MEASURED ENERGY SAVINGS AND COST-EFFECTIVENESS OF THE LIGHTING RETROFIT AT VATTENFALL'S OFFICE IN RÅCKSTA, STOCKHOLM: An Evaluation After One Year

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Abstract

The Vattenfall office, in the nothern suburbs of Stockholm called Råcksta, is a commercial complex containing 76,000 square metres of office space, built in the early sixties. The office is in the process of being modernised. In this process a corridor with thirty-six office rooms has been remodelled with the aim of saving electricity while at the same time providing an improved work environment. The project started with a test of different lighting designs in six office rooms installed by different manufacturers. The project in Råcksta, which is one of the Vattenfall energy conservation projects within Uppdrag 2000, is finished and the evaluation has been going on for one year.The corridor and office rooms have been totally renovated. The design of the lighting system is much more efficient than the old one. High-frequency ballasts are used and different kinds of control systems are tested; occupancy sensors, remote controls and daylight controls.

INTRODUCTION

The office in Råcksta is one of the biggest offices in the Stockholm area. Vattenfall is a high-voltage costumer to Stockholm Energi, the local utility for both electricity and district heat. The rate for electricity is a time-of-use rate with a fixed charge, a contratual demand charge and a peak-load charge. The energy charges are divided in on- and off-peak charges for three different seasons.The total electricity consumption is 16,400 MWh/year. Computers for the operation of the national grid and other big computers are the biggest electricity end-uses in the complex. The electricity consumption in the three main office buildings is 5,900 MWh/year or 78 kWh/m^2 The total electricity consumption for lighting in these buildings is 1,400 MWh/year or 19 kWh/m"2" which is 24 % of the total electricity consumption in the buildings. The biggest electricity end-use in the offices is the HVAC-system, 33 % of the total.In this paper the experience from a total renovation of one corridor (126 m^2) with 36 office rooms (505 m^2) will be presented. The project started summer 1988 with a test of different kinds of lighting designs in six office rooms[1].The corridor and the 36 office rooms were renovated 1989. Lars Hedström has been the project manager. This project is one of the 60 demonstration projects in the commercial sector conducted by Uppdrag 2000. Coordinator of projects in the commercial sector is Claes Hedenström..

Most of the results are presented in the report "Råckstaprojektet"[2].

LIGHTING SYSTEM

The old lighting system

The old lighting system in the Vattenfall office is about 30 years old. Luminaries with two tubes are placed in rows in the ceiling of the office rooms maintaining a uniform intensity of illumination in the whole room so that the desk can be placed wherever the person in the room likes. This was a rather common design during the sixties and seventies when many offices were constructed in Sweden. The electric load in office rooms was 98.6 W (measured) per luminary with two 36 W tubes. This means that the losses in the magnetic ballasts were 13.3

W per ballast which was suprisingly high. The reason for high losses was the high generation of heat in the luminary and that the ballasts were very old.In the corridor light luminaries with two 18 W tubes were used. The losses were the same as in the office rooms. The total electric load is 49 W (measured) per luminary.The electric capacity for the old lighting system was 1.2 kW in the corridor and 15.7 kW in the 36 office rooms. The intensity of illumination on the desk surface in office rooms was 600-800 lux and the contrast reduction was 15-25 % which is unacceptable.

The new lighting system

The new lighting system has been designed from a holistic point of view, which means that the choice of furniture, colour on walls, ceiling, carpets, curtains and the design of the luminaries are coordinated. The employees got the possibility to choose among three different colour combinations in their rooms.The criterion for the design of the lighting system was high energy efficiency with high lighting quality at the same time. To fullfill the high energy efficiency criteria high frequency (HF) lighting was chosen with the possibility to use different control systems. Light luminaries from Fagerhult, called Combilume Terazza with one or two flourescent tubes with uplights and high frequency ballasts from Philips are installed in the office rooms. In the corridor light luminaries from Asea Skandia with only one tube and HF-ballasts are installed. Full-colour 32 W flourescent tubes are used and delivered by Philips. All light luminaries are connected to a central control unit in each room.The high quality of lighting in office rooms is accomplished by the possibility to move the light luminaries hanging down in chains from movable rails in the ceiling. It's easy to change the position of the light luminaries depending on individual wishes.High frequency lighting has a lot of advantages like immediate switching, non flickering (it is working at 28 kHz) and the lifetime of the tubes are prolonged from 12,000 hours to about 15,000 hours.The luminaries adjacent to the window in the office rooms and the luminaries in the corriodor have an asymmetrical reflector. The others have a symmetrical reflector.With the new lighting the intensity of illumination is 640-820 lux on the desk surface. The contrast reduction has decreased to 6 %.The high electric efficiency is accomplished by the optimal design in each room, HF-ballasts and the control systems that limit the number of hours that the lighting is needed. The efficiency has increased from 1.6 lux/W to 3.3 lux/W.HF-lighting is today standard in the ongoing renovation of the office in Råcksta.

