

On site assessment of energy conservation systems in high school lighting

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ABSTRACT

Lighting systems were assessed in detail in eight high schools of the PACA region (south France). Funded by ADEME, ARENE, EDF and Region, the monitoring campaign covered the academic year 2000-2001.

Dedicated data loggers were designed to monitor lights energy consumption along with room occupancy and light levels. The small sized and autonomous devices worked successfully in the occupied buildings during extended periods.

More than 100 sensors allowed for precise evaluation of lighting time of use in different types of rooms as a function of the control strategy (switch, timer, IR sensor or using programmable automates).

The measurements show larger time of use in corridors and washrooms. It reaches around 1500 hours when controlled by a switch. Timers and occupancy sensors can cut energy cost by 2 or 3 provided that they are properly set and not forced on by cleaning staff.

Incandescent bulbs are still widely used. They are the best candidates for immediate replacement by CFL with shorter pay back times than control systems.

Classrooms have lower usage, typically below 1000 hours per year. The users seldom forget the lights on while leaving their room. Potential energy savings arise from improving the lighting systems. Electronic ballast, high efficiency tubes or reflectors make power drop but require

large investments. They can presently only be justified in new buildings.

Dimming ballast with constant lumen controls were tested. Large savings require sensitive cells. Initial light levels and position toward windows have a large impact on system efficacy. Circuit separation for lights near windows or improved building design can also take profit of natural lighting at lower expense.

DESCRIPTION OF THE SENSORS

Four types of small data loggers were designed to continuously measure the time of use of lighting, the occupancy of the rooms, the light levels on the tables and the energy consumption of non-constant power system. They are battery powered and a large memory allow them to record more than a year of data with 10 minute intervals. The memory can be downloaded to a personal computer to create the database and analyze the results.

LIGHTING CONSUMPTION OF CONSTANT POWER SYSTEM

The so called "Lamp-meter" version monitors lighting time of use. The small-sized device is installed near the light point to follow. It contains an optical sensor that must be directed toward the light source in order to detect the lighting periods.

It is necessary to measure once the light power in order to calculate the corresponding energy consumption (time of use multiplied by the active power of the lamp). Due to the building mains voltage variations, the lamp power changes and results in a slight error in the energy calculation. This error is very limited in cities having a good pub-

lic network quality. If not, periodic voltage measurements may be used to correct power variations.

LIGHTING CONSUMPTION OF NON-CONSTANT POWER SYSTEM

For dimming ballast with automatic control, the active power varies with time. In this case, energy meters with pulse output were installed. The pulse number, which is proportional to energy consumption, was stored every ten minutes in a the "Pulse-Meter".

OCCUPANCY DETECTION IN A CLASSROOM

The "IR-Meter" version uses an infrared sensor to monitor the occupancy in the classrooms. Every ten minutes, the duration of occupancy during the last period is stored in the recorder.

MEASUREMENT OF THE NATURAL LIGHT LEVEL

Luminosity recorders, called "Lux-Meter", have been developed to measure continuously the light levels on the desks. The devices have not been placed directly on desks because of vandalism risks. They have been installed on ceiling and measures actually the light reflected by a 1.5 meter diameter zone. This light is proportional to the light level on the table. Each recorder is calibrated on site for this coefficient.

4 to 6 "Lux-Meters" were installed per room in order to average the data and monitor the light variation versus distance to the windows.

ANOMALIES FOUND IN THE LIGHTING CONTROL.

One of the most surprising lesson of this measurement campaign is the number of the anomalies found. The incorrect implementations or settings of automatic control systems can result in even longer lighting time of use than a basic switch command. This is particularly true in corridors and washrooms.

In nearly all buildings equipped with timers in the corridor, it was found that the timer were forced on by the cleaning teams for as much as 4 to 14 hours per day! It led to an increase in the electricity consumption of up to 50%. It seems necessary to allow different timer delays - relatively short during working hours but longer for cleaning periods. "Clever" timers have different delays depending on the push button command (short push for short delay and long push for longer delay). They could be preferred but have not been tested in the scope of this project.

