Energy efficient lighting

Technologies and solutions for
significant energy savings compared to current practice

Tore Kolås, November 2011

Electric lighting: Factor 2 - 4 - 10

Annual energy consumption	Reference 300 kWh/m^2	TEK 07 165 kWh/m^2	**Factor 2** 150 kWh/m^2	Low-energy 100 kWh/m^2	**Factor 4** 75 kWh/m^2	**Factor 10** 30 kWh/m^2
Lighting	47 kWh/m^2	25 kWh/m^2	24 kWh/m^2	16 kWh/m^2	12 kWh/m^2	5 kWh/m^2

Is a reduction factor of 10 for
electric lighting a realistic possibility?

Energy efficient lighting?

Reference (office)

- Regular array of suspended T8 fluorescent luminaires.
- Luminaire efficiency (light output ratio) of 60%.
- 30 % of the energy used for indirect lighting.
- Magnetic ballasts.
- Near uniform horizontal work plane luminance of 500 lux.
- Little use of individual task lighting.
- Manual control of lighting - no daylight or occupancy sensors, and no timer.
- Little flexibility – few possibility for individual lighting adjustments.
- Surface reflectance values for floor, walls and ceiling of 20%, 50% and 70% respectively.

Factors influencing lighting energy use

- Lighting equipment
  - luminous efficacy of light source
  - luminaire efficiency
  - ballast type
  - maintenance factor
- Lighting installation design
  - electric lighting distribution (uniformity)
  - reflectance of interior surfaces
- Occupancy scheduling
  - occupant behavior
  - type of control system
- Daylight harvesting
  - occupant behavior
  - control system for lighting and shading
  - type of daylighting or shading system
  - building-related factors

Luminous efficacy of light source

- Future developments in solid state lighting (LED) is likely to improve luminous efficacy of electric light sources significantly.
- This could have a strong and direct impact on lighting energy loads!
- Estimated future saving potential is about 50 % compared to T5 fluorescent.
- Switch from the T8 fluorescent source (reference office) to the T5 source can save 15% energy.

Electric light source	Luminous efficacy [lm/W]
Incandescent bulb	5 – 15
Compact fluorescent	40 – 65
T5 linear fluorescent	80 -100
White LED (practice 2009)	50 – 70
White LED (laboratory 2009)	130
White LED (future potential)	160 - 200 ?

Luminaire efficiency

- Light output ratio (LOR) depends on luminaire design, including the optical properties of the reflector materials.
- Advances in reflector material optical properties have increased the light output ratio of luminaries considerably over the last two decades.
- Today, high performance fluorescent luminaires provide light output ratios of more than 0.9.
- Energy savings relative to the reference situation (LOR=0.6) is about 33%.

Ballast type

- Magnetic ballasts used to be the standard for fluorescent lighting.
- Today, electronic ballasts have replaced the old standard.
- Electronic ballasts typically use 25% less energy.
- Energy savings relative to the reference situation is about 25%.

Maintenance factor

The ratio between the maintained and the initial illuminance value is the maintenance factor (MF). MF depends on:

- Lamp data
  - Lumen maintenance curve
  - Lamp survival curve
- Dirt aspects
  - Luminaire
  - Room
  - Surroundings
- Maintenance procedure
  - Spot replacement or group replacement
  - time between group replacements

The energy saving potential according to Jacobsen (1997) can be as high as 15-20 % for fluorescent lighting installations.

In the LECO report on energy efficient lighting a more conservative estimate of 10% energy savings from improved maintenance is used.

Electric lighting distribution

- Separate individual task lighting and general building lighting as discussed by Loe (2003). This can produce a non-uniform lighting distribution with lower levels in areas where less light is needed.
- Care should be taken not to negatively influence the lighting comfort!
- Veitch et al. (1998) estimates around 50% energy saving potential.
- Loe (2003) provides a more conservative estimate of 25%.
- There has been little research in this field and the estimates given above are not well documented.

