

**AUTOMATION SYSTEM FOR LIGHTING CONTROL: COMPARISON  
BETWEEN DATA RECORDED AND SIMULATION MODEL**

A. Frattari  
Architecture and Civil Engineering, University of Trento  
Trento, Italy

M. Chiogn  
Department of Environmental and Civil Engineering, University of Trento  
Trento, Italy

J. de Boer  
Fraunhofer Institut für Bauphysik  
Stuttgard, Germany

**ABSTRACT**

Control and improvement of the energy demand in buildings is more and more importance because of many factors such as new. The best use of electricity for the lighting systems will also be an important goal in the European energy saving laws (PrEN 15193). For this reason the right use of natural light and the installation of automatic control system to regulate the artificial light is considered a significant tool.

The investigation aims to define a new methodology for the design of lighting systems to achieve both the standard comfort conditions and the low electricity demand. This paper deals in particular with the results of specific case study: three class rooms in the Faculty of Engineering in Trento where different automation systems for the light control have been installed.

The results refer in particular about the energy saving calculated with the software Adeline and the data monitored for the different implemented scenarios during the first winter semester of monitoring.

Key words: Lighting, intelligent building, visual comfort, energy saving, daylighting simulation tool.

### Introduction

This paper deals with a research activity carried out at the CUnEdI (*University Center for Intelligent Building*) - Department of Civil and Environmental Engineering of the University of Trento (Italy), with the aim to quantify how much energy it is possible to save using an on/off automation system or a dimming lighting system in lecture rooms.

For this purpose six class rooms at the second floor of the Faculty of Engineering of Trento have been monitored for one year. The cross layout is characterized by two parallel wings, both with the same south exposure. The lecture halls are symmetrical and have the same shape. This configuration allows the simultaneous comparison between the existing situation in the east wing (with the traditional electric system) and the new one with automation system designed and realized in the west wing ((see Frattari A., Albatici R., Chiogna M. "*Intervention strategies on lighting system in existing building towards energy efficiency and saving*", Sustainable Building 2007). In this paper will be compared the energy consumption carried out from the recorded data analysis with that ones obtained using a specific day lighting simulation tool. The data refer about the winter semester of the year monitored.

There are numerous simulation tools currently available for lighting analysis (Lumen Micro from Lighting Technologies Inc. [www.lighting-technologies.com](http://www.lighting-technologies.com); Super light and Radiance from the Environmental Energy Technology Division, Building Technologies Program at Lawrence Berkeley National Laboratory e t d . [lbl . gov/andradsite.lbl.gov/radiance/ HOME.html](http://lbl.gov/andradsite.lbl.gov/radiance/HOME.html); Light scape Visualization System from Light scape Technologies, Inc. [www.lightscape.com](http://www.lightscape.com) DOE-2, DELIGHT, LITESTAR, LIGHTESCAPE, etc.). They aim to generate appropriate architectural and/or technical solutions to achieve an enjoyable and productive built environment while simultaneously reducing the energy consumption of buildings through the substitution of daylight for electric light. Simulation based design aid tools that address lighting issues require a lighting analysis tool capable of determining interior lighting levels and some measure of lighting comfort.

Among these software tools, in the research activity presented in this paper has been used ADELIN (*Advanced Day lighting & Electric Lighting Integrated New Environment*) to create the model of the class rooms analyzed.

### Methods

The goals of the data comparison presented in this paper focus on the following issues:

- 1- calculate the difference between the inside luminance conditions for the simulation model and for the real class rooms;
- 2- calculate the outside conditions for the model (in particular the sunshine probability) and to verify the variance of statistical sky conditions;
- 3- understand how much the recorded users behavior differs in lecture halls, compared with that one used in Adeline simulation tool
- 4- analyze how the automated systems work in a real situation and how much energy saving has been expected looking for the Super-link output.