As for timers, the lighting of corridors equipped with IR sensors were forced on by the cleaning staff during several hours a day. Indeed in the two followed corridors there were too few sensors so that the detection field did not cover the whole corridor.

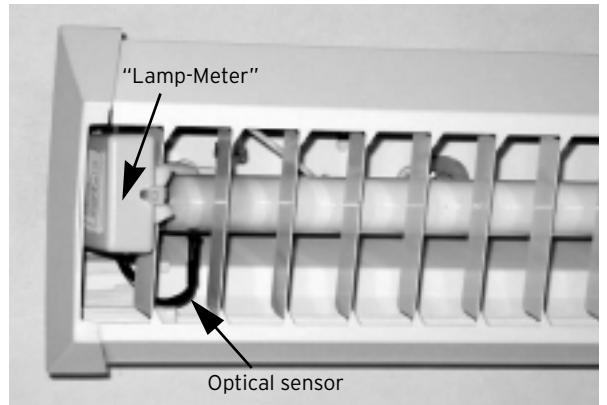
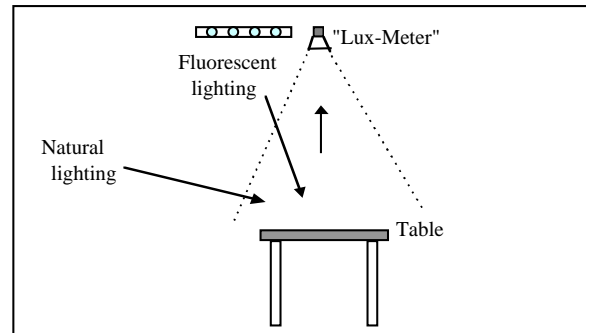


Figure 1. Principle of the light levels measurement



In both cases, the delays should be adjusted to the type of occupancy. A too short delay can be uncomfortable and leads to frequent switching that could decrease the life time of fluorescent tubes or lights.

In washrooms, imperfect position of the IR sensor associated with too long delay caused large lighting consumption. When the sensor can always "see" the occupant, the delay of the sensor can be set very short. In this case only, the savings are maximized.

Some classrooms reach lighting time of use of as high as 1488 hours per academic year, which is around 10 hours per working day. But generally, the users were found rather concerned with energy. The reason why some classrooms remain lit for very long period of time is that their command switch is hard to access, is not properly labeled or controls several rooms at the same time.

AVERAGE TIME OF USE OF LIGHTING SYSTEMS

It must be remembered that the building locations are all in the PACA region which is the sunniest part of France. They are based on one academic year of measurement in 8 high schools only. These figures should be extrapolated to other regions with care. But to our knowledge, it is one of the first time that such type of on site measurements on extended periods of time have been carried out.

Corridors	Switch	Timer	IR Sensor	Timer	IR Sensor
		With anomalies		Corrected	
Time of use (hours/academic year)	1560	1900	1665	750	600
Number of installed data-loggers	8	18	2		

Washrooms	Global control				Control by cabin		
	Switch	Timer	IR Sensor (wall)	IR Sensor (ceiling)	Switch	Timer	IR Sensor (wall)
Time of use (hours/academic year)	1577	403	862	1032	1310	620	359
Number of installed data-loggers	1	1	2	1	2	1	1

Corridors have the highest lighting time of use of high school. As explained earlier, the longest operating duration corresponds to lighting circuits equipped with automatic controls but improperly set or misused. When corrected for forced-on periods, they prove efficient energy saving systems.

The lighting times can be 45 to 75% shorter using a timer or a IR sensor than with a simple switch.

The time of use of artificial lighting in classroom can be very different (ranging from 1 to 5). It depends on several factors such as natural lighting and occupancy. Some specialized classrooms are very seldom used which increases pay back times of energy saving measures.

ENERGY SAVING SOLUTIONS FOR LIGHTING IN HIGH SCHOOLS

The average time of use of lighting in different configuration makes it very simple to estimate the energy saving of different system improvements and to evaluate their pay back time. The three following pages describe all the solutions tested during the measuring campaign. In each case, savings and pay back time are given compared to a reference lighting situation.