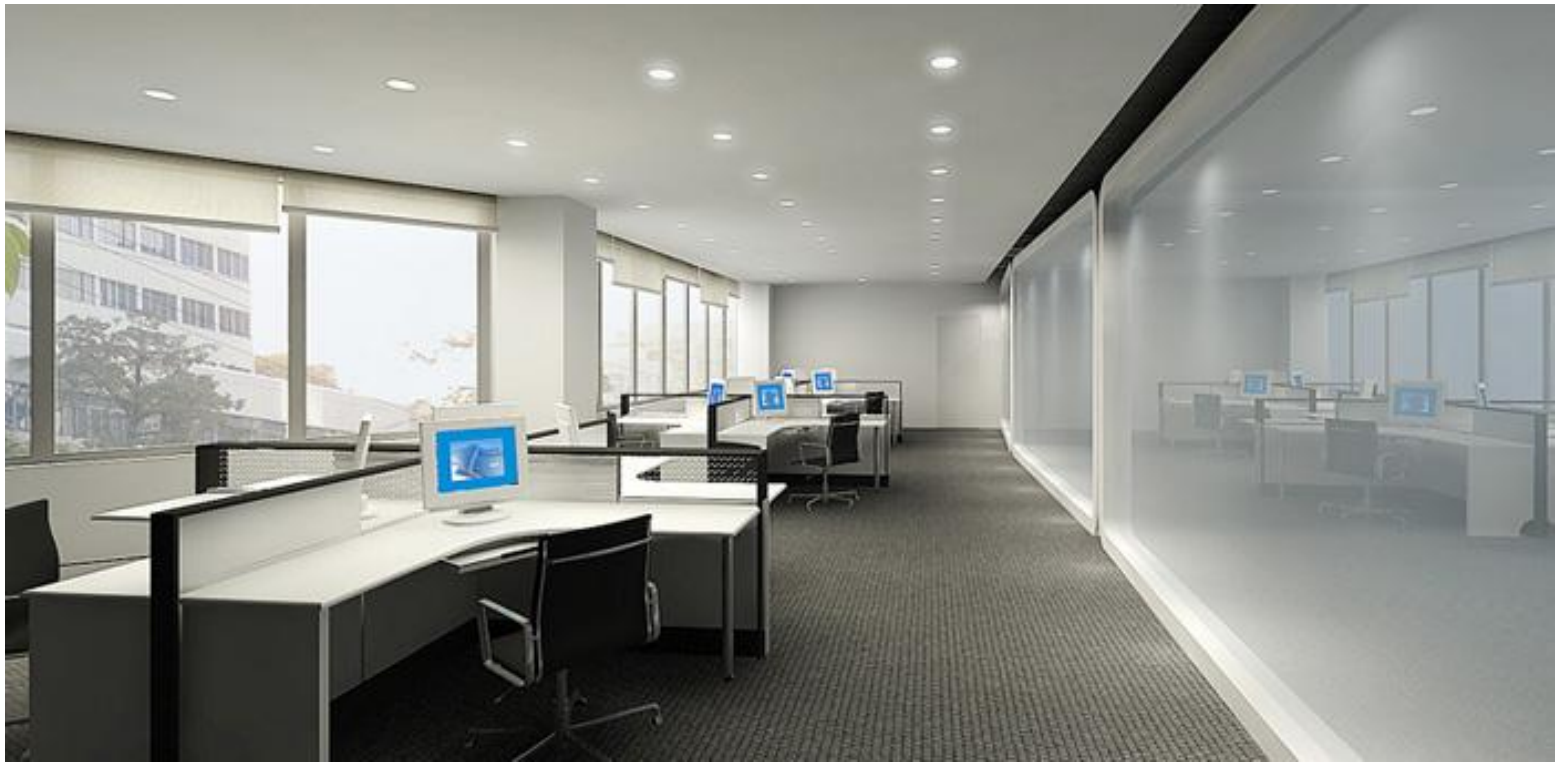
Interior surface reflectance

- Future possibilities with OLED

Interior surface reflectance

- The reflectance values of the interior are of great importance for the lighting comfort.
- Standard values used in calculations are 0.70 for ceiling, 0.50 for walls and 0.20 for the floor cavity.
- For typical interiors, significant savings can easily be obtained by increasing the interior reflectance values.
- When both direct and indirect lighting (30%) is used, estimated savings are about 25% when the interior surfaces of ceiling, walls and floor are set to 0.9, 0,7 and 0.5 repectively .