### Inside luminance

The inside luminance, calculated with Adeline (Super light) for different time and sky condition, has been compared both with the real condition measured in the classroom by a lux meter placed in reference points on the working places and the inside luminance calculated for a typical day of the month considered using the data measured by the light sensors installed into the classrooms monitored.

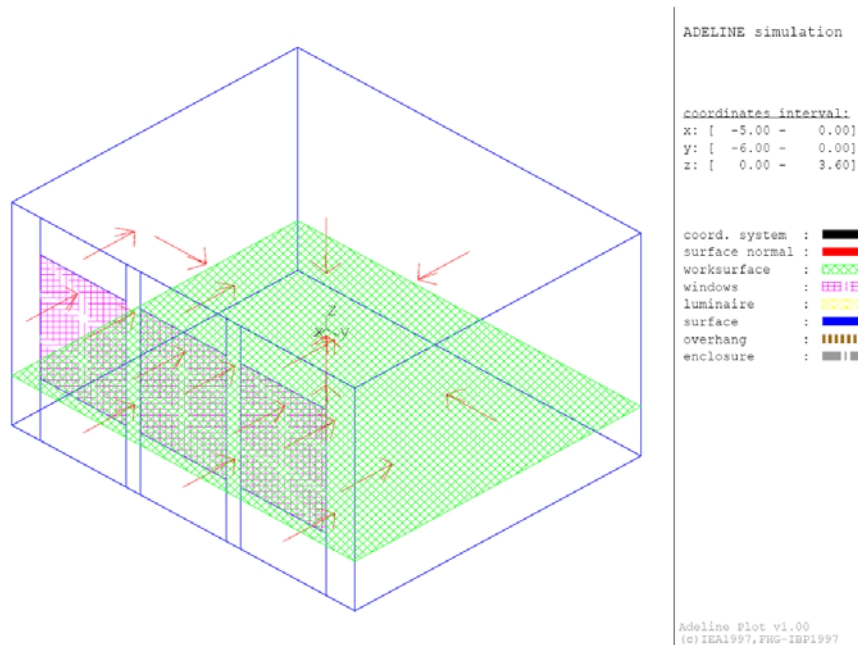
To create the model, Adeline uses the tool Super light, which typically involves two steps: the former creates an input file, the latter defines selected sky and location conditions [1].

The first step consists of creating an input file that contains a geometric description of the subject building space, as well as the solar and light data to be used for the simulation.

The input file can be created in different formats. Because of the simple geometry of the monitored classrooms, in this case a *simple input model* has been created (Fig.1).

To define the input file it is necessary to set the following parameters and data:

- geometric base case
- parameters for the base case selected
- materials for walls, ceiling(s) and floor(s)
- openings technical characteristics and position
- outside obstructions for the windows defined
- lights



**Figure 1** Input model (generated as simple input) of the classroom monitored.

Once an input file has been created, we can run the program. It is possible to type the sky definition, selecting among standard CIE sky condition (overcast sky, clear sky with sun, uniform sky, clear sky without sun).

The solar and weather data input for the program can be supplied as *geographical and atmospheric data*, that means that it is necessary to specify the latitude and longitude of the building location, time and date of the simulation under given sky conditions. In this way the simulation program provides for a series of simulations for given times of day and year.

The output can be displayed as contour plots of luminance (Fig. 2).

### Sunshine Probability

The design and performance of a daylight system depends strictly on the duration and frequency of sunshine over the year at the location of the building. Adeline tool uses a combination of detailed day lighting calculation programs for interior spaces and dynamic energetic computing routines based on hourly weather data, in which the sunshine probability (SSP) within a given time step is the central parameter. To obtain the SSP input file it is possible to implement an Adeline calculation based on the data contained in the test reference year file (TRY) for the specific location [2].

