Chapter 61
Evaluation of Thermal and Visual Comfort: Bioclimatic Strategies for Office Buildings

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61.1 Introduction

The starting point of this research project, funded by the National Council of Science and Technology (CONACYT), was an analysis of the conditions of use and consumption of energy at administrative and educational sites, taking as an example the physical spaces of the Cultural Building and Administrative Building at the University of Guadalajara, by interdisciplinary researchers from different universities to propose adequate solutions for each case in the process of achieving comprehensive energy saving.

The analysis was based mainly on the energy used in air conditioning, artificial lighting, and the connected equipment in each unit. On the basis of the results obtained through the various stages of the research, it has been possible to perform an energy audit and, in the process, propose recommendations for environmental adaptation of the architectural spaces at the institution in search of energy saving and optimization of the institutional resources, as well as improvement of the working conditions of the users.

The methodology is described below in three steps:

A. General inspection of the present condition of the analyzed buildings and observation of the physical characteristics of spaces, the daylighting, and the electrical power conditions. The kind of electrical installation is also analyzed, making it feasible to determine the annual energy consumption, percentages of annual costs, and kinds of energy used.
B. Diagnosis to determine the loss or excessive use of electrical energy inside the buildings by means of the specific consumption by electrical installations, artificial lighting, connected equipment, and special equipment. Besides that,

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Building space	levels	Area (square meters)	
		by level	by building
A. Parking lot	1	10,200	10,200
B. Green areas and small square	1	16,575	16,575
C. Auditorium	3	variable (see F3)	1,512
D. Hall	2	variable (see F3)	1,083
E. Tower	8	variable (see F3)	2,680
F. Calssrooms, South wing	3	variable (see F3)	4,103
G. Calssrooms, North wing	4	variable (see F3)	7,708
H. Workshops	3	variable (see F3)	3,138
I. Research modules	2	variable (see F3)	250
		Total (m ^{2})	47,249
		Surfase of the area (m ^{2})	41,275

Fig. 61.1 Census of building facilities

the available daylight and the bioclimatic conditions are delimited in the spaces, according to the layout of openings and the facades orentation.

Proposals are devised, mainly based on readjustment of previously established architectonic spaces (classroom type), as well as implementation of energy-saving systems in the aforementioned spaces.

C. Analysis.

Characteristics of the building: The building analyzed is located at a latitude of 20° north and 1450 meters above sea level. It is used as a teaching center, and activities such as reading, writing, and painting take place there. The total built surface is 18,017 square meters, distributed across nine buildings. A maximum of 1300 people congregate in it.

The areas are divided as shown in Fig. 61.1.

61.2 Census of Facilities

To obtain information on the total energy consumption of the existing electrical facilities in the School of Architecture buildings, we carried out a registration of the lighting system and all electrical equipment in each building. The results of the census showed, in a general way, that more than a third of the electricity consumption was used for artificial lighting at the School of Architecture. Two thirds of that lighting consumption occurred in buildings F and G, the classrooms. To reduce the consumption in these classrooms, a potential savings would be obtained by the implementation of energy-saving systems and by taking advantage of natural lighting (Fig. 61.2).

Concept	Consumo (kw-h/month)	Charge (kw)
Lightning	32,361.11	154.26
Air conditioned	2,898.43	40.88
Connections	13,008.86	116.59
Power	4,843.78	163.63
TOTAL	53,112.18	475.36