Classrooms	Average	Minimum	Maximum
Time of use (hours/academic year)	750	291	1488
Number of installed data-loggers	29		

For corridors, the reference is a lighting circuit controlled by a switch which works 1700 hours per academic year.

For washrooms, the initial lighting circuit is controlled by a switch and operates 1500 hours per academic year.

Finally, for classrooms, lighting are supposed to work 840 hours per academic year, 80% in peak period.

The prices of electricity are the ones of the French "Tarif Vert" which is the most common for high schools. It has 3 different rates in the winter and 2 in the summer. The average cost of one kWh for lighting was found to be near 0.065 Euro in high schools.

The profitability of all energy saving measures is very dependent on the installed price of the solution. This price can vary significantly with the existing installation but also with the experience of the electrician company and the action volume.

CORRIDORS

Solution	Fit to	Savings (%)	Estimated Pay back time (1)	Advantage(s)	Drawback(s)
Compact fluorescent bulbs	Corridors equipped with incandescent bulbs	68 to 80%	<1 year to 2,5 years	- Reduced maintenance	- Possible reduction of lamp life time in case of frequent switching - Checking of extinction necessary at the end of the day
Electronic ballast for T8 tubes	Corridors equipped with fluorescent tubes	24 to 27%	5 to 14 years	- Reduced maintenance - Improved quality of lighting - Rapid start	- Pay back time very dependent on existing installation.
Electronic ballast for T5 tubes	Corridors equipped with fluorescent tubes	33 to 47%	4 to 18 years	- Reduced maintenance - Improved quality of lighting - Instant start	- Pay back time very dependent on existing installation.
IR Sensor	Recessed corridors	50%	5 to 10,5 years	- Optimization of the time of lighting - Convenient for users - No checking of extinction necessary at the end of the day	- Accurate sensor setting required - To avoid with fluorescent lighting - Risk of vandalism
Timer + automate	All types of corridors.	35 to 47%	<1 year to 8,5 years	- No checking of extinction necessary at the end of the day - In case of centralized control automaton allow the lighting management of several corridors	- Check compatibility with fire safety codes
«Clever» timer (timer delay dependent on command type)	All types of corridors.	42%	1 to 5 years	- Time of lighting adjusted to the use - No checking of extinction necessary at the end of the day - Same efficiency as timer + automate	- Risk of wrong use - Not widespread system

WASHROOMS**Global lighting**

Solution	Fit to	Savings (%)	Estimated Pay back time	Advantage(s)	Drawback(s)
Compact fluorescent lights	Washrooms equipped with incandescent bulbs	80%	1 year	- Reduced maintenance if lighting controlled by a switch	- Checking of extinction necessary at the end of the day if lighting controlled by a switch
IR Sensor	All types of washrooms	30%	17 years	- Optimization of the time of lighting - Convenient for users - No checking of extinction necessary at the end of the day	- Proper sensor setting required - Necessity of a long delay - Risk of vandalism
Timer	All types of washrooms	-	-		- Unsuitable type of control: inconvenient for users - or one command per cabin required

Lighting by cabin

Solution	Fit to	Savings (%)	Estimated Payback time	Advantage(s)	Drawback(s)
IR Wall Sensor (2 wire type to replace a switch)	All types of washrooms	70%	8 years	- Optimization of the time of lighting - Easy to install and comfortable - No checking of extinction necessary at the end of the day	- Costly installation if the former switch position is not suitable for the sensor.