Control Systems

All office rooms have remote control units instead of traditional pushbutton switches. The light luminaries are switched on manually and controlled separately with a remote control. In addition to this, different kinds or combinations of control systems have been installed. The 36 office rooms have been divided in four test areas, about 8-10 room in each area, with four different control systems installed.In the first area of office rooms occupancy sensors are installed. Lighting is switched off automatically with a delay of 15 minutes after the occupant has left the room, or more correctly, if nobody moves in the room. There is no automatic switch on because all persons don't want to switch on the lights.In the second area there are both occupancy sensors and photocells (Philips) installed. The photocells measure the light intensity on the desk surface and switch off the luminary adjacent to the window if the intensity exceeds 600 lux for 30 minutes. The person in the room can switch on the unit again if needed with the remote control.In the third area there are only photocells with the same operation strategy as in the second area.In the fourth area there are photocells for both daylight control and manual dimming. The photocell dims the light luminary adjacent to the window in steps so that the light intensity on the desk maintains constant, around 600 lux. The window luminary can also be dimmed with the remote control.One goal in this project was to study the impact of different lighting control systems on the electricity consumption for lighting in office rooms. The size of the test areas were too small to make it possible to state any accurate conclusions. Though the practical experience has brought a lot of value. Because of the big variation in the employees ways of using lighting we assume that at least 50 office rooms with the same control system is required.

EVALUATION

Attitudes and Experience

The evaluation also included a survey among persons working in the actual office rooms about their attitudes and experiences of the new lighting system. They have a good knowledge about the new lighting system because they have been informed several times.Twenty-six persons answered the survey and here are the main results:

1. All persons except one really like the HF-lighting system. The dissatisfied person complains about glare. In this respect the project is a succes compared with the old system where glare was i big problem.
2. Sixty-two percent of the persons think that the non-flickering tubes are the most favorable thing with the new lighting system. This means that HF-lighting also improves the office work environment. The improved colour of light is important for 35 % of the persons and the new design to 19 %.
3. Of those who have photocells for switching-off or dimming the adjacent window luminary, 55 % think the

photocell has worked well. 45 % haven't noticed it at all or think it works poorly. 20 % have disconnected the photocell.

4. For 34 % of the persons the occupancy sensor has worked sufficiently well. Thirty-nine percent experience that the sensor is too sensitive which leads to too many switching-off even when they are present. Eleven percent have disconnected the sensor. Anyhow 88 % have a positive view on occupancy sensors if they work properly. Eight percent have without doubt a negative view. It is important to have this in mind and in economic pre-calculations, that maybe 5-10 % of the persons in an office will not accept occupancy sensors because they dislike the idea of automatic switching.
5. Occupancy sensors in the corridor have been considered to be a well working option by 93 % of the persons. Some have pointed out that the switching-on must work faster in the corridor for people working after normal business hours, so they don't have to step out in a dark corridor from their offfice rooms. There are fast working occupancy sensors on the market today.
6. The remote controls have in 35 % of the cases been used at the office desks. The rest of the persons use the remote control as an ordinary switchbutton close to the door.
7. Half of all persons put the possibility to control the lighting themselves on the top of a list on accepted ways to control lighting. Thirty percent put occupancy sensors on the top of the list. A daylight control system seems to be the most unpopular control system. Some persons have answered that they don't like the variation of illumination from the luminary although the intensity on the desk is constant.

The conclusion from the survey is that HF-lighting is most appreciated and an improved work environment is achieved. Most people accept occupancy sensors but it should also be possible to control the lighting manually. Daylight control systems at Råcksta is so far not preferable.

