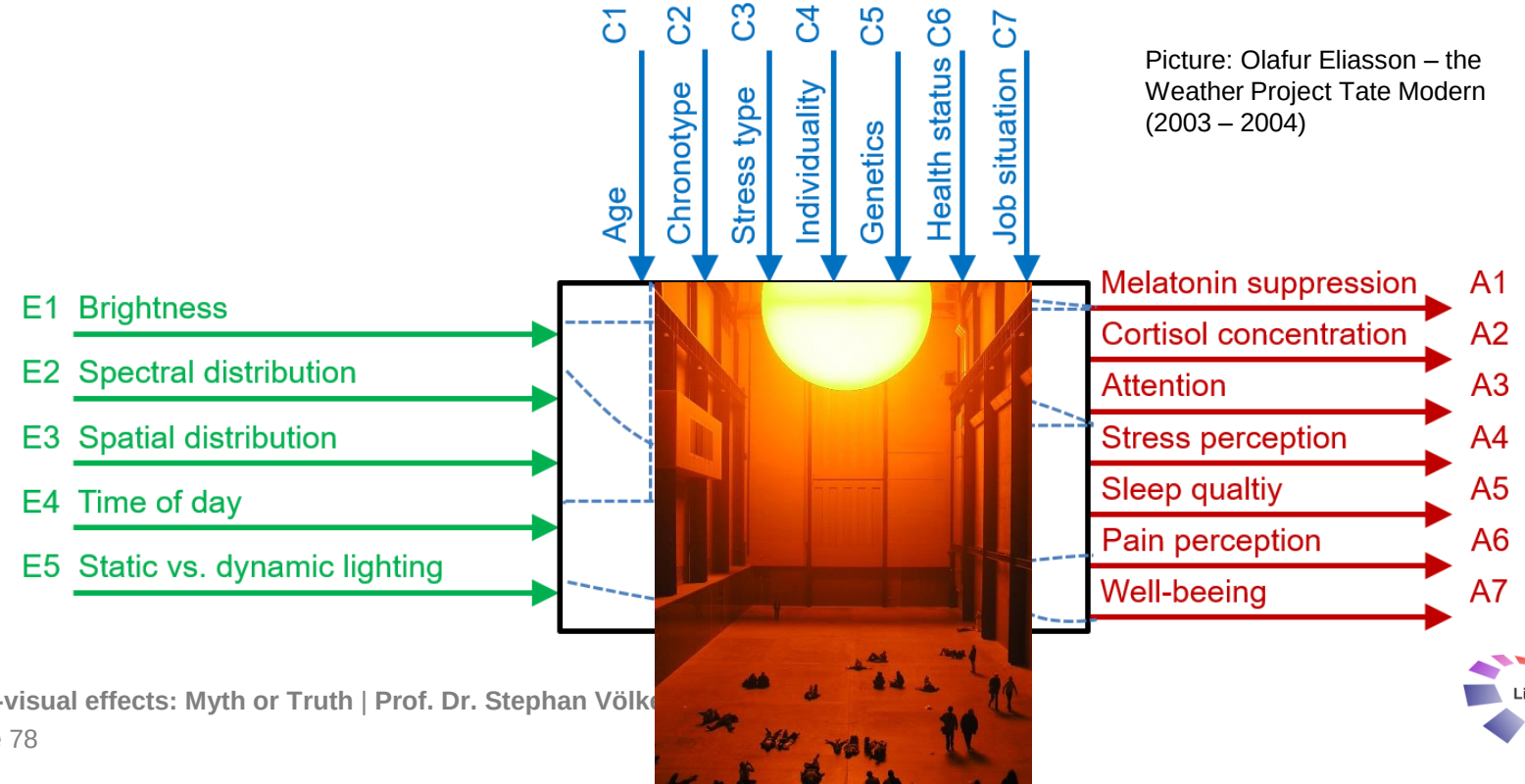


Research agenda

What research still has to do:

- Light in the ‘Black box’ → Background knowledge
- Definition of threshold values and limits
- Investigation about interactions between E and C variables
- Investigation about interaction between the different receptor typs –

  Do we use the right spectral sensitivity?
- Risk for night shift workers



Picture: Olafur Eliasson – the Weather Project Tate Modern (2003 – 2004)

Use LED, then you can

- Save a lot of Energy!
- Improve your lighting Quality through
  - Adapted lighting levels
  - Adapted lighting distribution
  - Adapted spectral distribution
- Lighting is an important factor … - use it!
- Improve the situation in the industry, offices, schools, nursery homes and hospitals for a better life!

… but don‘t believe everthing!

Thank you!