Centro de Referência e Informação em Habitação
Núcleo - UFSC
www.infohab.org.br
Fone: (48) 331-5183
E-mail: sexec@infohab.org.br

THE USE OF FIBRE OPTICS ON ENERGY EFFICIENT LIGHTING IN BUILDINGS

Enedir Ghisi

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The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others

Abstract

It is known that buildings consume large amounts of the electricity that is generated around the world; and that artificial lighting and air-conditioning consume a significant part of this energy. Furthermore, generating such electricity leads to the production of greenhouse gases. Therefore, it is desirable that the performance of these systems be optimised in order to achieve energy savings. An important factor that can lead to savings is the amount of daylight supplied to a space as this can reduce both the artificial lighting and air-conditioning load at the same time.

This work assesses the energy savings likely to be achieved in buildings where daylight and artificial lighting are properly integrated. Such an assessment comprises firstly of an appraisal of Daylight Factors to quantify the amount of daylight likely to be supplied by windows. The calculation of energy savings that can be obtained through this analysis identifies whether there is a potential for energy savings to be made on lighting by applying fibre optics to transport daylight to the rear side of rooms. As this analysis does not take into account the thermal effects related to glazed areas, a dynamic thermal model was selected and then used to identify the window area in which there is a balance between thermal load and daylight supply. Before using the dynamic thermal model, it was validated to ensure its capability to predict monthly energy consumptions and energy savings due to daylight integration. Its validation was performed through the simulation of a building located on the campus of Leeds University and also an office space in the Civil Engineering Building.

Once validation had been completed, rooms of different sizes, different window areas, and different room ratios were then simulated to identify their Ideal Window Area. To verify the influence of the climatic conditions and geographical location on daylight provision and thus on the Ideal Window Area, seven cities in Brazil and one in the UK were considered in the simulations. The methodology used in the first part of this work dealing with Daylight Factors was then used again to predict the daylight supply and energy savings on lighting likely to be obtained when the Ideal Window Area is applied. Thus the potential for energy savings on lighting due to the application of fibre optics could be obtained for each room size, room ratio and Ideal Window Area.

Having predicted the potential for energy savings due to the integration of fibre optics, a physical model was built to evaluate the accuracy of such predictions. Fibre optics were installed in the model to evaluate the energy savings when there is integration of daylight coming into the model from a window together with an artificial lighting system.

The final part of the work presents an economic analysis comparing the energy costs associated with providing adequate daylight in rooms using windows only; and secondly by using windows and the integration of a fibre optics system. An environmental impact assessment considering the reduction in greenhouse gasses due to the energy savings by incorporating fibre optics is then presented.

The main conclusion to be made from the research is that the integration of artificial lighting with daylight coming into rooms from windows would lead to significant energy savings in buildings, resulting in an investment much more attractive (shorter payback) than when there is integration of fibre optics.

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Chapter 1

Introduction

1.1. Man and light

Ancient men did not have light measuring equipment as we have today; they simply relied on their eyes to perceive that at night or during cloudy days their visual tasks could not be performed so well as they could during sunny days. This was perhaps the first indication of the need for basic lighting requirements.

The awareness about lighting requirements to perform different visual tasks made man search for sources of light other than the sunlight. He succeeded so well that he started with fire, which, besides providing heat to warm him and to cook food, could also provide light. Daylight was now not the only source of light any more; a form of artificial light was available. Later developments like whale oil and candles were supposed to provide more photometric comfort and the possibility to work at night. In later years, the electric lamp was developed and with it, days in the built environment became longer.

Artificial light fast became an alternative to daylight and architects now had the illusion of having total control over interior lighting levels. Their mistake was to overlook the fact that artificial lighting should be used as a supplement to daylight; to provide the required illuminance levels in the built environment, it should not be used as a total replacement because of its inherent energy demands. Such a situation persisted for many years but recently an energy awareness has developed amongst many nations and it has rapidly become apparent that artificial lighting systems consume large quantities of electricity. Therefore, efforts should be made to reduce such consumption as much as possible and at the same time improve the energy efficiency of lighting systems themselves.

Energy efficiency in a lighting system can be achieved mainly through the minimisation of two variables: the lighting power density and the lighting system use.

The reduction of the lighting power density, which is the ratio of total lamp wattage in a room to its floor area, can be obtained through the use of energy efficient lamps, luminaires and associated equipment. However, it must also be noted that energy efficient equipment – widely available in the market – do not provide energy savings by themselves. A lighting design needs to be carried out following all the steps required by this kind of design and the user requirements must be considered. In brief, one needs not only energy-efficient equipment, but also an energy-efficient lighting design (GHISI, 1997).

Amongst the many parameters that must be taken into account to achieve an energy-efficient lighting design, the most important is a suitable illuminance level. By providing high illuminance levels, the lighting designer is also providing high lighting power densities (W/m^2) and, as a consequence, high-energy consumption and high environmental pollution. In contrast, by providing too low an illuminance level could mean that a task cannot be performed adequately.

MILLS & BORG (1998) report that recommended illuminance levels have been changing quickly since the 1930s and that the variation of those levels specified for the same task between countries is very large. They report that of the 19 countries examined, Belgium, Brazil and Japan quote the highest illuminance levels for specific tasks in the building types that they analysed. Australia, China, Mexico, the former Soviet Union/Russia and Sweden quote the lowest illuminance levels.

The quality of equipment, maintenance period, luminaires distribution, use of task lighting and daylight integration are other variables that must be taken into account in the lighting design as a way of reducing lighting power density.

The second variable – the lighting system use – could be optimised through the use of control systems and also through the integration of daylight. Such an approach could reduce energy consumption and promote energy efficiency in the building.

It is interesting to note that in a book of almost three decades ago (BECKETT & GODFREY, 1974) the authors suggest that if integration between daylight and artificial lighting is to be achieved, the contribution of daylight from the windows needs to be known. It does not make sense to know the daylight levels obtained in inner spaces through a window if the artificial lighting system remains switched on all day. This may only be an indication that there is more illuminance on the working surface than needed. Thus, besides knowing the daylight levels, it is also important to define a strategy – the most difficult task – to integrate both systems.

The effective integration of the artificial lighting system and daylight occurs only when the artificial lighting system can be switched on or off as a function of daylighting levels reaching the working surface of spaces. Hence, this work assesses the potential for energy savings on lighting due to the effective integration of daylight with artificial lighting in buildings. A major part of the work considers new technologies such as fibre optics, which are evaluated as a means of transporting daylight to the rear side of rooms where the supply of daylight is low. Such an approach would contribute to the reduction in energy consumed by lighting and at the same time to the environmental pollution associated with buildings.

1.2. Energy consumption

Lighting systems are responsible for consuming large amounts of energy all over the world. Fortunately, advances have been made in lighting fitting design that have contributed to minimise this problem. However, this is a slow process and many building owners still operate energy-inefficient lighting systems.

BLEEKER (1993) reports that around 25% of the total electricity used in the business world is consumed by lighting systems. The use ranges greatly from country to country and is not only due to climatic conditions, but also to cultural habits. Table 1.1 presents the average lighting end-use in commercial buildings for some countries, where it can be noted that developed countries tend to present a higher lighting end-use.

Table 1.1. Lighting end-use in commercial buildings in different countries.

Country	Lighting end-use (%)	Source
China	15	MIN et al. (1995)
Korea	20	KOREAN NATIONAL TEAM (1996)
Brazil	24	PROCEL (1993)
Mexico	30	BANDALA (1995)
USA	39	EIA (1994)
Netherlands	55	SLIEPENBEEK & VAN BROEKHOVEN (1995)
UK	30-60	BS 8206-2 (1992)

In Brazil, the lighting end-use in commercial buildings with air-conditioning is about 24% as shown in the above table; but in commercial buildings without air-conditioning, the lighting end-use can reach 70% of the energy consumption of the whole building (PROCEL, 1993). This is due to the fact that the end-uses are calculated as a function of the total energy consumption of the building.

GELLER (1990) studied the public and commercial sector in São Paulo, Brazil, and obtained the energy end-uses presented in Figure 1.1. It can be seen that lighting accounts for 44% of the energy consumed in such buildings, which is much higher than the lighting end-use for the national average as presented in Table 1.1.

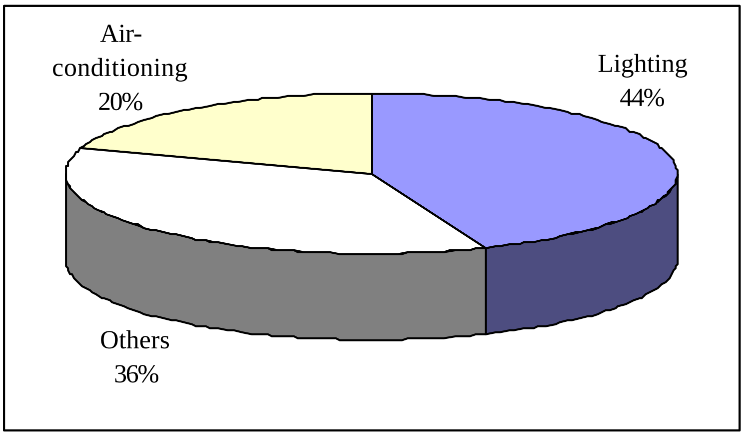

Figure 1.1. Electricity end-uses for air-conditioned public and commercial buildings in São Paulo, Brazil.

As shown in this section, lighting can be responsible for high energy end-use in buildings and this is an indication that strategies aiming to reduce energy consumption in buildings should effectively address the lighting system.

It is also important to mention that energy savings in buildings will not only lead to financial savings and reduction on the demand of electricity, but also to environmental benefits. The generation of electricity involving fuel combustion is associated with the production and emission of carbon dioxide into the atmosphere. This in turn causes environmental pollution and global warming due to the greenhouse effect.

1.3. Environmental issue

Most people are unaware that the operation of buildings and particularly the electric lighting are associated with environmental costs. The energy used to operate the artificial lighting system in buildings in many countries comes from burning fossil fuels (coal, gas and oil) and this process contributes to environmental pollution through the production and emission of carbon dioxide (CO_2) and other gasses into the atmosphere.

This in turn contributes to global warming (CARMODY et al., 1996).

The generation of carbon dioxide originates from the burning of many different types of fuel. As a general guide, the more developed a nation, the more CO_2 it produces. For an example, Figure 1.2 presents the carbon dioxide emission for Brazil, the UK and the USA from 1901 to 1997 (MARLAND et al., 2000).

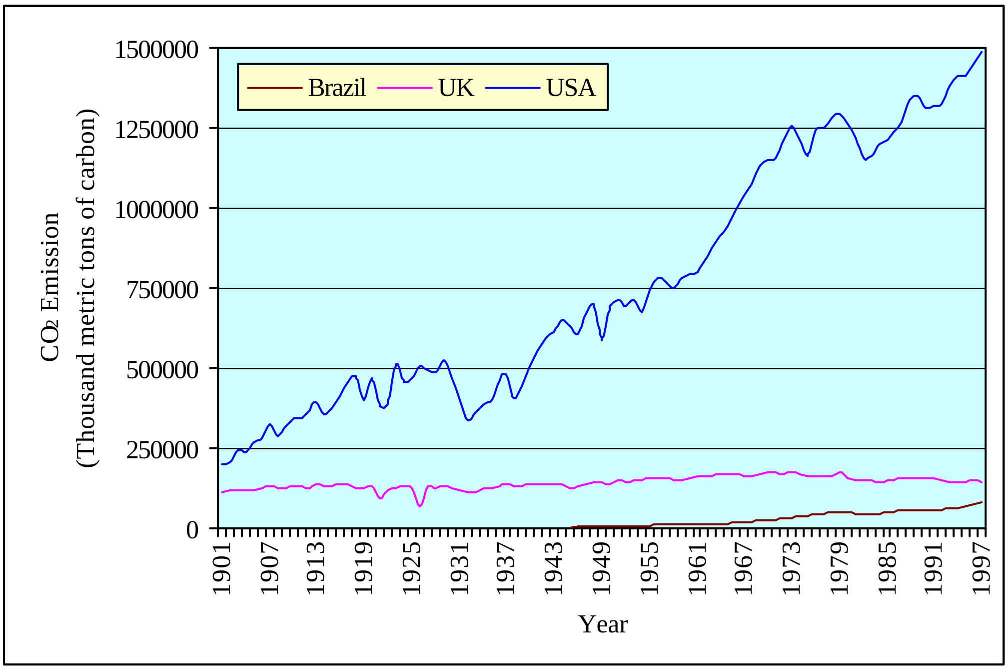

Figure 1.2. Carbon dioxide emission for Brazil, the UK and the USA.

The low emission of CO_2 observed in Brazil is due to the fact that the production of electricity based on hydroelectric power reaches about 93% of the national generation (GUIMARÃES JUNIOR, 2001) as there are thousands of rivers forming hydrographic basins.

EIA (2001) reports that approximately one-third of the countries in the world use hydropower for more than half of their electricity supply. Hydropower is considered a clean renewable energy source because there is no carbon dioxide or other greenhouse gas emissions associated with the generation as there is no fuel combustion involved. However, there are indications that the reservoirs associated with hydroelectric dams also emit carbon dioxide and methane emanating from the decomposition of biomass. Consequently, irrespective of the energy source, energy savings in buildings will result in a decrease of environmental pollution independent of whether the electricity comes from hydropower or thermopower.

1.4. Fibre optics and remote-source lighting

Fibre optics are a relatively recent technology that have found many uses. The first application of such a technology was in telecommunications whereby information is transmitted by light signals. However, fibre optics have also been used in many other applications such as medical imaging and as specialised lighting for dentistry, microscopes, cameras, and instrument displays. In building services, fibre optics have been used in sensors to measure pressure, temperature and humidity (BROMLEY et al., 1997).

Since the 1990s, such a technology has also been used in remote-source lighting systems. In this technique light travels from its source through a medium to one or more remote points, and the medium can be fibre optic cables. The technology has been used in museums and retail displays; for underwater lighting in pools, fountains, waterfalls and linear lighting along pool edges. It has also been used in architectural applications to emphasise the features of a building or to outline its exterior contours. Fibre optics can also be used to light exit signs, billboards, traffic signals, road signals, advertising, and aisles in theatres and aeroplanes.

There are, basically, two technologies that can be used in remote-source lighting: fibre optics and prism light guides. A brief description of both systems is presented below and additional technical information about physical properties of fibre optics is presented in Chapter 2 and also in Appendix A. A wide review about the development of remote-source lighting systems can be obtained from AYERS & CARTER (1995).

1.4.1. A basic fibre-optic system

A basic fibre-optic system comprises of an illuminator, a light guide and a fixture.

The illuminator is a light source coupled to the input end of a fibre-optic light guide. It contains a reflector, a lamp and a filter. It can also contain a ballast, a fan and a rotating colour wheel.

A bundle or a single fibre composes the light guide. The glass or plastic core of each fibre is coated with cladding (or sheath or coating) – a very thin layer of glass or plastic that prevents light from leaking out of the fibre. The fibre or fibre bundle is then covered with an opaque or transparent sheathing – a plastic, rubber, or metal tube that protects and supports the fibres. If the light guide is used to project light from the end, it is called end emitting. When used to project light through the side, it is called side emitting.

A fixture comes in many forms like recessed downlights, wall-washers, tracklights or diffusers. The fittings could be compared to the luminaires in a conventional lighting system.

1.4.2. A basic prism-light-guide system

A basic prism-light-guide system is composed of a light injector, a light guide, a housing and an extractor.

The light injector is equivalent to an illuminator. It contains a reflector, a lamp and a glass or plastic window that can filter infrared or ultraviolet rays or add colour.

The light guide is typically a cylinder that has a prismatic surface on one side and a very smooth surface on the other. It acts like a mirror for light striking it at certain angles. It is typically 10 to 25cm in diameter.

The housing is a rigid tube or backing of transparent or opaque plastic or metal. The extractor is a film that diverts light from its path down the light guide so that it exists at a particular location.

1.5. Fibre optics in lighting design

Fibre optics as mentioned previously, are a new technology that is growing quickly. If it is possible to carry artificial light through fibre optics, it should be possible to transport daylight through fibre optics into buildings. Then the integration of daylight and artificial light would lead to reductions on the artificial lighting system use and hence save energy and reduce environmental pollution.

In this respect, this research intends to perform a theoretical analysis to verify the energy savings likely to be obtained if fibre optics are used to transport daylight to the inner spaces in buildings when there is also integration with the artificial lighting system. Investigations will be made to evaluate if daylight can be economically transported to inner spaces of buildings using fibre optics and if the artificial lighting system can be integrated to be cost-effective.

1.6. Research methodology

Improved daylight penetration into a building to reduce the dependency on artificial lighting could be regarded as one of the easiest ways of improving energy efficiency and, as a consequence, of attaining energy savings and reducing environmental pollution.

The first part of this study concentrates on assessing and quantifying the daylight provision likely to be obtained on the working surface of rooms of different dimensions and different window areas. Such an analysis, which is performed through the calculation of Daylight Factors, quantifies the problem of lack of daylight supply towards the rear side of spaces. The calculation of energy savings that can be obtained through this analysis identifies whether there is a potential for energy savings to be made on lighting by applying fibre optics to transport daylight to the rear side of rooms. As this analysis does not take into account the thermal effects related to glazed areas, simulation modelling is then used to identify the window area in which there is a balance between thermal load and daylight supply. Such a window area is referred in this work as the Ideal Window Area.

Before simulation modelling could be used, a Dynamic Thermal Modelling (DTM) code suitable for the requirements of this work had to be selected. DTM codes have been used since the 1970s and many new codes have been reaching the market. If possible, it was intended to select a code not only for its reliability, but also for its wide availability. The selected code was VisualDOE, which is a commercial version based on the DOE-2.1E programme. It has an advantage over other codes in that it runs on a personal computer. It performs thermal and energy analysis of buildings provided that climatic data at the location of the building and details concerning the building components, systems, patterns of use, etc. are available as input data.

Having selected a DTM code for predicting energy consumptions, the code was then validated to ensure its capability in predicting monthly energy consumptions and energy savings due to daylight integration. The capability of the code in providing reliable monthly energy consumptions was identified through the simulation of a building located on the campus of Leeds University. The potential for energy savings due to daylight integration was evaluated through the simulation of an office space in the Civil Engineering Building.

Once validation had been completed, rooms of different sizes, different window areas, and different room ratios were then simulated. The major purpose of such simulations was to obtain the Ideal Window Area of such rooms. To verify the influence of the climatic conditions and geographical location on daylight provision and thus on the Ideal Window Area, seven cities in Brazil and one in the UK were considered in the simulations. The methodology used in the first part of this work dealing with Daylight Factors was then used again to predict the daylight supply and energy savings on lighting likely to be obtained when the Ideal Window Area is applied. Thus, the potential for energy savings on lighting due to the application of fibre optics was evaluated for each room size, room ratio and Ideal Window Area.

Having predicted the potential for energy savings due to fibre optics, a physical model was built to evaluate the accuracy of such predictions. Fibre optics were installed in the model to evaluate the energy savings when there is integration of daylight coming into the model from a window with the artificial lighting system.

The final part of the work presents an economic analysis comparing the energy costs associated with providing adequate daylight in rooms using windows only; and secondly by using windows and an integration of fibre optics systems. An environmental impact assessment considering the reduction in greenhouse gasses due to the energy savings by incorporating fibre optics is finally presented.

1.7. Aims of the study

This research aims to evaluate the integration of daylight using fibre optics to supplement light on working surfaces that comes in through windows. Such an evaluation allows the quantification of the energy savings that can be obtained by integrating the artificial lighting system with the daylight provided by windows and fibre optics.

1.7.1. Specific objectives

To achieve the overall aims of the study, specific objectives are defined as listed below:

i) To evaluate the energy savings likely to be obtained on the artificial lighting system due to the integration of daylight supplied through windows as a function of window area and room size through the calculation of Daylight Factors;

ii) To verify whether there is still a potential for energy savings by transporting daylight to the rear side of rooms using fibre optics;

iii) To select and appropriately validate a Dynamic Thermal Model that can be used to predict the energy consumption of buildings;

iv) To identify the Ideal Window Area of rooms of different room ratios and room sizes;

v) To investigate the tendency of the energy consumption as a function of room size and room ratio;

vi) To investigate the impact on the energy consumption when the window area is different than the Ideal Window Area;

vii) To determine the energy savings on lighting due to integration of daylight coming onto the working surface of spaces through the Ideal Window Area;

viii) To evaluate the potential for energy savings in case fibre optics are applied in conjunction with the Ideal Window Area;

ix) To evaluate the economic viability of using fibre optics as a tool to transport daylight to be integrated with the artificial lighting system in buildings;

x) To estimate environmental benefits achieved by making energy savings using fibre optics.

1.8. Structure of the thesis

This thesis is presented in eight chapters. Chapter 1 has presented a brief introduction to the problem under investigation and stated the aims and objectives of the work.

Chapter 2 covers the literature review of subjects relating to energy consumption in buildings located in some countries, energy efficiency in buildings, lighting load, daylight systems, window area, fibre optics, and dynamic thermal modelling programmes.

Chapter 3 evaluates the potential for energy savings on artificial lighting systems that can be obtained through the supply of daylight in buildings only from windows. This analysis is performed through the calculation of Daylight Factors.

Chapter 4 presents the validation of a Dynamic Thermal Modelling programme. Two validations were performed to define the capabilities of the programme. The first validation deals with an actual building located on the campus of Leeds University that was simulated over a year to identify the reliability of the code on predicting monthly energy consumptions. The potential for energy savings by daylight integration in the building was also assessed. The second validation was related to an office space located in the Civil Engineering Building to identify the capabilities of the programme for predicting energy consumption as a function of daylight integration and window area.

Chapter 5 presents the results of the simulations and discusses the energy consumption of rooms with different sizes and different window areas, which will allow the Ideal Window Area of such rooms to be determined. Through this analysis it will be possible to evaluate the energy savings likely to be achieved by the integration of daylight coming in through windows and also to assess the potential for energy savings by using fibre optics.

Chapter 6 describes an experiment that was designed to evaluate energy savings likely to be obtained by the integration of daylight (coming in from window and fibre optics) with artificial lighting.

An economic analysis to evaluate the cost-effectiveness of integrating daylight coming onto the working surface of rooms either through windows only or windows and fibre optics is presented in Chapter 7. An environmental impact assessment due to the energy savings on lighting likely to be achieved is also presented in Chapter 7.

Finally, conclusions from the work and recommendations for future work are presented in Chapter 8.

Chapter 2

Literature Review

2.1. Introduction

This chapter presents a literature review of the topics related to this work and it starts with a survey on energy consumption and energy end-uses in buildings located in some different countries. This is followed by a review on the reduction of energy consumption through the use of energy efficiency techniques, the application of daylight systems, and the influence of the window area and lighting load on energy consumption.

A review about dynamic thermal modelling programmes is also presented giving more cited references on the VisualDOE programme, which was the piece of software used in this research.

Research publications on the physical properties of fibre optics including data on losses associated to transmission of light and a scenario describing the current use of fibre optics is also presented.

Finally, the chapter presents published research on atmospheric pollution related to the use of energy in buildings.

2.2. Energy consumption

This section presents a survey of energy consumption and energy end-uses of buildings submitted to different activities and located in different countries. The main purpose of such an analysis is to present data showing how energy is used in buildings, identifying those end-uses that are responsible for the highest consumption, as any strategy to reduce energy consumption will depend on the analysis of how the energy is used in actual buildings.

Energy consumption and end-use for buildings located in Brazil, in the countries that join the Association of South East Asian Nations (ASEAN) and in the USA are presented in this section. A literature survey of energy consumption and energy end-use of buildings located in other countries is presented in Appendix B.

2.2.1. Energy consumption in Brazil

As for the survey in Brazil, energy consumption and end-use in commercial buildings are presented for some cities, that is, Florianópolis, Salvador, Rio de Janeiro, São Paulo, and for the bank sector in the state of Minas Gerais.

Two buildings and the Federal University of Santa Catarina (UFSC), located in Florianópolis, state of Santa Catarina, South Brazil, had their energy consumption evaluated. UFSC was studied between January 1992 and December 1996; FIESC between January 1995 and December 1997; and TELESC between January 1995 and December 1996. Energy consumption and end-uses are presented in Table 2.1 where it can be observed that the lighting end-use ranged from 30% to 63% of the total energy consumption. Lighting and cooling together ranged from 69% to 91%.

Table 2.1. Energy consumption and end-use in Florianópolis.

Building	Source	End-use (%)			Consumption
		Cooling	Lighting	Others	(kWh/m^2.year)
UFSC	GHISI (1997)	16	63	21	79.26
FIESC	WESTPHAL et al. (1998)	41	50	9	123.14
TELESC	RODAS et al. (1998)	39	30	31	219.93

In another work, TOLEDO (1995) reported on a survey covering 11 public buildings and 2 banks in Florianópolis. The resulting analysis is based on their energy consumption between July 1991 and June 1994. A summary of the results published by Toledo is presented in Table 2.2, from where it can be seen that the average energy consumption was deemed to be approximately 120.00 kWh/m² per year for the 13 buildings. However, consumptions ranged from 43.45 kWh/m² per year to 321.72 kWh/m² per year, a ratio of 7.40 times. As for the lighting end-use in public buildings, these ranged from 8.6% (Embratel Building) to 66.8% (Secretaria da Educação Building), with an average of 41.7%. For the banks, the lighting end-use observed ranged from 30.2% (Caixa Econômica Federal) to 54.2% (Banco do Brasil).

Table 2.2. Energy consumption and end-use in Florianópolis by TOLEDO (1995).

Public buildings	End-use (%)			Consumption
	Cooling	Lighting	Others	(kWh/m^2.year)
Assembléia Legislativa	27.1	52.0	20.9	66.26
Fórum	60.1	29.0	10.9	93.81
Edificio das Secretarias	52.0	39.9	8.1	147.18
Edificio das Diretorias	33.7	41.5	24.8	55.59
Secretaria da Educação	18.3	66.8	14.9	82.99
Eletrosul	13.0	40.9	46.1	201.28
Palácio do Governo	38.8	55.6	5.6	43.45
Tribunal de Contas	48.7	36.6	14.8	71.76
Celesc	39.9	46.8	13.3	135.77
Casan	47.7	40.8	11.5	108.56
Embratel	54.5	8.6	36.9	321.72
Average	39.4	41.7	18.9	120.76
Banks	End-use (%)			Consumption
	Cooling	Lighting	Others	(kWh/m^2.year)
Caixa Econômica Federal	42.4	30.2	27.4	61.22
Banco do Brasil	27.3	54.2	18.5	177.88
Average	34.9	42.2	23.0	119.55

In Salvador, located in the state of Bahia, Northeast Brazil, MASCARENHAS et al. (1995) studied 30 commercial buildings and related their energy consumption to their window area. The classification of the sample was done as a function of the window area (S_w) and resulted in four building types:

- Small window area ($S_w \leq 20\%$);
- Intermediate window area ($20\% < S_w < 40\%$);
- Large window area ($S_w \geq 40\%$);
- With solar protections (partially or totally).

The analysis covered data collected over the period between March 1994 and February 1995. Due to large differences in garage area between the buildings (ranging fom 0 to 4000.00m²), the energy consumption per floor area is presented with and without garage areas, as can be seen in Table 2.3. The data shows that there is a clear correlation between window area and energy consumption. Buildings with large window area present the highest consumption (130.8 kWh/m² per year), that is, 61.5% higher than buildings with small window area (80.4 kWh/m² per year).

Table 2.3. Energy consumption in commercial buildings in Salvador.

Window area	Consumption (kWh/m².year)	
	With garage	Without garage
Small window area	80.4	96.0
Intermediate window area	88.8	103.2
Large window area	130.8	145.2
With solar protections	84.0	96.0

In Rio de Janeiro, Southeast Brazil, LOMARDO (1988) studied the energy consumption in four commercial buildings between January 1985 and November 1986. Energy consumption and end-uses reported are presented in Table 2.4. The average energy consumption for the four buildings was estimated to be 340.08 kWh/m² per year. However, consumptions ranged from 300.60 kWh/m² per year to 420.00 kWh/m² per year. As for the lighting end-use, these ranged from 23.4% (Building D) to 47.8% (Building B), with an average of 37.1%.

Table 2.4. Energy consumption and end-use in commercial buildings in Rio de Janeiro.

Building	End-use (%)			Consumption
	Cooling	Lighting	Others	(kWh/m^2.year)
A	48.8	43.1	8.1	318.00
B	24.9	47.8	27.3	300.60
C	30.6	34.1	35.3	420.00
D	45.2	23.4	31.4	322.08
Average	37.4	37.1	25.5	340.08

In the state of Minas Gerais, Southeast Brazil, the bank sector is composed of approximately 2000 units. Table 2.5 presents the energy end-uses for those banks in a study performed by CEMIG (1993). Banks are classified by CEMIG as a function of their monthly energy consumption as follows:

- Small	Consumption up to 15,000.00 kWh;
- Medium	Consumption between 15,000.00 and 100,000.00 kWh;
- Large	Consumption higher than 100,000.00 kWh.

It can be noted that cooling accounts for most of the energy supplied to those banks, but artificial lighting still represents a large proportion of the energy consumption, ranging from 28.8% in small banks to 36.7% in large banks.

Table 2.5. Energy end-use in banks in the state of Minas Gerais.

Bank type	End-use (%)					
	Cooling	Lighting	Lifts	Pumps	Computers	Others
Small	62.9	28.8	-	-	7.0	1.3
Medium	56.0	32.0	3.5	0.3	8.0	0.2
Large	38.6	36.7	16.5	0.6	7.0	0.3

ROMÉRO (1991), through an analysis of the commercial building sector in São Paulo, Southeast Brazil, evaluated the energy end-use in different building types. Results are shown in Table 2.6, from where it can be observed that shops have the highest lighting end-use – 76.4% of the total energy consumption. In offices it was identified to be 50.3%.

Table 2.6. Energy end-use in São Paulo.

Building	End-use (%)				
	Lighting	Cooling	Cooking	Refrigeration	Others
Shops	76.4	11.9	0.0	0.0	11.7
Supermarkets	25.0	1.8	13.4	56.0	3.8
Petrol stations	42.9	0.4	0.0	7.5	49.2
Restaurants	20.3	7.1	26.2	44.2	22.2
Repair	56.3	4.4	0.0	0.0	39.2
Personal services	8.9	3.0	0.0	0.0	88.1
Banks	52.1	33.8	0.3	0.1	13.5
Offices	50.3	34.3	0.0	0.0	15.3
Large shops	49.5	33.6	6.1	6.1	4.6

As seen in this sub-section, lighting and cooling account for most of the energy used in buildings in Brazil. A literature review on the energy consumption in buildings located in the South East Asian Countries and also in the USA is presented next.

2.2.2. Energy consumption in the ASEAN countries

Indonesia, Philippines, Singapore, Malaysia and Thailand are the countries that join the Association of South East Asian Nations (ASEAN). Table 2.7 presents energy end-use for buildings located in those countries (LBL, 1992). In average, cooling end-use is approximately 60.0% of the energy consumption in offices, hotels, hospitals, and supermarkets. Lighting end-use ranges from 20.6% to 22.5% of the energy consumption in offices, hotels, and schools; and in the store analysed in Malaysia, it reaches 46.5%.

It must be taken into account that in supermarkets and hospitals the other equipment end-use is due to refrigerators, freezers, and technical machines.

Like in Brazil, it can be noted that lighting and cooling together account for most of the energy used in buildings in those countries.

Table 2.7. Energy end-use in the ASEAN countries.

Building type	Country	Quantity	End-use (%)		
			Cooling	Lighting	Others
Offices	Indonesia	1	80.1	11.8	8.1
	Malaysia	5	68.8	23.1	8.1
	Philippines	24	61.2	22.5	15.6
	Singapore	4	49.8	24.2	26.0
	Average	34	61.6	22.5	15.5
Hotels	Indonesia	4	57.6	18.5	23.9
	Malaysia	3	61.1	22.8	16.1
	Philippines	8	63.9	16.2	18.2
	Singapore	2	55.4	38.6	6.0
	Average	17	60.9	20.6	17.7
Hospitals	Malaysia	1	77.9	14.7	7.4
	Philippines	8	56.1	6.6	34.5
	Average	9	58.5	7.5	31.5
Stores	Malaysia	1	40.1	46.5	13.4
Schools	Singapore	1	71.0	22.0	7.0
Supermarkets	Philippines	4	58.9	6.6	34.5

2.2.3. Energy consumption in the USA

Energy end-uses for buildings located in the USA are presented in Table 2.8. The data was surveyed in 1989 through the Commercial Buildings Energy Consumption Survey in the USA (EIA, 1994). The energy consumption is presented under nine different end-uses and it can be seen that lighting accounts for most of the energy consumption in most types of buildings.

Table 2.8. Energy end-use in the USA.

Building type	End-use (%)				
	Heating	Cooling	Ventilation	Water heating	Lighting
Theatres [a]	10	13	14	1	34
Schools	5	8	11	1	53
Supermarkets [b]	-	15	8	1	18
Restaurants [c]	1	17	11	2	24
Hospitals	2	20	14	2	44
Lodgings [d]	8	12	15	4	34
Services [e]	2	9	5	1	37
Offices	3	10	17	-	35
Garage buildings	-	2	2	1	46
Publics and safety	-	5	8	-	44
Deposits	3	2	1	-	42
Others	-	7	-	-	38

Table 2.8. Energy end-use in the USA (cont.).

Building type	End-use (%)				
	Cooking	Refrigeration	Office equipment	Others	Total
Theatres [a]	-	6	3	19	100
Schools	-	5	5	13	100
Supermarkets [b]	9	42	1	6	100
Restaurants [c]	15	14	2	13	100
Hospitals	3	4	4	8	100
Lodgings [d]	10	11	1	5	100
Services [e]	1	2	21	23	100
Offices	-	4	21	8	100
Garage buildings	-	5	6	38	100
Publics and safety	-	6	5	29	100
Deposits	1	10	24	16	100
Others	-	3	6	44	100

a. Included auditoria, concert rooms, stadia and similar.
b. Included bakeries, grocery stores and similar.
c. Included snack bars and similar.
d. Included hotels, motels, cloisters, dormitories and similar.
e. Included stores, drugstores, petrol stations, post-offices and similar.

2.3. Energy efficiency in buildings

CIBSE (1998) states that new low-energy buildings consume 50% less energy than similar existing buildings. In an attempt to reduce the energy consumption in buildings, many monitoring projects have been carried out and many buildings all over the world have been successfully retrofitted. As a result, the artificial lighting system, which, as seen in the previous section, accounts for high amounts of energy consumption, is one of the easiest systems to be retrofitted in a building. Technical products in this field have been developing quickly and new products are reaching the market every day.

BLEEKER (1993) presents some examples about optimisation of lighting systems through the use of new technologies in fluorescent lamps. Very attractive payback periods are shown. However, there is no mention about lighting power density, illuminance levels or luminous efficiency of the whole system or even about daylight integration.

NE'EMAN & SHRIFTEILIG (1980) present a very interesting article related to the use of daylight as a way of controlling energy waste and providing welfare to the building users. In contrast to other publications, the authors report that *"it should be emphasized that the artificial lighting of buildings is not among the heavy consumers of energy"* – a point of disagreement with other researchers as shown by the data presented in the previous section.

LANCASHIRE & FOX (1996) use the Frank J. Lausche State Office Building in the USA as an example of the EPA's[1] Energy Star Building Showcase programme. Information about lighting and air-conditioning systems are presented to show that it is possible to obtain energy savings through the use of energy-efficient technologies. However, no information about daylight use is presented.

2.3.1. Daylighting systems

This section presents a brief description about some innovative daylighting systems that have been developed aiming to improve daylight use in buildings and in some cases some misconceptions are discussed.

Many daylighting systems have been developed over the last decades and much information can be obtained from books and guides such as CIBSE (1999), COMMISSION OF THE EUROPEAN COMMUNITIES (1993), TREGENZA & LOE

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[1] EPA stands for Environmental Protection Agency of the United States of America.

(1998), BELL & BURT (1995), and CRISP et al. (1988). LITTLEFAIR (1996) presents a review about innovative daylighting systems that have been used in buildings; the author also provides guidance on daylight design.

It is widely reported that in deep rooms daylight is not effective. In this sense, NE'EMAN & SHRIFTEILIG (1980) report that even with a fully glazed external wall the effectiveness of daylight occurs no more than 3 to 5 times the floor to ceiling height into the room.

TOMBAZIS & PREUSS (1998) describe the design, energy consumption and environmental features of an office building in Athens. The basis for the best exploitation of daylight is the narrow layout of the building, which restricts standard offices depth to 3.0 metres.

KNOLL & WELTEKE (1990) discuss the use of sun and wind as renewable energy sources to supply a house that served on a demonstration project in Germany. The two energy sources that supplied the house satisfy the heating, hot water and ventilation demand. However, on the subject of energy efficient lighting, the only attempt to obtain energy efficiency was the use of *"low-consumption light-bulbs that combine durability and economic advantages"*. There is no mention of an adequate lighting design or effective daylight use – two essential approaches to attain an energy efficient lighting system.

FAUCHER (1980) reported on a system composed of mirrors and diffusers called lumiducts, which intended to provide daylight to internal rooms. In this system, the first tracking mirror reflects sunlight towards a second mirror and so on until the sunlight reaches mirrors placed inside the lumiduct; and finally the sunlight is then scattered by a diffuser. Faucher identifies advantages and disadvantages of the system, though issues relating to solar spectrum are not mentioned. Carrying the entire solar spectrum to inner spaces also increases the heat loads, which may increase the air-conditioning use.

COHEN et al. (1990) reported on a passive solar design aimed to improve the energy efficiency of a single storey primary school in Berkshire, England. Daylight is taken into account through windows and roof-lights. Although the artificial lighting system is manually controlled, daylight is predicted to provide 52% of the total lighting demand.

ANDERSON & THOMPSON (1998) analysed the effect of 3 types of net curtain on the daylight factor in a domestic room of 4.8 metres in depth. Data was taken under eight conditions ranging from morning to afternoon, clear sky to overcast. Although the illuminance levels obtained with curtains are higher than without curtains at 10 measuring points out of a total of 200 measured points, the authors concluded that *“net curtains can provide considerable increases in Daylight Factor of up to 80% at distances over 3 metres from the window”.*

Light shelves are supposed to shade and reduce daylight near the window and to increase it in deeper parts of the room. In this sense, IWATA et al. (1998) verified the contribution of light shelves on energy savings through subjective response of people and using scale models. It was found that for a classroom measuring 11.0m width, 9.0m depth and 3.0m height, that “daylight colour” dimmable tubes could reduce electric consumption by 45% on a clear day in the winter while “white colour” could reduce it by 35%.

AIZLEWOOD (1993) presents the results from 18 months of experimental work on four innovative daylighting systems that were designed to even out the uneven daylighting effects provided by traditional windows. The four systems were evaluated under a range of different sun positions and sky conditions. Two mock offices were constructed; each was 9.0m deep, 3.0m wide, and 2.7m high. Both were painted and carpeted with the same materials to achieve two identical rooms. One room had conventional glazing, while the other was adapted to allow for the installation of an innovative daylighting system. The four systems tested were: internal light shelf, prismatic glazing, mirrored louvres, and a prismatic film system. Results showed that the prismatic glazing system was the only one to provide a large increase in illuminance at the back of the room. However, this increasing was verified only over a few days of the year and performed worse than the light shelves or prismatic film under cloudy conditions.

EAMES & NORTON (1994) presented a compound parabolic concentrating (CPC) reflector design to be employed in a daylight-enhancing window system. Such a device is designed to accept direct sunlight at solar altitude angles within the range -5^o to 65^o with no requirement of adjustment of orientation. Computer simulations were performed to illustrate the optical behaviour of the reflector blind. The conclusion of this article states that the reflector blind enabled daylight to penetrate deeply into rooms mainly through ceiling reflection. However, no information about the real increase of either daylight levels or costs is given.

CRESSWELL et al. (1995) evaluated an interior core daylighting system (similar to an internal light shelf) for a typical high-rise office building. A 4-6m deep, south-oriented light-guide system with a 31.0m by 0.9m cross section was used to provide daylight to a 12.2m deep interior core area (39% of the whole interior core). The evaluation was performed through simulations using DOE 2.1D for 3 cities in the United States: Edmonton, Boston, and Fort Worth. The authors concluded that such a system could transmit enough daylight to reduce the average lighting requirements of that 12.2m deep interior core area by 44% in Edmonton, 59% in Boston, and 66% in Fort Worth. However, the payback periods are about 10 years in Boston and Fort Worth, and over 20 years in Edmonton. As the core area taken into account represents only 20% of the built area (not commented by the authors), the total energy reduction in the building will be 8.8% in Edmonton, 11.8% in Boston, and 13.2% in Fort Worth. With these low percentages it is more than evident that the payback periods will be much longer.

DUGUAY & EDGAR (1977) presented a sun track concentrator that used mirrors and lenses that could provide daylight over a 3m x 5m room with an efficiency of 30%.

FRAAS et al. (1983) presented a theoretical analysis about the use of tracking concentrators and fibre optics in order to carry daylight to the working surface. Although, no experimental work is presented, the authors concluded that such a system, with a payback of 3.2 years, could be economically viable in the South-western United States.

SHARPLES et al. (2001) investigated the effect of urban air pollution on window daylight transmittance in buildings in Sheffield, UK. It was reported that the loss in transmittance due to dust deposition on vertical windows (single- and double-glazed) did not usually exceed 10%. For offices, the reduction in glazing transmittance ranged from 3% to 10%, with most windows showing a 3% reduction.

BODART & DE HERDE (2002) investigated the integration of daylight with artificial lighting using a daylighting simulation tool (ADELINE) and a dynamic thermal simulation software (TRNSYS). The simulations were performed for room widths of 2.7, 3.6, 4.5 and 5.4m and constant depth and height of 5.4m and 3.0m, respectively. It was reported that when the room width increases, the artificial lighting consumption per floor area decreases; and also that the energy savings on artificial lighting ranges from 50% to 80%, for a glazing having a luminous transmission of 60%.

Although much research has been done showing the benefits of integrating daylight and artificial light, many buildings in most countries still do not present any integration of both systems. LAM (2000) states that a survey of 146 commercial buildings to gather information about the predominant architectural designs and construction practices in Hong Kong revealed that none of the buildings surveyed incorporated any energy-saving daylighting scheme.

2.3.2. Luminous efficacy

This section presents a comparison of the luminous efficacy of daylight and of some artificial sources.

LITTLEFAIR (1985) presents a wide review on measured and calculated luminous efficacy of daylight obtained by different authors in various parts of the world. A summary of measured data is presented in Table 2.9 together with luminous efficacy measured in Garston, England, for one year as presented in LITTLEFAIR (1988).

Table 2.9. Measured average luminous efficacies of daylight.

Source	Luminous efficacy (lm/W)	
	Garston data	Other locations
Direct sun (solar altitude 10°)	70	55-90
Direct sun (solar altitude 60°)	95	100-110
Clear sky diffuse	144±7	120-140
Clear sky global	107±5	95-115
Overcast sky	115±8	105-120
Average diffuse	120±6	105-120
Average global	109±5	100-115

As for sources of artificial light, Table 2.10 shows the luminous efficacy of some lamps, as reported by EPRI (1992).

The comparison of luminous efficacy shown in Tables 2.9 and 2.10 demonstrates that daylight has a higher efficacy, which signifies a lower cooling load in the building. "*Since light is part of the radiant energy spectrum, its presence in a building or rather the absorption of that light by surfaces, constitutes a heat input. This is so not only for direct sunlight, but also for diffuse daylight.*" (BAKER, 1987).

Table 2.10. Luminous efficacy of artificil light sources.

Lamp type	Luminous efficacy (lm/W)
Standard incandescent	5-20
Tungsten Halogen	15-25
Halogen Infrared Reflecting	20-35
Mercury Vapour	25-50
Compact Fluorescent (5-26 watts)	20-55
Compact Fluorescent (27-40 watts)	50-80
Full-size fluorescent	60-100
Metal Halide	45-100
Compact Metal Halide	45-80
High Pressure Sodium	45-110
White Sodium	35-55

2.3.3. Window area

A proper assessment of the window area of buildings is essential in order to optimise energy efficiency when there is integration of daylight and artificial light in the building. BELL & BURT (1995) present a review about daylight in building design and give guidance on the design of windows and rooflights. Research was carried out both on existing buildings and in experiments that allowed observers to adjust the sizes of windows in large-scale models. It was found that there is a threshold size below which windows do not provide a sufficient view, depending on how far one is from the window. These critical minimum window sizes for when windows are restricted to one wall are given in Table 2.11. The same minimum window areas are recommended in the *Code of practice of daylighting* of the British Standard (BS 8206-2, 1992).

Table 2.11. Minimum glazed areas for view.

Maximum depth of room (distance from window wall)	Minimum area of window wall (as seen from inside)
< 8m	20%
8-11m	25%
11-14m	30%
>14m	35%

CIBSE (1998) states that to minimise energy consumption in buildings, window area should be limited and suggest 30% of the main façade area as a reasonable window size.

BOUBEKRI & BOYER (1992) evaluated the effect of window size on glare and verified that with only a low level of statistical significance, window size affects glare when the observer is facing the window. Through regression analysis the authors found that the change of window size explains only 29.9% of the variation in perceived glare. For a lateral position the effect of window size on glare was verified to be insignificant.

2.3.4. Lighting load

Energy cannot be created or destroyed, only its form can be changed. Therefore, energy used to operate artificial lighting systems will be changed into light and heat, it must also be understood that the visible spectrum, with wavelengths between 380 and 780nm, is situated within the thermal radiation range. In this way, part of the light will also become heat. *"All electrical energy used by a lamp is ultimately released as heat."* (CIBSE, 1986).

The heat generated by artificial lighting systems that has to be removed by mechanical cooling is called "lighting cooling load" i.e. it is heat produced that has to be removed to keep comfort levels, and "lighting heating load" when the heat helps to maintain comfort levels. Lighting load is usually presented as a percentage of the total heating sources in the building, natural or artificial, and therefore depends on many factors such as weather conditions, wattage installed in the building, area of windows and the fabric of external walls and roof, number of users etc.

LANCASHIRE & FOX (1996) report that in a typical office building, lighting generates 40% to 60% of the total internal cooling load. PARKER et al. (1997), through simulations of a specific building located in Orlando, in the USA, found that approximately 30% of the cooling load is due to artificial lighting.

IESNA (1995) presents the heat produced by artificial lighting, in general, as responsible for 15% to 20% of the total building cooling load.

2.3.5. Lighting control

New technologies which can promote the efficient integration of daylight have been developed. These comprise daylight-linked photoelectric switching, time switching, and localised manual control (LITTLEFAIR, 1990). Case studies reported by CRISP & URE (1980) resulted in 40% savings in lighting energy use in an open plan office whose control system combined all three of the above operation systems.

LITTLEFAIR (1999a,b) reports that a problem with this type of control has been user reaction to its operation. People do not like automatic controls which switch lights on when they could have been off under manual control. It is also mentioned that in spaces like offices, classrooms and residential accommodation switching on should be done manually, even if a daylight-linked automatic switch-off is provided. In a series of surveys of lighting controls in offices it was reported that where photoelectric controls had been installed, they had been disconnected (SLATER et al., 1996).

LITTLEFAIR (1999a) reports that a special problem with photoelectric switches is the rapid switching of lights on and off when daylight levels happen to fluctuate around the switching illuminance; this can annoy occupants and reduce lamp life. In the paper, techniques that have been developed to reduce this problem are described. Photoelectric dimming control, although more expensive and more complicated to install, should save more energy. However, problems have been reported. These include poor operation of the system when a single photocell controls a wide area of the building with different daylight levels in different locations, as well as inappropriate control algorithms which cannot maintain the required illuminance on the working surface.

GUGLIERMETTI et al. (2001) also acknowledges that many applications of lighting control systems do not conform to the design predicted energy savings due to occupant interaction.

EHRLICH et al. (2001) acknowledge that the use of photosensor-based lighting controls has been generally unreliable because of the significant effort required to properly place and calibrate the photosensor system and that the unreliability of such control systems constitutes a significant market barrier preventing widespread acceptance of daylight dimming controls in commercial buildings. The authors also describe a method to simulate the performance of photosensor-based controls, its validation and possible applications for designing, placing, calibrating and commissioning such controls.

Regarding commissioning of lighting controls, LITTLEFAIR (1999b) reports that this is particularly important because if the system does not perform properly there will be not only poor energy savings, but also occupant complaints and eventually system disconnection.

2.3.6. Prediction of energy savings on lighting

LITTLEFAIR (1990) evaluates four methods for calculating the distribution of internal daylight illuminances as this is an important parameter in the prediction of artificial lighting use. In order to test the methods, illuminance levels collected at Garston, England were used. These methods give the cumulative distribution of internal daylight illuminances. The first method, which was developed by HUNT (1977), is the traditional way of estimating the energy consumption of photoelectrically controlled lighting. The internal illuminances are calculated by multiplying the daylight factors obtained from the CIE[2] overcast sky with external horizontal illuminances. As this sky presents a relatively dark horizon and its luminance does not vary with azimuth, it will tend to underestimate illuminances and the effect of orientation. To take into account the different amounts of daylight entering rooms of different orientations, a second method, proposed in BRE Digest (1985), suggests the use of orientation factors. A third method, based on the BRE Average Sky, though complex, is the most accurate one as it considers luminance distribution for each particular sun position. A fourth method is based on research done by TREGENZA (1980), in which empirical results indicated that daylight levels in a side-lit room might be more proportional to the amount of daylight falling on the window, rather than to the external horizontal daylight illuminance. Therefore, this method consists of obtaining the internal illuminance distribution using the cumulative distribution of vertical illuminances on the window wall with a multiplying factor, which is the ratio of internal illuminance to vertical external illuminance under a CIE overcast sky. LITTLEFAIR (1990) concluded from the analysis that the standard method, which uses horizontal diffuse illuminances multiplied by daylight factors, can give large errors for certain window wall orientations. For the model room studied by Littlefair, the three alternative methods gave better approximations to internal illuminances.

In another work, LITTLEFAIR (1992) examined various methods for predicting hourly internal daylight illuminances for use in large environmental modelling computer programmes. It was reported that because the CIE overcast sky has a relatively dark horizon, it tends to underestimate internal illuminances in side-lit rooms by 24% on average throughout the year. The author of the paper acknowledges that none of the methods tested were by any means perfect and that further development of

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[2] CIE stands for Commission Internationale de L'Éclairage.

the sky luminance models would require long-term monitoring of sky luminance distribution. It was also mentioned that daylight factor methods are the simplest and most versatile.

TREGENZA (1980) also reports that based on weather conditions measured between May 1978 and July 1979, the recorded internal to external illuminance ratio varied widely and therefore a calculated daylight factor would have been a poor predictor of the horizontal illuminance in the model rooms considered in the work; the prediction of internal illuminance based on a daylight factor calculation tend to be underestimated.

Despite the above reports, AIZLEWOOD (1998) states that for the UK climate, the overcast sky is applicable for much of the year and has been adopted as the basis of most daylight design. Also WILSON (1998) reports that for the prediction of daylight factors under overcast skies, the CIE standard overcast sky is almost universally used.

Many algorithms for the calculation of daylight availability have been developed and a compilation of these can be found in TREGENZA & SHARPLES (1995). KITTLER et al. (1997) defined a set of standard skies to be applied in various aspects of energy conscious window design, daylight calculation methods and computer programmes.

2.4. Dynamic thermal modelling programmes

The purpose of this section is to present a brief review on the development and application of computer programmes used to evaluate thermal and energy aspects of a building performance.

The introduction of computer programmes for building simulations has helped architects and building services engineers to achieve a better thermal and energy performance in buildings as they facilitate the evaluation of building components and use. Previous manual calculations were likely to result in oversized plant and system capacities, inducing an inadequate energy performance.

According to HONG et al. (2000), building simulation started in the 1960s and became an important subject within the energy research community in the 1970s, when most of the research was dedicated to fundamental theory and algorithms of load and energy estimation.

Following the oil crisis in the early 1970s, countries like the USA and the UK allocated resources to the development of projects on energy conservation and computer simulation with programmes such as DOE-2 and ESP-r being developed. Also, growing concern about environmental matters, such as global warming and the destruction of the ozone layer at the beginning of the 1990s, induced building professionals to try to reduce energy consumption and therefore the negative impact on the environment. Thus, building simulation programmes started being used in professional practice. Many programmes were developed world wide, some with specific objectives.

For example, the ESP-r programme, which was developed and distributed by a consortium primarily based at the Energy Systems Research Unit, University of Strathclyde, allows an in-depth appraisal of the factors which influence the energy and environmental performance of buildings. The ESP-r system has been the subject of sustained developments since 1974 and enables the designer to explore the relationships between the form of the building, fabric, air flow, plant and control. ESP-r is based on a finite volume, conservation approach in which a problem is transformed into a set of conservation equations which are then integrated at successive time-steps in response to climate, occupant and control system influences (ESRU, 2000).

DOE-2, whose development was sponsored by the US Department of Energy, performs an hourly simulation of the energy consumption of buildings provided that a description of the geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, etc.), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs, and hourly weather data are known (WINKELMANN et al., 1993). It was first released in 1979 and has since been widely used in the USA and in more than forty countries (HONG et al., 2000). The DOE programme can also be used to analyse energy efficiency of given designs or efficiency of new technologies.

Both DOE-2 and ESP-r are based on a UNIX® operation system, which may be a limitation, as this requires time to build a model and also to perform the simulation. Hence, some adaptations, such as adding interfaces to make the DOE programme more friendly, were undertaken by the private sector in the USA. VisualDOE resulted from this and is a commercial version with a graphic interface developed by ELEY ASSOCIATES (1995) that utilises the DOE-2.1E calculating engine but works with the WINDOWS® operation system.

The VisualDOE programme allows rapid development of energy simulations, reducing the time required to build a DOE-2 model. Specifying the building geometry is much faster than other comparable software, making VisualDOE useful for schematic design studies of the building envelope or HVAC systems (ELEY ASSOCIATES, 1995). VisualDOE also implements the daylighting calculations from DOE-2, making it possible to evaluate the integration of daylight with the artificial lighting system.

The VisualDOE programme was therefore chosen to be used in this work because it offers a great capability for simulating a wide range of design features and energy conservation measures including integration of daylight with artificial light, and because it has been validated for accuracy and consistency. VisualDOE 2.6 was the version of the programme that was used to run the simulations presented in this work.

2.4.1. Validation of the DOE programme

As VisualDOE was the programme selected to be used in this work, and as it utilises the DOE calculating engine, this section presents work published on the validation of the DOE programme.

Validations carried out by Los Alamos National Laboratory, Lawrence Berkeley National Laboratory and some universities show that the DOE-2 programme can accurately predict energy use in real buildings. Such validations give users confidence that the results obtained from DOE-2 are reliable for buildings that are accurately modelled. More information about such validations can be obtained from MELDEM & WINKELMANN (1995), DIAMOND et al. (1986), and DIAMOND et al. (1981). One must assume that user experience of the programme is appropriate and essential to getting reliable results.

MELDEM & WINKELMANN (1995) report on a validation of DOE-2.1E concerning the thermal analysis of some test houses in Pala, California. To validate DOE-2.1E, results from simulations using the programme were compared with room air temperature measurements in a low-mass house and in a high-mass house. To test different aspects of the DOE-2 calculation, four different unoccupied, unconditioned thermal configurations of these houses were considered: unshaded windows, shaded windows, white exterior surfaces, and forced night ventilation. It is reported that the results obtained from DOE-2 agreed well with the air temperature measurement in all cases, with a mean deviation between simulation and measurement ranging from 0.2 to 1.0 degree Kelvin.

SCHRUM & PARKER (1996) worked on a validation of DOE-2.1E related to the application of daylight dimming systems and the effect of window orientation and blinds on energy savings. The research was carried out using the Daylighting Test

Facility located in Florida, USA. To evaluate the impact of blinds on dimming savings, the energy consumption was compared in two pairs of offices for all four window orientations: north, south, east and west. The study showed that daylight dimming systems can provide significant energy savings ranging from 24% to 51% depending on the orientation and whether the office had blinds. The simulation of the offices using DOE-2.1E agreed with measurements to within 17.4%. For offices with no blinds the percent difference between measured and simulated energy consumption ranged between –7.9% and 6.0%; and for offices with blinds, it ranged between 3.9% and 17.4%.

ASHRAE (1987) states that it is usually difficult to match the metered energy consumption with simulations and results within 10% to 20% in any month are considered adequate.

ZMEUREANU et al. (1995) analysed some works related to simulation of buildings and found out that the average difference between measured and simulated values of monthly energy consumption lies between 5% and 24%.

2.5. Fibre optics

This section presents information related to the physical properties of fibre optics as an attempt to evaluate their capability as a technology to transport light. The section is restricted to reviewing published works on fibre optics, but data on numerical aperture, conversion of attenuation looses from dB/km to %/m, flexibility, life span, and others can be found in Appendix A.

2.5.1. Losses

The longer the light-guide, the greater the light loss. In LIGHTING FUTURES (1995) it is reported that better quality fibres absorb about 1% to 2% per foot, and lower grades absorb 3% to 5% per foot; it depends on the quality and material of the fibre. Some manufacturers claim their large plastic fibres can be run over 100 feet while maintaining high-intensity brightness along the entire length.

Losses are also supposed to occur when fibre optics are joined. However, as fibre optics are manufactured in lengths of 1.5 to 2.0km (UNGAR, 1990), such losses will not be a problem in a building application.

The transmission of light in a fibre optic is determined mainly by the following loss mechanisms.

2.5.1.1. Fresnel losses

These kind of losses occur when the input and output media are of refractive indices different from the core. For fibre optics suspended in air these losses amount to around 10% (ALLAN, 1980). TIMSON & GREGSON (1994) mention these losses as being 8% for silica fibres and 11% for glass fibres.

2.5.1.2. Reflection losses

These losses are caused by degradation in the internal reflection process as a result of impurities or inhomogeneities at the core-cladding interface, but are negligible when compared to absorption losses.

2.5.1.3. Scattering losses

These losses occur when inhomogeneities in the core material cause the light to be scattered with the result that some rays may reach the core-cladding interface at a reduced angle of incidence and thus escape from the fibre. This mechanism is not significant in glass fibres but can be serious in plastic ones (ALLAN, 1980).

2.5.1.4. Attenuation losses

These losses are also called absorption losses and are wavelength dependent and thus determine the useful region of the spectrum for any fibre optic. This is the dominant loss mechanism and yields transmissions that vary exponentially with fibre length.

ALLAN (1980) reported that research had helped to reduce absorption losses from about 1000dB/km to between 5 and 20dB/km for some recently produced glasses. The development in the fibre optics field has been wide and in a book published in 1990, it is stated that attenuation losses varied from 0.15 to 5dB/km (YEH, 1990).

2.5.2. Comparison between glass and plastic fibres

It is difficult to state which fibre type (glass or plastic) is better. In general, glass has a longer life, but plastic is less expensive. Glass fibres have less light loss, but recently some plastic fibres have been developed that are as good or better than glass in terms of reducing light loss.

Comparing a bundle of small fibres to a single large fibre of the same overall diameter, the large fibre has a shorter life span because it is less flexible, but is more efficient at collecting light. In bundles, light is lost in the dead space between individual fibres, which is usually filled with an adhesive to hold the bundle together (LIGHTING FUTURES, 1995).

Glass fibres basically last indefinitely unless they break. Plastic fibres are less susceptible to breakage, but infrared and ultraviolet energy cause the plastic to deteriorate. Plastic fibre turns yellow and brittle with age; subsequently, light output dims and changes in colour occur.

TIMPSON (1994) states that long lengths of glass fibres result in a gradual loss of blue light, and similar lengths of plastic fibres result in a gradual loss of red light. Therefore, Timpson suggests that fibre lengths less than 10 metres should be used in order to avoid that effect. On the other hand, MORI (1989) states that light can be transmitted through up to 200m of fibre without significant change in the shape of the spectrum of the output light.

SIKKENS & ANSEMS (1993) state that attenuation losses vary from 0.1 to 0.4dB/m for plastic fibres, and from 0.2 to 0.6dB/m for glass fibres.

Regarding fire hazard, TIMPSON (1994) states that plastic fibres need careful considerations because the fibre core itself is a smoke and fire hazard.

2.5.3. Current use of fibre optics

This section presents data related to reported case studies using fibre optics. In most of the cases, the fibre optic system used an artificial light as its source, which may not be an energy efficient approach as claimed by many manufacturers. Some misconceptions related to the use of fibre optics in artificial lighting systems can be found in some references and will be discussed in this section.

BARDEN (1996) comments on the increasing applications for fibre optic lighting and the lack of standard methods to describe such technology.

KAY (1999) mentions that *“all light, whether natural or artificial, is injurious to fugitive organic materials if allowed to play on them long enough. Some types of light, however, like fiber optics, are much safer than others”*. It is well-known that organic materials are damaged by ultra-violet and infrared rays and not by light. The author also reports that fibre optic systems are cool, or eliminate destructive heat and ultraviolet rays produced by artificial light. However, the author does not mention about fibre optic wavelength transmission. When discussing about the heat produced by lamps, Kay states that if in conventional systems the heat is not properly disposed, problems such as lamp life shorten and fire risk can increase. It is also stated in the book that *"These problems are absent with fiber optics because no heat is introduced into the area being lit"*. These statements are composed of misconceptions and the information concerning fibre optics and their physical properties presented in Appendix A help to clarify the situation.

Many examples about fibre optic applications are also presented in KAY (1999). However, no information about lighting power density (W/m^2) or about illuminance levels (lux) or about the luminous efficacy (lm/W) of the whole lighting system is presented. Illuminance levels are presented only in some cases. It is interesting to note that no comparisons with conventional lighting systems are performed to prove that fibre optics systems comprise a new technology that can really improve energy efficiency in buildings.

An independent lighting consultant, in ANON (1995a) also classifies fibre optics as a light source. In the same article, the author discusses about innovation in food displays because *"fibre optics lack heat and size"*. In ANON (1995b) it is also said *"…fibre optics provide flexible light without power, heat…"*. There seems to be a general misconception about fibre optics and heat or a great effort to induce clients to think that such a technology is heat-free. In reality, the heat produced by the light bulb used in a fibre optic system will be incorporated to the building like in conventional systems.

An example of a restaurant where fibre optics were used is presented in ANON (1995c). However, no information about lighting power density, luminous efficacy of the system, or illuminance levels is presented. Through a photograph it is possible to notice that the restaurant is very well lit, but there is plenty of daylight coming in through large windows and nothing is reported about this.

Another example of fibre optic application is the auditorium of the *Campo de las Naciones*, a convention centre in Madrid (ANON, 1996a). Around 2400m^2 of space were lit through the use of metal halide lamps and fibre optics, but there is no information about illuminance levels achieved or the lighting power density.

In the wine department of a store, through the use of four 150W metal halide lamps and fibre optics, illuminance levels of 1200lux were achieved in the shelves (ANON, 1996b). However, there is no information about the lighting power of a conventional system needed to obtain the same illuminance levels.

KAY (1999) presents an example where replacing 8-50W lamps that consume 420W (lamp plus ballast) by a fibre optic system operating with a 150W metal halide lamp that consumes 172W there is a saving of 60% on the energy consumption. However, the reduction of 60% is experienced on the power density, not on the consumption as stated; and there is no mention about illuminance levels provided by both systems, or about the whole system luminous efficiency, or a comparison of payback periods.

The efficiency of a fibre optic artificial light source system depends on the lumen output of the source, on the size of the fibre bundle and on the number of cables connected to the light source. TIMPSON (1994) states that *"an example of the current industry standards for 6mm diameter bundles with 12 tails connected to a 150W metal halide source would deliver approximately 100 lumens at the extremity of a 5 metre fibre run"*. It should be noticed that metal halide lamps present a high lumen output, and a 150W metal halide lamp delivers 13,500 lumens (EPRI, 1993), which means that the system described by Timpson has an efficiency of only 0.74%.

ROPER & BROWN (2000) present some case studies in their Fibre Optic Lighting Guide. Data concerning the type and wattage of lamps, and costs are presented in Table 2.12. It can be observed that the total cost of the projects ranged from £7,700 (Case 5) to £90,000 (Case 4).

Table 2.12. Costs for installing fibre optics systems.

Case study	Light source			Material	Costs (£)	
	Type	Power	No. sources		Capital	Installation
1	Metal halide	150W	7	Glass fibre	14,000	2,000
2	Tungsten halogen	150W	3	Glass fibre	8,000	1,500
3	Metal halide	150W	8	Glass fibre	16,000	Unknown
4	Tungsten halogen	150W	33	Glass fibre	75,000	15,000
5	Metal halide	150W	3	Glass fibre	4,500	3,200

MORI (1989) presents a new technology for utilising sunlight that is composed of Fresnel lenses and fibre optics. Such a system – called Himawari (Japanese for sunflower) – has been used in Japan, with an 18-lens configuration and 10-metre-long fibre optics, and had an efficiency ranging from 20% to 50%. Up to 1989, the year in which that article was published, the Himawari had been used for interior plant growth and in a ship application. In addition, Mori foresaw a breakthrough for urban development, especially in residential areas of Japanese cities, where the right to a minimum amount of sunshine is guaranteed by law.

2.6. Environmental pollution

The operation of buildings through the use of electricity incurs environmental pollution as discussed in Chapter 1. Studies performed by the Intergovernmental Panel on Climate Change and the U.S. Department of Energy show that buildings account for 25-30% of the total energy-related carbon dioxide emissions (WIEL et al., 1998).

Using U. S. Environmental Protection Agency information, LANCASHIRE & FOX (1996) report that the energy required to operate office buildings in the United States of America contributes 16% of the carbon dioxide, 12% of nitrogen oxides, and 22% of the sulphur dioxides released into the atmosphere.

An option against the use of such pollutant resources is to use solar energy. In 1990, passive solar energy supplemented the energy requirements in eight northern countries in the European Community (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, and the United Kingdom) with an equivalent saving of 61 million tonnes of oil equivalent (mtoe) of primary energy a year (BURTON & DOGGART, 1990). The authors also suggest that if action were taken to use such an energy source for heating, cooling and lighting in buildings, then 74mtoe a year could be saved by 2000, and 87mtoe by 2010.

In terms of atmospheric pollution, BURTON & DOGGART (1990) report that in Northern Europe in 1990, passive solar design saved 162 million tonnes of CO_2 a year, 0.7 million tonnes of SO_2 and 0.2 million tonnes of NO_2 to be released into the atmosphere. If solar energy continues to be taken into account, the annual saving in CO_2 production could be 192 million tonnes by 2000 and 223 million tonnes by 2010.

In terms of kilowatt-hours (kWh), LANCASHIRE & FOX (1996) report that each kWh saved prevents the emission of 1.5 pounds (680.39g) of carbon dioxide, 0.20 ounces (5.67g) of sulphur dioxide, and 0.08 ounces (2.27g) of nitrogen oxides. Therefore, it can be noticed that the more energy-efficient a building is, the less environmental pollution will be produced.

Chapter 3

Daylight Provision

3.1. Introduction

This chapter assesses the potential for energy savings on the artificial lighting system of buildings that can be obtained through the integration of daylight coming onto the working surface through the windows. Whether there is an even higher potential for energy savings by applying new technologies, such as fibre optics, to increase the daylight levels in the rear side of rooms is also to be predicted.

Any analyses on innovative daylight systems should be preceded by detailed studies on the provision of daylight coming onto the working surface of rooms through windows, or rooflights. In other words, before deciding for the application of an innovative daylight system, conventional systems should be properly assessed.

It is well known that daylight provision decreases quickly as the distance from the window wall increases and that narrow rooms can get a better daylight supply. But the energy savings that can be obtained as a function of window area and room size are not precisely known. And whether the daylight supply to the rear side of rooms – though low compared to the window end – can provide energy savings on the artificial lighting system is not known either.

The objective of this chapter is to quantify the energy savings that can be made on lighting as a function of the amount of daylight reaching the working surface of spaces through windows. The evaluation is performed through the calculation of Daylight Factors for rooms of different sizes, different window areas, and different room ratios as described in the following sections. The analysis of such energy savings and patterns of Daylight Factors on the working surface of the rooms will indicate the capability of windows on the supply of daylight and whether there is still a potential for energy savings on lighting at the rear side of the rooms where fibre optics could be used to supply daylight.

3.2. Methodology

The methodology presented in this chapter aims to map out the behaviour of Daylight Factors in rooms of different dimensions and different window areas and to estimate energy savings that can be made on the artificial lighting system. The procedure used to calculate the Daylight Factors is the same as presented in HOPKINSON et al. (1966), and in BRE Digest (1986a,b).

Daylight Factors represent the ratio of indoor to outdoor daylight illuminance under a standard overcast sky condition. The Daylight Factor is composed of the total daylight reaching a reference point in the interior of a room and accounts for three components:

a) The sky component: is the daylight on the reference point in the room received directly from the sky.

b) The externally reflected component: is the daylight reflected into the room by any external surfaces.

c) The internally reflected component: is the daylight on the reference point reflected and inter-reflected at the surfaces inside the room.

These three components are calculated separately and the Daylight Factor is obtained by adding them together.

3.2.1. The sky component

There are different methods of calculating the sky component. It can be based on tables, protractors, diagrams, or graphical methods. As it is intended in this work to obtain the Daylight Factor for a large number of points in a large quantity of rooms, it was decided to use the BRS[1] Simplified Daylight Tables (HOPKINSON et al. (1966), and BRE (1986a)).

The CIE overcast sky, which represents a critical design condition, was the sky luminance condition chosen despite underestimating internal illuminance levels as reported in the literature review (LITTLEFAIR, 1992; TREGENZA, 1980). This sky is the one whose horizon is darker than the zenith and its luminance does not vary with azimuth. The use of the BRS Simplified Daylight Tables allowed the calculations to be performed electronically.

The sky component is determined by a geometrical procedure and the BRS

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[1] BRS stands for Building Research Station, which is the former name of the Building Research Establishment.

Simplified Daylight Tables are designed to provide the sky component as a function of the geometry of the window taken at each reference point.

3.2.2. The externally reflected component

The externally reflected component can be calculated by considering the external obstructions visible from the reference point as a patch of sky whose luminance is some fraction of that of the sky obscured (BRE, 1986a). This component is usually calculated as a fraction of the sky component as the luminance of the obstructing surfaces is assumed to be uniform and one-tenth of the average luminance of the sky.

As the luminance of an overcast sky near the horizon is approximately half the average luminance – and this correction has already been considered in the BRS Simplified Daylight Table – the externally reflected component is then obtained dividing the sky component by 5 (BRE, 1986a).

3.2.3. The internally reflected component

The internally reflected component depends upon the reflectances of the walls, ceiling and floor of the room, and upon the amount of daylight that reaches them from the sky and the obstructions and ground outside. The process of reflection and inter-reflection is complex and the amount of inter-reflected daylight varies according to the distance of the reference point from the window. However, as stated in BRE (1986b), for most purposes it is sufficient to assume an average internally reflected component.

Equation 3.1 presents the formula to calculate the average internally reflected component (IRC) for side-lit rooms.

$$\text{Average IRC} = \frac{0.85W}{A(1-R)}\left(CR_{fw} + 5R_{cw}\right) \tag{3.1}$$

Where:

W is the area of window (m^2);

A is the total area of ceiling, floor and walls including area of window (m^2);

R is the average reflectance of ceiling, floor and all walls, including window, expressed as a fraction;

R_{fw} is the average reflectance of the floor and those parts of the walls below the plane of the mid-height of the window, excluding the window wall;

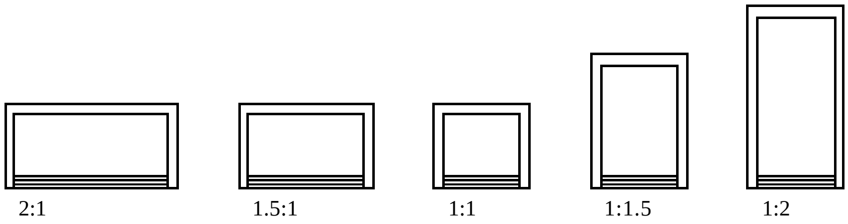
R_{cw} is the average reflectance of the floor and those parts of the walls above the plane of the mid-height of the window, excluding the window wall;

C is a coefficient having values dependent on the obstruction outside the window. As obstructions were not considered, the C coefficient is to be 39 (BRE, 1986b).

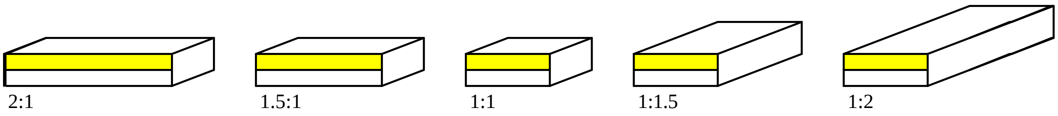
The three described components that compose the Daylight Factor were then calculated on the working surface of different models in order to obtain the potential for energy savings on lighting when there is integration with daylight.

3.2.4. The Models

The models in which the Daylight Factors were calculated comprised of rooms whose ratio of width to depth were 2:1, 1.5:1, 1:1, 1:1.5, and 1:2 as shown in Figure 3.1. These five room ratios were chosen in order to compare the supply of daylight in narrow rooms with the supply in deeper rooms. For reference purposes, the first dimension is related to the wall in which the window is located.



(a) Plan view.



(b) Isometric view.

Figure 3.1. Plan and isometric view of the five room ratios.

In order to evaluate the influence of the size of the room on the supply of daylight, each room ratio was assessed over ten different sizes. So as not to use room sizes obtained at random, the dimensions were calculated as a function of the Room Index (K), as used in lighting design. Such an index represents the relationship between area, perimeter and mounting height between the working surface and the ceiling. There are usually in catalogues ten room indices varying from 0.60 (small rooms) to 5.00 (large rooms). Equation 3.2 presents the room index formula (CIBSE, 1999).

$$K = \frac{WD}{(W + D)h} \tag{3.2}$$

Where:

K	is the room index (non-dimensional);
W	is the overall width of the room (m);
D	is the overall depth of the room (m);
h	is the mounting height between the working surface and the ceiling (m).