Energy Savings

The installation of the new lighting system can be divided into 3 steps. In Tables 1 and 2 results from these steps for office rooms and the corridor are presented.The first step is the renovation of the office rooms and the corridor and at the same time making the lighting design using new efficient luminaries orientated at the working spot in office rooms. This is a standard installation in office rooms today. The savings are 56 % and 27

Table 1: Installed capacity, peak load during winter and electricity consumption in office rooms for the different steps of conservation.

36 office rooms, 505 m²	Installed capacity W/m²	Peak load winter W/m²	Electricity consumption kWh/m²
Old lighting system (3-5 light luminaries/room)	31.0	20.2#)	25.1#)
1. New lighting system, efficient design and high efficiency luminaries with standard ballasts(2-3 light luminaries/room)	13.6	8.8	10.9
Savings		56 %	
2. Same as 1 with HF-ballasts	10.6	6.9#)	8.5#)
Savings compared with old system. Marginal savings compared with 1		66% 22 %	
3. Same as 2 with one occupancy sensor in each room.	10.6	6.9#)	6.8#)
Savings compared with old system Marginal savings compared with 2		66% 0%	73 % 20 %

#) monitoring data.

% for office rooms and the corridor respectively.The second step is like step 1 but with electronic, HF-lighting ballasts installed in the luminaries instead of magnetic ballasts. The savings in this step is 22 % in offices rooms and 28 % in the corridor compared to step 1 or totally 66 % and 48 % compared with the old system. The energy savings occur because of the electronic ballasts. The old magnetic ballasts consumed 30 % more electricity[1] than new standard ballasts. The tubes will last longer because of the more efficient operation with electronic ballasts.The third step is like step 2 combined with occupancy sensors. For office rooms one sensor is needed in each room. The savings potential for the sensor itself has measured to be 20-30 % in an other project[3] According to the acceptance, about 90-95 %, the total overall savings assumes to be 20 %. During a fulltime working day this means a reduction of 1.5 hours a day. In the corridor occupancy sensors will save a lot of electricity. Though it depends on how the existing system works, in other words which reference level the savings can be calculated from. At Vattenfall the corridor lighting is swichted on all day. The automatic switching off at nighttime doesn't work. Occupancy sensors in this situation will lead to a lot of savings. Normally corridor lighting during nights and weekends is reduced to one third of the daytime lighting level with a timer. When calculating the savings this is assumed also to be the base-case for Vattenfall. The savings with the occupancy control will then be 50 %.

Table 2: Installed capacity, peak load during winter and electricity consumption in the corridor for the different steps of conservation.

The corridor, 126 m²	**Installed capacity and peak load** W/m²		**Energy consumption** kWh/m²
Old lighting system (24 light luminaries)	9.4#)		49.2#)
1. New lighting system, efficient design and high efficiency luminaries with standard ballasts(21 light luminaries)	6.8		35.9
Savings		27 %	
2. Same as 1 with HF-ballasts	4.9#)		25.7#)
Savings compared with old system		48 %	
Marginal savings compared with 1		26 %	
3. Same as 2, with two occupancy sensor in the corridor.	4.9#)		12.8#)
Savings compared with old system	48 %		74 %
Marginal savings compared with 2	0 %		50 %

#)monitoring data.

Based on 12 months of hourly data the energy savings are 9.1 MWh/year or 73 % in the office rooms and 4.6 MWh/year or 74 % in the corridor. The correspondent peak load savings are 6.7 kW or 66 % and 0.6 kW or 48 %.The number of hours that lighting is switched on varies cosiderably. In a sample of ten office rooms the span has been measured to be between 400 and 1760 hours. The "typical" Vattenfall employee uses the lighting system 1250 hours per year. Though the average of all actual office rooms is only 810 hours. In comparison with other offices this seems to be a very low figure. With the occupancy sensor the number of hours is reduced by 20 %.

Economic analysis

First of all it is important to point out that a retrofit like this must, from an economic perspective be combined with renovation, modernisation etc when the lighting system is worn out and has to be replaced anyhow. The situation is then favorable for energy conservation because only the marginal costs for the conservation measures have to be included in the economic calculations. Though the renovation costs must be considered for the building owner. In the Råcksta office the renovation costs were 920 SEK/m²(120 ECU/m²) for the office rooms and 1250 SEK/m²(162 ECU/m²) for the corridor, see Table 3.