Occupancy scheduling

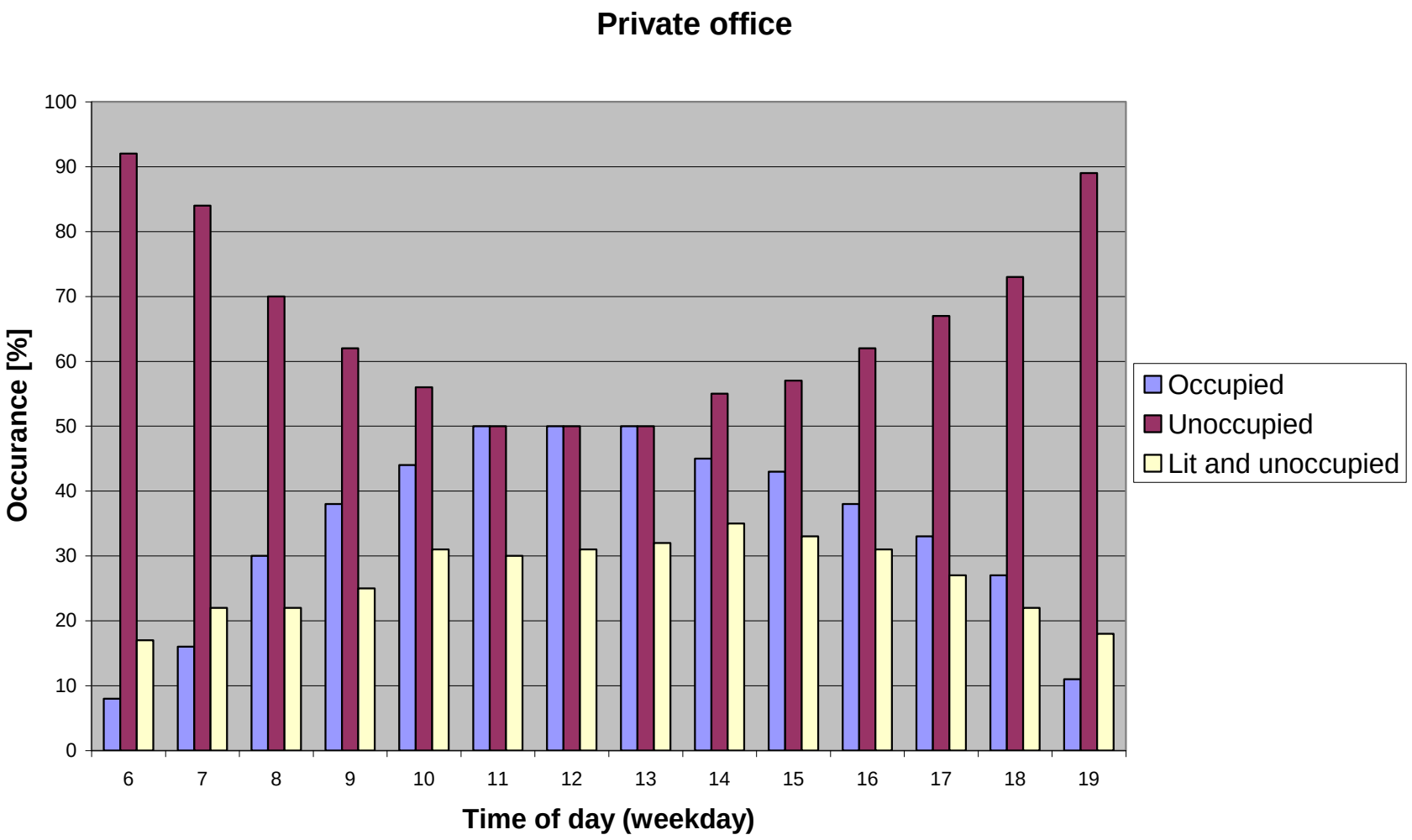


Where have all the workers gone...?

Occupancy scheduling - USA

- Detailed study by Lighting Research Center conducted in 1997 in USA.
- A total of 158 rooms, including 37 private offices with manual lighting controls.
- Study conducted for 60 different organizations in 24 different states.
- Monitored and recorded four conditions:
  1. Room occupied with the lights on
  2. Room occupied with the lights off
  3. Room unoccupied with the lights on
  4. Room unoccupied with the lights off

Occupancy scheduling – LRC findings



Occupancy scheduling - LRC findings

Room type	Lighting energy saving potential [%]		
	No delay	5 min. delay	20 min. delay
Restroom	72	68	47
Classroom	59	58	52
Conference	55	50	39
Private office	**48**	**38**	**28**
Break room	40	29	17

Occupancy scheduling - Norway

- The foundation Vekst made a report to ENOVA regarding Asker Kulturhus in 2005.
- Dataloggings carried out in 32 private offices in the library section of the building.
- The results showed occupancy rates (samtidighet) of 47 % during the working hours (08 to 16).
- The report states that occupancy rates of 60 % to 70 % are normally given as typical for office buildings.