Different data source have been consulted to get this data format for Trento but none contained the data collection required. Among the cities monitored in North of Italy, only for Milan and Venice IWEC data file are available [3] but these two cities have a different orography compared with Trento and so different radiation conditions. The wheatear data contained in the IGDG data source include Bolzano, which is very close to Trento and with the some geographic conditions. However it has been not possible to use these data because they are structured as hourly data for only one typical day for each month [4], instead 365 days of hourly data have been required for the Adeline simulation. Furthermore it is not possible for Trento to get a complete TRY data format, because only some of the parameter required are recorded for a significant number of years, in particular only the global radiation is available for the last 20 years, whereas diffuse and direct radiation have been recorded only from the last 5 years. Nevertheless the hourly sunshine seconds have been monitored from the 1983 by the S. Michele whether station [4], close to the Faculty of Engineering in Trento. With this dataset, according to the method to compute a test reference year exposed in *IGDG Italian Climatic data Collection* [5], it was possible calculated the hourly SSP for this location, considering the data recorded in the last 20 years. The result is a vector that contains the amount of the hourly sunshine seconds measured for each day, selecting from the total amount of the years sample the real days for which has been calculated the minimum variance. In this way has been calculated a virtual year that contains the hourly sunshine duration of real days, selected from different years of the sample.

To understand the possible deviation between the weather data calculated for a probabilistic year using measured data and that ones computed with a theoretic method, the two data series has been statistically compared. The method used to get the theoretical radiation is contained in [6].

#### Probability to Turn on the Light as Function of the Inside Illuminance

The probability to turn on manually the light considered by Adeline tool to calculate the energy saving for a manual use of the artificial light has been compared with that one calculated for a typical day in the monitored classrooms.

Adeline tool uses the *Manual On/Off Probability* defined by Hunt that predicts the probability for use of artificial lighting in a manually operated on/off-switching control system [4]. The method is based on patterns of switching behavior observed in field studies in England. Hunt found that the probability of someone switching on the artificial lights in a space is correlated with the minimum daylight luminance on the working plane. From the data set of the field study, an empirical algorithm was defined.

This algorithm has been compared with the probability to have the light on in the classrooms monitored as a function of the inside luminance measured. For this aim has been used a typical day calculation derived from the winter semester data of the yearly data analysis.

### Energy Saving Comparison

The energy saving calculated by Super-link for 2 light systems (*Lights with on/off and Continuous Dimming*) has been compared with the data monitored in the classrooms where automated light control systems have been installed.

In particular the energy saving of the following scenarios have been recorded, simulated and compared:

- Scenario 1: control of the light system through the *light switch on/off* Adeline simulation option ( $E_m > 300$  lx); this automated system has been implemented in the classroom 2P, where one occupancy sensor and light sensors have been installed for an on/off light control.
- Scenario 2: control of the light system through a *continuous dimming* Adeline simulation option ( $E_m > 300$  lx); this automated system has been implemented in the classroom 2N, where one occupancy sensor, light sensors and dimming actuators have been installed for a continuous dimming light control.

For these scenarios have been considered two different type of luminaries: the ceiling light already used for the traditional classrooms, 4x18 W (fluorescent tube T8) and a more efficient kind of ceiling light 4x14 W (with new fluorescent tubes T5), that have been installed in the classroom 2M.

In the simulation tool it is not possible to include the effect of the presence sensors, installed in each automated classrooms.

## Results

### Inside Illuminance Analysis

The Fig. 2 shows the output of the Super lite calculation for the classroom modeled. These results correspond to that ones measured directly with the luxmeter, when the curtain are completely open, as in the Adeline simulation. The measure has been repeated several times for different sky condition so that it is possible to attest that the model simulate the effective inside luminance conditions.

The Fig.3 shows the inside luminance level for a typical day calculation, derived from the data analysis of the October monitoring. This graph demonstrates that until 9.30

and later 16.00 o'clock there is a minimum level of inside luminance at the work place lower than 300 lx in the traditional classrooms. The real inside luminance level is lower than that one simulated with Adeline or measured directly check that shading status (curtains completely open).