The marginal cost for HF-ballast is 250 SEK/luminary (32 ECU) which means 40 kr/m˅2˅ (5.2 ECU/m²) in both office rooms and the corridor. The total installation cost for a occupancy sensor is 1000 SEK (130 ECU). One sensor is needed in each room and at least 2 in the corridor. The installation cost will be 75 kr/m²(9.8 ECU/m² in average in the office rooms and 16 kr/m² (2.1 ECU/m² in the corridor.The average electricity price, tax and VAT excluded for the year 1991, is 0.50 SEK/kWh (0.065 ECU/kWh) in the office rooms. 36 % of that is the cost for the peak load. The correspondent price for electricity in the corridor is 0.30 SEK/kWh (0.039 ECU/kWh). 14 % of that is the cost for the peak load.Normally the energy tax for this kind of building is 0.072 SEK/kWh (0.0094 ECU/kWh). The VAT is 25 % on top of all energy costs including the tax.How the energy and maintenance costs drop in the different steps of conservation is presented in Tables 4 and 5. The cost for the fluorescent standard one-colour tubes is 15 SEK (2.0 ECU) each and full-colour tubes 30 SEK (3.9 ECU) each. This cost and the labour cost for changing them (30 SEK (3.9 ECU) per luminary) are included in the maintenance cost. The lifetime of the fluorescent tubes assumes to be 9,000 hours for one-colour tubes and 12,000 hours for full-colour tubes. When HF-ballasts is used the lifetime of the full-colour flourescent tubes is assumed to be prolonged to 15,000 hours.

Table 3: Installation costs in office rooms and corridor for the year 1991. VAT is excluded.

INSTALLATION COSTS	Office rooms	Corridor
Total renovation	920 SEK/m² (120 ECU/m²)	1,250 SEK/m² (162 ECU/m²)
New efficient lighting design with standard ballasts	341 SEK/m² 44 ECU/m²)	478 SEK/m² (62 ECU/m²)
Marginal cost for HF-ballast	250 SEK/luminary (32 ECU) 41 SEK/m² (5.3 ECU/m²	42SEK/m² (5.5 ECU/m²)
Occupancy sensor	1000 SEK each (130 ECU) 75 SEK/m² (9.8 ECU/m²	16SEK/m² 2.1 ECU/m²

The installation cost for new efficient lighting without HF-ballasts is 340 SEK/m˅2˅ (44 ECU/m²) in office rooms and 480 SEK/m²(62 ECU/m² in the corridor.

Table 4: Energy and maintenance costs in office rooms for the year 1991. Energy tax and VAT are excluded.

ENERGY ANDMAINTENANCE COSTS IN OFFICE ROOMS	The old system	The new system		
		1. New design	2. 1+HF-ball.	3. 2+sensors
Total energy cost	12.4 SEK/m² (1.6 ECU/m²)	5.4 SEK/m² (0.7 ECU/m²)	4.2 SEK/m² (0.6 ECU/m²)	3.7 SEK/m² (0.5ECU/m²)
Maintenance cost	2.6 SEK/m² (0.3 ECU/m²	1.4 SEK/m² (0.2 ECU/m²)	1.1 SEK/m² (0.1 ECU/m²)	0.9 SEK/m² (0.1ECU/m²)

Table 5: Energy and maintenance costs in the corridor for the year 1991. Energy tax and VAT are excluded.

ENERGY ANDMAINTENANCE COSTS IN THE CORRIDOR	The old system	The new system		
		1. New design	2. 1+HF-ball.	3. 2+sensors
Total energy cost	14,7 SEK/m² (1.9 ECU/m²)	10.7 SEK/m² (1.4 ECU/m²)	7.7 SEK/m² (1.0 ECU/m²)	4.8 SEK/m² (0.6ECU/m²)
Maintenance cost	11,1 SEK/m² (1.4 ECU/m²	7.3 SEK/m² (0.9 ECU/m²)	5.8 SEK/m² (0.8 ECU/m²)	1.7 SEK/m² (0.2ECU/m²)

In Tables 6 and 7 results from the economic calculations are presented. In the first step no installation cost is included because the lighting system should be changed anyhow. Only the marginal costs are included in steps 2 and 3. The economics is presented for two cases. In the total system calculations, the total savings are included in each step from step 1. The marginal costs are also accumulated. In the marginal system calculations, only the marginal savings and costs are considered in each step.