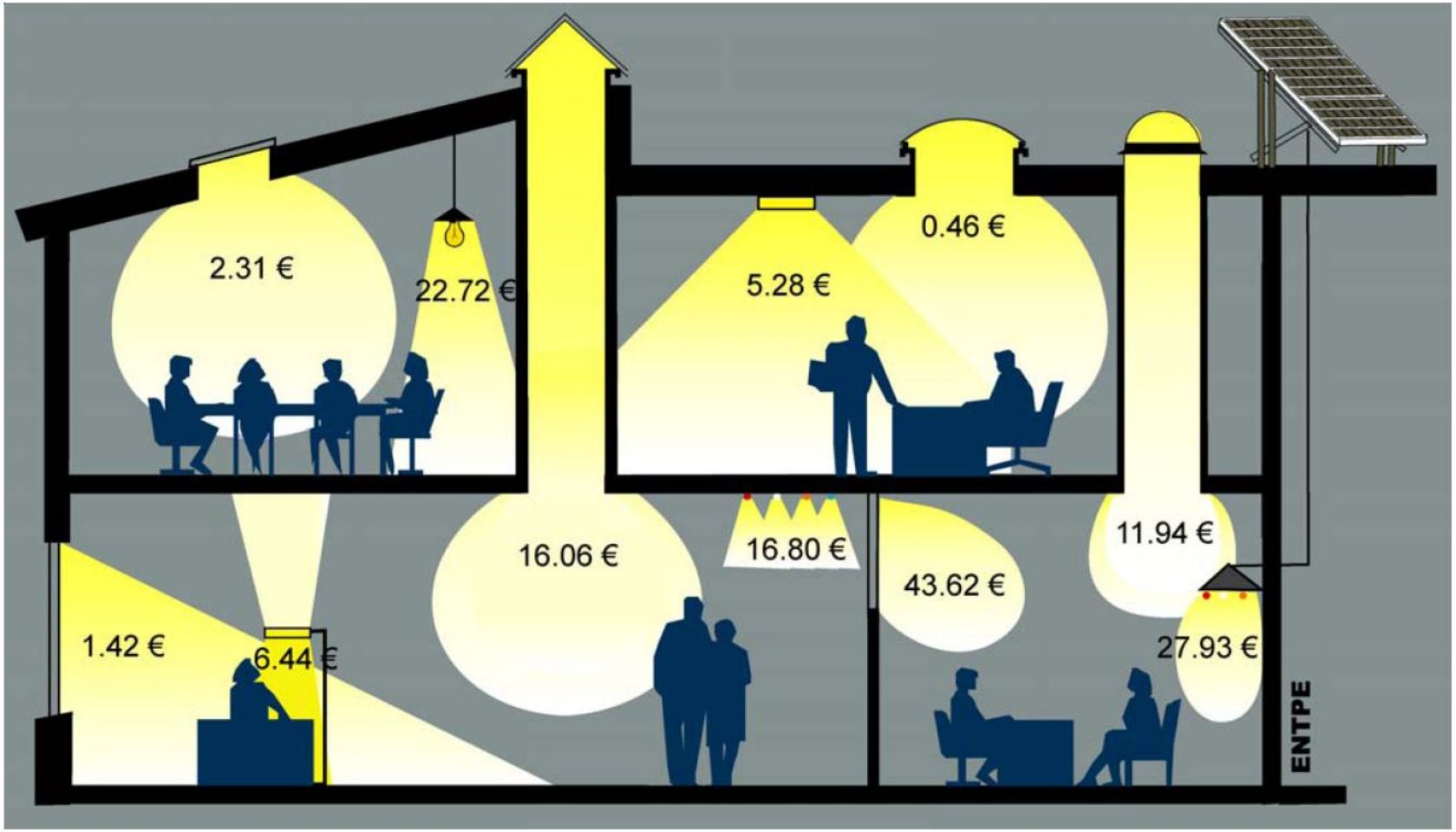
Occupancy scheduling - Norway

- Measurements were carried out in 10 offices in Statens Hus in Trondheim in 1993.
- The results showed occupancy rates (samtidighet) as low as 28 % in average during the working hours (08 to 16).

Occupancy scheduling - conclusions

- The literature findings indicate typical occupancy rates of about 30-50 % during office hours.
- This gives a savings potential of about 50-70 % compared to an “always on during office hours” lighting regime.
- The saving potential compared to a manual switching regime is 54-67 %.
- More field studies are needed to verify the saving potential in Norway.
- However, it seems clear that the saving potential is greater than the 20% indicated by NS3031 (2007).
- In the LECO report a saving potential of 40% compared to manual switching is used.

Daylight harvesting - cost of daylight



Energy saving potential depends on:

Building-related factors:

- Location (climate, latitude)
- Window to floor area
- Window transmittance
- Room depth (building geometry)
- Facade orientation
- Interior reflectance values (wall, ceiling, etc.)

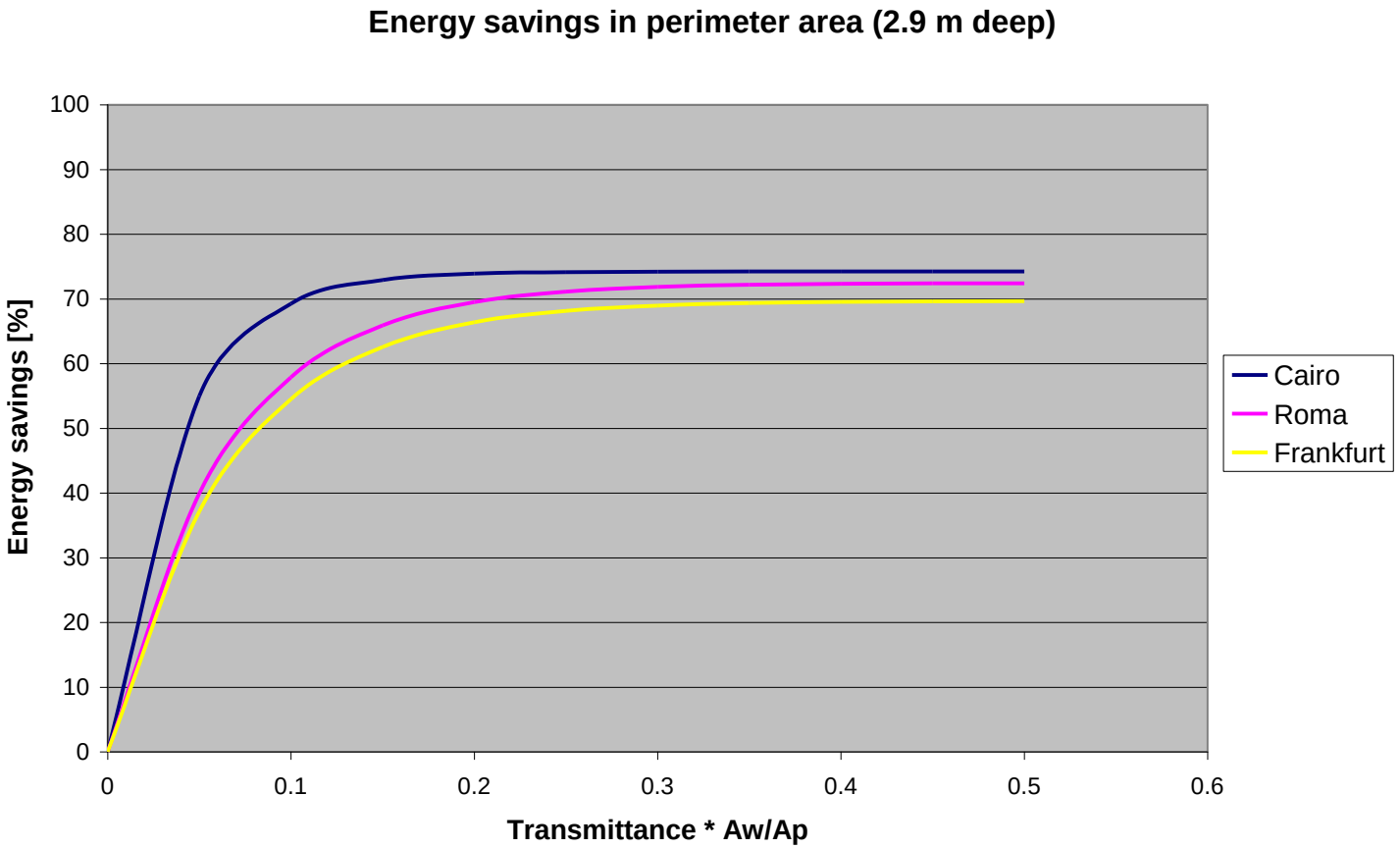
Control system:

- Manual or automatic shading control
- On-off or continuous dimming of electric lighting
- Sensors to monitor and control indirect electric lighting

Daylighting components:

- Exterior capture of daylight
- Shading transmittance under various daylight conditions
- Light redirection properties of daylighting system

Daylight harvesting – perimeter area



- A simplified model by Krarti (2005) shows that energy savings are depending strongly on window transmittance and window area.

Daylight dimming – field studies

Reference	Location	Daylight aperture (T_wA_w/A_p)	Area depth [m]	Shading components	Daylighting components	Lighting control system	Annual savings
Ihm 2009	Boulder, USA	0.105	2.9	Automatic interior shades	No	Dimming (500 lux)	All directions: 64%
Opdal 1995	Trondheim, Norway	0.101	4.25	Manual curtains / blinds	No	Dimming (500 lux)	South: 29% North: 22.5%
						On / off 500 / 900 lux	South: 35% North: 2.5%
Lee 2006	New York, USA	0.077 - 0.135	7.0	Automated roller blinds	No	Dimming 500 lux	West: Feb. to Sept.: 23%
Bülow-Hübe 2007	Lund, Sweden	0.195	4.1	Automated interior white blinds	No	Dimming 500 lux	South: May: 77% Nov.: 5%

Daylight harvesting - conclusions

- Several studies indicate large saving potential (30% to 70%) in the daylit area, even without the use of any special daylighting components.
- Window area and transmittance are important, and savings are reported to increase linearly for typical values of the “daylight aperture” ($T_w A_w / A_p$).
- Savings increase significantly with automatic control systems for electric lighting and for shading.