Having defined the five room ratios, the width of the room can now be expressed as a function of the depth, or vice versa, and equation 3.2 can be rewritten as follows:

When the room ratio is 1:1, $D = W$, then $W = 2Kh$ (3.3)

When the room ratio is 1:1.5, $D = 1.5W$, then $W = \frac{2.5}{1.5}Kh$ (3.4)

When the room ratio is 1.5:1, $W = 1.5D$, then $D = \frac{2.5}{1.5}Kh$ (3.5)

When the room ratio is 1:2, $D = 2.0W$, then $W = \frac{3.0}{2.0}Kh$ (3.6)

When the room ratio is 2:1, $W = 2.0D$, then $D = \frac{3.0}{2.0}Kh$ (3.7)

Table 3.1 presents the room dimensions for the ten room indices and five room ratios calculated using equations 3.3 to 3.7. The overall height of the rooms is taken as 2.80m and the working surface as 0.75m above floor level so that h = 2.05m.

Table 3.1. Room dimensions for each room index (K) and room ratio.

K	Room ratio									
	2:1		1.5:1		1:1		1:1.5		1:2	
	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)
0.60	3.69	1.85	3.08	2.05	2.46	2.46	2.05	3.08	1.85	3.69
0.80	4.92	2.46	4.10	2.73	3.28	3.28	2.73	4.10	2.46	4.92
1.00	6.15	3.08	5.13	3.42	4.10	4.10	3.42	5.13	3.08	6.15
1.25	7.69	3.84	6.41	4.27	5.13	5.13	4.27	6.41	3.84	7.69
1.50	9.23	4.61	7.69	5.13	6.15	6.15	5.13	7.69	4.61	9.23
2.00	12.30	6.15	10.25	6.83	8.20	8.20	6.83	10.25	6.15	12.30
2.50	15.38	7.69	12.81	8.54	10.25	10.25	8.54	12.81	7.69	15.38
3.00	18.45	9.23	15.38	10.25	12.30	12.30	10.25	15.38	9.23	18.45
4.00	24.60	12.30	20.50	13.67	16.40	16.40	13.67	20.50	12.30	24.60
5.00	30.75	15.38	25.63	17.08	20.50	20.50	17.08	25.63	15.38	30.75

Each room was evaluated with four different glazed areas to one elevation as seen in Figure 3.2. The third window area (73.2%) is the one in which the window sill coincides with the working surface height. As the effect of urban air pollution on window daylight transmittance in buildings is not very significant as presented in the literature review (SHARPLES et al., 2001), this was not be taken into account.

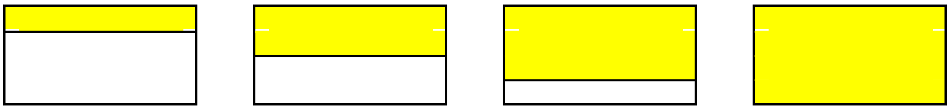

25% 50% 73.2% 100%

Figure 3.2. Window area of the rooms.

Then, to accurately evaluate the distribution of daylight in the rooms, the floor plan of each room was divided into hypothetical rectangles as close to squares of 50x50cm as possible. The Daylight Factor was calculated in the centre of each rectangle. Table 3.2 presents the number of rectangles and their dimensions obtained for each room ratio and room index.

As noted previously, the determination of the internally reflected component depends on the reflectances of the internal surfaces of the space. BS 8206-1 (1985) states that these surfaces should be light in colour to improve the efficiency of the lighting system. But considering that furnishings will contribute to reducing such reflectances, the reflectances of the internal surfaces assumed in the calculation of the Daylight Factors are presented in Table 3.3.

Table 3.2. Number and dimensions of rectangles for each room index and room ratio.

K	Room ratio					
	1:1		1.5:1 & 1:1.5		2:1 & 1:2	
	Number of rectangles	Dimension (cm)	Number of rectangles	Dimension (cm)	Number of rectangles	Dimension (cm)
0.60	25 (5x5)	49x49	24 (4x6)	51x51	28 (4x7)	46x53
0.80	49 (7x7)	47x47	40 (5x8)	55x51	50 (5x10)	49x49
1.00	64 (8x8)	51x51	70 (7x10)	49x51	72 (6x12)	51x51
1.25	100 (10x10)	51x51	117 (9x13)	47x49	120 (8x15)	48x51
1.50	144 (12x12)	51x51	150 (10x15)	51x51	162 (9x18)	51x51
2.00	256 (16x16)	51x51	294 (14x21)	49x49	300 (12x25)	51x49
2.50	441 (21x21)	49x49	442 (17x26)	50x49	465 (15x31)	51x50
3.00	625 (25x25)	49x49	651 (21x31)	49x50	666 (18x37)	51x50
4.00	1089 (33x33)	50x50	1107 (27x41)	51x50	1225 (25x49)	49x50
5.00	1681 (41x41)	50x50	1734 (34x51)	50x50	1922 (31x62)	50x50

Table 3.3. Reflectance of the internal surfaces.

Surface	Reflectance (%)
Wall	50
Ceiling	70
Floor	30
Window	10

As there are five room ratios and each room ratio is assessed in ten different room sizes and four different window areas, the total number of models for which the Daylight Factors were calculated was 200. In total, 95008 Daylight Factors were calculated.

3.2.5. Procedure for estimating energy savings on lighting

Having calculated the Daylight Factors as previously described for each room size and window area, the procedure used to estimate energy savings on the artificial lighting system could then be completed.

As an example, Figure 3.3 shows the Daylight Factors calculated in the centre of each of the 25 rectangles of a square room, whose room index was 0.60, and window area of 73.2%. An estimation of the energy savings that could be made on lighting was based on the following assumptions:

(a) If the lowest calculated Daylight Factor in the room were equal or higher than the design illuminance level, the daylight reaching the working surface in the room would be sufficient to supply the lighting requirement all over the working surface and the artificial lighting system could be switched off.

(b) If the highest calculated Daylight Factor were lower than the design illuminance level, the daylight levels on the working surface would be lower than the requirements, but should not be overlooked as they could lead to energy savings in case of integration of daylight with artificial lighting.

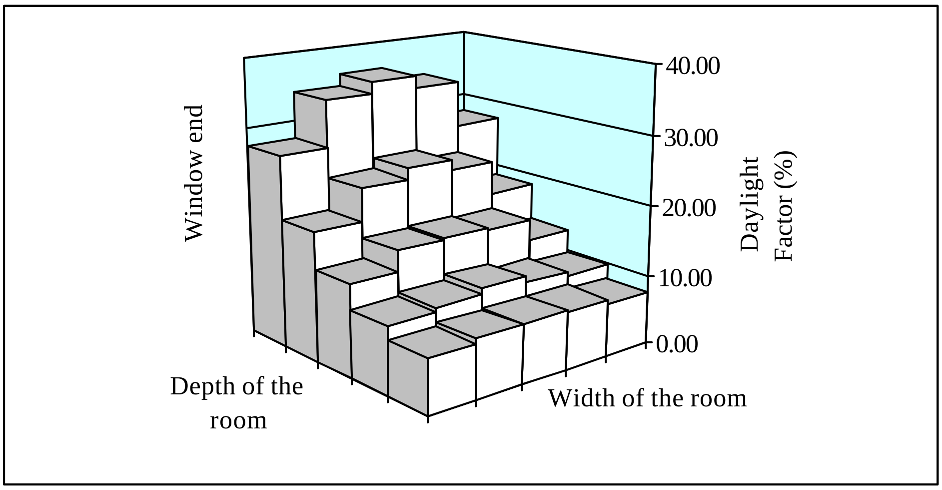


Figure 3.3. Daylight Factors for a square room of room index of 0.60 and window area of 73.2%.

To estimate the energy savings on the artificial lighting system in a room, each Daylight Factor was hypothetically assumed to be a reference value that supplies the requirements of illuminance levels on the working surface, and the other Daylight Factors were compared to the reference value.

Therefore, two assessments were performed in order to estimate the energy savings likely to be achieved on the artificial lighting system. First, the percentage of floor area near the window, in which the Daylight Factors are higher than the reference value, was calculated. And then, for the rest of the room, where the Daylight Factors are lower than the reference value, the percentage contribution of each Daylight Factor compared to the reference value was also calculated. The percentages mentioned above can be easily calculated because each Daylight Factor represents the same fractional area of the room (the rectangles have the same dimensions). Figures 3.4 and 3.5 help to understand the adopted procedure.

In Figure 3.4, when the reference value is, for instance, 16%, there are 13 rectangles whose Daylight Factor is equal to or higher than 16% and these are shown in blue. Therefore, the percentage of the room area in which the artificial lighting system could be switched off is 52%, obtained from the fraction 100x13/25, recalling that 25 is the total number of Daylight Factors (rectangles) calculated in the model.

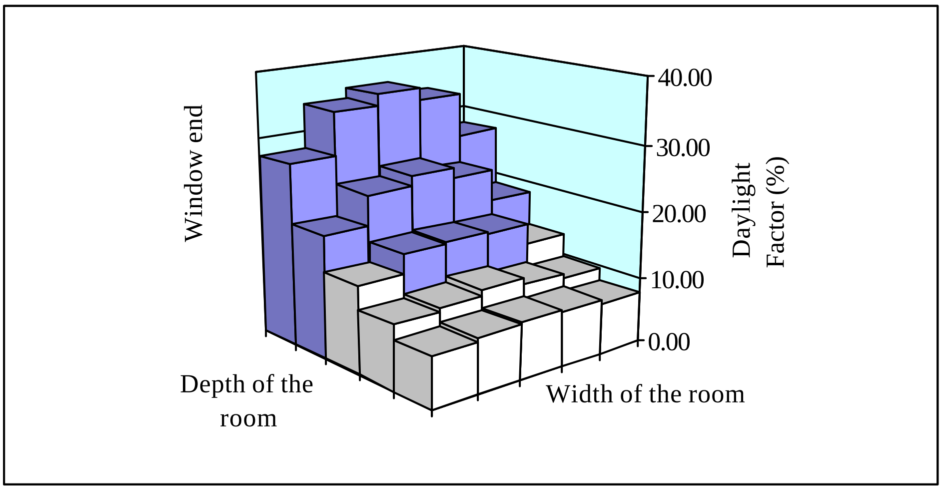


Figure 3.4. Daylight Factors higher than a reference value.

Figure 3.5 shows the Daylight Factors lower than 16% in yellow. It is suggested that the artificial lighting system at the back side of the room be considered to supplement the lighting requirements as the Daylight Factors in this area, though lower than the reference value of 16%, can still contribute to energy savings. This can be evaluated by calculating the percentage contribution of each Daylight Factor lower than the 16% value. For this example, the daylight at the back side of the room, represented by Daylight Factors in yellow, supplies 61.2% of the lighting requirement.

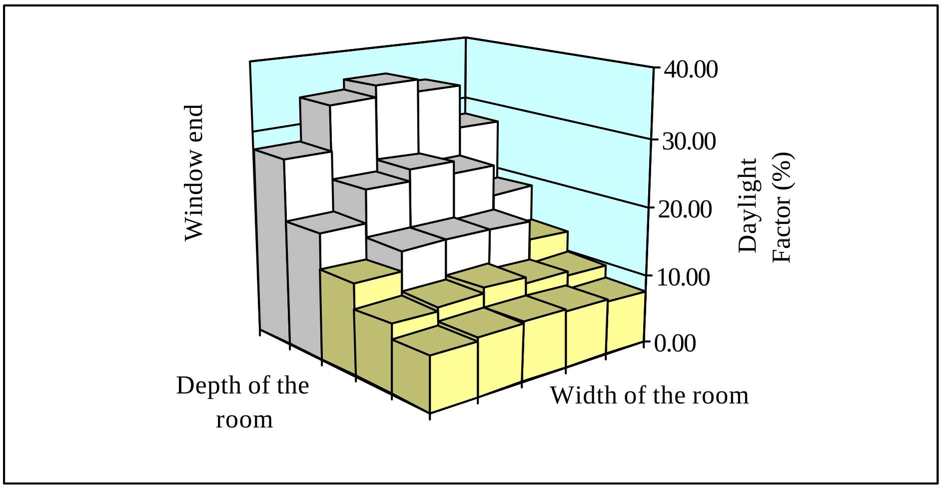


Figure 3.5. Daylight Factors lower than a reference value.

Therefore, taking into account that the artificial lighting system is usually evenly distributed over the ceiling area, the savings calculated through these models can be assumed to represent savings on the artificial lighting system.

For the example presented above, where 52% of the floor area has Daylight Factors higher than the reference value, it can be stated that 100% of the lighting power density (W/m^2) can be assumed to be turned off in 52% of the room area. As for the rest of the room (48% of the floor area), 61.2% of the lighting power density could be switched off. Therefore, the total energy savings on the artificial lighting system for this case would be 81.4% (0.52x1.00+0.48x0.612) for a reference Daylight Factor of 16% and if the room were equipped with a dimmer system.

This procedure is then repeated for each Daylight Factor being considered as the reference value.

3.2.6. Typical design sky

SECKER & LITTLEFAIR (1987) discuss the influence of geographical variation on daylight availability and the problems of predicting daylight based on daylight data of other regions. The authors also suggest that the prediction of daylight can be easily done using luminous efficacy and radiation data.

To assess the energy savings to be made on the lighting system, a reference Daylight Factor value has to be known or estimated. Therefore, besides knowing the illuminance level desired on the working surface, the external illuminance has also to be known. KOENIGSBERGER et al. (1974) present the illuminance of a typical design sky for six locations as shown in Table 3.4.

Table 3.4. Illuminance of a typical design sky for different locations.

Location	Latitude	Illuminance (lux)
London	52^o	5000
Hobart	43^o	5500
Sydney	33^o	8000
Brisbane	27^o	10000
Darwin	10^o	15000
Nairobi	1^o	18000

Therefore, if a design illuminance level of 500lux were considered then the design Daylight Factor would be 10% for London, 5% for Brisbane, etc. This concept of design Daylight Factor will be used in section 3.4.2.

3.3. Validation of the sky component

From the three components that compose the Daylight Factor the sky component is the most important one as it depends on assumptions related to sky conditions. Therefore, to confirm that the calculated Daylight Factors would provide reliable data, a model was built and daylight levels were measured in order to validate the sky component.

The model comprised of a square box of dimensions 41.0x41.0cm and height of 11.2cm, which represents a real room of 10.25x10.25x2.80m reduced to a scale of 1:25. The room index of both the model and the real room is K=2.50. As the objective of this experiment was to validate the sky component, models of any dimensions could have been used provided that the sky components were calculated for a model of same dimensions and conditions.

The internal surfaces of the scale model were painted matt black to avoid reflections as the intention was to determine the sky component only. The daylight levels were measured on a point outside the model and on three reference points inside the model as shown in Figure 3.6.

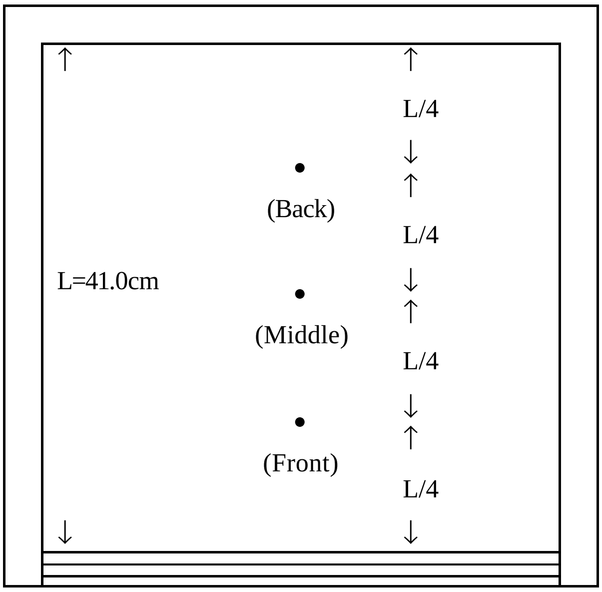


Figure 3.6. Plan view of the model.

The window of the model was not glazed and its height and geometry can be seen in Figure 3.7. The window area considered was 73.2%, and the window sill coincided with the working surface height, which was 3.00cm.

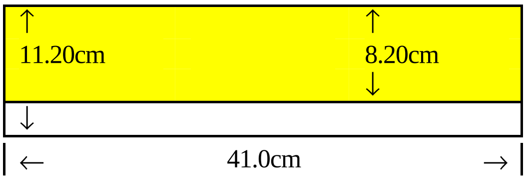


Figure 3.7. Façade of the model.

The daylight measurements were performed between the 22nd and the 25th of February 2000 on the roof of the Civil Engineering Building, at Leeds University. Two new portable luxmeters ‘Testo 545’ were used. A calibration certificate accompanied the luxmeters to confirm that they were calibrated to the requirements of ISO 9001.

As the sky component comprised of a single value at each reference point, it was decided to perform sets of measurements in order to obtain an average sky component at each point and compare the average to the calculated value. Ten sets of measurements, which was considered to provide a reliable average, were taken at each reference point on each of four days over an interval of about 5 minutes. Each internal measurement was immediately followed by an external one, so that the sky component could be calculated. An average value was then calculated for each point.

The differences between measured and calculated sky components are presented in Table 3.5 where it can be seen that the average errors ranged from ±6.7% at the front to ±14.1% at the back of the model. The errors increased towards the back of the model because the sky components were lower and therefore more sensitive to any variations.

Table 3.5. Error between measured and calculated sky component.

Reference point	Error (%) 22/02/00	23/02/00	24/02/00	25/02/00	Average
Front	3.8	-1.8	11.7	-9.5	±6.7
Middle	21.9	1.7	1.1	21.1	±11.5
Back	1.9	-23.9	-18.2	12.5	±14.1

Figure 3.8 shows the measured sky components for the four days and also the calculated values at the same points. The comparison of measured and calculated sky components showed that there is not a significant difference between them. Therefore, the sky components used in the calculations of Daylight Factors are assumed to provide reliable data.

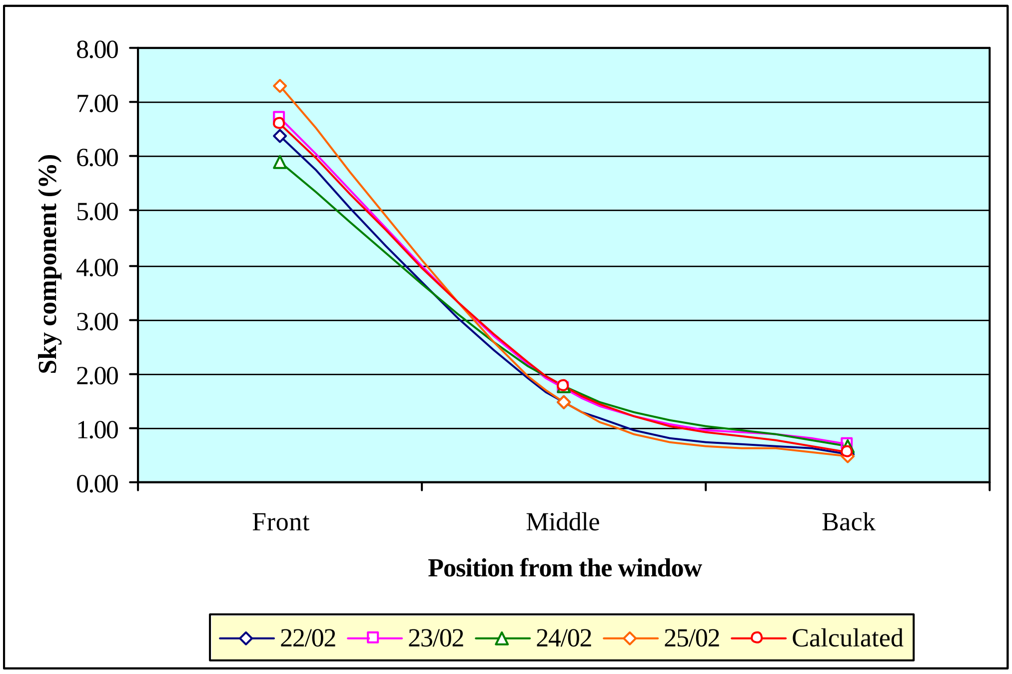


Figure 3.8. Measured versus calculated sky components.

3.4. Results

The results concerning this theoretical investigation into daylight supply, whose methodology has been described, are presented next. Daylight Factors are presented first and followed by a discussion on the potential for energy savings to be made on artificial lighting, that were predicted by analysing the Daylight Factors.

3.4.1. Daylight Factors

Based on the methodology developed in this chapter, the Daylight Factors were calculated for each of the five room ratios, ten room indices and four window areas.

All the calculated Daylight Factors were analysed but to avoid repetition, the results presented in this thesis have been confined to a few examples. Figures 3.9 to 3.12 show the Daylight Factors calculated for each room index and each window area related to the room ratio of 1:1. It can be noticed that the Daylight Factors closer to the window are more sensitive to the increasing of the window area up to 73.2%, which represents a window area in which the window sill coincides with the working surface height. For window areas larger than 73.2% – window area moving down towards the floor, below the working surface level – there is not a significant increase of the Daylight Factors, as the only contribution on the working surface is due to the internal reflected component. Similar trends were observed for all other room ratios.

Figures 3.9 to 3.12 also show that the Daylight Factors in larger rooms are apparently insignificant when compared to the Daylight Factors near the window. This is an indication that there is a potential for energy savings on lighting if a new technology, such as fibre optics, were used to increase the daylight levels in the rear side of large rooms. Even though low, such Daylight Factors can still contribute to energy savings on lighting as it will be shown in the next section.

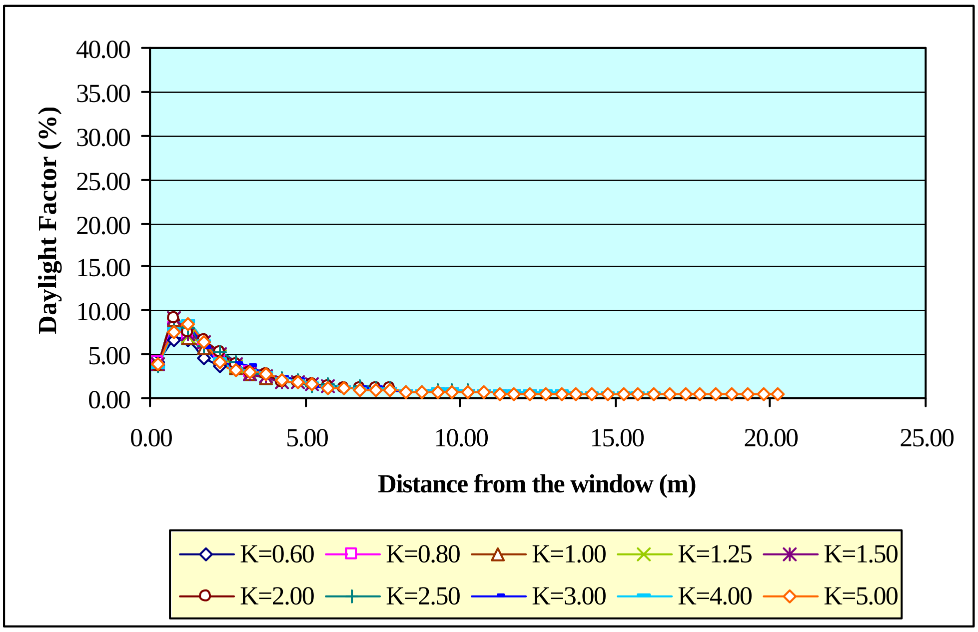


Figure 3.9. Daylight Factors for room ratio of 1:1 and window area of 25%.

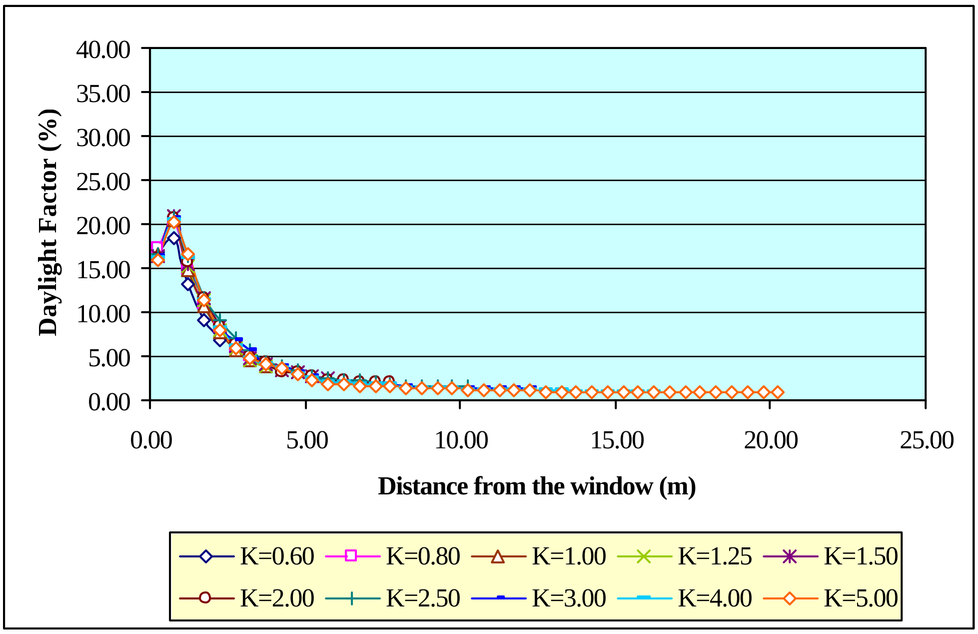


Figure 3.10. Daylight Factors for room ratio of 1:1 and window area of 50%.

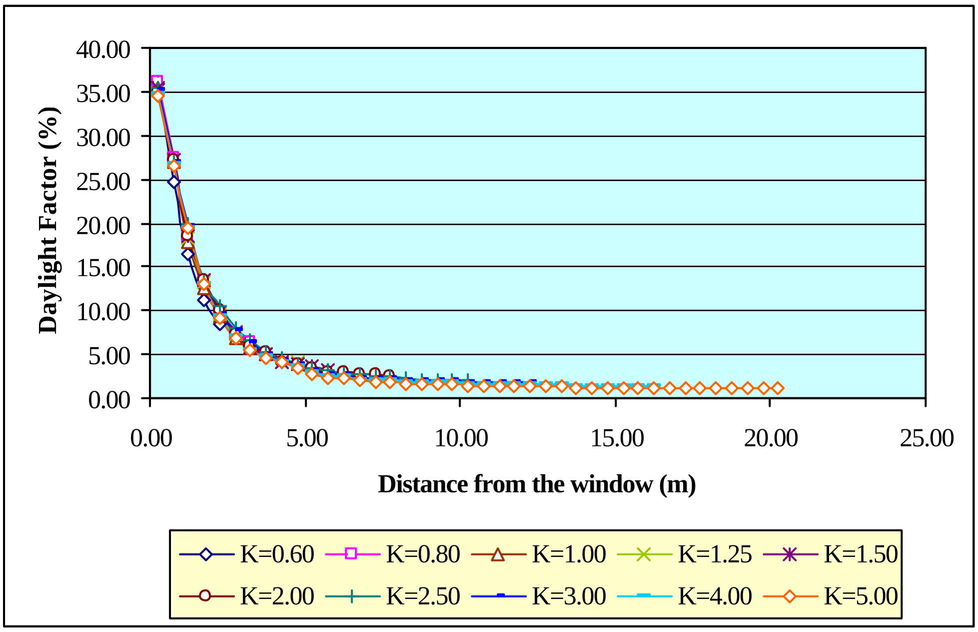


Figure 3.11. Daylight Factors for room ratio of 1:1 and window area of 73.2%.

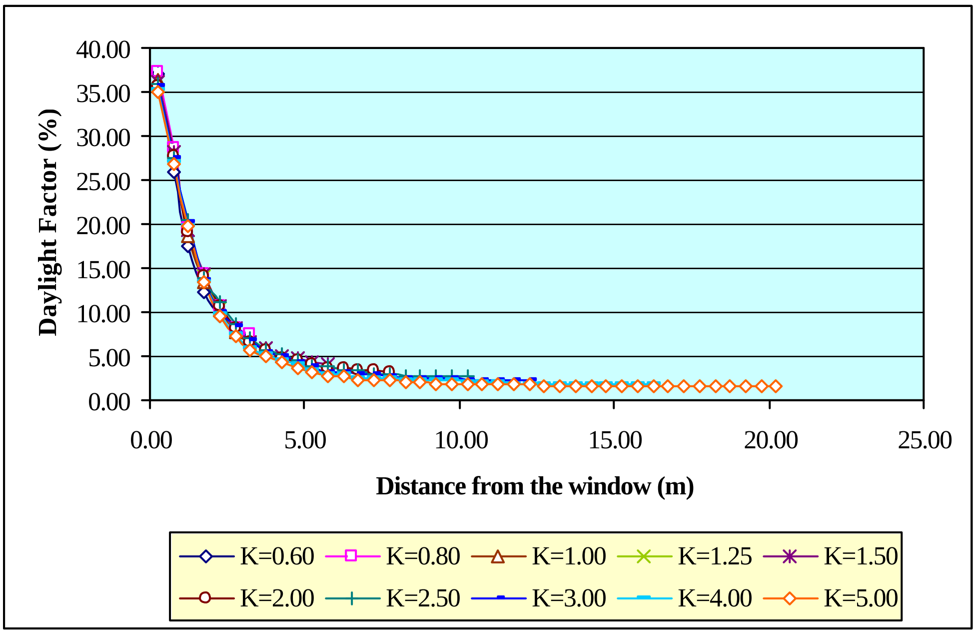


Figure 3.12. Daylight Factors for room ratio of 1:1 and window area of 100%.

To investigate the daylight supply in rooms of different room ratios, Figure 3.13 shows the Daylight Factors calculated on a section at the centre of the room for the five room ratios considered in this work, at a room index of 2.00 and window wall ratio of 50%. As seen in the figure, Daylight Factors are lower for room ratios whose façade is narrower indicating a better potential for fibre optics application.

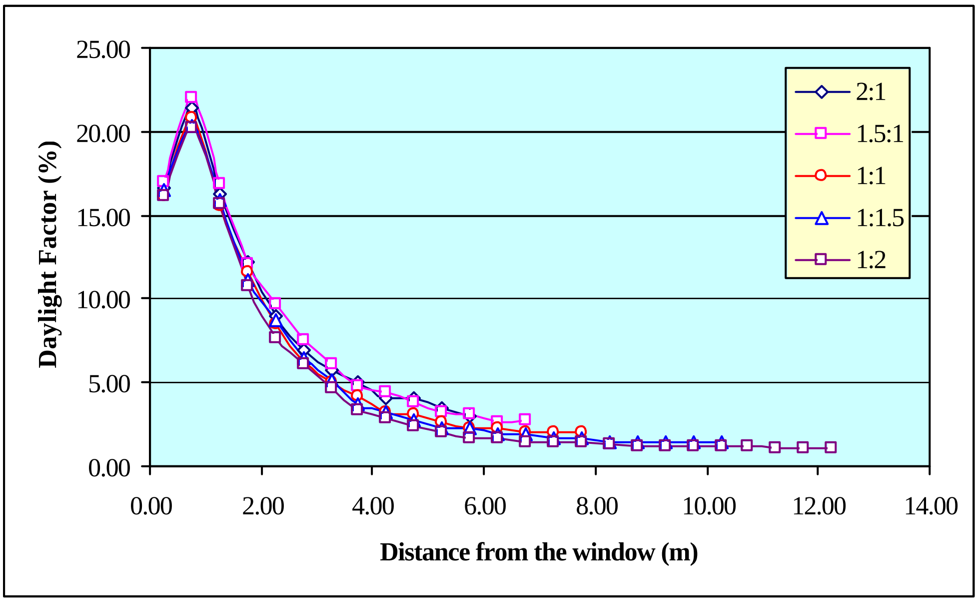


Figure 3.13. Daylight Factors for room index of 2.00 and window area of 50%.

3.4.2. Energy savings

Having calculated the Daylight Factors for all the room sizes, room ratios and window areas, it was then possible to calculate the energy savings on lighting likely to be obtained due to the integration of artificial lighting with daylight coming from the window. The calculation of these energy savings is based on the methodology presented previously in section 3.2.5.

Tables 3.6 to 3.9 present the energy savings on lighting for the room ratios of 2:1 and for the window areas of 25%, 50%, 73.2% and 100%. Tables 3.10 to 3.13 present the energy savings on artificial lighting that were predicted for room ratios of 1:2 and for the same four window areas. The figures presented in these tables are probably underestimated as they are based on Daylight Factors calculated for the CIE overcast sky condition (see section 2.3.6 in the literature review). The results for the other room ratios determined using the methodology previously described can be found in Appendix C.

Prior to discussing the results of energy savings it is important to explain the tables. The A value represents the percentage of the floor area in which the Daylight Factors are higher than the design illuminance level and the artificial lighting could be switched off. The B value represents the percentage of the lighting power density that can be switched off due to daylight reaching the working surface in the rear side of the room. The total value represents the energy savings on lighting likely to be obtained in the room and it was calculated using the formula represented by equation 3.8.

$$\text{Total} = A + (A - 100)\,B \tag{3.8}$$

Therefore, assuming a design illuminance of 500lux and considering a design sky of 5000lux (design Daylight Factor = 10%) – average value for England –, the integration of daylight with artificial lighting would lead to savings of about 64.4% in a room of room ratio of 2:1, room index of 0.60 and window area of 25% (Table 3.6). This shows that the daylight obtained from the window in this case produces significant savings but there is still a potential for more energy savings of about 35.6%, which is the complement to 100%. From the same table, it can be noted that the energy savings on lighting decrease as the room indices increase. For room index of 5.00 the energy savings on lighting would be 19.1%, which means that there is still a potential for energy savings on lighting of 80.9% that could be achieved if more daylight could be transported into the room.

If the same example was assumed to be located in Brazil, with a hypothetical sky illuminance of 10000lux (design Daylight Factor = 5%), the integration of daylight would lead to even higher energy savings on lighting. For a room index of 0.60 the energy savings on lighting would be 97.5% (Table 3.6) indicating that there is an excellent daylight supply from the window and that there is no need to use fibre optics to bring daylight into the room. But for a room ratio of 5.00 the energy savings on lighting due to daylight from the window is about 33.8%, showing that there is a potential for energy savings on lighting through the use of fibre optics of about 66.2%.

Increasing the window area to 50% (Table 3.7), and still considering Daylight Factor = 10%, the energy savings on lighting would increase to 100% (no need for artificial lighting) for a room index of 0.60 and to 32.1% for a room index of 5.00. Still there is a potential for energy savings through the use of fibre optics for larger room indices. Even for window areas of 100% (Table 3.9), there is still a potential for energy savings on lighting by applying fibre optics to transport daylight to the rear side of the rooms.

Considering Tables 3.10 to 3.13 it can be noted that for room ratios of 1:2 the energy savings on lighting follow the same trend as shown in Tables 3.6 to 3.9. However, the energy savings are lower indicating a higher potential for energy savings on lighting if fibre optics are to be used to transport daylight to the rear side of the rooms.

Table 3.6. Energy savings on artificial lighting for room ratio of 2:1 and window area of 25% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.58																												100.0	100.0	100.0
0.71																									100.0	100.0	100.0	58.0	92.1	96.7
0.87																						100.0	100.0	100.0	70.4	88.9	96.7	53.5	76.8	89.2
1.00																						93.6	93.4	99.6	63.2	81.7	93.3	46.9	69.8	84.0
1.16																			100.0	100.0	100.0	82.9	89.5	98.2	49.8	75.8	87.9	39.3	64.0	78.1
1.20																			97.7	98.0	100.0	80.5	87.6	97.6	49.1	73.6	86.6	36.8	63.4	76.9
1.25																			94.5	96.5	99.8	75.3	86.8	96.7	47.5	71.6	85.1	35.4	61.6	75.2
1.33																			88.4	94.5	99.4	68.1	84.8	95.2	43.1	69.5	82.6	35.0	58.1	72.8
1.40																100.0	100.0	100.0	82.5	92.2	98.6	65.0	82.2	93.8	42.2	66.5	80.6	34.9	55.2	70.8
1.50																97.7	96.8	99.9	76.3	89.1	97.4	60.6	78.7	91.6	40.4	63.3	78.1	34.3	52.0	68.5
1.60																95.7	92.9	99.7	72.7	85.1	95.9	59.0	74.8	89.7	39.1	60.0	75.6	33.7	49.2	66.3
1.67																91.6	93.2	99.4	71.5	82.8	95.1	58.6	72.1	88.4	38.9	57.6	74.1	33.4	47.3	64.9
2.00																82.7	85.3	97.5	64.2	73.4	90.5	51.9	64.6	83.0	37.1	49.3	68.1	27.9	43.4	59.2
2.30										100.0	100.0	100.0				71.8	81.8	94.9	53.9	70.5	86.4	43.6	61.5	78.3	33.0	46.1	63.9	24.9	40.1	55.0
2.31										99.9	99.8	100.0	100.0	100.0	100.0	71.7	81.4	94.7	52.9	71.3	86.5	43.6	61.2	78.1	32.8	45.9	63.6	24.9	40.0	54.9
2.50										96.9	94.5	99.8	96.9	95.0	99.8	65.3	79.1	92.7	51.8	66.4	83.8	42.6	57.4	75.5	31.1	43.7	61.2	24.4	37.3	52.6
2.67										94.3	92.2	99.6	92.2	93.1	99.5	64.1	74.9	91.0	50.4	62.8	81.5	41.6	54.4	73.4	30.4	41.4	59.2	23.9	35.3	50.8
3.00										85.5	89.0	98.4	80.0	90.6	98.1	58.5	70.4	87.7	47.0	58.4	78.0	39.1	50.2	69.7	27.1	39.7	56.0	20.3	34.4	47.7
3.33										80.6	84.2	96.9	69.3	86.0	95.7	51.6	68.1	84.6	39.2	58.3	74.6	32.2	50.2	66.2	26.2	36.3	53.0	17.3	33.2	44.8
3.34							100.0	100.0	100.0	80.4	83.9	96.8	69.0	86.3	95.8	51.4	67.9	84.4	38.9	58.2	74.5	31.9	50.3	66.2	26.2	36.2	52.9	16.9	33.6	44.8
3.65				100.0	100.0	100.0	94.0	94.6	99.7	72.2	82.3	95.1	63.0	81.6	93.2	46.4	65.1	81.3	36.7	54.6	71.3	29.8	47.5	63.1	21.4	37.2	50.6	14.1	33.7	43.0
3.85	100.0	100.0	100.0	96.6	94.8	99.8	92.5	89.7	99.2	70.2	78.6	93.6	59.6	78.6	91.4	43.8	63.4	79.4	30.6	55.9	69.4	25.7	47.8	61.2	19.9	36.4	49.1	12.6	32.0	40.6
4.00	98.3	96.4	99.9	94.7	94.2	99.7	89.3	89.5	98.9	67.2	77.8	92.7	57.6	76.9	90.2	37.4	64.7	77.9	29.9	54.4	68.0	25.0	46.6	60.0	18.3	36.2	47.9	12.3	31.0	39.5
5.00	78.3	88.7	97.5	60.6	89.3	95.8	59.1	82.4	92.8	43.8	72.9	84.8	38.8	68.9	81.0	29.5	55.6	68.7	23.5	47.0	59.5	19.8	40.5	52.3	11.4	33.4	41.0	9.4	26.9	33.8
5.33	76.7	83.2	96.1	54.8	84.8	93.1	54.7	79.6	90.8	40.0	70.0	82.0	35.2	66.5	78.3	27.5	53.4	66.2	22.3	46.2	58.2	17.4	39.5	50.0	11.1	31.6	39.2	9.3	25.2	32.2
6.00	65.3	81.6	93.6	42.9	79.8	88.5	42.8	74.9	85.6	30.5	67.8	77.6	29.6	62.1	73.3	21.7	50.6	61.3	17.6	42.8	52.9	14.8	37.0	46.3	8.8	30.5	36.6	9.0	22.6	29.6
6.67	50.8	80.0	90.2	34.0	74.3	83.0	32.7	72.2	81.3	21.7	64.3	72.0	23.9	58.4	68.3	19.0	47.2	57.2	15.8	39.7	49.2	13.4	34.1	42.9	7.5	27.7	33.1	6.3	22.8	27.7
8.00	17.8	77.1	81.2	22.0	66.8	74.1	15.7	66.5	71.8	15.9	56.0	63.0	11.0	55.8	60.7	8.1	45.9	50.3	6.4	39.0	42.9	5.7	33.8	37.6	3.5	26.1	28.7	2.9	21.5	23.8
10.00	0.0	64.4	64.4	0.0	60.0	60.0	0.0	58.6	58.6	0.0	51.3	51.3	0.0	49.0	49.0	0.0	40.8	40.8	0.0	34.8	34.8	0.0	30.3	30.3	0.0	23.1	23.1	0.0	19.1	19.1
12.00	0.0	53.6	53.6	0.0	50.0	50.0	0.0	48.9	48.9	0.0	42.7	42.7	0.0	40.9	40.9	0.0	34.0	34.0	0.0	29.0	29.0	0.0	25.2	25.2	0.0	19.3	19.3	0.0	16.0	16.0
14.00	0.0	46.0	46.0	0.0	42.8	42.8	0.0	41.9	41.9	0.0	36.6	36.6	0.0	35.0	35.0	0.0	29.1	29.1	0.0	24.9	24.9	0.0	21.6	21.6	0.0	16.5	16.5	0.0	13.7	13.7
16.00	0.0	40.2	40.2	0.0	37.5	37.5	0.0	36.6	36.6	0.0	32.0	32.0	0.0	30.6	30.6	0.0	25.5	25.5	0.0	21.8	21.8	0.0	18.9	18.9	0.0	14.5	14.5	0.0	12.0	12.0
20.00	0.0	32.2	32.2	0.0	30.0	30.0	0.0	29.3	29.3	0.0	25.6	25.6	0.0	24.5	24.5	0.0	20.4	20.4	0.0	17.4	17.4	0.0	15.1	15.1	0.0	11.6	11.6	0.0	9.6	9.6

Table 3.7. Energy savings on artificial lighting for room ratio of 2:1 and window area of 50% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.07																												100.0	100.0	100.0
1.20																												83.8	93.2	98.9
1.25																												79.7	91.2	98.2
1.33																												63.1	91.0	96.7
1.37																									100.0	100.0	100.0	62.2	88.6	95.7
1.43																									93.4	97.8	99.9	60.0	85.6	94.2
1.50																									82.9	96.0	99.3	57.5	82.5	92.6
1.60																									74.7	92.0	98.0	49.8	80.1	90.0
1.67																									70.3	89.4	96.9	48.9	77.1	88.3
1.76																						100.0	100.0	100.0	61.7	87.6	95.3	47.4	73.9	86.3
2.00																						86.7	95.2	99.4	56.7	79.0	90.9	39.3	68.7	81.0
2.16																			100.0	100.0	100.0	81.3	90.6	98.2	48.7	76.6	88.0	35.0	65.7	77.7
2.50																			84.9	93.8	99.1	65.7	84.4	94.6	42.8	68.7	82.1	33.9	57.5	71.9
2.54																100.0	100.0	100.0	82.1	93.3	98.8	64.2	83.9	94.2	42.6	67.7	81.5	33.8	56.6	71.3
2.67																97.9	97.9	100.0	78.3	90.3	97.9	60.4	81.3	92.6	41.7	64.9	79.5	31.6	55.2	69.4
3.00																90.3	93.5	99.4	68.8	84.2	95.1	55.7	74.7	88.8	38.3	59.8	75.2	30.7	49.8	65.2
3.33																83.3	88.6	98.1	62.9	79.2	92.3	51.2	69.6	85.2	36.8	54.8	71.4	28.0	46.6	61.6
3.81													100.0	100.0	100.0	73.6	83.1	95.5	55.6	73.2	88.1	43.3	65.4	80.4	33.6	49.9	66.7	25.5	43.2	57.7
4.00													98.0	95.9	99.9	69.8	81.6	94.4	51.8	71.8	86.4	42.7	62.7	78.6	31.1	49.7	65.3	24.6	41.3	55.7
4.30										100.0	100.0	100.0	93.4	93.8	99.6	64.2	78.7	92.4	50.5	67.6	84.0	41.7	59.1	76.2	30.2	46.6	62.7	22.0	40.4	53.5
5.00										93.8	92.3	99.5	79.2	89.0	97.7	57.5	71.8	88.0	43.9	62.4	78.9	36.6	54.0	70.8	27.1	42.2	57.9	19.3	36.9	49.1
5.33										87.7	91.9	99.0	73.7	86.5	96.4	53.8	69.5	85.9	43.0	59.1	76.7	35.1	51.8	68.7	26.6	40.0	56.0	18.9	34.8	47.1
5.68							100.0	100.0	100.0	84.1	88.9	98.2	68.8	83.7	94.9	52.0	66.6	84.0	38.8	58.2	74.4	32.1	50.8	66.6	25.9	38.0	54.1	18.8	32.7	45.4
6.00							97.8	94.6	99.9	81.7	85.2	97.3	65.4	81.2	93.5	48.1	65.3	82.0	38.0	55.7	72.5	31.5	48.5	64.7	23.8	38.0	52.8	18.4	31.2	43.9
6.67							94.5	88.2	99.4	74.7	81.3	95.3	60.8	75.1	90.2	45.0	60.9	78.5	36.2	51.3	68.9	27.6	46.5	61.3	22.8	34.7	49.6	15.9	30.1	41.2
7.23				100.0	100.0	100.0	85.0	90.6	98.6	69.5	78.8	93.5	57.0	71.6	87.8	40.5	59.1	75.7	32.3	50.1	66.2	27.0	43.3	58.6	19.7	34.7	47.6	15.7	28.0	39.3
8.00				96.3	90.3	99.6	79.6	84.9	96.9	64.0	74.6	90.9	53.1	66.7	84.4	38.9	54.8	72.4	31.3	45.9	62.8	26.1	39.8	55.5	19.0	31.8	44.8	15.4	25.5	37.0
9.91	100.0	100.0	100.0	77.0	86.5	96.9	63.9	78.7	92.3	53.6	66.5	84.5	42.5	60.8	77.5	32.1	48.5	65.0	25.7	41.1	56.2	21.4	35.4	49.2	15.5	28.2	39.3	12.5	22.6	32.3
10.00	99.6	99.1	100.0	76.5	85.7	96.6	63.6	78.0	92.0	53.2	65.9	84.0	42.4	60.2	77.1	32.0	48.1	64.7	25.6	40.7	55.9	21.3	35.1	48.9	15.5	27.9	39.1	12.5	22.4	32.1
12.00	89.6	89.5	98.9	63.9	80.5	93.0	54.7	70.1	86.5	42.7	61.3	77.8	38.2	53.5	71.3	28.4	43.0	59.2	23.1	36.0	50.8	16.9	32.9	44.2	11.9	26.3	35.1	9.9	21.3	29.1
14.00	64.7	86.3	95.2	53.6	72.9	87.4	43.3	66.2	80.8	33.1	57.9	71.8	29.4	51.3	65.6	22.5	40.6	54.0	18.2	34.3	46.3	15.2	29.4	40.1	11.3	22.9	31.6	9.2	18.5	26.0
16.00	46.4	83.0	90.9	42.4	69.7	82.5	33.1	63.9	75.8	29.0	53.7	67.1	24.4	48.1	60.8	18.1	39.0	50.0	12.3	34.5	42.6	9.6	30.1	36.8	10.6	20.6	29.0	8.5	16.8	23.9
20.00	14.6	73.5	77.4	13.2	66.1	70.6	11.6	58.8	63.6	9.2	52.0	56.4	8.6	46.6	51.2	6.6	37.5	41.6	5.4	31.5	35.2	4.7	27.1	30.5	3.5	21.4	24.2	2.8	17.4	19.7

Table 3.8. Energy savings on artificial lighting for room ratio of 2:1 and window area of 73.2% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.49																												100.0	100.0	100.0
1.50																												99.1	99.8	100.0
1.60																												86.7	95.4	99.4
1.67																												80.0	93.5	98.7
1.87																									100.0	100.0	100.0	59.4	88.2	95.2
2.00																									84.1	96.8	99.5	50.5	85.0	92.6
2.38																						100.0	100.0	100.0	60.3	86.3	94.6	40.6	75.1	85.2
2.50																						95.5	97.6	99.9	57.1	83.2	92.8	39.9	71.9	83.1
2.67																						85.0	94.9	99.2	49.9	80.4	90.2	35.0	69.5	80.2
2.85																			100.0	100.0	100.0	77.9	91.5	98.1	47.8	76.4	87.7	34.7	65.4	77.4
3.00																			95.2	97.4	99.9	69.3	89.8	96.9	43.1	74.4	85.4	34.1	62.4	75.2
3.33																			81.0	92.9	98.7	59.6	84.6	93.8	41.6	67.8	81.2	31.2	57.9	71.0
3.42																100.0	100.0	100.0	78.7	91.5	98.2	58.7	82.7	92.9	40.9	66.4	80.1	31.0	56.5	70.0
4.00																87.7	93.7	99.2	65.8	82.9	94.2	52.3	73.6	87.4	36.3	59.4	74.1	27.9	50.1	64.0
4.83													100.0	100.0	100.0	71.3	85.7	95.9	52.0	75.4	88.2	42.9	65.8	80.5	30.8	52.4	67.1	24.4	43.8	57.5
5.00													98.1	97.1	99.9	67.4	84.6	95.0	51.7	72.8	86.9	42.4	63.7	79.1	30.4	50.9	65.8	23.5	42.9	56.3
5.33													93.7	95.6	99.7	64.3	80.7	93.1	50.1	69.3	84.7	41.0	60.7	76.8	28.3	49.7	63.9	21.7	41.6	54.3
5.51										100.0	100.0	100.0	92.7	92.5	99.5	63.1	78.8	92.2	49.2	67.5	83.5	40.4	59.1	75.6	27.4	48.2	62.4	21.6	40.3	53.2
6.00										96.4	96.0	99.9	81.4	91.9	98.5	58.8	74.7	89.6	44.1	65.3	80.6	36.5	56.7	72.5	26.9	44.6	59.5	18.9	38.9	50.4
6.67										87.1	92.5	99.0	72.3	86.6	96.3	53.0	70.3	86.0	39.1	61.9	76.8	32.1	54.0	68.8	24.9	41.6	56.1	18.7	35.1	47.2
7.11							100.0	100.0	100.0	82.7	88.9	98.1	67.6	83.6	94.7	48.4	68.8	83.9	38.1	58.6	74.4	31.7	50.8	66.4	23.3	40.3	54.2	18.2	35.2	47.0
8.00							95.3	91.8	99.6	74.8	83.9	95.9	61.2	77.4	91.2	45.0	63.2	79.8	34.9	54.1	70.1	27.2	48.2	62.3	22.6	36.3	50.7	15.8	31.3	42.2
8.97				100.0	100.0	100.0	83.3	90.2	98.4	67.8	79.2	93.3	54.1	73.2	87.7	40.1	59.4	75.7	32.1	50.0	66.1	26.5	43.6	58.5	19.2	34.8	47.3	15.5	28.2	39.3
10.00				95.5	94.4	99.7	78.8	83.7	96.5	59.8	75.5	90.2	51.4	67.2	84.1	38.3	54.7	72.0	30.7	46.1	62.6	25.4	39.8	55.1	17.2	34.0	45.4	13.9	27.5	37.6
12.00				76.9	87.5	97.1	63.7	79.4	92.5	52.7	66.8	84.3	43.0	61.2	77.9	32.1	49.2	65.5	25.4	42.0	56.7	21.2	36.1	49.6	15.4	28.6	39.6	12.4	23.2	32.7
12.28	100.0	100.0	100.0	75.8	87.4	97.0	63.1	77.5	91.7	48.0	68.5	83.6	42.4	59.8	76.8	31.4	48.6	64.7	25.2	41.0	55.9	21.1	35.3	49.0	15.3	28.1	39.1	12.4	22.7	32.3
14.00	93.8	87.7	99.2	70.3	79.4	93.9	55.7	71.4	87.3	43.3	63.6	79.4	38.7	54.9	72.4	29.2	44.5	60.7	22.8	38.0	52.1	16.6	34.7	45.5	12.0	27.3	36.0	10.1	22.2	30.1
16.00	72.3	90.1	97.3	58.7	75.4	89.8	48.3	67.0	82.9	37.2	59.0	74.3	32.0	52.8	67.9	24.0	42.3	56.1	19.3	35.5	47.9	16.1	30.6	41.8	11.8	24.0	33.0	9.5	19.5	27.1
20.00	63.2	77.1	91.6	46.9	67.8	82.9	34.3	61.9	75.0	31.4	50.5	66.0	22.2	48.9	60.2	17.9	39.3	50.2	13.2	33.0	41.8	12.2	28.4	37.1	9.0	22.5	29.5	7.6	18.3	24.5

Table 3.9. Energy savings on artificial lighting for room ratio of 2:1 and window area of 100% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.95																												100.0	100.0	100.0
2.00																												88.5	98.7	99.9
2.40																									100.0	100.0	100.0	53.2	89.2	94.9
2.50																									88.9	98.3	99.8	50.0	86.4	93.2
2.67																									72.2	94.3	98.4	47.2	81.7	90.3
3.00																									57.9	87.0	94.5	39.4	75.2	85.0
3.02																						100.0	100.0	100.0	57.4	86.6	94.3	39.2	74.7	84.6
3.33																						84.8	95.5	99.3	48.7	80.9	90.2	34.5	69.7	80.2
3.57																			100.0	100.0	100.0	73.3	92.5	98.0	43.0	77.5	87.2	33.7	65.3	77.0
4.00																			82.7	94.8	99.1	59.5	86.6	94.6	39.4	71.1	82.5	30.7	59.8	72.1
4.24																100.0	100.0	100.0	75.5	91.6	97.9	57.1	82.5	92.5	38.0	67.5	79.9	28.6	57.8	69.9
5.00																84.7	92.7	98.9	61.6	82.4	93.2	48.4	73.8	86.5	33.7	59.4	73.1	24.9	51.1	63.3
5.33																77.5	90.2	97.8	57.6	79.1	91.1	43.3	71.4	83.8	30.9	57.4	70.6	24.4	48.2	60.8
5.78													100.0	100.0	100.0	69.5	86.3	95.8	51.4	75.7	88.2	41.9	66.6	80.6	29.4	54.1	67.6	21.7	46.2	57.9
6.00													97.8	96.8	99.9	64.8	85.0	94.7	50.4	73.3	86.8	40.8	64.9	79.2	27.5	53.1	66.0	21.5	44.6	56.5
6.55										100.0	100.0	100.0	91.8	93.3	99.5	61.5	79.4	92.1	47.4	68.8	83.6	36.6	61.7	75.7	26.9	49.0	62.7	18.9	42.6	53.4
6.67										99.3	98.2	100.0	87.7	93.9	99.2	60.3	78.7	91.5	44.3	69.3	82.9	36.4	60.8	75.1	26.8	48.2	62.1	18.9	41.8	52.8
8.00										84.0	92.0	98.7	68.1	85.6	95.4	48.3	71.4	85.2	37.9	61.1	75.8	31.2	53.6	68.1	23.0	42.7	55.9	16.3	37.0	47.3
8.26							100.0	100.0	100.0	82.1	90.0	98.2	65.2	84.5	94.6	47.1	69.9	84.1	37.2	59.7	74.7	30.6	52.1	66.8	22.8	41.5	54.8	15.9	35.9	46.1
10.00							84.8	92.3	98.8	67.8	81.4	94.0	54.0	75.2	88.6	39.9	61.5	76.9	31.5	52.6	67.5	26.2	45.8	60.0	18.9	36.8	48.7	14.5	30.8	40.8
10.22				100.0	100.0	100.0	82.8	91.6	98.6	67.1	79.7	93.3	53.7	73.5	87.7	39.7	60.2	76.0	31.3	51.5	66.7	26.0	44.8	59.2	18.6	36.3	48.1	14.1	31.4	41.1
12.00				90.8	92.5	99.3	72.7	82.7	95.3	56.3	73.3	88.3	46.9	67.0	82.5	33.0	56.0	70.5	25.9	47.3	60.9	21.7	41.0	53.8	15.6	32.9	43.4	12.6	26.9	36.1
13.66	100.0	100.0	100.0	75.4	87.8	97.0	62.6	78.1	91.8	47.1	69.6	83.9	40.9	61.5	77.2	30.8	50.1	65.5	24.8	42.5	56.8	20.8	36.7	49.9	15.0	29.4	40.0	11.5	24.6	33.3
14.00	98.8	97.6	100.0	74.6	85.6	96.3	62.0	76.2	91.0	46.7	67.9	82.9	40.3	60.8	76.6	30.5	49.3	64.8	24.6	41.4	55.8	20.4	36.0	49.1	14.1	29.6	39.5	10.3	25.5	33.2
16.00	90.8	91.6	99.2	61.9	81.4	92.9	51.9	72.7	86.9	38.3	65.5	78.7	33.0	57.9	71.8	24.2	47.4	60.1	19.5	40.0	51.7	16.3	34.6	45.3	11.8	27.4	36.0	9.5	22.4	29.8
20.00	68.5	79.9	93.7	54.0	69.1	85.8	42.7	62.6	78.6	34.4	53.4	69.4	27.4	49.4	63.3	19.5	41.3	52.7	13.3	36.6	45.0	12.6	31.6	40.2	11.0	22.4	30.9	8.5	19.1	26.0

Table 3.10. Energy savings on artificial lighting for room ratio of 1:2 and window area of 25% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.26																												100.0	100.0	100.0
0.32																									100.0	100.0	100.0	60.6	84.6	93.9
0.43																						100.0	100.0	100.0	44.9	84.0	91.2	29.7	71.5	80.0
0.48																			100.0	100.0	100.0	61.6	93.4	97.5	37.4	77.3	85.8	28.6	64.6	74.7
0.59																100.0	100.0	100.0	58.1	88.0	95.0	47.3	78.6	88.7	33.6	64.6	76.5	25.2	54.3	65.8
0.70													100.0	100.0	100.0	64.8	87.6	95.6	51.6	76.1	88.4	40.4	69.0	81.5	29.2	56.7	69.3	22.4	47.3	59.1
0.85										100.0	100.0	100.0	74.3	92.3	98.0	50.7	77.8	89.1	39.1	68.4	80.8	32.2	60.7	73.4	24.6	49.2	61.7	19.3	40.9	52.3
0.95							100.0	100.0	100.0	77.9	94.4	98.8	62.7	86.0	94.8	44.6	72.3	84.7	36.3	62.7	76.2	30.0	55.7	69.0	22.4	45.4	57.6	17.6	37.8	48.7
1.00							97.3	95.4	99.9	74.7	90.1	97.5	62.0	82.1	93.2	43.1	69.4	82.6	36.0	59.6	74.1	29.8	52.9	66.9	22.2	43.2	55.8	17.5	35.9	47.1
1.20							85.3	91.5	98.8	67.7	79.2	93.3	57.7	70.7	87.6	40.2	59.1	75.5	34.2	50.9	67.7	28.2	45.3	60.7	21.5	36.5	50.2	16.8	30.4	42.1
1.21				100.0	100.0	100.0	84.0	90.7	98.5	67.5	78.6	93.0	56.7	71.0	87.4	40.2	58.6	75.2	34.0	50.4	67.3	28.2	45.0	60.5	21.4	36.3	49.9	16.8	30.3	42.0
1.25				95.1	98.3	99.9	74.1	91.2	97.7	65.3	78.2	92.4	52.8	71.4	86.5	40.0	57.2	74.3	33.0	49.5	66.2	28.0	43.5	59.3	20.9	35.5	49.0	16.5	29.6	41.2
1.33				86.0	94.6	99.2	69.1	87.5	96.1	56.3	78.4	90.6	47.8	69.5	84.1	38.3	55.2	72.4	31.5	47.8	64.2	26.6	42.1	57.5	20.3	33.8	47.2	16.1	28.0	39.6
1.50				81.2	85.7	97.3	67.3	77.6	92.7	54.3	69.5	86.1	44.9	63.2	79.7	34.9	50.7	67.9	27.9	44.8	60.2	24.5	38.8	53.8	18.7	31.3	44.1	14.9	25.8	36.9
1.59	100.0	100.0	100.0	76.2	83.6	96.1	65.5	75.1	91.4	52.5	66.7	84.2	44.7	59.7	77.7	34.1	48.3	65.9	27.8	42.3	58.3	23.4	37.6	52.2	18.0	30.1	42.7	14.4	24.8	35.6
1.60	99.4	99.6	100.0	75.8	85.4	96.5	65.1	74.6	91.1	51.6	67.4	84.2	44.6	59.3	77.5	34.0	49.1	66.4	27.7	42.4	58.4	23.4	37.4	52.0	18.0	29.9	42.5	14.4	24.7	35.5
1.67	93.2	95.4	99.7	73.4	81.8	95.2	63.1	73.4	90.2	51.0	64.6	82.7	44.5	56.8	76.0	32.3	47.5	64.5	26.5	41.3	56.9	22.8	36.3	50.8	17.6	28.9	41.4	13.9	24.2	34.7
2.00	86.6	81.7	97.5	70.1	69.5	90.9	52.5	68.2	84.9	43.8	58.6	76.7	37.8	52.2	70.3	30.8	40.6	58.9	23.6	36.9	51.8	20.1	32.6	46.1	15.4	25.9	37.3	12.2	21.5	31.1
2.50	59.8	81.2	92.4	53.9	67.9	85.2	46.2	58.6	77.7	38.7	50.1	69.4	32.1	45.4	62.9	25.6	36.5	52.8	18.6	33.2	45.6	16.4	28.7	40.4	13.2	22.5	32.7	10.9	18.2	27.1
2.67	55.8	78.9	90.7	49.8	67.5	83.7	43.8	58.8	76.8	34.9	50.6	67.8	30.6	44.4	61.4	24.1	35.2	50.8	17.1	32.3	43.9	14.6	28.3	38.8	11.8	22.3	31.5	9.8	18.1	26.1
3.00	51.4	70.2	85.5	39.8	64.8	78.8	40.0	52.3	71.4	32.3	46.3	63.6	28.0	41.5	57.9	22.2	33.0	47.9	14.9	30.3	40.7	12.7	26.7	36.0	10.0	21.4	29.3	9.0	16.8	24.3
3.33	41.1	70.5	82.6	31.9	63.9	75.4	34.3	51.0	67.8	27.4	45.4	60.4	24.5	39.7	54.5	18.7	32.3	45.0	14.0	28.3	38.3	11.9	24.8	33.7	9.8	19.4	27.3	7.3	16.6	22.7
4.00	30.6	61.6	73.4	22.2	55.9	65.7	24.4	49.4	61.7	20.0	43.3	54.6	18.8	36.9	48.8	11.9	32.1	40.2	10.4	25.9	33.6	8.8	22.9	29.7	7.6	18.0	24.2	5.6	15.3	20.0
5.00	13.1	59.0	64.4	15.5	50.2	57.9	15.9	44.4	53.2	15.4	36.8	46.5	13.3	33.1	42.0	9.3	27.1	33.9	8.2	22.5	28.9	7.1	19.6	25.3	5.6	16.1	20.8	4.5	13.0	16.9
5.33	10.7	55.3	60.1	13.9	47.1	54.5	14.4	41.6	50.0	13.0	38.0	46.1	12.5	32.0	40.5	7.5	26.9	32.4	7.8	21.4	27.5	6.8	18.7	24.2	5.4	15.2	19.8	4.4	12.3	16.2
6.00	0.0	52.6	52.6	6.9	45.3	49.1	7.5	41.9	46.3	7.9	35.9	41.0	7.6	31.4	36.6	6.7	24.4	29.5	6.8	19.8	25.3	5.9	17.3	22.2	4.8	14.1	18.2	4.0	11.2	14.8
6.67	0.0	47.3	47.3	0.0	43.8	43.8	6.2	37.7	41.6	5.7	33.4	37.2	4.8	30.4	33.7	5.3	23.5	27.6	4.6	19.7	23.4	4.1	17.1	20.5	3.3	13.8	16.6	2.8	11.2	13.7
8.00	0.0	39.4	39.4	0.0	36.5	36.5	0.0	34.8	34.8	3.0	30.1	32.2	3.0	27.1	29.3	1.8	22.0	23.4	1.7	18.5	19.9	1.6	16.1	17.4	1.4	13.2	14.4	1.2	10.7	11.8
10.00	0.0	31.5	31.5	0.0	29.2	29.2	0.0	27.8	27.8	0.0	25.0	25.0	0.0	22.8	22.8	0.0	18.5	18.5	0.0	15.9	15.9	0.0	14.0	14.0	0.0	11.5	11.5	0.0	9.4	9.4
12.00	0.0	26.3	26.3	0.0	24.3	24.3	0.0	23.2	23.2	0.0	20.9	20.9	0.0	19.0	19.0	0.0	15.4	15.4	0.0	13.2	13.2	0.0	11.6	11.6	0.0	9.5	9.5	0.0	7.8	7.8
14.00	0.0	22.5	22.5	0.0	20.9	20.9	0.0	19.9	19.9	0.0	17.9	17.9	0.0	16.3	16.3	0.0	13.2	13.2	0.0	11.3	11.3	0.0	10.0	10.0	0.0	8.2	8.2	0.0	6.7	6.7
16.00	0.0	19.7	19.7	0.0	18.3	18.3	0.0	17.4	17.4	0.0	15.6	15.6	0.0	14.3	14.3	0.0	11.6	11.6	0.0	9.9	9.9	0.0	8.7	8.7	0.0	7.2	7.2	0.0	5.9	5.9
20.00	0.0	15.8	15.8	0.0	14.6	14.6	0.0	13.9	13.9	0.0	12.5	12.5	0.0	11.4	11.4	0.0	9.3	9.3	0.0	7.9	7.9	0.0	7.0	7.0	0.0	5.7	5.7	0.0	4.7	4.7

Table 3.11. Energy savings on artificial lighting for room ratio of 1:2 and window area of 50% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.51																												100.0	100.0	100.0
0.62																									100.0	100.0	100.0	44.0	87.0	92.7
0.81																						100.0	100.0	100.0	43.2	83.9	90.9	30.8	70.9	79.9
0.92																			100.0	100.0	100.0	59.6	91.9	96.7	38.4	75.3	84.8	27.6	63.9	73.9
1.00																			77.1	95.6	99.0	53.9	85.8	93.5	33.9	71.1	80.9	25.3	60.0	70.1
1.12																100.0	100.0	100.0	58.6	88.6	95.3	43.9	79.6	88.6	31.3	64.7	75.7	23.5	54.5	65.2
1.20																80.0	94.7	98.9	51.9	84.4	92.5	43.3	74.3	85.4	30.1	61.0	72.7	22.3	51.7	62.5
1.25																66.9	93.5	97.8	51.7	81.0	90.8	40.8	72.6	83.8	28.8	59.2	71.0	21.6	50.0	60.8
1.33																64.3	88.4	95.9	47.8	77.8	88.4	36.3	70.3	81.1	25.8	57.3	68.3	19.9	48.0	58.3
1.38													100.0	100.0	100.0	61.3	86.4	94.7	43.6	76.8	86.9	34.4	68.6	79.4	25.1	55.7	66.8	19.5	46.7	57.1
1.50													88.5	93.3	99.2	52.4	82.4	91.6	40.2	71.9	83.2	32.3	64.2	75.8	23.7	52.0	63.4	18.4	43.5	53.9
1.59										100.0	100.0	100.0	72.6	92.7	98.0	48.7	79.0	89.2	37.2	69.4	80.8	30.6	61.5	73.3	22.4	49.9	61.1	17.4	41.7	51.8
1.60										97.8	99.4	100.0	72.5	92.1	97.8	48.2	79.3	89.3	37.0	69.0	80.5	30.4	61.1	72.9	22.3	49.6	60.8	17.4	41.4	51.6
1.67										86.5	97.8	99.7	68.6	90.1	96.9	45.7	77.0	87.5	35.7	66.7	78.6	29.4	59.2	71.2	22.1	47.7	59.3	17.3	39.9	50.3
1.81							100.0	100.0	100.0	74.6	93.0	98.2	61.6	84.7	94.1	44.2	71.0	83.8	34.8	62.0	75.2	29.0	54.8	67.9	21.5	44.4	56.4	16.9	37.1	47.7
2.00							92.2	91.8	99.4	68.2	86.9	95.8	57.5	78.2	90.7	41.7	65.7	80.0	33.5	56.9	71.3	27.7	50.4	64.1	20.7	40.7	53.0	16.2	34.0	44.7
2.21				100.0	100.0	100.0	80.9	89.3	98.0	64.5	80.5	93.1	52.3	73.6	87.4	38.9	61.0	76.2	31.4	52.6	67.5	26.2	46.5	60.5	19.4	37.8	49.9	15.4	31.4	42.0
2.50				85.1	92.1	98.8	67.7	83.5	94.7	55.8	75.3	89.1	45.0	68.6	82.7	35.4	55.9	71.5	28.2	48.7	63.2	24.0	42.8	56.5	18.3	34.2	46.2	14.6	28.4	38.9
2.67				78.7	90.1	97.9	65.2	79.7	92.9	51.4	72.4	86.6	44.5	64.2	80.1	34.3	53.3	69.3	27.2	46.5	61.1	23.0	40.8	54.4	17.8	32.5	44.5	13.9	27.2	37.3
2.84	100.0	100.0	100.0	72.0	87.2	96.4	61.7	76.4	91.0	50.2	68.0	84.1	42.7	61.9	78.2	32.7	51.0	67.0	26.9	43.7	58.8	22.7	38.6	52.5	17.0	31.2	42.9	13.5	25.8	35.8
3.00	92.6	97.0	99.8	71.4	82.5	95.0	59.5	73.9	89.4	48.7	65.4	82.3	41.5	59.4	76.2	31.0	49.6	65.2	25.3	42.8	57.3	21.7	37.2	50.8	16.5	29.9	41.5	13.1	24.8	34.7
3.33	88.1	87.4	98.5	70.1	74.4	92.3	54.8	70.1	86.5	45.3	61.0	78.7	38.3	55.5	72.5	28.5	46.6	61.8	23.2	40.2	54.1	19.6	35.1	47.8	15.0	28.2	39.0	11.9	23.3	32.4
4.00	74.1	80.9	95.1	60.9	68.2	87.6	48.2	61.7	80.2	39.6	55.0	72.8	32.9	49.9	66.4	26.6	40.3	56.2	20.3	35.4	48.5	17.1	31.0	42.8	13.1	24.9	34.7	10.6	20.5	28.9
5.00	61.4	71.6	89.0	50.1	60.5	80.3	42.2	52.6	72.6	34.0	47.3	65.2	28.3	43.1	59.2	22.7	34.7	49.5	17.7	30.1	42.5	14.9	26.6	37.5	11.5	21.1	30.2	9.3	17.4	25.1
5.33	60.1	67.1	86.9	47.7	59.5	78.8	40.9	51.5	71.3	32.7	45.7	63.5	27.6	41.4	57.6	22.0	33.7	48.3	17.0	28.9	41.0	14.4	25.2	36.0	11.2	20.1	29.0	9.2	16.4	24.1
6.00	57.3	59.6	82.7	41.6	57.0	74.9	37.0	47.9	67.2	30.4	41.8	59.5	26.5	37.8	54.3	19.5	31.6	44.9	15.5	26.9	38.2	13.1	23.6	33.6	9.9	18.9	26.9	8.9	14.8	22.4
6.67	49.4	63.8	81.7	40.3	51.2	70.9	34.3	45.1	63.9	27.8	40.2	56.8	25.1	35.1	51.4	18.4	29.5	42.5	14.9	24.6	35.8	12.6	21.8	31.7	9.7	17.3	25.3	7.7	14.4	21.0
8.00	43.9	53.2	73.7	32.6	48.1	65.0	30.2	41.9	59.4	25.1	34.7	51.1	21.1	31.5	46.0	15.3	27.2	38.3	12.4	22.8	32.4	10.5	19.9	28.3	8.0	15.9	22.6	6.3	13.2	18.7
10.00	32.5	51.7	67.4	28.9	42.6	59.2	23.9	37.5	52.4	19.4	32.8	45.8	16.8	29.1	41.0	13.5	22.9	33.3	11.2	18.9	28.0	9.6	16.5	24.5	7.4	13.1	19.5	6.0	10.9	16.2
12.00	20.3	51.5	61.3	18.0	43.0	53.3	18.3	35.5	47.3	15.8	29.9	41.0	14.1	26.7	37.0	10.8	21.1	29.6	8.9	17.7	25.0	7.6	15.4	21.8	5.8	12.3	17.4	4.5	10.3	14.3
14.00	10.0	48.1	53.3	13.2	39.3	47.3	11.2	34.2	41.6	9.7	30.7	37.4	9.6	25.8	32.9	9.0	19.7	26.9	7.7	16.2	22.7	6.9	13.7	19.7	5.3	11.1	15.8	4.3	9.1	13.0
16.00	0.0	45.5	45.5	6.9	38.2	42.5	6.6	33.6	38.0	6.0	29.3	33.5	4.6	26.2	29.6	5.6	20.0	24.5	4.7	16.6	20.5	4.6	14.1	18.1	3.0	11.7	14.3	1.5	10.5	11.8
20.00	0.0	36.4	36.4	0.0	33.7	33.7	0.0	30.2	30.2	0.0	26.8	26.8	0.0	24.1	24.1	1.3	19.4	20.4	1.2	16.0	17.0	1.1	14.0	14.9	0.9	11.1	11.9	0.5	9.2	9.7