CLASSROOMS

Solution	Fit to	Savings (%)	Estimated Pay back time	Advantage(s)	Drawback(s)
Compact fluorescent bulbs	Classrooms equipped with incandescent bulbs	68 to 80%	1,25 to 4,5 years	- Reduced maintenance - Low bulb temperature	- Choose a model that fit in the luminaire
Electronic ballast for T8 tubes	Classrooms equipped with fluorescent tubes	24 to 27%	8 to 20 years	- Reduced maintenance - Good quality of lighting - Rapid start	- Very long pay back time except when classroom is extensively used
Electronic ballast for T5 tubes	Classrooms equipped with fluorescent tubes	33 to 47%	7 to 25 ans	- Reduced maintenance - Good quality of lighting - Very good color rendering - Instant start	- Very long pay back time except when classroom is extensively used
Dimming electronic ballast	Classrooms equipped with fluorescent tubes and having good natural lighting	7 à 33% (1)	19 to 40 years	- Reduced maintenance - Good quality of lighting - Instant start - Maximum savings	- Very long pay back time except when classroom is extensively used or over lit (2)

(1) : Average savings on the whole academic year, initial artificial lighting level of 300 lux

(2) : Most of the classrooms followed had light level above 300 lux and in some case more than 600 lux!

For a classroom with an initial light level of 600 lux, the use of dimming ballast to set it to 300 - 400 lux and take advantage of natural light makes it more. The savings can reach 60% leading to a pay back time of about 8 years.

NATURAL LIGHTING AND DIMMING SYSTEMS

An extensive monitoring was done in a classroom equipped with dimming electronic ballast. Light level meters ("Lux-meters") were installed in 4 different spots and room occupation was measured along with the energy consumption of each artificial lighting zone. It was thus possible to separately estimate natural lighting by subtracting the artificial lighting (proportional to the energy consumption of the ballast) from the total light level measured on the table.

Each zone consists in 3 blocs of one dimming electronic ballast supplying two T8 fluorescent tubes. One zone is located near the south facing windows and the other one is near the opposite blind wall. Dimming of the electronic ballast is controlled thanks to ceiling sensors. The regulation tends to create a total constant light level on the table so reduces the artificial lighting when the sunlight allows it. Each sensor controls the 3 electronic ballast of the corresponding zone.

The study first revealed the need for a very careful setting of the sensors of the dimming control. The sensor were initially set in their middle position and the light level measured on the table (classroom unoccupied) was found around 300 - 400 lux. But during a first recording period, the dimming was hardly noticed, even in the window zone. In fact, when people are in the classroom, the light reflected in the area seen by the sensor is decreased, so as the sensor output. As a result, the controller forced the electronic ballast to full power in order to increase the light level.