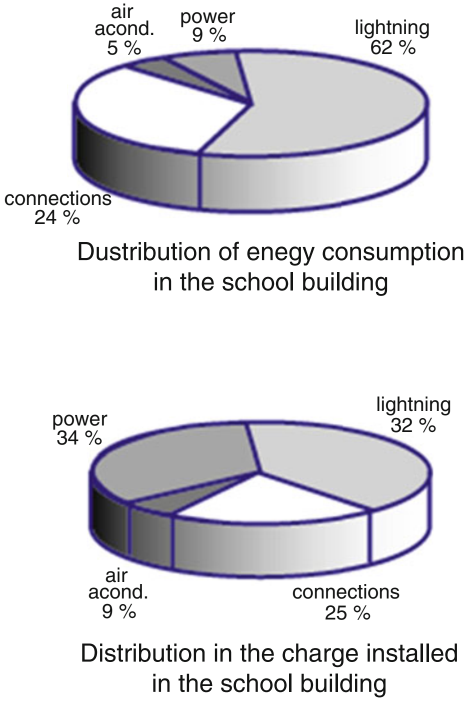

Fig. 61.2 Energy consumption and electric charge installed

61.2.1 Air Conditioning Requirements

Energy requirements depend on activities. It is necessary to define acclimatization strategies according to the seasons of the year to obtain environmental comfort:

In the hot season:

- Ventilation needs to be maximized (0.3–2.5 m/s) to obtain an internal building temperature within the comfort range.
- The external ambience of the building needs to be humidified (2–3.5 kg/cm^2) to improve internal comfort.
- Direct sun radiation over inhabitable spaces needs to be avoided.
- The air is humid.
- Cross-ventilation needs to be optimized (0.3–2 m/s) to avoid humidity inside the buildings.
- Protection is needed to avoid direct sun radiation, which results in an undesired calorific contribution to the building.

In the dry and temperate seasons:

- An adequate reduction between external and internal temperatures to optimize the entire comfort of the building (thermic delay).

- Direct solar radiation is favored only in the early morning in order to obtain light heating of the buildings (70–3500 W).

Such recommendations allow us to define the means of environmental control in the buildings by examining the constructive elements in an analytical way or by tests in models in simulated environments.

61.2.2 Available Natural Illumination

The setting of the applicable illumination grade is made using a Dresler graphic. Here it is observed that at a latitude of 20°N we can easily obtain high levels of illumination (9000–13,000 lux) of 90–95% during the working day, which determines the daylight factor (DLF). This graphic is based on average conditions of time and climate. If seasons are drier or more humid, it is obvious that these values are only a design guide, because absolute values are not usable for adequate lightning design anyway. Once the abovementioned information is analyzed, it is feasible to know the lighting strategies needed according to the energy saving program [1] (Fig. 61.3).

61.3 Diagnostics

Energy revision: For the present work, classrooms of the same kind as those in the north and south wings were chosen as ones that summarize the light and climatic conditions of all classrooms (general characteristics), as well as its place on the whole and general characteristics. The results obtained here would be used in all of the center’s educational spaces since, according to the initial analysis, they were considered suitable for this area survey.

Measurements of available electrical power: There is a need to know the energetic behavior of the consumption curve and the demand for electrical power, obtained by means of measurements of the feed transforms. Such measurements produce two basic graphs: the energy demand and the power factor. The behavior of the demand of the 300 kVA transformer is connected to the charges of equipment and lighting that correspond to Buildings A, B, C, D, E, F, and I. It is shown that a maximum value of 75 kW is reached near the hour of highest demand (19.00 h).

Making a detailed forecast of energy consumption based on measurements during a typical day, it is shown that the hour of highest demand for energy at the center is the hour of maximum demand established by the CFE (Federal Commission of Electricity). The foregoing means that the energy consumption in this hour represents a higher cost (Fig. 61.4).