Miljøbygget – Prof. Brochs gt 2

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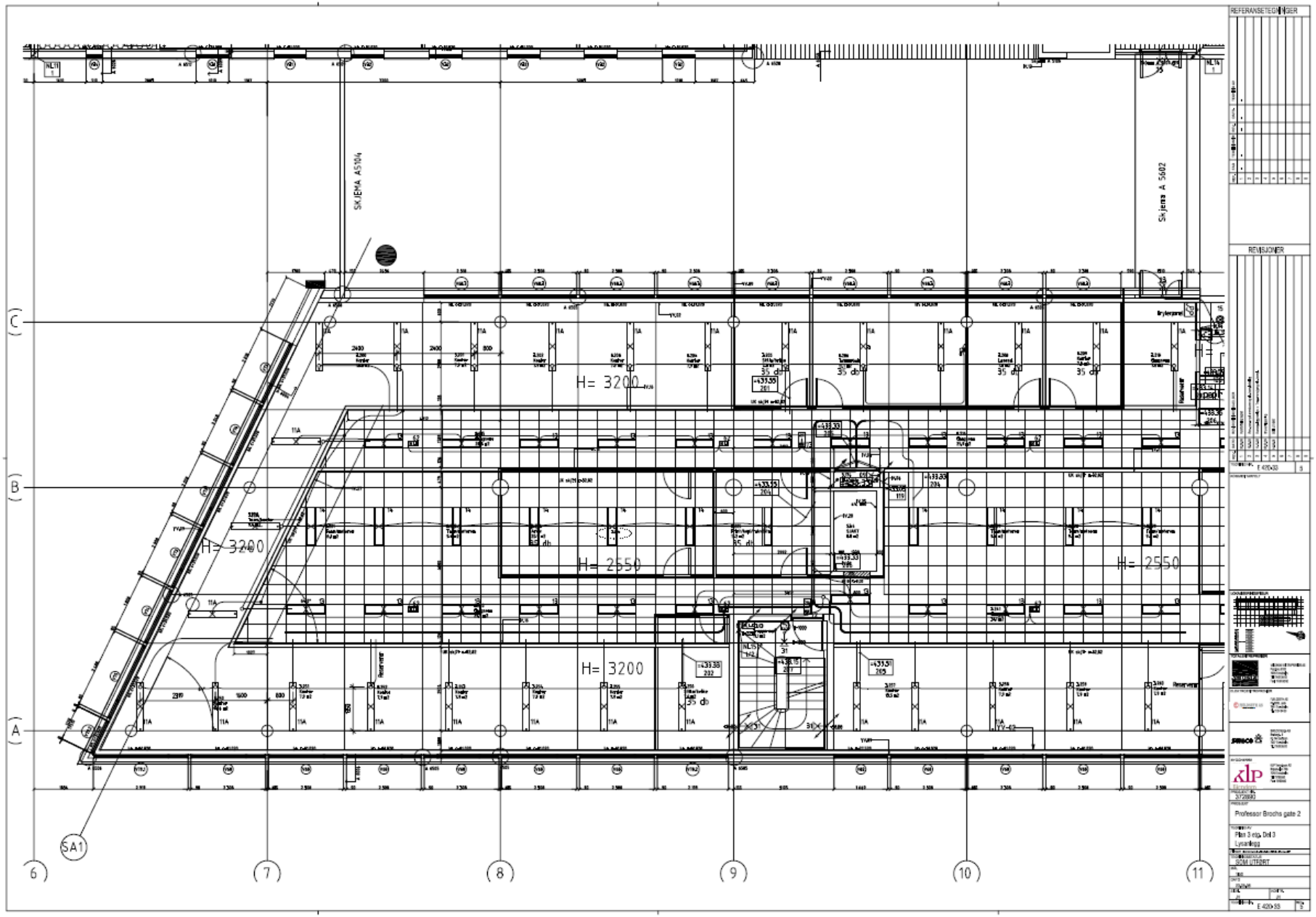
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