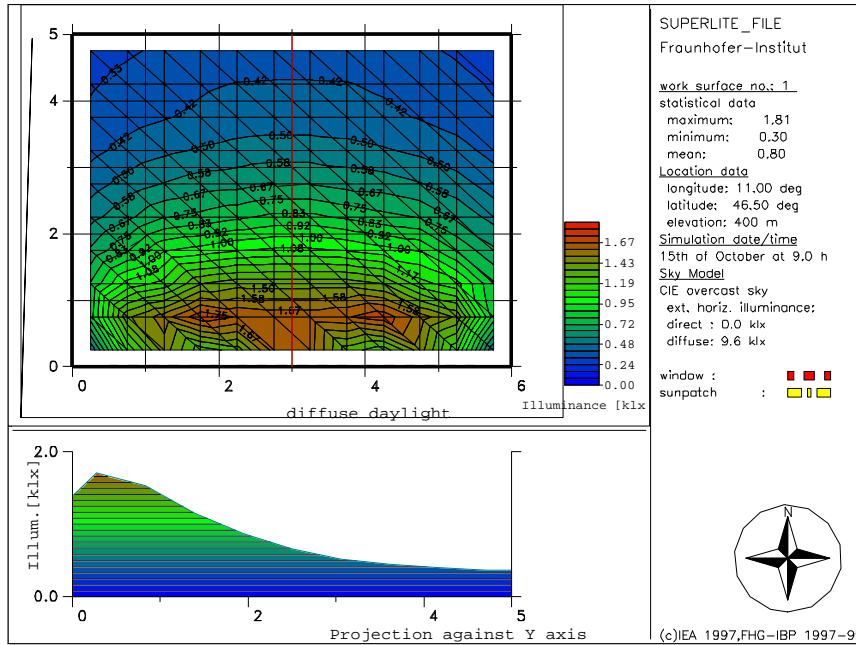


Figure 2 Isolux and section plot representation of Super light results for the classroom model.

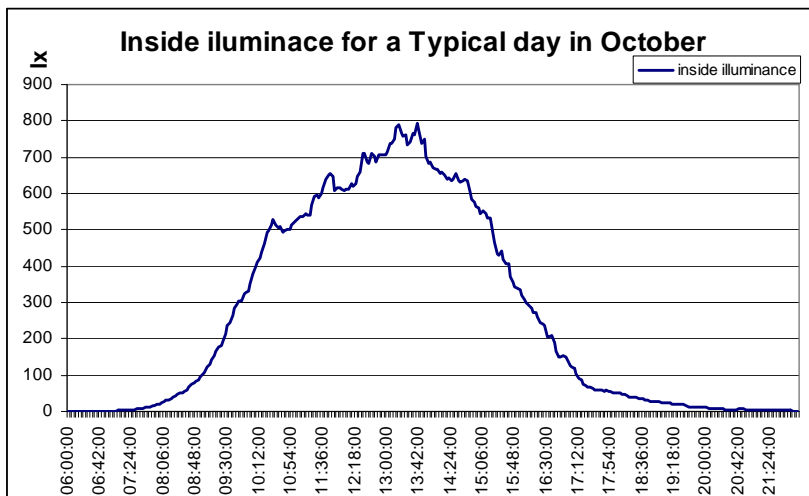
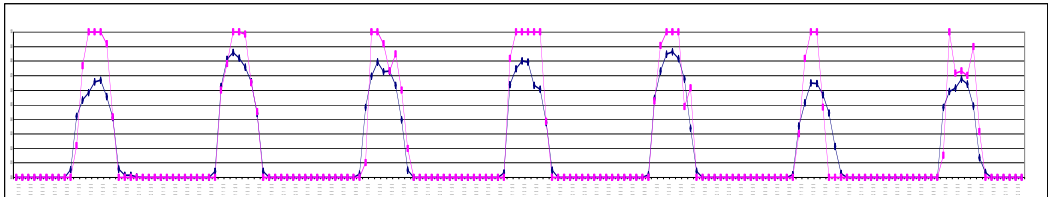