Table 3.12. Energy savings on artificial lighting for room ratio of 1:2 and window area of 73.2% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.73																												100.0	100.0	100.0
0.88																									100.0	100.0	100.0	43.8	86.6	92.5
1.14																						100.0	100.0	100.0	40.9	83.3	90.1	28.0	70.9	79.0
1.20																						73.2	95.7	98.8	38.3	79.9	87.6	26.0	68.2	76.5
1.25																						59.9	94.1	97.6	34.4	77.9	85.5	24.9	65.9	74.4
1.30																			100.0	100.0	100.0	54.2	91.2	96.0	32.8	75.5	83.5	24.5	63.5	72.4
1.33																			89.1	98.0	99.8	54.1	89.1	95.0	32.5	73.9	82.4	24.3	62.3	71.5
1.43																			64.8	94.5	98.1	44.0	85.4	91.8	31.0	69.4	78.9	22.6	58.8	68.1
1.50																			58.3	91.2	96.3	43.5	81.4	89.5	29.8	66.6	76.6	21.6	56.5	65.9
1.56																100.0	100.0	100.0	52.0	89.0	94.7	42.3	78.7	87.7	27.5	65.3	74.8	20.3	55.0	64.1
1.60																82.4	98.2	99.7	51.8	86.8	93.6	40.5	77.4	86.6	26.4	64.1	73.6	20.0	53.9	63.1
1.67																71.0	95.6	98.7	51.1	83.4	91.9	36.9	75.5	84.5	25.3	61.9	71.5	19.7	51.8	61.3
1.90													100.0	100.0	100.0	53.4	87.8	94.3	41.0	76.4	86.1	32.7	67.9	78.4	23.5	55.3	65.8	17.9	46.6	56.2
2.00													88.9	95.7	99.5	52.2	83.6	92.2	38.8	73.5	83.8	30.7	65.7	76.2	22.2	53.4	63.7	17.3	44.6	54.2
2.17										100.0	100.0	100.0	72.5	91.9	97.8	46.3	79.8	89.2	35.4	69.2	80.1	29.2	61.1	72.5	21.6	49.5	60.4	16.8	41.4	51.2
2.48							100.0	100.0	100.0	74.1	91.5	97.8	59.1	84.0	93.5	42.2	70.7	83.1	33.2	61.7	74.4	27.4	54.5	67.0	20.1	44.3	55.5	15.4	37.2	46.9
2.50							99.0	99.3	100.0	73.9	90.8	97.6	58.6	93.3	97.2	41.8	70.5	82.8	33.1	61.2	74.0	27.2	54.2	66.7	20.0	44.0	55.2	15.4	36.9	46.6
2.67							92.4	94.2	99.6	67.9	87.3	95.9	55.9	79.2	90.8	39.5	67.0	80.0	31.4	58.1	71.3	25.7	51.7	64.1	19.3	41.6	52.9	15.1	34.9	44.7
2.96				100.0	100.0	100.0	72.6	92.3	97.9	59.1	83.9	93.4	45.9	76.0	87.0	35.9	62.6	76.0	28.4	54.3	67.3	24.2	47.6	60.3	18.0	38.4	49.5	14.4	31.9	41.7
3.00				97.6	98.5	100.0	69.4	92.4	97.7	58.5	82.8	92.9	45.6	75.0	86.4	35.5	61.8	75.4	28.3	53.6	66.7	23.9	47.2	59.8	18.0	37.9	49.1	14.2	31.7	41.4
3.33				83.8	93.2	98.9	67.0	83.3	94.5	53.6	74.6	88.2	44.6	67.8	82.2	33.4	56.8	71.2	26.9	49.1	62.8	22.5	43.5	56.2	16.9	35.1	46.1	13.4	29.2	38.7
3.72	100.0	100.0	100.0	71.8	87.3	96.4	60.3	78.4	91.4	48.8	69.3	84.3	41.3	62.8	78.2	30.8	52.4	67.1	24.2	45.8	58.9	20.2	40.4	52.4	15.3	32.6	42.9	12.1	27.1	35.9
4.00	91.3	94.8	99.5	70.7	81.1	94.5	56.8	74.4	88.9	46.3	66.4	82.0	38.5	60.2	75.5	28.6	50.5	64.7	23.0	43.5	56.5	19.2	38.5	50.3	14.9	30.5	40.9	11.8	25.4	34.2
5.00	74.7	83.2	95.7	60.2	70.3	88.2	46.7	65.7	81.7	39.0	56.8	73.6	32.4	51.5	67.2	25.8	42.2	57.1	19.1	37.5	49.4	16.3	32.7	43.7	12.2	26.6	35.6	9.7	22.1	29.7
5.33	71.7	78.0	93.8	53.7	70.7	86.4	44.1	63.3	79.5	36.1	55.5	71.6	31.6	49.1	65.2	24.3	40.6	55.0	18.5	35.4	47.4	15.6	31.3	42.0	11.8	25.1	33.9	9.5	20.8	28.3
6.00	62.2	76.2	91.0	50.6	64.0	82.2	42.4	56.2	74.8	34.0	50.4	67.3	28.1	45.9	61.1	22.5	37.6	51.6	17.3	32.4	44.1	14.6	28.6	39.0	11.3	22.7	31.4	9.2	18.7	26.2
6.67	59.7	68.5	87.3	46.5	60.1	78.7	39.9	52.6	71.5	31.7	46.5	63.5	27.2	42.1	57.8	20.9	34.8	48.4	15.8	30.3	41.3	13.2	26.9	36.5	10.0	21.5	29.4	8.9	17.1	24.5
8.00	49.6	66.7	83.2	40.3	53.7	72.4	34.2	47.6	65.5	27.5	42.3	58.2	24.5	37.0	52.4	17.9	31.5	43.8	14.5	26.3	37.0	12.4	22.9	32.5	9.5	18.4	26.2	7.6	15.3	21.7
10.00	43.6	53.3	73.7	31.6	49.2	65.3	28.7	41.9	58.6	24.3	36.2	51.7	20.5	32.6	46.4	15.0	27.2	38.1	12.2	22.8	32.2	10.4	20.0	28.3	7.9	15.9	22.5	6.3	13.3	18.8
12.00	35.1	53.8	70.0	29.5	44.1	60.6	24.2	38.8	53.6	19.4	33.9	46.7	16.0	30.6	41.7	12.9	24.3	34.1	10.8	20.1	28.7	9.3	17.7	25.4	7.2	13.8	20.0	5.9	11.4	16.6
14.00	31.9	46.1	63.3	26.9	37.8	54.5	22.3	33.3	48.2	17.9	30.4	42.9	15.5	26.2	37.6	11.6	21.8	30.9	9.5	18.4	26.2	8.0	16.1	22.8	6.0	12.8	18.0	4.8	10.7	15.0
16.00	28.6	40.3	57.4	20.9	37.5	50.6	18.2	33.3	45.4	15.7	28.0	39.3	13.8	24.9	35.3	10.9	19.7	28.5	8.9	16.5	23.9	7.6	14.3	20.8	5.8	11.4	16.5	4.6	9.5	13.7
20.00	21.2	41.8	54.1	17.4	32.6	44.3	14.9	28.5	39.2	12.3	24.7	34.0	10.1	22.1	30.0	7.8	18.4	24.8	6.3	15.5	20.8	5.3	13.5	18.1	4.0	10.7	14.3	3.4	8.8	11.9

Table 3.13. Energy savings on artificial lighting for room ratio of 1:2 and window area of 100% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.97																												100.0	100.0	100.0
1.17																									100.0	100.0	100.0	39.8	86.5	91.9
1.20																									81.8	97.7	99.6	34.9	85.4	90.5
1.25																									56.0	96.0	98.2	32.1	82.6	88.2
1.33																									44.7	90.8	94.9	30.2	78.2	84.8
1.43																									40.9	86.3	91.9	26.2	73.9	80.7
1.49																						100.0	100.0	100.0	38.1	83.7	89.9	24.9	71.4	78.5
1.50																						88.6	99.5	99.9	37.1	83.2	89.4	24.9	70.9	78.1
1.60																						59.9	95.3	98.1	32.7	79.1	85.9	24.0	66.9	74.8
1.67																						54.1	91.9	96.3	31.5	76.3	83.8	22.6	64.7	72.7
1.69																			100.0	100.0	100.0	53.6	90.9	95.8	31.4	75.4	83.1	22.4	64.0	72.1
2.00																			51.8	89.2	94.8	37.7	80.4	87.8	25.2	66.0	74.6	19.1	55.6	64.1
2.02																100.0	100.0	100.0	51.7	88.3	94.3	35.7	79.6	86.9	25.1	65.4	74.1	19.0	55.0	63.6
2.44													100.0	100.0	100.0	52.3	87.2	93.9	37.4	77.1	85.7	29.4	68.7	77.9	21.6	55.6	65.2	16.7	46.8	55.7
2.50													89.7	98.1	99.8	51.4	85.3	92.9	36.3	75.7	84.5	29.3	67.0	76.7	21.2	54.6	64.2	16.6	45.7	54.7
2.67													72.9	94.9	98.6	45.6	81.9	90.2	34.8	71.2	81.2	28.5	63.2	73.7	20.7	51.4	61.5	15.9	43.2	52.2
2.77										100.0	100.0	100.0	68.1	92.5	97.6	44.2	79.0	88.3	34.3	68.8	79.5	27.7	61.2	71.9	20.1	49.9	60.0	15.4	42.0	50.9
3.00										74.8	95.4	98.8	59.6	87.4	94.9	41.3	73.9	84.7	31.5	64.9	76.0	26.1	57.3	68.4	19.2	46.6	56.9	14.8	39.3	48.3
3.15							100.0	100.0	100.0	73.3	91.4	97.7	56.3	84.1	93.1	39.2	71.6	82.7	30.8	62.3	73.9	25.2	55.3	66.6	18.6	44.7	55.0	14.5	37.5	46.6
3.33							92.5	95.5	99.7	67.3	87.9	96.0	52.6	81.2	91.1	36.6	69.0	80.3	28.5	60.0	71.4	24.1	52.8	64.2	17.8	42.8	53.0	13.8	36.1	44.9
3.69				100.0	100.0	100.0	69.2	93.2	97.9	57.1	83.4	92.9	44.9	75.8	86.7	34.4	63.2	75.9	27.0	55.0	67.2	22.5	48.7	60.2	16.7	39.5	49.6	13.1	33.1	41.9
4.00				84.9	94.6	99.2	66.9	85.9	95.3	51.4	78.4	89.5	43.1	71.1	83.6	31.1	60.1	72.5	24.4	52.5	64.1	20.4	46.3	57.3	15.4	37.4	47.0	12.0	31.3	39.5
4.54	100.0	100.0	100.0	71.5	87.7	96.5	58.2	80.2	91.7	46.8	70.7	84.4	38.5	64.9	78.4	28.0	55.0	67.6	22.3	47.7	59.4	18.7	41.8	52.7	13.9	34.1	43.3	10.8	28.5	36.2
5.00	89.2	92.4	99.2	65.6	82.8	94.1	52.0	75.4	88.2	41.4	67.6	81.0	35.3	60.3	74.3	27.0	50.4	63.8	20.5	44.2	55.6	17.2	39.0	49.5	13.0	31.4	40.3	10.4	26.2	33.9
5.33	83.5	90.9	98.5	63.3	79.7	92.5	50.6	70.7	85.5	40.2	63.4	78.1	33.0	58.4	72.1	26.1	47.7	61.4	19.3	42.3	53.4	16.3	37.2	47.4	12.1	30.3	38.7	9.6	25.3	32.5
6.00	73.2	83.1	95.5	54.2	75.0	88.6	44.1	67.3	81.7	35.8	59.2	73.8	31.4	52.6	67.5	23.2	44.6	57.5	18.3	38.3	49.6	15.3	33.7	43.8	11.5	27.3	35.7	9.3	22.6	29.8
6.67	62.7	80.9	92.9	50.8	68.6	84.6	42.4	60.6	77.3	33.8	54.3	69.7	27.9	49.3	63.4	21.9	41.1	54.0	16.9	35.4	46.3	14.2	31.2	41.0	10.7	25.2	33.2	9.1	20.6	27.8
8.00	57.8	67.4	86.2	41.5	62.9	78.3	36.2	54.0	70.7	29.8	48.5	63.8	25.9	42.7	57.5	18.8	36.1	48.1	15.1	30.9	41.3	12.6	27.1	36.3	9.6	21.8	29.3	7.6	18.3	24.5
10.00	46.1	61.6	79.3	33.7	55.2	70.3	30.5	48.6	64.3	25.1	40.9	55.7	21.0	38.0	51.0	15.2	31.7	42.1	12.3	26.8	35.8	10.6	23.5	31.6	8.0	18.8	25.3	6.3	15.7	21.0
12.00	37.9	55.9	72.6	30.4	47.2	63.3	24.8	44.4	58.2	19.8	38.9	51.0	17.3	33.6	45.1	13.8	27.5	37.5	11.2	23.4	32.0	9.5	20.3	27.9	7.4	16.1	22.3	5.9	13.3	18.4
14.00	33.2	52.0	67.9	27.8	43.0	58.8	22.9	38.0	52.2	18.4	33.3	45.6	15.6	30.0	40.9	11.7	25.1	33.9	9.6	21.2	28.8	8.1	18.6	25.2	6.0	14.9	20.0	4.8	12.4	16.6
16.00	30.0	45.5	61.9	21.7	42.1	54.7	19.2	37.4	49.4	16.8	30.4	42.1	14.4	27.2	37.7	11.1	22.5	31.1	9.0	18.9	26.2	7.6	16.5	22.8	5.8	13.2	18.2	4.6	10.9	15.0
20.00	22.7	40.7	54.2	18.1	36.3	47.8	15.3	31.8	42.2	12.5	27.7	36.7	10.2	24.8	32.5	7.9	20.6	26.9	6.4	17.4	22.7	5.3	15.2	19.7	4.0	12.1	15.6	3.5	10.1	13.2

Figures 3.14 to 3.17 illustrate the energy savings on lighting that can be expected in room ratios of 1:1 for the ten room indices and the four window areas, respectively. It can be seen that for lower Daylight Factors, or higher external illuminance, the energy savings on lighting are greater. The energy savings are also greater for lower room indices, which means smaller rooms.

It can also be seen by comparing the four figures, that for window areas apparently larger than 50%, the energy savings do not increase significantly indicating that there might be a misconception in terms of window areas adopted in actual buildings. Similar behaviour was identified for the other room ratios.

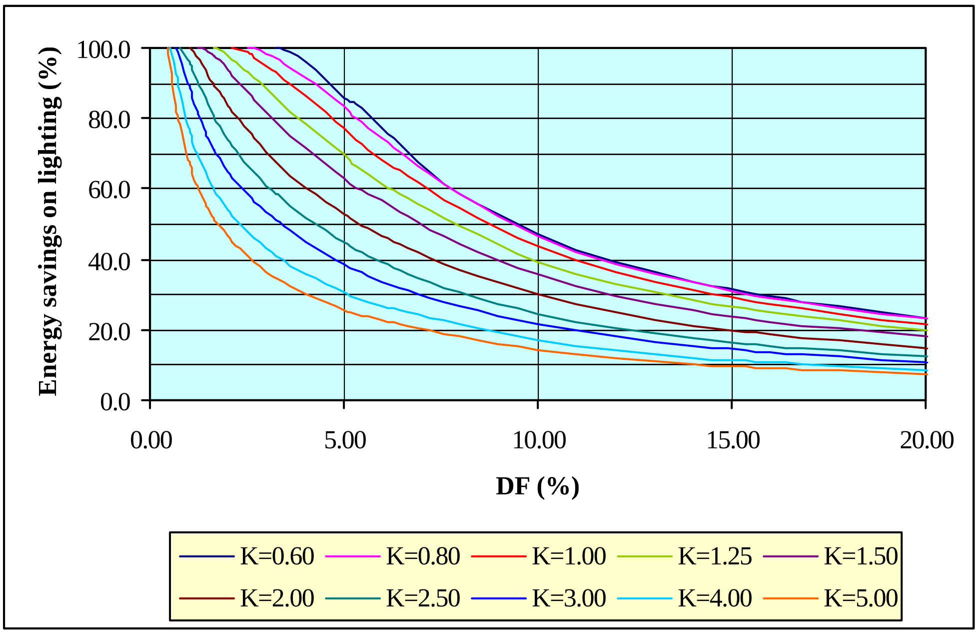


Figure 3.1. Energy savings on lighting for room ratio of 1:1 and window area of 25%.

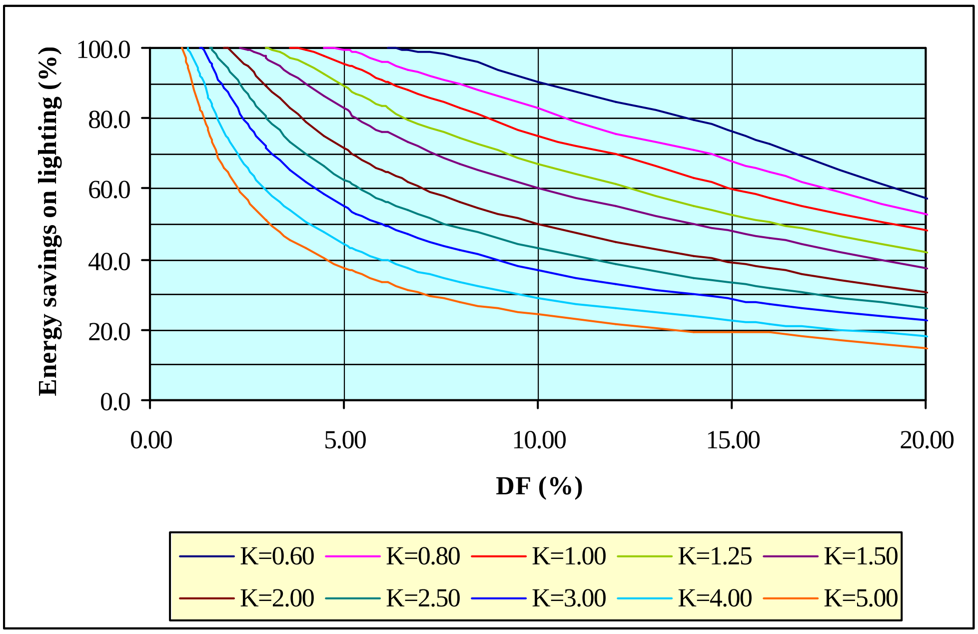


Figure 3.2. Energy savings on lighting for room ratio of 1:1 and window area of 50%.

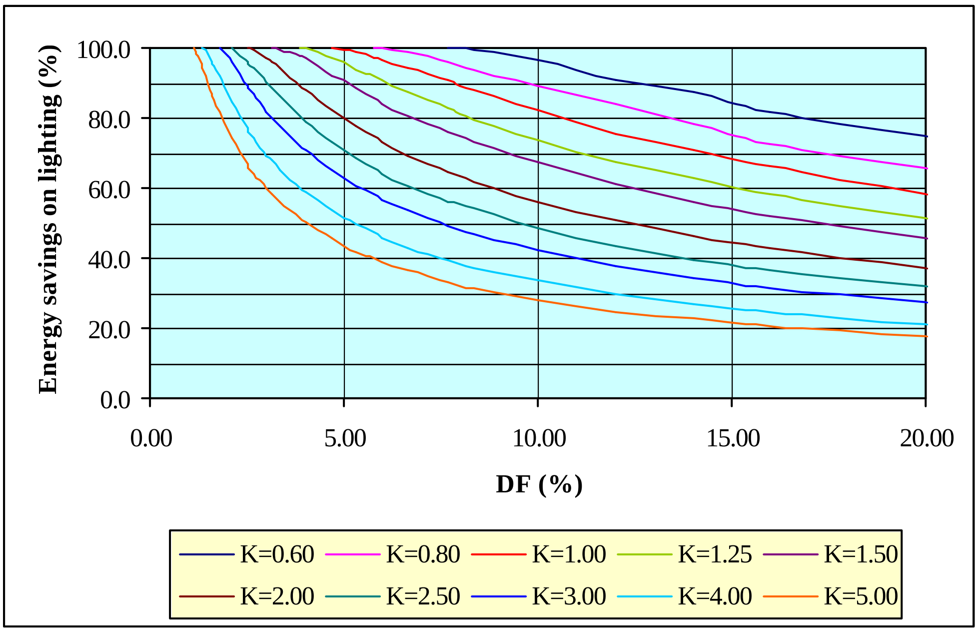


Figure 3.3. Energy savings on lighting for room ratio of 1:1 and window area of 73.2%.

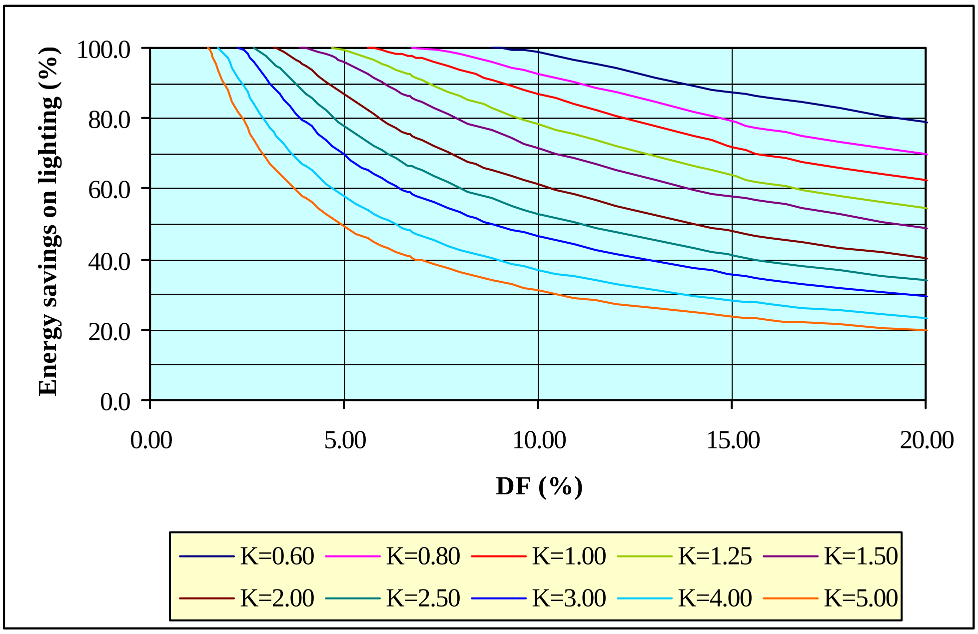


Figure 3.4. Energy savings on lighting for room ratio of 1:1 and window area of 100%.

In order to gain an insight on the influence of window area on energy savings on lighting, some figures relating these two variables were produced. Figures 3.18 to 3.20 show the effect of the window area on the energy savings on lighting for Daylight Factor of 10% and room ratios of 2:1, 1:1 and 1:2, respectively. It is clear that for all the ten room indices there is no significant increase in the energy savings when the window area is larger than 50%.

Figure 3.21 shows the relationship between energy savings on lighting and window area for room ratio of 1:1 and Daylight Factor of 5%. In this case, window areas larger than 40% do not provide significant energy savings on lighting. It can be seen in Figure 3.22 that for a room ratio of 1:1 and Daylight Factor of 20%, there are no significant energy savings to be made on lighting for window areas larger than about 70%.

The analysis shows that as the external illuminance increases, the use of larger window areas does not provide for significant increments on the energy savings on lighting. This indicates that an ideal window area in which there is a balance between daylight provision and heat losses or gains should be investigated.

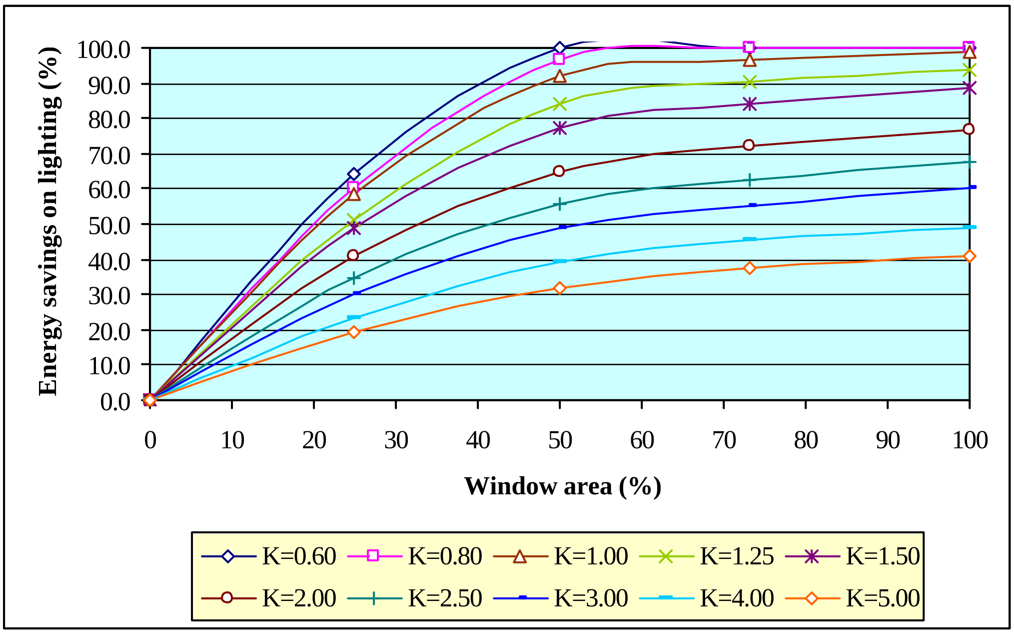


Figure 3.5. Energy savings on lighting for room ratio of 2:1 and Daylight Factor of 10%.

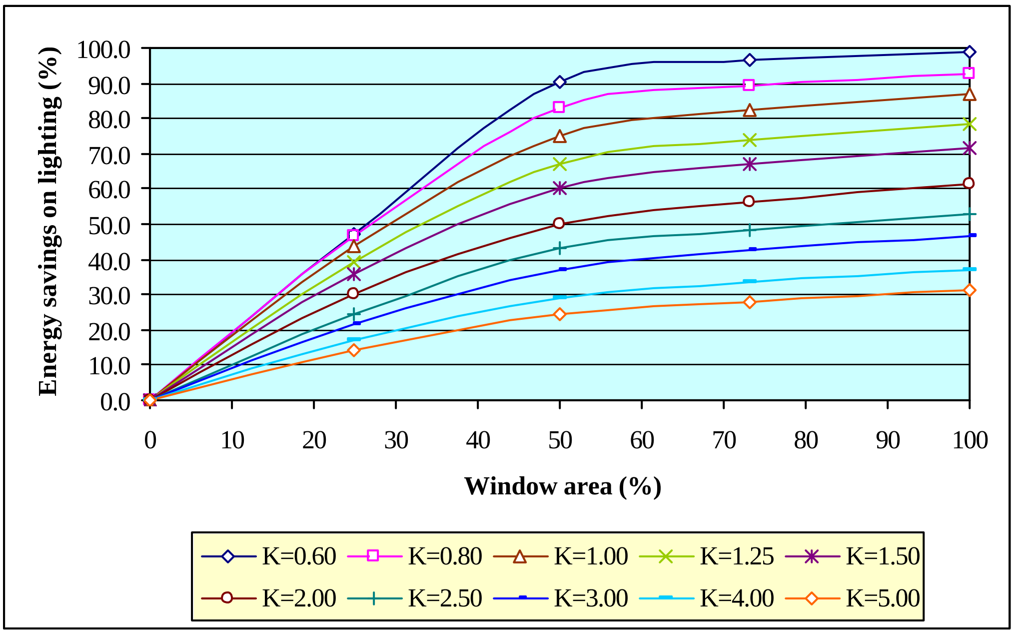


Figure 3.6. Energy savings on lighting for room ratio of 1:1 and Daylight Factor of 10%.

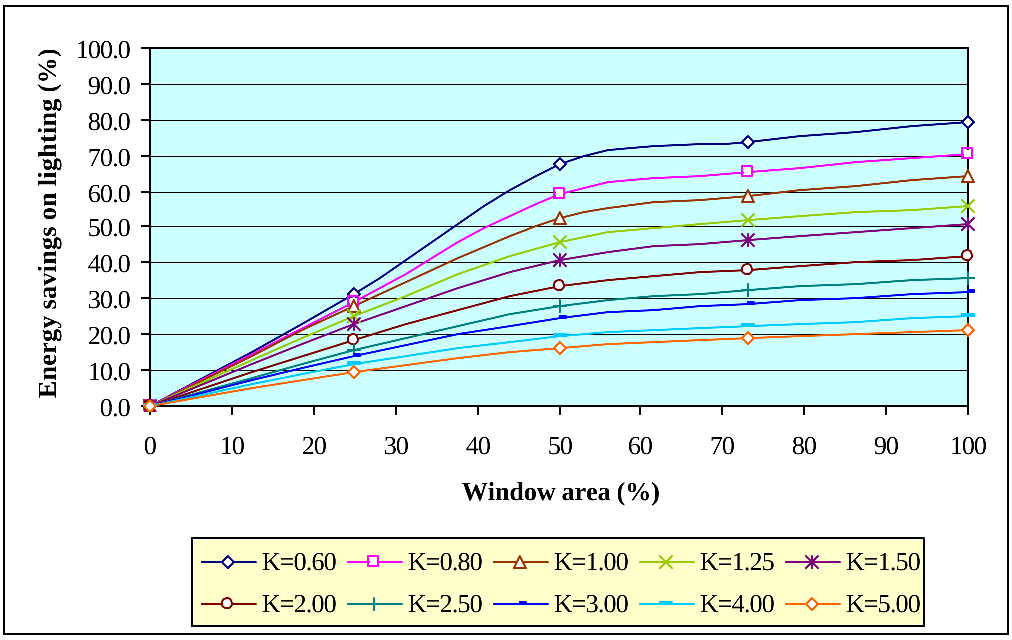


Figure 3.7. Energy savings on lighting for room ratio of 1:2 and Daylight Factor of 10%.

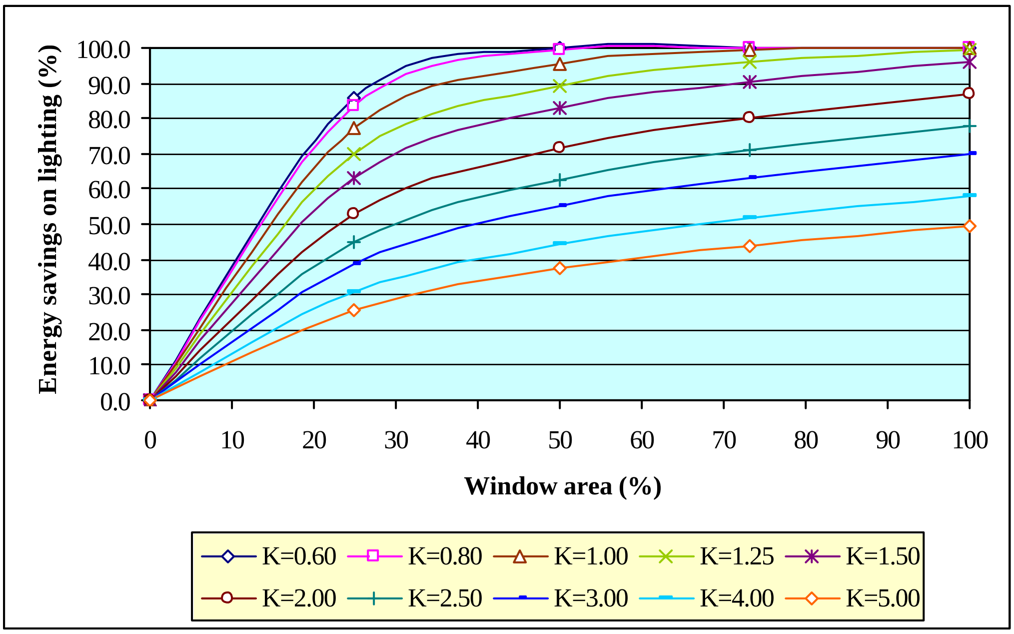


Figure 3.8. Energy savings on lighting for room ratio of 1:1 and Daylight Factor of 5%.

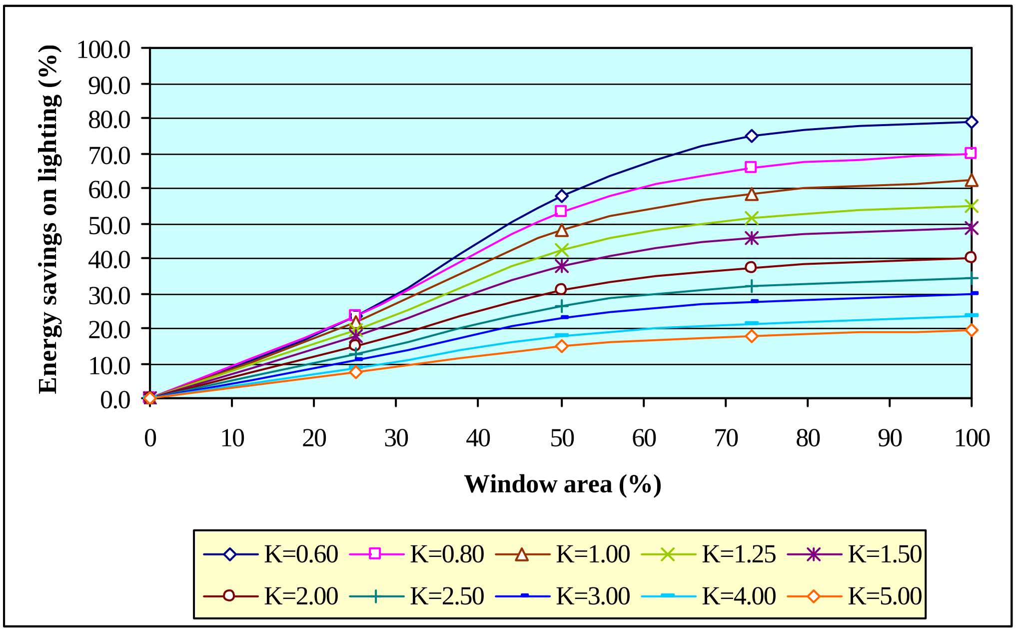


Figure 3.9. Energy savings on lighting for room ratio of 1:1 and Daylight Factor of 20%.

3.5. Summary

The approach presented in this chapter proved effective in showing that there could be significant energy savings made on lighting if there were an integration of artificial lighting with the daylight coming into the room through the windows. Such an analysis also showed that the energy savings on lighting are lower in larger rooms, which means that there is a higher potential for energy savings if new technologies, such as fibre optics, were to be applied to increase the daylight provision in such rooms.

The method used in this chapter deals only with quantifying of daylight provision, which indicates - not surprisingly - that the larger the window area the better the daylight supply. The method does not take into account that windows allow heat gains or losses into the building depending on the climatic conditions of the building location, which affects its energy consumption. Therefore, a Dynamic Thermal Modelling code was selected to optimise the thermal balance and energy consumption of buildings by identifying the Ideal Window Area of rooms of different sizes and different room ratios.

Chapter 4

Validation of the Dynamic Thermal Modelling Code

4.1. Introduction

The previous chapter assessed the provision of daylight in rooms of different dimensions, room ratios and window areas to quantify the potential for energy savings on lighting. Such an analysis was carried out through calculations of Daylight Factors and results showed that integration of daylight from windows is likely to provide significant energy savings on lighting in buildings. It was further observed that depending on the room size, room ratio and window area there is still a potential for greater energy savings to be made on lighting through the use of fibre optics if this technology could be proved to be effective to transport daylight into spaces. This potential grows as the window area of the room decreases. Therefore, at this stage, the purpose of this work was to identify the Ideal Window Area for rooms in which there is a balance between daylight supply and thermal load gains or losses.

A Dynamic Thermal Modelling code was regarded as an appropriate tool to be used to obtain the Ideal Window Area of spaces through the simulation of their energy consumption. However, prior to any simulations, the code had to be validated, which is the main purpose of this chapter.

As seen in the literature review presented in Chapter 2, validations on DOE have been widely reported and these confirm that the software can provide reliable and accurate data when the input data is properly modelled. However, this chapter intends to validate the VisualDOE programme specifically related to the parameters involved in this work and also to gain confidence in its use.

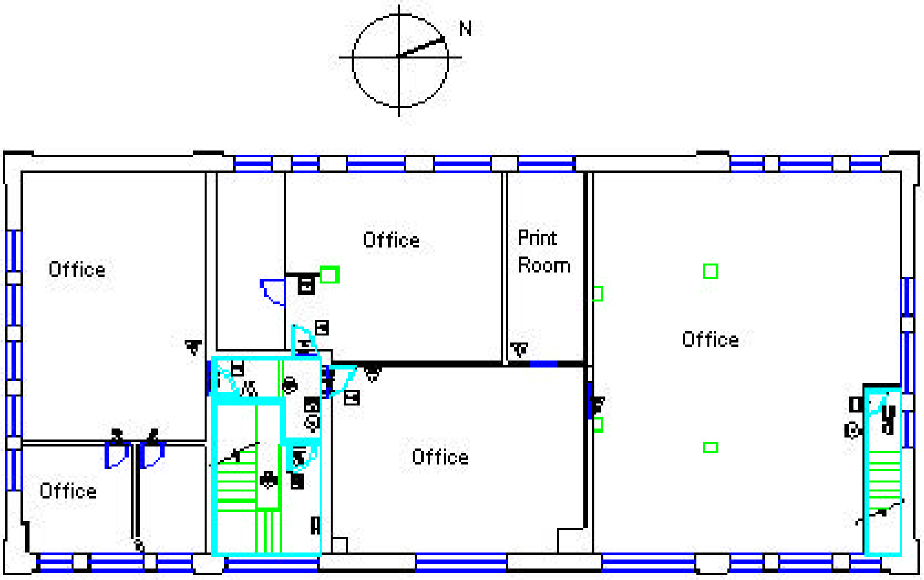
To gain confidence in the programme, two validations were performed by comparing energy consumption measured experimentally with that simulated by the programme. In the first validation, results of monthly energy consumption measured over a year in a building located on the campus of Leeds University were compared to results simulated by the programme. In order to compare results of energy savings on lighting simulated by the VisualDOE programme to those predicted by using the methodology presented in Chapter 3, two offices in the same building were simulated and daylight levels were measured on their working surface. The second validation takes into account the effect of window size and daylight integration on the energy consumption of an office space located in the Civil Engineering Building, at Leeds University.

4.2. The first validation

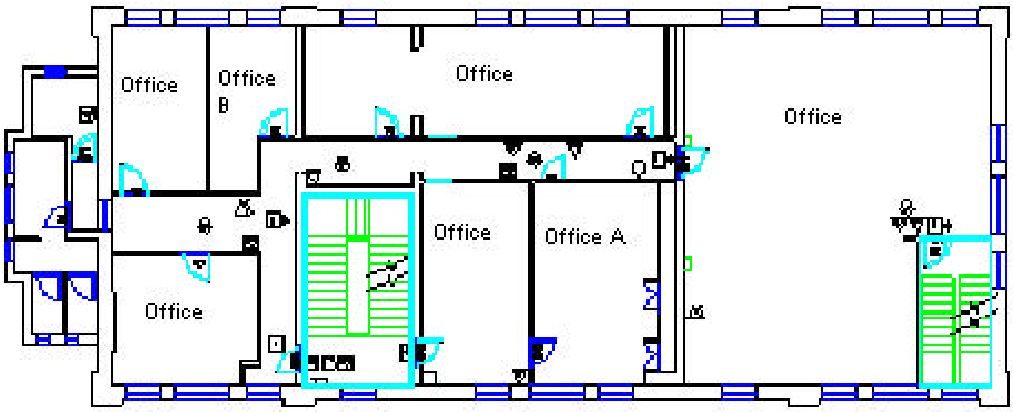
The Estates Services Building, located on the campus of the University of Leeds, was selected to be analysed. Such a building was chosen mainly due to the office activities taking place in it and because of the interest of the Energy Managers in charge in evaluating the potential for energy savings of the building.

The building is three storeys high, measuring 8 x 20m on plan. Each floor comprises offices of different dimensions. Figure 4.1 shows a view of the Southeast façade of the building. Figure 4.2 shows the floor plan of each of the three floors.

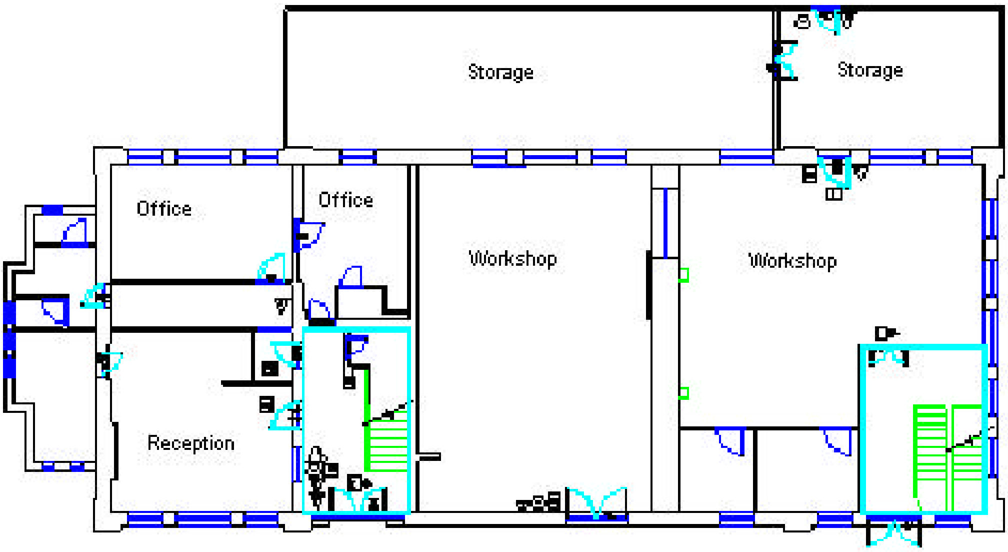
Figure 4.1. View of the Southeast façade of the Estates Services Building.



(a) Second Floor.



(b) First Floor.



(c) Ground Floor.

Figure 4.2. Floor plan of the Estates Services Building.

All information concerning the number of people in the building and working hours, occupancy patterns, the type of equipment installed and their use, building components, and the lighting system were surveyed by visiting the building and speaking to the users.

Table 4.1 presents the floor area, the lighting power density (LPD), and the equipment power density (EPD) for each zone of the building as modelled in the VisualDOE programme (see Figure 4.4). The LPD was obtained by counting lighting bulbs and checking their respective wattage, and then dividing the total wattage in each room by its floor area. The EPD is basically due to computers and was obtained in a similar way (PALMER, 1994).

Table 4.1. Floor area, LPD and EPD for the building.

Ground Floor				
Zone	Type	Area (m^2)	LPD (W/m^2)	EPD (W/m^2)
1	Reception	16.80	50.30	17.86
2	Corridor	5.70	23.95	0.00
3	Office	13.50	25.78	29.63
4	Staircase	10.00	38.48	0.00
5	Office	10.00	28.80	10.00
6	Workshop	48.00	36.83	0.00
7	Workshop	45.92	40.14	0.00
8	Staircase	10.08	21.92	0.00
9	Storage	5.12	66.02	0.00
10	Toilet	5.12	31.74	0.00
11	Storage	31.00	20.97	0.00

First Floor				
Zone	Type	Area (m^2)	LPD (W/m^2)	EPD (W/m^2)
1	Office	9.80	44.08	10.20
2	Corridor	18.78	34.06	0.00
3	Staircase	10.00	31.98	0.00
4	Office	10.00	48.00	30.00
5	Office	14.00	34.29	0.00
6	Office	8.80	59.32	22.73
7	Office	8.20	56.59	12.20
8	Office	25.50	52.31	19.61
9	Office	51.20	50.98	27.34
10	Staircase	4.80	46.04	0.00
11	Toilet	6.64	15.66	0.00
12	Kitchen	2.52	29.92	1100.00

Table 4.1. Floor area, LPD and EPD for the building (cont.).

Second Floor				
Zone	Type	Area (m^2)	LPD (W/m^2)	EPD (W/m^2)
1	Office	7.50	46.40	26.67
2	Computers	3.75	86.67	160.00
3	Staircase	10.00	54.08	0.00
4	Office	24.00	33.00	8.33
5	Office	24.75	63.27	24.24
6	Office	6.40	46.88	15.63
7	Office	20.40	29.41	14.71
8	Print room	7.20	54.17	27.78
9	Office	53.60	34.93	20.52
10	Staircase	2.40	46.04	0.00

The schedules of occupancy of the building were calculated considering the working hours of the staff who work in the building, and their start and finish times. Table 4.2 presents the occupancy pattern identified in the building and used in the simulations.

Table 4.2. Schedule of occupancy of the building.

Hour	People (%)
7-8am	55
8-9am	75
9am-5pm	100
5-6pm	30

The measurement of the energy consumption of the building was obtained from the Energy Managers. The analysis covered the period between April 1999 and March 2000 and this corresponded to the period over which the climatic data of Leeds was available (and subsequently translated into computer language to be used in the VisualDOE programme). The measured monthly energy consumption of the building is presented in Figure 4.3, where it can be seen that the consumption ranges from approximately 10000-12000kWh between the months of April and September, and from approximately 15000-19000kWh from October to March. The disjunction between March and April is discussed in page 80.

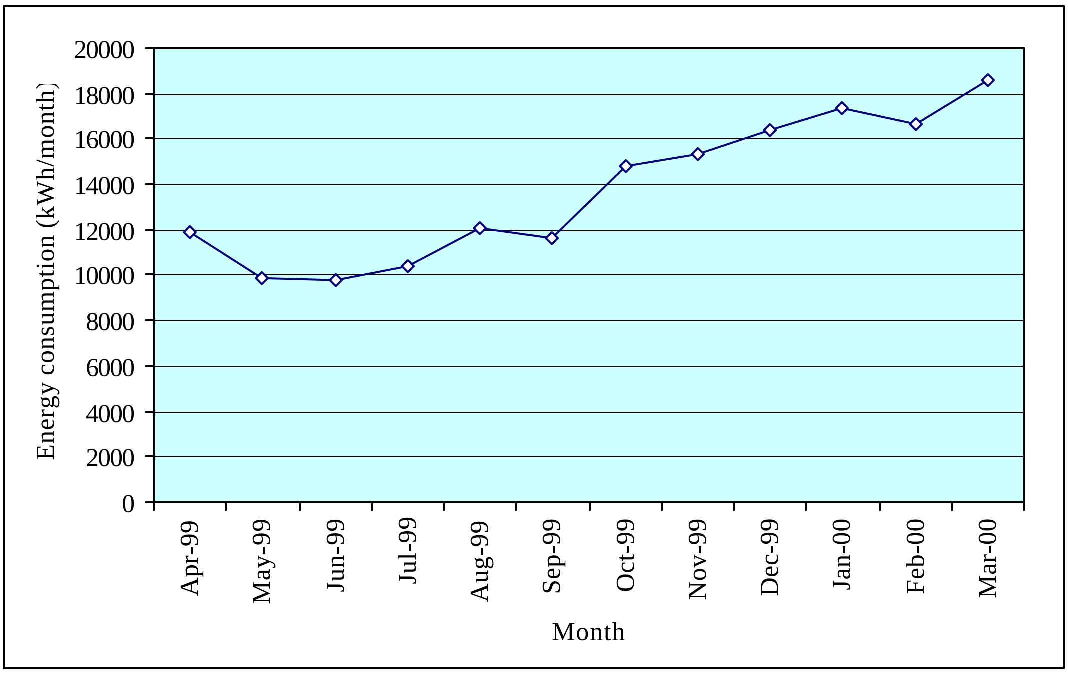


Figure 4.3. Measured monthly energy consumption of the Estates Services Building.

As for the building components, all plans and sections through the building were supplied, as were the material used. Unfortunately, there was no record of their thermal properties and so the calculation of U-values and heat capacity of the walls and roof relied upon data obtained from literature sources. Thickness of components was obtained on site. To account for eventual errors due to these assumptions, a sensitivity analysis was performed using the VisualDOE programme.

4.2.1. Sensitivity analysis

As there was a degree of uncertainty about some of the thermophysical variables related to the building components (and used in the simulations), a sensitivity analysis was performed to evaluate the influence of such variables on the energy consumption of the building.

The variables that were evaluated are colour (α-value), U-value and heat capacity of the external walls and roof, and infiltration. Values used in the simulations are presented in Table 4.3.

Table 4.3. Thermal properties and infiltration rate used in the simulations.

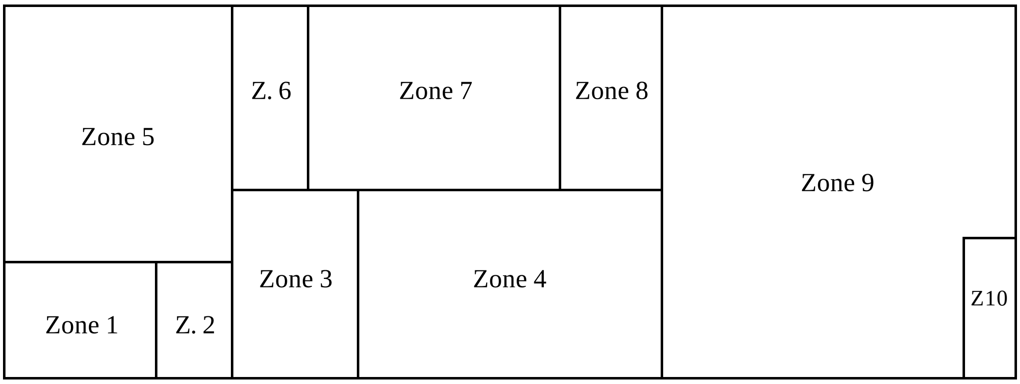
Properties	Wall	Roof
α-value (%)	80	80
U-value (W/m^2K)	1.75	2.38
Heat capacity (KJ/m^2K)	626	424
Infiltration (Air-changes/hour)	0.20 / 0.30 / 0.60 / 0.90	

With reference to the infiltration rates adopted, support from other authors is presented. NILSSON et al. (1994) reported that an existing office building in Stockholm, Sweden, had an air infiltration rate of 0.24 air changes per hour throughout the year. AL BUIJAN (1997) states that an infiltration rate of 0.30 air changes per hour was used to simulate a 100% glazed building in Damman, Saudi Arabia, using the ESP-r code.

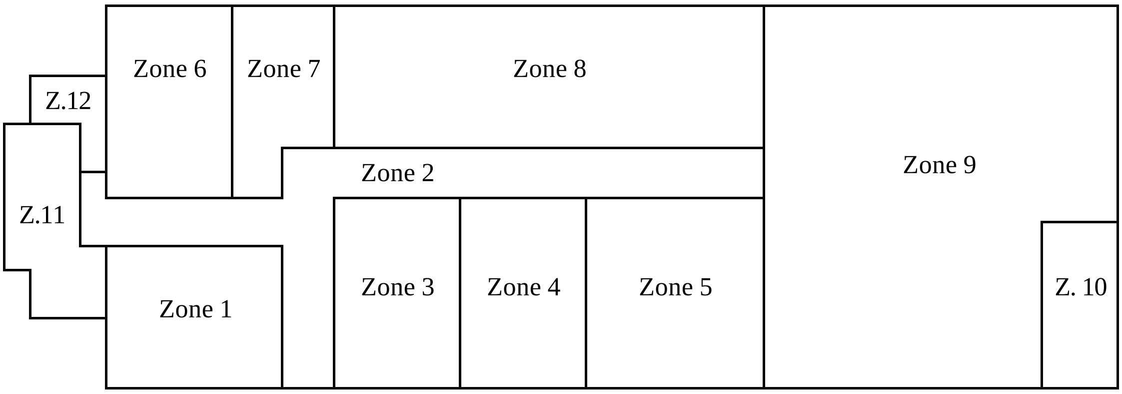
SAID (1997) measured infiltration rates in two large single-cell aircraft hangar buildings and obtained values ranging from 0.32 to 0.47 air changes per hour. From ASHRAE (1985) it can be found that the median infiltration value of a sample of 312 houses located in different areas in North America is 0.50 air changes per hour. From measurements in 266 houses located in 16 cities in the United States of America it was found a median infiltration value of 0.90 air changes per hour.

Therefore, the infiltration rates used in the validation were 0.20, 0.30, 0.60, and 0.90 air changes per hour.

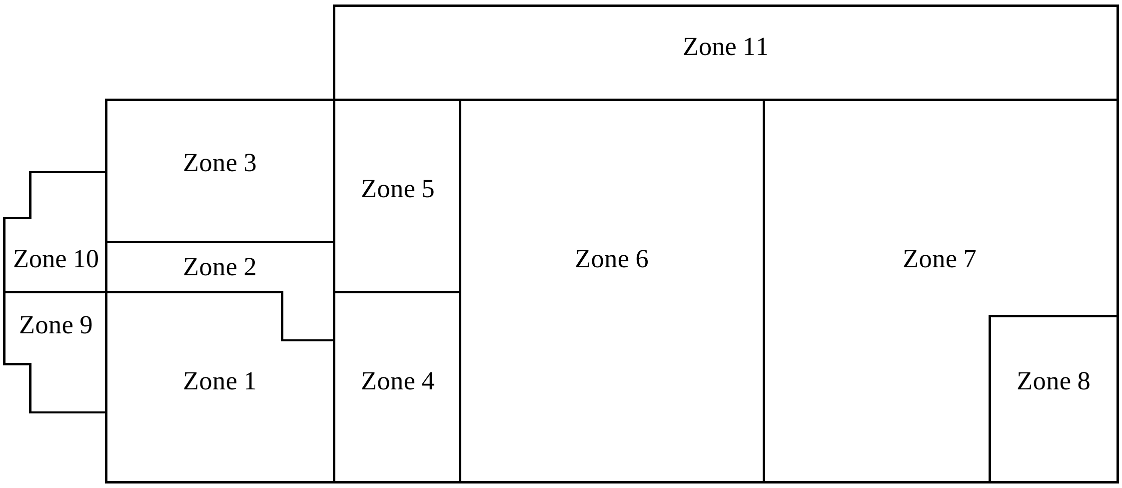
Having defined the variables to be analysed and having surveyed all the information concerning the building components and use, the building had to be modelled into VisualDOE. This was done by modelling the geometry of the building, defining space dimensions, glazing area, thermo-physical properties of the building components, schedules of use and operation of the building, etc into the programme. Figure 4.4 shows the floor plan of the building as used in the sensitivity analysis and further simulations concerning the Estates Services Building.



(a) Second floor.



(b) First floor.



(c) Ground Floor.

Figure 4.4. Floor plan of the Estates Services Building as used in the simulations.

Table 4.4 shows the results of the sensitivity of infiltration on the energy consumption of the building. Case 1 was simulated with an infiltration rate 50% higher (0.30 air changes per hour) than the base case (0.20 air changes per hour). Case 2 was simulated with an infiltration rate 200% higher (0.60 air changes per hour) than the base case; and finally, case 3 was simulated with an infiltration rate 350% higher (0.90 air changes per hour) than the base case. It is shown that the difference on the energy consumption due to infiltration rate is not significant and ranges, for the worst situation (case 3 compared to the base case), from –0.20% to 2.64% a month, and increases only 1.17% a year. The low influence of infiltration rate on the energy consumption is supported by other authors.

THAM (1993) performed a parametric analysis using DOE2.1B to identify the influence of different parameters on the energy consumption of an office building located in Singapore. The building had an infiltration rate of 0.6 air changes per hour and it was found that by increasing such a value to 0.9 changes per hour would lead to a variation on the energy consumption of the building of only 0.2%. Fourteen parameters were simulated and the infiltration was found to be the second parameter least likely to affect the energy consumption.

LAM et al. (1997) carried out a survey of the existing commercial buildings in Hong Kong to identify the design characteristics common to most buildings and found the infiltration rate to be 0.6 air changes per hour. Then, using the DOE2.1E programme to perform a parametric study, the authors identified the twelve design parameters that have a high sensitivity on the energy consumption and infiltration is not amongst these parameters.

Table 4.4. Sensitivity of infiltration on the energy consumption.

Month/year	Base case 0.2air-chg/hr	Case 1 0.3air-chg/hr		Case 2 0.6air-chg/hr		Case 3 0.9air-chg/hr	
	E.C. (kWh)	E.C. (kWh)	Diff. (%)	E.C. (kWh)	Diff. (%)	E.C. (kWh)	Diff. (%)
April/99	11883	11902	0.16	11960	0.64	12019	1.14
May/99	11941	11945	0.04	11965	0.20	11982	0.35
June/99	11377	11375	-0.02	11376	-0.01	11378	0.00
July/99	11381	11377	-0.04	11366	-0.13	11358	-0.20
August/99	12039	12037	-0.01	12037	-0.01	12036	-0.02
September/99	11144	11146	0.02	11152	0.07	11155	0.10
October/99	13385	13403	0.13	13458	0.55	13514	0.96
November/99	15536	15571	0.23	15679	0.92	15788	1.62
December/99	16983	17031	0.28	17173	1.12	17313	1.94
January/00	17914	17965	0.28	18113	1.11	18258	1.92
February/00	15064	15121	0.37	15292	1.51	15462	2.64
March/00	15513	15557	0.28	15688	1.13	15817	1.96
Total	164160	164429	0.16	165260	0.67	166080	1.17

E. C. stands for Energy Consumption.

Results of sensitivity of colour (α-value) of the external walls and roof are presented in Table 4.5. Considering a reduction in α-value from 0.8 to 0.6 for either walls or roof, shows an insignificant difference on the energy consumption of the building, being lower than 1%.

Table 4.5. Sensitivity of α-value on the energy consumption.

Month/year	Base case $\alpha_{wall}=\alpha_{roof}=0.8$	Case 4 $\alpha_{wall}=0.6$		Case 5 $\alpha_{roof}=0.6$	
	E. C. (kWh)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)
April/99	11883	11976	0.78	11948	0.55
May/99	11941	12027	0.72	11976	0.30
June/99	11377	11399	0.20	11355	-0.19
July/99	11381	11310	-0.62	11292	-0.78
August/99	12039	12034	-0.04	12002	-0.30
September/99	11144	11149	0.04	11127	-0.16
October/99	13385	13445	0.45	13422	0.28
November/99	15536	15571	0.22	15556	0.13
December/99	16983	17002	0.11	16991	0.04
January/00	17914	17947	0.18	17933	0.10
February/00	15064	15107	0.28	15096	0.21
March/00	15513	15597	0.54	15575	0.40
Total	164160	164563	0.25	164273	0.07

E. C. stands for Energy Consumption.

The influence of varying the U-value of the walls and roof is shown in Table 4.6. By changing the U-value of the external walls by ±30%, the difference on the energy consumption of the building ranges from –4.27% to 3.47% a month, and from –2.21% to 1.95% a year. As for the roof, by changing its U-value by ±30%, the difference on energy consumption ranges from –0.86% to 0.67% a year.

Results concerning changing the heat capacity of the walls and roof are presented in Table 4.7. It is shown that any increase or reduction of the heat capacity by 30% affects the energy consumption of the building by less than 1% for either walls or roof.

Table 4.6. Sensitivity of U-value of walls and roof on the energy consumption.

		Wall				Roof			
Month/year	Base case	Case 6 (+30%)		Case 7 (-30%)		Case 8 (+30%)		Case 9 (-30%)	
	E. C. (kWh)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)
April/99	11883	12135	2.12	11616	-2.24	11972	0.75	11783	-0.84
May/99	11941	12051	0.93	11856	-0.71	12017	0.64	11890	-0.42
June/99	11377	11403	0.22	11378	0.00	11420	0.38	11355	-0.20
July/99	11381	11299	-0.72	11480	0.87	11388	0.07	11386	0.05
August/99	12039	12033	-0.05	12063	0.20	12076	0.31	12020	-0.15
September/99	11144	11154	0.09	11146	0.02	11186	0.37	11121	-0.21
October/99	13385	13663	2.07	13084	-2.25	13503	0.88	13237	-1.10
November/99	15536	16006	3.03	15000	-3.45	15682	0.94	15321	-1.38
December/99	16983	17572	3.47	16259	-4.27	17125	0.84	16757	-1.33
January/00	17914	18505	3.30	17190	-4.04	18047	0.74	17692	-1.24
February/00	15064	15575	3.39	14473	-3.93	15200	0.90	14866	-1.31
March/00	15513	15971	2.95	14997	-3.33	15650	0.88	15322	-1.23
Total	164160	167365	1.95	160540	-2.21	165266	0.67	162752	-0.86

E. C. stands for Energy Consumption.

Table 4.7. Sensitivity of heat capacity of walls and roof on the energy consumption.

		Wall				Roof			
Month/year	Base case	Case 10 (+30%)		Case 11 (-30%)		Case 12 (+30%)		Case 13 (-30%)	
	E. C. (kWh)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)	E. C. (kWh)	Diff. (%)
April/99	11883	11893	0.09	11889	0.05	11866	-0.14	11919	0.31
May/99	11941	11914	-0.22	11998	0.48	11905	-0.30	12009	0.57
June/99	11377	11351	-0.23	11419	0.37	11348	-0.26	11432	0.48
July/99	11381	11370	-0.09	11389	0.07	11363	-0.16	11415	0.30
August/99	12039	12016	-0.19	12072	0.28	12013	-0.21	12089	0.42
September/99	11144	11129	-0.14	11166	0.20	11124	-0.18	11191	0.42
October/99	13385	13384	-0.01	13399	0.10	13371	-0.11	13411	0.19
November/99	15536	15559	0.15	15508	-0.18	15538	0.02	15534	-0.01
December/99	16983	17019	0.21	16917	-0.39	16992	0.05	16965	-0.11
January/00	17914	18005	0.51	17791	-0.69	17939	0.14	17879	-0.20
February/00	15064	15103	0.26	15014	-0.33	15070	0.04	15056	-0.05
March/00	15513	15538	0.16	15488	-0.17	15510	-0.02	15523	0.06
Total	164160	164281	0.07	164049	-0.07	164038	-0.07	164423	0.16

E. C. stands for Energy Consumption.

The sensitivity analysis presented in this section was performed to evaluate the influence of four variables on the energy consumption of the Estates Services Building as there was no certainty about the actual significance of these variables because they were not documented. Therefore, amongst the four variables simulated, the U-value of the walls is the variable more likely to influence the energy consumption of the Estates Services Building as obtained in the simulations, though not significantly. Figure 4.5 shows the simulated energy consumption of the Estates Building for the sensitivity analysis of all cases presented previously.

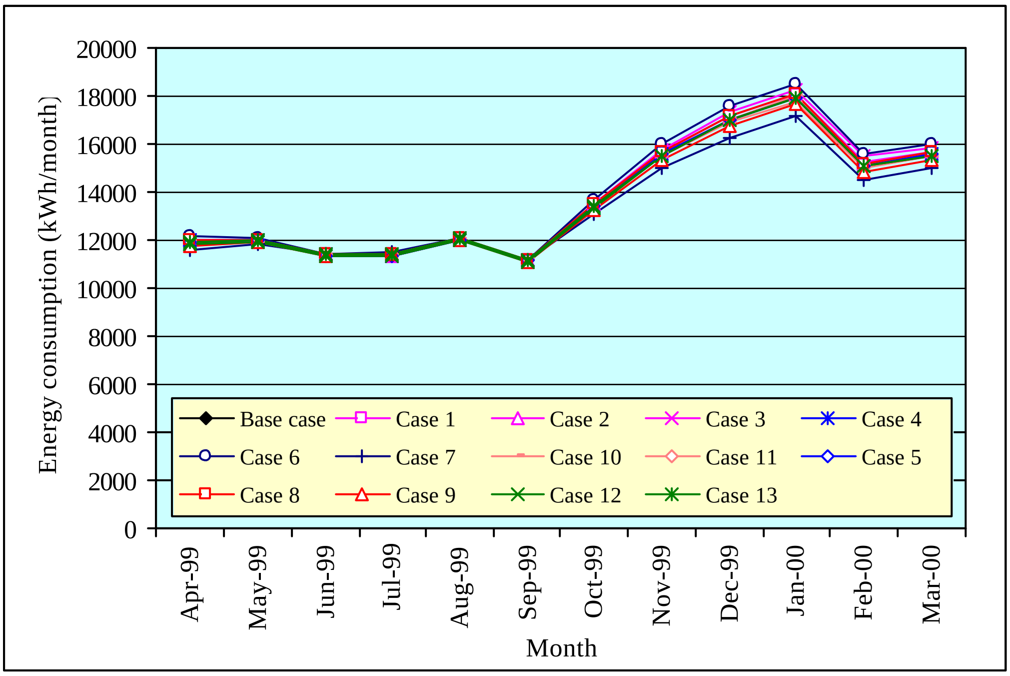


Figure 4.5. Sensitivity analysis for the Estates Services Building.

The sensitivity analysis showed that there is not a significant difference on the energy consumption of the building when the U-value, heat capacity and α-value of walls and roof, and infiltration rate are taken as sensitive parameters. Resulting from this, the energy consumption of the base case can be compared to the actual consumption of the building with some confidence.

4.2.2. Energy consumption

Having performed the sensitivity analysis and shown that the model simulated can provide reliable output results, a comparison of measured and simulated energy consumption follows.

Table 4.8 presents the measured and simulated energy consumption of the Estates Services Building over the period April 1999 to March 2000 as simulated using VisualDOE. The right hand column shows the percentage difference between the two values. The highest differences between measured and simulated energy consumption occur in May 1999 with a discrepancy of 20.6% and also in March 2000 with a difference of –16.6%. Though high, these differences between measured and simulated monthly energy consumptions lie within the error range considered acceptable by ASHRAE (1987) and ZMEUREANU et al. (1995) as presented in the literature review.

Figure 4.6 shows measured versus simulated energy consumption of the Estates Services Building where error bars of ±20% on the measured energy consumption are presented. It is shown that there is a significant difference on the energy consumption in the months of May 1999, June 1999, and March 2000. However, as shown by the error bars, the simulated values lie within the range of 20% of the measured energy consumption. In consultation with the Energy Managers of the building, an attempt was made to identify reasons for the discrepancies in some months, but no significant change in patterns of use in those months could be recollected. However, during the measurements of daylight levels performed in the building in May 2001, it was noted that some users switch off the lights when there is plenty of daylight reaching the working surface. This may indicate a reason for the discrepancies between measured and simulated energy consumption over some months.

Table 4.8. Measured versus simulated energy consumption.

Month/year	Energy consumption (kWh)		Difference
	Measured	Simulated	(%)
April/99	11890	11883	-0.1
May/99	9901	11941	20.6
June/99	9772	11377	16.4
July/99	10429	11381	9.1
August/99	12033	12039	0.0
September/99	11638	11144	-4.2
October/99	14782	13385	-9.4
November/99	15295	15536	1.6
December/99	16388	16983	3.6
January/00	17350	17914	3.3
February/00	16668	15064	-9.6
March/00	18591	15513	-16.6
Total	164737	164160	-0.4

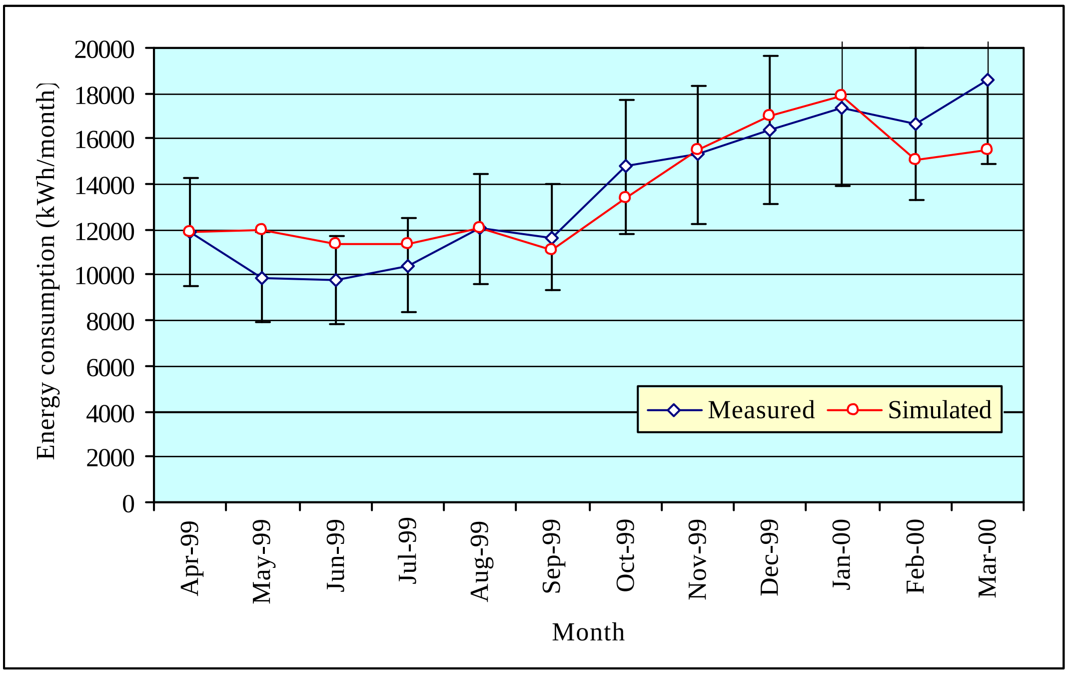


Figure 4.6. Measured versus simulated energy consumption.

Having completed a validation of the VisualDOE programme by simulating the Estates Services Building with encouraging results, an analysis on integration of daylight is to follow.

4.2.3. Daylight integration

This section deals with energy savings on lighting likely to be obtained when there is integration of daylight with artificial lighting. Results obtained by simulations using VisualDOE were compared to results obtained by using the methodology presented in Chapter 3, in which energy savings on lighting are calculated as a function of Daylight Factors.

To perform the analysis, two different offices in the Estates Services Building were selected. Figures 4.7 and 4.8 show an internal view of the offices. Office A is located at the front of the building on the Southeast façade. Office B is located at the rear side, Northwest orientation. Both offices are located on the first floor and they can be identified in Figure 4.1 presented at the beginning of this chapter.

Figure 4.7. Internal view of Office A.

Figure 4.8. Internal view of Office B.

It was noted that there are external obstructions surrounding the Estates Services Building limiting the amount of daylight available directly from the sky. Figures 4.9 and 4.10 show the obstructions outside offices A and B, respectively.

Figure 4.9. View from the window of Office A.

Figure 4.10. View from the window of Office B.

Daylight levels in both of the offices were measured on the working surfaces at specific times of the day over the period 9 May 2001 to 14 May 2001. Lux reading were recorded using a portable luxmeter 'Testo 545' as shown in Figure 4.11 and described in the previous chapter.

Figure 4.11. Portable luxmeter used in the measurements.

Daylight levels in Office A

Office A is 4.00m wide and 5.80m deep and daylight levels were measured at five locations across the room and at nine locations from front to back (45 locations in total). Measurements of daylight levels were recorded under two conditions:

(a) no blinds covering the windows,
(b) blinds lowered in order to cover 50% of the window area – see Figure 4.12.

Measurements were taken under these two conditions to verify the influence of window areas on energy savings on lighting. Two sets of measurements were recorded with no blinds to the window, one in the afternoon of 9 May 2001 and a second in the morning of 11 May 2001. A third set of measurements was recorded with blinds lowered to cover 50% of the window area in the afternoon of 9 May 2001.

The daylight levels measured for both conditions are presented in Figures 4.13 and 4.14, respectively, and values higher than 500lux are presented in red. This identified areas in the office where the illuminance level was adequate for working surfaces in offices as defined in BS 8206-1 (1985) and where, therefore, the artificial lighting could be turned off. As for the rest of the room, although the daylight levels were comparatively low, they could contribute to energy savings. Thus, applying the methodology used in Chapter 3, the energy savings on lighting that such daylight levels could provide are 66% and 78%, respectively for 9 and 11 May 2001 with no blinds on the window. As for the condition with blinds covering 50% of the window area the energy savings on lighting would be 48%.

An example of the calculation of these energy savings is given below for the condition of illuminance level measured on 9 May 2001 with no blinds covering the window (see Figure 4.13, left hand side).

The energy savings due to illuminance levels higher than 500lux are:

$$S_{front} = 100\frac{16}{45} = 36\%$$

Where 16 is the number of locations in which the illuminance levels are higher than 500lux and 45 is the total number of locations.

The energy savings due to illuminance levels lower than 500lux are:

$$S_{rear} = 100\frac{\sum_{1}^{29}\frac{L}{500}}{29} = 100\frac{\frac{328}{500}+\frac{397}{500}+...+\frac{108}{500}+\frac{102}{500}}{29} = 47\%$$

Where L is the illuminance level lower than 500lux and 29 is the number of locations in which the illuminance level is lower than 500lux.

And the total energy savings on lighting are:

$S_{total} = 100\ (S_{front} + (1 - S_{front})\ S_{rear}) = 100\ (0.36 + (1 - 0.36)\ 0.47) = 66\%$

Figure 4.12. Internal view of office A with blinds enclosing 50% of the windows.

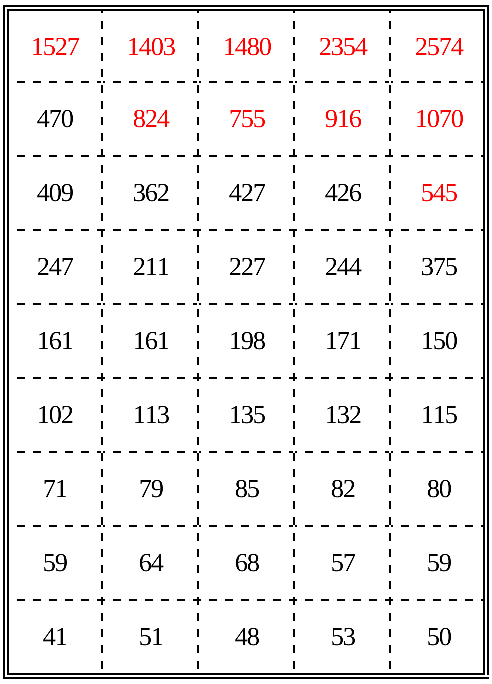
863	671	948	1359	1322
1019	1038	1133	1405	1215
653	625	690	750	890
328	397	383	503	414
256	351	378	397	405
190	248	245	276	340
130	190	208	207	205
102	147	132	160	184
80	91	104	108	102

9 May 2001 – 1.00-1.10pm.

2435	2224	2592	4204	2465
1659	1900	2219	2355	2243
894	960	1122	1172	1299
622	552	615	552	610
459	377	425	471	462
360	293	328	350	305
392	248	271	304	315
230	231	251	219	220
147	187	188	191	218

11 May 2001 – 10.00-10.10am.

Figure 4.13. Daylight levels (lux) measured in Office A with no blinds.



1527	1403	1480	2354	2574
470	824	755	916	1070
409	362	427	426	545
247	211	227	244	375
161	161	198	171	150
102	113	135	132	115
71	79	85	82	80
59	64	68	57	59
41	51	48	53	50

9 May 2001 – 1.10-1.20pm.

Figure 4.14. Daylight levels (lux) measured in Office A with blinds covering 50% of the window area.