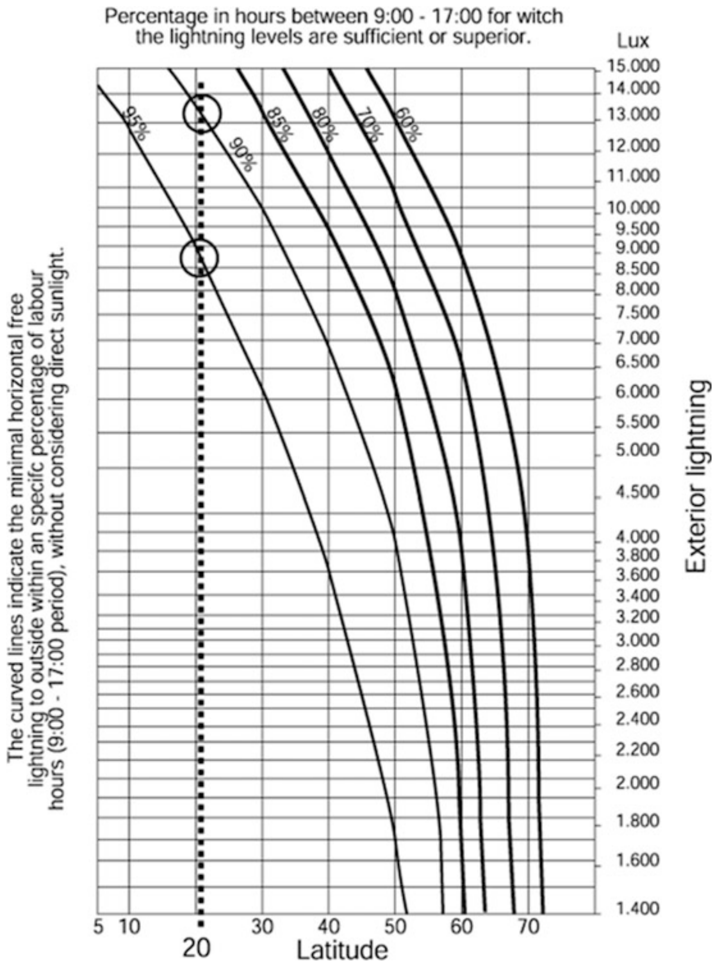

Fig. 61.3 Dresler graphic

Behavior of electrical demand: On the other hand, we must consider—besides the demand cost, which coincides in a proportional way during most of the year—the electrical demand in kilowatts. Except in the months of January and April, the real cost of the energy is greater that the demand, which means that with the highest demand, the energy cost is greater per kilowatt hour. Regarding energy consumption for each kilowatt hour, the proportional cost of energy is presented during the whole year. For example, in January the consumption is higher and so is the cost [2].

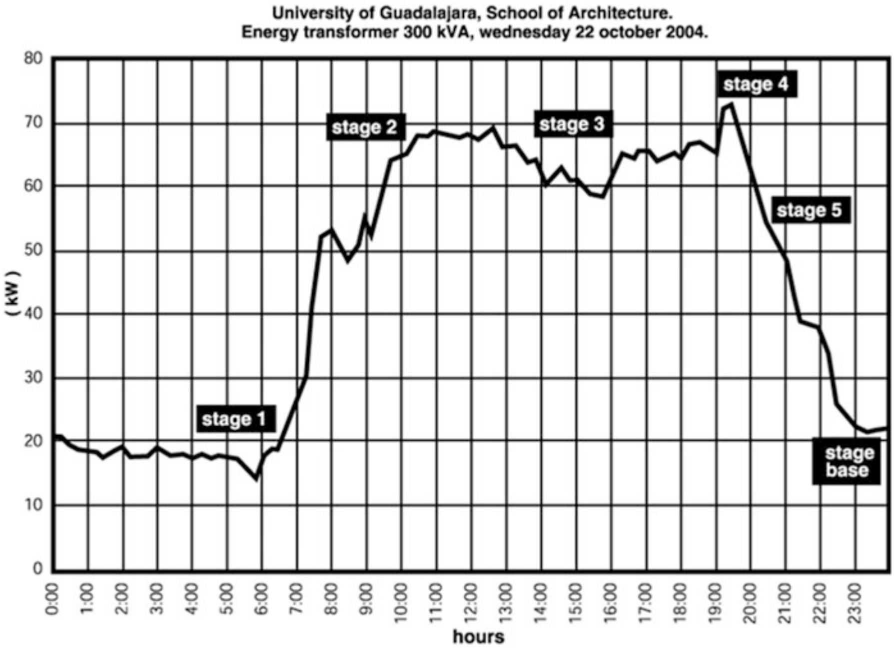

Fig. 61.4 Behavior of electrical demand

61.3.1 Lightning Behavior of Real Measurements in Model Classrooms

The analyses of real conditions in model classrooms are performed taking into account two aspects: measurement at 16 points of work levels using luxometers in real conditions of the sky CIE and through graphic analysis of fisheye photos regarding the resulting daylight (Fig. 61.5).