The heat losses from the lighting system that contribute to heating the building have to be replaced from the ordinary heating system when making the lighting more efficient. How much heat that have to be replaced is impossible to measure in a small project like this. To avoid an overestimation of the benefits in the economic calculation it is assumed that 50 % of the heat losses have to be replaced. In the marginal system calculations this is neglected.

Table 6: Net present value and simple pay back time for the different steps of conservation in office rooms. (6 % real interest rate, 2 % real escalation of electricity price, 15 years lifetime)

36 OFFICE ROOMS	The new system		
	1. New design	2. 1+HF-ball.	3. 2+sensors
Net present value			
- total system*)	44,500 SEK (5,800 ECU)	20,780 SEK (2,700 ECU	-810 SEK (-105 ECU)
- marginal system		-12,900 SEK (-1,700 ECU)	-33,800 SEK (-4,400 ECU)
Pay back time			
- total system*)	0 years	5,4 years	11.1 years
- marginal system		28 years	98 years

*) energy savings from step 1 and the compensation for heat losses are included.

Table 7: Net present value and simple pay back time for the different steps of conservation in the corridors. (6 % real interest rate, 2 % escalation of electricity price, 15 years lifetime)

THE CORRIDOR	The new system		
	1. New design	2. 1+HF-ball.	3. 2+sensors
Net present value			
- total system*)	16,800 SEK (2,200 ECU)	16,200 SEK (2,100 ECU	12,000 SEK (1,600 ECU)
- marginal system		2,000 SEK (260 ECU)	9,700 SEK (1,300 ECU)
Pay back time			
- total system*)	0 years	544 years	3,9 years
- marginal system		9,2 years	2,3 years

*) energy savings from step 1 and the compensation for heat losses are included.

In office rooms, with the assumptions presented above, HF-ballasts and occupancy sensors are not cost-effective in the marginal cost perspective from a strict energy economic point of view. The pay back times are 48 and 98 years with a negative net present value. The number of hours for operation has to be about 2,200-2,500 or the installation cost reduced by 50 % to make the HF-ballasts cost-effective with today's prices. Though it must be considered that the work environment is improved a lot. If this leads to a higher productivity among the personnel the economics will look much better.In the corridor both HF-ballasts and occupancy sensors are cost-effective. The pay back times are 9.2 years for the HF-ballasts and 2.3 years for the occupancy sensors.

CONCLUSION

The savings for a new standard lighting system itself, efficient luminaires and better design, are 56 % compared with the standard from the sixties. The use of HF-ballasts lead to savings about 22 % from the new design level and occupancy sensors to another 20 % marginal savings. In total 73 % electric energy is saved and 66 % electric load. In the corridor the savings are 27 % for the more efficient design and the marginal savings for HF-ballasts and occupancy sensors are 26 % and 50 % respectively. In total 74 % electric energy and 48 % electric load are saved in the corridor.At current prices, HF-ballasts and occupancy sensors are not cost effective from a limited energy saving perspective in office rooms like the ones in Råcksta, because of the short number of hours the lighting system is used. Though the HF-lighting have so many good qualities for the work environment so it is recommended and decided to be the standard in the ongoing renovation of the office. In the corridors both HF-ballasts and occupancy sensors are cost effective.HF-lighting is very appreciated in the office primarily because it doesn't flicker. Occupancy sensors switching off lights are accepted among the majority of the personnel but the the lighting must also be possible to control manually.

REFERENCES

[1] Carlsson, Lars 1989, "Utvärdering av belysning i kontorsrum" (Evaluation of lighting in office rooms) Report 2000 89 1410, Uppdrag 2000.

[2] Hedström, Nilsson and Hedenström, 1991, "Råckstaprojektet, El- och värmeeffektivisering för Vattenfalls kontor, Stockholm" (The Råcksta project, Electricity and Heat Conservation in Vattenfall's Office, Stockholm) Draft report, Uppdrag 2000 Vattenfall.

[3] Lundquist Peter, unpublished monitoring data from the Rättscentrum office in Sollentuna. Uppdrag 2000, Vattenfall Mellansverige.