Having estimated the potential for energy savings on lighting in Office A by applying the methodology presented in Chapter 3, the same office was then simulated using VisualDOE. The potential energy savings on lighting for specific times of day (about 10am and 1pm in May) obtained from the simulations were compared to the results estimated previously to identify the accuracy of the programme in predicting energy savings on lighting.

The energy savings on lighting in Office A that were obtained from simulations using VisualDOE are presented in Tables 4.9 and 4.10 for the two situations (a) no blinds covering the windows and (b) blinds covering 50% of the windows, respectively. The results from the simulations represent an average of energy savings on lighting likely to occur during each hour of the month. It can be noticed from the data presented in Table 4.9, that the predicted energy savings on lighting likely to occur in Office A at 10am and 1pm in May are 70% (red figures in Table 4.9), when there are no blinds covering the windows. From Table 4.10 it can be noted that the energy savings on lighting when the blinds cover 50% of the window area are 44% (red figure in Table 4.10).

Table 4.9. Potential energy savings on lighting in Office A as simulated using VisualDOE (no blinds).

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Month	Energy savings on lighting due to daylight integration (%)																							
Jan	0	0	0	0	0	0	0	0	0	23	49	59	58	56	47	25	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	21	57	68	70	68	66	61	57	33	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	19	56	66	68	69	67	65	62	54	49	33	0	0	0	0	0	0
Apr	0	0	0	0	0	0	24	65	68	68	68	68	68	68	67	65	63	55	37	0	0	0	0	0
May	0	0	0	0	0	14	54	68	70	70	70	70	70	70	70	70	69	64	53	27	0	0	0	0
Jun	0	0	0	0	2	29	60	68	70	70	70	68	69	68	66	63	64	63	55	45	10	0	0	0
Jul	0	0	0	0	1	27	62	70	70	70	70	70	70	70	66	68	68	65	58	47	6	0	0	0
Aug	0	0	0	0	0	2	33	62	69	70	70	70	70	69	67	61	58	57	40	7	0	0	0	0
Sep	0	0	0	0	0	0	5	42	63	68	70	70	69	67	66	63	59	45	12	0	0	0	0	0
Oct	0	0	0	0	0	0	0	4	40	63	68	68	67	64	63	59	34	4	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	3	35	55	64	61	57	50	33	3	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	10	40	53	57	56	43	16	0	0	0	0	0	0	0	0
Annual	0	0	0	0	0	6	30	37	48	56	64	67	66	65	61	53	31	23	21	11	1	0	0	0

Table 4.10. Potential energy savings on lighting in Office as simulated using VisualDOE A (blinds covering 50% of the window area).

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Month	Energy savings on lighting due to daylight integration (%)																							
Jan	0	0	0	0	0	0	0	0	0	3	9	12	13	12	8	4	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0	3	12	21	27	26	23	18	12	6	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	3	13	27	33	35	26	24	19	13	10	6	0	0	0	0	0	0
Apr	0	0	0	0	0	0	4	15	30	48	56	48	48	39	29	20	17	12	7	0	0	0	0	0
May	0	0	0	0	0	2	11	23	43	56	55	48	44	37	29	24	20	16	11	5	0	0	0	0
Jun	0	0	0	0	0	5	15	29	48	55	54	46	39	31	24	22	20	17	12	8	2	0	0	0
Jul	0	0	0	0	0	4	15	31	52	57	59	52	49	38	24	24	23	18	13	8	1	0	0	0
Aug	0	0	0	0	0	0	5	17	36	51	51	49	45	36	26	19	14	12	7	1	0	0	0	0
Sep	0	0	0	0	0	0	1	8	21	38	48	50	42	32	25	19	15	9	2	0	0	0	0	0
Oct	0	0	0	0	0	0	0	1	8	19	28	32	27	22	19	13	6	1	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	0	6	11	15	15	14	10	6	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	0	1	6	10	11	10	7	3	0	0	0	0	0	0	0	0
Annual	0	0	0	0	0	1	6	12	23	32	36	35	32	27	20	15	8	5	4	2	0	0	0	0

Table 4.11 shows a comparison of the energy savings on lighting for Office A estimated through the application of the methodology presented in Chapter 3 with the output

results obtained using the VisualDOE programme. As it can be seen there is a difference of –8% to 4% between the energy savings that were estimated and those predicted by VisualDOE. This indicates that the energy savings on lighting predicted by VisualDOE are close to those estimated using the methodology presented in Chapter 3.

Table 4.11. Comparison of energy savings on lighting in Office A.

Blinds	Date	Time	Energy savings (%)		Difference
			Estimated	VisualDOE	(%)
No blinds	9 May 2001	1.00pm-1.10pm	66	70	4
No blinds	11 May 2001	10.00am-10.10am	78	70	-8
Blinds 50%	9 May 2001	1.10pm-1.20pm	48	44	-4

Daylight levels in Office B

Office B is 2.80m wide and 3.20m deep. Daylight levels were measured at four locations across the room and at four locations from front to back (16 locations in total).

The measurements were performed on 10 May 2001 over three different times. The estimation of energy savings on lighting and also simulations were performed in the same way as for Office A. Therefore, to avoid repetition and duplication of data, Table 4.12 presents energy savings on lighting obtained by using the methodology presented in Chapter 3 and by using VisualDOE.

In this case, the differences on energy savings on lighting are more significant than those obtained for Office A. A probable reason is that the VisualDOE programme seems to constraint the energy savings on lighting at 70% and the calculations provided energy savings as high as 92%.

Table 4.12. Comparison of energy savings on lighting in Office B.

Date	Time	Energy savings (%)		Difference
		Estimated	VisualDOE	(%)
10 May 2001	10.00am-10.05am	58	70	12
10 May 2001	1.00pm-1.05pm	89	70	-19
10 May 2001	4.00pm-4.05pm	92	70	-22

The previous sections in this chapter showed that the VisualDOE programme can predict energy consumption and energy savings on lighting in buildings with reasonable accuracy. Therefore, two more simulations were run to evaluate the energy savings likely to occur in the Estates Services Building when there is integration of daylight in all offices.

4.2.4. Daylight in the whole building

In the actual building there are lighting dimmers installed in four offices other than Offices A and B. To evaluate the savings that these dimmers can promote in the whole building, a simulation was performed not considering the use of such dimmers. Additionally, to evaluate the energy savings that could be achieved through the integration of daylight in the whole building, a simulation using dimmers in all offices was also performed.

These simulations were performed using the computer model discussed in section 4.2.1, which represents the Estates Services Building modelled into VisualDOE. The integration of daylight using VisualDOE can be easily modelled by indicating the zones (spaces) in which such an integration is to occur.

Table 4.13 shows the results of the simulations. Case 1 represents a situation in which the dimmers in the four offices are deactivated. Comparing the results from this case to the energy consumption of the base case (actual energy consumption of the building) it is possible to verify the energy savings that the dimmers in the four offices can provide. Case 2 represents a situation in which dimmers are installed in all offices, so that energy savings due to daylight integration in the whole building can be predicted. It can be seen from the table that the use of dimmers in the four offices accounts for energy savings of 2.3% over the year for the whole building. If similar dimmers were installed in all the offices allowing for the effective integration of daylight, energy savings of 11.0% would be achieved over the year in comparison to the actual energy consumption of the building.

Table 4.13. Energy savings in the building due to daylight integration.

Month/year	Base case	Case 1		Case 2	
	E. C. (kWh)	E. C. (kWh)	Savings (%)	E. C. (kWh)	Savings (%)
April/99	11883	12149	2.2	10449	12.1
May/99	11941	12444	4.0	9507	20.4
June/99	11377	11931	4.6	8836	22.3
July/99	11381	12018	5.3	8615	24.3
August/99	12039	12630	4.7	9389	22.0
September/99	11144	11632	4.2	8875	20.4
October/99	13385	13587	1.5	12024	10.2
November/99	15536	15642	0.7	14952	3.8
December/99	16983	17062	0.5	16707	1.6
January/00	17914	18006	0.5	17588	1.8
February/00	15064	15181	0.8	14546	3.4
March/00	15513	15687	1.1	14546	6.2
Total	164160	167967	2.3	146034	11.0

E. C. stands for Energy Consumption.

The validation of the VisualDOE programme using the Estates Services Building proved effective in showing the capabilities of the programme and in gaining confidence in its use. However, as the main purpose of using this programme was to obtain the Ideal Window Area of rooms, it was felt that a second validation relating the energy consumption predicted by VisualDOE to the window area of a space should be investigated.

4.3. The second validation

In the scope of this work, the VisualDOE programme was validated to evaluate its accuracy when predicting the energy consumption of rooms as a function of window areas and under circumstances of integrating daylight with artificial lighting.

To perform the second validation the energy consumption of an office space was monitored from 7 to 9 March 2000. The office was located on the third floor of the Civil Engineering Building, at Leeds University, and composed of a small room measuring 3.00x3.00m, and 3.00m high.

The room was equipped with a portable heater and an artificial lighting array. The heater was used to keep the internal temperature at 21^{o}C and the artificial lights used to maintain the illuminance on the working surface at 500lux. To measure the energy consumption of the office under the above condition, a kWh meter was installed in series with the portable heater and the artificial lighting array as seen diagrammatically in Figure 4.15. The energy consumption of the office was measured between 10am and 5pm; and there were no blinds to the window.

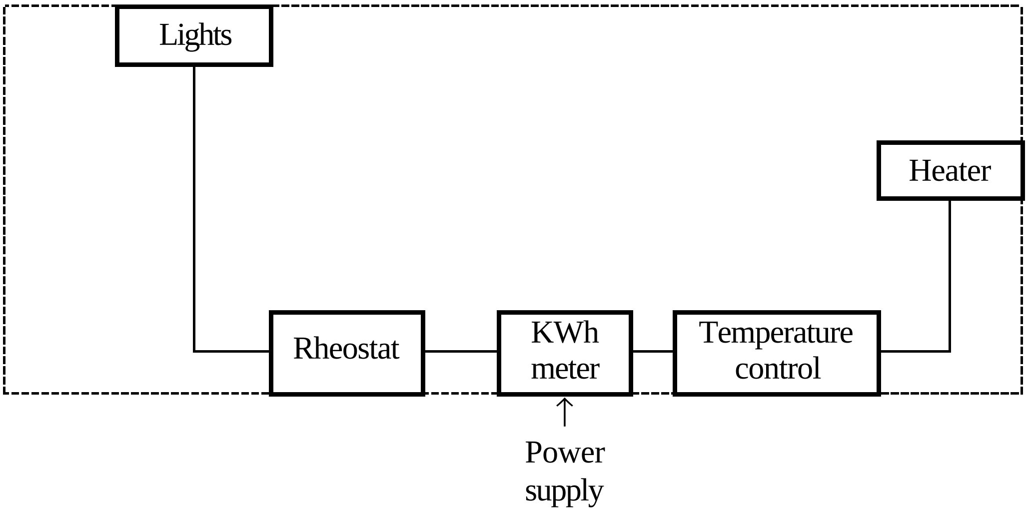


Figure 4.15. Diagram of equipment and kWh meter in the office.

On the first day of the measurement period the lights and the heater were switched on all the time. This was done in an attempt to validate VisualDOE in predicting the energy consumption of a space with no integration of daylight.

During the second and third day the artificial lights were switched on manually using a rheostat when the daylight levels on the working surface fell below 500lux. Daylight and artificial lighting levels were measured every 30 minutes through the use of a portable luxmeter placed upon a work desk in the office. Whenever the daylight levels fell below 500lux, the artificial lighting array was switched on and the power supply controlled using a rheostat in order to provide an illuminance level on the working surface close to 500lux. This approach would validate VisualDOE in predicting the energy consumption of spaces in which there is integration of daylight.

On the third day, the window area was reduced from 65.6% to 39.0% by covering the lower part of the window with cardboard paper. This approach would validate the VisualDOE programme in predicting the energy consumption of spaces subjected to varying window areas and the influence this has on the amount of daylight entering the space.

The energy consumption of the room was measured for the three different conditions described and the office was then simulated under the same conditions using the VisualDOE programme.

The office was modelled into the programme following the same way as described for the Estates Services Building.

Table 4.14 presents a comparison of the measured and simulated energy consumption for the office. It can be seen that this particular validation of the VisualDOE programme proved effective as the error between measured and simulated energy consumption of the office space ranged from –4.0% to –4.9%. Such errors lie well within acceptable accuracy ranges defined by other sources as presented in the literature review.

Table 4.14. Comparison of measured and simulated energy consumption for the office in the Civil Engineering Building.

Day	Window area	Energy consumption (kWh)		Error
	(%)	Measured	Simulated	(%)
1	65.6	10.33	9.83	–4.9
2	65.6	8.99	8.56	–4.7
3	39.0	9.80	9.41	–4.0

4.4. Summary

The validations performed in this chapter by analysing of the energy consumption of the Estates Services Building and of the office space in the Civil Engineering Building using the VisualDOE programme showed that the difference between measured and simulated values lie within the range presented by ASHRAE (1987) as acceptable.

Therefore, the programme was considered adequate to perform the simulations to identify the Ideal Window Area of rooms of different sizes and room ratios and such an analysis is presented in the next chapter.

Chapter 5

Computer Simulations: Results and Discussions

5.1. Introduction

Chapter 3 assessed the effect of different window areas on the provision of daylight on the working surface of rooms with different sizes and different room ratios. The analysis was performed through the calculation of Daylight Factors, but unfortunately the method does not consider the thermal effect related to glazed area and its implications on the energy consumption of the rooms.

When the daylight entering a building through the windows is integrated with the artificial lighting system to illuminate a working surface, energy savings can be determined as presented in Chapter 3. In naturally ventilated buildings, such energy savings are related to savings on the artificial lighting system only. In mechanically conditioned buildings, the integration of daylight with artificial light causes energy savings not only on the artificial lighting system, but also on the air-conditioning system due to the reduction of lighting thermal load.

Large glazed areas allow more daylight to reach the working surface, but they also permit unwanted solar heat gains to enter the space, which may increase the air-conditioning load. Therefore, this chapter investigates the window area of spaces in which there is an optimised balance between daylight supply, artificial lighting and air-conditioning. Such a window area is referred to as the Ideal Window Area (IWA) and it is the one in which the energy consumption of the space is the lowest.

The Ideal Window Area is assessed through simulations using the VisualDOE computer programme, which was validated in the previous chapter and proved accurate and adequate to be used in this work. The same room sizes and room ratios as presented in Chapter 3 will be simulated to identify their Ideal Window Area under mechanically conditioned circumstances.

Once the Ideal Window Areas have been identified, the potential for energy savings on lighting due to daylight integration and also the potential for more energy savings due to fibre optics integration are to be investigated by using the methodology presented previously in Chapter 3.

In order to investigate the influence of climatic conditions on daylight provision and consequently on the energy consumption and Ideal Window Area of spaces, one city in the UK and seven in Brazil were selected to compose the analysis. Prior to presenting the location of the cities and their weather conditions, the models used in the simulations are presented.

5.2. The model building

In order to investigate the relationship between window area, room size, floor ratio and energy consumption, the rooms whose Ideal Window Area is to be investigated are the same as presented in Chapter 3. For clarity, the isometric view of the five room ratios is presented again in Figure 5.1 and the room dimensions in Table 5.1.

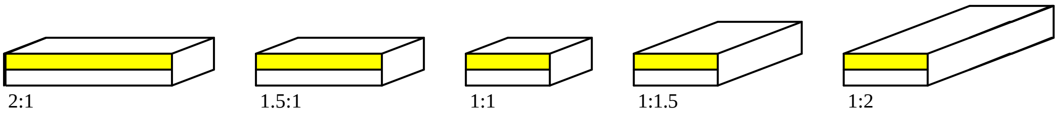


Figure 5.1. Isometric view of the five room ratios simulated.

Table 5.1. Room dimensions for each room index (K) and room ratio used in the simulations.

K	Room ratio									
	2:1		1.5:1		1:1		1:1.5		1:2	
	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)	W (m)	D (m)
0.60	3.69	1.85	3.08	2.05	2.46	2.46	2.05	3.08	1.85	3.69
0.80	4.92	2.46	4.10	2.73	3.28	3.28	2.73	4.10	2.46	4.92
1.00	6.15	3.08	5.13	3.42	4.10	4.10	3.42	5.13	3.08	6.15
1.25	7.69	3.84	6.41	4.27	5.13	5.13	4.27	6.41	3.84	7.69
1.50	9.23	4.61	7.69	5.13	6.15	6.15	5.13	7.69	4.61	9.23
2.00	12.30	6.15	10.25	6.83	8.20	8.20	6.83	10.25	6.15	12.30
2.50	15.38	7.69	12.81	8.54	10.25	10.25	8.54	12.81	7.69	15.38
3.00	18.45	9.23	15.38	10.25	12.30	12.30	10.25	15.38	9.23	18.45
4.00	24.60	12.30	20.50	13.67	16.40	16.40	13.67	20.50	12.30	24.60
5.00	30.75	15.38	25.63	17.08	20.50	20.50	17.08	25.63	15.38	30.75

W stands for width and D for depth.

As for the glazed area in each room ratio, in order to facilitate the identification of the IWA of each room, simulations were performed considering an incremental glazed area ranging from 0 to 100% at increments of 10% of the façade area. This is shown in Figure 5.2.

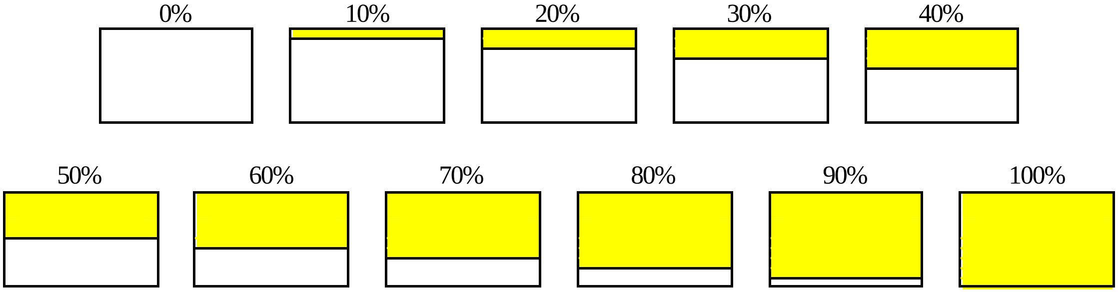


Figure 5.2. Glazed window area of the rooms simulated.

Having defined the room sizes and the increments of window area to be simulated, a computer model was built that represented the energy consumption of the room, and not the energy consumption of the floor area as this would bias the results.

Prior to any simulations work being undertaken, a model building in which the room sizes and room ratios would fit had to be defined. Figure 5.3 presents four models that were considered. Model A is a one-storey building composed of a single room whose four façades are all subjected to external conditions. Model B is a one-storey building composed of a single room whose window façade is the only one that is external. Models C and D are equivalent to models A and B, respectively, but are composed of 10 storeys. The complexity of models grows from model A to model D. Model D represents a more realistic building, but may require more computer modelling time, while model A, though quickly modelled, tends not to characterise a real-life building.

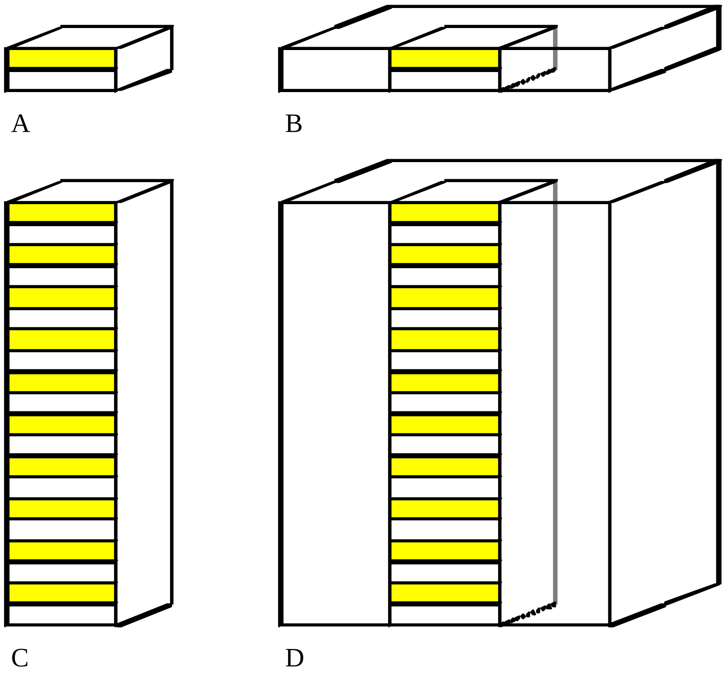


Figure 5.3. Model buildings under selection for the simulations.

In order to define the final model to be used in the simulations, a comparison of the energy consumption trends of the four models as a function of their window area had to be determined. To do this, the four models were simulated using the VisualDOE programme. As the purpose of these simulations was simply to identify which model was to be used in further work, simulations using only a room index (K) of 0.60, room ratio of 1:1 was considered, and north orientation. Other variables considered included the equipment power density (15W/m^2 – CIBSE, 1998), occupation density (15m^2/person – ASHRAE, 1987), lighting power density (22.0W/m^2 – GHISI & LAMBERTS, 1998), and an illuminance level of 500lux with integration of daylight. Such an illuminance level was chosen, as it is more appropriate for office spaces according to the British Standard (BS 8206-1, 1985). Climatic data for the city of Florianópolis (Brazil) was used in the simulations. This city is one of the seven located in Brazil that compose the sample of cities used in this work.

Figure 5.4 presents the results of the simulations carried out on the four model buildings expressed by their energy consumption as a function of the window area. So as to aid the comparison, the results of energy consumption are presented per unit of floor area. As expected, in a situation where insulation is not used, the energy consumption of Model A is higher than Model B's, and so is the energy consumption of Model C compared to Model D's. This can be easily explained as Models A and C have all four elevations subjected to external weather conditions. As for the window area, it can be seen that the Ideal Window Area – the window area in which the energy consumption of the room is the lowest – is not the same over the four models. It ranges from about 15% for Model D to 20% for the other models. Therefore, as Model D did not show to be computationally much more time consuming than the other models and since it represented a more realistic building, it was selected to identify the Ideal Window Area of different room sizes and different room ratios. But before going further, it is necessary to present and discuss the climatic conditions of the cities selected for the analysis.

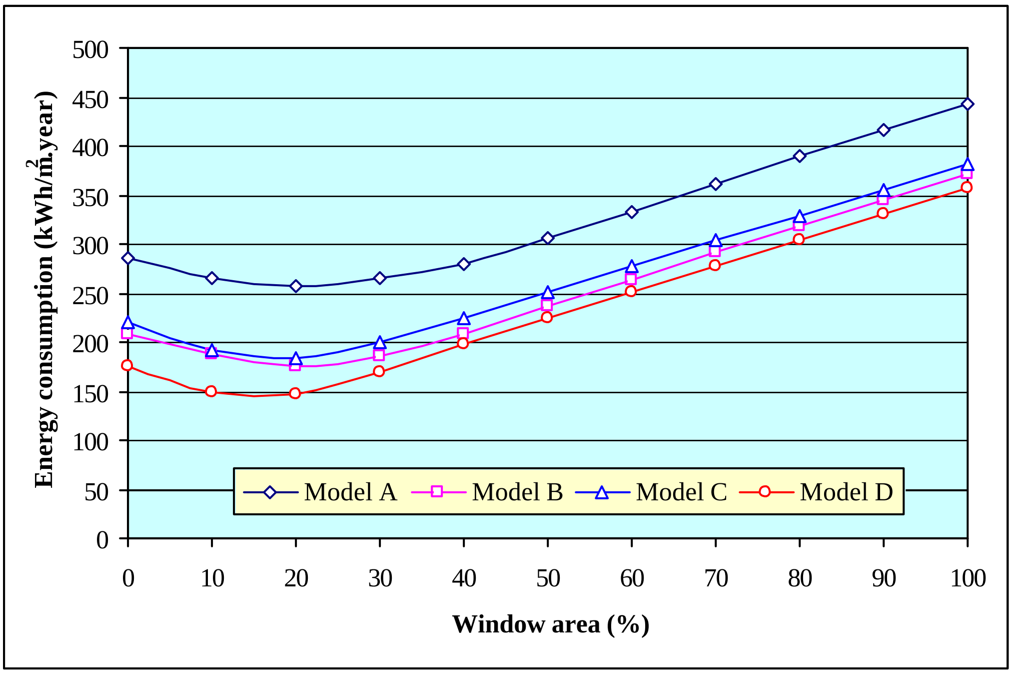


Figure 5.4. Energy consumption of the four models as a function of the window area and for an illuminance of 500lux.

5.3. The cities

The energy consumption of a building depends, amongst other factors, on the climatic conditions of its location and on the availability of daylight if there is integration with the artificial lighting system. Because of this, it was necessary to determine the energy consumption of the model under different climatic conditions. A range of climates was defined and then cities having that climate were selected. The research was undertaken in the UK, therefore a UK city was deemed appropriate. The author had extensive access to climatic data for cities in Brazil and since these experienced the range of climates required, seven Brazilian cities were selected to complete the range required.

In the UK, it was decided to select the city of Leeds. Figure 5.5 shows a map of Great Britain, where the location of Leeds can be identified. Its climatic data was obtained from the British Atmospheric Data Centre for the period April 1999 to March 2000 and converted to a format recognisable by the VisualDOE programme. This was performed in the Laboratory of Energy Efficiency in Buildings, Federal University of Santa Catarina, Brazil.

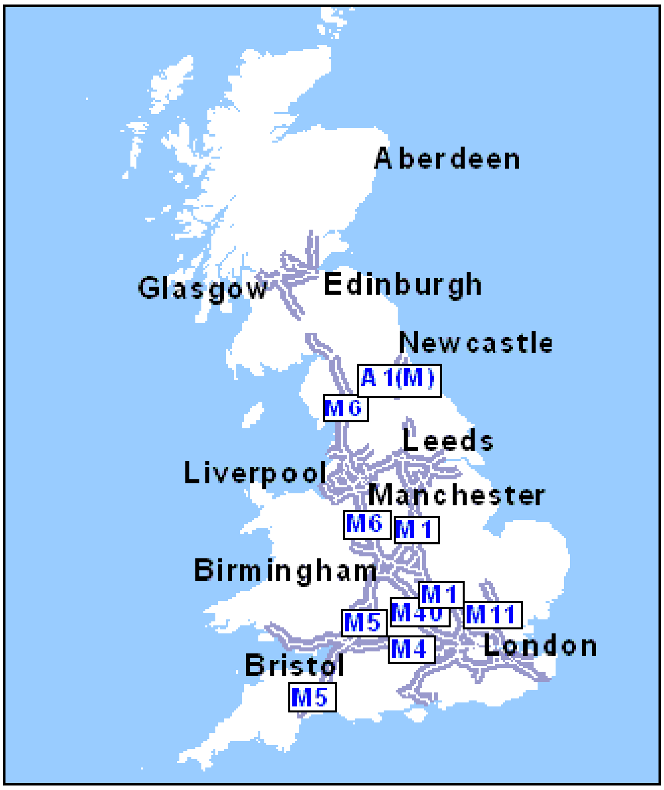


Figure 5.5. Map of Great Britain.

In Brazil, the seven cities selected for the analysis were Belém, Brasília, Curitiba, Florianópolis, Natal, Rio de Janeiro and Salvador. Figure 5.6 shows a map of Brazil, where the seven named cities can be seen. As for the climatic data, they were obtained from the previously mentioned laboratory and were ready to be used in the VisualDOE programme in the form of a Test Reference Year (GOULART et al., 1998).

A Test Reference Year (TRY) consists of 8760 hours of climatic information for one year selected by eliminating extreme months in order of importance until only one year remains (ASHRAE, 1985). The data includes hourly dry-bulb, wet-bulb and dew-point temperatures, wind speed and direction, barometric pressure, weather (precipitation, fog, haze and dust) and total sky cover.

Figure 5.6. Map of Brazil.

As the geographical location is a factor that affects daylight availability, the latitude and longitude of the seven cities located in Brazil and also for the city of Leeds are shown in Table 5.2. The cities in Brazil selected for the analysis lie within the latitudes -01°27’ to -27°36’, in the southern hemisphere; and the city of Leeds is located at a latitude of 53°48’, in the northern hemisphere.

Table 5.2. Latitude and longitude of the eight cities.

City	Latitude	Longitude
Belém	-01°27’	-48°30’
Natal	-05°48’	-35°13’
Salvador	-12°58’	-38°31’
Brasília	-15°47’	-47°56’
Rio de Janeiro	-22°54’	-43°12’
Curitiba	-25°26’	-49°16’
Florianópolis	-27°36’	-48°33’
Leeds	53°48’	-1°34’

Several aspects of the climatic conditions of each city are converted into climatic files to be used in the simulations. In order to compare the climatic differences between the eight cities selected, this section presents monthly average temperatures and daily average total horizontal solar radiation for each city.

Figure 5.7 presents the monthly average temperatures for each city. It can be seen that Salvador has the highest consistent monthly temperature, followed by Belém and Natal whose temperatures follow a similar trend. The cities of Brasília, Curitiba, Florianópolis and Rio de Janeiro present a larger difference between summer and winter temperatures. The city of Leeds, located in the northern hemisphere, presents the largest amplitude of temperatures, ranging from about 5°C in the winter to about 18°C in the summer.

Figure 5.8 presents the daily average total horizontal solar radiation for the eight cities. Such values can give an indication of the sky conditions of each location. Salvador has the highest horizontal solar radiation ranging from about 1700W/m^2 to 2700W/m^2. The total horizontal solar radiation for the other cities located in Brazil follow a similar trend, just ranging from about 700W/m^2 to 2000W/m^2. For the city of Leeds, the total horizontal solar radiation ranges from 200W/m^2 to 1500W/m^2.

Having defined a model building and established a range of climatic data under which it is to be simulated, it is necessary to present the other input data that were assumed in the simulations.

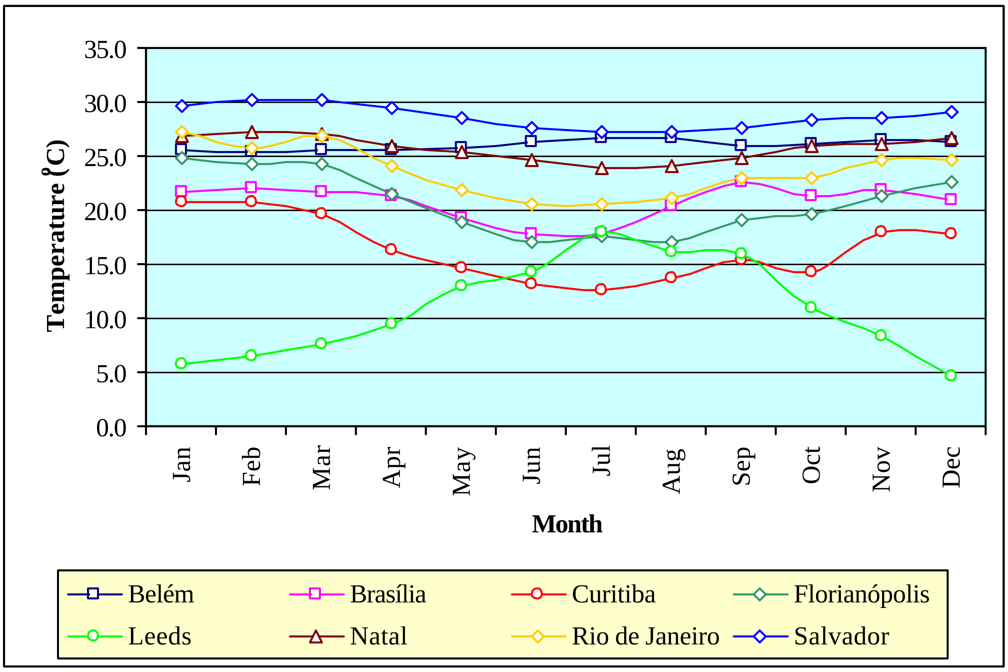


Figure 5.7. Monthly average temperatures for the eight cities.

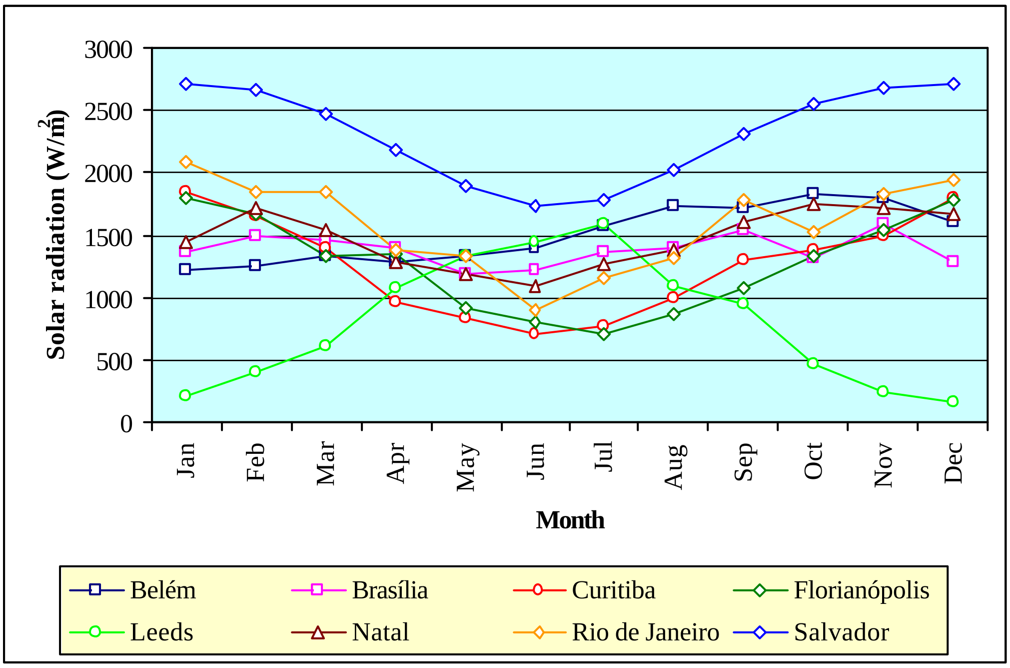


Figure 5.8. Average daily total horizontal solar radiation for the eight cities.

5.4. Input data for the simulations

All the simulations took into account the differences in building use between England and Brazil, such as occupancy schedules, building components, climate etc.

For the simulations using the climatic data for the cities in Brazil, the occupancy schedule considered an occupation of 100% between 8am-12noon and 2pm-6pm, with artificial lighting and equipment operating over the period. The set-point cooling temperature for summer was defined as 24^{o}C, with no heating over the winter period as this is common practice in Brazil.

For the simulation under the climatic conditions of Leeds, a cooling set-point temperature of 23^{o}C was assumed for summer operation and 20^{o}C for winter heating. The occupancy schedule was assumed as 100% between 9am-5pm, with artificial lighting and equipment operating over the period.

The thermal properties of the walls and roof were considered differently for each country as shown in Table 5.3. This is due to the fact that the adopted values attempt to represent common practice in both countries. Brazil still does not have a standard to limit U-value of building components and the values used in this analysis try to represent common practice (RORIZ et al., 1999).

Table 5.3. Thermal properties of walls and roof used in the simulations.

Component	U (W/m²K)	HC (kJ/m²K)	Absorption (%)
Brazil			
Walls	1.92	202	70
Roof	2.22	77	70
England			
Walls	0.45	324	50
Roof	0.25	228	70

HC stands for Heat Capacity.

Apart from the above mentioned parameters and climatic conditions that were different for England and Brazil, other input data used in the simulations were the same. For example, only single sheet clear glass was considered in the simulations; and its properties are presented in Table 5.4. Solar protection on windows is usually needed on some building orientations in Brazil but they are not usually adopted and therefore were not included in the simulations.

Table 5.4. Thermal properties of the glass used in the simulations.

Glass type	Thickness (mm)	U (W/m²K)	Light transmission (%)
Single clear	6	5.7	88

In terms of equipment, the input data into the programme is expressed in watts per floor area (W/m^2) and the adopted equipment power density was 15.0W/m^2. The occupation density is expressed in m^2/person and was assumed to be 15.0m^2/person. As for the infiltration rate, it was assumed to be 0.20 air changes per hour. Regarding the lighting system, the input data into the VisualDOE programme is expressed by the lighting power density (LPD), which represents the relationship between the total wattage due to lights in the room to the floor area of the room. It is reported that the smaller the room, the higher the LPD necessary to provide the same illuminance level as in larger rooms (GHISI & LAMBERTS, 1998). Because of this, it was decided to consider this particular statement in the simulations. Table 5.5 shows the lighting power density as a function of the room index (K) necessary to provide 500lux on the working surface as obtained from GHISI & LAMBERTS (1998) and used as input data for the simulations.

Table 5.5. LPD used in the simulations.

K	LPD (W/m^2)
0.60	22.0
0.80	18.9
1.00	17.1
1.25	15.5
1.50	14.5
2.00	13.1
2.50	12.2
3.00	11.5
4.00	10.6
5.00	10.0

Finally, the model building was simulated with its window wall facing either one of the four main orientations: North, East, South, or West. This was done as the daylight conditions and solar radiation vary according to the orientation.

Having defined the input data to be used in the simulations, an analysis was performed to verify that using values different than those presented in this section will not affect the Ideal Window Area and impair the results.

5.5. Analysis on the input data

Prior to the simulations, an analysis was performed to identify the influence of the parameters used to establish the Ideal Window Area. This analysis was performed under the climatic conditions of Florianópolis over a whole year, north window orientation, room ratio of 1:1, and room indices (K) of 0.60 and 5.00. These two room indices were selected as they represent, respectively, the smallest and the biggest room size for the room ratio 1:1. The lighting power density was kept at the value to provide 500lux on the working surface, namely, 22.0W/m^2 and 10.0W/m^2, respectively for room index 0.60 and 5.00. The other parameters that were assessed to evaluate their impact on the Ideal Window Area are:

- Equipment power density (EPD);
- Occupant density (OD);
- Infiltration rate;
- Transmittance (U-value) of roof and walls;
- Heat capacity (HC) of roof and walls;

- Colour (α-value) of roof and walls;
- U-value of the glazing;
- Light transmission of the glazing.

The possible influence of these variables on the final energy results and on the IWA was performed through ten simulations. Table 5.6 presents the input data used for each simulation. The letter code used for roof, wall and glazing is explained in Tables 5.7, 5.8 and 5.9, respectively.

Case 1 represents the base case against which any changes will be compared. In case 2, the equipment power density is increased from 15.0W/m^2 to 30.0W/m^2. In case 3, the occupant density is increased from 15.0m^2/person to 7.5m^2/person. Case 4 combines cases 2 and 3, using equipment power density of 30.0W/m^2 and occupant density of 7.5m^2/person. Case 5 considers a reduction of the absorption (α-value) of the roof colour from 70% to 30%. In case 6 there is a reduction of both the α-value of the roof colour and the wall colour to 30%. Case 7 represents an increase on the infiltration rate from 0.20 to 0.80 air changes per hour. In case 8, the walls have their U-value increased to 2.27W/m^2.K, their heat capacity increased to 445kJ/m^2.K, and their α-value reduced from 70% to 30%. In case 9, the roof has its U-value decreased to 1.79W/m^2.K and its heat capacity increased to 183kJ/m^2.K (by increasing the thickness of the slab). Finally, case 10 combines cases 8 and 9 with double clear glass, equipment power density of 20W/m^2, occupant density of 20m^2/person, and infiltration rate of 0.60 air changes per hour.

Table 5.6. Cases and parameters in the analysis.

Case	LPD (W/m^2)	EPD (W/m^2)	OD (m^2/person)	Infiltration (air-changes/h)	Roof	Wall	Glass
1	22.0	15.0	15.0	0.20	A	A	A
2	22.0	30.0	15.0	0.20	A	A	A
3	22.0	15.0	7.5	0.20	A	A	A
4	22.0	30.0	7.5	0.20	A	A	A
5	22.0	15.0	15.0	0.20	B	A	A
6	22.0	15.0	15.0	0.20	B	B	A
7	22.0	15.0	15.0	0.80	A	A	A
8	22.0	15.0	15.0	0.20	A	C	A
9	22.0	15.0	15.0	0.20	C	A	A
10	22.0	20.0	20.0	0.60	C	C	B

Table 5.7. Properties of the roofs used in the analysis.

Roof	U (W/m^2K)	HC (kJ/m^2K)	Absorption (%)
A	2.22	77	70
B	2.22	77	30
C	1.79	183	70

Table 5.8. Properties of the walls used in the analysis.

Wall	U (W/m^2K)	HC (kJ/m^2K)	Absorption (%)
A	1.92	202	70
B	1.92	202	30
C	2.27	445	30

Table 5.9. Properties of the glazing types used in the analysis.

Glazing	Type	Thickness (mm)	U (W/m^2K)	Light transmission (%)
A	Single clear	6	5.7	88
B	Double clear	6-12-6	2.7	78

Having established all the parameters to be evaluated, the ten cases were simulated using the VisualDOE programme. Figure 5.9 presents the energy consumption as a function of the window area for the ten cases previously described, for room index of 0.60. It is shown that there is a significant difference on the energy consumption for each case, but the Ideal Window Area is approximately the same for each of the ten cases. Plotting polynomial trendlines for the ten cases it was obtained Ideal Window Areas ranging from 14% to 17%, for R-squared ranging from 0.9988 to 0.9996. This shows that there is not a significant difference on the IWA when the input data presented previously differ from that for the base case.

The same procedure was then applied to large rooms with room index of 5.00. The results are shown in Figure 5.10. The Ideal Window Areas ranged from 31% to 40% between the ten cases, with R-squared ranging from 0.9827 to 0.9987. For this situation, it can be stated that there is a significant difference on the IWA for input data different than that for the base case. However, the curve of energy consumption as a function of window area for larger rooms is flat, indicating that applying window areas different than the IWA will not affect the energy consumption of the room significantly. This is discussed later in the results.

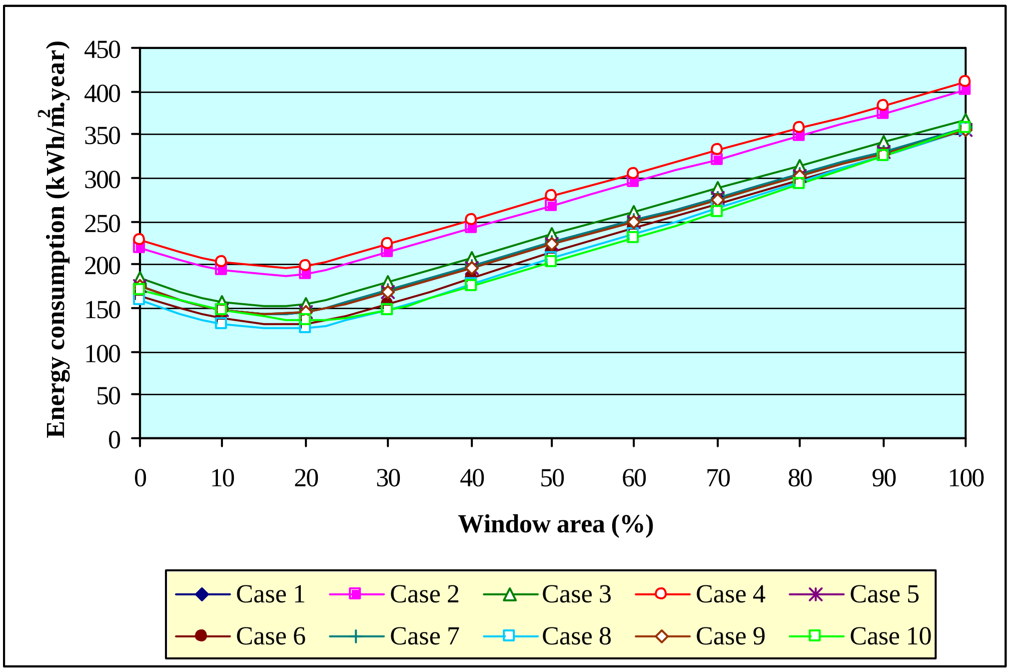


Figure 5.9. Analysis of input data for room index of 0.60.

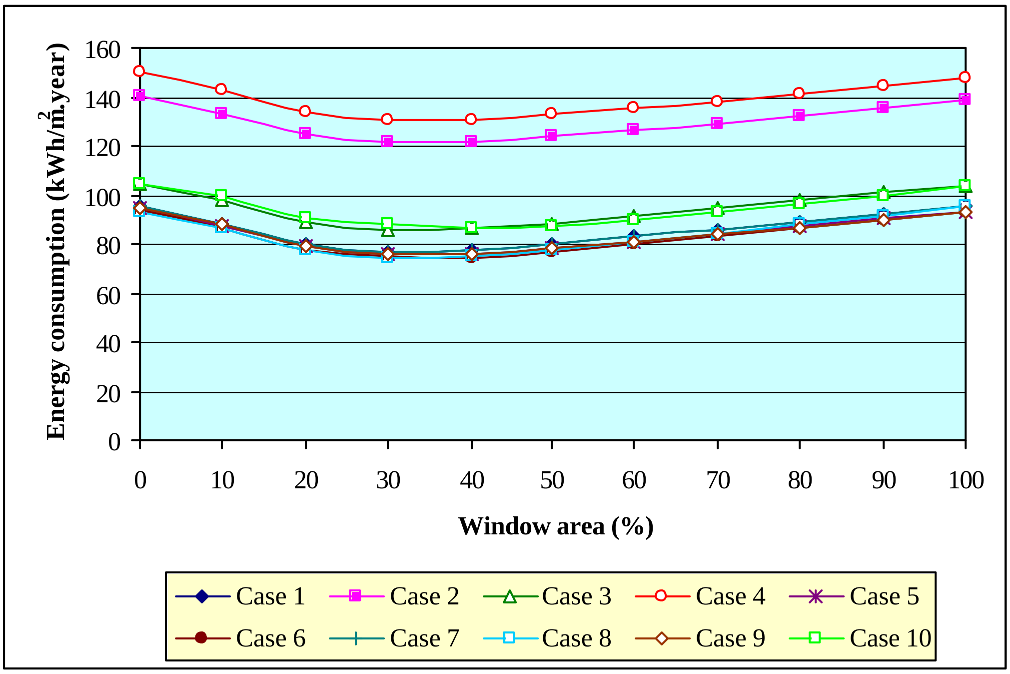


Figure 5.10. Analysis of input data for room index of 5.00.

Next section presents the results obtained from the simulations of the building model considering the different room sizes, room ratios, window areas, and different climatic conditions as described previously. Such simulations allowed to determine the Ideal Window Area of all room sizes and room ratios that were described in this work.

5.6. Results

As commented at the beginning of this chapter, ten room sizes were simulated for each of the five room ratios, the eleven window areas and each of the four orientations. Therefore, 2200 simulations were run for each city, making a total of 17600 simulations over the eight cities.

The results obtained from the simulations are the energy consumptions of the rooms as a function of their window area; and then the Ideal Window Area can be obtained.

5.6.1. Energy consumption

The energy consumption of the model as a function of room sizes and window areas is assessed first. Energy consumption was simulated over a year period and is presented as a function of the floor area (kWh/m^2 per year). This facilitates a better comparison of the energy consumption between the different room sizes and room ratios.

This section presents the energy consumption obtained from the simulations using the VisualDOE programme over the city of Florianópolis as an example. To avoid replication, results obtained for all other cities are presented in Appendix D; and an example of an input/output file obtained from simulations using the VisualDOE programme is shown in Appendix E.

Florianópolis is located at the latitude 27^{o}36’ South. The energy consumptions obtained from the simulations for the climatic conditions of this city as a function of the window area for the room ratio of 2:1 and for the four orientations are presented in Figures 5.11 to 5.14, respectively. The first observation that can be made from the figures is that the energy consumption per floor area decreases as the room indices increase independent of the orientation of the window façade. The same trend is observed for all other room ratios in all other cities and a discussion on the influence of the room width on the energy consumption is presented in section 5.6.2. It can also be seen in these figures that the energy consumption of rooms facing the South orientation is lower than the energy consumption of rooms facing the three other orientations. This is due to the fact that Florianópolis is located in the southern hemisphere where south façades are least likely to be reached by sunshine.

In terms of window area, it can be observed that the Ideal Window Area is larger for larger rooms (larger room index). The Ideal Window Areas were obtained by determining a polynomial trendline for each case. Figure 5.11 presents the energy consumption as a function of the window area for the North orientation and it can be observed that the Ideal Window Areas range from 10% (R^2=0.9999) for K=0.60 to 22% (R^2=0.9979) for K=5.00. Figure 5.12 shows the energy consumption as a function of the window area for the East orientation; it can be seen that the Ideal Window Areas range from 12% (R^2=0.9997) to 31% (R^2=0.9973) for K=0.60 to K=5.00, respectively. Figure 5.13 presents the energy consumption as a function of the window area for the South orientation and it can be observed that the Ideal Window Areas range from 18% (R^2=0.9991) for K=0.60 to 33% (R^2=0.9880) for K=5.00. Figure 5.14 shows the energy consumption as a function of the window area for the West orientation and it can be noted that the Ideal Window Areas range from 9% (R^2=0.9998) to 22% (R^2=0.9962) for K=0.60 to K=5.00, respectively.

As the Ideal Window Areas for rooms of room ratio 2:1 are relatively small, this may be an indication that there might be a potential for more energy savings to be made on artificial lighting if fibre optics were to be used for promoting the integration of daylight.

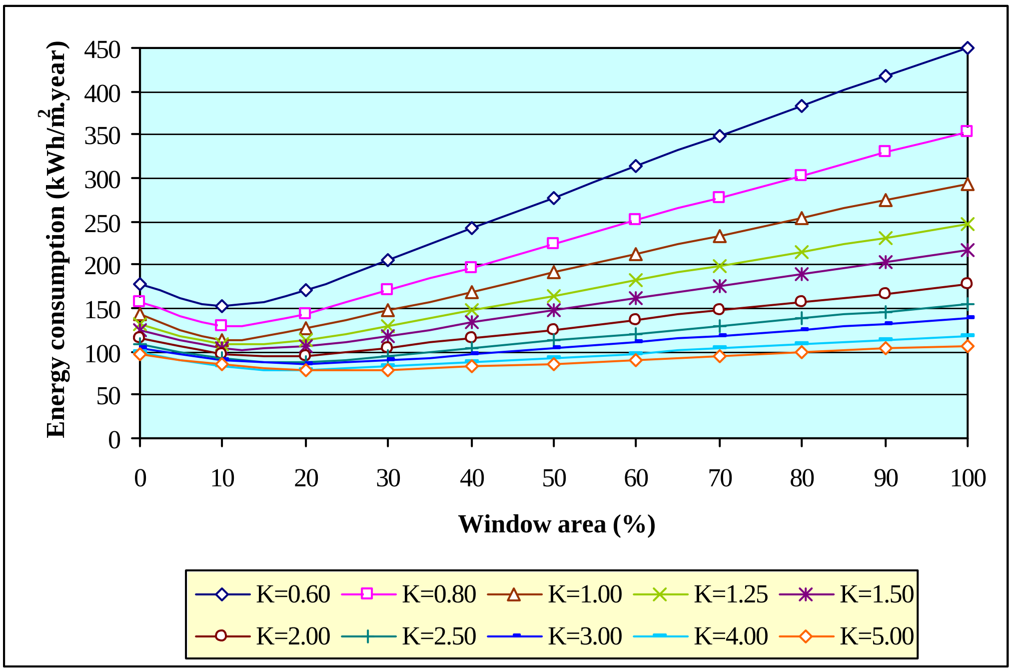


Figure 5.11. Energy consumption for Florianópolis, room ratio of 2:1, North orientation.

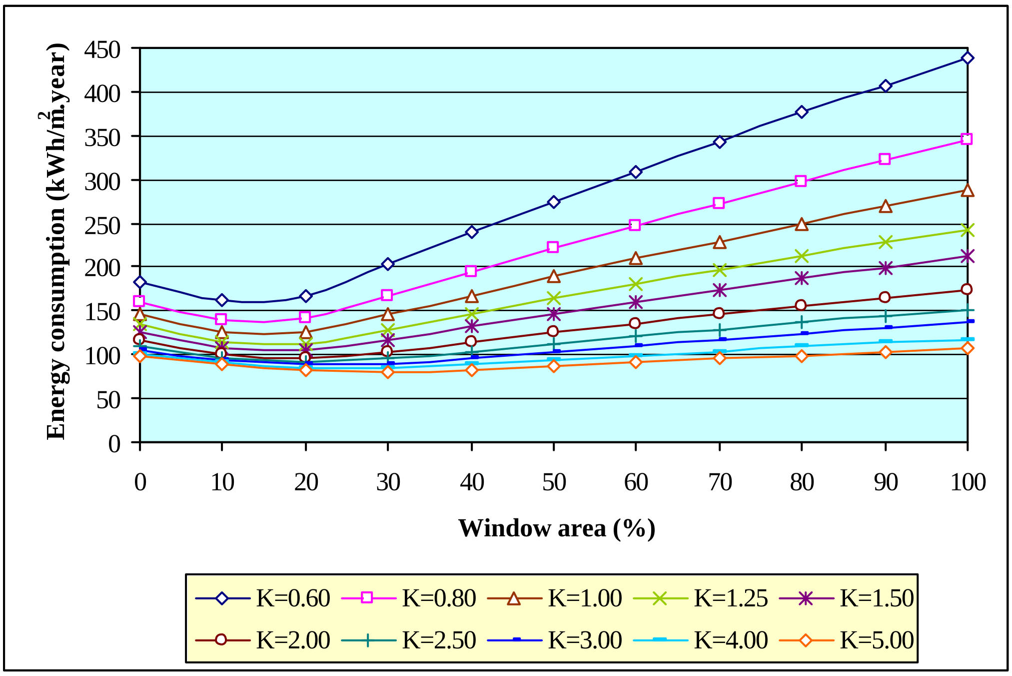


Figure 5.12. Energy consumption for Florianópolis, room ratio of 2:1, East orientation.

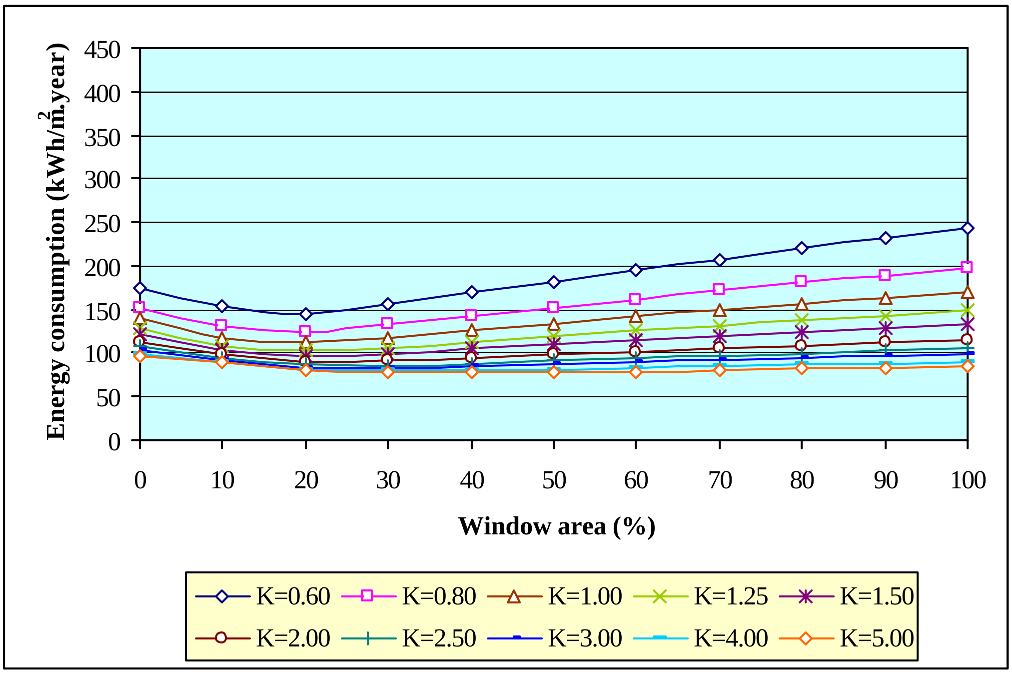


Figure 5.13. Energy consumption for Florianópolis, room ratio of 2:1, South orientation.

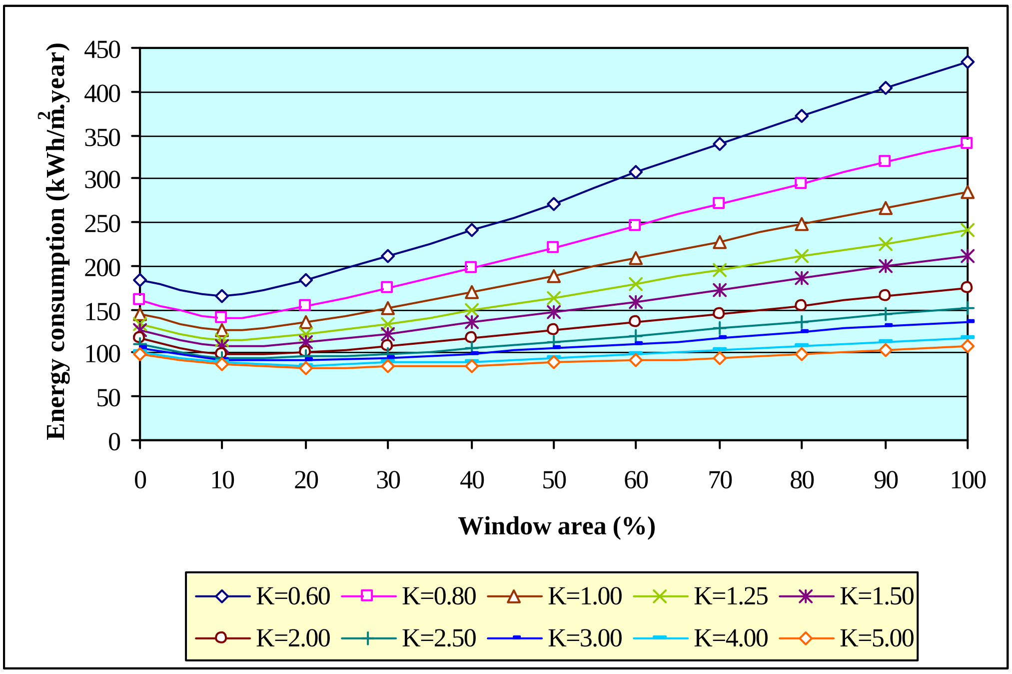


Figure 5.14. Energy consumption for Florianópolis, room ratio of 2:1, West orientation.

As a matter of comparison, Figures 5.15 to 5.18 present the results of the energy consumption for the rooms whose room ratio is 1:2 under the climatic conditions of Florianópolis. The results are presented as a function of the window area, and for the four orientations, respectively.

Figure 5.15 presents the energy consumption as a function of the window area for the North orientation where it can be observed that the Ideal Window Areas range from 23% (R^2=0.9986) for K=0.60 to 53% (R^2=0.9747) for K=5.00. Figure 5.16 shows the energy consumption as a function of the window area for the East orientation and it can be noted that the Ideal Window Areas range from 26% (R^2=0.9996) to 59% (R^2=0.9794) for K=0.60 to K=5.00, respectively. Figure 5.17 presents the energy consumption as a function of the window area for the South orientation and it can be observed that the Ideal Window Areas range from 34% (R^2=0.9828) for K=0.60 to 77% (R^2=0.9798) for K=5.00. Figure 5.18 shows the energy consumption as a function of the window area for the West orientation; it can be seen that the Ideal Window Areas range from 17% (R^2=0.9997) to 26% (R^2=0.9952) for K=0.60 to K=5.00, respectively.

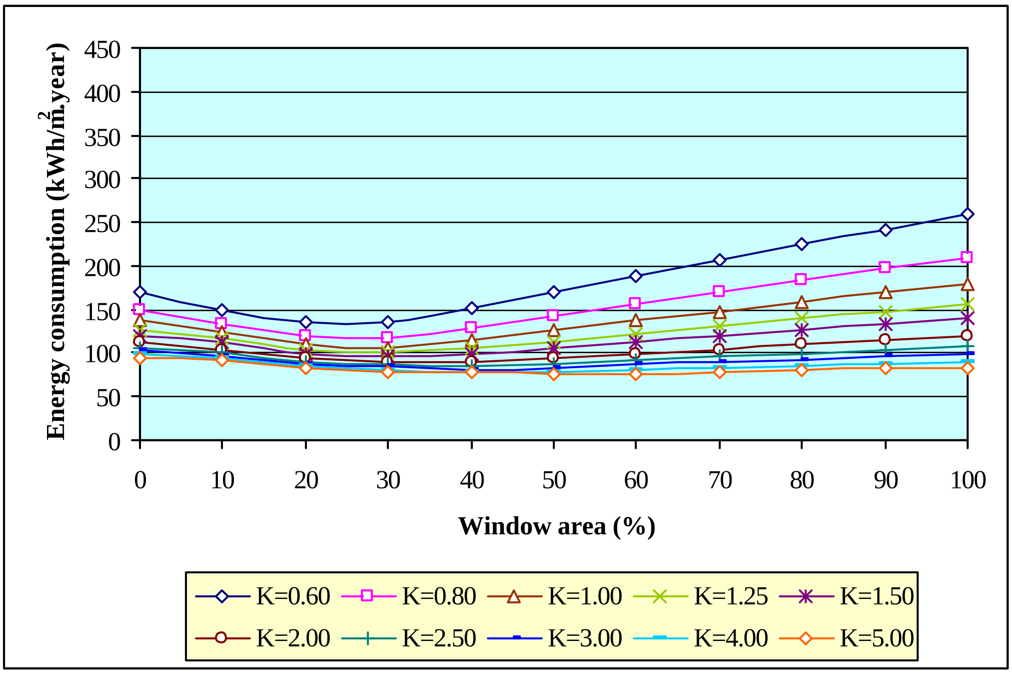


Figure 5.15. Energy consumption for Florianópolis, room ratio of 1:2, North orientation.

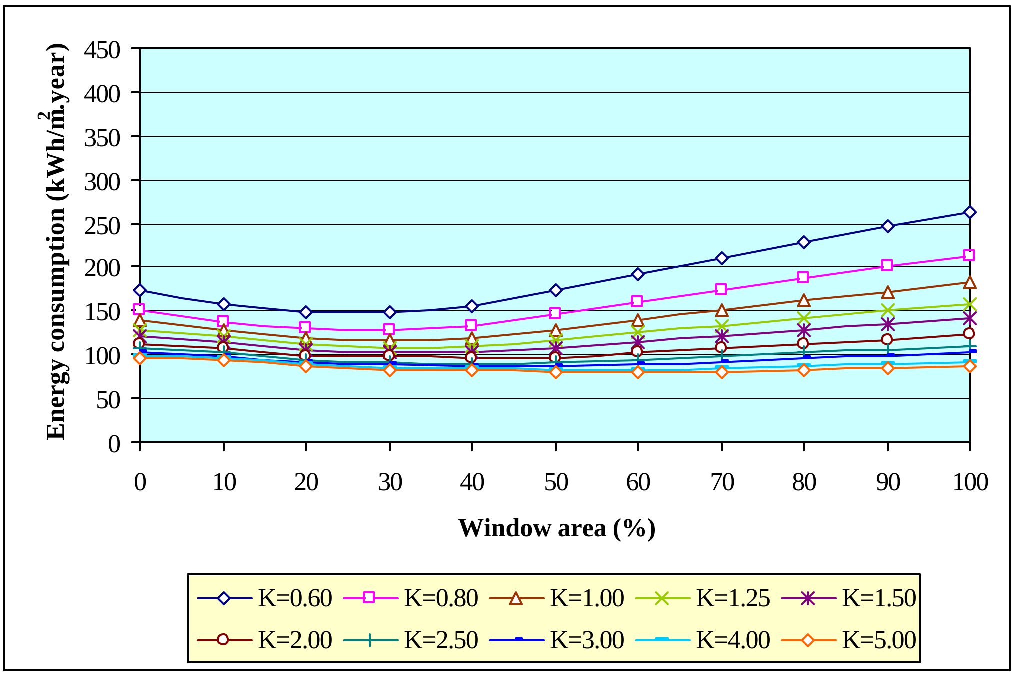


Figure 5.16. Energy consumption for Florianópolis, room ratio of 1:2, East orientation.

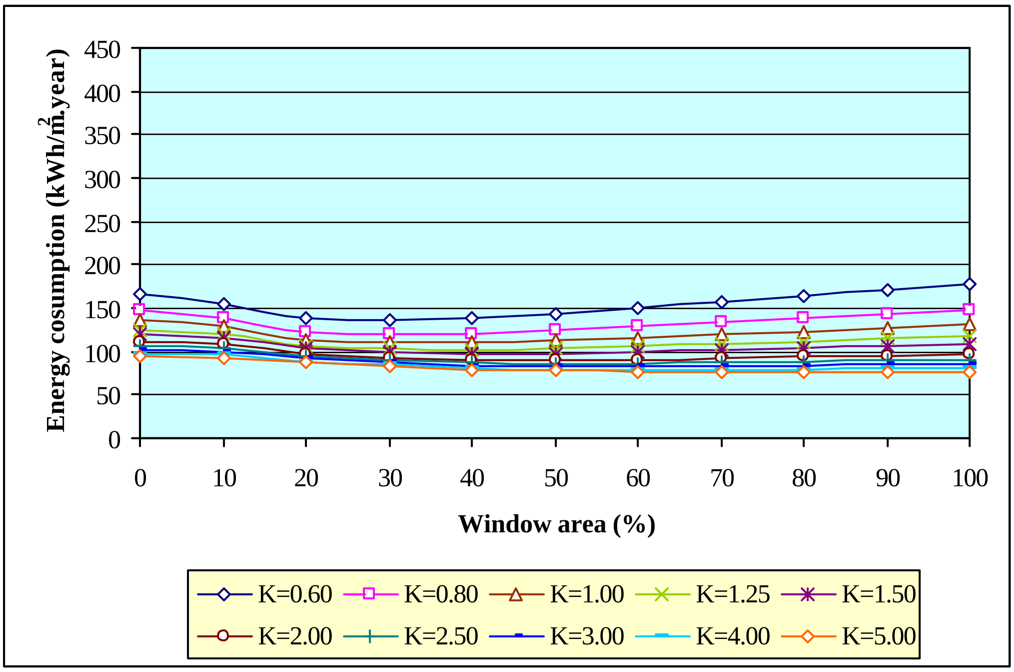


Figure 5.17. Energy consumption for Florianópolis, room ratio of 1:2, South orientation.

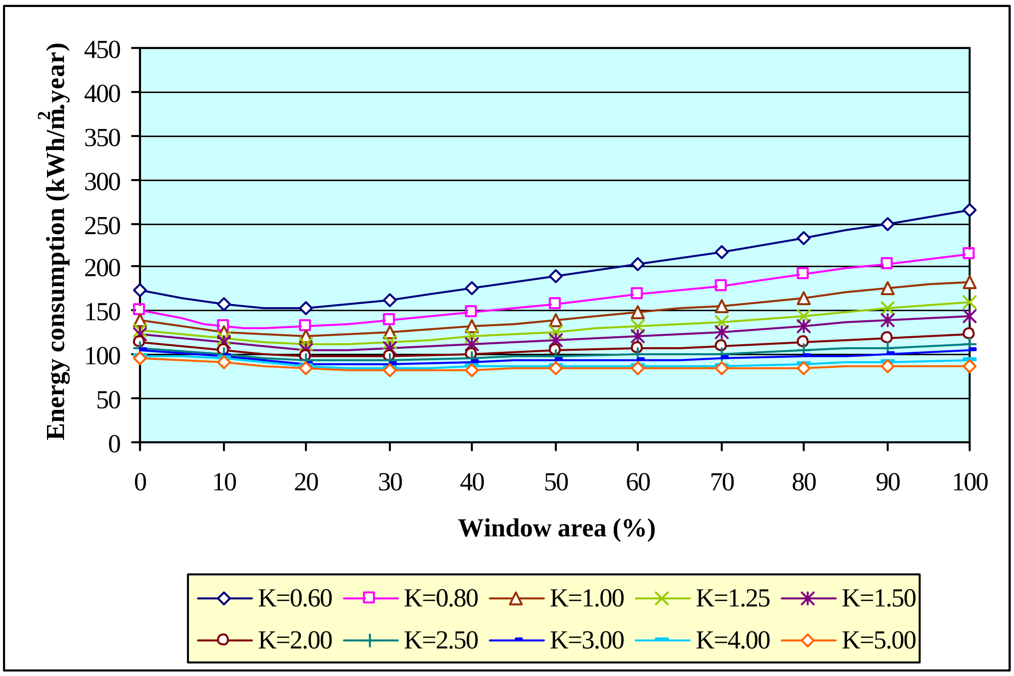


Figure 5.18. Energy consumption for Florianópolis, room ratio of 1:2, West orientation.

By comparing the results of the two room ratios presented in this section, it can be seen from the figures that the Ideal Window Areas tend to increase from a room ratio of 2:1 to a room ratio of 1:2. However, there may still be a potential for the use of fibre optics to integrate daylight and artificial lighting aiming to reduce the lighting energy consumption of rooms whose room ratio is 1:2, as they are deep and daylight cannot reach far from the façade.

In terms of energy consumption, it can be seen from the figures that both larger rooms and rooms with a narrower width have a lower energy consumption per unit of floor area. It was presented in the literature review that BODART & DE HERDE (2002) found that increasing the room width results in a decrease of the electric lighting consumption. Such information is correct, but the total energy consumption of a space increases by increasing its width, as obtained from the simulations over a year for the eight cities. Next section investigates this trend.

5.6.2. Influence of the room ratio on the energy consumption

It was observed from results presented in the previous section that the energy consumption of rooms obtained from the simulations decreases from room ratios 2:1 towards 1:2, that is, the energy consumption is lower for room ratios whose width is narrower. This can be clearly seen from Figure 5.19, where energy consumption is plotted against window area for a room index of 0.60, for the five room ratios under the climatic conditions of Florianópolis, North window orientation. Figure 5.20 presents the same information for room index of 5.00.

From both figures it can be observed that the energy consumption is greater for rooms with wide width, such as those with room ratios of 2:1, 1.5:1 and 1:1. This is probably due to the larger façade area of these room ratios that is exposed to the external weather conditions. This means either higher solar heat gains or thermal losses that may affect the air temperature of the rooms and hence the energy consumption.

Another interesting observation to be made from the two figures is that the Ideal Window Area increases as the rooms become deeper. An explanation for this trend is that as deeper rooms have smaller façade areas that allow lower solar heat gains or thermal losses, the window area can be larger in order to obtain the balance between daylight supply and thermal load.

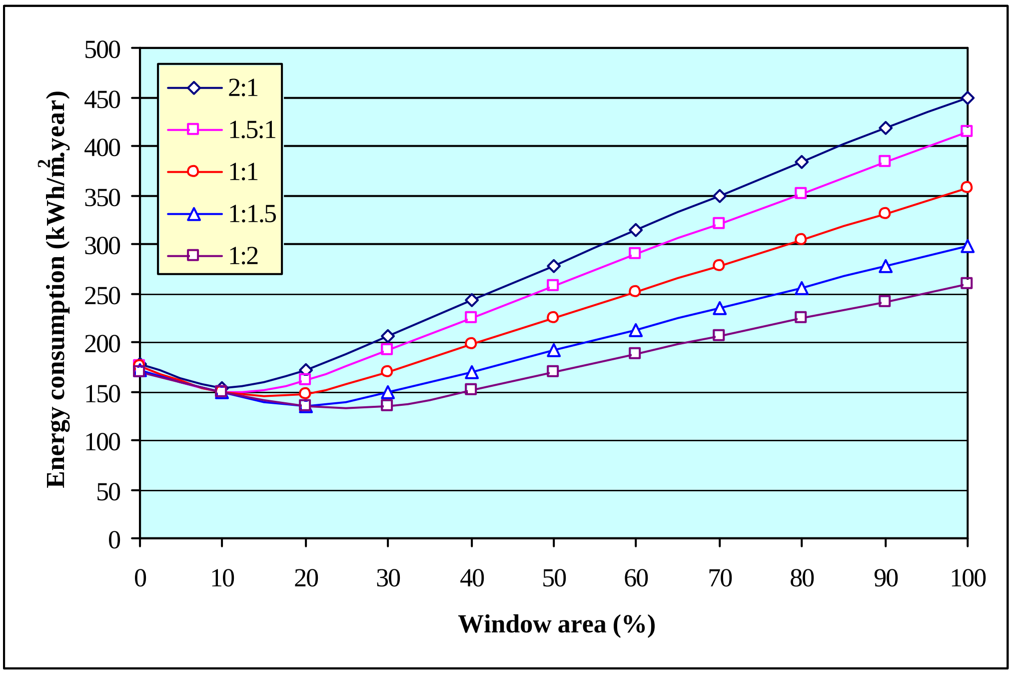


Figure 5.19. Energy consumption for Florianópolis, North orientation, K=0.60.

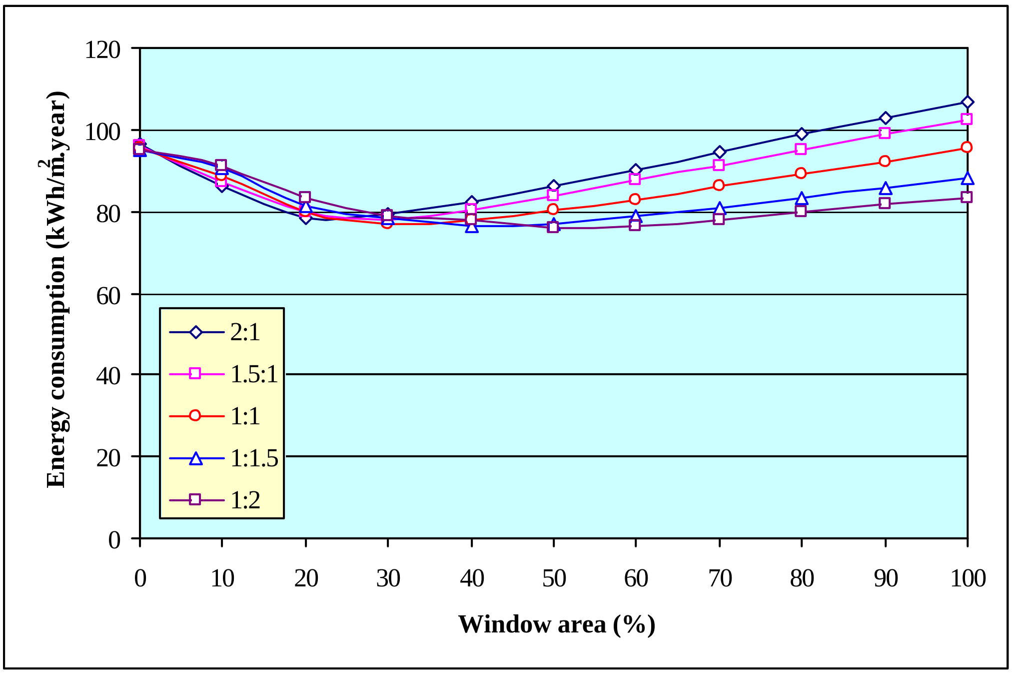


Figure 5.20. Energy consumption for Florianópolis, North orientation, K=5.00.