The abovementioned helps to establish certain criteria for the proportions of the optimum size, form, and placement of windows. Using the lecture survey and the position of such measurement points (fisheye), it was intended to make a proposal to modify classrooms. The parameters analyzed in the openings were:

- Coefficient and proportion of windows
- Form and geometry
- Layout and location
- Illumination of working levels
- External reflected levels

For the two points of view of the analysis in model classrooms, they could be divided into two groups: those referring to aspects of opening and those related to receptor surfaces [3].

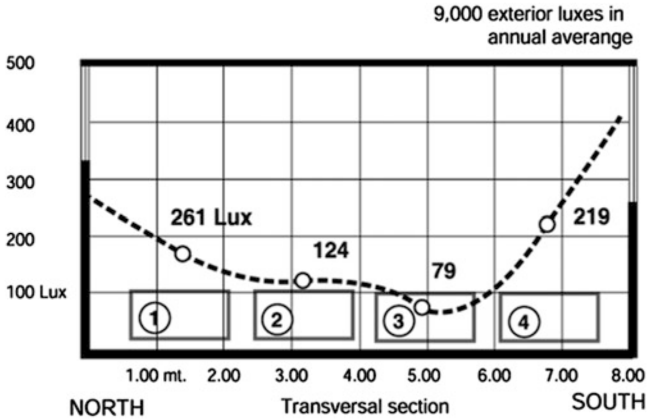

Fig. 61.5 Percentages of available natural lighting

61.4 Proposals

Selection of the components of the steps: First, it is convenient to remember the main principles that must guide the steps in the analysis of natural illumination of the architectural project; three different objectives can be observed:

- Optimization of the reception of diffusion of light
- Selection of direct sun penetrations according to the season
- Homogeneous distribution of light in spaces of interest

It can be seen that there are two great groups of natural illumination components: the lateral and the zenithal. The available light in a spot in the space depends on the sky type, the horizontal exterior component, the solid angle of the opening, and the cosine of the angle of media incidence of that light over a respective level.

It is deduced, by this relation, that zenithal openings are more effective in a horizontal plane than lateral openings, because they produce high interior illumination over the horizontal surface. Concerning the direct sun incidences (sunlight) it can be said that lateral openings are more favorable because the penetration is selective depending on the season of the year, the day, and the hour, as opposed to zenithal openings where the incidence in summer is critical and in winter it is lower, even though in the case of the classrooms we contemplated only the lateral analysis of the sky CIE classification (2; covered sky), which means the diffusion of light. This also takes into account consideration of control devices for direct solar incidence. The bioclimatic criteria mark the guides to reach this preconclusion regarding the percentages of windows and their geometry and disposition on different walls. Even though the proportion is marked according to climatic matters, illumination levels that can be reached with these proportions are well accepted to accomplish visual tasks in solar orientation. The results