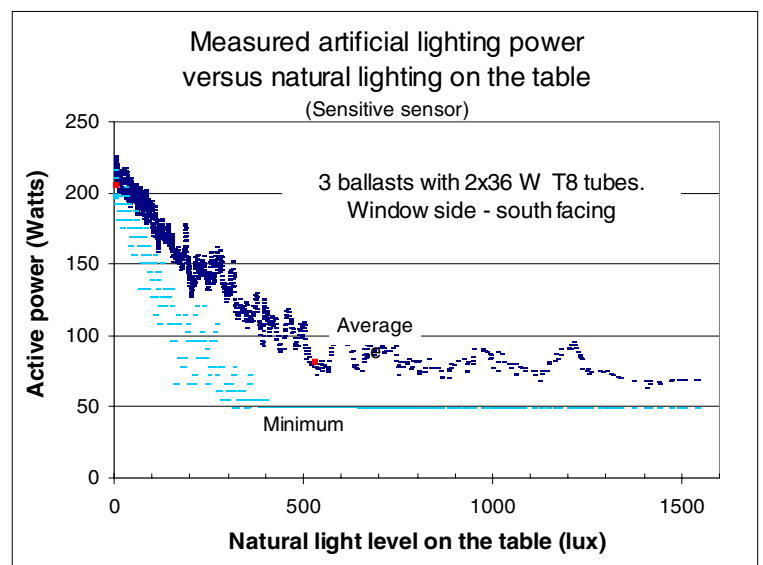
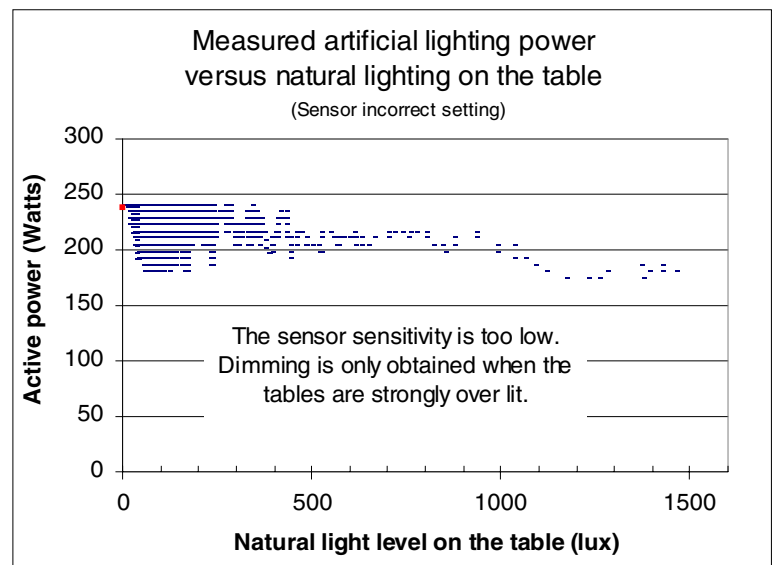
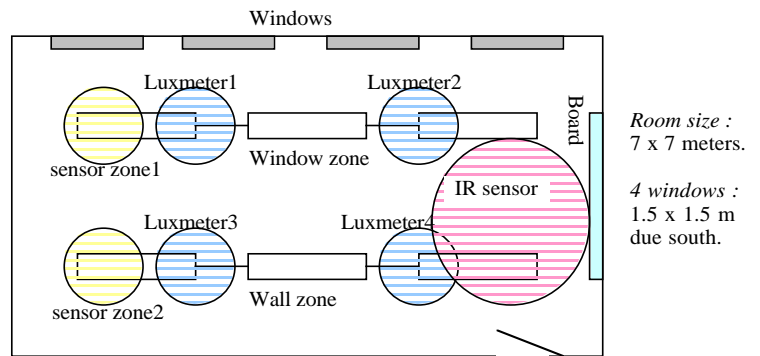
A new setting of the sensor was done in a much more sensitive way. In this case, dimming was obtained even for low natural levels and resulted in near to constant light levels on the table when the classroom was occupied.