Having presented the results of the simulations of energy consumption as a function of room sizes, room ratios, window areas and climatic conditions, the next section deals with the Ideal Window Areas that were obtained from the simulations.

5.6.3. The Ideal Window Area

From the results of energy consumption as a function of window areas obtained in the simulations presented in section 5.6.1, the Ideal Window Area was obtained for each one of the ten room sizes (room indices), five room ratios, on the four orientations for each of the eight cities. The Ideal Window Areas had to be obtained so that the potential for energy savings on lighting due to the use of fibre optics could be evaluated.

The Ideal Window Areas were obtained from the figures presented in section 5.6.1 (and also in Appendix D); and then they were plotted as a function of the room indices as shown in Figure 5.21, which is an example for Florianópolis, room ratio of 1:1. It was noted that there is a linear increase of the Ideal Window Area as the room index increases. Therefore, a best-fit straight line and the equivalent equation were determined to express the Ideal Window Area as a function of the room index for each orientation. This procedure was then adopted to determine the Ideal Window Area over the different room sizes, room ratios, and different orientations for each of the eight cities.

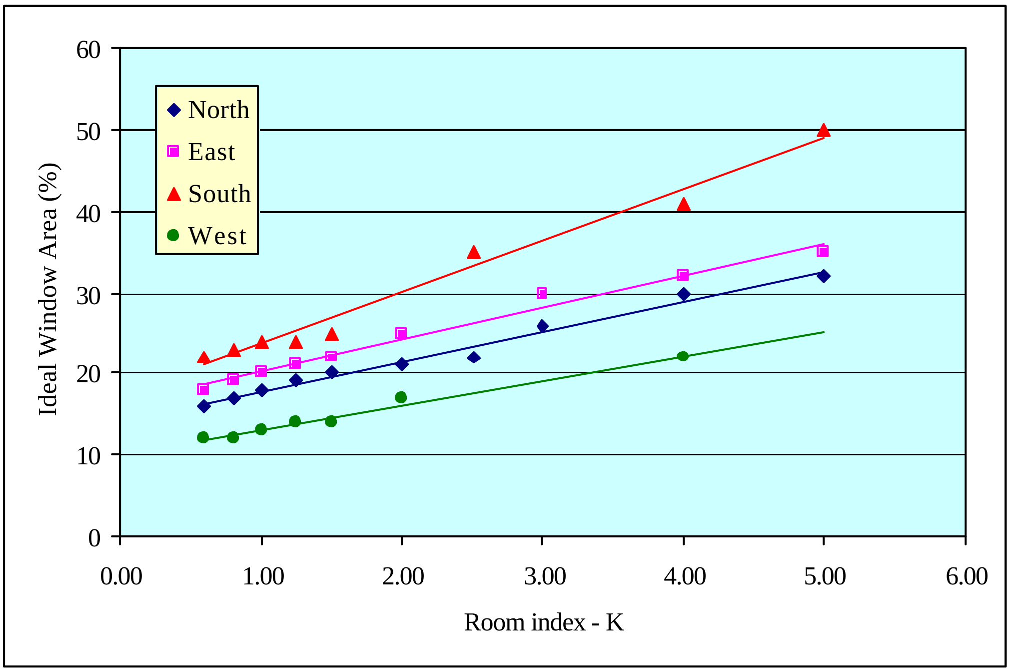


Figure 5.21. Ideal Window Area versus room indices for Florianópolis, room ratio 1:1.

The equations representing the best-fit line in Figure 5.21 are presented in Table 5.10 where IWA stands for Ideal Window Area and K for room index. All the equations representing the Ideal Window Area as a function of the room index for each room ratio and city are presented in Appendix F. Such equations were then used to determine the

Ideal Window Areas given next.

Table 5.10. Equations of the IWA for Florianópolis, room ratio of 1:1.

Orientation	Equation	R^2
North	IWA = 3.73 K + 14.04	0.9830
East	IWA = 3.98 K + 16.20	0.9806
South	IWA = 6.34 K + 17.30	0.9824
West	IWA = 3.06 K + 9.98	0.9813

Tables 5.11 to 5.18 show the Ideal Window Areas for each room size, room ratio, and orientation for each of the eight cities. In these tables, N stands for North, E for East, S for South, and W for West. It can be observed that the Ideal Window Area increases in larger rooms (those with a larger room index – K) and also in rooms with a narrower width (from room ratio 2:1 towards 1:2) in all the eight cities.

It can also be noted that for the cities located in Brazil, the Ideal Window Areas tend to be larger on the East and South orientations as the solar thermal load is lower on these orientations. The Ideal Window Areas also have a tendency to be smaller on the West orientation as this is the orientation under the most severe solar condition.

For the city located in the UK, the Ideal Window Areas are larger over the North orientation, as the city is located in the northern hemisphere, and the solar thermal load on this orientation is negligible.

Table 5.11. Ideal Window Areas for Belém, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	11	14	10	12	10	14	11	14	12	17	11	18	16	22	14	19	18	26	18
0.80	12	13	15	11	13	12	15	12	15	14	19	12	19	18	24	15	21	21	28	19
1.00	12	14	16	12	14	13	16	13	15	15	20	12	20	21	25	16	22	24	30	21
1.25	13	15	17	13	14	15	18	14	16	18	22	13	21	24	27	18	24	27	33	23
1.50	14	17	17	13	15	18	19	15	17	20	23	14	22	27	29	19	25	31	35	24
2.00	15	20	19	15	17	22	21	17	19	24	26	16	24	33	33	22	29	38	40	28
2.50	16	23	21	17	18	26	24	19	21	28	30	17	26	39	37	25	32	45	45	31
3.00	17	26	23	19	20	30	26	21	23	33	33	19	28	45	41	28	36	52	50	35
4.00	20	32	26	22	23	39	31	26	27	42	39	22	32	57	49	34	42	67	60	42
5.00	22	38	30	26	26	47	36	30	31	50	46	25	36	69	57	40	49	81	70	49

Table 5.12. Ideal Window Areas for Brasília, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	12	16	20	10	15	16	21	11	17	19	27	13	20	26	31	17	24	30	41	19
0.80	13	17	21	11	16	17	23	11	18	21	29	14	21	28	34	18	26	33	44	20
1.00	13	18	22	11	16	18	24	12	19	23	30	15	22	30	36	18	27	35	46	21
1.25	14	19	23	12	17	20	26	13	20	25	32	16	24	32	39	19	30	38	49	22
1.50	15	20	24	13	18	21	27	14	21	27	34	17	26	34	42	20	32	41	52	23
2.00	16	23	27	14	19	24	30	16	23	31	38	19	29	39	48	22	36	48	57	26
2.50	18	25	29	15	21	27	34	17	25	35	42	22	33	44	54	24	40	54	63	28
3.00	19	27	32	17	22	29	37	19	27	39	46	24	36	49	60	25	45	60	69	30
4.00	23	32	37	19	26	35	44	23	31	47	53	28	43	58	71	29	53	72	80	34
5.00	26	36	42	22	29	41	50	26	36	55	61	32	50	68	83	32	62	84	91	39

Table 5.13. Ideal Window Areas for Curitiba, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	12	14	18	10	15	17	20	11	17	20	24	12	23	26	32	16	29	32	43	19
0.80	13	14	19	11	16	18	21	11	19	21	26	13	24	28	34	17	31	33	45	19
1.00	14	15	20	12	17	19	23	12	20	22	27	13	26	29	36	17	33	35	48	20
1.25	15	16	22	12	18	20	24	12	21	23	29	15	27	30	39	18	35	37	50	21
1.50	16	17	24	13	18	21	26	13	22	24	31	16	29	32	42	19	36	39	53	22
2.00	17	20	27	14	20	23	30	14	25	27	35	18	32	35	47	21	40	44	58	23
2.50	19	22	30	16	22	24	33	15	27	29	39	20	35	39	52	23	44	48	64	25
3.00	21	24	33	17	24	26	37	17	30	32	43	22	38	42	58	25	48	52	69	26
4.00	25	28	39	20	27	30	44	19	35	36	51	27	45	49	68	29	56	61	80	30
5.00	28	32	46	23	31	34	51	22	40	41	59	31	51	55	79	33	64	69	91	33

Table 5.14. Ideal Window Areas for Florianópolis, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	15	18	10	11	15	20	10	16	19	21	12	20	25	25	15	25	26	31	19
0.80	11	15	19	11	12	16	21	11	17	19	22	12	21	26	26	16	27	27	33	19
1.00	12	16	20	11	13	17	22	11	18	20	24	13	22	27	28	17	28	29	36	20
1.25	13	17	20	12	14	18	23	12	19	21	25	14	24	28	30	17	29	31	38	21
1.50	13	18	21	12	15	19	24	13	20	22	27	15	25	29	32	18	31	32	41	21
2.00	15	20	23	14	17	20	26	15	21	24	30	16	27	31	36	20	34	36	47	23
2.50	16	21	25	15	19	22	28	16	23	26	33	18	30	34	40	22	37	40	53	25
3.00	18	23	26	16	22	24	30	18	25	28	36	19	32	36	44	23	40	43	58	26
4.00	21	27	30	19	26	28	35	21	29	32	43	22	37	41	52	27	45	50	69	29
5.00	24	30	33	22	30	31	39	24	33	36	49	25	42	46	59	30	51	58	81	33

Table 5.15. Ideal Window Areas for Leeds, England (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	16	11	10	7	19	12	11	7	16	16	11	7	18	20	11	8	23	20	14	9
0.80	18	12	11	7	20	13	11	7	18	17	12	7	21	21	12	9	26	21	14	10
1.00	19	13	11	8	21	14	12	8	20	17	12	8	24	22	13	10	29	23	15	11
1.25	21	13	11	8	23	15	12	8	23	18	13	9	27	24	14	11	32	25	17	12
1.50	23	14	12	9	25	16	12	9	26	20	14	10	31	25	16	12	36	27	18	13
2.00	27	16	13	10	28	19	13	10	31	22	15	11	37	28	18	14	43	31	20	15
2.50	30	17	14	11	31	21	14	11	37	24	17	13	44	31	20	15	50	35	22	18
3.00	34	19	14	12	34	23	14	12	42	26	18	14	51	34	22	17	58	39	25	20
4.00	41	22	16	14	40	28	16	14	53	31	21	18	65	40	27	21	72	47	29	24
5.00	49	25	18	16	47	32	17	17	64	35	24	21	79	46	32	25	87	55	34	29

Table 5.16. Ideal Window Areas for Natal, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	11	12	11	9	12	12	14	9	13	12	15	9	18	16	19	11	20	16	18	18
0.80	12	13	12	9	13	13	14	9	15	14	16	10	19	18	20	12	22	19	20	19
1.00	12	14	13	10	13	15	15	10	16	16	18	11	20	20	22	13	24	21	22	19
1.25	13	15	14	11	14	16	16	11	17	18	19	12	22	23	23	15	26	24	24	19
1.50	14	16	15	11	15	18	17	11	19	20	20	13	24	25	25	16	28	27	26	20
2.00	16	19	17	13	17	21	19	13	22	24	23	14	28	31	28	19	33	33	31	21
2.50	18	21	19	14	19	24	21	14	25	28	26	16	32	36	32	21	37	38	35	22
3.00	20	24	21	15	21	27	23	16	28	32	29	18	35	42	35	24	42	44	40	23
4.00	24	29	25	18	25	34	27	18	34	41	35	22	43	52	42	29	51	56	49	25
5.00	28	34	30	21	29	40	31	21	40	49	40	25	50	63	48	34	60	68	58	26

Table 5.17. Ideal Window Areas for Rio de Janeiro, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	9	9	18	8	10	11	16	9	14	14	20	9	16	18	22	10	20	26	29	13
0.80	10	9	18	8	10	11	17	9	14	15	21	9	17	20	24	11	21	28	31	13
1.00	10	10	19	8	11	12	18	9	15	16	22	10	17	21	26	12	22	29	33	14
1.25	11	11	19	9	13	14	19	9	15	17	23	10	18	23	28	13	23	31	35	15
1.50	12	12	20	9	14	15	20	10	16	19	25	11	19	24	30	14	24	33	37	15
2.00	13	14	21	10	16	17	22	10	17	21	28	12	21	28	34	16	26	37	42	17
2.50	15	16	22	10	18	19	24	11	19	24	31	13	22	31	39	18	28	41	47	18
3.00	16	18	24	11	21	22	26	12	20	26	34	14	24	35	43	20	31	45	51	20
4.00	19	22	26	12	26	26	31	13	23	32	39	16	27	42	52	23	35	52	60	23
5.00	22	26	29	13	30	31	35	14	26	37	45	19	31	49	60	27	40	60	69	26

Table 5.18. Ideal Window Areas for Salvador, Brazil (% of the room façade area).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	10	9	16	7	10	11	18	8	11	16	20	9	16	17	23	10	20	21	29	11
0.80	10	10	17	8	10	11	19	8	12	16	21	10	16	18	25	11	20	22	31	12
1.00	11	10	18	8	11	12	19	9	13	17	22	10	17	19	26	12	21	23	33	13
1.25	11	11	19	9	12	12	20	10	14	17	23	11	17	20	28	13	21	25	35	15
1.50	12	12	20	10	12	13	21	10	15	18	24	12	18	21	30	15	22	26	38	16
2.00	13	13	21	11	14	15	23	12	17	19	27	14	19	23	35	17	24	29	42	19
2.50	14	14	23	13	15	16	25	13	18	20	29	16	21	24	39	19	25	32	47	22
3.00	15	16	25	14	16	17	27	14	20	22	32	18	22	26	43	22	26	35	52	25
4.00	18	18	29	17	19	20	31	17	24	24	37	22	25	30	51	26	29	42	61	30
5.00	20	21	33	20	22	23	35	20	28	27	42	26	28	34	59	31	32	48	70	36

By comparing the Ideal Window Areas determined in this work to the minimum glazed areas recommended for view by BS 8602-2 (1992) as a fnction of the depth of the room, it can be observed that rooms with narrower width (room ratio 1:2) tend to have IWAs larger than the minimum figures suggested by the British Standard. Table 5.19 shows the percentage in which the IWA is larger than the minimum glazed area for view (see BS 8206-2, 1992, as quoted in the literature review - page 24). This indicates that there is a high disagreement between the IWA and the minimum glazed area for view. Therefore, it is recommended that more work be done in future to investigate this trend and possibly the minimum glazed areas for view should be presented not only as a function of the depth of the room, but also of its width, room ratio, and orientation of the window façade.

Table 5.19. Percentage in which the IWA is larger than the minimum glazed area for view.

City	Room ratio				
	2:1	1.5:1	1:1	1:1.5	1:2
Belém	17.5	22.5	32.5	57.5	82.5
Brasília	40.0	42.5	60.0	77.5	85.0
Curitiba	25.0	40.0	70.0	75.0	80.0
Florianópolis	22.5	27.5	40.0	72.5	80.0
Leeds	17.5	22.5	25.0	45.0	50.0
Natal	2.5	10.0	27.5	62.5	67.5
Rio de Janeiro	7.5	12.5	27.5	47.5	65.0
Salvador	10.0	17.5	25.0	30.0	57.5

Having determined the Ideal Window Areas and investigated their agreement with the minimum glazed areas for view, the impact on the energy consumption by adopting a window area different than the Ideal Window Area is presented next.

5.6.4. Window area versus energy consumption

It was noticed through all the figures presented in section 5.6.1 that the adoption of a window area different than the Ideal Window Area may cause the energy consumption to be much higher for rooms of small room index. However, for rooms of large room index the energy consumption does not increase significantly when the adopted window area is different than the Ideal Window Area.

Therefore, it was deemed necessary to assess the influence of applying window areas other than the Ideal Window Area on the energy consumption of rooms. Tables 5.20 and 5.21 present, as an example, percentages of the energy consumption increase for window areas different than the Ideal Window Area for the city of Florianópolis. The data is related to room ratios of 2:1 and 1:2, and room indices of 0.60 and 5.00.

From Table 5.20 it can be observed that, for a room ratio of 2:1, applying a window area of 30% of the façade area on the North orientation implies an energy consumption 35.6% higher than if applying the Ideal Window Area, which is 11% in this case (Table 5.14). Still from Table 5.20, it can be noted that, for a room ratio of 1:2, adopting a window area of 30% on the North orientation induces an energy consumption only 1.0% higher than if applying the Ideal Window Area; this is due to the fact that the Ideal Window Area in this case is 25%.

From Table 5.21 it can be noted that, for room ratio of 1:2, applying window areas different than the Ideal Window Area may not imply on a high increase on the energy consumption. However, as seen in Chapter 3, window areas larger than 50% will not provide significant increase on energy savings and therefore, such large window areas should be regarded carefully.

The percentage of the increase on the energy consumption for window areas different than the Ideal Window Area for two room ratios (2:1 and 1:2), ten room indices, four orientations and eight cities is presented in Appendix G.

Table 5.20. Percentage of the energy consumption increase for window areas different than the IWA, Florianópolis, K=0.60.

Energy consumption increase (%) due to the window area (%), room ratio 2:1, K=0.60											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	17.0	0.0	12.9	35.6	59.4	82.6	106.3	129.0	151.9	174.5	195.6
East	13.5	0.7	3.1	25.0	47.6	69.6	90.3	111.6	132.1	151.7	170.4
South	19.6	5.7	0.5	7.4	16.6	25.7	34.6	43.3	51.7	59.8	67.9
West	10.5	0.0	11.1	27.0	45.5	63.8	84.8	104.8	124.0	142.9	160.9
Energy consumption increase (%) due to the window area (%), room ratio 1:2, K=0.60											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	26.2	11.6	1.2	1.0	12.9	26.8	40.5	54.0	67.3	80.3	93.1
East	16.6	6.1	0.2	0.3	4.6	16.9	29.2	41.6	53.8	66.0	77.6
South	23.0	14.8	2.5	0.0	1.8	5.8	10.5	15.6	20.7	25.7	30.5
West	13.5	3.1	0.2	6.8	15.3	24.5	33.9	42.1	53.2	63.7	74.0

Table 5.21. Percentage of the energy consumption increase for window areas different than the IWA, Florianópolis, K=5.00.

Energy consumption increase (%) due to the window area (%), room ratio 2:1, K=5.00											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	23.6	10.4	0.4	1.5	5.5	10.7	15.8	21.2	26.7	32.1	37.2
East	20.7	11.1	2.9	0.0	3.0	7.6	12.6	17.7	22.8	27.8	32.6
South	24.4	15.8	3.9	0.1	0.5	1.4	2.7	4.3	6.1	7.8	9.5
West	19.0	6.5	0.3	3.1	4.0	7.8	11.7	15.8	20.9	25.7	30.4
Energy consumption increase (%) due to the window area (%), room ratio 1:2, K=5.00											
Orientation	0	10	20	30	40	50	60	70	80	90	100
North	25.0	20.4	9.5	4.2	2.5	0.0	0.5	2.7	5.1	7.6	10.0
East	20.9	17.2	9.5	5.5	4.3	1.2	0.5	2.2	4.4	6.7	8.9
South	24.8	23.3	14.7	9.2	4.7	3.0	1.6	0.4	0.0	1.8	2.1
West	17.0	12.4	4.0	0.4	1.1	1.7	2.5	3.6	3.2	4.9	6.7

5.6.5. Potential for energy savings by using fibre optics

Having obtained the Ideal Window Areas for the different room ratios and room sizes for each of the eight cities, it is important to identify the impact that such a window area will have on the supply of daylight. To assess the impact, the methodology described in Chapter 3 was used to determine the energy savings on lighting that could be achieved due to the availability of daylight on the working surface of each room. Such an analysis would also identify the potential for energy savings on lighting likely to occur if fibre optics were used to transport daylight to the rear side of the rooms.

Results of energy savings on lighting due to daylight from Ideal Window Areas are shown in Tables 5.22 to 5.29 for each city and are probably underestimated as they are based on Daylight Factors calculated for the CIE overcast sky (see section 2.3.6 in the literature review). The data shown in these tables is based on an illuminance level on the working surface of 500lux for the eight cities. As for the average outdoor illuminance, 5000lux was the value used for Leeds, which is approximately the figure used in daylight design in the UK. For the seven cities in Brazil an outdoor illuminance of 10000lux was assumed, as this is a typical value from an overcast sky (TREGENZA & LOE, 1998). These relatively low illuminance levels will assure that the values presented in the tables are the minimum expected savings to be made on artificial lighting, and therefore the maximum savings to be made through the use of new technologies such as fibre optics.

The data shown in the tables indicates that there is a tendency for energy savings on lighting to be greater for smaller room indices (K) and for room ratios whose room width is larger (room ratios of 2:1, 1.5:1 and 1:1). Therefore, the potential for energy savings on lighting due to the application of fibre optics is higher for rooms having a larger room index and a narrower width. The potential for energy savings on lighting due to the use of fibre optics was determined from the energy savings presented in Tables 5.22 to 5.29. If the energy saving presented in any of these tables is, for example, 60%, then the potential for energy savings due to the integration of fibre optics will be 40%.

Hence, the energy savings on lighting likely to be attained in Belém (Table 5.22) when there is integration of daylight coming in from the Ideal Window Area with artificial lighting range from 24.8% to 70.6% across all the room sizes and room ratios investigated. Therefore, if fibre optics were used to transport more daylight to the rear side of the rooms, the potential for energy savings on lighting would range from 29.4% in small rooms to 75.2% in large rooms.

For Brasília (Table 5.23), the energy savings on lighting vary from 22.4% (for large rooms) to 92.0% (for small rooms), which implies that the potential for energy savings on lighting due to the integration of fibre optics will lie within 8.0% and 77.6%, in small and large rooms respectively.

For Curitiba (Table 5.24), it can be noted that the energy savings on lighting range from 20.6% to 87.7% across all the rooms that were evaluated. Thus, the potential for energy savings on lighting due to fibre optics will range from 12.3% (in small rooms) to 79.4% (in large rooms).

Results obtained for Florianópolis are presented in Table 5.25 and it can be observed that energy savings on lighting range from 20.6% to 86.2% across all room sizes. Hence, the potential for energy savings on lighting if fibre optics are used to transport daylight to the rear side of the rooms will lie within 13.8% and 79.4%, in small and large rooms, respectively.

Table 5.26 shows the results of energy savings on lighting likely to occur in Leeds when there is integration of daylight coming into the rooms from the Ideal Window Area with the artificial lighting system. The energy savings likely to be achieved range from 10.8% to 44.0%. In this case, the potential of energy savings on lighting due to the use of fibre optics would lie within 56.0% and 89.2%.

For Natal, the results presented in Table 5.27 show that the energy savings on lighting lie within the range of 17.7% and 62.1% for large and small rooms, respectively. Thus, the potential for energy savings on lighting likely to be obtained with the use of fibre optics lie within the range of 37.9% and 82.3% for small and large rooms, respectively.

From Table 5.28 it can be noted that the energy savings on lighting in Rio de Janeiro range from 17.7% to 82.2% across all the rooms that were evaluated. Hence, the potential for energy savings on lighting due to the use of fibre optics will lie within the range of 17.8% (in small rooms) and 82.3% (in large rooms).

Finally, results obtained for Salvador are presented in Table 5.29 and it can be observed that energy savings on lighting range from 20.3% to 80.5% across all room sizes and room ratios. Thus, the potential for energy savings on lighting if fibre optics are used to transport daylight to the rear side of the rooms will lie within the range of 19.5% and 79.7%, in small and large rooms, respectively.

Due to the large number of room sizes and room ratios considered in this work, it can be noted that the range of energy savings on lighting just presented is much wider than that reported by BODART & DE HERDE (2002) and shown in the literature review. This is due to the fact that the rooms studied by Bodart and De Herde have small dimensions (room indices ranging from 0.80 to 1.20).

Table 5.22. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Belém, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	51.6	51.6	64.8	44.8	48.4	42.2	55.6	47.0	50.0	42.4	58.0	35.9	53.8	46.2	67.5	38.2	48.9	46.0	66.7	46.0
0.80	55.4	62.1	69.1	46.6	59.6	56.0	69.0	56.0	51.4	45.8	67.6	42.5	53.2	52.0	67.6	39.0	47.8	47.8	62.2	44.4
1.00	51.4	59.2	70.6	51.4	58.9	52.5	62.4	52.5	46.8	46.8	66.2	38.6	51.4	54.5	62.5	40.8	47.5	51.3	60.0	46.2
1.25	50.2	61.5	65.3	50.2	52.3	58.4	63.9	52.3	48.0	54.5	62.4	38.4	47.8	53.5	59.4	43.6	45.0	49.2	55.9	43.0
1.50	50.2	64.6	64.6	47.8	51.0	59.0	60.1	51.0	47.7	53.8	58.4	36.8	45.1	53.4	54.7	40.3	42.0	48.8	51.0	40.5
2.00	44.8	59.4	56.9	44.8	47.7	59.5	56.1	47.7	42.4	50.7	53.8	37.2	40.6	49.9	49.9	39.3	38.2	44.5	45.3	37.3
2.50	42.7	55.5	53.0	46.8	43.8	54.9	51.6	44.6	39.3	48.8	50.2	33.6	36.6	46.0	45.0	35.0	34.6	40.5	40.5	33.5
3.00	40.7	53.1	48.6	42.9	41.1	52.5	48.6	41.6	36.9	46.0	46.0	32.5	33.2	42.5	40.6	33.2	31.8	38.2	37.5	31.6
4.00	35.9	48.2	42.5	38.6	35.1	47.7	43.4	38.9	32.7	41.2	39.9	28.4	29.2	37.8	35.9	30.0	27.7	34.4	32.7	27.7
5.00	31.4	42.6	38.0	35.1	32.5	43.6	38.3	35.0	29.8	37.6	36.1	25.7	25.6	34.4	32.0	27.3	24.8	30.6	29.0	24.8

Table 5.23. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Brasília, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	58.0	80.5	92.0	44.8	60.6	67.8	89.9	47.0	58.0	61.6	91.6	47.5	58.8	78.1	88.7	50.2	62.5	72.8	84.1	48.9
0.80	62.1	73.9	87.1	46.6	70.4	75.7	89.8	44.8	61.1	74.3	89.4	45.8	61.1	74.3	81.4	52.0	60.8	69.7	77.8	46.8
1.00	56.4	77.0	87.3	50.2	62.4	73.1	86.6	46.6	61.7	71.8	84.1	46.8	56.1	70.4	76.3	48.5	56.7	64.7	71.4	46.2
1.25	56.0	73.9	83.6	45.0	61.0	69.3	79.2	46.3	59.4	69.7	78.1	48.0	53.5	65.3	70.3	46.1	52.5	59.1	64.8	41.4
1.50	53.1	70.4	76.9	47.8	59.0	65.8	75.8	44.4	55.9	65.0	72.5	47.7	52.1	59.6	65.3	42.6	49.2	54.7	60.0	38.9
2.00	49.6	64.4	70.8	42.4	53.6	60.8	68.9	45.6	48.9	59.6	64.9	42.4	46.7	53.8	58.2	39.3	43.2	49.1	52.1	35.3
2.50	47.8	59.5	63.5	38.7	48.6	56.2	62.6	40.9	44.7	54.2	58.4	42.3	42.3	48.3	52.3	33.9	38.6	44.0	46.7	31.4
3.00	42.9	54.0	59.4	40.7	44.4	51.9	57.7	39.8	41.1	49.9	53.2	37.2	38.1	44.2	48.3	30.4	35.9	40.6	42.6	29.0
4.00	39.1	48.2	51.4	34.8	38.9	45.6	50.6	35.1	35.4	43.3	45.7	33.2	33.7	38.6	41.5	27.3	31.0	35.3	36.7	25.1
5.00	35.1	41.8	45.3	31.4	34.5	40.7	44.7	32.5	32.1	39.3	40.2	30.4	30.1	34.3	36.9	24.3	27.6	31.0	31.9	22.4

Table 5.24. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Curitiba, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	58.0	64.8	82.2	44.8	60.6	74.8	86.2	47.0	58.0	73.9	86.0	42.4	70.7	78.1	87.7	46.2	71.4	76.5	85.4	48.9
0.80	62.1	65.2	84.7	46.6	70.4	77.9	85.8	44.8	67.6	74.3	84.1	43.5	67.6	74.3	81.4	48.2	68.1	69.7	78.3	44.4
1.00	59.2	69.1	83.2	51.4	67.5	77.0	86.1	46.6	66.2	70.0	79.8	42.0	63.6	67.5	76.3	45.0	63.5	64.7	71.8	43.4
1.25	61.5	62.7	78.9	45.0	63.9	69.3	77.8	43.2	62.1	64.5	74.3	47.3	59.4	62.3	70.3	43.6	56.5	58.3	65.2	40.8
1.50	59.0	64.6	76.9	47.8	59.0	65.8	74.9	42.6	56.9	60.9	70.4	43.6	54.7	58.5	65.3	40.3	52.1	53.4	60.7	37.8
2.00	54.0	59.4	70.8	42.4	55.3	60.2	68.9	42.6	52.6	54.5	62.2	41.0	49.0	51.2	57.5	36.5	45.3	47.4	52.6	32.8
2.50	48.9	53.6	65.2	42.7	49.3	51.6	61.7	35.0	47.9	49.8	56.9	39.3	43.7	46.0	51.4	33.4	40.2	41.9	47.0	28.9
3.00	46.3	50.1	60.4	40.7	45.8	48.6	57.7	35.6	43.6	45.8	51.8	36.5	39.3	41.2	47.6	30.4	36.9	38.2	42.6	26.7
4.00	41.0	44.7	52.5	35.9	39.8	42.1	50.6	30.8	37.7	38.0	44.9	32.7	34.3	35.9	40.9	27.3	31.8	33.0	36.7	23.3
5.00	36.6	39.9	47.1	31.9	36.0	37.4	45.1	28.6	33.9	34.2	40.2	29.8	30.4	31.5	36.2	24.5	28.0	28.9	31.9	20.6

Table 5.25. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Florianópolis, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	51.6	69.2	82.2	44.8	47.0	60.6	86.2	42.2	54.1	61.6	75.0	42.4	58.8	74.3	74.3	45.2	64.4	66.7	74.8	48.9
0.80	46.6	69.1	84.7	46.6	56.0	70.4	85.8	44.8	58.6	67.6	76.6	42.5	61.1	71.6	71.6	44.0	62.3	62.3	69.7	44.4
1.00	51.4	70.6	83.2	50.2	52.5	67.5	84.1	42.4	60.6	66.2	74.8	42.0	56.1	64.6	66.1	45.0	58.1	58.2	65.7	43.4
1.25	50.2	65.3	76.9	45.0	52.3	63.9	75.0	43.2	55.7	62.1	69.7	40.2	53.5	60.2	62.3	40.7	50.5	54.1	59.1	40.8
1.50	47.8	66.2	72.8	44.2	51.0	60.1	71.0	42.6	53.8	56.9	65.0	39.0	50.7	54.7	58.5	38.9	48.8	49.2	54.7	37.1
2.00	44.8	59.4	64.4	42.4	47.7	55.3	64.6	43.2	46.8	50.7	58.4	37.2	44.6	47.8	51.4	36.0	41.7	43.2	48.1	32.8
2.50	42.7	53.0	59.5	38.7	44.6	49.3	57.0	37.7	43.2	46.3	53.1	35.6	39.9	42.9	46.5	33.3	37.0	38.6	43.6	28.9
3.00	41.5	48.6	53.1	37.5	44.4	45.8	52.5	37.7	38.5	42.1	47.8	32.5	36.2	38.1	42.1	28.8	33.9	35.1	40.1	26.7
4.00	36.6	43.8	46.3	34.8	38.9	40.5	45.6	34.1	35.1	36.2	41.7	28.4	31.4	32.8	36.8	26.3	28.9	30.2	34.6	22.7
5.00	32.4	38.0	40.4	31.4	35.0	36.0	40.1	30.0	30.8	32.1	37.2	25.7	27.8	29.0	32.4	23.3	25.3	26.9	30.6	20.6

Table 5.26. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Leeds, England, with an outdoor illuminance of 5000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	41.0	25.8	22.4	17.2	41.0	24.2	23.5	12.5	27.1	27.1	17.9	11.9	26.9	29.4	16.0	10.9	28.3	24.5	17.3	10.8
0.80	43.3	27.7	23.3	15.6	44.0	29.8	22.4	16.5	30.5	29.3	21.2	10.7	29.6	29.6	16.0	11.3	30.7	23.9	16.0	10.9
1.00	41.6	28.2	25.1	16.8	42.7	29.2	23.3	15.9	33.3	28.9	19.3	11.9	31.6	28.9	16.3	12.9	32.2	24.8	15.0	12.0
1.25	43.7	25.1	22.0	15.3	42.4	29.2	21.6	14.0	35.3	27.8	19.2	13.5	33.2	28.5	16.6	12.5	33.0	25.0	16.7	11.2
1.50	43.9	25.1	22.1	16.1	43.5	26.6	19.7	14.1	37.1	27.7	18.4	13.9	35.3	28.0	17.1	12.6	33.0	24.3	16.1	11.1
2.00	43.2	25.0	20.0	16.1	41.4	28.3	19.1	14.8	37.0	25.4	26.5	13.3	33.6	26.2	16.8	13.2	30.9	23.5	15.0	10.9
2.50	40.9	23.6	18.2	15.7	38.0	26.1	17.0	13.8	36.1	24.1	16.7	13.3	32.3	24.7	15.6	11.4	28.0	22.3	14.1	11.5
3.00	39.0	22.3	15.9	14.1	35.4	24.7	15.4	12.6	34.1	22.5	15.7	12.2	29.5	22.8	15.1	7.8	26.3	21.4	14.0	11.0
4.00	35.6	20.7	14.2	13.2	31.9	23.5	13.6	11.4	29.9	21.4	14.1	12.6	26.0	20.9	15.1	11.8	22.5	19.2	13.3	10.9
5.00	31.8	19.1	13.9	11.9	28.6	22.3	12.2	12.2	26.8	19.7	13.7	12.4	24.0	18.7	14.5	11.5	20.5	16.8	12.4	10.8

Table 5.27. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Natal, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	51.6	58.0	51.6	40.6	48.4	48.4	55.6	33.2	47.5	42.4	53.0	29.5	53.8	46.2	54.6	32.0	52.6	41.4	46.0	46.0
0.80	55.4	62.1	55.4	39.0	59.6	59.6	61.0	38.6	51.4	45.8	57.5	34.2	53.2	52.0	57.2	32.0	51.8	44.4	46.8	44.4
1.00	51.4	59.2	56.4	44.4	52.5	60.3	60.3	41.2	53.0	53.0	60.6	37.7	51.4	51.4	56.1	32.6	51.3	46.2	47.5	40.0
1.25	50.2	61.5	56.0	44.0	52.3	59.8	59.8	40.2	53.1	54.5	55.7	35.4	51.8	53.0	53.0	34.8	47.9	45.0	45.0	36.6
1.50	50.2	59.0	53.1	43.2	51.0	59.0	57.9	38.4	50.6	53.8	53.8	34.8	48.9	50.7	50.7	34.2	45.0	43.9	43.2	35.5
2.00	49.6	56.9	54.0	40.0	47.7	56.1	53.6	38.4	47.1	50.7	48.9	31.0	45.5	47.8	45.5	34.8	41.2	41.2	39.7	29.8
2.50	47.8	53.0	48.9	36.4	44.6	51.6	48.6	34.0	44.7	48.8	46.3	30.8	42.1	44.1	42.1	30.9	37.0	37.3	35.9	26.8
3.00	44.9	50.1	46.3	35.4	41.6	50.2	45.1	33.0	42.1	45.8	42.9	31.4	37.8	41.2	37.8	29.3	34.8	35.4	33.9	23.9
4.00	39.7	45.5	41.0	32.8	38.5	45.1	39.8	30.4	37.2	40.7	37.7	28.4	33.7	36.8	33.3	27.3	30.4	31.8	29.9	20.8
5.00	36.6	40.9	38.0	30.5	34.5	40.4	36.0	28.1	33.9	37.2	33.9	25.7	30.1	33.4	29.5	25.1	27.2	28.6	26.9	17.7

Table 5.28. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Rio de Janeiro, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	40.6	40.6	82.2	36.0	42.2	47.0	67.8	33.2	50.0	50.0	73.9	29.5	46.2	53.8	67.5	28.4	52.6	66.7	71.4	30.2
0.80	45.2	39.0	81.2	32.6	43.4	44.8	75.7	38.6	45.8	51.4	74.3	29.2	48.2	57.2	67.6	31.0	47.8	62.2	68.1	30.6
1.00	44.4	44.4	78.1	33.6	42.4	46.6	73.1	36.6	46.8	53.0	70.0	32.8	45.0	54.5	63.6	30.0	47.5	58.2	63.5	28.2
1.25	44.0	44.0	73.9	34.8	46.3	52.3	66.5	34.2	47.3	53.1	64.5	30.4	43.6	53.0	60.2	32.0	43.0	54.1	56.5	27.4
1.50	44.2	44.2	70.4	32.2	44.4	51.0	64.0	33.8	43.6	50.6	62.9	31.6	40.3	48.9	56.9	28.8	40.5	50.0	52.6	26.6
2.00	40.0	42.4	61.4	32.2	45.6	47.7	59.5	29.6	40.3	46.8	55.4	27.2	36.5	45.5	50.4	28.0	35.3	43.7	46.2	24.0
2.50	38.7	42.7	53.6	27.8	43.8	44.6	51.6	27.6	37.8	43.6	51.0	26.6	33.3	40.8	46.0	28.2	31.4	38.9	41.4	22.7
3.00	37.5	41.5	50.1	27.4	41.6	44.4	48.6	25.2	32.9	40.6	46.6	24.4	29.3	37.8	41.8	25.6	29.5	35.9	37.9	21.3
4.00	34.8	38.6	42.5	22.4	38.9	38.9	43.4	21.6	28.8	36.2	39.9	21.5	26.3	33.3	36.8	23.1	25.4	30.8	32.7	19.1
5.00	31.4	35.1	37.4	20.2	35.0	36.0	37.9	19.4	27.4	32.7	35.8	21.3	24.0	29.8	32.7	22.1	22.6	27.2	28.9	17.7

Table 5.29. Energy savings (%) on artificial lighting when using the Ideal Window Areas in Salvador, Brazil, with an outdoor illuminance of 10000lux.

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	44.8	40.6	80.5	34.4	42.2	47.0	79.8	30.0	35.9	54.1	73.9	29.5	46.2	50.2	70.7	28.4	52.6	55.7	71.4	25.4
0.80	45.2	45.2	73.9	32.6	43.4	44.8	81.0	37.2	42.5	57.5	74.3	34.2	44.0	52.0	68.7	31.0	46.8	51.8	68.1	27.2
1.00	50.2	44.4	77.0	33.6	42.4	46.6	77.0	36.6	42.0	57.8	70.0	32.8	45.0	49.6	63.6	30.0	46.2	48.9	63.5	26.8
1.25	44.0	44.0	73.9	34.8	43.2	43.2	69.3	35.2	40.2	53.1	64.5	34.6	40.7	46.7	60.2	32.0	40.8	46.5	56.5	27.4
1.50	44.2	44.2	70.4	38.0	39.4	42.6	65.8	33.8	39.0	49.3	60.9	32.4	38.9	44.4	56.9	30.6	37.8	43.2	53.2	28.0
2.00	40.0	40.0	61.4	36.4	42.6	43.2	60.2	34.6	40.3	42.4	54.5	31.0	34.8	39.9	51.2	30.4	32.9	38.2	46.2	28.1
2.50	36.4	36.4	55.5	34.4	35.0	37.7	53.6	32.4	35.6	39.3	49.8	30.8	30.9	33.9	46.0	29.5	28.9	34.6	41.4	26.8
3.00	35.4	37.5	52.3	31.8	33.0	35.6	50.2	30.8	32.9	36.5	45.8	31.4	28.4	31.7	41.8	28.4	26.7	31.6	38.2	25.3
4.00	32.8	32.8	45.5	31.3	30.8	32.4	43.4	29.4	29.3	29.3	39.0	28.4	24.6	27.8	36.5	25.8	22.7	27.7	33.0	23.3
5.00	29.1	30.5	40.4	29.1	28.6	28.9	37.9	26.7	28.4	28.0	34.7	27.4	22.3	25.1	32.4	24.0	20.3	24.5	29.0	21.4

5.7. Summary

The methodology presented in this chapter proved effective in obtaining the Ideal Window Area of rooms. A model comprising of rooms with five room ratios and ten room sizes were simulated using the VisualDOE programme for each of the four orientations in seven cities in Brazil and one in the UK.

The assessment of the energy savings on artificial lighting as a function of the daylight supply and the Ideal Window Area through the methodology presented in Chapter 3 shows that the integration of daylight and artificial lighting provides savings that are greater for smaller rooms and also for rooms with a larger width, as expected. Therefore, the potential for energy savings on lighting by using fibre optics to transport daylight to the rear side of rooms is higher for larger rooms and also for rooms with narrower width.

It was recognised that there is a potential for energy savings on lighting if fibre optics (or any other technology) are used to transport daylight to the rear side of rooms. Therefore, the next chapter presents an assessment of fibre optics in order to identify their capabilities as a technology to be used for the integration of daylight with artificial lighting.

Chapter 6

Fibre Optics Evaluation

6.1. Introduction

The previous chapters have assessed the amount of daylight coming onto the working surface in buildings through windows. Such an evaluation has shown that the integration of daylighting and artificial lighting can provide significant energy savings on lighting. However, it should also be noted that there is still a high potential for energy savings on lighting that could be made if the supply of daylight to the rear side of rooms were higher. Hence, this chapter studies the possibility of using fibre optics as a technology to bring daylight to the rear side of rooms where the supply from windows is low.

The assessment is performed using an experiment designed to evaluate the energy savings that could be obtained through the use of fibre optics to provide illumination coming from the ceiling as in a regular lighting system. The energy savings obtained through this experiment will be compared to the predictions presented in Chapter 5 for a specific room index and a specific room ratio for a space located in Leeds.

6.2. Description of the model

In Chapters 3 and 5, the supply of daylight and the Ideal Window Area were assessed for rooms of ten different dimensions and five different room ratios. For the experiment involving fibre optics as presented in this chapter, only one out of the many room sizes and room ratios studied in the previous chapters will be assessed.

It was shown in Chapter 5 that rooms with a narrower width (smaller façade area) and larger size present a higher potential for energy savings on lighting due to the use of fibre optics. Therefore, the room ratio selected to be used in the experiment was 1:2, and the room dimensions had a room index (K) of 1.50. Hence, a room measuring

4.61x9.23m with 2.80m height (Table 5.1, Chapter 5) was selected. Due to the difficulties of building a room to those dimensions, a 1/5 scale model was used whose dimensions were 92x184cm with 56cm height – see Figure 6.1. The height of the working surface was taken to be 0.75m above floor level, which to scale meant 15cm in the model.

Scale models have been used by many researchers around the world as a design tool for daylight studies. This is feasible due to the fact that physical models for daylight do not require any scaling corrections as the wavelengths of visible light are so short, relative to the size of the model, that the behaviour of light is unaffected (COMMISSION OF THE EUROPEAN COMMUNITIES, 1993).

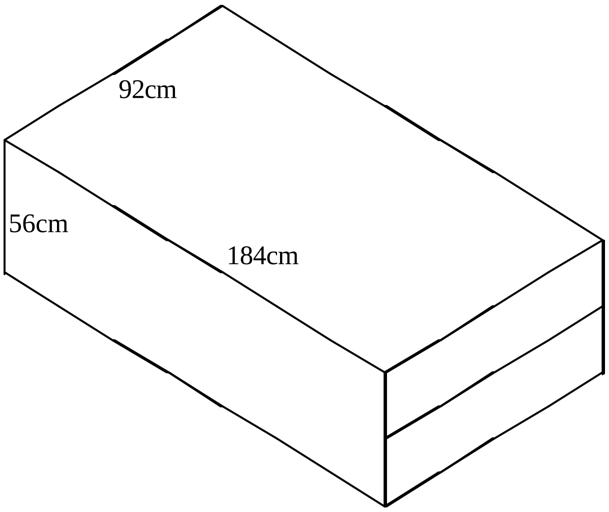


Figure 6.1. Dimensions of the model used for the experiment.

In terms of window area, four different standardised window areas were considered as used in Chapter 3. These are shown in Figure 6.2.

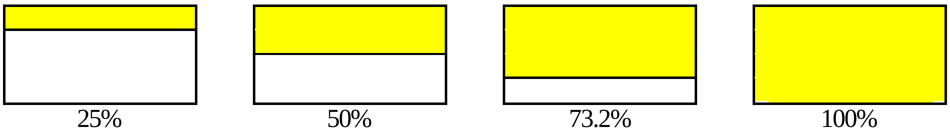


Figure 6.2. Window areas used in the model.

The base and walls of the model were constructed using 50mm polystyrene sheets, and the ceiling using a thick sheet of cardboard. The COMMISSION OF THE EUROPEAN COMMUNITIES (1993) acknowledges that materials that cannot be scaled easily are a limitation of scale modelling and may cause errors in the quantitative measurements.

However, this is not a concern in this case as the internal surfaces of the model were white and represented the colour, if not the finish, of an actual space realistically.

Two incandescent light bulbs were installed on the ceiling of the model. To avoid errors due to the integration of artificial light in scale models, the illuminance level was controlled using a rheostat in order to produce an illuminance of 500lux on the working surface.

Two luxmeters were installed in the model in order to measure the illuminance levels on the working surface. The photocells were placed on blocks as shown in Figure 6.3. All the outside edges of the model were sealed to avoid unwanted light penetration.

The energy consumption due to the artificial lighting was measured by installing a kWh meter between the light bulbs and the electricity supply.

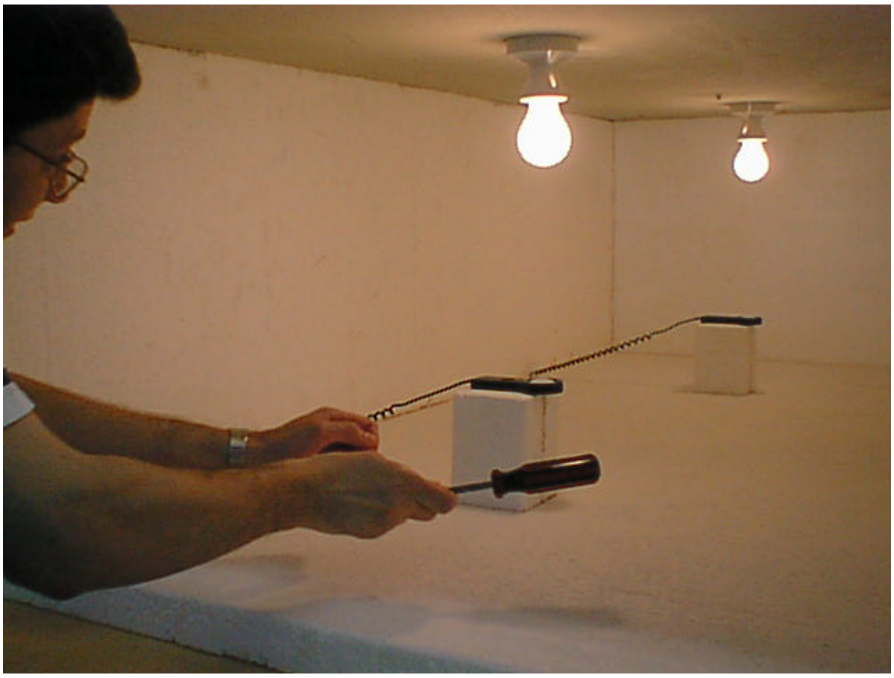


Figure 6.3. Light bulbs and photocells installed in the model.

6.3. The fibre optic system

The purpose of the experiment was to evaluate the possibility of using fibre optics to transport daylight, but as this experiment was designed to confirm the energy savings on lighting that could be obtained in buildings, artificial lights were used in conjunction with fibre optics.

The fibre optic system used in this experiment comprises an artificial light source of 150W and six 3-metre-long fibre optic tails. This system was loaned from

Schott Fibre Optics Ltd and can be seen in Figure 6.4.

Figure 6.4. Fibre optic system used in the experiment.

The six fibre-optic tails were located on the ceiling of the model and symmetrically distributed around the light bulb located at the rear side, where daylight levels are known to be lower. An internal view of the model showing both light bulbs and fibre optics can be seen in Figure 6.5.

Figure 6.5. The fibre optic system and the light bulbs installed in the model.

6.4. Location of the model

To evaluate the integration of daylight with artificial light, the model was placed against a Northeast-facing window in the Building Science Laboratory, located on the third floor of the Civil Engineering Building. Figure 6.6 shows the model in its position against the window where it remained during the measurements.

Figure 6.6. Model against the window.

6.5. Period of evaluation

The measurements of lighting levels and energy consumption were performed over a ten-day period between the 2nd and the 18th of October 2000, between the hours of 10.00am and 5.00pm.

6.6. Methodology

The first step was to measure the energy consumption of the two light bulbs necessary to provide an illuminance of 500lux on the working surface with no integration of daylight or lighting from the fibre optics. This was measured using the kWh meter installed between the light bulbs and the electricity supply. Such a measurement was important to obtain as it would provide a reference value (base case) against which to compare other results.

The next part of the experiment used different window areas as shown in Figure 6.2. The energy lighting consumption and the lighting levels achieved on the working surface were measured for three different situations:

(1) The artificial lights were switched on to supplement the daylighting coming onto the working surface of the model through the window in order to obtain 500lux on that surface. Lighting from the fibre optic system was not used. This would determine the energy savings to be made on artificial lighting due to daylight integration.

(2) The artificial lights were switched on to supplement both the daylighting coming onto the working surface of the model through the window and lighting from the fibre optic system. The fibre optic system had its power controlled in order to provide 50lux on the working surface while the artificial lights were controlled to provide a total illuminance level of 500lux on that surface.

(3) The final experiment was similar to situation (2), but the fibre optic system had its power controlled to provide an illuminance level of 300lux on the working surface.

For situations 2 and 3, the illuminance levels of 50lux and 300lux due to lighting from the fibre optics were selected at random. This was to represent a real life scenario where fibre optics are used to transport daylight and illuminance levels cannot be guaranteed. An illuminance level of 500lux was not considered for the fibre optics as this would lead to no need for artificial lighting and therefore to a 100% energy savings on lighting.

The lighting levels on the working surface in the model under outside sky conditions were measured every 15 minutes and the rheostats were adjusted at the same interval of time in order to obtain 500lux on the working surface for the 3 situations above described.

6.7. Results

The results obtained from the experiments are presented in two sections. First, the daylight levels and artificial lighting levels measured every 15 minutes are presented for each of the three situations described above. Then the energy savings on lighting due to the integration of daylight coming into the model through the window and also from fibre optics are calculated as a function of the energy consumption measured during the period 10am to 5pm for each specific situation and window area. The energy consumption for the base case – in which the two light bulbs are switched on from 10am to 5pm to provide an illuminance of 500lux on the working surface – was 0.86kWh.

6.7.1. Lighting levels

Figures 6.7 to 6.14 show the lighting levels measured on the working surface for each different window area at the window side and also rear side of the model for the situation in which fibre optics are not used. It can be seen that for most cases there is adequate daylight at the window side of the model, and also at the rear side.

Figures 6.7 and 6.8 show the illuminance levels measured at the window side and rear side of the model, respectively, for a window area of 25% and no use of fibre optics. It can be observed that at the window side of the model there was plenty of daylight over most of the day, only being slightly lower than 500lux at the end of the day when the artificial light at the window side was switched on. The illuminance levels due to artificial lighting that can be observed in Figure 6.7 over most of the day are due to the fact that the light bulb at the rear side of the model was kept on all day long.

As for the rear side (Figure 6.8), artificial light was needed over the whole period of measurement as the daylight levels were not enough to provide 500lux on the working surface. This is an indication of the need for fibre optics to transport daylight to the rear side of the model in order to achieve higher energy savings.

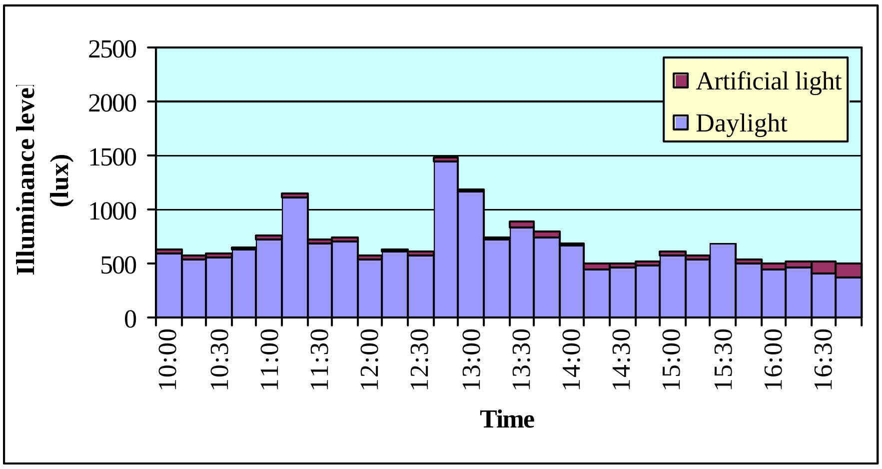


Figure 6.7. Lighting levels at the window side, window area of 25%, no fibre optics.

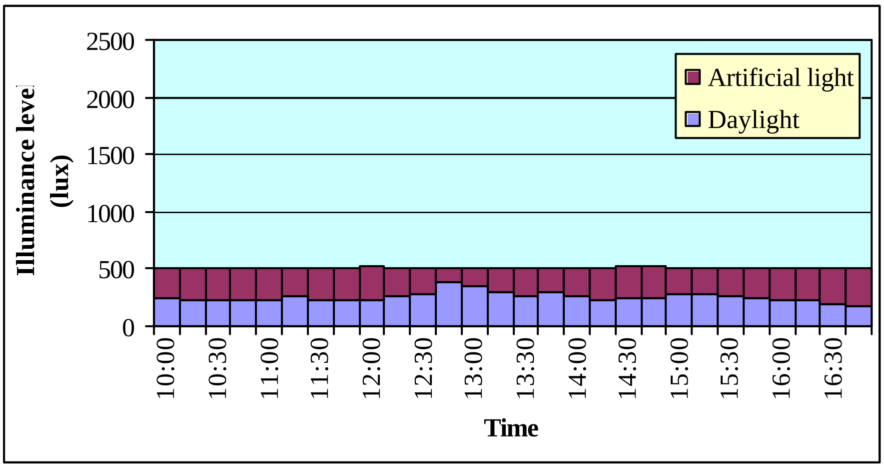


Figure 6.8. Lighting levels at the rear, window area of 25%, no fibre optics.

Figures 6.9 and 6.10 show the illuminance levels at the window side and rear side of the model, respectively, with no contribution of lighting from fibre optics for a window area of 50%. At the window side, daylight levels were lower than 500lux only from 10.00am-10.30am, but the turning on of the light bulb at the rear side was enough to increase the illuminance level at the window side to 500lux. Artificial light was needed most of the day at the rear side of the model. It should be noted that although the window area is 50% of the façade area – a relatively large window area – the daylight levels at the rear side of the model are low and could be increased through the use of fibre optics.

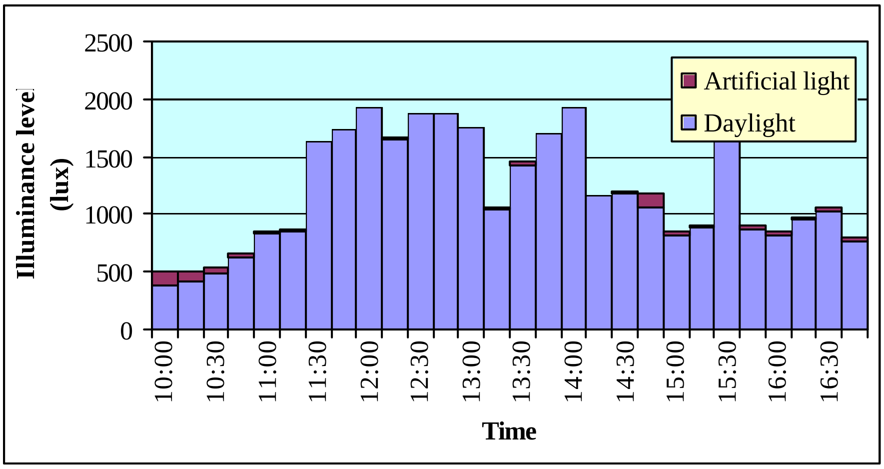


Figure 6.9. Lighting levels at the window side, window area of 50%, no fibre optics.

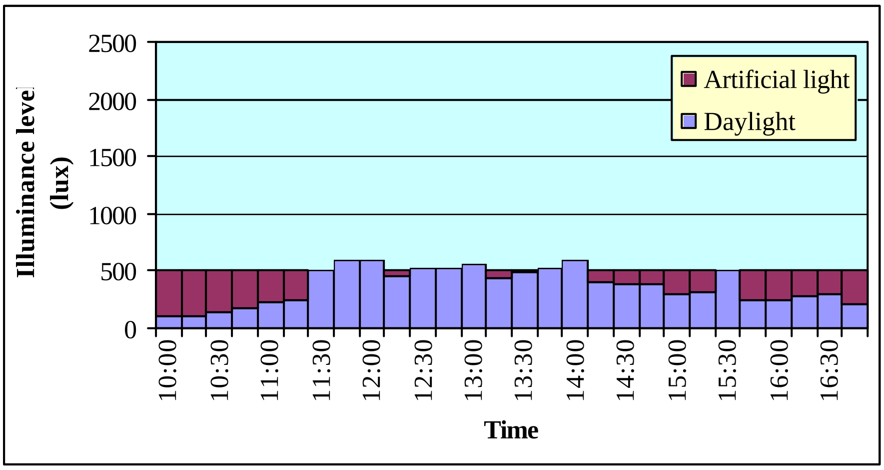


Figure 6.10. Lighting levels at the rear side, window area of 50%, no fibre optics.

The illuminance levels on the working surface in the model for a window area of 75%, and no contribution of light from fibre optics are presented in Figures 6.11 and 6.12 for the window side and rear side of the model, respectively. Due to the sky conditions and large window area, it can be noted from both figures that artificial light was only needed towards the end of the day both at the window and rear side of the model.

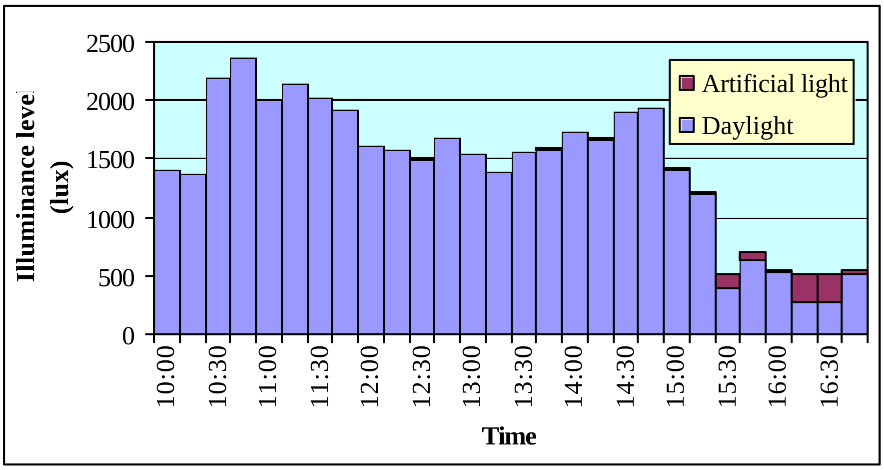


Figure 6.11. Lighting levels at the window side, window area of 75%, no fibre optics.

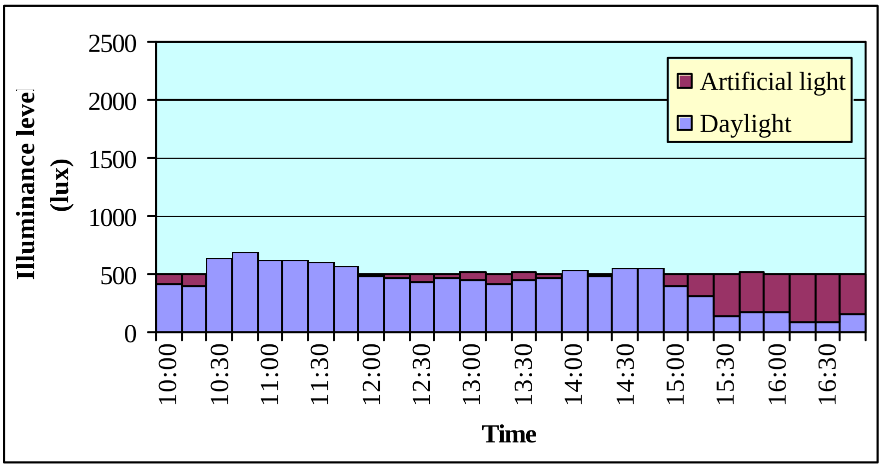


Figure 6.12. Lighting levels at the rear side, window area of 75%, no fibre optics.

Figures 6.13 and 6.14 show the illuminance levels at the window side and rear side of the model, respectively, for a window area of 100% and no contribution of lighting from fibre optics. At the window side (Figure 6.13), daylight levels were enough to supply with the lighting requirements, being much higher than 500lux over all measurement period. As for the rear side of the model, artificial light was needed only in the end of the measuring period, as shown in Figure 6.14.

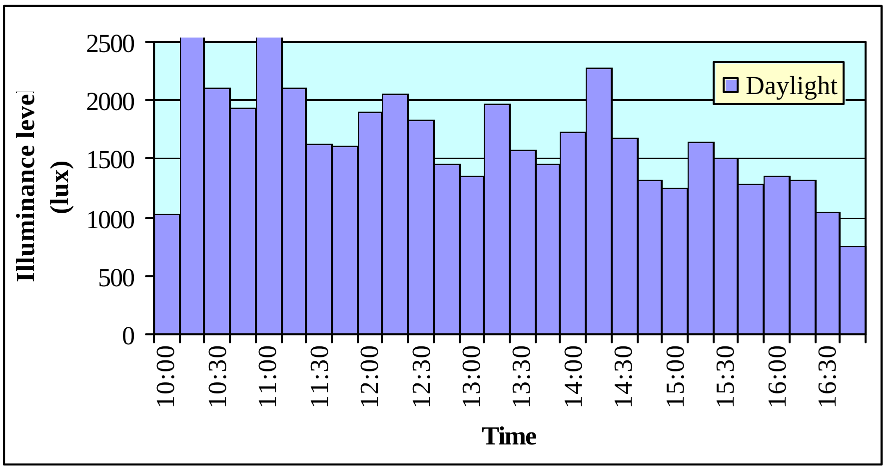


Figure 6.13. Lighting levels at the window side, window area of 100%, no fibre optics.

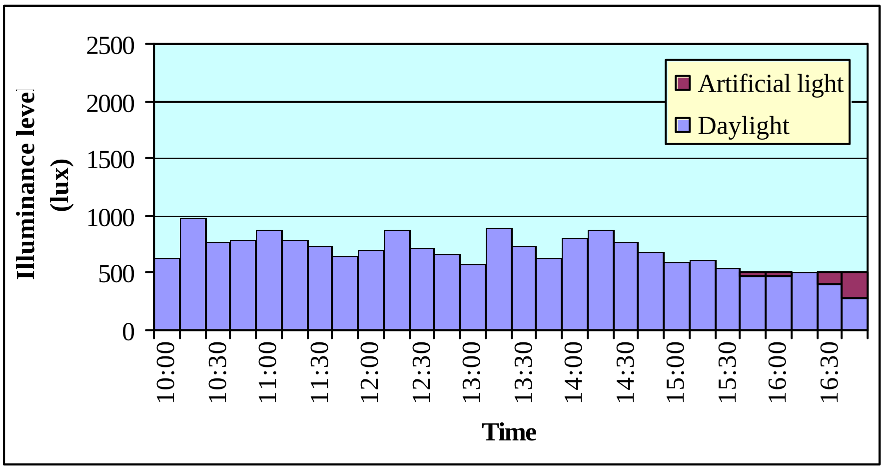


Figure 6.14. Lighting levels at the rear side, window area of 100%, no fibre optics.

Having completed the experiment in which artificial lights were switched on to supplement the daylighting coming onto the working surface of the model through the window, results on illuminance level due to the integration of fibre optics are to follow. Figures 6.15 to 6.20 show the illuminance levels obtained on the working surface in the model when the fibre optic system had its power controlled in order to provide 50lux on the working surface and for window areas of 25%, 50% and 75%. Window area of 100% was not considered because the daylight levels observed previously for this window area were higher than 500lux most of the time.

As the purpose of these experiments was to identify energy savings on lighting that can be obtained by using fibre optics to transport daylight, the lighting levels provided by fibre optics in all following figures in this section are included in the daylight level.

Figures 6.15 and 6.16 show the illuminance levels on the working surface in the model with a window area of 25% and with fibre optics adding 50lux to the parcel of daylight. It can be noted that the daylight levels even with the contribution of the fibre optics were very low due to the external conditions of a cloudy day. Both artificial lights were kept on most of the day so as to provide 500lux on the working surface.

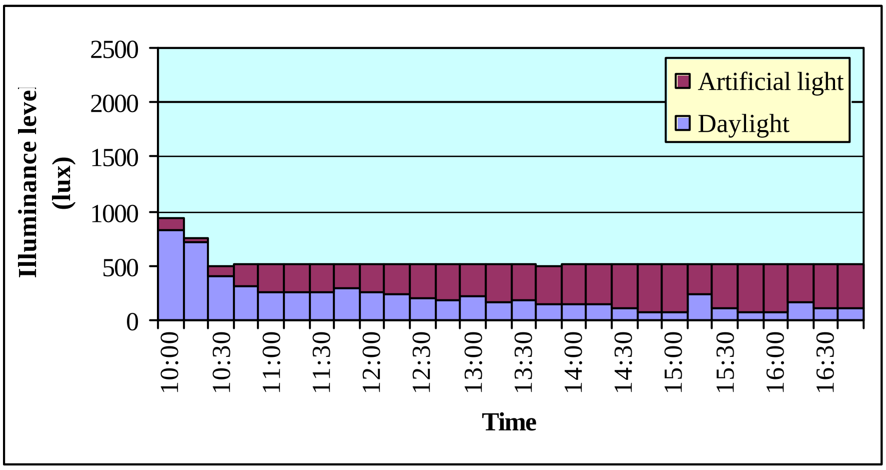


Figure 6.15. Lighting levels at the window side, window area of 25%, 50lux from fibre optics.

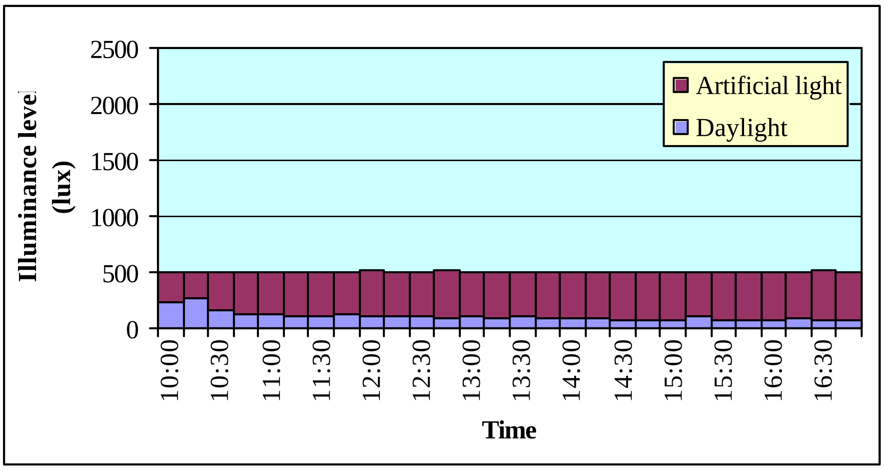


Figure 6.16. Lighting levels at the rear side, window area of 25%, 50lux from fibre optics.

Figures 6.17 and 6.18 show the illuminance levels on the working surface in the model with a window area of 50% and with fibre optics adding 50lux to the parcel of daylight. At the window side, daylight from the window provided illuminance levels higher than the required 500lux, but at the rear side of the model there was still a need for artificial light to supply with the required 500lux on the working surface.

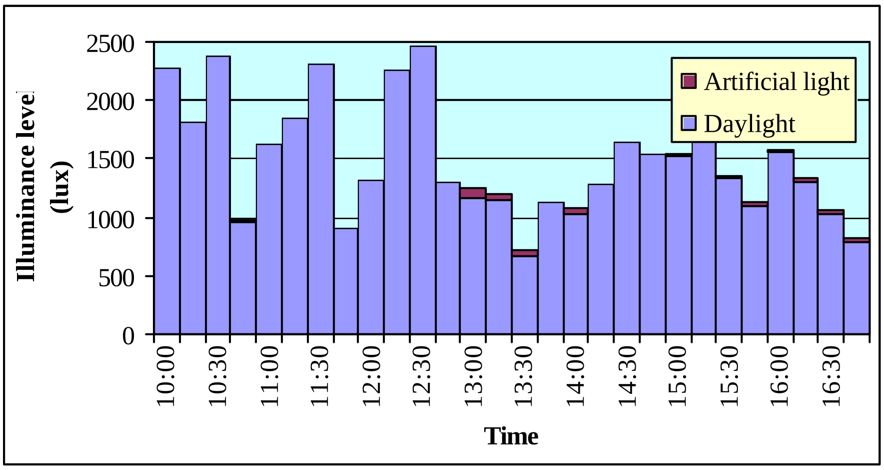


Figure 6.17. Lighting levels at the window side, window area of 50%, 50lux from fibre optics.

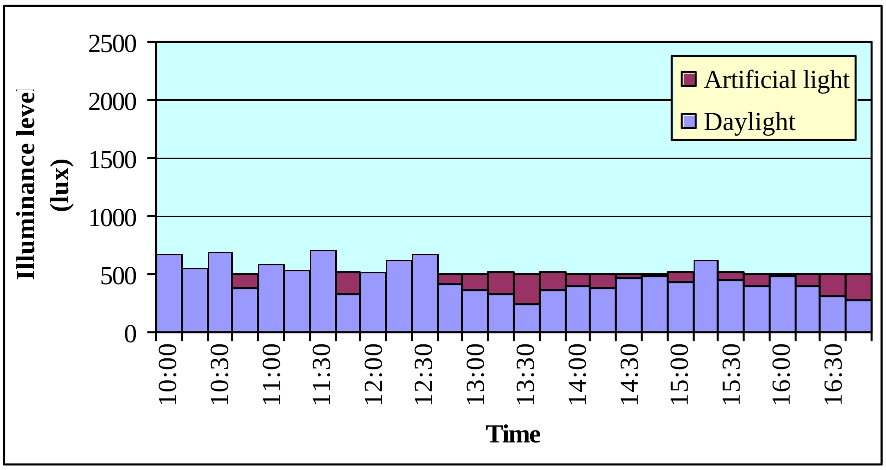


Figure 6.18. Lighting levels at the rear side, window area of 50%, 50lux from fibre optics.

Figures 6.19 and 6.20 show the results of illuminance levels on the working surface in the model when 50lux delivered by fibre optics was added to the daylight levels at the rear side of the model. It can be observed that artificial light was needed only at the end of the day and mostly over the last hour of the measurements.

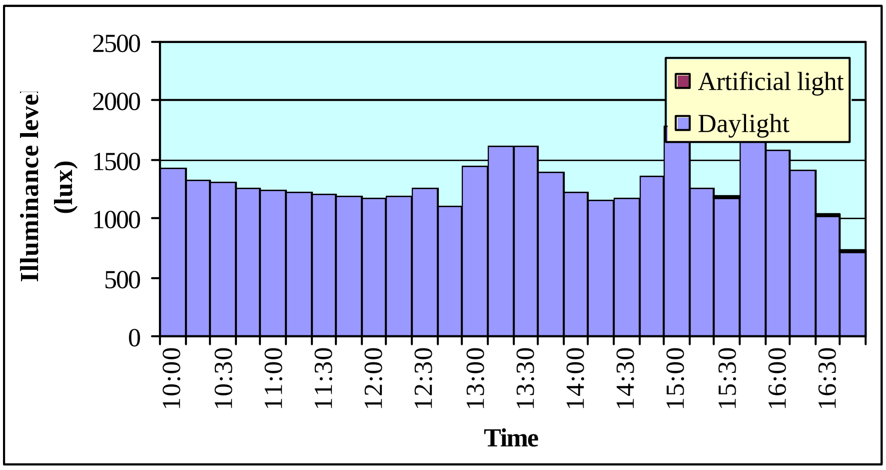


Figure 6.19. Lighting levels at the window side, window area of 75%, 50lux from fibre optics.