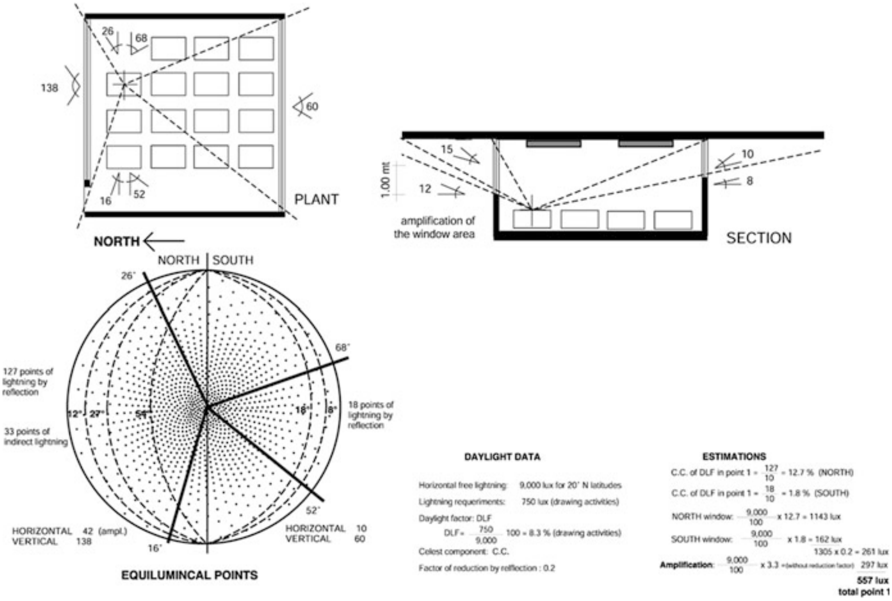

Fig. 61.6 Daylight data and estimation

obtained show that the proportions of the original north–south windows provide only 261 lux in the position shown in, which are the activity visual requirements in drawing 750 lux (Fig. 61.6).

61.4.1 Complementary Saving Measures

Some complementary measures are set forth in the readjustment of typical spaces to obtain an integral saving inside the buildings, from which are obtained a series of savings in consumption, in maximum demand, and in costs, besides the percentages of consumption and maximum demand [4] (Fig. 61.7).

Photometry of the interior surfaces: The factor of reflection of the light in a space depends to a great extent on the materials used for construction of the walls, floor, and roof. The light consequences due to the factor of reflection off the walls are in direct relation to the light comfort that will be had in the space. With the help of the computer program GENELUX, we verified the aerial map-making of the coating materials' effects on the distribution of light inside a given volume (Fig. 61.8).

The top figure shows the light distribution (in curves) of different finishes. In the aforementioned analysis it appeared that between curve 2 and curve 3 there was a decrease of 20% in the part close to the window and that at the back of the space, both diminished by 100%. From this it is possible to conclude that half of the available lighting at the back of the space comes only from interreflections of light

Measure	initial investment (US dollars)	Savings				
		Consumption kw-h/month	Maximum demand	Economic $/month	% of consumption	maximum demand
Advantage of natural lightning in WC, F and G buildings	$ 0.00	249	0	85	1%	0%
Advantage of natural lightning in building E	$ 0.00	584	0	200	2%	0%
Elimination of innecesary incandescent lamps	$ 0.00	23	0	10	9%	0%
Adequate lightning levels in surveillance corridor	$ 122.10	2,2260	0	768	9%	0%
Substitute lamps and balasts by lamps T8 and electron balasts	$ 900.00	441	1	219	2%	2%

Fig. 61.7 Savings in the different buildings

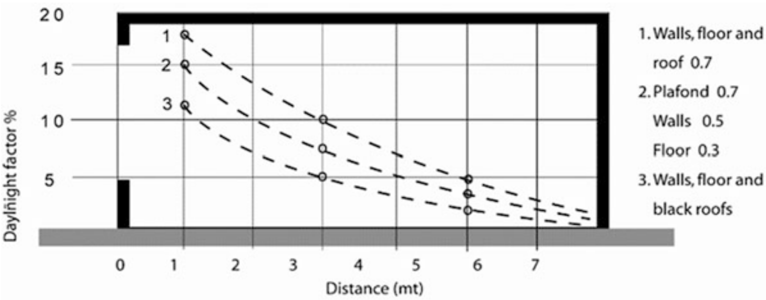

Fig. 61.8 Materials of coating photometry

on the walls, floor, and roof of the space. If we compare curves 1 and 2, it can be appreciated that the available quantities of light at the back of the space are of the order of multiplication by two, or half of a totally white space. Both comparisons show the importance of bearing in mind the aerial map-making of the coating materials in an architectural space.

Therefore, it is possible to affirm that with different interior surfaces the behavior would be as described below.

Clear sky: In general, the roof does not receive natural lighting in a direct way; it does not intervene in an important way in the distribution of the light. On the other hand, in cases where light is turned upward (mantelpieces of light), it receives a certain quantity that it can redistribute in turn to the whole space. As a consequence, the factor of reflection of this surface will have to be raised (0.7–0.8).

