Daylighting analysis and energy saving measures in the Sino-Italy Environment & Energy Building (SIEEB)

F. Butera and R.S. Adhikari
Dipartimento BEST - Building Environment Science & Technology, Politecnico di Milano, Italy

N. Aste
Dipartimento di Energetica, Politecnico di Milano, Italy

ABSTRACT

The Sino-Italy Environment & Energy Building (SIEEB) is regarded as a platform to develop the bilateral long-term cooperation between Italy and China in the environment and energy fields, and a model case for showing the CO_2 emission reduction potential in the building sector in China.

In the present study, by means of computer simulations, the interaction between natural and artificial light and the related illumination conditions expected in the SIEEB offices have been analysed. In this way, it was possible to evaluate the relevant loads for artificial illumination, that has been considered not as the principal but a complementary light source. The main goal of this study is to show the potential of drastically reducing the electrical energy consumptions for illumination, by adopting simple daylighting solutions.

1. INTRODUCTION

Artificial illumination is one of the major electricity consumption items in many office buildings. In a world newly concerned about GHGs emissions, global warming, and sustainable design, the planned use of natural light in commercial buildings has become an important strategy to improve energy efficiency by minimizing lighting, heating, and cooling loads. The introduction of innovative, advanced daylighting strategies and systems can considerably reduce a building’s electricity consumption and also significantly improve the quality of light in an indoor environment (IEA, 2000). Daylighting often reduces also air conditioning energy requirements because internal cooling loads due to the lamps are reduced and solar heat gains are controlled.

Recently, both China and Italy expressed strong interests in the cooperation in the field of environment and energy, and reached an agreement on the construction of a Sino-Italy Environment and Energy Building (SIEEB) in Beijing.

The Politecnico di Milano is involved as project leader in the design of SIEEB Building, which intended to house educational rooms, offices, laboratories and a large exhibition centre. The total building floor area is about 20,000 m^2 and the site of the project is located in the south-east area of the Campus of the University of Tsinghua in Beijing.

Energy savings and rational utilization of the conventional energy sources represent one of the most important issue in the design process of the SIEEB. For this purpose the utilization of the renewable energy sources, especially the sun, has been optimised. In fact, during the pre-

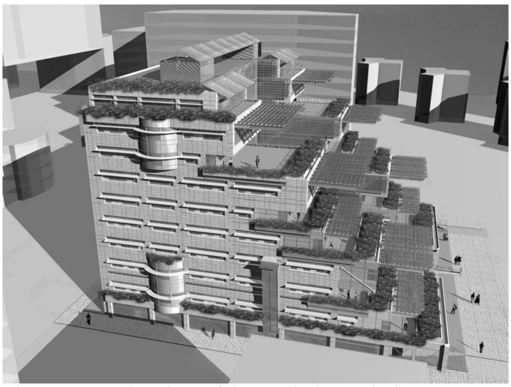

Figure 1: Render view of the preliminary design.

liminary design, the geometry and the shape of the building envelope were studied to enhance the contribution of solar energy and minimize the requirements of artificial illumination for indoor spaces (Butera et al., 2003, 2004).

In this study, by means of computer simulations, a detailed analysis is presented, for the interaction between natural and artificial light and the related illumination conditions expected in the SIEEB offices. The results on the estimation of electrical energy savings for illumination in SIEEB by adopting simple daylighting solutions, are also shown.

2. OBJECTIVES

The goal of a strong reduction in electrical consumption due to artificial lighting can be reached mainly by adoption of the following criteria:

- maximum integration with natural lighting;
- intelligent control of inside illumination, according to the specific needs;
- use of high efficient equipments (lamps, luminaires, dimmer, control systems).

This study was used as a reference in the preliminary design stage of the SIEEB for the definition of architectural, technological and HVAC solutions to guarantee the best energy performance in respect of the specific internal comfort requirements.

3. METHODOLOGY

The evaluations presented in this work are based on computer simulations carried out by means of two specific software for building and lighting simulation, *e.g. Ecotect* and *Lightscape*.

As a first step, a virtual model of the building and site compatible with both softwares was created, in which data related to Beijing climate, geometrical and reflectance characteristics of the building and the surroundings were used (Fig. 2).