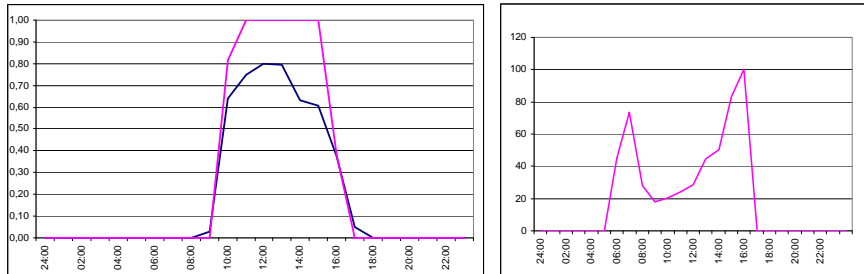
Figure 3 Inside luminance level for a typical day in October for a traditional classroom.

### Sunshine Probability Calculation

The graphs represented in Fig. 4 shows the results of the sunshine probability calculated for the monitored building location during October. In Fig. 5 in particular has been presented the difference between an averaged data analysis and the statistic hourly data derived from the reference year calculated for the specific day of the Adeline simulation (15<sup>th</sup> October). For the same day has been calculated the percentage difference between the global radiation calculated for the reference year and the data derived from the theoretical global radiation calculated in conformity with the SERI method [6].



**Figure 4** Sunshine probability calculation for the October reference year month.



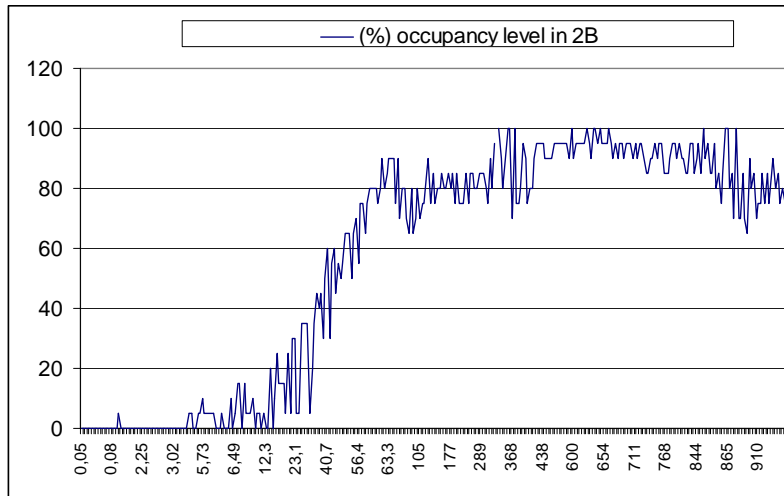
**Figure 5** Comparison between the daily insolation amount as average for the data set and the sunshine probability calculated for the reference year on the 15<sup>th</sup> October; global radiation percentage difference between the SERI theoretical model and the reference year calculation.

### Operating Time Probability Calculation

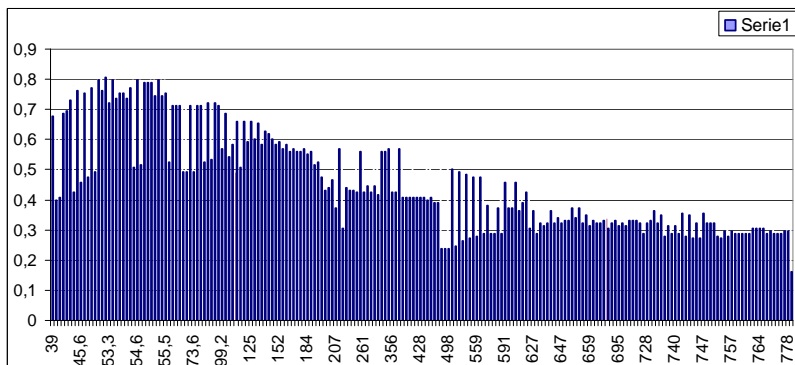
The Fig. 6 represents the occupancy level in the traditional classroom 2B as a function of the inside illumination level measured. The typical day derived from the winter semester data analysis shows that the occupancy level probability grows up significantly for an inside luminance level higher than 40 lx.