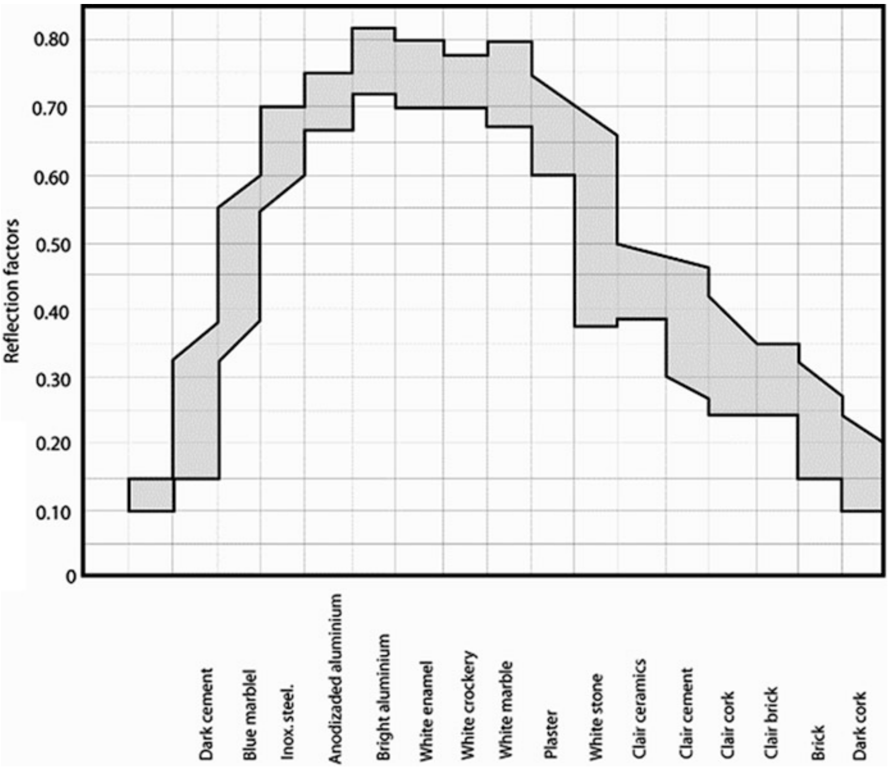

Fig. 61.9 Reflection factors of materials. (Source: Damelincourt et Rangueil, Universite Paul Sabatier. Adapted by David Carlos Avila)

Floor: First of all, it suits to add in a general way that the surfaces of the floors are strange free or clear. The furniture and especially the tables (levels) of work cover a great part of the surface.

The analysis centers on considering the horizontal levels of work, which are those that will receive the most important quantity of light, and it places major importance on taking care that there are not high levels of lighting that provoke discomfort by dazzling the eye (Fig. 61.9).

61.4.2 Walls

Since it is verified in the simulations that the walls receive both direct and diffuse lighting, they play the most important role in the architectural space in terms of distributing the aforementioned light to the interior. As a general rule, it is possible to say that if the factor of reflection of the walls is lower than 0.5, it will be difficult for the lighting to adequately illuminate the back of the space in question (Fig. 61.10).