Further a typical office room inside the SIEEB was selected, which could be representative in respect of the whole building.

This typical office was tested with reference to few alternative window solutions, which were compared on the basis of the daylight factor (DLF) indicator. The best solution found was

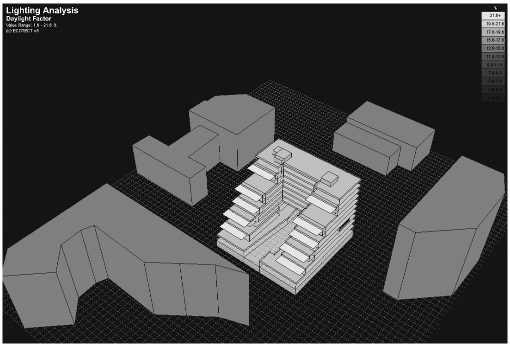

Figure 2: Model of the building and the surroundings.

further developed through the definition of the chromatic characteristics of walls and ceiling and the choice of the lamps to be installed.

At this point a set of simulations was carried out to analyse the interaction between natural and artificial light during the whole year, day by day, and to evaluate the corresponding electric energy consumption.

4. ANALYSIS

4.1 Selection of the case study

The analysed test room shown in Figure 3 is a typical office room, facing on the external east façade and situated on the third floor of the building (level +12.40).

The geometrical characteristics of the room are shown in Figure 4 and can be described as

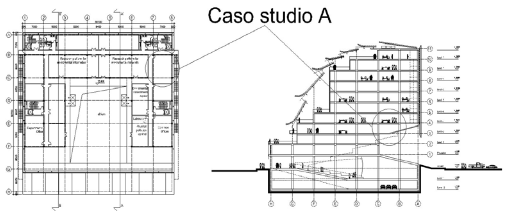

Figure 3: Location of the case study.

Figure 4: Geometrical characteristics of the room.

follows:

- width 7m;
- length 9.9 m;
- floor area 69.3 m^2;
- internal height 2.7 m;
- work plane level 0.8 m;
- minimum ratio of glazed surface to total surface 1/6 (as prescribed by the local building regulation).

It was defined that visual comfort should be guaranteed by illuminance level of 300 lux on the work plane with maximum possible homogeneous distribution.

With the aim to optimise the daylighting contribution, a rapid analysis was made on 5 different types of windows (common for office buildings) to identify the best suited for daylighting requirements.

The analyzed hypotheses are:

1. continuous ribbon fenestration;
2. ribbon fenestration splitted in 2 windows;
3. common fenestration splitted in 4 windows;
4. floor-to-ceiling fenestration, splitted in 4 windows;
5. curtain wall.

The first four solutions fulfils the exact requirement of minimum glazing ratio (1/6), while the last one, with completely glazed façade, corresponds to windows area double than the others.

The analysis on the daylight factor (DLF) was made for the five different cases by using software *Ecotect*. The minimum, maximum and average values of DLF for different cases are shown in Table 1.

Distribution of daylight factor corresponding to hypothesis 4 is shown in Figure 5.

The best solution selected on the basis of this analysis corresponds to hypothesis 1, which is able to provide satisfactorily natural light contribution while reducing glare and summer overheating risks.

Table 1: DLF values with different fenestration solutions.

Hypothesis	DLF (%)		
	average	minimum	maximum
1	4.27	1.6	21.6
2	4.25	1.6	21.6
3	4.17	1.6	21.6
4	3.41	1.5	21.5
5	7.14	3.63	23.63

Figure 5: Distribution of DLF (hypothesis 4).

In order to optimise the lighting characteristics of the room, the parameters able to increase the contribution of natural lighting and to guarantee the visual comfort were adopted, *i. e.* clear colours for walls and ceiling and glazing with a good value of transmission coefficient in the visible spectrum.

- white walls, reflection coefficient $\rho = 0.8$;
- white ceiling , reflection coefficient $\rho = 0.8$;
- grey work plane reflection coefficient $\rho = 0.3$;
- brown floor, reflection coefficient $\rho = 0.3$;
- windows with low-e glass, visual transmission coefficient $\tau = 0.77$, reflection coefficient $\rho = 0.13$.