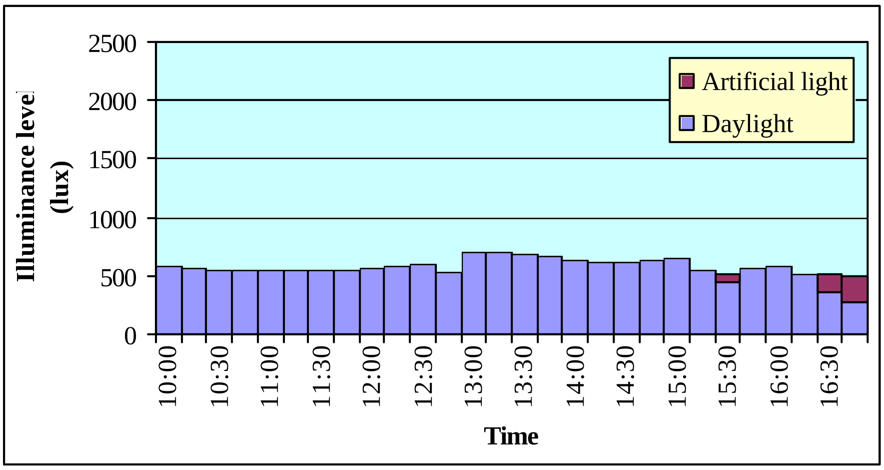


Figure 6.20. Lighting levels at the rear side, window area of 75%, 50lux from fibre optics.

Figures 6.20 to 6.25 show the results of illuminance levels measured on the working surface in the model when fibre optics were used to provide 300lux.

Figures 6.20 and 6.21 present the illuminance levels at the window side and rear side of the model, respectively, for a window area of 25% and fibre optics adding 300lux to the daylight levels. It can be observed that the illumination from the window and fibre optics supplies with most of the requirements on the working surface of the model, being slightly lower than 500lux at the end of the day.

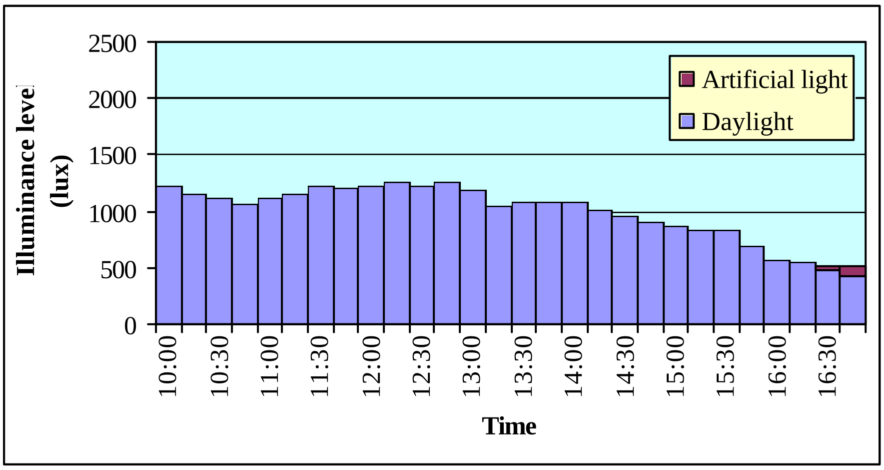


Figure 6.21. Lighting levels at the window side, window area of 25%, 300lux from fibre optics.

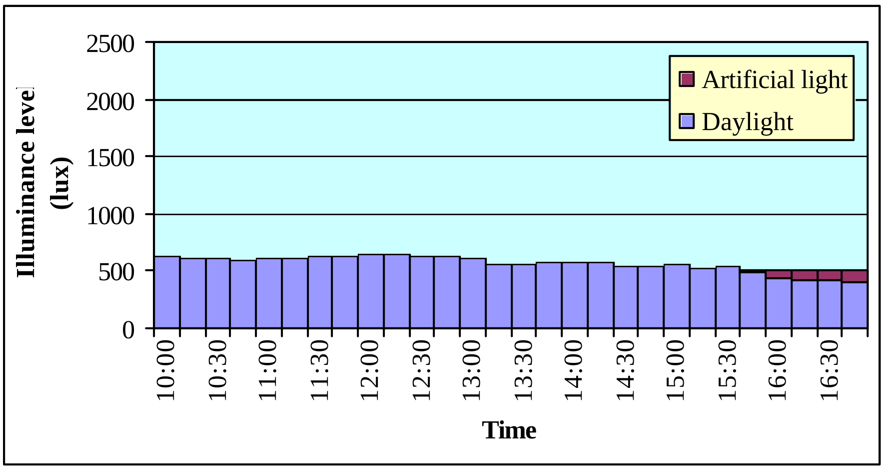


Figure 6.22. Lighting levels at the rear side, window area of 25%, 300lux from fibre optics.

Figures 6.23 and 6.24 show the results of illuminance levels when 300lux delivered by fibre optics is added to the daylight levels at the rear side of the model for a window area of 50%. As the external conditions were not very favourable in the morning, artificial light was needed in order to produce 500lux on the working surface of the model.

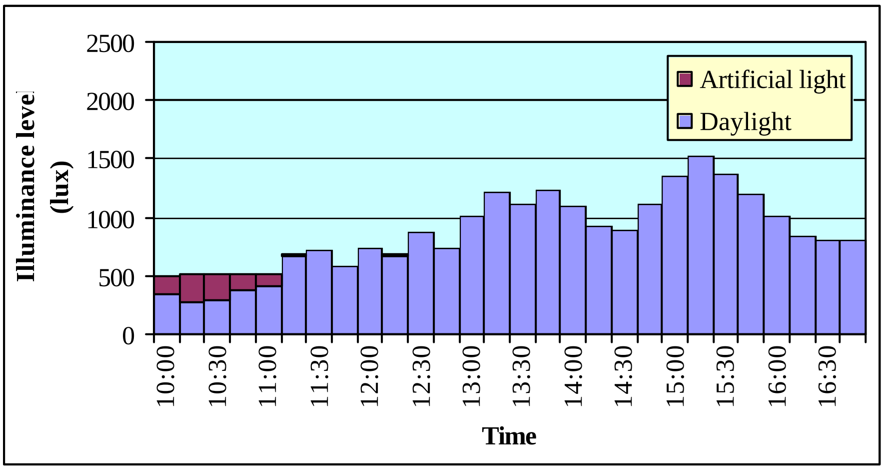


Figure 6.23. Lighting levels at the window side, window area of 50%, 300lux from fibre optics.

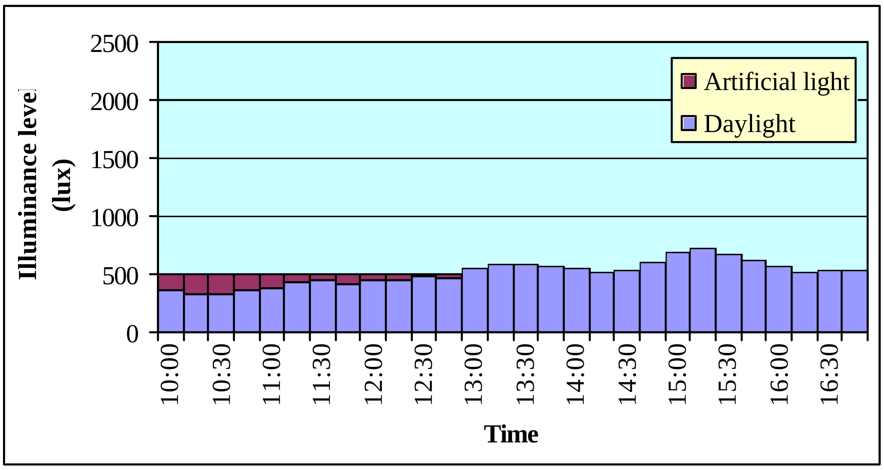


Figure 6.24. Lighting levels at the rear side, window area of 50%, 300lux from fibre optics.

Figures 6.25 and 6.26 show the illuminance levels measured on the working surface in the model for a window area of 75% when 300lux are delivered by the fibre optic system. It can be observed that at the window side, daylight from the window provided illuminance levels much higher than the required 500lux due to the bright external conditions. At the rear side of the model the integration of daylight from the window and fibre optics produced illuminance levels on the working surface higher than 500lux and therefore there was no need for artificial light.

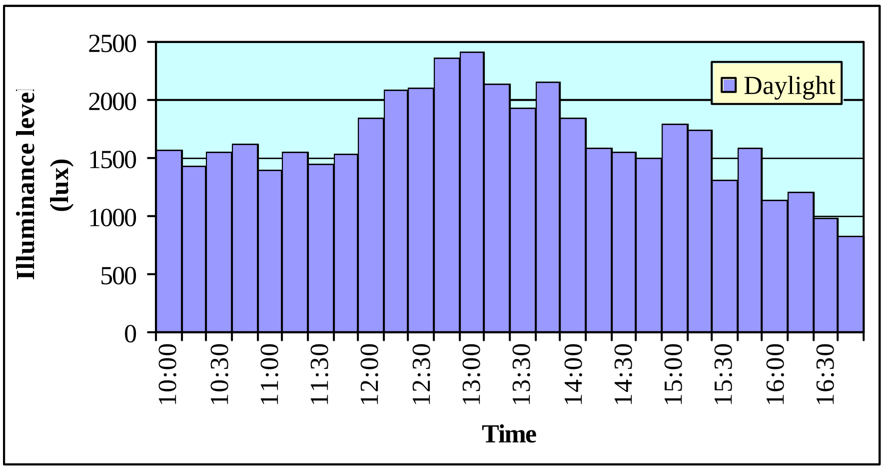


Figure 6.25. Lighting levels at the window side, window area of 75%, 300lux from fibre optics.

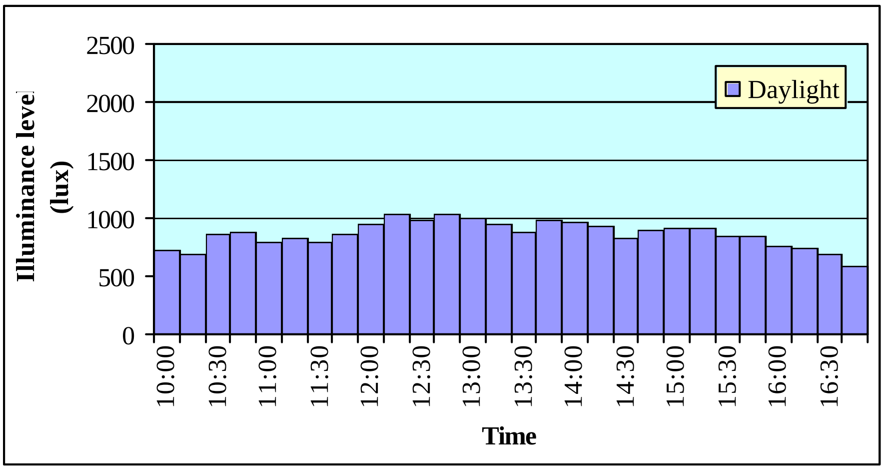


Figure 6.26. Lighting levels at the rear side, window area of 75%, 300lux from fibre optics.

Having presented and discussed the results concerning the illuminance levels obtained in the model for different window areas and integration of daylight and fibre optics with artificial light, it is then necessary to present the energy savings that were calculated as a function of the measured energy consumption.

6.7.2. Energy savings

The energy consumption of the lighting system measured in the model for the different window areas is presented in Table 6.1. Such energy consumptions account for the power supplied to the two incandescent light bulbs to supplement the daylighting on the working surface to the requirements of 500lux. It can be observed that there is a trend for the energy consumption to reduce as the window areas increase. For the base case, with no window area and the artificial lights kept on all the time, the energy consumption is the same independent of integration by the fibre optics.

The figures shown in the column "Without fibre optics" represent the energy consumption obtained when there is integration of daylight with artificial light but fibre optics are not applied; daylight comes onto the working surface in the model from the window only. The energy consumption for the window area of 75% is higher than the one for window area of 50% because the sky conditions were not as clear. The columns headed "50lux" and "300lux" represent the energy consumption when there is integration of daylight from the window and also from the fibre optics with the artificial lighting system. The energy consumption for the window area of 50% and illuminance provided by fibre optics of 300lux is higher than the one for window area of 25% for the same reason as described previously. The column "average" represents the average between the figures for 50lux and 300lux.

Table 6.1. Energy consumption obtained from the model.

Window area (%)	Energy consumption (kWh)			
	Without fibre optics	Illuminance provided by fibre optics		
		50lux	300lux	Average
None (Base case)	0.86	0.86	0.86	0.86
25	0.47	0.65	0.05	0.35
50	0.22	0.15	0.20	0.18
75	0.23	0.01	0.00	0.01
100	0.05	-	-	-

From the energy consumptions presented in the table above, energy savings for the two systems (with and without fibre optics) were calculated and are presented in Table 6.2. It can be noted that significant energy savings can be obtained when there is integration of daylight from window only (without fibre optics) but only a small increment on the energy savings when fibre optics are applied. It should be noted that these results are influenced by sky conditions and could vary for sky conditions different than those experienced during the measurements performed in October in Leeds.

Table 6.2. Energy savings obtained from the model.

Window area (%)	Energy savings (%)	
	Without fibre optics	With fibre optics
None (Base case)	0.0	0.0
25	45.3	59.3
50	74.4	79.7
75	73.3	98.8
100	94.2	100.0

A comparison of the energy savings that take into account the amount of light provided by fibre optics to the energy savings obtained by integrating the daylight coming from windows only are presented in Figure 6.27. It can be noted that the integration of daylight coming in from windows provides significant energy savings, and the addition of fibre optics to bring light to the rear side of the model provide only a small increase on the energy savings. This may be an indication that the application of fibre optics might not prove to be cost effective, but this topic is discussed in the next chapter.

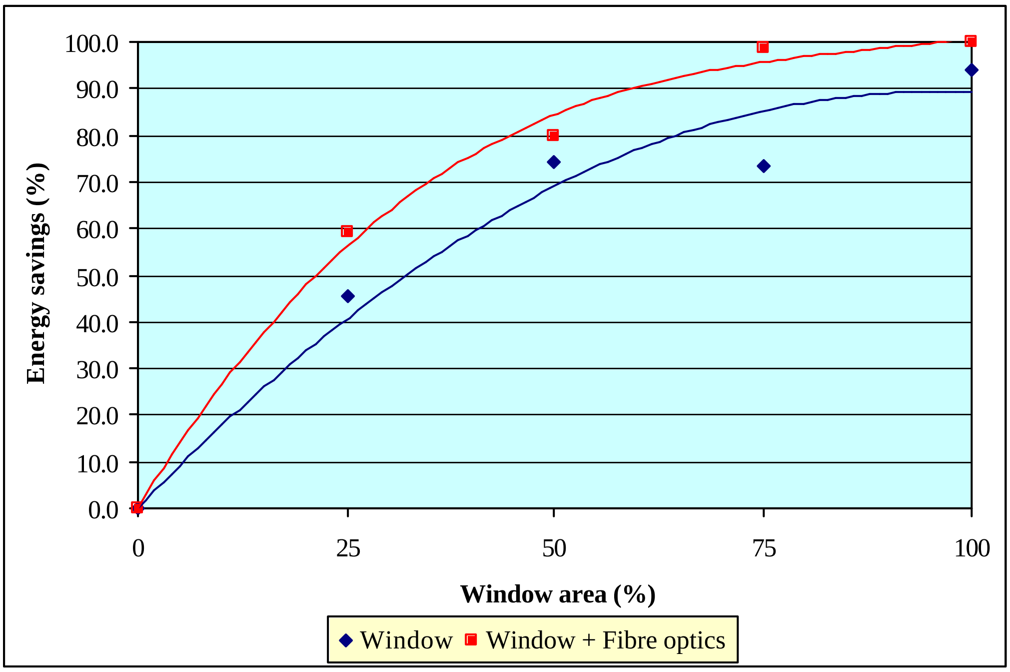


Figure 6.27. Energy savings obtained by using fibre optics.

Figure 6.28 presents the energy savings related to daylight coming onto the working surface from windows only and as a function of the window area; energy savings on lighting provided by fibre optics are not considered in this case. This allowed for a comparison of the results obtained from the experiment regarding energy savings due to integration of daylight coming in from windows only, with the results presented in Chapter 3. As it can be seen in Figure 6.28, the energy savings achieved from the experiment are significantly higher than the energy savings predicted in Chapter 3 for room index of 1.50, room ratio of 1:2 – which represents the dimensions of the model used – and DF of 10%. From Chapter 3, the DF of 10% is the one for an average illuminance of a typical design sky of 5000lux – which represents the design sky in Leeds – and lighting requirement on the working surface of 500lux. However, there is a better equivalence of values if the DF taken is equal to 5%, or even lower. This shows that the energy savings likely to occur in England due to integration of daylight may be even higher than the values predicted in Chapter 3 for DF of 10% and in Chapter 5.

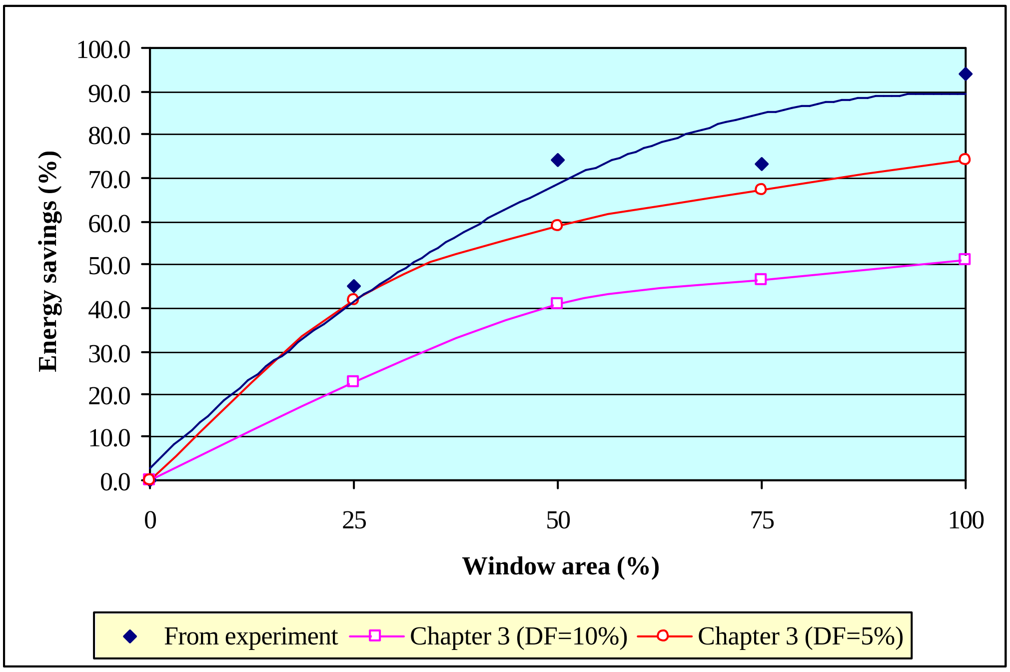


Figure 6.28. Energy savings obtained from experiment and from Chapter 3.

6.8. A proposal for a fibre optics installation in an actual building

The experiment presented in this chapter involved the integration of daylight, artificial lighting and fibre optics in a model room. Fibre optics were used to transport light generated by an artificial source, but in an actual building fibre optics would be used to transport daylight.

This section describes a way in which the integration of a fibre optics system would be possible in an actual building in order to transport daylight to the working surface. The applicability of what is presented below will depend on further research.

The first matter regarding the use of fibre optics in buildings concerns collecting and redirecting sunlight into the fibre optics. Collectors could be composed of Fresnel lenses, which were successfully used by MORI (1989) as presented in the literature review, or parabolic mirrors, or converging lenses etc.

The collecting system, in order to be effective over the whole year, should be composed of sun tracking concentrators. The best location for this equipment would be on the roof of the building. In this case, there should be horizontal and vertical ducts in the building in order to allow the distribution of the fibre optic cables from the roof to different floor levels and then to the individual rooms. There is also the possibility of installing a collecting system on the façade, just above the windows. This option would lead to fewer ducts being needed, shorter fibre lengths and therefore lower light losses. It also seems appropriate that, in this case, the daylight transported by fibre optics could be delivered directly on the working surface as an attempt to improve task lighting. For this situation, the fibre optic cables could be concealed in the ceiling and there would be no need for vertical ducts.

The application of these systems in an actual building would depend on cost. Based on costs of the projects involving fibre optics and artificial light sources presented in the literature review (ROPER & BROWN, 2000), it can be implied that costs involving the integration of fibre optics with daylight would tend to be high. However, costs can actually only be estimated by carrying out research on full-scale models, but this is out of the scope of this work.

The different ways of integrating fibre optics in buildings as presented above does not mean to cover all possible ways, as there are probably many other possibilities that could prove effective.

6.9. Summary

The information presented in this chapter and also in the literature review showed that fibre optics are a new technology that may present a great potential for lighting applications. Their use in this work has been limited to a simple experiment combining the integration of artificial light with daylight coming in from windows and fibre optics;

but the best scenario would be the one in which fibre optics could be used to transport daylight to improve the energy efficiency of buildings.

The experiment conducted in this research showed that if fibre optics were to be used to transport daylight this could increase energy savings on lighting and therefore improve the energy efficiency of buildings. However, the savings are relatively low compared to the savings that can be obtained by integrating the daylight supplied by windows only.

To evaluate the cost effectiveness of using fibre optics in buildings to improve their energy efficiency, an economic analysis was performed and this is presented in the next chapter together with an analysis on environmental pollution.

Chapter 7

Economic Analysis & Environmental Impact Assessment

7.1. Introduction

In the previous chapters it was shown that the integration of daylight with artificial lighting can provide significant energy savings on lighting and that the installation of fibre optics to transport light to the rear side of rooms can increase such savings. This chapter deals with the economic analysis of such an integration. Life cycle costing will be evaluated for each of the ten room sizes and five room ratios, with Ideal Window Area, and for each of the eight cities.

In order to verify whether fibre optics will be a cost-effective technology to apply in buildings or not, two assessments were performed. The first is related to the integration of artificial lighting with daylight coming onto the working surface of a room through windows only. The second deals with the integration of artificial lighting not only with daylight supplied by windows, but also with light being transported onto a working surface by fibre optics. Such an assessment was performed through different economic analysis methods, as presented in the next section.

In the last part of this chapter, using published data on the emission of pollutant gases, an evaluation of the environmental benefits that can be obtained through the integration of daylight in buildings is presented.

7.2. Economic analysis of the rooms

Theoretical methods and aspects of economic analysis are presented in Appendix H. Further information on economic analysis can be obtained in BUSSEY (1978), and BIERMAN JR & SMIDT (1975).

The economic analysis of the rooms is performed by calculating the corrected payback and also the internal rate of return as a function of the ratio of investment to benefits. The ratio investment/benefit, which gives the payback, is calculated for all room sizes and room ratios of all eight cities. The Corrected Payback and the Internal Rate of Return are determined for all room sizes and room ratios only for the city facing the highest paybacks. For the other cities, the Corrected Payback and Internal Rate of Return are calculated only for room indices of 0.60 and 5.00 to avoid repetition.

To perform the economic analysis of the rooms studied in this work, capital costs involved in energy savings and financial benefits have to be calculated.

In order to verify the viability of applying the Ideal Window Area and installing fibre optics systems, two analyses will be performed separately for each room size for each of the eight cities. The first assessment will consider the energy savings that are achieved by using daylight coming onto the working surface through the Ideal Window Area only. The second evaluation takes into account the savings obtained through the combined use of daylight coming through the IWA with fibre optics. Such an analysis will show which project is most likely to be viable.

7.2.1. The investment costs

The costs involved are related to the window costs, the dimming system and the fibre optics system. The costs of the dimming system and fibre optics are taken as a percentage of the total cost of the building. Equation 7.1, which was derived in this work, expresses the capital cost of the investment.

$$C_c = C_t\, A\, \alpha + IWA\, C_w\, W\, h - A_w\, C_w\, W\, h \qquad (7.1)$$

Where:

C_c is the capital cost of the investment ($);

C_t is the total cost of the building per square metre obtained from Table 7.1 ($/m^2);

A is the area of the building obtained through the room dimensions shown in Table 3.1, Chapter 3 (m^2);

α is the percentage of increase of the building costs due to the application of dimmers and fibre optics (in decimals). This percentage was taken as 5% for the case with dimmers only, and 20% for dimmers plus fibre optics;

IWA	is the Ideal Window Area obtained from Tables 5.11 to 5.18, Chapter 5 (in decimals);
C_w	is the cost of the window obtained from Table 7.1 (R\$/m^2) and 7.2 (£/m^2);
W	is the overall width of the room obtained from Table 3.1, Chapter 3 (m);
h	is the height of the room – taken as 2.80m;
A_w	is the window area for inefficient buildings – taken as 50% (in decimals).

Building costs and window costs considered in the calculations are presented in Tables 7.1 and 7.2. Costs for Brazil were obtained from PINI (2001), and for Leeds from SPON’S (1999) and LAXTON’S (2000).

Table 7.1. Costs per unit area for the cities in Brazil.

City	Costs (R\$/m^2)	
	Window (C_w)	Total (C_t)
Belém	168.13	538.88
Brasília	159.98	567.51
Curitiba	178.17	576.35
Florianópolis	191.89	608.04
Natal	157.80	529.10
Rio de Janeiro	230.23	606.72
Salvador	147.73	514.83

Table 7.2. Costs per unit area for Leeds.

City	Costs (£/m^2)	
	Window (C_w)	Total (C_t)
Leeds	207.48	662.00

7.2.2. The benefits

To evaluate the financial benefits expected to be gained due to the integration of daylight in the rooms, two variables have to be known. The first is the cost of energy and the second the amount of energy that is to be saved (in kWh).

7.2.2.1. Energy tariffs

Energy tariffs for the commercial sector in Brazil range according to the region in which the building is located. Table 7.3 presents the location per region of the seven cities in Brazil considered in this study and the respective energy tariffs that were used to perform the economic analysis. Such tariffs are the ones applied in the year 2001 and obtained from ANEEL (2001).

Table 7.3. Location and energy tariffs for the seven cities in Brazil.

City	Region	Tariff (R$/MWh)
Belém	Northeast	125.34
Brasília	Centre-West	147.82
Curitiba	South	142.89
Florianópolis	South	142.89
Natal	Northeast	125.34
Rio de Janeiro	Southeast	148.67
Salvador	Northeast	125.34

For Leeds, a tariff of 7 pence per kWh was assumed, which is equivalent to £70/MWh. Considering that the average exchange rate between the Pound Sterling (£) and the Brazilian Real in the last two years has been about 3, the tariff applied to the commercial sector in Brazil is about £50/MWh.

7.2.2.2. Energy saved

To evaluate the reduction of energy consumption in the rooms assessed in this work, the energy consumption of existing buildings (E_{actual}) have to be known. ENERGY EFFICIENCY OFFICE (1989) states that air-conditioned office buildings in which significant energy savings could be achieved have an energy consumption ranging from 220 to 310kWh/m^2 per year. Therefore, an average of 265kWh/m^2 per year was considered adequate and used in the calculations for Leeds. For the cities located in Brazil, LAMBERTS et al. (1998) present the average energy consumption for Salvador (292kWh/m^2 per year), Brasília (237kWh/m^2 per year), and Florianópolis (192kWh/m^2 per year). For the other four cities in Brazil used in this work, an average of 225kWh/m^2 per year was assumed appropriate – and also obtained from LAMBERTS et al. (1998) as an average of energy consumptions presented for five cities.

When only windows are considered on the provision of daylight, the amount of energy saved can be expressed by equation 7.2, derived in this work.

$$S_{kWh} = (E_{actual} - E_{IWA})\,A \qquad (7.2)$$

Where:

S_{kWh}	is the amount of energy saved (kWh);
E_{actual}	is the energy consumption of existing buildings (kWh/m^2 per year);
E_{IWA}	is the energy consumption of the building corresponding to the IWA, obtained from Appendix I (kWh/m^2 per year);
A	is the area of the building obtained through the room dimensions shown in Table 3.1, Chapter 3 (m^2).

When not only windows, but also fibre optics are considered on the provision of daylight, the amount of energy saved increases and this is expressed by equation 7.3, which was derived in this work.

$$S_{kWh} = (E_{actual} - E_{IWA} + E_{fo})\ A \qquad (7.3)$$

Where:

S_{kWh}	is the amount of energy saved (kWh);
E_{actual}	is the energy consumption of existing buildings (kWh/m^2 per year);
E_{IWA}	is the energy consumption of the building corresponding to the IWA obtained from Appendix I (kWh/m^2 per year);
E_{fo}	is the amount of energy saved due to the use of fibre optics (kWh/m^2 per year);
A	is the area of the building obtained through the room dimensions shown in Table 3.1, Chapter 3 (m^2);

And the amount of energy saved due to the use of fibre optics (E_{fo}) on the provision of daylight can the expressed by equation 7.4, developed in this work.

$$E_{fo} = (1 - \phi_{daylight})\ (\varphi_{lighting} + \varphi_{ac}\ \theta_{lcl})\ E_{IWA} \qquad (7.4)$$

Where:

E_{fo}	is the amount of energy saved due to the use of fibre optics (kWh/m^2 per year);
$\phi_{daylight}$	is the energy savings expected on lighting due to integration of daylight obtained from Tables 5.22 to 5.29, Chapter 5 (in decimals);
$\varphi_{lighting}$	is the lighting end-use over a year (in decimals);

φ_{ac}	is the air-conditioning end-use (in decimals);
θ_{lcl}	is the lighting cooling load (in decimals);
E_{IWA}	is the energy consumption of the building corresponding to the IWA, obtained from Appendix I (kWh/m^2 per year).

From the data on energy consumption presented in Chapter 2 and also in Appendix B, a lighting end-use of 40% and air-conditioning end-use of 30% were considered adequate to be used in the calculations. For the lighting cooling load a figure of 20% was assumed (IESNA, 1995). Hence, the monetary benefit can be expressed by equation 7.5, which was derived in this work.

$$B = T\ S_{kWh} \tag{7.5}$$

Where:

B	is the financial benefit (£ or R$);
T	is the energy tariff obtained from Table 7.3 (£/kWh or R$/kWh);
S_{kWh}	is the amount of energy saved and calculated using either equation 7.2 or 7.3 (kWh).

7.3. Results

Performing the calculations following the procedure presented above, the simple payback (ratio of investment to benefits) for each room size, each room ratio, and each of the eight cities are presented in Tables 7.4 to 7.11. The ratios are presented for the two options discussed above: (1) daylight supplied by windows only, and (2) by windows and fibre optics. The values presented for each room ratio represent the average of the values for the four orientations.

As the window area for existing buildings was assumed to be 50% of the façade area, some rooms that present a very low IWA will have the investment costs even lower than actual buildings resulting in a nil ratio of investment to benefit. This means that such rooms are highly recommended in terms of monetary benefits as they will cost even less than they would cost when there is no concern about their energy efficiency.

From the results presented in Tables 7.4 to 7.11, it is possible to note that investments in buildings to ensure the integration of daylight coming onto the working surface from windows only with artificial light is more attractive than those with fibre optics. It can be observed for all eight cities that the ratio of investment to benefits is lower for smaller rooms (lower room index), and for rooms with a larger width and narrower depth. Such an analysis also shows that the integration of daylight from windows only is more attractive as the ratio of investment to benefits is lower than those in which fibre optics are considered.

For the cities located in Brazil it can be observed that the maximum simple payback when there is integration of daylight from windows only, ranges from 1.0 to 1.9 years; and when there is integration of fibre optics the maximum payback ranges from 4.4 to 8.2 years. As for Leeds, the maximum payback is 2.3 years when there is integration of daylight from windows only, and 8.5 years when fibre optics are used.

The simple payback periods shown in this section agree with figures presented in SANTAMOURIS (1995), who performed an analysis on daylight integration in buildings located in Greece and verified that the payback periods ranged from 1 to 9 years, being lower than 2.5 years for 12 out of 17 buildings.

Table 7.4. Simple payback (years) for Belém, Brazil.

	Windows only					Windows + fibre optics				
K	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	1.1	1.9	3.4	5.2	6.0
0.80	0.0	0.0	0.0	0.0	0.0	3.1	3.7	4.4	5.4	5.8
1.00	0.0	0.0	0.0	0.0	0.6	3.8	4.1	4.6	5.4	5.8
1.25	0.0	0.0	0.0	0.5	1.0	4.2	4.5	4.8	5.4	5.7
1.50	0.0	0.0	0.2	0.8	1.2	4.5	4.7	5.0	5.4	5.5
2.00	0.1	0.4	0.7	1.1	1.4	4.7	4.9	5.1	5.4	5.5
2.50	0.5	0.7	1.0	1.3	1.5	4.9	5.0	5.1	5.3	5.4
3.00	0.8	1.0	1.1	1.4	1.6	4.9	5.1	5.1	5.3	5.3
4.00	1.1	1.2	1.3	1.5	1.6	5.0	5.1	5.1	5.2	5.3
5.00	1.2	1.3	1.4	1.6	1.7	5.0	5.1	5.1	5.2	5.2

Table 7.5. Simple payback (years) for Brasília, Brazil.

	Windows only					Windows + fibre optics				
K	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.1	1.6	2.1	3.0	3.8	4.4
0.80	0.0	0.0	0.0	0.1	0.6	2.5	2.9	3.5	4.0	4.4
1.00	0.0	0.0	0.0	0.4	0.7	2.9	3.2	3.7	4.1	4.3
1.25	0.0	0.0	0.2	0.6	0.9	3.3	3.5	3.8	4.1	4.3
1.50	0.0	0.1	0.5	0.8	1.0	3.5	3.6	3.9	4.1	4.3
2.00	0.3	0.4	0.7	0.9	1.1	3.7	3.8	4.0	4.2	4.3
2.50	0.5	0.7	0.9	1.1	1.2	3.8	3.9	4.1	4.2	4.2
3.00	0.7	0.8	1.0	1.1	1.2	3.9	3.9	4.1	4.2	4.2
4.00	0.8	0.9	1.1	1.2	1.2	3.9	4.0	4.1	4.1	4.2
5.00	0.9	1.0	1.1	1.2	1.3	4.0	4.0	4.1	4.1	4.2

Table 7.6. Simple payback (years) for Curitiba, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.1	0.9	1.7	2.5	3.7	4.4
0.80	0.0	0.0	0.0	0.0	0.5	2.1	2.6	3.3	4.0	4.5
1.00	0.0	0.0	0.0	0.3	0.8	2.7	3.2	3.6	4.1	4.5
1.25	0.0	0.0	0.1	0.6	0.9	3.2	3.5	3.8	4.2	4.6
1.50	0.0	0.0	0.3	0.8	1.0	3.5	3.7	4.0	4.4	4.6
2.00	0.2	0.4	0.7	1.0	1.2	3.8	4.0	4.2	4.4	4.6
2.50	0.5	0.6	0.8	1.1	1.2	4.0	4.1	4.3	4.5	4.6
3.00	0.7	0.8	1.0	1.2	1.3	4.1	4.2	4.3	4.5	4.5
4.00	0.9	1.0	1.1	1.2	1.3	4.3	4.3	4.4	4.5	4.5
5.00	1.0	1.1	1.2	1.3	1.4	4.3	4.3	4.4	4.5	4.5

Table 7.7. Simple payback (years) for Florianópolis, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	1.8	3.0	4.9	7.1	8.2
0.80	0.0	0.0	0.0	0.0	0.5	3.7	4.5	5.5	6.7	7.4
1.00	0.0	0.0	0.0	0.2	1.0	4.6	5.0	5.8	6.5	7.1
1.25	0.0	0.0	0.0	0.7	1.3	5.0	5.3	5.9	6.5	6.8
1.50	0.0	0.0	0.4	1.0	1.5	5.3	5.5	5.9	6.4	6.7
2.00	0.2	0.5	0.9	1.3	1.7	5.6	5.8	6.0	6.3	6.5
2.50	0.6	0.8	1.2	1.5	1.8	5.7	5.8	6.0	6.2	6.4
3.00	0.9	1.1	1.3	1.6	1.8	5.7	5.9	6.0	6.2	6.3
4.00	1.2	1.4	1.5	1.7	1.9	5.8	5.9	6.0	6.1	6.2
5.00	1.4	1.5	1.6	1.8	1.9	5.8	5.9	6.0	6.0	6.1

Table 7.8. Simple payback (years) for Leeds, England.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	1.0	2.5	4.2	6.0	7.2
0.80	0.0	0.0	0.0	0.0	0.0	3.4	4.3	5.4	6.6	7.3
1.00	0.0	0.0	0.0	0.0	0.3	4.6	5.3	6.0	7.0	7.6
1.25	0.0	0.0	0.0	0.4	0.9	5.4	6.0	6.6	7.3	7.7
1.50	0.0	0.0	0.2	0.8	1.2	6.0	6.4	7.0	7.6	7.9
2.00	0.1	0.4	0.8	1.4	1.6	6.7	7.0	7.4	7.9	8.1
2.50	0.6	0.9	1.3	1.6	1.9	7.1	7.3	7.7	8.0	8.2
3.00	1.0	1.2	1.5	1.8	2.0	7.4	7.5	7.9	8.2	8.3
4.00	1.4	1.6	1.8	2.1	2.2	7.7	7.9	8.1	8.3	8.4
5.00	1.7	1.8	2.0	2.2	2.3	7.9	8.0	8.3	8.4	8.5

Table 7.9. Simple payback (years) for Natal, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	1.2	2.1	3.1	4.7	5.4
0.80	0.0	0.0	0.0	0.0	0.0	2.8	3.4	4.0	4.9	5.4
1.00	0.0	0.0	0.0	0.0	0.5	3.5	4.0	4.5	5.0	5.4
1.25	0.0	0.0	0.0	0.5	0.8	4.0	4.3	4.7	5.1	5.3
1.50	0.0	0.0	0.2	0.8	1.0	4.3	4.5	4.8	5.2	5.3
2.00	0.1	0.4	0.7	1.1	1.3	4.6	4.7	4.9	5.2	5.2
2.50	0.5	0.7	1.0	1.2	1.4	4.7	4.8	5.0	5.2	5.2
3.00	0.8	0.9	1.1	1.3	1.4	4.8	4.8	5.0	5.1	5.1
4.00	1.0	1.1	1.3	1.5	1.5	4.8	4.9	5.0	5.1	5.1
5.00	1.2	1.2	1.4	1.5	1.5	4.9	4.9	5.0	5.1	5.0

Table 7.10. Simple payback (years) for Rio de Janeiro, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.0	4.9	7.5
0.80	0.0	0.0	0.0	0.0	0.0	1.7	2.5	3.9	5.2	6.3
1.00	0.0	0.0	0.0	0.0	0.3	2.8	3.3	4.3	5.1	5.9
1.25	0.0	0.0	0.0	0.0	0.8	3.5	3.9	4.5	5.2	5.6
1.50	0.0	0.0	0.0	0.5	1.0	3.8	4.2	4.7	5.1	5.5
2.00	0.0	0.0	0.4	0.9	1.3	4.2	4.5	4.8	5.1	5.3
2.50	0.1	0.4	0.7	1.1	1.4	4.4	4.6	4.8	5.1	5.2
3.00	0.4	0.7	0.9	1.2	1.4	4.5	4.7	4.8	5.0	5.1
4.00	0.8	1.0	1.2	1.4	1.5	4.6	4.7	4.8	5.0	5.0
5.00	1.0	1.1	1.3	1.5	1.6	4.7	4.8	4.8	5.0	5.0

Table 7.11. Simple payback (years) for Salvador, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
0.60	0.0	0.0	0.0	0.0	0.0	1.1	1.8	2.8	3.7	4.4
0.80	0.0	0.0	0.0	0.0	0.1	2.1	2.5	3.2	3.7	4.1
1.00	0.0	0.0	0.0	0.0	0.4	2.6	2.9	3.3	3.6	3.9
1.25	0.0	0.0	0.0	0.3	0.6	2.9	3.0	3.4	3.6	3.8
1.50	0.0	0.0	0.2	0.5	0.7	3.0	3.1	3.4	3.6	3.8
2.00	0.1	0.2	0.5	0.7	0.9	3.2	3.3	3.5	3.6	3.7
2.50	0.3	0.4	0.6	0.8	0.9	3.3	3.3	3.5	3.6	3.6
3.00	0.5	0.6	0.7	0.9	1.0	3.3	3.4	3.5	3.5	3.6
4.00	0.7	0.7	0.8	0.9	1.0	3.4	3.4	3.5	3.5	3.6
5.00	0.8	0.8	0.9	1.0	1.0	3.4	3.4	3.5	3.5	3.6

From the results of ratio of investment to benefits presented for the eight cities, it is possible to calculate the Corrected Payback and the Internal Rate of Return as presented in Appendix H.

Tables 7.12 to 7.19 present the Corrected Payback and the Internal Rate of Return for the eight cities considering a life span of 30 years. Data for all room indices are presented only for Leeds, which presented the highest simple paybacks. For the other cities in Brazil, it is presented data only for the room indices of 0.60 and 5.00. The calculation of the Corrected Payback was based on an interest rate of 10% a year. Rooms that presented a nil ratio of investment to benefit have a nil Corrected Payback and an infinite IRR.

For all eight cities, rooms considering integration of daylight from windows only presented more attractive Corrected Paybacks and IRRs than rooms with daylight from windows and fibre optics. Rooms with smaller room index and larger façade (from room ratio 2:1 to 1:2) are more attractive in terms of monetary investment as the Corrected Payback is lower and the Internal Rate of Return is higher for such rooms.

From Table 7.12 it can be observed that when only windows are considered for the supply of daylight in Belém, the maximum Corrected Payback likely to occur is 1.96 years and the minimum IRR is 58.82% per year, which represents a very attractive investment. As for when fibre optics are used to supply daylight to the rear side of rooms, the investment is not as attractive as for the previous situation, but the maximum Corrected Payback of 9.63 years is still acceptable and the minimum IRR of 19.13% per year is still higher than the interest rate of 10% used in the calculations. Similar results can be identified for all the other cities in Brazil.

As for Leeds (Table 7.16), it can be noted that the investment is not as attractive as for the cities located in Brazil. But even though, when only windows are considered for the supply of daylight, Corrected Paybacks for all the rooms analysed are lower than 2.75 years and IRRs are higher than 43.47% per year. When fibre optics are taken into account to supply daylight to the rear side of rooms, Corrected Paybacks are lower than 19.91 years and the IRRs are higher than 11.29% per year.

Table 7.12. Corrected Payback and IRR for Belém, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	1.23	2.22	4.37	7.71	9.63
5.00	1.35	1.47	1.59	1.84	1.96	7.28	7.50	7.50	7.71	7.71
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	90.90	52.63	29.40	19.13	16.50
5.00	83.33	76.87	71.40	62.49	58.82	19.91	19.51	19.51	19.13	19.13

Table 7.13. Corrected Payback and IRR for Brasília, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0.11	1.84	2.49	3.75	5.02	6.09
5.00	0.99	1.11	1.23	1.35	1.47	5.37	5.37	5.55	5.55	5.72
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	994.13	62.49	47.61	33.32	26.29	22.68
5.00	111.06	99.98	90.90	83.33	76.87	24.96	24.96	24.35	24.35	23.77

Table 7.14. Corrected Payback and IRR for Curitiba, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0.11	0.99	1.96	3.02	4.85	6.09
5.00	0.77	0.88	1.11	1.35	1.47	5.90	5.90	6.09	6.28	6.28
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	994.13	111.06	58.82	40.00	27.01	22.68
5.00	142.84	125.00	99.98	83.33	76.87	23.21	23.21	22.68	22.17	22.17

Table 7.15. Corrected Payback and IRR for Florianópolis, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	2.09	3.75	7.07	12.99	17.99
5.00	1.59	1.72	1.84	2.09	2.22	9.11	9.37	9.63	9.63	9.88
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	55.55	33.32	20.33	13.79	11.76
5.00	71.40	66.65	62.49	55.55	52.63	17.09	16.79	16.50	16.50	16.21

Table 7.16. Corrected Payback and IRR for Leeds, England.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	1.11	3.02	5.72	9.63	13.37
0.80	0	0	0	0	0	4.37	5.90	8.15	11.33	13.75
1.00	0	0	0	0	0.33	6.48	7.93	9.63	12.64	14.97
1.25	0	0	0	0.44	0.99	8.15	9.63	11.33	13.75	15.43
1.50	0	0	0.22	0.88	1.35	9.63	10.73	12.64	14.97	16.39
2.00	0.11	0.44	0.88	1.59	1.84	11.64	12.64	14.14	16.39	17.44
2.50	0.66	0.99	1.47	1.84	2.22	12.99	13.75	15.43	16.89	17.99
3.00	1.11	1.35	1.72	2.09	2.35	14.14	14.56	16.39	17.99	18.60
4.00	1.59	1.84	2.09	2.49	2.62	15.43	16.39	17.44	18.60	19.24
5.00	1.96	2.09	2.35	2.62	2.75	16.39	16.89	18.60	19.24	19.91
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	99.98	40.00	23.77	16.50	13.58
0.80	∞	∞	∞	∞	∞	29.40	23.21	18.40	14.92	13.38
1.00	∞	∞	∞	∞	332.60	21.68	18.76	16.50	14.01	12.80
1.25	∞	∞	∞	249.94	111.06	18.40	16.50	14.92	13.38	12.62
1.50	∞	∞	499.23	125.00	83.33	16.50	15.41	14.01	12.80	12.26
2.00	994.13	249.94	125.00	71.40	62.49	14.68	14.01	13.18	12.26	11.93
2.50	166.60	111.06	76.87	62.49	52.63	13.79	13.38	12.62	12.09	11.76
3.00	99.98	83.33	66.65	55.55	49.98	13.18	12.99	12.26	11.76	11.60
4.00	71.40	62.49	55.55	47.61	45.45	12.62	12.26	11.93	11.60	11.44
5.00	58.82	55.55	49.98	45.45	43.47	12.26	12.09	11.60	11.44	11.29

Table 7.17. Corrected Payback and IRR for Natal, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	1.35	2.49	3.90	6.67	8.15
5.00	1.35	1.35	1.59	1.72	1.72	7.07	7.07	7.28	7.50	7.28
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	83.33	47.61	32.25	21.21	18.40
5.00	83.33	83.33	71.40	66.65	66.65	20.33	20.33	19.91	19.51	19.91

Table 7.18. Corrected Payback and IRR for Rio de Janeiro, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	0	0.11	3.75	7.07	14.56
5.00	1.11	1.23	1.47	1.72	1.84	6.67	6.87	6.87	7.28	7.28
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	∞	994.13	33.32	20.33	12.99
5.00	99.98	90.90	76.87	66.65	62.49	21.21	20.76	20.76	19.91	19.91

Table 7.19. Corrected Payback and IRR for Salvador, Brazil.

K	Windows only					Windows + fibre optics				
	2:1	1.5:1	1:1	1:1.5	1:2	2:1	1.5:1	1:1	1:1.5	1:2
	Corrected payback (years)									
0.60	0	0	0	0	0	1.23	2.09	3.46	4.85	6.09
5.00	0.88	0.88	0.99	1.11	1.11	4.37	4.37	4.53	4.53	4.69
	Internal Rate of Return (% per year)									
0.60	∞	∞	∞	∞	∞	90.90	55.55	35.71	27.01	22.68
5.00	125.00	125.00	111.06	99.98	99.98	29.40	29.40	28.56	28.56	27.76

7.4. Environmental impact

As discussed in Chapter 1 and also in the literature review in Chapter 2, there is just an indication that the reservoirs associated with hydroelectric dams emit carbon dioxide and methane. But as there is no published data to quantify such emissions, the environmental benefits of saving electricity in the cities located in Brazil cannot be calculated.

As for the environmental benefits of saving energy in Leeds, they were calculated using the indices determined by LANCASHIRE & FOX (1996) as presented in Chapter 2. Therefore, considering the mentioned published data and the energy savings determined in this work, the amount of carbon dioxide, sulphur dioxide, and nitrogen oxides that can be prevented from emission in Leeds was calculated. Table 7.20 presents the results. The minimum, maximum and average values were obtained from values for each orientation and room ratio.

Values are presented per unit of floor area per year. Therefore, there would be a reduction of about 122kg of carbon dioxide emission for each square metre of offices in Leeds per year if there were an integration of daylight from windows with artificial lighting. If the integration were complemented by fibre optics, the reduction of carbon dioxide emission would be about 138kg/m^2 per year. The integration of daylight in offices in Leeds would also prevent the emission of 1.02kg/m^2 per year of sulphur dioxide into the atmosphere, and the prevention of emission would increase to 1.15kg/m^2 per year if fibre optics were to be used. As for the prevention of nitrogen oxides, it would be 0.41kg/m^2 and 0.46kg/m^2, respectively, for integration of daylight from windows only and for integration of daylight from windows and fibre optics.

Table 7.20. Environmental benefits for Leeds, England.

	Carbon dioxide (kg/m^2 per year)					
K	Windows only			Windows + Fibre optics		
	Minimum	Average	Maximum	Minimum	Average	Maximum
0.60	62	74	82	97	104	111
0.80	89	100	105	117	122	128
1.00	103	113	118	126	132	136
1.25	114	122	126	134	138	141
1.50	120	127	131	138	142	145
2.00	125	133	136	142	146	148
2.50	128	135	139	145	148	150
3.00	130	137	140	146	149	151
4.00	133	138	141	148	151	152
5.00	134	139	142	149	151	153
Average		122			138	

Table 7.20. Environmental benefits for Leeds, England (cont.).

	Sulphur dioxide (kg/m² per year)					
K	Windows only			Windows + Fibre optics		
	Minimum	Average	Maximum	Minimum	Average	Maximum
0.60	0.52	0.62	0.68	0.80	0.86	0.93
0.80	0.74	0.83	0.88	0.97	1.02	1.07
1.00	0.86	0.94	0.98	1.05	1.10	1.14
1.25	0.95	1.02	1.05	1.12	1.15	1.18
1.50	1.00	1.06	1.09	1.15	1.18	1.20
2.00	1.04	1.11	1.13	1.19	1.22	1.23
2.50	1.07	1.13	1.16	1.21	1.23	1.25
3.00	1.08	1.14	1.17	1.22	1.24	1.26
4.00	1.11	1.15	1.18	1.23	1.25	1.27
5.00	1.12	1.16	1.18	1.24	1.26	1.27
Average		1.02			1.15	

	Nitrogen oxides (kg/m² per year)					
K	Windows only			Windows + Fibre optics		
	Minimum	Average	Maximum	Minimum	Average	Maximum
0.60	0.21	0.25	0.27	0.32	0.35	0.37
0.80	0.30	0.33	0.35	0.39	0.41	0.43
1.00	0.35	0.38	0.39	0.42	0.44	0.46
1.25	0.38	0.41	0.42	0.45	0.46	0.47
1.50	0.40	0.42	0.44	0.46	0.47	0.48
2.00	0.42	0.44	0.45	0.48	0.49	0.49
2.50	0.43	0.45	0.46	0.48	0.49	0.50
3.00	0.43	0.46	0.47	0.49	0.50	0.50
4.00	0.44	0.46	0.47	0.49	0.50	0.51
5.00	0.45	0.46	0.47	0.50	0.50	0.51
Average		0.41			0.46	

7.5. Summary

The economic analysis presented in this chapter shows that the integration of artificial lighting with daylight coming in through windows, when the windows are properly assessed and their area carefully studied, is a very good option to save energy and improve energy efficiency in buildings. The use of fibre optics can increase energy savings on lighting but they are not as attractive an investment as the integration of artificial lighting with daylight coming onto working surface through windows only.

In terms of environmental impact, it is shown that the energy savings obtained from the integration of daylight can reduce the emission of greenhouse gases into the atmosphere in countries whose energy is produced by combustion of fossil fuels.

Having finalised the study of energy savings on lighting due to daylight integration, conclusions and findings are presented in the next chapter.

Chapter 8

Conclusions

8.1. Introduction

It is known that buildings account for high amounts of energy consumption all over the world and that artificial lighting systems are responsible for high percentages of this consumption. Since the 1980s, lighting equipment has seen great improvements in its energy efficiency and this has subsequently helped to improve the energy efficiency of buildings. However, many of the buildings in the world, even new ones, are still energy-inefficient and lack well-designed integration of daylight with artificial lighting systems.

This work has assessed the role of windows on daylight supply by quantifying energy savings likely to be achieved by integrating daylight with artificial light. The potential for even higher energy savings by using fibre optics to provide daylight to the rear side of rooms was also investigated.

The first part of the work focused on the assessment of daylight provision on the working surfaces of rooms of different dimensions, room ratios and window areas through the calculation of Daylight Factors. It was observed that if there was integration of daylight with the artificial lighting system significant energy savings could be achieved. It was also found that there was still a high potential for energy savings on lighting in either large rooms or rooms with a narrow width. This was an indication that if new technologies, such as fibre optics, could be used to transport daylight to the rear side of rooms, there could be a further increase made to the energy savings on lighting.

The second part of the work dealt with defining an Ideal Window Area for rooms of different sizes and room ratios, using computer simulation techniques. Before undertaking the simulations, the computer programme was validated. A comparison of measured against simulated energy consumption showed that the computer programme would produce energy data within acceptable accuracy limits.

Following validation of the programme, rooms were simulated under various climatic conditions in cities in Brazil and the UK. This allowed the Ideal Window Areas to be determined; and the potential for energy savings on lighting due to the use of fibre optics was evaluated through the methodology presented in the second part of the work.

The third part of the study dealt with fibre optics and their potential to provide energy savings on lighting. A scale model was built and the integration of daylight from windows, lighting from fibre optics, and artificial lighting system was evaluated.

The latter part of the work presented an economic analysis comparing the cost-effectiveness of using daylight coming into rooms through windows only, and then combined with fibre optics. Finally, reductions in the amount of carbon dioxide emitted into the atmosphere due to energy savings were determined for the city of Leeds, whose electricity generation depends on burning fossil fuel.

Under this scenario, the main findings resulting from this work are presented in the following section.

8.2. Findings

8.2.1. Daylight provision

The use of Daylight Factors to evaluate the energy savings probable to be achieved on lighting when there is integration of daylight and artificial light proved effective despite the fact that the calculations were based on the CIE overcast sky condition, which is acknowledged to underestimate internal illuminance levels. It was shown that such an integration would lead to significant energy savings on lighting not only due to high daylight levels near the window, but also to the daylight that reaches the working surface at the rear side of rooms, a factor usually overlooked.

The Daylight Factors assessment also showed that the window area from which there is no significant increase on energy savings on lighting depended on the daylight levels likely to be achieved in the room but not on the room ratio. For rooms located where a DF of 10% can be obtained there is no significant increase on energy savings on lighting if the window area is larger than 50% of the façade area. The greater the external illuminance condition, the smaller the limit window area from which there is no significant increase on energy savings on lighting.

In terms of room sizes, it was shown that larger rooms would have a lower potential for energy savings on lighting due to daylight coming onto the working surface through windows. In terms of room ratio, rooms with a narrower width will also tend to provide lower energy savings on lighting due to the integration of daylight and artificial light. Therefore, it was observed that there was still a potential for energy savings on lighting if fibre optics were to be used to transport daylight to the rear side of rooms.

8.2.2. Validation of the Dynamic Thermal Modelling code

The simulation of the Estates Services Building and the office space in the Civil Engineering Building showed that the VisualDOE programme is an appropriate Dynamic Thermal Model to use for the assessment of energy consumption of buildings and for the prediction of energy savings.

The differences between measured and simulated energy consumption for both the building and the office space lay within the range considered adequate by ASHRAE (1987) and ZMEUREANU et al. (1995). Therefore, the programme was considered to provide reliable data.

8.2.3. Ideal Window Area and guidelines for building designers

The simulation of rooms of ten different sizes and five different ratios to obtain their Ideal Window Area under the climatic condition of seven different cities in Brazil and one in the UK proved successful. Using data obtained from the simulations the following conclusions can be made:

- The Ideal Window Area tends to be larger on the orientations whose energy consumption is lower.
- The larger the room and the narrower its width, the larger its Ideal Window Area.
- The Ideal Window Areas presented in this work can be used as a guideline to improving energy efficiency in buildings.
- Rooms with a narrower width have lower energy consumptions. This shows that rooms whose width is wider than its depth, as recommended in daylight guides, may experience higher daylight levels, but may not have the lowest energy consumption.
- The larger the room, the lower the energy consumption per unit of floor area.
- The adoption of a window area different than the Ideal Window Area causes the energy consumption to be much higher in rooms with a small room index. For rooms with a large room index, the increase in energy consumption is not significant when the adopted window area is different than the Ideal Window Area.
- Using the Daylight Factor approach in rooms with the Ideal Window Area also

showed that there is a great potential for energy savings on lighting that can be achieved if the artificial lighting system is integrated with the daylight coming into rooms through the window. This potential is larger for rooms of small room index and wider width.

- The potential for energy savings on artificial lighting presented for the eight cities considered in this work is valid for the specific condition of external illuminance of 5000lux for Leeds and 10000lux for the cities in Brazil.
- It was also observed that there is a higher potential for energy savings on lighting if fibre optics are used to transport daylight to the rear side of rooms. This potential is larger for rooms of large room index and narrower width.

8.2.4. Fibre optics evaluation

Fibre optics are a new technology that present a vast potential in lighting applications. Literature review and also the experimental work carried out in this research showed that the use of fibre optics to transport light, and therefore daylight, is possible. Such a technology could be used to transport daylight to improve energy efficiency in buildings.

The research has shown that fibre optics can increase energy savings on lighting and therefore improve energy efficiency in buildings. However, the energy savings on lighting experienced through the integration of daylight with artificial lighting when the former comes onto the working surfaces through windows are significantly higher than the savings when fibre optics are used to transport daylight to the rear side of rooms.

It should also be highlighted that a daylight system intending to integrate fibre optics would have to undergo a significant development in order to produce a fibre optic system that would collect and transport daylight into a building.

8.2.5. Economic analysis

The economic analysis carried out in this work evaluated two scenarios. The first considered the integration of artificial lighting with daylight coming in through windows only, when the windows are properly assessed and their area carefully studied. The second took into account not only the daylight coming in through windows, but also through fibre optics.

Some assumptions had to be made and it was considered that the first scenario would lead to an increase of 5% in the total cost of a building. For the second scenario, an increase of 20% was considered, as the fibre optic system to transport daylight would require an adequate light collector system.

Results showed that the use of fibre optics can increase the energy savings but they represent an investment not as attractive as the integration of artificial lighting with daylight coming in through windows only.

8.2.6. Environmental impact assessment

It is shown that the energy savings achieved by the integration of daylight can reduce the emission of pollutant gases into the atmosphere in countries whose energy is produced by the combustion of fossil fuels.

It was also shown that if buildings in Leeds were to have integration of daylight with artificial lighting there would be a reduction in carbon dioxide emission of 122kg for each square metre of built area per year if daylight were supplied by windows only. If the integration took into account contributions from fibre optics, such a reduction would be about 138kg/m^2 per year.

As for Brazil, where most of the electricity is produced by hydropower, successful integration of daylight with artificial lighting would avoid the construction of more dams, which also contribute to the emission of carbon dioxide and methane due to decomposition of biomass.

8.3. Recommendations for future work

This work has made a start on the investigation of fibre optics as a technology to be used in buildings aiming to improve their energy efficiency by integrating daylight with artificial lighting systems. Therefore, some recommendations for further research can be outlined.

This research assessed only windows fitting the whole width of the room. Therefore, it is suggested that the daylight supply through different shaped window configurations be investigated as this may lead to higher energy savings on lighting.

Glare and its implications on the welfare of building users and also on the energy consumption was not assessed in this research. Hence, it is recognised that further research should be undertaken in order to evaluate glare as function of window size, room size and building location.

It is also suggested that obstructions to the windows as well as different types of glazing be considered in future works, as the Daylight Factors approach and the computer simulations performed in this work considered only buildings with no external obstructions and only single clear glass panes.

Research should also be carried out to investigate the minimum glazed areas for view as these highly differed from the Ideal Window Areas determined in this work.

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Appendices

Appendix A. Fibre Optics

1. Definition

An optical fibre is a light guide governed by Snell's Law, which defines the passage from a medium of refractive index n_1 to a medium of refractive index n_2 by a light ray having an angle of incidence θ_1 as shown in Figure A.1 and expressed by equation A.1 (UNGAR, 1990).

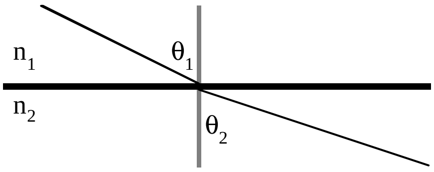

Figure A.1. Snell's Law.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \tag{A.1}$$

Where:

n_1 is the refractive index of medium 1;
n_2 is the refractive index of medium 2;
θ_1 is the angle of incidence in the medium 1;
θ_2 is the angle of refraction in the medium 2.

Assuming that $n_1 > n_2$, the angle of refraction is always greater than the angle of incidence ($\theta_2 > \theta_1$) and tend to become 90^o when de angle of incidence is less than 90^o. Therefore, for angles of incidence greater than this critical value the light is reflected with high efficiency. The value of this limiting angle (φ) is expressed by equation A.2 (UNGAR, 1990).

$$\sin\varphi = \frac{n_2}{n_1} \tag{A.2}$$

In this way, it can be noticed that *total internal reflection* occurs at the interface between two mediums of differing refractive indices when: (a) the light is incident on the medium of higher index, and (b) the angle of incidence of the light exceeds a certain critical value.

2. The numerical aperture

The numerical aperture defines the maximum angle that the incident beam must make to ensure that it propagates in the fibre; and this section aims to obtain an equation to determine the numerical aperture.

When the light rays enter the fibre (Figure A.2) from a medium of refractive index n_o ($n_1 > n_2 > n_o$), there will be, from Snell's Law, a relationship between the refractive indices and the incident ray of light as expressed by equation A.3.

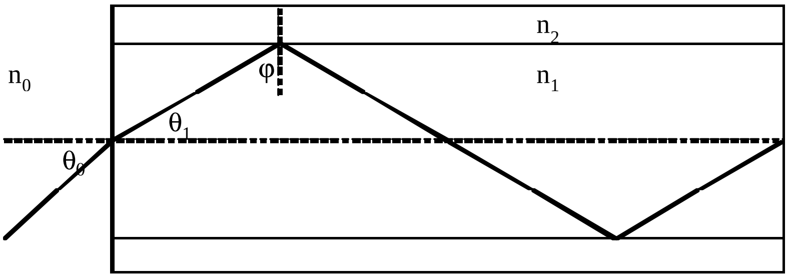

Figure A.2. Angle of incidence.

$$n_1 \sin\theta_1 = n_o \sin\theta_o \tag{A.3}$$

From Figure A.2 it can be seen that $\sin\theta_1 = \cos\varphi$ because sine of any angle (β) is equal to the cosine of the complementary angle ($90-\beta$). Thus equation A.3 can be rewritten as equation A.4.

$$n_1 \cos\varphi = n_o \sin\theta_o \tag{A.4}$$

But, knowing that cosine of any angle β is equal to $\sqrt{1-\sin^2\beta}$, equation A.4 can be rewritten as equation A.5.

$$n_1\sqrt{1-\sin^2\varphi} = n_o \sin\theta_o \tag{A.5}$$

As the condition for reflection to occur in a fibre optic is the one expressed by equation A.2, the replacement of $\sin\varphi$ in equation A.5, results in equation A.6. And, with some mathematical adjustments it is possible to obtain equation A.7 (UNGAR, 1990).

$$n_o \sin\theta_o \le n_1\sqrt{1-\left(\frac{n_2}{n_1}\right)^2} \tag{A.6}$$

$$\sin\theta_o \le \frac{\sqrt{(n_1^2 - n_2^2)}}{n_o} \tag{A.7}$$

Assuming that the right-hand side of equation A.7 be lower than 1, the largest angle at which light can be transmitted through the fibre is obtained when the two sides of the equation are equal. If the right-hand side is equal 1, rays up to 90^o to the axis are accepted, and at 90^o the ray reaches the core-cladding interface at the limiting angle of reflection. If the right-hand side is lower than 1, rays up to 90^o to the axis are accepted, but at 90^o the ray reaches the interface at an angle greater than the limiting value. Therefore, the right-hand side of equation A.7 is an important expression in fibre optics and is defined as the numerical aperture (NA) of the fibre as shown by equation A.8 (UNGAR, 1990).

$$NA = \frac{\sqrt{(n_1^2 - n_2^2)}}{n_o} \qquad (A.8)$$

The NA of an optical fibre is usually of the order of 0.2 to 0.3 (UNGAR, 1990). TIMPSON (1994) states that practical working zones of numerical aperture for illumination are between the values of 0.4 and 0.6. The greater the NA, the greater the luminous power injected into the fibre because the greater the NA, the greater the angle of incidence, as can be seen in Figure A.3. This Figure was developed for a situation where the medium o is the air, that is, when $n_o = 1$.

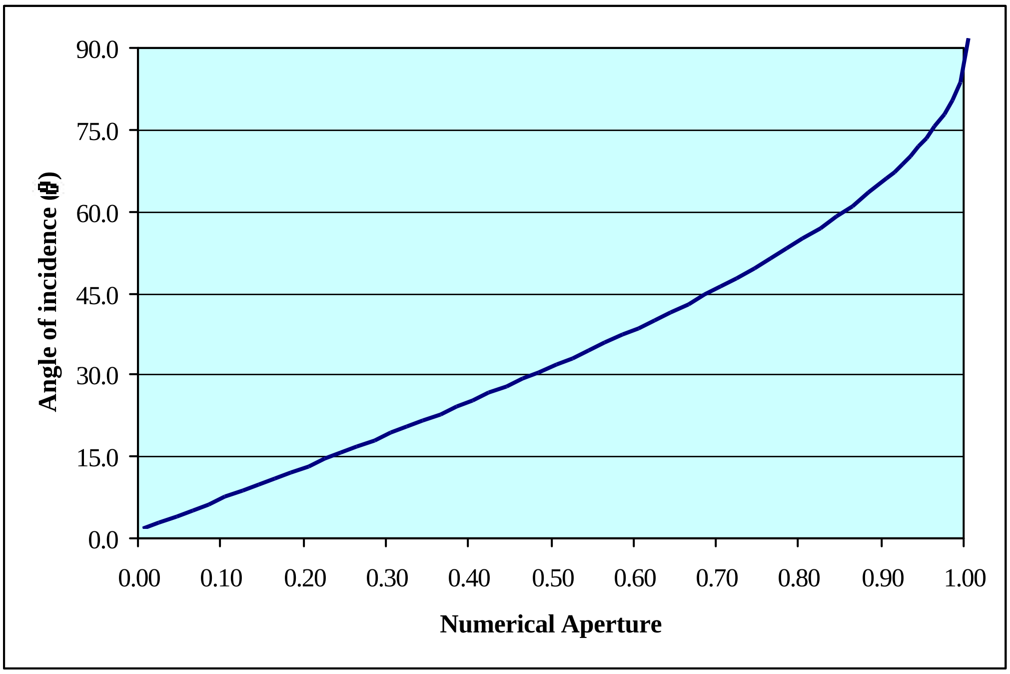

Figure A.3. Equation for the Angle of Incidence as a function of the NA.

Finally, having the NA, the angle of incidence can be determined by using equation A.9, derived in this work.

$$\theta = \frac{180}{\pi} a\sin(NA) \qquad (A.9)$$

3. Attenuation losses

Losses in dB/km

Attenuation losses are defined as a number calculated as 10 times the logarithm (base 10) of the amount of light that comes in the fibre at a particular point divided by the amount of light that goes out at a point 1km further (TIMSON & GREGSON, 1994). This is shown by equation B.10.

$$\rho_{dB/km} = 10\log_{10}\left(\frac{\alpha_{in}}{\alpha_{out}}\right) \tag{A.10}$$

Where:

$\rho_{dB/km}$ is the attenuation loss in dB/km;

α_{in} is the amount of light that comes in the fibre;

α_{out} is the amount of light that goes out the fibre.

Through mathematical rules it is known that if $\log_{10} A = B$, then $A = 10^B$. Thus, from equation A.10, it is possible to obtain equation A.11, which becomes the first step to convert losses from dB/km to percentage.

$$\frac{\alpha_{in}}{\alpha_{out}} = 10^{\left(\frac{\rho_{dB/km}}{10}\right)} \tag{A.11}$$

Losses in %/km

As it is intended to convert these losses to percentage losses, it is important to know that, in general, percentage losses are given by equation A.12.

$$\rho_{\%} = 100\left(\frac{\alpha_{in} - \alpha_{out}}{\alpha_{in}}\right) = 100\left(1 - \frac{1}{\alpha_{in}/\alpha_{out}}\right) \tag{A.12}$$

Therefore, it is then possible to replace equation A.11 into equation A.12 and obtain equation A.13 – derived in this work, which permits to calculate percentage losses as a function of dB/km.

$$\rho_{\%/km} = 100\left(1 - \frac{1}{10^{\left(\frac{\rho_{dB/km}}{10}\right)}}\right) = 100\left(1 - 10^{-\left(\frac{\rho_{dB/km}}{10}\right)}\right) \tag{A.13}$$

Figure A.4 and Table A.1 present the percentage attenuation losses (%/km) as a function of dB/km obtained from equation A.13.

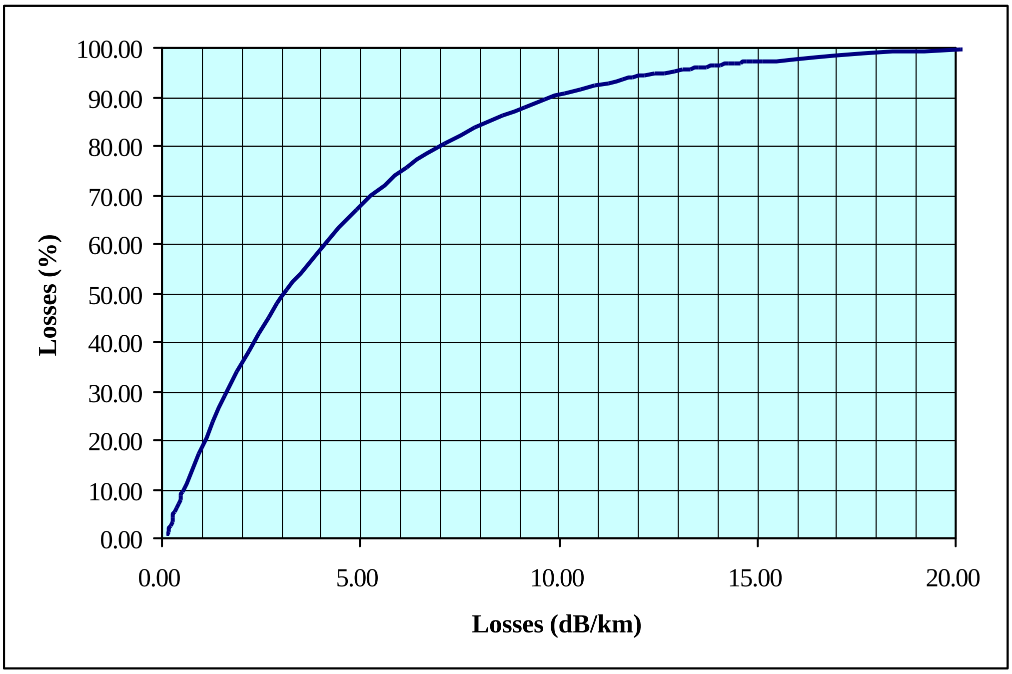

Figure A.4. Variation of losses in %/km as a function of dB/km.

Table A.1. Losses in %/km as a function of dB/km.

Attenuation losses					
(dB/km)	(%/km)	(dB/km)	(%/km)	(dB/km)	(%/km)
0.00	0.00	2.00	36.90	13.00	94.99
0.10	2.28	3.00	49.88	14.00	96.02
0.20	4.50	4.00	60.19	16.00	96.84
0.30	6.67	6.00	68.38	16.00	97.49
0.40	8.80	6.00	74.88	17.00	98.00
0.50	10.87	7.00	80.05	18.00	98.42
0.60	12.90	8.00	84.15	19.00	98.74
0.70	14.89	9.00	87.41	20.00	99.00
0.80	16.82	10.00	90.00	30.00	99.90
0.90	18.72	11.00	92.06	40.00	99.99
1.00	20.57	12.00	93.69	50.00	100.00

Losses in %/m as a function of dB/km

In terms of building applications it is preferable to have attenuation losses expressed per metre rather than kilometre. Therefore, it is important to deal with Lambert's Law, which states that equal lengths of material cause equal amounts of attenuation. Thus, if 1km of fibre attenuates 50.00% of the light then 2km of fibre will attenuate 76.00%, 3km 87.50% and so on – in other words, attenuation is exponential. Table A.2 shows the exponential variation of absorption and the equal amounts of attenuation to equal lengths.

Table A.2. Lambert's Law.

Length (km)	Loss (%)	Loss (%/km)
1	50.0000	50.0000
2	76.0000	50.0000
3	87.5000	50.0000
4	93.7500	50.0000
5	96.8750	50.0000
6	98.4375	50.0000
7	99.2188	50.0000
8	99.6094	50.0000
9	99.8047	50.0000
10	99.9023	50.0000

Thus, using the Lambert's Law approach, attenuation losses in the first kilometre are given by equation A.13 and ensuing losses are given by equation A.14.

$$\rho_n = \rho_{(n-1)} + \rho_1\left(\rho_{(n-1)} - \rho_{(n-2)}\right) \tag{A.14}$$

Where:

ρ is the attenuation loss (%/km);
n is the length unit (km).

Following Lambert's Law and using equation A.14 it is now possible to determine an equation appropriate to each length unit as shown in Table A.3.

Table A.3. Equations derived from equation A.14.

$\rho_2 =$	$\rho_1 + \rho_1^2$	$= \rho_1 + \rho_1^2$
$\rho_3 =$	$\rho_1 + \rho_1^2 + \rho_1^3$	$= \rho_2 + \rho_1^3$
$\rho_4 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4$	$= \rho_3 + \rho_1^4$
$\rho_5 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5$	$= \rho_4 + \rho_1^5$
$\rho_6 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5 + \rho_1^6$	$= \rho_5 + \rho_1^6$
$\rho_7 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5 + \rho_1^6 + \rho_1^7$	$= \rho_6 + \rho_1^7$
$\rho_8 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5 + \rho_1^6 + \rho_1^7 + \rho_1^8$	$= \rho_7 + \rho_1^8$
$\rho_9 =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5 + \rho_1^6 + \rho_1^7 + \rho_1^8 + \rho_1^9$	$= \rho_8 + \rho_1^9$
$\rho_{10} =$	$\rho_1 + \rho_1^2 + \rho_1^3 + \rho_1^4 + \rho_1^5 + \rho_1^6 + \rho_1^7 + \rho_1^8 + \rho_1^9 + \rho_1^{10}$	$= \rho_9 + \rho_1^{10}$

Therefore, attenuation losses per length unit will be given by equation A.15, derived in this work.

$$\rho_{(n-1)\to n} = \left(\rho_n - \rho_{(n-1)}\right)^{\frac{1}{n}} = \frac{\rho_n - \rho_{(n-1)}}{\rho_{(n-1)} - \rho_{(n-2)}} = \rho_1 = \text{Constant} \tag{A.15}$$

Where:

ρ is the attenuation loss in %/km or %/m;

n is the length unit in km or m.