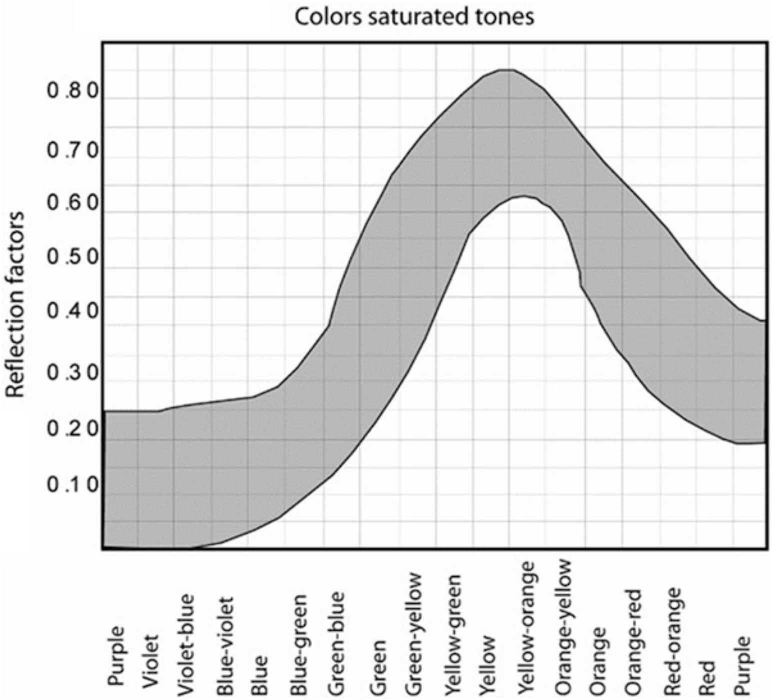

Fig. 61.10 Reflection factors of different paint colors. (Source: Damelincourt et Rangueil, Universite Paul Sabatier)

With regard to the variety of available materials in the construction market, where it is possible to compare the characteristics of each of them (Fig. 61.11).

61.5 Conclusion

For a suitable saving in energy consumption for artificial lighting, it becomes necessary to take into account all of the variables that intervene in the distribution of the luminous flow, from the disposition of the windows (form, size, orientation, and location) to the architectural elements that intervene in the process, and the materials, the textures, the colors, the proportions, etc.

- Physical readjustments in classrooms can obtain a substantial saving by taking maximum advantage of natural illumination.
- Taking into account integration of the five saving measures that were introduced, it has been deduced that with an initial investment of US$1022.00 and a useful lifetime of 6.6 years, the savings are 3556.63 KWh/month or 42,679.5 KWh/year,

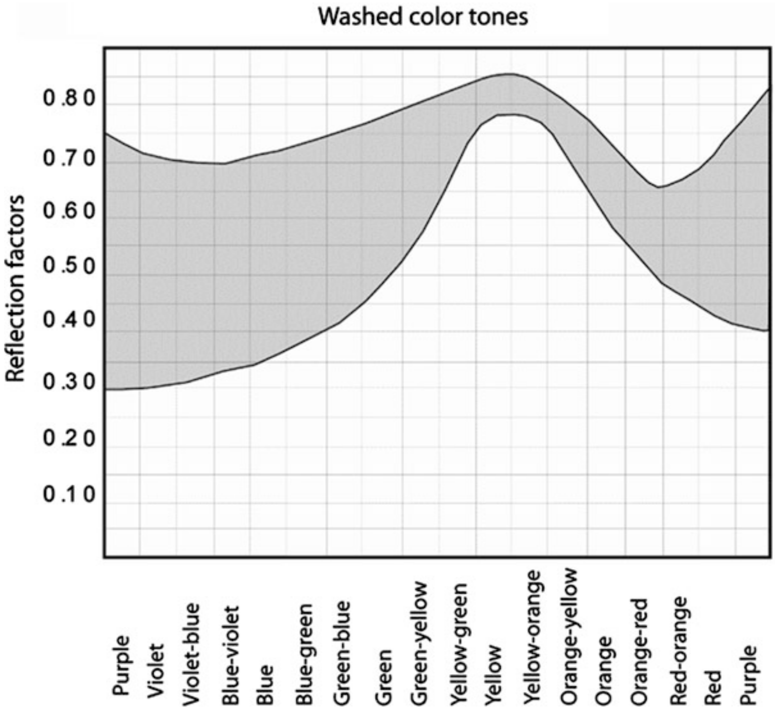

Fig. 61.11 Reflection factors of different paint colors. (Source: Damelincourt et Rangueil, Universite Paul Sabatier. Adapted by David Carlos Avila)

recovering the investment in only 0.75 years (9 months), as well as saving expenses of US$128/month or US$1539/year.

In addition, the following ecological benefits are obtained during the lifetime of the project, estimated at 6.6 years:

Reduction of CO^2: 128,848 kg
Reduction of SO^2: 2343 kg
Reduction of NO_X: 264 kg
Conservation of hydrocarbons: 53,858 kg
Reduction in water consumption: 662,637 kg

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