The work plane was considered as a single continuous surface with a free strip around (0.5 m width), as a result the surface is 6 m wide and 8.9 m long.

4.2 Daylighting analysis

For daylighting analysis, two different climatic characteristics corresponding to clear and overcast sky and the simulation periods considered significant (average monthly days from sunrise to sunset) were defined. The criterion chosen to define the clear and overcast sky is based on the value of incident direct solar radiation at the horizontal plane. The clear sky conditions corresponds to the direct solar radiation > 200 W/m^2. Below this value, the sky is defined as overcast.

Finally, from the analysis of Beijing climate, the hourly distribution of the sky conditions (clear and overcast) for each month were identi-

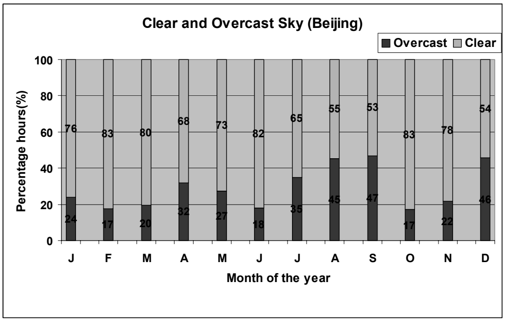

Figure 6: Monthly distribution of sky conditions.

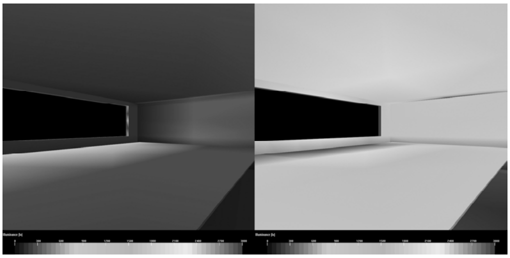

Figure 7: Daylighting simulation (15 June, 10 am , covered and clear sky).

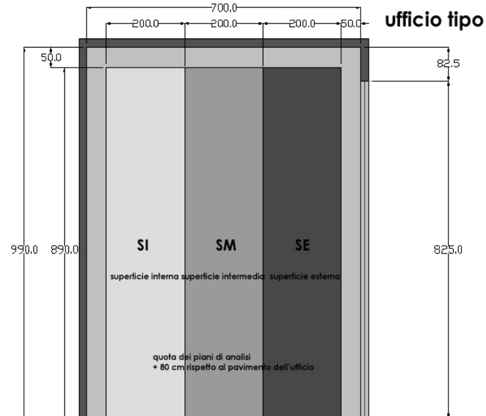

Figure 8: Subdivision of analysed areas.

fied, as illustrated in Figure 6.

Natural illumination on the work plane was simulated using the software *Lightscape* for each of the indicated days.

The simulations were performed for two cases corresponding to the weather condition of clear and overcast sky. A typical result of daylighting simulation for 15 June, 10 a.m. is shown in Figure 7.

To obtain a greater detail in the simulations, the work plane was subdivided into three parallel layers, 2 meters deep each. The three surfaces (Fig. 8) resulting were named SE (surface close to the external façade), SM (intermediate surface) and SI (inside surface) and the same were analysed separately.

The results of the simulations are summarized in Figure 9 and 10. The average monthly values of illuminance are shown for the periods between sunrise and sunset (daytime) and for the whole building occupation time (7 am-10 pm) corresponding to both the clear and overcast sky conditions.

As it can be seen from figure, the type of windows adopted, ensure good daylighting conditions: the average value of illuminance is rarely lower than 300 lux.

4.3 Artificial light calculations

For the estimation of the artificial illumination loads, it was assumed that the lamps were used to integrate the daytime availability of light, only in the periods and in the zones of the room in which it is required. If the contribution of the sun and of the sky guarantees the prescribed level of illuminance (300 lux), the lamps do not work; if such contribution is partial or nonexistent, the lamps supply strictly only the quantity of light necessary to reach the minimum pre-

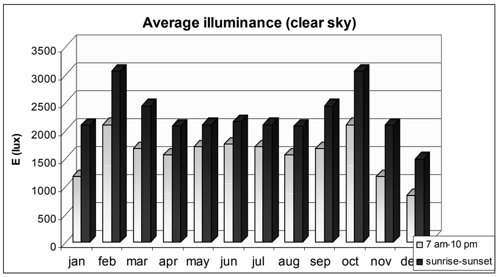

Figure 9: Monthly average illuminance (clear sky).