It must be remembered that if attenuation is given in dB per km, then percentage losses will also be per km. Losses per meter can again be calculated following Lambert's Law. Therefore, using equations in Table A.3 it is noticed that when ρ_{10} is a known %/km loss, ρ_1 will be the equivalent %/100m. When this ρ_1 becomes ρ_{10}, the new ρ_1 will be equivalent to %/10m and so on. In this way, developing an equation of a factor $(\rho_{\%/km})/(\rho_{\%/m})$ as a function of $(\rho_{\%/km})$ it is possible to obtain an equation of $\rho_{\%/m}$ as a function of $\rho_{dB/km}$. This is expressed by equation A.16, derived in this work

$$\frac{\rho_{\%/km}}{\rho_{\%/m}} = 0.03(\rho_{\%/km}) + 1 \qquad \text{(A.16)}$$

The variation of the factor $(\rho_{\%/km})/(\rho_{\%/m})$ as a function of $(\rho_{\%/km})$ is shown in Figure A.5 where y = 0.03x + 1.

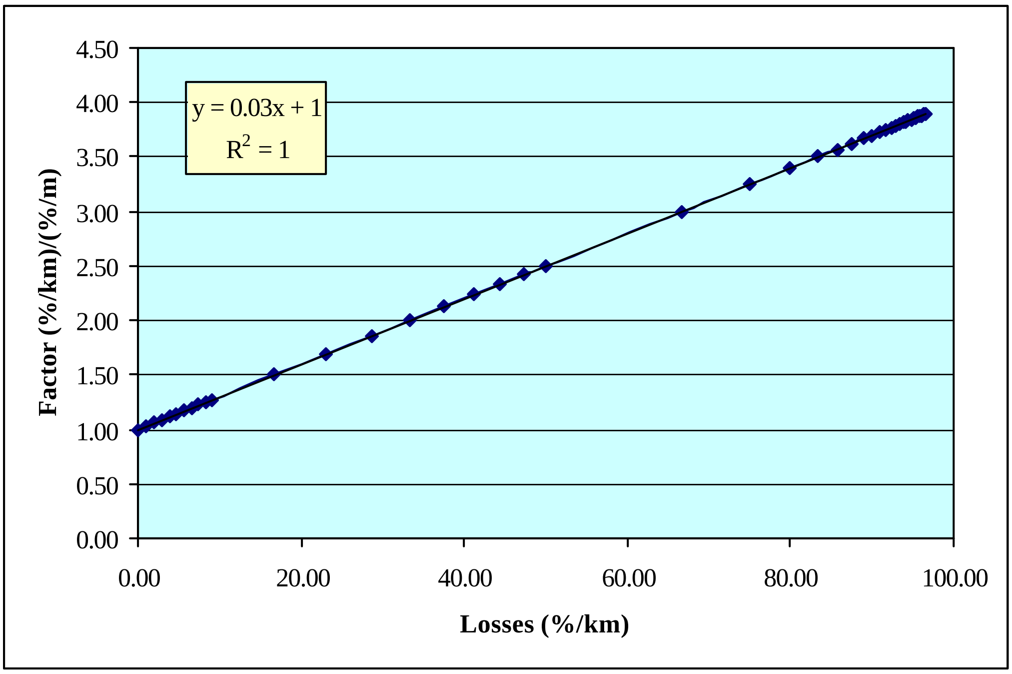

Figure A.5. Determination of the factor $(\rho_{\%/km})/(\rho_{\%/m})$ as a function of $(\rho_{\%/km})$.

Similarly, it is possible to determine factors of (%/km)/(%/10m) and (%/km)/(%/100m) as shown in equations A.17 and A.18, respectively, which were also developed in this work.

$$\frac{\rho_{\%/km}}{\rho_{\%/10m}} = 0.02(\rho_{\%/km}) + 1 \qquad \text{(A.17)}$$

$$\frac{\rho_{\%/\mathrm{km}}}{\rho_{\%/100\mathrm{m}}} = 0.01\left(\rho_{\%/\mathrm{km}}\right)+1 \tag{A.18}$$

Finally, using equations A.13 and A.16, equation A.19 shows the formula to determine losses in %/m as a function of dB/km. This equation and also the following ones were derived in this work.

$$\rho_{\%/\mathrm{m}} = \frac{100\left(1-10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}{4\left(1-\frac{3}{4}10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)} \tag{A.19}$$

Similarly, it is possible to determine losses in %/10m and %/100m as shown by equations A.20 and A.21, respectively.

$$\rho_{\%/10\mathrm{m}} = \frac{100\left(1-10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}{3\left(1-\frac{2}{3}10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)} \tag{A.20}$$

$$\rho_{\%/100\mathrm{m}} = \frac{100\left(1-10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}{2\left(1-\frac{1}{2}10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)} \tag{A.21}$$

Through some mathematical rules, equations A.19 to A.21 can be rewritten in a better way as shown by equations A.22 to A.24.

$$\rho_{\%/\mathrm{m}} = \frac{100}{3}\left(1-\frac{1}{1+3\left(1-10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}\right) \tag{A.22}$$

$$\rho_{\%/10\mathrm{m}} = \frac{100}{2}\left(1 - \frac{1}{1 + 2\left(1 - 10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}\right) \tag{A.23}$$

$$\rho_{\%/100\mathrm{m}} = 100\left(1 - \frac{1}{1 + 1\left(1 - 10^{-\left(\frac{\rho_{\mathrm{dB/km}}}{10}\right)}\right)}\right) \tag{A.24}$$

If attenuation losses are given in dB/m, losses in %/m should be determined directly through equation A.13.

Using the equations previously presented, attenuation losses in %/m, %/10m, %/100m and %/km as a function of losses in dB/km were calculated and are shown in Figure A.6 and Table A.4.

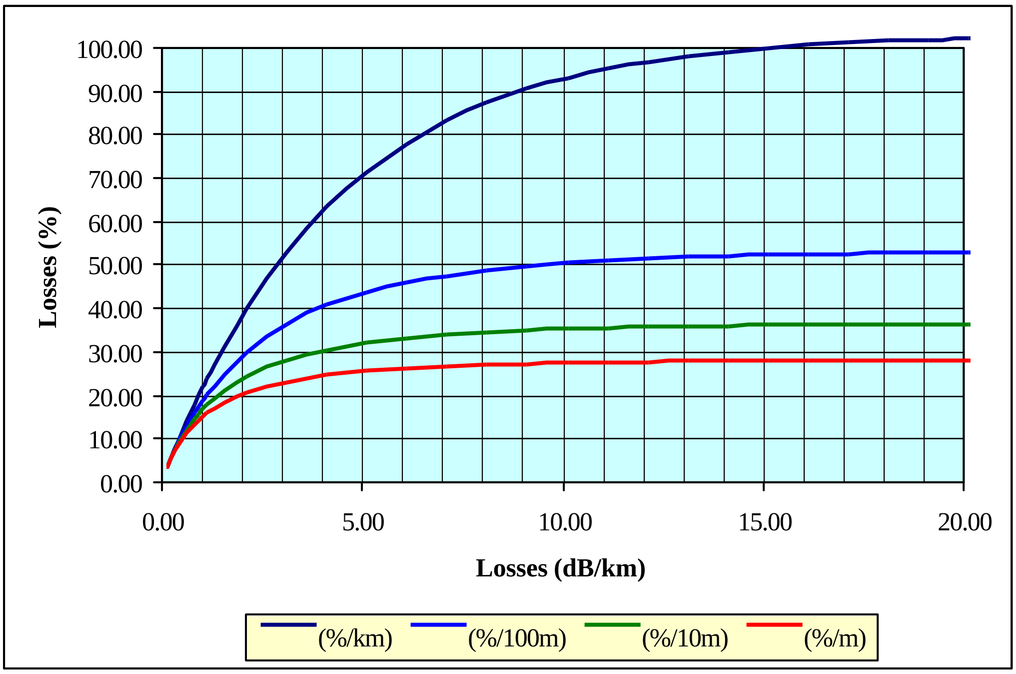

Figure A.6. Variation of losses in percentage as a function of dB/km.

Table A.4. Attenuation losses in percentage as a function of dB/km.

Attenuation losses				
(dB/km)	(%/km)	(%/100m)	(%/10m)	(%/m)
0.0	0.00	0.00	0.00	0.00
0.1	2.28	2.23	2.18	2.13
0.2	4.50	4.31	4.13	3.97
0.3	6.67	6.26	6.89	6.56
0.4	8.80	8.09	7.48	6.96
0.5	10.87	9.81	8.93	8.20
0.6	12.90	11.43	10.26	9.30
0.7	14.89	12.96	11.47	10.29
0.8	16.82	14.40	12.59	11.18
0.9	18.72	16.77	13.62	11.99
1.0	20.57	17.06	14.57	12.72
2.0	36.90	26.96	21.23	17.51
3.0	49.88	33.28	24.97	19.98
4.0	60.19	37.57	27.31	21.45
6.0	68.38	40.61	28.88	22.41
6.0	74.88	42.82	29.98	23.07
7.0	80.05	44.46	30.78	23.53
8.0	84.15	46.70	31.36	23.88
9.0	87.41	46.64	31.81	24.13
10.0	90.00	47.37	32.14	24.32
11.0	92.06	47.93	32.40	24.47
12.0	93.69	48.37	32.60	24.59
13.0	94.99	48.71	32.76	24.67
14.0	96.02	48.98	32.88	24.74
15.0	96.84	49.20	32.97	24.80
16.0	97.49	49.36	33.05	24.84
17.0	98.00	49.50	33.11	24.87
18.0	98.42	49.60	33.16	24.90
19.0	98.74	49.68	33.19	24.92
20.0	99.00	49.75	33.22	24.94
30.0	99.90	49.97	33.32	24.99
40.0	99.99	50.00	33.33	26.00
50.0	100.00	50.00	33.33	26.00

Losses in %/m as a function of the length

Through the development of the equations presented previously, it was noticed that there are factors of 3, 2 and 1, respectively for attenuation losses per 1m, 10m and 100m. This logarithmic variation shows that it is possible to have factors for specific lengths of fibre and these factors can be determined by using equation A.25, derived in this work. This equation is obtained through the chart presented in Figure A.7.

$$\delta = -0.4343\ln(x) + 3 \tag{A.25}$$

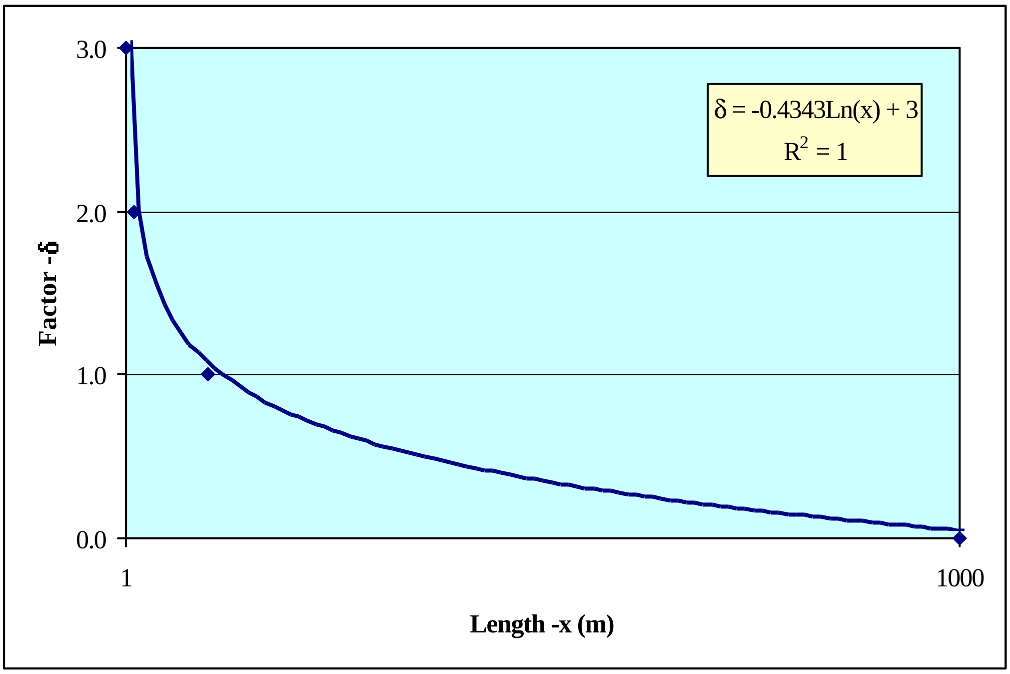

Figure A.7. Determination of a logarithmic factor as a function of the fibre length.

Therefore, attenuation losses in a specific length of fibre (x) will be given by equation A.26, which is valid for fibre lengths shorter than 1000m.

$$\rho_{\%/xm} = \frac{100}{\delta}\left(1-\frac{1}{1+\delta\left(1-10^{-\left(\frac{\rho_{dB/km}}{10}\right)}\right)}\right) \tag{A.26}$$

4. Flexibility

Fibre optics are produced in long lengths and so it is impossible to handle them without bending. WOLFE (1998a) reported that manufacturer's guidelines on bending radii should be followed, otherwise bending stresses can be produced, which reduces the life span of the fibre and affects the system reliability. In this respect, fibre flexibility must be known because fibre-optic cables have to be bent when used in building applications.

LUMENYTE (1993) suggests a minimum bend radius of 8 times the core diameter when fibres are end-emitting and 4 times the core diameter when fibres are side-emitting. WATSON (1995) recommends a minimum bend radius of 30 mm. KAY (1999) states that glass fibres should not be bent more than 10 times (radius) the diameter of the light guide. For plastic fibres the bend radius should be between 4 and 10 times the diameter of an individual fibre. Kay also emphasises that no type of fibre should be bent beyond 90^{o}. However, that author does not mention that if the bend radius is large the fibre can be bent past 360^{o}.

5. Life span

When fibre optics are installed and cabled in accordance with recommended procedures it is expected that the fibres have a long service life (CORNING, 1995). BELDEN (1998) mention that the expected life span of their fibre optics is higher than 30 years. WOLFE (1998b) reports that optical fibres are specifically designed to operate for more than 40 years. And KAY (1999) states that there are operating examples of glass fibres over 30 years old.

6. Typical diameters of fibre optics

In LIGHTING FUTURES (1995) typical fibre diameter are presented as follows: Glass fibres have a diameter typically between 0.05 and 0.15mm; Small plastic fibres have a diameter typically between 0.13 and 2.03mm; and Large plastic fibres have a diameter typically between 2.03 and 11.94mm.

Nowadays, the international standard is to have cladding diameter of 125µm. Table A.5 shows typical fibre optics sizes (CORNING, 1995). It is possible to obtain multimode fibres in several core sizes, however, the most commonly used sizes are 50µm and 62.5µm.

Table A.5. Fibre optic sizes.

Fibre optic type	Diameter (µm)	
	Core	Cladding + Core
Single-mode	8-10	125
Multimode	50	125
	62.5	125

The difference between single-mode – or monomode – and multimode fibres is that the latter have a much larger core than the former, which permits hundreds of rays, or modes, of light to be propagated through the fibre simultaneously. Single-mode fibres have a much smaller diameter, which allows only one mode of light to be propagated through the core. CORNING (1995) reports that single-mode fibres have higher information-carrying capacity because they can retain the integrity of each light pulse over longer distances.

LUMENYTE (1993) manufactures their fibre optics in different diameters as shown in Table A.6.

Table A.6. Fibre optic sizes from LUMENYTE (1993).

Fibre optic type	Diameter (mm)	
	Core	Cladding + Core
End-emitting	3.1	6.5
	4.8	7.4
	6.4	9.0
	9.5	12.8
	12.7	17.7
	18.0	26.3
Side-emitting	4.7	6.7
	6.0	7.0
	8.8	10.2
	12.2	13.7

7. Strength

Fibre optics, despite being made of glass or plastic, are not fragile. Fibres are proof-tested to a minimum stress level equal to 100kpsi[1] (CORNING, 1995). The theoretical strength of fibre optics is 2,000kpsi, and typical strength is about 600kpsi (WOLFE, 1998b).

8. The effect of water

In most outside applications, water will have little effect on the performance of fibre optics. Nevertheless, if fibre optics are under tension and in presence of moisture, a flaw may grow, causing the fibres to break (WOLFE, 1998a).

9. Maintenance and installation

SMITH et al. (1998) demonstrated empirically that actual field ageing of a fibre optic cable does not degrade the fibre's ability to be handled. That was verified even after five years of field ageing concluding that there is no difficulty in handling fibre optics for maintenance and also for installation.

Fibres need to be kept clean. Therefore, dirt, moisture and oil from an operator's hands need to be avoided when handling them (WOLFE, 1998a).

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[1] 1 psi = 703.235 kg/m^2 = 0.0703235 kg/cm^2; 1 kpsi = 703,235 kg/m^2 = 70.3235 kg/cm^2.

Appendix B. Energy Consumption in Buildings

This Appendix presents a literature review about energy consumption in buildings in different countries as a way of showing that improvements in their energy efficiency through the use of energy-efficient lighting and effective daylight integration could allow energy savings to be obtained.

Information about energy consumption in the countries that join the Association of South East Asian Nations (ASEAN) – Indonesia, Philippines, Singapore, Malaysia and Thailand – is presented, as well as for the United States of America, Mexico, Greece, and Ivory Coast.

1. Energy consumption in Thailand

The Thailand researchers Chirarattananon and Rakwamsuk, in a proposal of a standard related to energy consumption in buildings in Thailand, shown in LBL (1989), found out that the energy consumption in 1989 was growing 15% a year and that the number of commercial buildings was also growing significantly. Table B.1 presents the annual energy consumption of some buildings in Thailand and their cooling and lighting end-use.

As it can be seen, the two offices and the hospital have equivalent annual energy consumption. Hotels are responsible for the highest consumption. Comparing the hotel with the highest consumption (453 kWh/m² per year) to the office with the lowest consumption (165 kWh/m² per year), the ratio is 2.75 times. As for end-uses, the cooling is the main responsible for the energy consumption, ranging from 49% to 61%; lighting end-use ranges from 8% to 40%.

Table B.1. Energy consumption and end-use in Thailand.

Building type	Name	Consumption (kWh/m².year)	End-use (%)	
			Cooling	Lighting
Offices	Ua-Chuliang	167	62	13
	Siam Motor	165	68	22
Hospital	Bumrungraj	169	54	29
Hotels	Montien	327	56	16
	Siam Intercontinental	258	61	21
	Sheraton	389	49	14
	Shangrila	453	58	8
	Tara	351	49	40

2. Energy consumption in Malaysia

Also in LBL (1989) it is possible to obtain the study of the Pan Pacific Hotel in Kuala Lumpur, Malaysia. The study was performed by K.S. Kanan. Its energy end-uses are presented in Table B.2. Energy consumption in kWh/m² per year was not presented.

Table B.2. Energy end-use of the Pan Pacific Hotel in Malaysia.

System	End-use (%)
Cooling	59.9
Lighting	12.4
Others	23.0
Lifts and escalators	4.7

3. Energy consumption in the Philippines

To survey energy consumption data in commercial buildings in the Philippines, 52 buildings amongst offices, hotels, hospitals, and supermarkets were studied in Manila. In this city, commercial buildings consume from 11% to 13% of the total energy in the Philippines and around 32% to 33% of the total energy available in Manila (LBL, 1989). Table B.3 presents the energy consumption and end-use for some buildings in the Philippines.

The cooling end-use is the highest one ranging from 58.9% to 65.5% with an average of 62.0%. The author states that hospitals present the highest cooling end-use because many of these buildings use window sets.

The highest lighting end-use (22.5%) is found in hotels because incandescent lamps are used. In the other buildings, the lighting system is performed by fluorescent lamps.

In terms of equipment located outside conditioned areas, supermarkets consume more than the other buildings because of the use of refrigerators and freezers located outside the commercial area.

Table B.3. Energy consumption and end-use in Philippines.

Building type	Consumption	End-use (%)			
	(kWh/m².year)	Cooling	Lighting	Others 1*	Others 2**
Offices	234.1	60.4	19.3	6.7	13.6
Hotels	347.0	61.9	22.5	4.0	11.6
Hospitals	379.7	65.5	16.3	4.6	13.6
Supermarkets	271.4	58.9	6.6	3.6	30.9
Average	308.2	62.0	16.5	4.6	16.9

* Equipment located in conditioned areas.
** Equipment located outside conditioned areas.

4. Energy consumption in Singapore

Y. W. Wong studied, between 1988 and 1989, 7 buildings in Singapore; 4 of them are offices, 2 are hotels, and 1 is a school (LBL, 1992). The results are presented in Table B.4.

Amongst the three types of buildings studied in Singapore, hotels present the highest energy consumption, reaching 518.0 kWh/m² per year in the Golden Landmark Hotel. In terms of energy end-use, the cooling is noticed as the main energy consumption, ranging around 50.2% and reaching 71.7% in the School of Accountancy & Commerce. Lighting end-use ranges between 15.5% and 35.3%.

Table B.4.Energy consumption and end-use in Singapore.

Building type	Name	Consumption (kWh/m².year)	End-use (%)		
			Cooling	Lighting	Others
Office	Albert Complex	198.7	55.3	15.5	29.3
	URA Building	131.2	50.3	48.7*	-
	Sanford Building	201.9	40.9	30.8	28.4
	Jurong Town Hall	122.0	50.2	26.3	23.5
Hotels	Century Park Sheraton	339.0	57.6	42.3*	-
	Golden Landmark	518.0	46.9	35.3	17.7
School of Accountancy & Commerce		227.0	71.7	21.5	6.8

* Energy consumption with other equipment as lifts and bombs are included.

5. Energy consumption in the ASEAN countries and in the USA

In the *Buildings Energy Conservation Project Report* of 1992, new data about energy consumption in the Asian Southeast countries are presented (LBL, 1992). The total energy consumption grew from 20 to 101 billions of kWh between 1970 and 1987 in those countries. In 1970, dwellings were responsible for a consumption of 3.5 billions of kWh and commercial buildings for 4.3 billions. In 1987, this consumption grew to 22 billions of kWh in dwellings and to 23 billions in commercial buildings. In this way, commercial and residential buildings in the ASEAN countries consume around 45% of the total energy available.

Table B.5 shows the energy consumption in the ASEAN countries and in the United States of America. Such comparison can seem improper because of climatic differences between the USA and the Asian Southeast countries. In the USA, buildings need more heating than cooling. However, only buildings with similar characteristics (South of the USA) to those of ASEAN in each category were included in Table B.5. In the ASEAN countries, the highest average (379 kWh/m² per year) corresponds to hospitals and the lowest (233 kWh/m² per year), to offices. Malaysia is responsible for the highest consumption both in offices (269 kWh/m² per year) and retail buildings (483 kWh/m² per year). However, Malaysia presents the lowest consumption in hotels (285 kWh/m² per year) and hospitals (250 kWh/m² per year). Singapore is responsible for the highest consumption in hotels (429 kWh/m² per year) and for the lowest consumption in retail buildings (124 kWh/m² per year). The ASEAN countries present higher energy consumption than the USA in hotels (318 against 252 kWh/m² per year) and in retail buildings (352 against 270 kWh/m² per year). The authors report that the consumption of 82 kWh/m² per year in hotels built in the USA between 1970 and 1983, should not be taken into account because of the small sample and eventual statistical problems.

Table B.5. Energy consumption in the ASEAN countries and in the USA.

Building type	Country	Number of buildings	Consumption (kWh/m².year)
Offices	Indonesia	4	147
	Malaysia	26	269
	Philippines	26	235
	Singapore	65	222
	Thailand	7	237
	Average to ASEAN	128	233
	USA: 1971-1983	8,702	263
	USA: all buildings up to 1983	20,719	233
Hotels	Indonesia	4	287
	Malaysia	6	285
	Philippines	9	342
	Singapore	2	429
	Thailand	15	311
	Average to ASEAN	36	318
	USA: 1971-1983	116	82
	USA: all buildings up to 1983	599	252
Hospitals	Malaysia	1	250
	Philippines	10	430
	Thailand	7	324
	Average to ASEAN	18	379
	USA: 1971-1983	3,201	586
	USA: all buildings up to 1983	3,418	571
Retail	Malaysia	2	483
	Singapore	2	124
	Thailand	3	418
	Average to ASEAN	7	352
	USA: 1971-1983	857	198
	USA: all buildings up to 1983	3,724	270
Supermarkets	Philippines/ASEAN	6	265

6. Energy consumption in the USA

Energy consumption in commercial buildings in the USA is presented through nine end-uses, that is, heating, cooling, ventilation, water heating, lighting, cooking, refrigerators, office equipment, and others. The data was surveyed in 1989 through the Commercial Buildings Energy Consumption Survey – CBECS in the USA (EIA, 1994). Approximately 6000 commercial buildings were analysed and Table B.6 presents their energy end-use.

Table B.6. Energy end-use in the USA.

System	End-use (10^{10} kWh)	End-use (%)
Heating	59.10	39
Lighting	29.97	16
Others	24.38	14
Water heating	14.62	10
Office equipment	11.10	10
Cooling	8.88	7
Ventilation	8.15	3
Cooking	7.94	2
Refrigerators	5.48	1

However, as natural gas is widely used in that country, Tables B.7 and B.8 present the end-use due to gas and electricity. Lighting is the main responsible for the consumption of electricity, responding for 39% of the total. In terms of heating, it consumes 61% of natural gas and only 3% of electricity.

Table B.7. End-use of electricity in the USA.

System	End-use (%)
Lighting	39
Others	16
Office equipment	14
Ventilation	10
Cooling	10
Refrigerators	7
Heating	3
Cooking	2
Water heating	1

Table B.8. End-use of natural gas in the USA.

System	End-use (%)
Heating	61
Water heating	15
Others	14
Cooking	10

Energy consumption for different building types in the USA are presented in Tables B.9.

Table B.9. Energy end-use (kWh/m².month) in the USA.

Building type	End-use (kWh/m².month)				
	Heating	Cooling	Ventilation	Water heating	Lighting
Theatres [a]	0.82	1.05	1.08	0.06	2.70
Schools	0.38	0.64	0.88	0.06	4.16
Supermarkets [b]	0.09	5.86	2.96	0.50	6.86
Restaurants [c]	0.35	4.81	3.22	0.70	6.74
Hospitals	0.41	4.42	2.99	0.35	9.67
Lodgings [d]	0.97	1.44	1.70	0.44	3.96
Services [e]	0.29	1.20	0.62	0.09	4.75
Offices	0.67	2.02	3.31	0.09	6.77
Garage buildings	-	0.12	0.12	0.03	2.46
Publics and safety	-	0.70	1.08	0.03	6.09
Deposits	0.26	0.21	0.12	0.03	3.40
Others	-	2.67	0.12	0.09	14.47

Table B.10. Energy end-use (kWh/m².month) in the USA (cont.).

Building type	End-use (kWh/m².month)				Consumption
	Cooking	Refrigeration	Office equipment	Others	(kWh/m².year)
Theatres [a]	0.03	0.47	0.26	1.46	95.64
Schools	0.03	0.38	0.38	1.00	94.56
Supermarkets [b]	3.34	16.55	0.38	2.43	467.64
Restaurants [c]	4.37	4.01	0.44	3.66	339.24
Hospitals	0.67	0.88	0.76	1.76	263.40
Lodgings [d]	1.17	1.32	0.12	0.53	139.56
Services [e]	0.09	0.29	2.72	2.93	156.48
Offices	0.06	0.85	4.10	1.52	232.80
Garage buildings	0.03	0.26	0.32	2.02	63.96
Publics and safety	0.06	0.88	0.64	4.04	165.24
Deposits	0.03	0.79	1.90	1.32	96.36
Others	0.12	1.32	-	16.91	461.64

a. Included auditoria, concert rooms, stadia and similar.
b. Included bakeries, grocery stores and similar.
c. Included snack bars and similar.
d. Included hotels, motels, cloisters, dormitories and similar.
e. Included stores, drugstores, gas stations, post-offices and similar.

7. Energy consumption in the Ivory Coast

MOURTADA (1996) studied 26 buildings in the Ivory Coast, Africa, and found out an average energy consumption of 235 kWh/m^2 per year in offices. Table B.10 shows the average energy consumption for Cameroon, Burkina Faso, and Senegal.

Table B.10. Energy consumption in offices in the Ivory Coast.

Country	Consumption (kWh/m^2.year)
Cameroon	249
Burkina Faso	210
Senegal	229

8. Energy consumption in Mexico

BANDALA (1995) found out the energy end-use in different building types in Mexico. As it can be seen in Table B.11, lighting accounts for 40% of the energy end-use in offices.

Table B.11. Energy end-use in Mexico.

Building type	Quantity	End-use (%)			
		Lighting	Cooling	Refrigerators	Others
Offices	22	40	52	-	8
Supermarkets	11	21	-	60	19
Stores	7	38	55	-	7
Restaurants	3	39	-	50	11
Hotels	15	27	-	58	15

9. Energy consumption in Greece

SANTAMOURIS (1995) analysed 17 buildings in Greece and determined their energy end-use. Table B.12 presents the results. Energy consumption and end-uses in Greek buildings are very variable. The highest consumption (657.87 kWh/m^2 per year) is roughly 14 times higher than the lowest one (47.50 kWh/m^2 per year). Heating end-uses range from 9.92% to 64.23%, cooling end-uses from 2.94% to 50.66%, and lighting end-uses from 5.71% to 62.90%.

Table B.12. Energy end-use in Greece.

Building	End-use (%)				Consumption (kWh/m².year)
	Heating	Cooling	Lighting	Others	
A	32.62	12.81	22.34	32.23	92.32
B	48.24	21.42	15.97	14.37	73.16
C	17.29	15.24	17.44	50.03	167.83
D	51.06	16.62	27.95	4.38	47.50
E	26.01	6.77	62.90	4.33	160.70
F	9.92	50.66	36.82	2.61	103.17
G	17.24	45.01	27.40	10.31	119.76
H	36.33	14.35	29.05	21.28	64.71
I	24.91	13.93	31.18	29.97	261.48
J	22.39	7.62	49.61	20.37	657.87
K	26.43	32.05	27.78	13.73	93.07
L	38.12	17.26	23.49	21.13	139.64
M	43.18	22.81	21.04	12.97	135.90
N	64.23	24.94	8.63	2.20	47.79
O	36.14	2.94	37.61	23.31	85.90
P	21.28	13.64	40.39	24.69	122.36
Q	13.56	10.05	5.71	70.68	79.50

Building	Name
A	Building of the General Secretariat of Research and Tecnology
B	Mult-Use Office Building on Amerikis Street
C	The Bank of Attica Building
D	Ministry of Culture: General Secretariat of Adult Education
E	National Research Institute
F	Private Office Building
G	Private Office Building in Halandri
H	The Building of the Ministry of Presidency
I	The B. P. Oil Company Building
J	"Heraklis" General Cement Company S.A., Headquarters
K	The El.Ke.Pa. Building (Headquarters)
L	The El.Ke.Pa. Building (Branch Office)
M	The "Mechaniki Headquarters" Building
N	Building of Meletitiki
O	Office Building in Kipseli
P	The National Bank of Industrial Development Building
Q	The National Center of Oceanographic Research Building

In another work, SANTAMOURIS et al. (1996) present the average energy consumption for different building types in Greece, as shown in Table B.13.

Table B.13. Energy consumption in Greece.

Building type	Consumption (kWh/m^2.year)
Hotels	273.0
Hospitals	406.8
Offices	187.0
Commercial buildings	152.0
Schools	92.0

Appendix C. Energy Savings on Lighting

Tables C.1 to C.12 present the energy savings on artificial lighting estimated by calculations of Daylight Factors as discussed in Chapter 3. Such savings are presented for each one of the ten room indices, room ratios of 1.5:1, 1:1, and 1:1.5, and four window areas considered in the work.

Table C.1. Energy savings on artificial lighting for room ratio of 1.5:1 and window area of 25% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.53																												100.0	100.0	100.0
0.65																									100.0	100.0	100.0	62.0	89.2	95.9
0.80																						100.0	100.0	100.0	68.7	89.1	96.6	48.7	76.0	87.7
0.90																			100.0	100.0	100.0	90.4	94.2	99.4	59.9	82.5	93.0	43.7	69.9	83.1
1.00																			95.0	93.6	99.7	80.1	90.1	98.0	53.5	77.0	89.3	37.0	66.4	78.8
1.20																			83.4	88.7	98.1	63.9	82.0	93.5	43.6	68.7	82.3	32.2	58.0	71.5
1.25																			74.8	89.9	97.5	63.3	79.0	92.3	40.6	67.6	80.8	32.0	55.9	70.0
1.29																100.0	100.0	100.0	72.3	87.8	96.6	61.7	77.6	91.4	40.4	65.5	79.4	31.8	54.2	68.8
1.33																98.9	98.2	100.0	71.6	85.8	96.0	60.2	76.1	90.5	40.2	63.6	78.2	31.7	52.6	67.6
1.50																88.4	94.3	99.3	64.1	79.3	92.6	53.0	71.7	86.7	39.2	57.1	73.9	30.7	47.3	63.5
1.60																82.9	91.5	98.5	62.6	75.2	90.7	50.0	68.8	84.4	38.5	54.0	71.7	30.1	44.8	61.4
1.67																79.0	89.1	97.7	62.1	72.4	89.5	48.7	66.9	83.0	37.8	52.3	70.3	29.5	43.4	60.1
1.87													100.0	100.0	100.0	71.7	83.2	95.2	57.7	67.8	86.4	45.7	61.6	79.1	34.5	49.2	66.7	26.9	40.7	56.7
2.00													94.2	95.3	99.7	66.9	80.4	93.5	54.1	66.0	84.4	43.2	59.3	76.9	32.6	47.7	64.7	25.2	39.3	54.6
2.11										100.0	100.0	100.0	89.3	92.8	99.2	64.6	77.8	92.1	51.6	64.5	82.8	41.2	57.7	75.1	31.9	45.3	62.7	24.6	37.7	53.0
2.50										82.8	92.3	98.7	76.9	84.3	96.4	56.0	70.6	87.1	44.4	59.0	77.2	36.3	51.8	69.3	29.7	40.1	57.9	22.0	33.7	48.3
2.67										77.4	88.4	97.4	74.2	80.9	95.1	53.7	67.7	85.0	42.4	56.8	75.1	35.1	49.4	67.2	26.9	39.8	56.0	21.5	32.0	46.6
2.96							100.0	100.0	100.0	74.1	82.0	95.3	66.6	78.0	92.7	48.7	64.3	81.7	39.1	53.6	71.7	32.6	46.8	64.1	23.3	38.6	52.9	18.1	31.6	44.0
3.00							99.6	98.6	100.0	73.7	80.9	95.0	64.1	78.6	92.3	48.4	63.4	81.1	38.2	53.6	71.3	31.1	47.1	63.6	22.8	38.6	52.6	17.8	32.1	44.2
3.33							92.1	95.3	99.6	65.9	77.4	92.3	57.0	74.7	89.1	42.7	60.8	77.5	32.6	51.9	67.6	27.3	45.3	60.2	18.8	37.8	49.5	14.6	30.9	41.0
3.54				100.0	100.0	100.0	84.7	92.9	98.9	62.7	75.3	90.8	55.7	71.1	87.2	40.3	58.8	75.4	28.8	51.5	65.5	26.5	43.1	58.2	18.1	36.0	47.6	14.4	29.1	39.3
3.56	100.0	100.0	100.0	99.4	99.5	100.0	84.2	92.4	98.8	62.6	74.9	90.6	55.0	70.7	86.8	40.2	58.4	75.1	28.8	51.2	65.3	26.4	43.1	58.1	18.1	35.8	47.4	14.4	29.1	39.3
4.00	93.2	88.9	99.2	85.5	91.3	98.7	71.7	87.0	96.3	56.8	70.0	87.0	44.3	69.1	82.8	31.5	57.8	71.1	27.7	46.2	61.1	20.8	42.2	54.2	17.1	32.7	44.2	12.3	28.2	37.0
5.00	72.0	84.6	95.7	57.7	83.5	93.0	47.3	77.8	88.3	39.9	64.3	78.5	32.6	60.9	73.6	24.2	50.1	62.2	20.2	41.9	53.6	16.1	36.7	46.9	12.8	29.5	38.5	9.7	23.9	31.3
5.33	57.2	85.7	93.9	54.6	80.4	91.1	40.0	76.4	85.8	34.9	63.1	76.0	29.3	58.6	70.7	22.2	48.3	59.8	16.8	41.8	51.6	14.0	36.2	45.1	10.7	28.9	36.5	8.4	23.6	30.0
6.00	46.9	79.0	88.8	34.8	79.1	86.4	25.6	73.0	79.9	27.8	60.1	71.2	25.2	54.6	66.0	15.1	47.6	55.5	15.3	38.0	47.5	9.3	35.6	41.6	9.8	26.3	33.5	8.0	21.2	27.5
6.67	24.3	78.9	84.0	29.6	73.0	81.0	23.6	65.6	73.7	25.6	55.0	66.5	19.1	52.8	61.8	12.4	43.8	50.8	12.4	36.2	44.1	8.2	32.5	38.0	6.5	26.2	31.0	5.4	21.2	25.5
8.00	15.7	68.8	73.7	11.9	66.4	70.4	14.4	58.4	64.4	12.2	52.7	58.5	7.9	49.5	53.5	8.6	39.0	44.2	5.5	35.2	38.8	0.0	32.6	32.6	0.0	26.4	26.4	2.5	19.9	21.9
10.00	0.0	57.7	57.7	0.0	56.2	56.2	0.0	52.0	52.0	0.0	47.3	47.3	0.0	43.5	43.5	0.0	35.6	35.6	0.0	30.9	30.9	0.0	26.1	26.1	0.0	21.1	21.1	0.0	17.7	17.7
12.00	0.0	48.1	48.1	0.0	46.8	46.8	0.0	43.4	43.4	0.0	39.4	39.4	0.0	36.3	36.3	0.0	29.7	29.7	0.0	25.7	25.7	0.0	21.8	21.8	0.0	17.6	17.6	0.0	14.7	14.7
14.00	0.0	41.2	41.2	0.0	40.1	40.1	0.0	37.2	37.2	0.0	33.8	33.8	0.0	31.1	31.1	0.0	25.4	25.4	0.0	22.0	22.0	0.0	18.6	18.6	0.0	15.1	15.1	0.0	12.6	12.6
16.00	0.0	36.1	36.1	0.0	35.1	35.1	0.0	32.5	32.5	0.0	29.6	29.6	0.0	27.2	27.2	0.0	22.2	22.2	0.0	19.3	19.3	0.0	16.3	16.3	0.0	13.2	13.2	0.0	11.0	11.0
20.00	0.0	28.9	28.9	0.0	28.1	28.1	0.0	26.0	26.0	0.0	23.7	23.7	0.0	21.8	21.8	0.0	17.8	17.8	0.0	15.4	15.4	0.0	13.1	13.1	0.0	10.5	10.5	0.0	8.8	8.8

Table C.2. Energy savings on artificial lighting for room ratio of 1.5:1 and window area of 50% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.97																												100.0	100.0	100.0
1.00																												87.9	98.7	99.8
1.20																												63.0	88.3	95.7
1.25																									100.0	100.0	100.0	56.7	86.7	94.2
1.33																									84.8	97.1	99.6	53.8	82.4	91.9
1.43																									70.6	92.7	97.9	46.1	79.7	89.1
1.50																									66.3	89.5	96.5	45.3	76.4	87.1
1.60																									57.9	86.6	94.4	43.6	72.2	84.3
1.62																						100.0	100.0	100.0	57.7	85.6	93.9	43.1	71.6	83.8
1.67																						94.4	98.0	99.9	56.6	83.4	92.8	42.3	69.9	82.6
1.82																			100.0	100.0	100.0	77.1	94.4	98.7	52.2	78.4	89.7	36.2	67.2	79.1
2.00																			93.1	95.9	99.7	71.4	87.6	96.5	45.5	74.3	86.0	32.0	63.4	75.1
2.35																100.0	100.0	100.0	71.9	90.1	97.2	59.5	79.6	91.7	39.3	66.2	79.5	31.0	54.4	68.5
2.50																95.4	96.8	99.9	66.1	86.6	95.5	54.6	77.0	89.6	38.7	62.6	77.1	29.8	51.9	66.2
2.67																88.0	95.0	99.4	62.9	82.3	93.4	52.6	73.1	87.2	36.9	59.6	74.5	28.3	49.6	63.9
3.00																77.4	88.8	97.5	58.8	75.4	89.9	45.5	68.8	83.0	34.5	54.5	70.2	27.5	44.7	59.9
3.28													100.0	100.0	100.0	68.6	85.3	95.4	55.0	71.1	87.0	43.3	64.4	79.8	31.9	51.8	67.2	25.2	42.6	57.1
3.33													96.2	98.8	100.0	68.1	84.0	94.9	53.9	70.6	86.4	43.1	63.4	79.2	31.8	51.1	66.7	25.1	41.9	56.5
3.70										100.0	100.0	100.0	87.6	94.3	99.3	61.7	79.1	92.0	49.6	66.4	83.1	40.2	58.9	75.4	30.5	46.8	63.0	22.8	39.8	53.5
4.00										95.0	95.1	99.8	78.2	90.1	97.8	59.3	74.6	89.7	47.4	62.9	80.5	38.3	55.7	72.7	27.6	45.5	60.5	22.0	37.2	51.0
4.98							100.0	100.0	100.0	77.1	86.0	96.8	65.6	79.4	92.9	48.5	66.0	82.5	37.8	56.3	72.8	32.2	48.5	65.1	22.9	39.7	53.5	17.3	33.3	44.8
5.00							99.8	99.5	100.0	77.0	85.6	96.7	65.5	79.0	92.8	48.4	65.8	82.4	37.8	56.1	72.7	32.1	48.3	64.9	22.6	39.8	53.4	17.2	33.2	44.7
5.33							97.5	93.4	99.8	74.9	81.5	95.4	61.7	76.6	91.0	47.5	62.1	80.1	35.0	54.5	70.4	31.3	46.0	62.9	21.4	38.2	51.4	17.1	31.2	43.0
6.00							84.9	93.2	99.0	67.3	78.2	92.9	56.7	70.7	87.3	44.1	57.5	76.2	33.0	49.9	66.4	27.6	43.8	59.3	20.7	34.5	48.1	16.5	28.3	40.1
6.50				100.0	100.0	100.0	81.6	87.4	97.7	63.9	73.8	90.5	53.3	67.0	84.6	39.9	56.2	73.7	31.1	47.5	63.8	26.9	40.9	56.8	18.4	33.8	46.0	14.5	27.6	38.1
6.67				97.8	97.4	99.9	80.8	85.2	97.2	63.3	71.9	89.7	52.4	66.1	83.9	39.7	54.8	72.7	28.9	47.9	63.0	26.8	39.9	56.0	18.2	32.9	45.1	14.4	27.0	37.5
8.00				81.7	89.2	98.0	68.8	77.4	92.9	53.4	67.0	84.6	45.8	59.8	78.2	33.8	49.7	66.7	27.2	40.9	57.0	22.7	36.2	50.7	17.3	28.1	40.5	13.7	23.1	33.6
8.73	100.0	100.0	100.0	77.0	84.1	96.3	63.2	74.6	90.7	51.6	62.7	81.9	42.5	56.7	75.1	32.8	46.5	64.0	23.1	40.7	54.4	21.9	33.9	48.4	14.9	28.0	38.7	11.7	22.9	31.9
10.00	88.2	91.8	99.0	71.0	76.4	93.2	54.7	70.0	86.4	43.4	60.1	77.4	37.4	52.5	70.3	27.7	44.4	59.8	22.6	35.8	50.3	18.1	32.6	44.8	14.2	24.8	35.5	11.3	20.2	29.2
12.00	70.5	83.0	95.0	56.9	71.4	87.7	43.3	64.9	80.1	39.4	52.2	71.0	31.0	48.4	64.4	21.6	41.5	54.1	17.1	34.5	45.7	13.8	30.5	40.1	10.7	23.6	31.8	8.7	19.1	26.1
14.00	52.6	78.8	90.0	47.2	67.2	82.7	36.1	60.4	74.7	27.5	52.9	65.9	25.2	45.4	59.2	19.2	37.2	49.3	16.1	30.2	41.4	13.1	26.6	36.2	10.2	20.5	28.6	8.4	16.7	23.7
16.00	32.1	76.9	84.3	32.5	65.9	77.0	28.6	57.7	69.8	23.5	48.9	60.9	19.7	43.3	54.5	16.9	34.0	45.2	14.5	27.5	38.0	11.8	24.5	33.4	6.7	20.9	26.2	7.7	15.1	21.6
20.00	8.6	66.4	69.3	10.2	61.0	65.0	8.8	53.8	57.9	7.4	47.9	51.8	7.0	41.7	45.8	5.8	34.3	38.1	4.6	28.6	31.9	3.9	24.7	27.6	3.1	19.2	21.7	2.5	15.9	18.0

Table C.3. Energy savings on artificial lighting for room ratio of 1.5:1 and window area of 73.2% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.35																												100.0	100.0	100.0
1.43																												79.9	96.4	99.3
1.50																												75.2	93.2	98.3
1.60																												60.6	91.1	96.5
1.67																												56.1	88.2	94.8
1.70																									100.0	100.0	100.0	54.6	86.8	94.0
2.00																									63.4	90.7	96.6	43.7	77.1	87.1
2.18																						100.0	100.0	100.0	56.0	85.0	93.4	37.2	73.4	83.3
2.45																			100.0	100.0	100.0	74.4	93.5	98.3	46.4	79.0	88.7	35.1	66.3	78.1
2.50																			98.8	98.6	100.0	73.5	91.9	97.9	45.8	77.7	87.9	34.0	65.8	77.4
2.67																			90.5	96.7	99.7	67.1	88.3	96.2	43.6	73.7	85.2	31.6	62.5	74.4
3.00																			72.4	91.8	97.7	59.2	81.4	92.4	39.0	67.5	80.2	30.2	56.4	69.6
3.15																100.0	100.0	100.0	69.5	88.4	96.5	54.3	79.6	90.7	38.1	64.8	78.2	28.5	54.7	67.6
3.33																93.6	97.1	99.8	63.7	85.8	94.8	52.7	76.0	88.6	35.8	62.6	76.0	27.8	52.2	65.5
4.00																71.5	88.8	96.8	55.5	75.2	89.0	43.2	67.8	81.7	31.6	54.6	68.9	24.8	45.4	58.9
4.21													100.0	100.0	100.0	67.3	86.1	95.5	52.6	72.9	87.2	41.0	65.8	79.8	31.0	52.3	67.1	23.6	44.0	57.2
4.82										100.0	100.0	100.0	81.6	93.5	98.8	59.9	78.4	91.3	47.4	66.7	82.5	36.5	60.1	74.7	27.6	47.9	62.3	21.1	40.1	52.7
5.00										97.5	97.2	99.9	78.3	91.4	98.1	57.9	76.7	90.2	44.3	66.3	81.2	36.0	58.1	73.2	27.0	46.6	61.0	19.8	39.7	51.6
5.33										91.8	94.4	99.5	75.9	87.2	96.9	53.7	74.4	88.1	42.5	63.0	78.7	34.7	55.5	70.9	24.6	45.4	58.8	19.5	37.4	49.6
6.00										78.5	90.9	98.0	66.8	82.1	94.1	48.4	68.9	84.0	37.7	58.9	74.4	31.7	51.2	66.7	21.9	42.3	54.9	17.1	35.0	46.1
6.21							100.0	100.0	100.0	77.1	87.8	97.2	65.1	80.0	93.0	47.8	67.0	82.8	37.0	57.5	73.2	31.3	49.6	65.4	21.5	41.1	53.8	17.1	33.8	45.1
6.67							96.8	96.4	99.9	73.5	83.7	95.7	59.7	77.4	90.9	45.5	63.7	80.2	33.9	55.2	70.4	30.5	46.9	63.1	21.2	38.4	51.5	16.9	31.6	43.2
7.95				100.0	100.0	100.0	81.4	87.8	97.7	63.5	75.3	91.0	52.7	69.0	85.3	39.5	57.0	74.0	28.8	49.9	64.3	26.5	41.9	57.3	18.1	34.5	46.4	14.4	28.3	38.6
8.00				99.4	99.3	100.0	81.2	87.3	97.6	63.3	74.8	90.8	52.5	68.5	85.0	39.4	57.1	74.0	28.8	49.6	64.1	26.5	41.6	57.1	18.1	34.3	46.2	14.3	28.2	38.5
10.00				79.9	89.2	97.8	66.8	77.4	92.5	52.5	66.1	83.9	44.1	60.0	77.6	33.1	49.3	66.1	26.3	41.3	56.7	22.1	36.2	50.3	15.2	30.2	40.8	12.3	24.7	34.0
10.68	100.0	100.0	100.0	76.8	83.5	96.2	61.8	76.0	90.8	50.8	63.0	81.8	41.2	58.0	75.3	31.5	47.7	64.2	23.9	41.3	55.3	21.0	34.9	48.6	14.6	28.2	38.7	11.7	23.2	32.2
12.00	89.3	93.3	99.3	71.4	77.3	93.5	54.6	70.8	86.7	43.1	61.1	77.9	37.6	53.7	71.1	27.2	45.1	60.0	22.4	37.1	51.2	18.1	33.0	45.1	14.1	25.6	36.1	11.2	20.9	29.8
14.00	73.6	86.9	96.5	58.3	74.4	89.3	44.8	67.3	81.9	39.5	54.6	72.5	32.6	49.6	66.0	21.7	43.0	55.4	18.4	35.6	47.4	14.1	31.5	41.2	11.0	24.3	32.6	8.9	20.0	27.1
16.00	68.0	76.0	92.3	54.2	68.4	85.5	41.2	60.4	76.7	33.7	52.5	68.5	28.3	46.5	61.6	20.8	37.9	50.8	17.2	31.6	43.4	13.9	27.8	37.8	10.7	21.6	30.0	8.6	17.6	24.7
20.00	48.9	72.9	86.2	38.6	63.2	77.4	32.2	53.8	68.7	26.5	45.9	60.2	19.2	43.1	54.0	17.7	32.8	44.7	14.7	27.0	37.7	11.4	24.2	32.8	8.2	19.9	26.5	6.5	16.5	21.9

Table C.4. Energy savings on artificial lighting for room ratio of 1.5:1 and window area of 100% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.77																												100.0	100.0	100.0
2.00																												63.2	92.9	97.4
2.19																									100.0	100.0	100.0	51.7	87.0	93.7
2.50																									63.2	92.0	97.1	42.2	78.7	87.7
2.67																									55.4	87.9	94.6	36.8	75.6	84.6
2.77																						100.0	100.0	100.0	52.6	85.4	93.1	36.1	73.1	82.8
3.00																						74.7	96.0	99.0	45.7	80.9	89.6	31.7	69.4	79.1
3.11																			100.0	100.0	100.0	72.7	93.0	98.1	44.4	78.6	88.1	31.5	67.1	77.5
3.33																			90.5	97.4	99.8	64.2	89.4	96.2	39.7	75.1	85.0	30.6	63.0	74.3
3.90																100.0	100.0	100.0	66.4	89.4	96.4	52.8	80.0	90.6	35.5	66.1	78.1	27.6	55.3	67.6
4.00																96.9	98.4	100.0	63.6	88.0	95.6	51.6	78.6	89.6	35.1	64.6	77.0	27.0	54.5	66.8
5.00																67.1	87.5	95.9	51.7	75.1	88.0	40.1	67.5	80.5	28.2	55.5	68.0	22.2	46.2	58.1
5.09													100.0	100.0	100.0	66.5	86.3	95.4	50.4	74.6	87.4	39.8	66.4	79.8	28.1	54.6	67.4	22.0	45.5	57.5
5.33													93.3	96.7	99.8	61.5	84.3	94.0	48.4	72.0	85.6	37.9	64.7	78.1	27.5	52.4	65.5	20.4	44.9	56.1
5.78										100.0	100.0	100.0	78.6	94.2	98.8	57.7	79.4	91.3	43.6	69.0	82.5	35.2	61.0	74.7	24.6	50.2	62.5	19.5	41.7	53.1
6.00										97.1	97.0	99.9	77.9	90.8	98.0	54.9	77.8	90.0	42.3	67.2	81.1	34.1	60.4	73.9	24.4	48.5	61.1	18.4	40.9	51.8
6.67										84.9	92.7	98.9	70.8	84.8	95.6	49.1	72.9	86.2	37.7	62.9	76.9	31.4	55.1	69.2	21.5	45.6	57.3	17.1	37.7	48.4
7.27							100.0	100.0	100.0	76.5	88.2	97.2	63.2	81.7	93.3	47.0	68.0	83.0	34.1	59.8	73.5	30.4	51.1	66.0	21.1	42.1	54.3	16.6	34.9	45.7
8.00							93.4	95.3	99.7	71.0	82.6	95.0	57.4	76.4	89.9	42.7	64.8	79.8	32.7	55.1	69.8	27.1	48.5	62.5	18.4	40.2	51.2	14.5	33.2	42.9
9.11				100.0	100.0	100.0	81.0	88.3	97.8	62.3	77.2	91.4	50.2	71.3	85.7	38.6	58.9	74.8	28.6	50.8	64.9	23.5	45.2	58.1	17.7	35.7	47.1	14.1	29.5	39.4
10.00				91.2	93.3	99.4	70.8	86.2	96.0	55.5	74.2	88.5	47.6	66.1	82.2	34.2	56.4	71.3	27.3	47.2	61.6	22.7	41.6	54.9	17.1	33.1	44.5	12.6	28.9	37.9
11.97	100.0	100.0	100.0	76.2	84.2	96.2	60.5	76.6	90.8	49.1	66.4	82.9	38.9	61.1	76.2	29.7	49.8	64.7	23.1	42.4	55.7	18.5	37.7	49.2	14.2	29.5	39.5	11.3	24.3	32.9
12.00	99.8	99.8	100.0	76.1	84.0	96.2	60.3	76.4	90.6	48.9	66.3	82.8	38.9	61.0	76.2	29.2	50.2	64.7	23.1	42.3	55.6	18.5	37.6	49.1	14.2	29.5	39.5	11.3	24.3	32.9
14.00	83.7	89.2	98.2	62.7	80.3	92.7	51.5	69.7	85.3	41.5	60.2	76.7	34.6	54.9	70.5	25.4	45.4	59.3	20.9	37.5	50.6	16.9	33.4	44.7	11.2	27.8	35.9	8.9	22.9	29.8
16.00	71.6	84.1	95.5	56.6	72.4	88.0	42.2	67.0	80.9	37.7	54.8	71.8	28.9	51.0	65.2	20.9	42.6	54.6	17.5	35.3	46.6	14.0	31.2	40.8	10.8	24.5	32.7	8.7	20.2	27.1
20.00	53.1	75.3	88.4	39.7	69.0	81.3	36.3	57.2	72.7	28.0	50.7	64.5	22.5	45.2	57.5	18.8	35.5	47.6	15.5	29.6	40.5	12.6	26.1	35.4	8.5	22.3	28.9	6.7	18.6	24.1

Table C.5. Energy savings on artificial lighting for room ratio of 1:1 and window area of 25% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.45																												100.0	100.0	100.0
0.53																									100.0	100.0	100.0	56.9	89.6	95.5
0.69																						100.0	100.0	100.0	53.7	83.8	92.5	40.9	72.6	83.8
0.78																			100.0	100.0	100.0	72.0	90.3	97.3	48.7	76.0	87.7	36.6	66.1	78.5
1.00																			73.5	86.1	96.3	55.0	77.3	89.8	37.3	64.7	77.9	29.3	55.2	68.3
1.04																100.0	100.0	100.0	70.0	84.7	95.4	49.8	76.8	88.4	36.7	62.5	76.3	28.5	53.6	66.8
1.20																75.0	91.5	97.9	61.4	77.4	91.3	43.3	69.9	82.9	33.0	56.2	70.7	26.3	47.8	61.5
1.25													100.0	100.0	100.0	71.9	89.3	97.0	58.2	76.2	90.1	42.6	67.4	81.3	32.8	54.3	69.3	26.2	45.9	60.1
1.33													94.6	96.7	99.8	69.3	84.8	95.3	55.7	72.9	88.0	41.5	63.9	78.9	32.3	51.2	67.0	25.8	43.4	58.0
1.43													92.4	90.7	99.3	68.5	79.4	93.5	51.3	70.5	85.6	39.8	60.6	76.3	31.5	48.3	64.6	25.1	40.9	55.7
1.50													91.8	86.5	98.9	67.5	76.2	92.3	49.5	68.2	83.9	39.0	58.2	74.5	30.8	46.4	62.9	24.7	39.4	54.4
1.60													88.1	86.3	98.4	62.8	74.6	90.6	47.9	64.9	81.7	38.2	55.0	72.2	29.9	44.4	61.0	23.7	37.6	52.4
1.65										100.0	100.0	100.0	86.3	85.1	98.0	61.7	72.9	89.6	46.0	64.2	80.7	37.9	53.6	71.2	29.2	43.5	60.0	22.9	37.3	51.7
1.67										99.1	99.1	100.0	82.7	87.6	97.9	59.2	74.1	89.4	45.7	63.8	80.3	37.7	53.2	70.8	28.7	43.4	59.6	22.8	36.8	51.2
1.78										85.8	97.5	99.6	75.4	85.9	96.5	56.4	70.9	87.3	44.0	60.7	78.0	36.7	50.6	68.7	27.4	41.6	57.6	22.0	35.1	49.4
2.00										81.3	88.1	97.8	67.5	80.2	93.6	49.2	67.9	83.7	39.9	56.9	74.1	33.8	47.1	65.0	25.3	38.6	54.1	20.2	32.8	46.4
2.13							100.0	100.0	100.0	80.4	82.7	96.6	66.1	76.3	92.0	48.4	64.3	81.6	38.5	54.4	72.0	32.6	45.2	63.1	23.9	37.4	52.4	18.7	32.0	44.7
2.50				100.0	100.0	100.0	81.2	93.3	98.7	68.3	78.8	93.3	57.9	70.8	87.7	44.5	57.6	76.5	35.2	48.7	66.8	30.1	40.3	58.3	21.7	33.5	47.9	17.7	27.9	40.7
2.67				94.4	96.5	99.8	78.4	87.4	97.3	64.4	76.1	91.5	54.6	68.0	85.5	41.2	56.3	74.3	32.6	47.7	64.7	28.6	39.0	56.4	20.6	32.3	46.2	16.3	27.5	39.3
3.00				85.0	90.0	98.5	73.0	81.2	94.9	55.9	73.6	88.4	47.2	65.7	81.9	35.8	53.8	70.3	29.0	45.0	61.0	25.9	36.8	53.2	16.7	31.9	43.3	13.6	26.6	36.6
3.24	100.0	100.0	100.0	77.7	86.0	96.9	67.0	78.7	93.0	54.8	68.2	85.6	46.3	60.8	78.9	34.5	50.4	67.5	27.0	43.1	58.5	24.4	35.4	51.2	14.5	31.2	41.2	11.9	26.0	34.8
3.33	95.6	97.4	99.9	73.0	86.7	96.4	66.0	76.6	92.0	54.4	66.3	84.6	45.9	59.1	77.9	33.9	49.6	66.7	26.3	42.7	57.8	24.2	34.5	50.4	14.3	30.5	40.4	11.8	25.4	34.2
4.00	60.6	90.0	96.1	61.1	78.3	91.6	48.7	73.7	86.5	39.0	64.4	78.3	31.6	58.4	71.5	23.7	47.9	60.2	18.6	40.7	51.7	14.5	35.8	45.1	11.1	27.7	35.7	9.0	23.4	30.3
5.00	41.7	75.5	85.7	42.0	71.2	83.3	31.1	67.3	77.5	25.9	59.1	69.7	23.0	51.8	62.9	18.5	41.8	52.6	14.7	35.2	44.7	10.8	31.1	38.5	8.5	24.0	30.5	6.9	20.2	25.7
5.33	38.2	74.2	84.1	37.3	68.7	80.4	29.8	63.1	74.1	25.0	55.4	66.6	21.6	49.4	60.3	17.0	40.3	50.4	11.9	35.1	42.8	10.1	29.6	36.7	8.4	22.7	29.2	6.8	19.1	24.6
6.00	27.1	68.6	77.1	27.9	64.7	74.5	22.5	59.3	68.5	20.7	51.6	61.6	18.0	47.4	56.9	14.3	38.0	46.9	8.6	33.6	39.3	7.4	28.5	33.8	7.8	20.4	26.6	6.5	17.2	22.6
6.67	0.0	70.3	70.3	17.0	62.6	69.0	13.8	57.6	63.5	13.5	50.8	57.4	12.8	45.2	52.2	9.8	36.8	43.0	7.5	30.8	36.0	6.9	25.9	31.0	5.3	20.6	24.8	4.4	17.2	20.8
8.00	0.0	58.6	58.6	2.5	57.5	58.6	7.8	50.8	54.6	6.9	45.4	49.2	6.2	40.8	44.5	5.0	33.6	36.9	0.0	30.8	30.8	3.0	24.6	26.9	2.4	19.4	21.3	2.0	16.3	18.0
10.00	0.0	46.9	46.9	0.0	46.7	46.7	0.0	43.5	43.5	0.0	39.4	39.4	0.0	35.8	35.8	0.0	29.9	29.9	0.0	24.6	24.6	0.0	21.5	21.5	0.0	17.1	17.1	0.0	14.4	14.4
12.00	0.0	39.1	39.1	0.0	38.9	38.9	0.0	36.3	36.3	0.0	32.9	32.9	0.0	29.8	29.8	0.0	24.9	24.9	0.0	20.5	20.5	0.0	17.9	17.9	0.0	14.3	14.3	0.0	12.0	12.0
14.00	0.0	33.5	33.5	0.0	33.4	33.4	0.0	31.1	31.1	0.0	28.2	28.2	0.0	25.6	25.6	0.0	21.3	21.3	0.0	17.6	17.6	0.0	15.4	15.4	0.0	12.2	12.2	0.0	10.3	10.3
16.00	0.0	29.3	29.3	0.0	29.2	29.2	0.0	27.2	27.2	0.0	24.8	24.8	0.0	22.4	22.4	0.0	18.7	18.7	0.0	15.4	15.4	0.0	13.4	13.4	0.0	10.7	10.7	0.0	9.0	9.0
20.00	0.0	23.5	23.5	0.0	23.4	23.4	0.0	21.8	21.8	0.0	19.7	19.7	0.0	17.9	17.9	0.0	14.9	14.9	0.0	12.3	12.3	0.0	10.7	10.7	0.0	8.6	8.6	0.0	7.2	7.2

Table C.6. Energy savings on artificial lighting for room ratio of 1:1 and window area of 50% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.82																												100.0	100.0	100.0
0.97																									100.0	100.0	100.0	61.90	87.20	95.1
1.00																									82.5	98.3	99.7	57.5	86.0	94.1
1.20																									59.2	88.6	95.3	42.7	76.1	86.3
1.25																									56.7	85.8	93.9	41.0	73.7	84.5
1.30																						100.0	100.0	100.0	55.1	83.0	92.4	38.0	72.2	82.8
1.33																						87.0	98.8	99.8	52.3	82.3	91.6	37.3	70.9	81.8
1.50																						70.9	90.7	97.3	45.8	75.3	86.6	34.3	64.4	76.6
1.56																			100.0	100.0	100.0	64.2	89.1	96.1	44.3	73.0	85.0	33.6	62.2	74.9
1.60																			86.6	98.6	99.8	63.2	87.2	95.3	42.2	72.2	83.9	32.0	61.6	73.9
1.67																			76.6	95.7	99.0	61.3	84.2	93.9	40.2	70.2	82.2	29.6	60.3	72.1
1.93																100.0	100.0	100.0	66.0	86.9	95.5	48.9	77.6	88.6	34.4	63.5	76.1	26.3	53.9	66.0
2.00																90.3	98.1	99.8	63.6	84.6	94.4	47.3	75.8	87.2	32.8	62.1	74.5	26.0	52.2	64.6
2.32													100.0	100.0	100.0	70.6	89.0	96.8	55.2	77.2	89.8	42.4	67.3	81.2	31.3	54.5	68.7	24.8	45.8	59.2
2.50													92.5	94.7	99.6	67.2	83.7	94.7	51.6	73.1	87.0	40.7	63.5	78.4	29.5	51.8	66.0	23.4	43.5	56.7
2.67													89.1	91.0	99.0	62.5	81.2	93.0	47.4	70.6	84.5	38.9	60.5	75.9	28.6	49.0	63.6	22.7	41.1	54.5
2.97										100.0	100.0	100.0	79.0	88.5	97.6	57.2	75.3	89.4	44.5	65.0	80.6	36.3	56.1	72.0	27.4	44.8	59.9	21.1	38.4	51.4
3.00										98.2	99.1	100.0	78.3	87.6	97.3	56.8	74.9	89.2	44.3	64.7	80.3	36.2	55.5	71.6	27.2	44.5	59.6	21.0	38.0	51.0
3.33										82.0	92.8	98.7	67.9	84.1	94.9	49.2	71.8	85.7	40.3	60.6	76.5	33.7	51.8	68.0	25.1	41.6	56.3	20.1	34.9	48.0
3.61							100.0	100.0	100.0	79.3	87.5	97.4	64.9	79.0	92.6	47.6	67.2	82.8	38.8	56.8	73.6	32.3	48.7	65.3	23.7	39.4	53.8	18.4	33.5	45.7
4.00							89.4	94.2	99.4	69.9	84.6	95.4	60.1	74.1	89.7	45.0	62.2	79.2	34.9	54.1	70.1	29.6	45.9	61.9	21.9	36.9	50.7	16.9	31.8	43.3
4.48				100.0	100.0	100.0	79.9	89.0	97.8	65.5	78.0	92.4	54.7	69.3	86.1	40.8	58.0	75.1	32.4	50.1	66.3	27.0	42.9	58.3	19.7	34.7	47.6	16.0	28.8	40.2
5.00				89.8	92.3	99.2	74.0	83.2	95.6	58.4	73.4	88.9	48.6	66.5	82.8	37.0	54.6	71.4	31.4	45.5	62.6	26.0	39.2	55.0	17.4	32.8	44.5	14.1	27.3	37.6
5.33				85.5	90.5	98.6	70.9	80.0	94.2	57.1	70.0	87.1	47.8	62.4	80.4	35.7	52.3	69.3	29.9	43.7	60.5	25.2	37.3	53.1	17.3	30.8	42.8	14.0	25.7	36.1
6.00				75.8	84.1	96.2	64.5	74.8	91.1	50.0	67.6	83.8	43.3	58.3	76.4	33.2	48.1	65.3	26.6	41.4	57.0	22.5	35.2	49.8	16.1	28.4	39.9	12.2	24.5	33.7
6.11	100.0	100.0	100.0	75.0	84.9	96.2	63.3	73.4	90.2	49.7	66.4	83.1	42.5	58.2	76.0	32.8	47.9	65.0	26.5	40.7	56.4	22.3	34.9	49.4	14.9	28.9	39.5	12.2	24.0	33.3
6.67	91.0	95.6	99.6	71.7	77.7	93.7	60.4	69.2	87.8	48.4	60.8	79.8	40.2	55.3	73.3	30.2	45.6	62.0	25.4	38.3	54.0	21.5	32.5	47.0	14.7	26.6	37.4	11.9	22.1	31.4
8.00	78.7	86.1	97.0	61.7	73.0	89.7	49.8	66.2	83.0	40.9	56.5	74.3	35.6	49.2	67.3	27.1	40.3	56.5	22.1	34.1	48.7	18.0	29.8	42.4	13.7	22.9	33.5	10.2	19.9	28.1
10.00	61.4	74.3	90.1	51.8	64.7	83.0	44.0	55.0	74.8	35.6	49.2	67.3	29.6	43.2	60.0	22.5	35.6	50.1	17.5	30.9	43.0	14.9	26.0	37.0	11.4	20.0	29.1	9.3	16.7	24.4
12.00	54.7	66.1	84.6	39.5	59.9	75.7	34.3	53.8	69.6	27.5	46.5	61.2	23.8	41.0	55.0	17.5	33.3	45.0	13.5	28.8	38.4	11.5	24.4	33.1	8.8	18.9	26.0	7.2	15.7	21.8
14.00	31.3	70.4	79.7	29.4	58.6	70.8	25.5	50.1	62.8	22.0	42.6	55.2	19.2	38.2	50.1	15.0	30.3	40.8	12.5	25.3	34.6	10.6	21.7	30.0	8.2	16.8	23.6	6.7	13.7	19.5
16.00	21.5	65.0	72.5	18.9	56.4	64.6	16.2	49.1	57.3	14.3	42.4	50.6	12.2	38.2	45.7	8.9	31.2	37.3	10.3	24.0	31.8	9.1	20.3	27.6	6.7	16.0	21.6	5.8	14.3	19.3
20.00	0.0	57.6	57.6	3.1	51.5	53.0	4.8	45.4	48.0	4.9	39.3	42.3	4.7	34.5	37.6	4.0	27.8	30.7	3.4	23.7	26.3	2.9	20.4	22.7	2.3	16.0	17.9	1.9	13.2	14.8

Table C.7. Energy savings on artificial lighting for room ratio of 1:1 and window area of 73.2% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.14																												100.0	100.0	100.0
1.20																												66.1	96.6	98.8
1.25																												65.8	92.8	97.5
1.33																												56.2	89.4	95.4
1.36																									100.0	100.0	100.0	50.8	88.7	94.4
1.43																									84.0	95.7	99.3	46.5	85.4	92.2
1.50																									74.7	93.7	98.4	43.6	82.2	90.0
1.60																									58.9	90.8	96.2	38.7	78.9	87.1
1.67																									56.3	87.7	94.6	37.6	75.8	84.9
1.78																						100.0	100.0	100.0	49.1	84.0	91.9	35.3	72.0	81.9
2.00																						66.9	93.1	97.7	42.7	77.0	86.8	30.5	66.2	76.5
2.10																			100.0	100.0	100.0	62.8	89.2	96.0	39.8	74.5	84.6	29.7	63.4	74.3
2.50																			65.9	88.7	96.1	48.9	79.2	89.4	32.8	65.6	76.9	25.9	55.3	66.9
2.55																100.0	100.0	100.0	64.7	87.6	95.6	48.0	78.0	88.6	32.5	64.5	76.0	25.6	54.3	66.0
2.67																83.4	97.6	99.6	62.0	84.5	94.1	45.1	75.8	86.7	32.1	61.8	74.1	25.2	52.1	64.2
3.00																70.1	90.4	97.1	54.2	78.2	90.0	41.4	69.1	81.9	30.0	56.2	69.3	23.2	47.7	59.8
3.12													100.0	100.0	100.0	67.8	87.7	96.0	52.4	76.1	88.6	40.6	66.8	80.3	29.0	54.7	67.8	22.8	46.1	58.4
3.33													92.3	95.3	99.6	65.8	82.9	94.2	47.3	73.8	86.2	38.0	64.1	77.7	27.8	51.9	65.3	22.4	43.4	56.1
3.86										100.0	100.0	100.0	77.0	89.7	97.6	55.5	75.8	89.2	41.2	66.8	80.5	34.3	57.5	72.1	25.3	46.4	60.0	20.2	38.9	51.2
4.00										89.3	98.3	99.8	71.4	89.2	96.9	51.6	75.5	88.1	40.3	64.9	79.0	33.9	55.6	70.7	24.8	45.2	58.8	19.0	38.5	50.2
4.69							100.0	100.0	100.0	77.6	87.4	97.2	64.2	78.4	92.3	46.7	66.7	82.3	35.6	58.2	73.1	29.9	50.0	65.0	21.8	40.6	53.5	16.8	34.7	45.7
5.00							90.6	95.9	99.6	70.0	86.3	95.9	59.4	76.8	90.6	43.7	64.5	80.0	34.0	55.7	70.8	28.2	48.3	62.9	19.9	39.4	51.5	16.1	32.8	43.6
5.33							85.8	92.3	98.9	68.2	81.0	94.0	55.4	74.3	88.5	41.0	61.9	77.5	32.2	53.3	68.3	26.9	46.0	60.5	19.5	37.3	49.5	15.2	31.5	41.9
5.75				100.0	100.0	100.0	78.1	88.2	97.4	62.8	78.3	91.9	52.8	69.7	85.7	37.9	59.4	74.8	31.6	49.7	65.6	26.0	43.3	58.0	17.7	35.9	47.2	14.1	30.0	39.9
6.00				91.4	98.1	99.8	75.8	85.9	96.6	59.2	77.2	90.7	48.9	69.2	84.3	36.7	57.9	73.4	30.3	48.6	64.2	25.7	41.8	56.8	17.4	34.6	46.0	14.1	28.8	38.8
6.67				84.8	91.4	98.7	70.1	80.6	94.2	56.5	70.5	87.2	47.3	63.0	80.5	34.6	53.2	69.4	27.6	45.9	60.8	22.7	39.9	53.5	16.9	31.4	43.0	13.5	26.5	36.4
7.66	100.0	100.0	100.0	74.0	84.5	96.0	62.2	75.4	90.7	49.2	66.2	82.8	41.1	59.1	75.9	30.4	49.5	64.9	25.6	41.2	56.3	21.5	35.4	49.3	14.8	29.1	39.6	11.9	24.2	33.2
8.00	95.3	95.8	99.8	72.4	80.9	94.7	60.9	72.2	89.1	48.5	63.4	81.2	40.2	57.6	74.6	30.1	47.4	63.2	24.5	40.9	55.4	19.3	35.8	48.2	14.6	28.0	38.5	11.7	23.2	32.2
10.00	75.7	85.2	96.4	58.6	73.3	88.9	48.7	65.5	82.3	39.2	57.2	74.0	33.1	50.9	67.2	25.0	41.3	56.0	21.0	34.8	48.5	16.1	31.5	42.5	11.9	24.5	33.5	9.8	20.3	28.1
12.00	62.2	76.1	91.0	52.8	66.4	84.1	44.1	56.5	75.7	36.1	48.9	67.3	28.9	45.5	61.3	22.1	36.6	50.6	17.4	31.5	43.4	14.7	27.0	37.7	11.3	20.9	29.8	9.2	17.2	24.8
14.00	57.7	70.0	87.3	40.4	63.2	78.1	36.0	54.1	70.6	29.3	47.2	62.7	24.6	41.9	56.2	18.4	34.3	46.4	14.0	29.6	39.5	11.9	25.3	34.2	9.0	19.8	27.0	7.4	16.4	22.6
16.00	52.4	61.2	81.5	39.2	55.3	72.8	33.4	49.6	66.4	27.2	42.8	58.4	22.9	37.7	52.0	17.3	30.6	42.6	13.7	26.3	36.4	11.5	22.4	31.3	8.8	17.4	24.7	7.1	14.4	20.5
20.00	37.4	59.8	74.8	27.7	52.9	65.9	23.8	45.5	58.5	19.3	39.6	51.3	16.2	35.0	45.5	12.2	28.5	37.2	9.7	24.5	31.8	8.0	21.0	27.3	6.0	16.4	21.4	5.0	13.6	17.9