The Fig. 7 shows the probability to have the light system operating as function of inside luminance. In particular it is still possible (probability > 0,3) to have the light turn on with an inside luminance higher than 500 lx.





**Figure 6** Occupancy level calculation for the typical day.



**Figure 7** Operating time probability as function of the inside luminance.

### Energy Saving Level Simulated and Measured

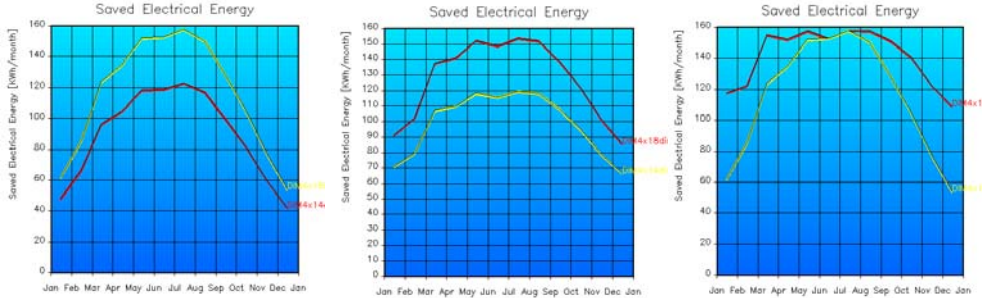
The 3 graphs of Fig.8 represent the Super link saved electrical energy calculation for  $E_m=300$  lx respectively for following light control systems:

- automated light witch on/off, for ceiling lights 4x14 W (dark grey) and 4x18 W (light grey);
- ideal dimming, for ceiling lights 4x14 W (light grey) and 4x18 W (dark grey);
- manual on/off automated (dark grey) and light switch on/off(light grey) both for ceiling lights 4x14 W

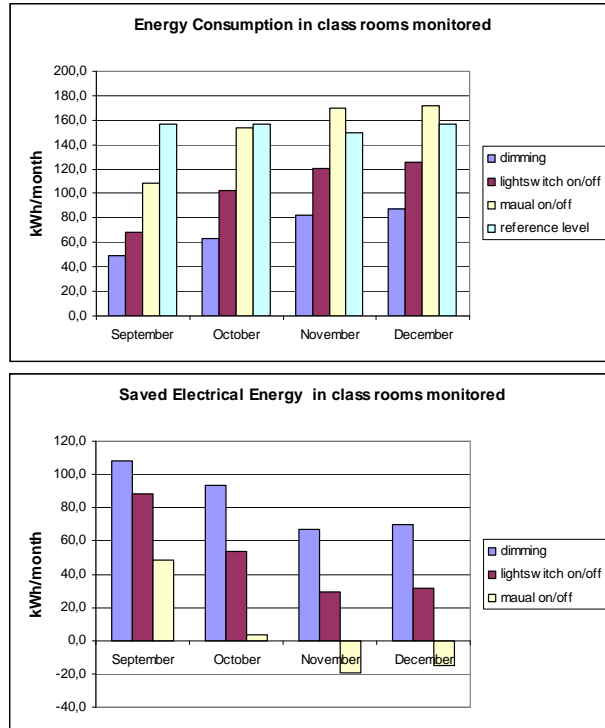
It is important to precise that the reference energy consumption level has been calculated by Super link considering the 100% light on condition during the working time.

The Fig. 9 shows the energy consumption and the electrical energy saved recorded in the classrooms monitored for the different scenarios.