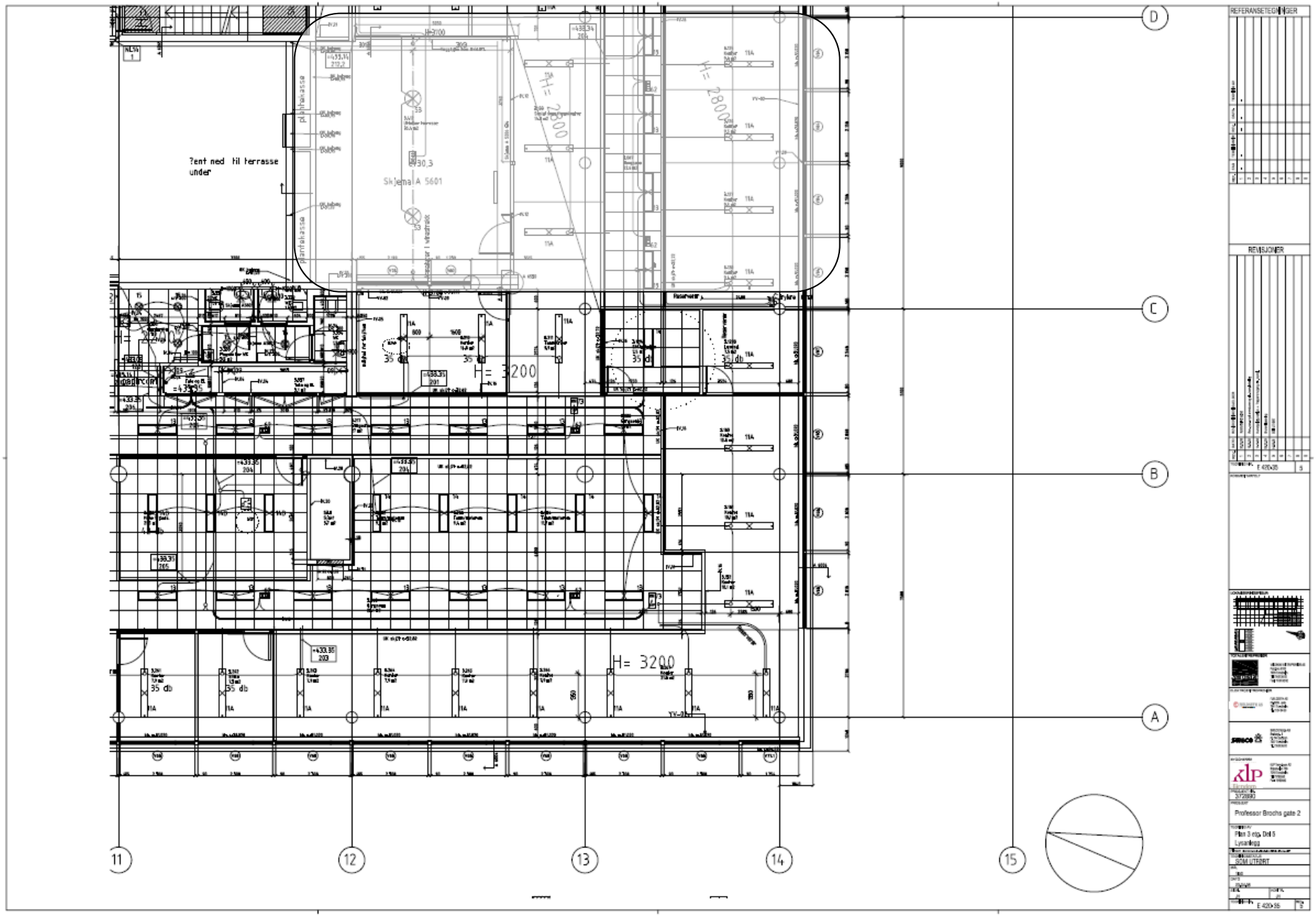
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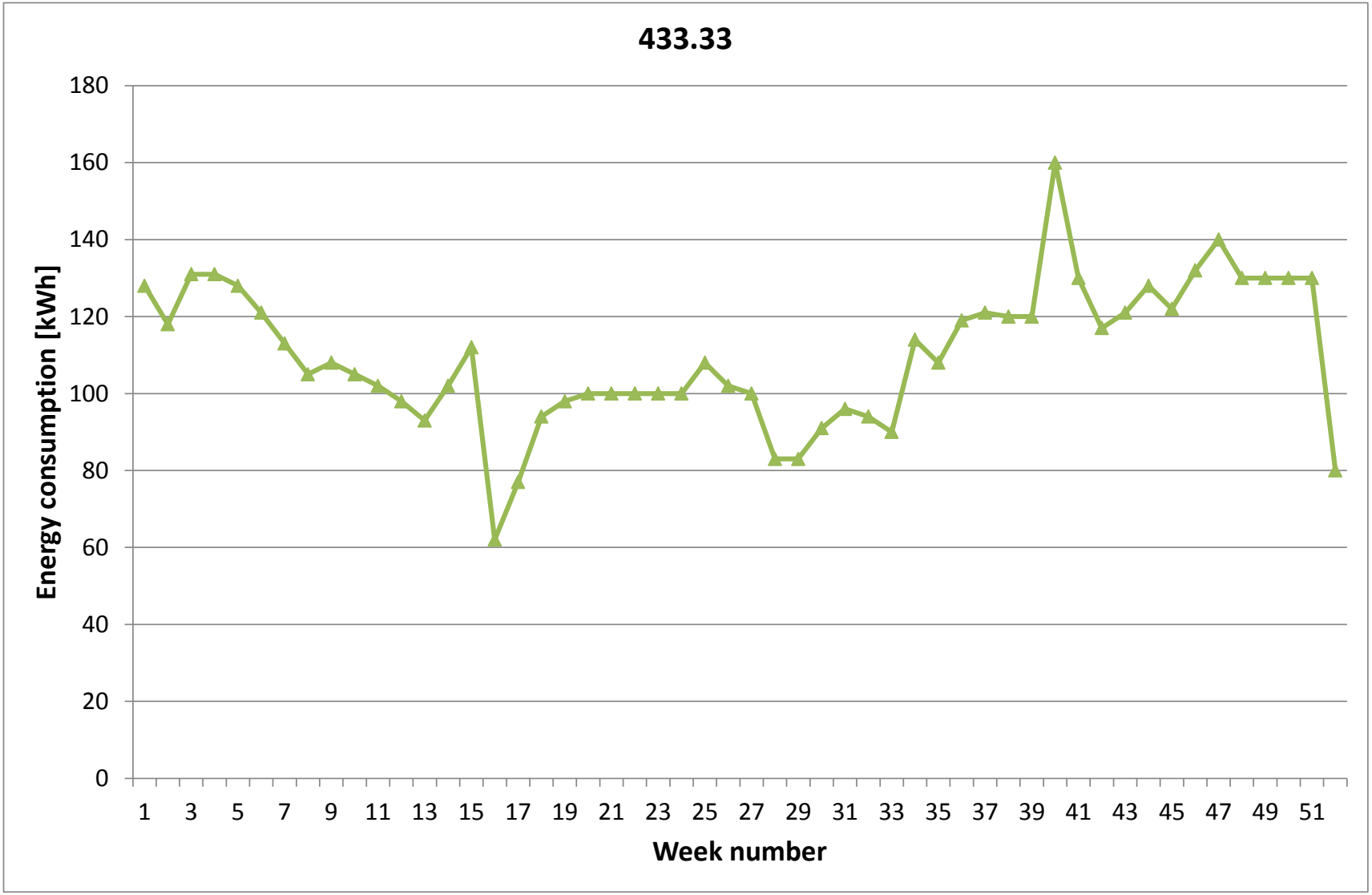
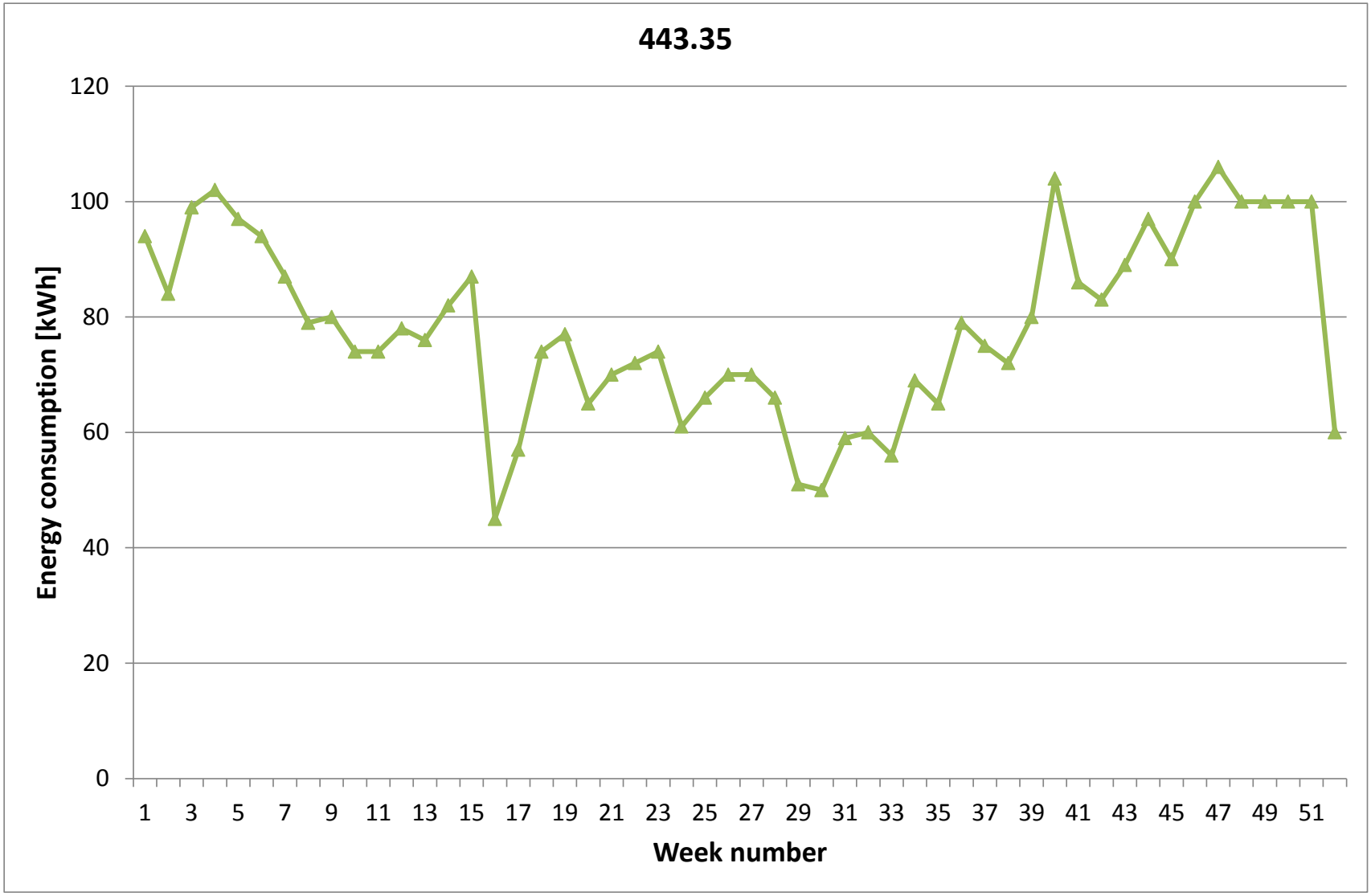
Lighting measurements