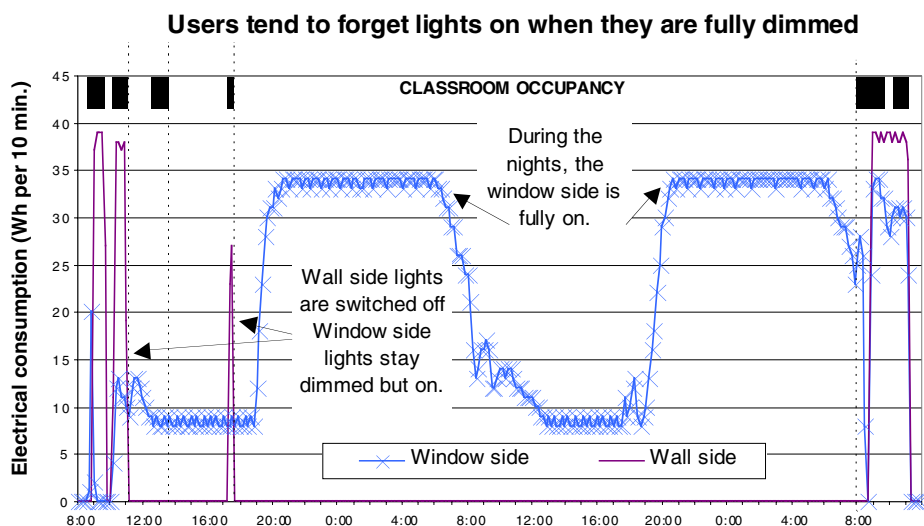
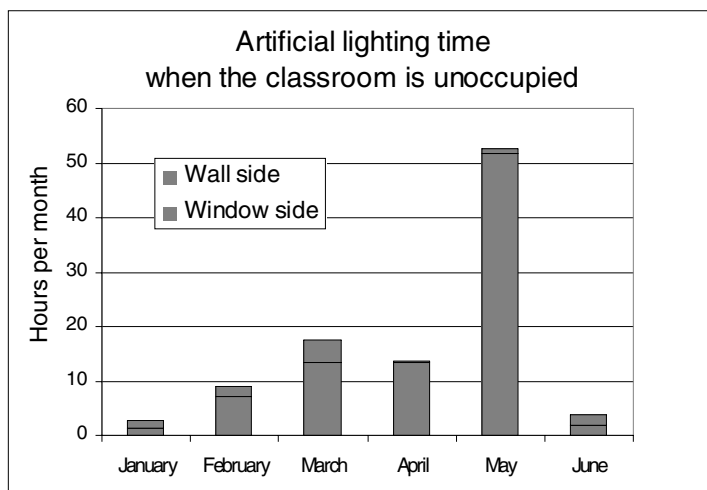
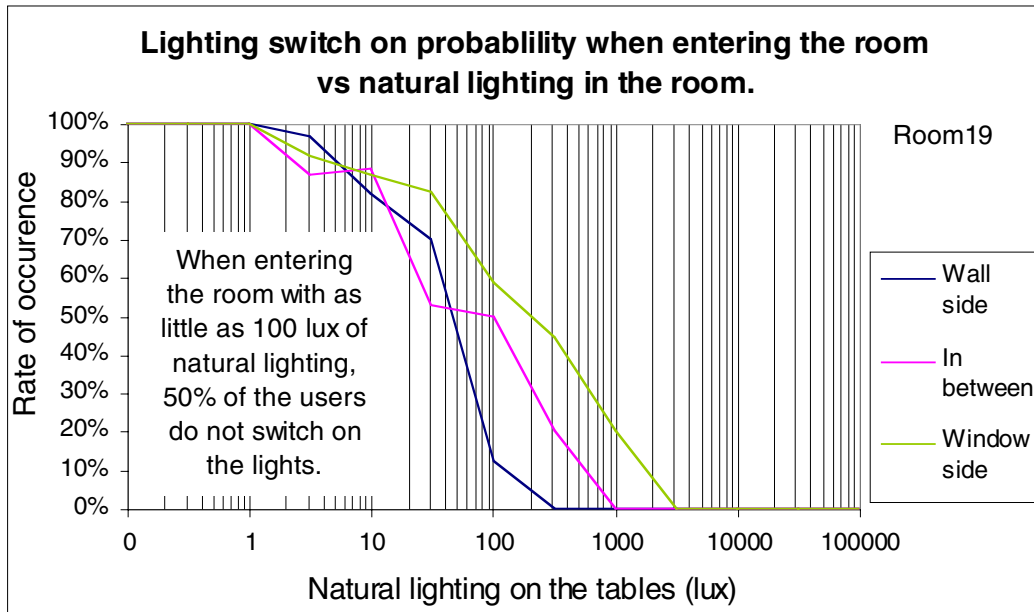
Light levels measurements on the tables was also used to determine the probability of artificial lighting to be switched on when people enter a room. Surprisingly enough, the required natural light levels are fairly low for the users not to switch the lights on. This may indicate that with natural lighting, lower levels are required to obtain a comparable comfort than with artificial lighting.

Another anomaly was found during the analysis of the measurements. The tendency to forget the lights on while leaving the room strongly increased with the dimming ballast and was found much higher for the window side than for the wall zone.

The reason is very clear: people tend to switch off properly the lights when leaving the room. But when natural light level is high, the artificial lighting is fully dimmed and appears nearly off. The appliances located near the window are much more subject to reduced output and therefore more often left on. The person in charge of controlling the extinction of lights each day also may also fail to switch off the dimmed lighting. In this case, the artificial light slowly increases as the sun sets and stay fully on during the night.

Finally, the profitability of dimming ballast was calculated, based on the savings measured in the monitored classroom.