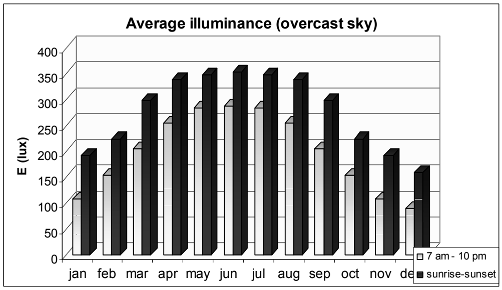

Figure 10: Monthly average illuminance (overcast sky).

scribed level.

It was assumed that high efficiency lamps are placed at the height of 2.4 m from the floor, with the following technical features:

- luminous flux 3,650 lm;
- absorption power 35 W;
- luminous efficacy 104.3 lm/W;
- maintenance factor, to allow for deterioration, 1.3.

The data obtained from the described simulation were used to determine the power absorbed from the lamps and the related energy consumption due to the variable conditions of daylighting. The values of artificial lighting were calculated applying the total flow method in the different zones (SE, SM, SI) in respect of the difference between the prescribed value and the one obtained from the natural light.

As well known, the total flow method is used in general only for all parallelepiped environments, nevertheless, it can be used with good approximation also for the portions of a same room (like the surfaces in analysis), considering that the phenomena of reflection from adjacent walls and of artificial lighting from near zones can compensate each other.

4.4. Energy consumption evaluation

Once determined the artificial illumination requirements, the values corresponding to the different weather conditions during different hours of the monthly average days were correlated with the values concerning the temporal distribution of the sky conditions, deduced from the climatic data. In this way it was possible to simulate with good accuracy the interaction between natural and artificial light during the typical reference year and therefore to estimate the corresponding energy consumption.

The artificial lighting energy consumption, related to the unit surface area of the room, is shown in Figure 11.

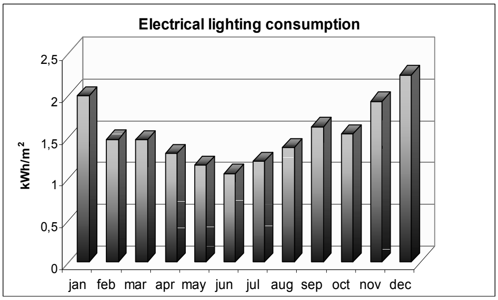

Figure 11: Monthly energy consumption for artificial lighting.

5. CONCLUSIONS

The estimated total energy consumption for artificial illumination in the SIEEB appears very low and approximately varies from 1 to 2 kWh/m^2 month, with a yearly average amount of about 18 kWh/m^2.

In terms of equivalent absorbed power, it means a value about 3.15 W/m^2, which is definitely significant, especially if compared with the common energy consumption in office buildings. In fact a power of about 10 to 15 W/m^2 is usually necessary to obtain an illuminance level like the one required in SIEEB.

It means that the lighting strategy proposed in the present study is able to reduce the electrical consumption due to illumination about 3 to 5 times in respect of usual cases.

REFERENCES

Butera, F., S. Ferrari, N. Aste, P. Caputo, P. Oliaro, U. Beneventano and R.S. Adhikari, 2003. Ecological Design Procedures for Sino-Italian Environment and Energy Building: Results of the Ist Phase on Shape Analysis, Conference PLEA 2004, Santiago, Chile.

Butera, F., R.S. Adhikari, N. Aste, U. Beneventano, P. Caputo, F. Ferrari and P. Oliaro, 2004. Advanced Technological Solutions for Building Load Reduction in the Sino-Italy Environment and Energy Building (SIEEB), Conference Eurosun 2004, Freiburg, Germany.

IEA, 2000. Daylight in Buildings: A source book on Daylighing Systems and Components. Report of IEA SHC Task 21/ ECBCS Annex 29, July 2000.