Lighting measurements



Miljøbygget – Prof. Brochs gt 2

	Total area [m^2]	LENI calculated [kwh/m^2]	LENI measured [kwh/m^2]
Area 1: meter 33	400	17.3	14.3
Area 2: meter 35	17.3	15.8	16.2

Total energy saving potential for lighting

Step	Measure	Saving potential [%]	Energy consumption [kWh/m^2]	
	Reference conditions (no measure)	-	47	
1	Better light source (T8→T5)	15	40	
1	Switch from electromagnetic to electronic ballasts	25	30	
1	Better luminaires (LOR 0.6→0.9)	33	20	factor 2
2	Presence detectors (real occupancy control strategy)	40	12	factor 4
3	Daylight dimming	15*	10	
4	Automatic shading (+ daylight dimming)	15*	8.7	
5	Daylight redirection systems (+ daylight dimming)	20*	7.0	
6	Improved maintenance procedures	10	6.3	
7	Non-uniform spatial distribution of electric lighting	25	4.7	factor 10
8	Brighter interior surfaces	25	3.5	
	LED with 200 lm/W (future savings)	50	1.8	

* Numbers refer to average savings for the whole building. Higher savings can be obtained in the daylit areas.

Conclusion

- The combination of
  - more efficient lighting equipment
  - occupancy scheduling
  - daylight harvesting and daylight dimming
  - improved lighting maintenance
  - application of a non-uniform electric lighting scheme

  can provide lighting energy savings of approximately 90% (factor 10!) compared to the reference conditions.

- In the near future, solid state lighting (LED and OLED) can be utilized in order to provide even higher energy savings.