It should be noted that the performance of the system is

	Average saving Window side	Average saving Wall side	Energy saving Window side (kWh)	Energy saving Wall side (kWh)
October	40%	7%	10,7	1,7
November	35%	6%	10,0	1,9
December	20%	7%	5,6	2,0
January	20%	7%	5,3	2,0
February	35%	6%	5,7	1,0
March	40%	7%	10,3	1,5
April	33%	6%	4,2	0,6
May	45%	8%	13,2	1,4
June	27%	13%	0,9	0,4
		Total :	65,8	12,7
Average saving :			33,3%	6,9%

(data corrected for proper setting of the sensor from the beginning of the study)

Dimming ballast estimated savings :

Total table light level setting : 300 lux

Initial lighting level: (lux)	250	300	350	400	450	500	600	800
Zone around a south facing window	20%	33%	43%	50%	55%	60%	67%	75%
Opposite side of the south facing window	-12%	7%	20%	30%	38%	44%	54%	65%
Zone around a north facing window	10%	25%	36%	44%	50%	55%	63%	72%
Opposite side of the north facing window	-8%	10%	23%	33%	40%	46%	55%	66%

affected by the use of shutters to prevent annoying light reflections on the blackboard. The shutters are sometimes left closed which in turn forces the artificial lighting fully on.

Based on our field measurement, we found that the performance of the dimming ballast is strongly related to the difference between the initial and the final setting of the lighting level on the tables. If the classroom has higher than necessary initial lighting levels, then the dimming ballast can always provide savings, even without use of natural lighting.

The performances claimed by the manufacturers of constant lumen systems using electronic ballast are often over evaluated as compared to the results in practice.

Savings of 50% or more can only be achieved near windows and when the room has large initial lighting levels.

Due to the rather high investment required for dimming ballast, its large scale implementation in high school renovation is economically difficult to justify although substantial savings can be expected from this technology.

The pay back times are much lower in offices where time of use are much greater, especially during the summer when natural light is maximal.

In high schools, simpler solutions should be applied to take advantage of natural light. Clever separation of lighting circuits near the windows and clear labeling should make it possible for the user to switch on only the necessary lights. This was already observed but not on a regular basis. Other low cost techniques such as small voltage reduction of lighting circuits near the windows when the sunlight reaches a certain level could be used. As one device controls many circuits, the return on investment is higher.

Light level data show deep variations when moving from the window to the opposite wall. A small increase in natural lighting near the wall resulting in 50 to 100 lux on the tables in this area could make most users leave lights off when entering the room. The design of buildings with more constant natural lighting distribution within the classrooms should be encouraged.

CONCLUSION

Several energy efficient lighting systems were assessed in great detail in 8 high schools from the PACA region.

Automatic controls can dramatically reduce the energy consumption provided they are carefully designed, trimmed and maintained. Several anomalies were observed in the control systems settings and in their usage

particularly regarding to the cleaning staff. Lighting time of use can then be much higher than expected. Furthermore some solutions proved inadequate to their use. When choosing a solution the users must be taken into account in order to obtain the maximum energy savings and provide an equal or even better service.

The larger lighting time of use in corridors and wash-rooms allow for short pay back times for CFL conversion or for the installation of well adjusted automatic controls. On the contrary in classrooms, present solutions for energy savings are often less profitable due to the more limited lighting usage. Efforts should be concentrated on new buildings where electronic ballast should be implemented systematically.

Natural lighting is strongly underused. Dimming ballast with light sensor can reduce energy consumption but are difficult to implement and expensive. Simpler solution like electrical separation of light circuits near the windows should be adequately separated and the users made aware of the possibility to use only part of the lights. Improved building designs could homogenize natural distribution of light in classrooms and make it possible to switch completely off artificial lighting most of the day.

One more time, a detailed monitoring campaign revealed unexpected behavior of control systems or users. Without measurements, those anomalies would have been very difficult to find. Finally, the study gives a more precise estimate of lighting time in high school which allow precise economic evaluation of energy saving actions. Similar analysis should be carried out in other regions in order to assess the differences related to climate and latitude.