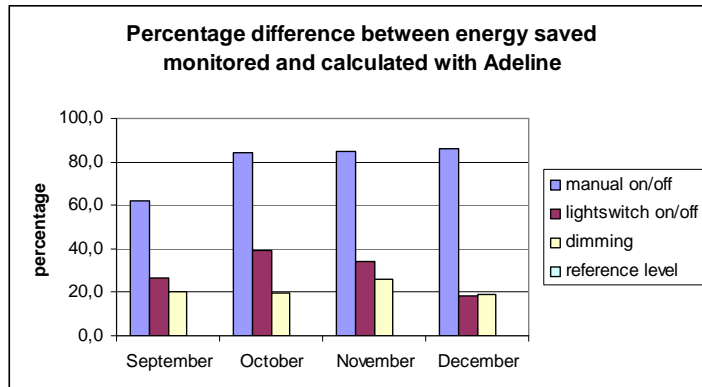
By mean of the comparison between the two graphs series reported respectively in Fig. 8 and 9, it is possible to calculate the percentage difference between light switch on/off, ideal dimming and manual on/off simulated or monitored, as reported in the Fig. 10.



**Figure 8** Saved electrical energy graphic outputs of Super link simulation for different scenarios (automated light switch on/off, ideal dimming, manual on/off)



**Figure 9** Energy consumption and saved electrical energy measured in the classrooms monitored.



**Figure 10** Percentage difference between the energy saving monitored and estimated.

### Conclusion

The difference between the saved electrical energy estimated by Super link and recorded can be amenable to the factors that follow.

The inside luminance simulated by Adeline is underestimated, because of the user's behavior positioning the curtains. It has been verified that during the lessons the windows can be partially covered (because they could have been forgotten close by the previous lesson, because the lesson could include partially projections, sometimes for any specific reason) so that it would be necessary to select a shading factor = 0,5 to simulate better the real situation.

There is an intrinsic deviation between the real weather conditions and the probabilistic condition estimated.

The manual on/off probability used by Adeline doesn't correspond to the real condition monitored. The difference could be explained by the different use of the room considered: the first one is an office, where a person works alone; the second one is a classroom where more persons should attend a lesson.

The future research step will include a critical comparison between the classrooms conditions and that one required by the prEN 15193, in particular with reference to a shading system design.

The residential energy demand for lighting has been estimated the 28% of the global lighting electricity generation. The energy saving calculated for housing is included between 40-60%, using smart devices and new luminaries types. For the services sector the lighting energy use is about the 48% of the global lighting electricity generation and the energy saving potential has been estimated between 25-40% [8].

### References

1. International Energy Agency, 2000, *Superlite User's Manual and Technical Manual*, Documentation of the Software Package ADELIN, Version 3
2. International Energy Agency, 2000, *Superlink/Radlink User's Manual and Technical Manual*, Documentation of the Software Package ADELIN, Version 3
3. ASHRAE, 2001. *International Weather for Energy calculations (IWECC Weather Files) Users Manual and CD-ROM*, Atlanta
4. Servizio Metereologico del Trentino, Istituto Agrario di S.Michele A.Adige, Rete Agrometeorologica IASMA, <http://217.222.71.209/meteo/datimeteo/ricercadati.php>
5. U.S. Department of Energy, Energy Efficiency and Renewable Energy, *Weather Data*, available in: [http://eere.energ.gov/buildings/energyplus/weatherdata\\_sources.html#IGDG](http://eere.energ.gov/buildings/energyplus/weatherdata_sources.html#IGDG)
6. Richard E. Bird, Roland L.Hulstro, 1981, *A Simplified Clear Sky Model for Direct and Diffuse Insulation on Horizontal Surfaces*, SERI
7. Chiogna M., Frattari A., 2006, *Visual comfort and low energy consumption: lighting strategies in university lecture halls*, Proceeding XXXIV IAHS World Housing Congress, Luciano Editore, Napoli.
8. Mills E., May 2002, *The \$230-billion Global Lighting Energy Bill*, Proceedings of the 5th International Conference on Energy-Efficient Lighting, Nice, France