Table C.8. Energy savings on artificial lighting for room ratio of 1:1 and window area of 100% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.49																												100.0	100.0	100.0
1.50																												97.8	99.7	100.0
1.60																												65.9	94.4	98.1
1.67																												57.9	91.9	96.6
1.77																									100.0	100.0	100.0	46.8	88.7	94.0
2.00																									59.5	93.0	97.2	37.7	80.7	88.0
2.28																						100.0	100.0	100.0	46.2	84.5	91.7	32.1	72.9	81.6
2.50																						67.2	94.3	98.1	40.6	78.8	87.4	29.5	67.4	77.0
2.67																			100.0	100.0	100.0	60.5	89.6	95.9	37.1	75.0	84.3	26.3	64.6	73.9
3.00																			69.7	91.8	97.5	48.9	82.8	91.2	32.4	68.7	78.8	25.3	58.0	68.6
3.20																100.0	100.0	100.0	63.1	87.7	95.5	44.4	79.2	88.4	31.5	64.8	75.9	23.6	55.4	65.9
3.33																82.3	97.8	99.6	58.6	85.9	94.2	42.8	76.7	86.7	30.6	62.7	74.1	23.3	53.3	64.2
3.88													100.0	100.0	100.0	67.1	87.5	95.9	47.6	77.8	88.4	37.9	68.0	80.1	27.5	55.4	67.7	20.9	47.3	58.3
4.00													93.0	98.3	99.9	64.7	86.1	95.1	45.6	76.3	87.1	37.3	66.3	78.9	26.3	54.5	66.5	20.7	46.0	57.2
4.69										100.0	100.0	100.0	74.9	91.0	97.7	49.5	78.8	89.3	40.0	67.6	80.6	32.7	58.9	72.3	22.8	48.7	60.4	18.2	40.9	51.7
5.00										82.8	96.1	99.3	67.4	87.5	95.9	48.6	74.3	86.8	38.0	64.4	77.9	30.2	56.7	69.8	22.1	46.0	57.9	17.0	39.2	49.5
5.33										80.5	90.6	98.2	64.7	83.2	94.1	46.8	70.8	84.5	35.3	62.1	75.5	29.2	53.8	67.3	20.1	44.5	55.7	16.1	37.3	47.4
5.61							100.0	100.0	100.0	76.9	87.9	97.2	62.7	79.8	92.5	44.6	68.1	82.3	33.8	59.8	73.4	27.2	52.5	65.4	19.7	42.6	53.9	15.6	35.9	45.9
6.00							89.5	96.2	99.6	69.1	85.8	95.6	56.0	77.9	90.3	40.8	65.8	79.8	31.9	57.1	70.8	26.8	49.2	62.8	17.8	41.2	51.7	14.2	34.5	43.8
6.67							78.2	89.9	97.8	60.8	81.0	92.6	49.4	73.6	86.6	36.6	61.8	75.8	30.0	52.5	66.8	25.5	45.1	59.1	17.2	37.5	48.3	13.9	31.2	40.8
6.77				100.0	100.0	100.0	77.2	89.8	97.7	59.6	80.7	92.2	48.8	72.5	85.9	36.4	60.9	75.1	29.9	51.8	66.2	24.9	44.9	58.6	17.2	36.9	47.8	13.9	30.9	40.5
8.00				81.1	90.9	98.3	64.8	81.9	93.6	52.5	71.5	86.5	43.1	64.4	79.7	32.3	53.9	68.8	26.1	46.2	60.2	21.8	40.2	53.2	14.8	32.9	42.8	11.9	27.5	36.1
8.80	100.0	100.0	100.0	73.4	85.1	96.0	61.4	76.1	90.8	48.6	67.1	83.1	40.1	61.0	76.6	30.0	50.4	65.3	23.3	44.1	57.1	19.0	38.3	50.0	14.3	30.3	40.3	11.6	25.3	34.0
10.00	82.7	91.9	98.6	67.7	77.1	92.6	56.0	70.9	87.2	44.5	61.6	78.7	36.7	55.5	71.8	27.3	46.5	61.1	22.0	39.4	52.7	17.6	34.9	46.4	12.0	28.6	37.2	10.0	23.8	31.4
12.00	66.4	83.7	94.5	56.1	72.0	87.7	46.1	64.2	80.7	37.1	55.9	72.3	31.1	49.7	65.3	23.4	41.4	55.1	18.1	35.9	47.5	15.2	30.7	41.2	11.4	24.2	32.8	9.2	20.2	27.5
14.00	60.5	73.3	89.5	49.8	64.2	82.0	37.0	60.7	75.2	30.4	51.8	66.5	26.4	45.3	59.7	19.7	37.7	50.0	14.1	33.7	43.0	12.0	28.9	37.4	9.0	22.7	29.7	7.5	18.9	25.0
16.00	55.4	68.3	85.9	39.8	61.7	76.9	34.9	53.1	69.5	28.2	46.5	61.6	23.5	42.5	56.0	17.7	34.7	46.3	13.8	29.5	39.2	11.6	25.6	34.2	8.8	20.0	27.0	7.1	16.6	22.5
20.00	39.3	65.4	79.0	28.5	58.0	70.0	24.4	50.1	62.3	19.7	43.7	54.8	16.4	38.8	48.8	12.3	31.7	40.1	11.7	25.3	34.0	9.8	22.0	29.6	6.1	18.5	23.5	5.1	15.3	19.6

Table C.9. Energy savings on artificial lighting for room ratio of 1:1.5 and window area of 25% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.31																												100.0	100.0	100.0
0.42																									100.0	100.0	100.0	51.1	84.0	92.2
0.51																						100.0	100.0	100.0	49.2	88.5	94.2	36.6	73.7	83.3
0.61																			100.0	100.0	100.0	58.8	91.1	96.3	42.7	75.6	86.0	32.4	63.5	75.3
0.71																100.0	100.0	100.0	68.2	89.0	96.5	53.2	80.8	91.0	37.4	67.2	79.5	28.8	56.4	69.0
0.96													100.0	100.0	100.0	65.6	83.7	94.4	47.1	73.7	86.1	38.9	65.3	78.8	28.8	53.9	67.2	22.5	45.1	57.5
1.00													88.9	96.9	99.7	64.6	80.6	93.1	45.5	71.4	84.4	37.8	63.4	77.2	27.2	52.7	65.6	21.4	44.1	56.1
1.07										100.0	100.0	100.0	79.1	93.3	98.6	60.7	77.5	91.2	41.7	68.6	81.7	35.7	60.5	74.6	26.6	49.7	63.1	21.3	41.3	53.8
1.20										81.8	94.3	99.0	73.8	84.7	96.0	53.4	73.0	87.4	39.9	62.2	77.3	34.9	54.3	70.2	25.9	44.8	59.1	20.9	37.1	50.2
1.25										78.4	91.5	98.2	73.4	81.3	95.0	52.1	70.9	86.1	38.7	60.5	75.8	34.4	52.6	68.9	25.8	43.0	57.7	20.5	35.9	49.0
1.33										77.7	86.0	96.9	70.8	78.2	93.6	49.4	68.2	83.9	38.0	57.5	73.7	33.8	49.8	66.8	25.1	41.0	55.8	20.1	34.1	47.3
1.43							100.0	100.0	100.0	75.8	81.3	95.5	64.4	77.0	91.8	46.8	65.2	81.5	37.2	53.8	71.0	32.1	47.5	64.4	24.2	38.8	53.6	19.5	32.3	45.5
1.50							85.0	96.5	99.5	70.9	81.6	94.6	56.9	77.9	90.5	45.5	63.0	79.8	36.1	52.2	69.5	31.1	46.1	62.9	23.4	37.7	52.3	18.9	31.2	44.2
1.60							83.2	90.5	98.4	66.6	78.7	92.9	55.0	73.7	88.2	42.4	60.9	77.5	34.9	49.6	67.2	29.6	44.3	60.8	22.4	36.0	50.3	18.0	29.9	42.5
1.67							82.0	86.7	97.6	63.0	77.8	91.8	54.4	71.3	86.9	41.4	59.2	76.1	33.7	48.8	66.1	28.7	43.2	59.5	21.9	34.9	49.2	17.7	29.0	41.6
1.88				100.0	100.0	100.0	76.3	81.3	95.6	61.6	69.1	88.1	53.4	63.4	82.9	37.4	55.5	72.1	31.6	44.7	62.2	26.1	40.3	55.9	20.1	32.5	46.1	16.3	26.8	38.7
2.00				81.7	95.9	99.2	70.9	80.5	94.3	58.3	67.4	86.4	50.6	62.5	81.5	36.8	52.1	69.7	30.0	43.2	60.2	25.5	38.4	54.1	18.7	31.8	44.6	15.1	26.3	37.4
2.34	100.0	100.0	100.0	77.3	83.4	96.2	61.6	73.6	89.9	54.2	60.5	81.9	43.3	58.0	76.2	34.1	46.5	64.7	28.2	38.3	55.7	22.5	35.0	49.6	17.6	27.9	40.6	14.2	23.1	34.0
2.50	90.8	95.9	99.6	75.6	78.1	94.7	60.3	68.9	87.7	52.9	58.0	80.2	40.9	56.2	74.1	31.1	46.1	62.9	26.4	37.4	53.9	21.2	33.8	47.8	16.7	26.9	39.1	13.7	22.1	32.8
2.67	88.1	89.8	98.8	67.0	79.7	93.3	57.8	66.5	85.9	49.9	57.3	78.6	37.9	54.5	71.7	29.0	44.7	60.7	24.5	36.7	52.2	19.0	33.5	46.1	14.9	26.8	37.7	12.4	21.8	31.5
3.00	82.0	86.2	97.5	60.4	75.0	90.1	49.9	65.9	82.9	41.2	56.5	74.4	36.4	49.4	67.8	26.8	41.2	57.0	23.8	33.0	48.9	16.2	32.0	43.0	12.6	25.5	34.9	10.5	21.0	29.3
3.33	65.3	85.6	95.0	54.2	70.5	86.5	43.6	63.2	79.2	34.5	55.4	70.8	30.7	49.5	65.0	24.5	38.7	53.7	20.3	32.6	46.3	14.8	29.9	40.3	11.5	23.9	32.7	9.5	19.7	27.3
4.00	41.9	76.2	86.2	36.7	68.3	79.9	30.6	59.0	71.5	22.5	53.4	63.9	24.2	44.6	58.0	17.1	37.4	48.1	12.8	32.5	41.1	11.2	27.5	35.6	8.6	22.3	29.0	7.5	18.1	24.2
5.00	25.3	65.6	74.3	21.3	60.2	68.7	22.3	51.7	62.5	16.2	46.9	55.5	16.8	40.7	50.7	12.0	33.7	41.7	9.7	28.0	35.0	8.7	23.8	30.4	6.7	19.2	24.6	5.6	16.2	20.9
5.33	20.9	64.8	72.2	20.2	56.5	65.3	16.9	52.6	60.6	13.7	45.6	53.1	16.2	38.2	48.2	10.3	32.6	39.5	8.6	27.3	33.6	8.4	22.6	29.1	6.6	18.2	23.6	5.4	15.3	19.9
6.00	13.3	60.9	66.1	11.8	56.0	61.2	11.5	48.3	54.2	12.3	40.5	47.8	10.7	37.6	44.3	7.5	31.4	36.5	6.9	25.4	30.5	7.3	20.8	26.6	6.0	16.6	21.6	5.0	13.8	18.1
6.67	0.0	58.4	58.4	9.5	50.4	55.1	7.9	45.6	49.9	9.2	38.6	44.2	8.1	35.5	40.7	6.4	28.7	33.3	6.0	23.5	28.1	5.2	20.6	24.7	4.1	16.5	19.9	3.4	13.8	16.7
8.00	0.0	48.7	48.7	0.0	45.7	45.7	4.5	39.6	42.3	0.0	37.3	37.3	4.2	32.0	34.9	0.0	28.1	28.1	2.3	22.5	24.3	2.1	19.4	21.1	1.7	15.6	17.0	1.5	13.1	14.4
10.00	0.0	38.9	38.9	0.0	36.6	36.6	0.0	33.8	33.8	0.0	29.8	29.8	0.0	28.0	28.0	0.0	22.5	22.5	0.0	19.4	19.4	0.0	16.9	16.9	0.0	13.7	13.7	0.0	11.5	11.5
12.00	0.0	32.4	32.4	0.0	30.5	30.5	0.0	28.2	28.2	0.0	24.9	24.9	0.0	23.3	23.3	0.0	18.8	18.8	0.0	16.1	16.1	0.0	14.1	14.1	0.0	11.4	11.4	0.0	9.6	9.6
14.00	0.0	27.8	27.8	0.0	26.1	26.1	0.0	24.2	24.2	0.0	21.3	21.3	0.0	20.0	20.0	0.0	16.1	16.1	0.0	13.8	13.8	0.0	12.1	12.1	0.0	9.8	9.8	0.0	8.2	8.2
16.00	0.0	24.3	24.3	0.0	22.9	22.9	0.0	21.1	21.1	0.0	18.6	18.6	0.0	17.5	17.5	0.0	14.1	14.1	0.0	12.1	12.1	0.0	10.6	10.6	0.0	8.6	8.6	0.0	7.2	7.2
20.00	0.0	19.5	19.5	0.0	18.3	18.3	0.0	16.9	16.9	0.0	14.9	14.9	0.0	14.0	14.0	0.0	11.3	11.3	0.0	9.7	9.7	0.0	8.5	8.5	0.0	6.9	6.9	0.0	5.8	5.8

Table C.10. Energy savings on artificial lighting for room ratio of 1:1.5 and window area of 50% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.61																												100.0	100.0	100.0
0.78																									100.0	100.0	100.0	52.9	83.3	92.1
0.96																						100.0	100.0	100.0	49.7	87.0	93.5	36.8	72.8	82.8
1.00																						87.3	97.4	99.7	48.8	83.7	91.7	35.8	70.3	80.9
1.16																			100.0	100.0	100.0	64.6	89.3	96.2	39.7	75.4	85.2	30.4	62.9	74.2
1.20																			81.0	98.4	99.7	61.3	87.6	95.2	38.6	73.3	83.6	29.7	61.2	72.7
1.25																			77.0	94.9	98.8	53.4	86.5	93.7	37.5	70.8	81.8	28.8	59.3	71.0
1.33																			65.8	92.1	97.3	51.7	81.6	91.1	35.2	67.7	79.1	27.3	56.5	68.4
1.40																100.0	100.0	100.0	61.9	88.3	95.5	49.4	78.7	89.2	34.2	64.8	76.8	26.1	54.4	66.3
1.43																92.0	98.7	99.9	61.7	86.4	94.8	49.1	77.0	88.3	32.9	64.1	75.9	25.1	53.9	65.5
1.50																76.8	95.8	99.0	59.2	83.5	93.3	45.1	75.2	86.4	30.6	62.4	73.9	23.6	52.3	63.6
1.60																76.2	90.1	97.6	51.9	81.2	91.0	40.0	72.8	83.7	29.0	59.4	71.2	22.7	49.6	61.0
1.67																69.6	88.5	96.5	48.0	79.2	89.2	39.0	70.1	81.8	28.1	57.3	69.3	21.4	48.4	59.4
1.78													100.0	100.0	100.0	64.7	84.9	94.7	45.4	75.3	86.5	36.6	67.0	79.1	26.5	54.8	66.8	21.0	45.5	56.9
1.98										100.0	100.0	100.0	77.7	93.8	98.6	57.4	79.2	91.1	41.7	69.4	82.2	34.7	61.1	74.6	25.7	49.7	62.6	20.4	41.4	53.4
2.00										99.2	99.1	100.0	76.6	93.2	98.4	57.3	78.4	90.8	41.6	68.7	81.7	34.6	60.5	74.2	25.6	49.2	62.2	20.3	41.0	53.0
2.50										77.4	85.0	96.6	64.4	79.4	92.7	46.4	67.8	82.7	36.6	57.9	73.3	30.4	51.0	65.9	22.6	41.4	54.6	18.1	34.3	46.2
2.57							100.0	100.0	100.0	74.6	84.8	96.1	59.7	80.0	91.9	46.0	66.3	81.8	36.0	56.6	72.2	30.2	49.7	64.9	22.3	40.4	53.7	17.9	33.5	45.4
2.67							85.1	97.3	99.6	70.0	84.0	95.2	55.9	78.9	90.7	44.0	65.1	80.5	35.4	54.8	70.8	29.5	48.2	63.5	21.8	39.3	52.5	17.8	32.4	44.4
3.00							80.4	86.6	97.4	62.9	79.2	92.3	53.6	70.9	86.5	39.8	60.3	76.1	32.4	50.6	66.6	27.0	44.7	59.6	20.4	36.0	49.1	16.4	30.0	41.5
3.16				100.0	100.0	100.0	76.0	85.4	96.5	59.7	77.1	90.8	51.6	68.9	84.9	39.1	57.7	74.2	31.6	48.7	64.9	26.3	42.9	57.9	19.8	34.6	47.5	15.9	28.7	40.0
3.33				89.8	96.1	99.6	72.8	82.8	95.3	57.6	74.2	89.1	50.6	66.3	83.4	36.7	56.6	72.5	30.5	47.3	63.4	25.3	41.7	56.4	19.1	33.4	46.1	15.2	27.9	38.9
4.00	100.0	100.0	100.0	77.4	84.2	96.4	61.7	75.1	90.5	53.3	64.3	83.3	43.3	59.2	76.9	32.8	49.4	66.0	26.3	42.1	57.3	21.2	37.5	50.8	16.0	30.3	41.5	12.9	25.1	34.8
5.00	85.5	81.8	97.4	63.5	73.9	90.5	52.5	66.5	84.1	44.9	56.6	76.1	37.6	50.6	69.2	28.7	42.4	58.9	23.8	35.4	50.8	18.2	32.2	44.5	13.9	25.8	36.1	11.2	21.3	30.1
5.33	82.2	84.2	97.2	62.5	69.3	88.5	51.0	62.4	81.6	43.7	54.4	74.3	35.4	49.5	67.4	27.5	40.8	57.1	21.7	35.2	49.3	17.8	30.7	43.0	13.6	24.4	34.7	11.1	20.2	29.1
6.00	72.0	79.4	94.2	54.8	68.3	85.7	46.0	59.4	78.1	36.6	53.8	70.7	32.5	45.8	63.4	25.5	37.8	53.7	20.3	32.4	46.1	15.6	28.9	40.0	12.0	23.1	32.3	9.7	19.1	26.9
6.67	67.0	71.4	90.6	51.2	63.0	81.9	41.2	56.5	74.4	34.9	49.7	67.3	31.3	42.2	60.3	23.0	36.2	50.9	18.6	30.5	43.4	15.4	26.2	37.6	11.7	20.9	30.2	9.4	17.4	25.2
8.00	55.0	68.9	86.0	46.7	55.9	76.5	38.1	49.1	68.5	29.8	44.4	61.0	25.9	39.2	54.9	21.0	31.8	46.1	15.8	27.5	39.0	12.6	24.1	33.7	9.6	19.4	27.1	7.8	16.0	22.6
10.00	45.8	60.2	78.4	36.1	52.8	69.8	29.3	46.5	62.2	25.1	39.4	54.6	22.1	34.4	48.9	16.5	28.5	40.3	13.7	23.6	34.1	11.7	20.2	29.5	9.1	15.8	23.5	7.3	13.1	19.4
12.00	31.7	60.0	72.7	25.7	50.8	63.4	23.5	42.9	56.3	20.2	35.9	48.8	17.6	31.6	43.6	13.2	26.4	36.1	10.8	22.0	30.4	9.1	18.8	26.2	7.1	14.9	20.9	5.7	12.3	17.3
14.00	18.7	55.6	63.9	17.4	47.9	57.0	14.9	41.6	50.3	16.3	33.2	44.1	13.5	30.1	39.5	11.4	24.2	32.8	9.4	19.9	27.4	8.1	16.8	23.5	6.4	13.2	18.8	5.3	10.9	15.6
16.00	0.0	56.1	56.1	9.3	46.2	51.2	8.6	39.9	45.1	10.2	34.4	41.1	7.6	32.1	37.3	7.8	24.5	30.4	6.2	20.3	25.2	5.2	17.5	21.8	4.6	13.9	17.9	3.2	11.5	14.3
20.00	0.0	44.9	44.9	0.0	40.7	40.7	0.0	36.8	36.8	1.9	32.8	34.1	2.5	28.4	30.2	2.4	22.8	24.7	2.2	18.9	20.7	2.0	16.1	17.8	1.5	13.0	14.3	1.1	10.8	11.8

Table C.11. Energy savings on artificial lighting for room ratio of 1:1.5 and window area of 73.2% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
0.87																												100.0	100.0	100.0
1.09																									100.0	100.0	100.0	46.8	85.6	92.3
1.20																									66.3	92.3	97.4	37.7	79.9	87.5
1.25																									54.3	91.2	96.0	36.5	77.3	85.6
1.33																									48.4	86.7	93.1	32.6	73.9	82.4
1.35																						100.0	100.0	100.0	47.1	86.0	92.6	32.1	72.9	81.6
1.43																						87.3	95.4	99.4	42.9	82.1	89.8	30.3	69.5	78.7
1.50																						66.8	95.1	98.4	39.0	79.4	87.4	29.4	66.7	76.5
1.60																						60.2	90.6	96.3	37.4	75.0	84.4	27.3	63.5	73.5
1.61																			100.0	100.0	100.0	58.3	90.1	95.9	36.8	74.8	84.1	27.3	63.1	73.2
1.67																			77.1	97.6	99.5	51.9	88.2	94.3	36.1	72.4	82.4	26.3	61.3	71.5
1.91																100.0	100.0	100.0	61.6	87.9	95.4	44.9	79.7	88.8	30.0	65.8	76.1	23.4	55.1	65.6
2.00																76.9	97.5	99.4	55.8	85.8	93.7	41.1	77.5	86.7	29.4	63.1	73.9	22.6	53.0	63.6
2.39													100.0	100.0	100.0	61.7	86.2	94.7	43.3	75.8	86.3	35.0	67.2	78.7	25.7	54.7	66.3	20.4	45.7	56.8
2.50													87.6	96.4	99.6	58.2	83.6	93.1	41.7	73.2	84.4	34.4	64.6	76.8	25.4	52.4	64.5	19.9	44.0	55.1
2.67													74.6	93.8	98.4	55.2	79.2	90.7	40.8	69.0	81.6	33.0	61.1	73.9	24.1	49.9	62.0	18.8	41.9	52.8
2.70										100.0	100.0	100.0	74.4	92.7	98.1	53.9	78.9	90.3	40.5	68.4	81.2	32.9	60.6	73.6	23.9	49.5	61.6	18.8	41.5	52.5
3.00										82.2	93.2	98.8	68.2	85.5	95.4	46.8	74.3	86.3	37.0	63.4	76.9	30.4	56.1	69.4	22.5	45.5	57.8	17.9	37.9	49.0
3.33										74.1	87.2	96.7	56.2	82.1	92.2	42.2	69.5	82.4	33.7	59.1	72.9	27.9	52.1	65.5	20.9	42.0	54.1	16.6	35.1	45.9
3.36							100.0	100.0	100.0	73.3	87.3	96.6	55.8	81.9	92.0	42.1	68.8	81.9	33.5	58.6	72.5	27.7	51.6	65.0	20.8	41.8	53.9	16.5	34.8	45.6
4.00							76.6	87.9	97.2	59.7	79.4	91.7	51.4	70.8	85.8	37.0	60.5	75.1	29.5	51.6	65.9	24.8	45.3	58.9	18.2	36.9	48.4	14.6	30.7	40.8
4.12				100.0	100.0	100.0	75.2	85.4	96.4	58.3	77.1	90.5	50.8	68.7	84.6	36.5	59.1	74.0	29.1	50.4	64.8	23.9	44.7	57.9	18.0	36.0	47.5	14.4	30.0	40.1
5.00				77.6	86.4	97.0	61.5	77.2	91.2	52.6	66.5	84.1	41.9	61.8	77.8	32.1	51.1	66.8	25.6	44.0	58.3	20.3	39.2	51.5	15.6	31.4	42.1	12.6	26.0	35.3
5.10	100.0	100.0	100.0	76.9	84.8	96.5	61.1	75.6	90.5	52.2	65.2	83.4	40.4	61.4	77.0	31.7	50.6	66.3	25.4	43.2	57.6	20.2	38.5	50.9	15.5	30.8	41.5	12.0	26.0	34.9
5.33	91.5	97.6	99.8	75.4	81.1	95.4	60.0	74.2	89.7	48.3	65.8	82.3	39.2	59.6	75.4	31.0	48.9	64.7	25.1	41.3	56.0	19.4	37.4	49.5	14.3	30.5	40.4	11.5	25.3	33.9
6.00	87.1	86.7	98.3	64.0	78.2	92.2	52.9	68.5	85.2	44.9	60.1	78.0	37.5	53.7	71.1	27.8	45.9	60.9	22.8	38.7	52.7	18.0	34.3	46.1	13.7	27.5	37.4	11.1	22.7	31.3
6.67	81.3	84.9	97.2	62.0	73.8	90.0	50.4	63.2	81.7	41.4	57.6	75.2	33.2	52.0	67.9	26.3	42.3	57.5	21.2	36.0	49.6	17.0	31.6	43.2	12.1	26.1	35.0	9.8	21.7	29.4
8.00	68.0	74.7	91.9	51.4	65.9	83.4	41.2	59.1	76.0	34.9	51.9	68.7	31.1	44.3	61.6	22.7	37.7	51.8	18.0	32.2	44.4	15.1	27.8	38.7	11.5	22.2	31.1	9.3	18.4	26.0
10.00	54.3	68.3	85.5	45.3	55.9	75.9	36.9	51.2	69.2	29.1	45.4	61.3	25.1	40.1	55.1	19.1	32.7	45.6	14.9	28.3	39.0	12.8	24.3	34.0	9.5	19.3	27.0	7.7	16.0	22.5
12.00	47.0	62.1	79.9	36.6	54.3	71.0	29.5	47.8	63.2	25.2	40.5	55.5	21.6	35.5	49.4	16.2	29.9	41.3	13.5	24.7	34.9	11.4	21.0	30.0	8.9	16.6	24.0	7.2	13.7	19.9
14.00	40.4	58.6	75.3	33.0	46.6	64.2	27.1	43.2	58.6	21.7	36.5	50.3	19.1	32.3	45.2	14.0	27.1	37.3	11.3	22.8	31.5	9.4	19.6	27.2	7.3	15.6	21.8	5.9	12.9	18.0
16.00	36.2	51.2	68.9	26.8	45.8	60.3	23.9	40.0	54.3	20.6	33.2	47.0	17.4	29.3	41.6	13.3	24.3	34.4	10.8	20.3	28.9	9.2	17.4	25.0	7.0	13.8	19.8	5.7	11.4	16.5
20.00	27.6	46.1	61.0	22.7	39.9	53.5	18.6	34.8	46.9	14.7	30.9	41.1	12.6	27.2	36.4	9.4	22.7	30.0	7.8	19.0	25.3	6.5	16.3	21.7	4.8	13.0	17.2	4.0	10.7	14.3

Table C.12. Energy savings on artificial lighting for room ratio of 1:1.5 and window area of 100% (%).

DF	K = 0.60			K = 0.80			K = 1.00			K = 1.25			K = 1.50			K = 2.00			K = 2.50			K = 3.00			K = 4.00			K = 5.00		
(%)	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total	A	B	Total
1.16																												100.0	100.0	100.0
1.20																												78.6	96.9	99.3
1.25																												54.5	95.9	98.1
1.33																												52.8	90.2	95.4
1.43																									100.0	100.0	100.0	39.2	86.7	91.9
1.50																									68.6	96.3	98.8	37.3	83.2	89.5
1.60																									51.3	92.7	96.4	33.3	79.0	86.0
1.67																									48.2	89.3	94.5	30.6	76.6	83.8
1.77																						100.0	100.0	100.0	42.6	85.7	91.8	29.5	72.6	80.7
2.00																						62.1	92.5	97.2	36.2	77.3	85.5	24.6	66.2	74.5
2.07																			100.0	100.0	100.0	52.5	91.0	95.7	34.1	75.6	83.9	24.4	64.1	72.9
2.45																100.0	100.0	100.0	57.4	88.8	95.2	40.8	80.1	88.2	28.1	65.9	75.5	21.0	55.8	65.1
2.50																81.3	99.1	99.8	53.2	87.9	94.3	39.9	78.8	87.3	27.3	65.0	74.6	20.8	54.8	64.2
2.67																73.4	93.9	98.4	47.9	83.7	91.5	36.9	74.9	84.2	25.9	61.5	71.5	20.4	51.5	61.4
3.00																58.5	87.1	94.6	41.6	76.5	86.3	33.8	67.9	78.7	24.2	55.6	66.3	18.7	46.8	56.7
3.02													100.0	100.0	100.0	58.3	86.9	94.5	41.5	76.0	86.0	33.3	67.7	78.5	24.0	55.4	66.1	18.7	46.5	56.5
3.33													74.4	94.1	98.5	52.4	80.6	90.8	37.9	70.6	81.7	30.8	62.6	74.1	22.5	51.1	62.1	17.8	42.8	53.0
3.39										100.0	100.0	100.0	73.9	92.5	98.0	49.5	80.5	90.2	37.6	69.4	80.9	30.5	61.6	73.3	22.0	50.5	61.4	17.7	42.1	52.3
4.00										74.6	90.0	97.5	55.7	84.6	93.2	41.7	71.2	83.2	32.5	61.3	73.9	26.9	54.1	66.4	19.9	44.1	55.2	15.7	37.0	46.9
4.14							100.0	100.0	100.0	69.8	88.5	96.5	54.6	82.2	91.9	40.2	69.5	81.8	32.1	59.5	72.5	26.3	52.7	65.1	19.3	43.0	54.0	14.8	36.5	45.9
4.97				100.0	100.0	100.0	74.4	86.3	96.5	56.5	78.6	90.7	46.3	72.4	85.2	34.4	61.0	74.4	27.6	52.2	65.4	21.8	46.8	58.4	16.0	37.9	47.8	12.8	31.7	40.4
5.00				97.7	99.4	100.0	73.3	87.2	96.6	55.9	78.5	90.5	46.2	72.0	84.9	34.1	60.6	74.0	27.4	51.9	65.1	21.7	46.5	58.1	16.0	37.8	47.8	12.8	31.5	40.3
5.33				83.4	95.6	99.3	67.8	83.6	94.7	54.3	74.4	88.3	44.1	68.2	82.2	32.6	58.0	71.7	25.8	49.7	62.7	20.4	44.5	55.8	15.6	35.8	45.8	12.3	30.0	38.6
6.00				76.6	86.3	96.8	60.5	77.2	91.0	48.5	70.0	84.6	39.0	63.5	77.7	30.7	52.4	67.0	24.1	45.4	58.6	18.7	40.7	51.8	14.0	32.9	42.3	11.2	27.4	35.5
6.05	100.0	100.0	100.0	76.3	85.6	96.6	60.2	76.5	90.6	47.9	69.5	84.1	38.8	62.9	77.3	30.6	51.9	66.6	24.0	45.0	58.2	18.6	40.4	51.5	13.9	32.6	42.0	11.2	27.2	35.4
6.67	89.0	92.3	99.2	64.5	83.2	94.0	53.8	73.2	87.6	45.0	64.4	80.4	37.5	57.8	73.6	27.6	49.3	63.3	21.7	42.6	55.1	17.7	37.3	48.4	13.5	30.0	39.5	10.9	25.2	33.4
8.00	74.2	86.7	96.6	57.9	72.2	88.3	46.4	65.8	81.7	36.4	59.3	74.1	32.2	51.3	67.0	24.0	43.4	57.0	19.3	37.3	49.4	15.6	32.5	43.0	11.7	26.2	34.8	9.4	21.9	29.2
10.00	57.6	77.8	90.6	48.4	64.4	81.6	38.8	56.8	73.6	29.9	51.1	65.7	26.0	45.4	59.6	20.6	37.0	50.0	15.1	33.0	43.1	13.1	28.4	37.8	10.0	22.7	30.4	7.7	18.9	25.1
12.00	50.6	64.9	82.7	39.3	58.1	74.6	31.8	51.2	66.7	27.5	43.6	59.1	22.6	40.7	54.1	17.3	33.2	44.8	14.0	27.8	37.9	11.6	24.4	33.2	9.0	19.4	26.7	7.3	16.0	22.1
14.00	43.0	60.1	77.3	34.5	52.7	69.0	28.0	46.5	61.5	21.9	41.4	54.2	19.5	36.8	49.1	14.1	31.0	40.7	11.4	26.1	34.5	9.5	22.5	29.9	7.4	18.0	24.1	5.9	15.0	20.0
16.00	38.2	57.2	73.5	28.4	49.4	63.8	25.3	42.6	57.1	21.1	37.6	50.8	18.0	33.2	45.2	13.5	27.6	37.4	11.0	23.2	31.6	9.2	20.0	27.4	7.0	15.9	21.8	5.7	13.2	18.1
20.00	29.7	50.9	65.5	23.5	44.1	57.2	19.0	38.7	50.3	15.0	34.4	44.2	12.8	30.3	39.2	9.5	25.3	32.4	7.9	21.3	27.5	6.5	18.4	23.7	4.8	14.7	18.8	4.0	12.1	15.6

Appendix D. Energy consumptions obtained from the simulations

1. Energy consumption for Belém

Figures D.1 to D.4 show the energy consumption for the 10 room sizes (expressed by room indices – K – from 0.60 to 5.00) as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.5 to D.8 show the same information for room ratio of 1:2.

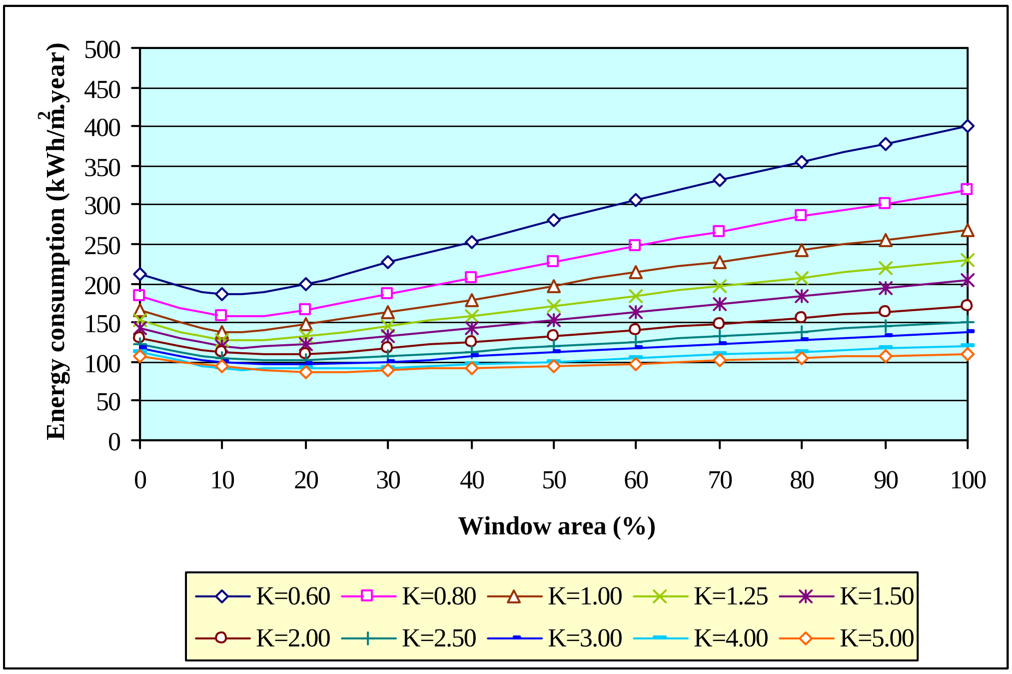

Figure D.1. Energy consumption for Belém, room ratio of 2:1, North orientation.

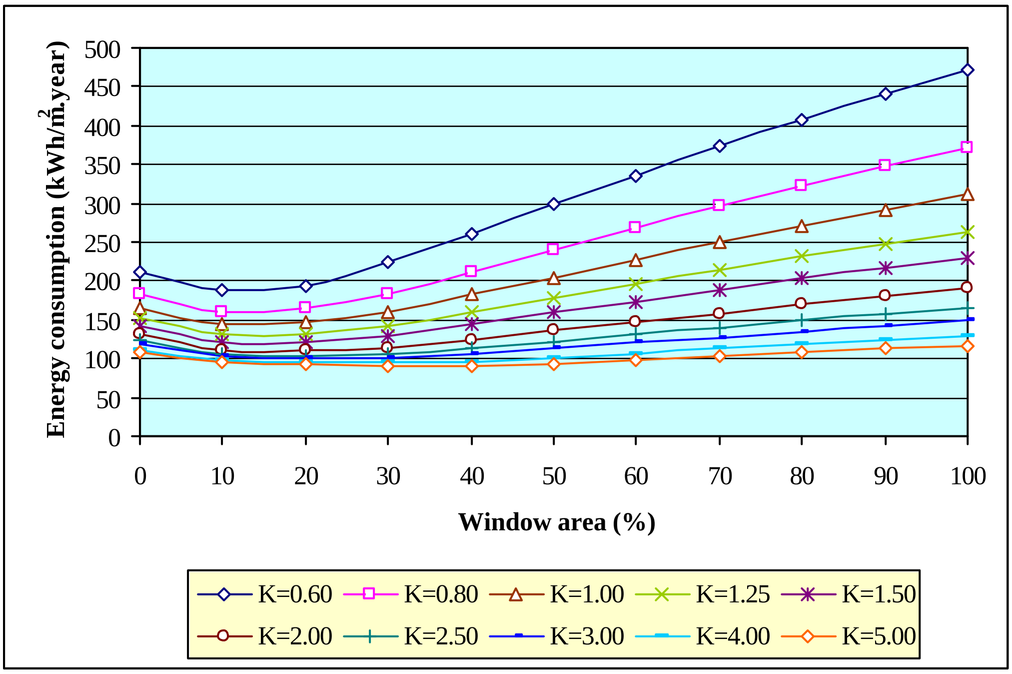

Figure D.2. Energy consumption for Belém, room ratio of 2:1, East orientation.

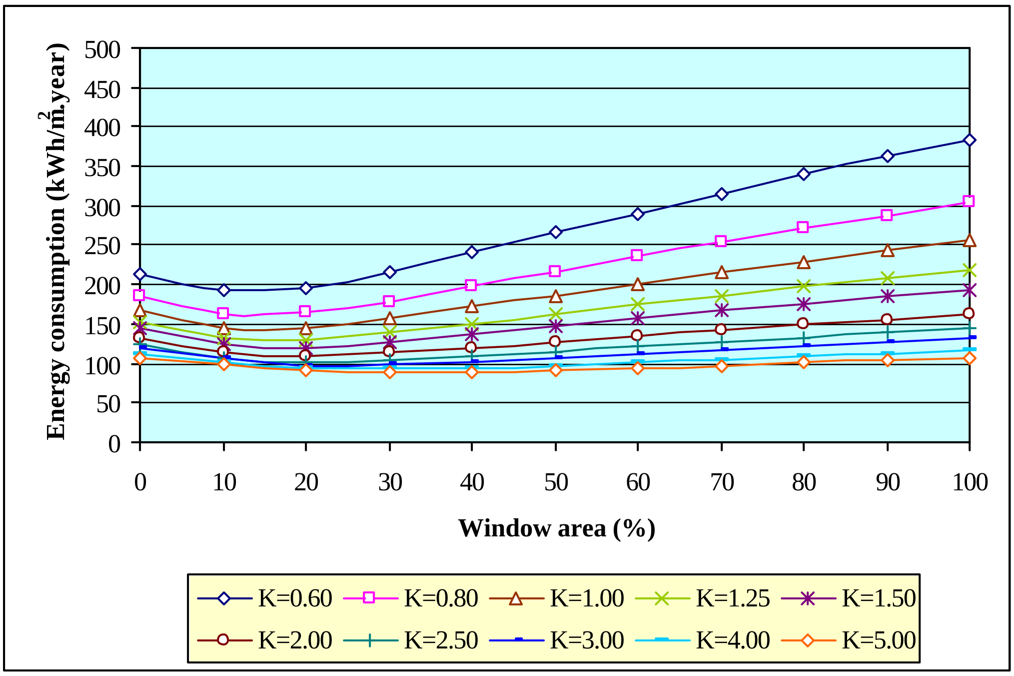

Figure D.3. Energy consumption for Belém, room ratio of 2:1, South orientation.

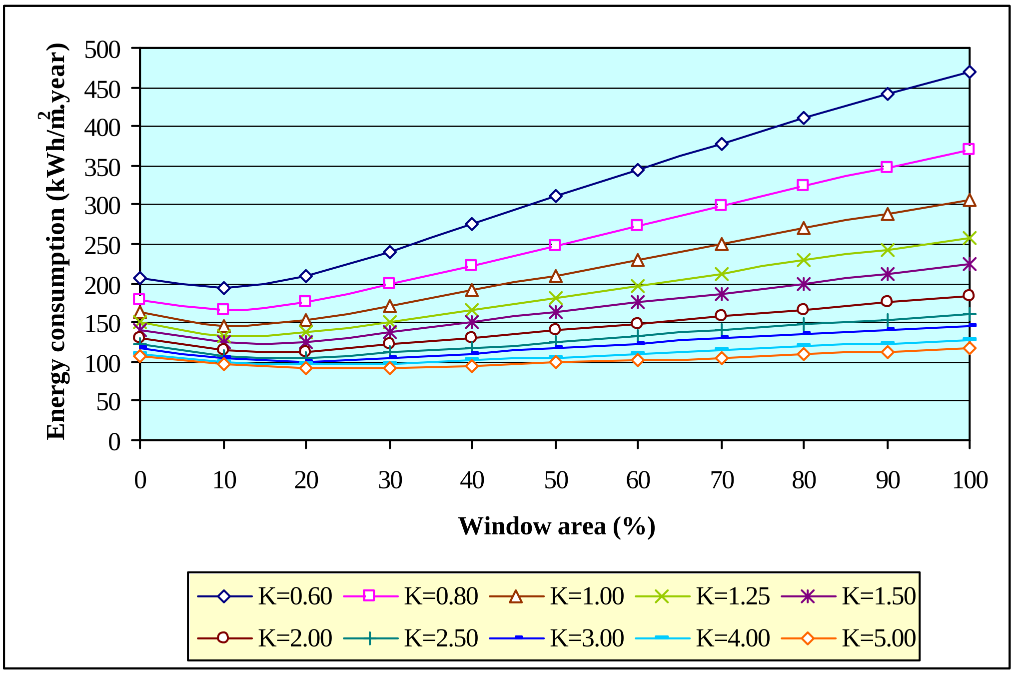

Figure D.4. Energy consumption for Belém, room ratio of 2:1, West orientation.

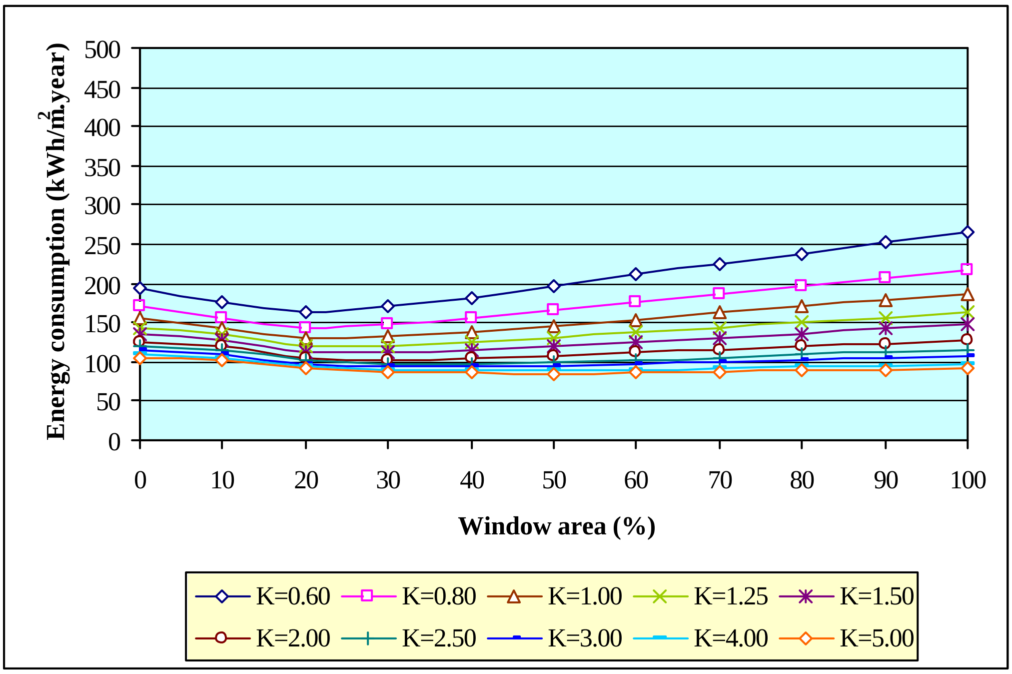

Figure D.5. Energy consumption for Belém, room ratio of 1:2, North orientation.

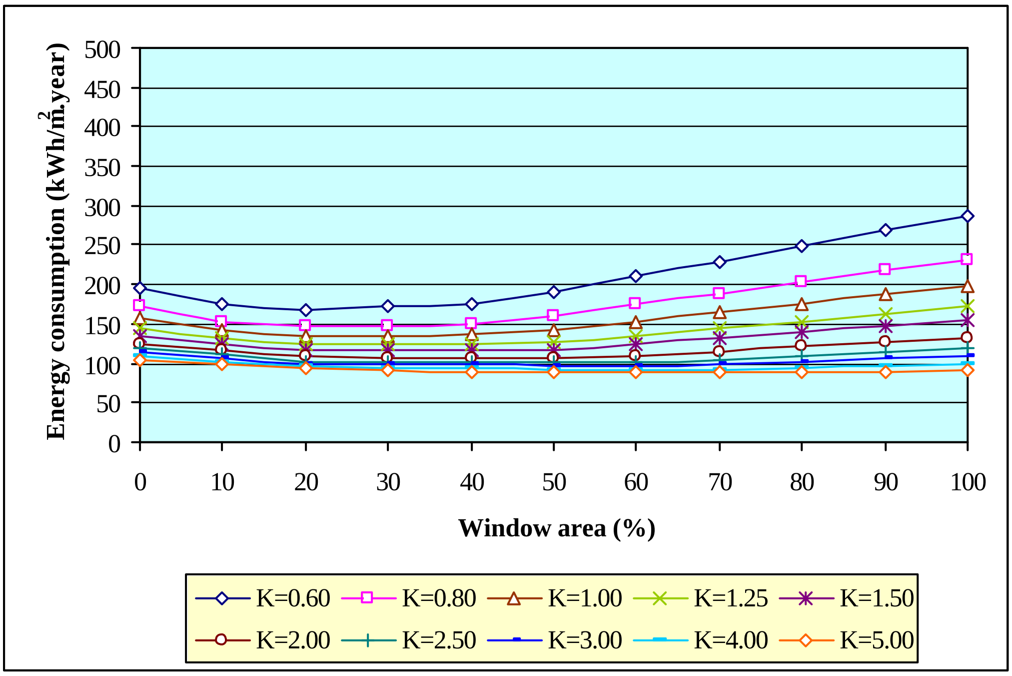

Figure D.6. Energy consumption for Belém, room ratio of 1:2, East orientation.

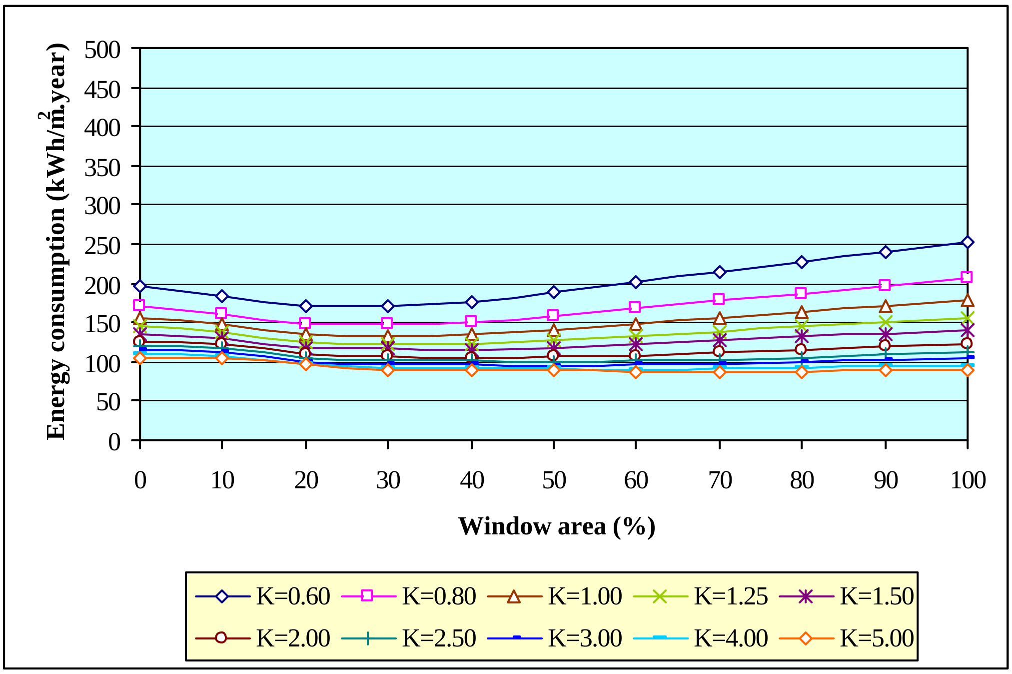

Figure D.7. Energy consumption for Belém, room ratio of 1:2, South orientation.

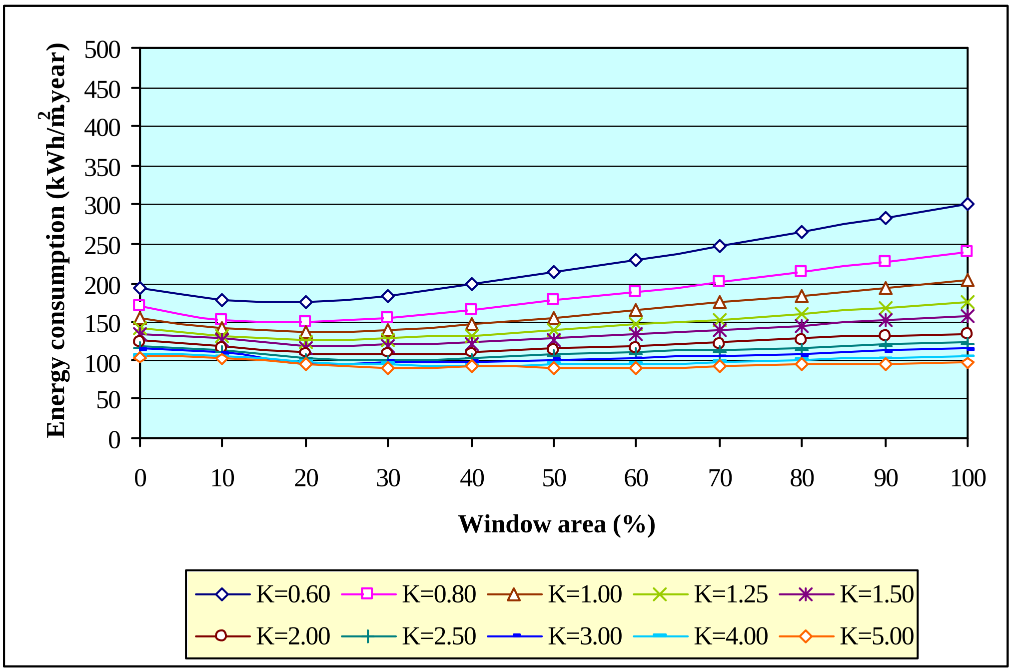

Figure D.8. Energy consumption for Belém, room ratio of 1:2, West orientation.

2. Energy consumption for Brasília

Figures D.9 to D.12 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.13 to D.16 show the same information for room ratio of 1:2.

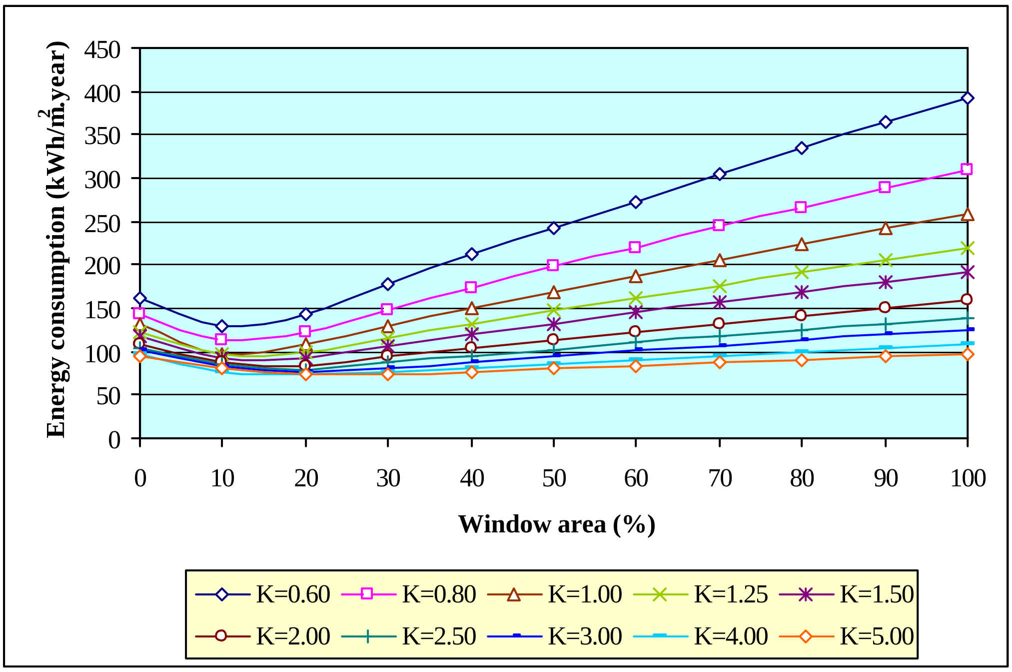

Figure D.9. Energy consumption for Brasília, room ratio of 2:1, North orientation.

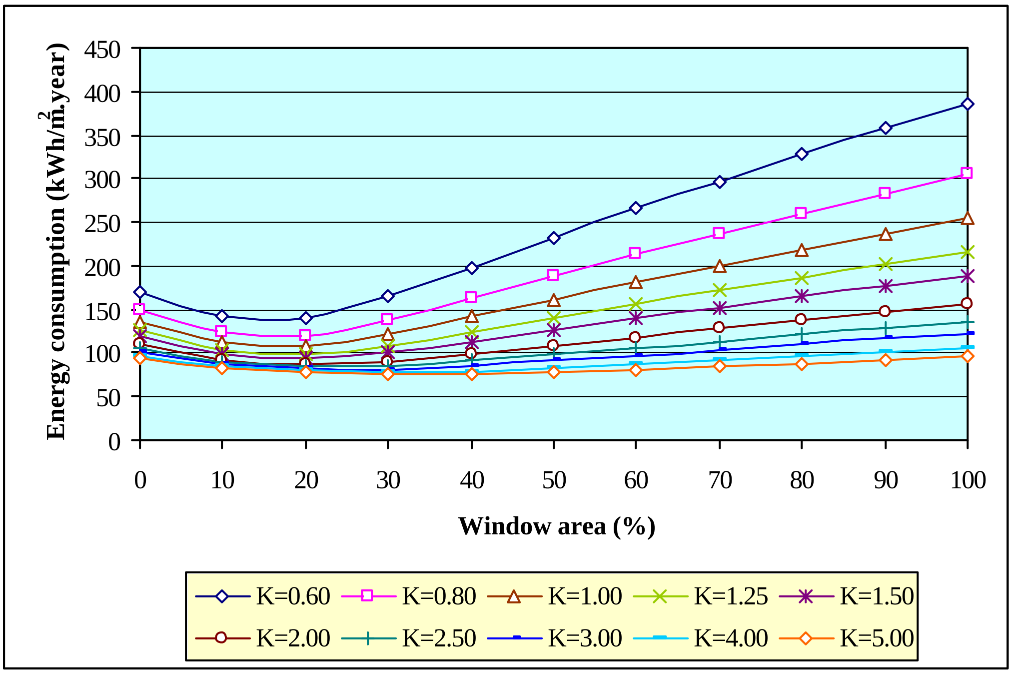

Figure D.10. Energy consumption for Brasília, room ratio of 2:1, East orientation.

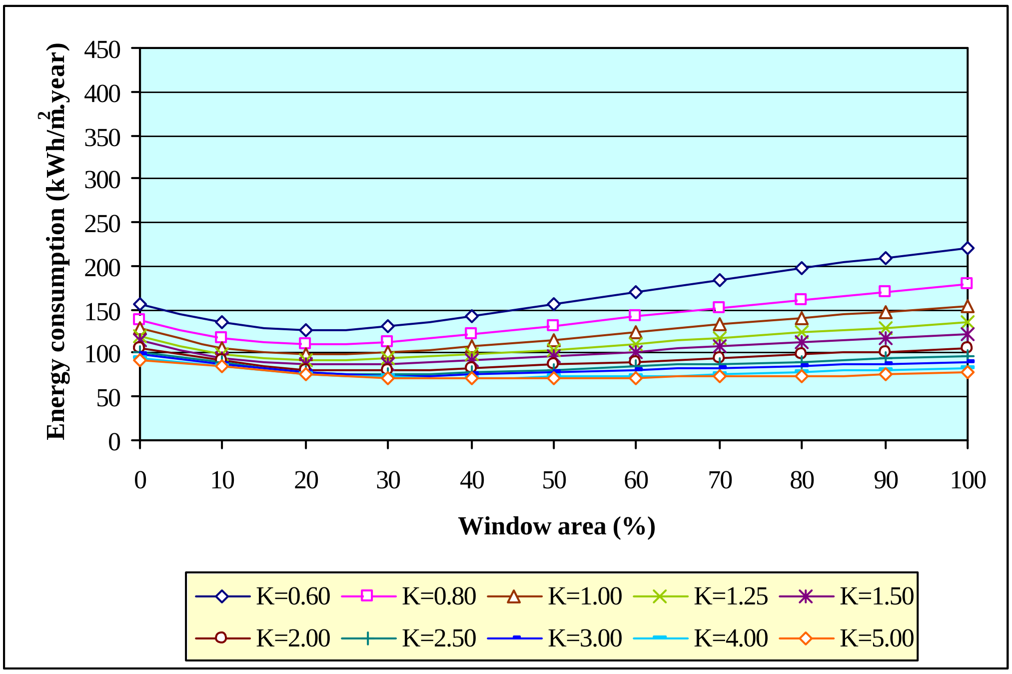

Figure D.11. Energy consumption for Brasília, room ratio of 2:1, South orientation.

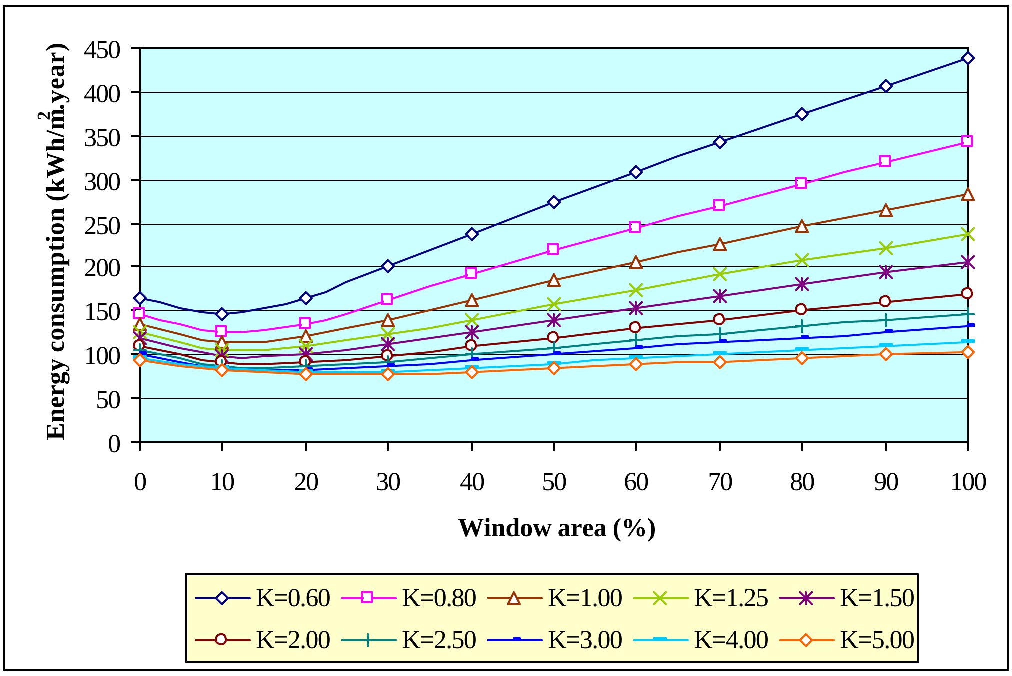

Figure D.12. Energy consumption for Brasília, room ratio of 2:1, West orientation.

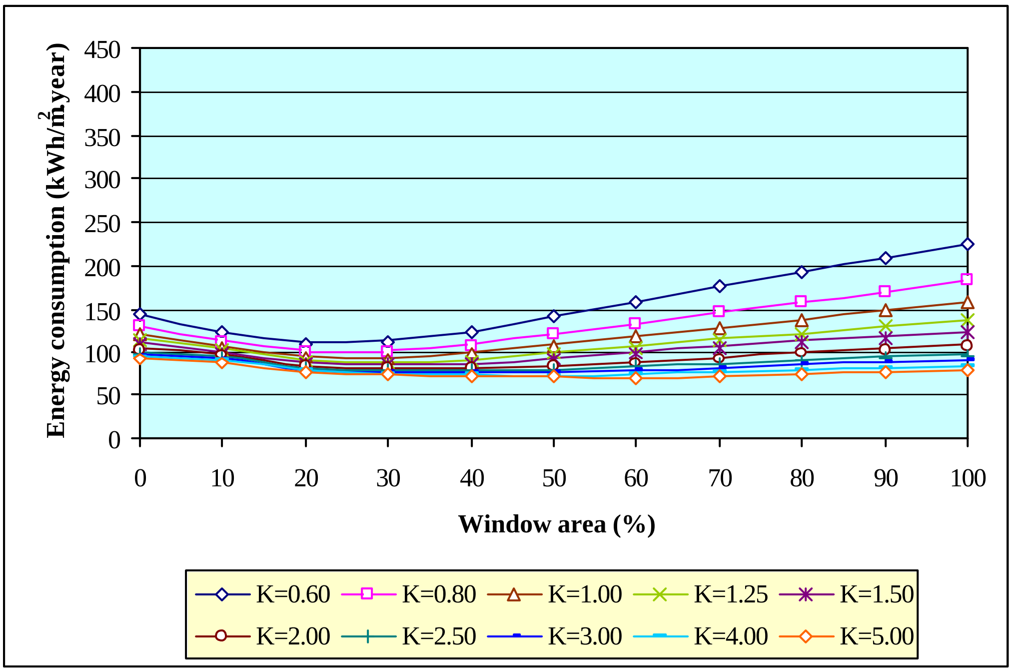

Figure D.13. Energy consumption for Brasília, room ratio of 1:2, North orientation.

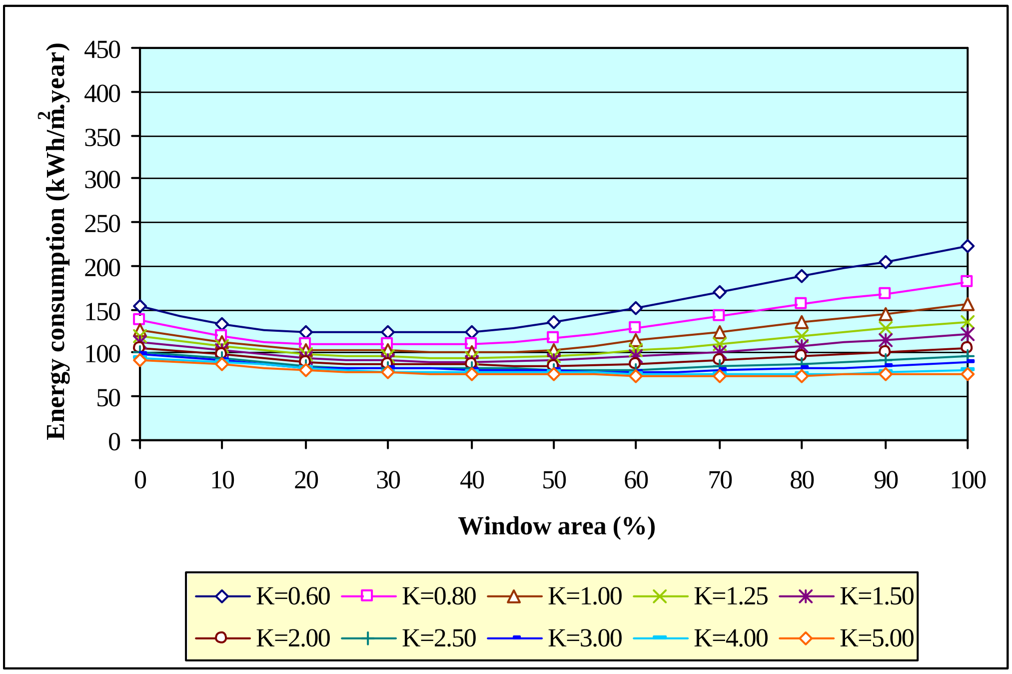

Figure D.14. Energy consumption for Brasília, room ratio of 1:2, East orientation.

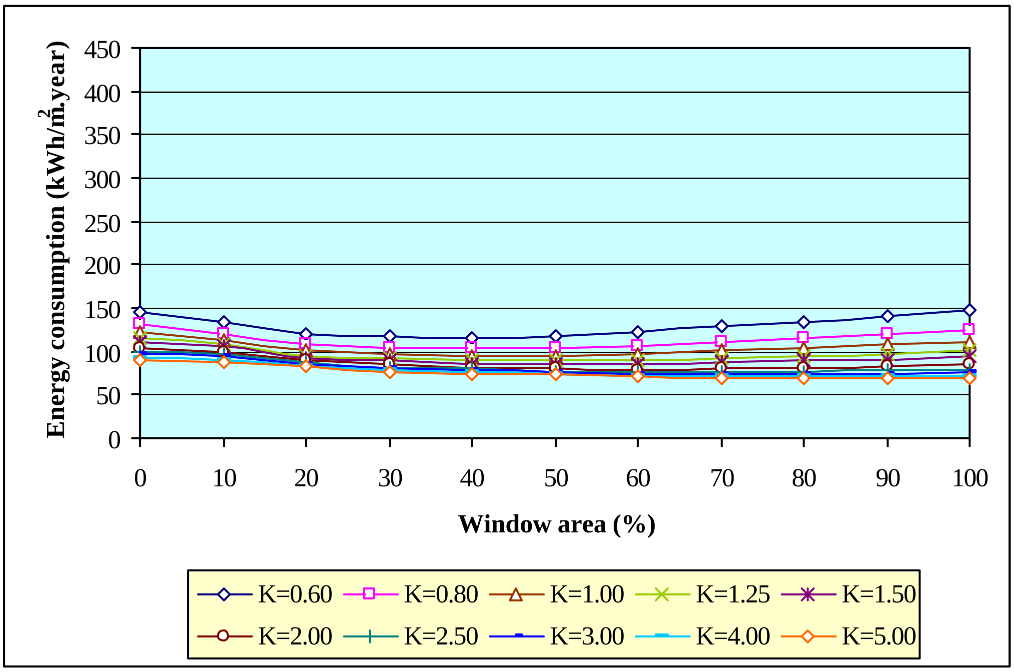

Figure D.15. Energy consumption for Brasília, room ratio of 1:2, South orientation.

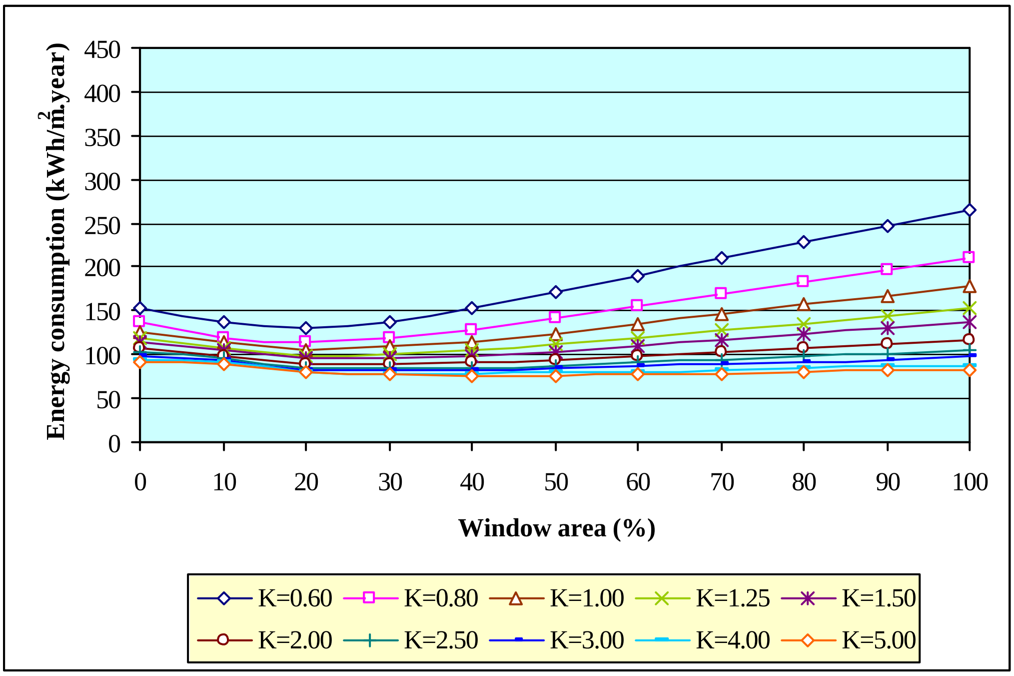

Figure D.16. Energy consumption for Brasília, room ratio of 1:2, West orientation.

3. Energy consumption for Curitiba

Figures D.17 to D.20 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.21 to D.24 show the same information for room ratio of 1:2.

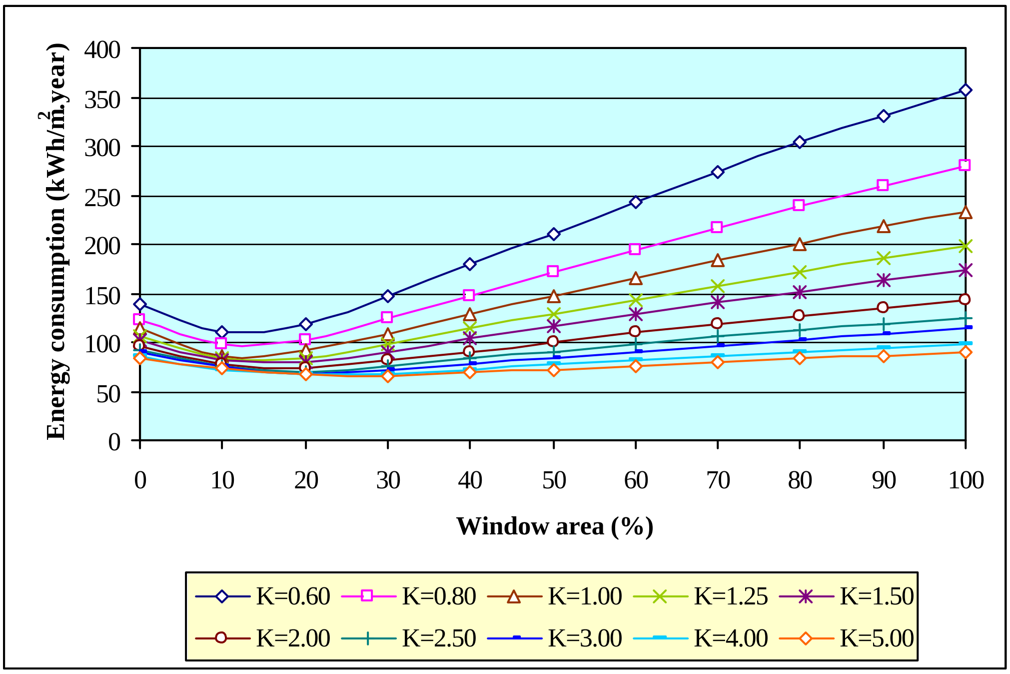

Figure D.17. Energy consumption for Curitiba, room ratio of 2:1, North orientation.

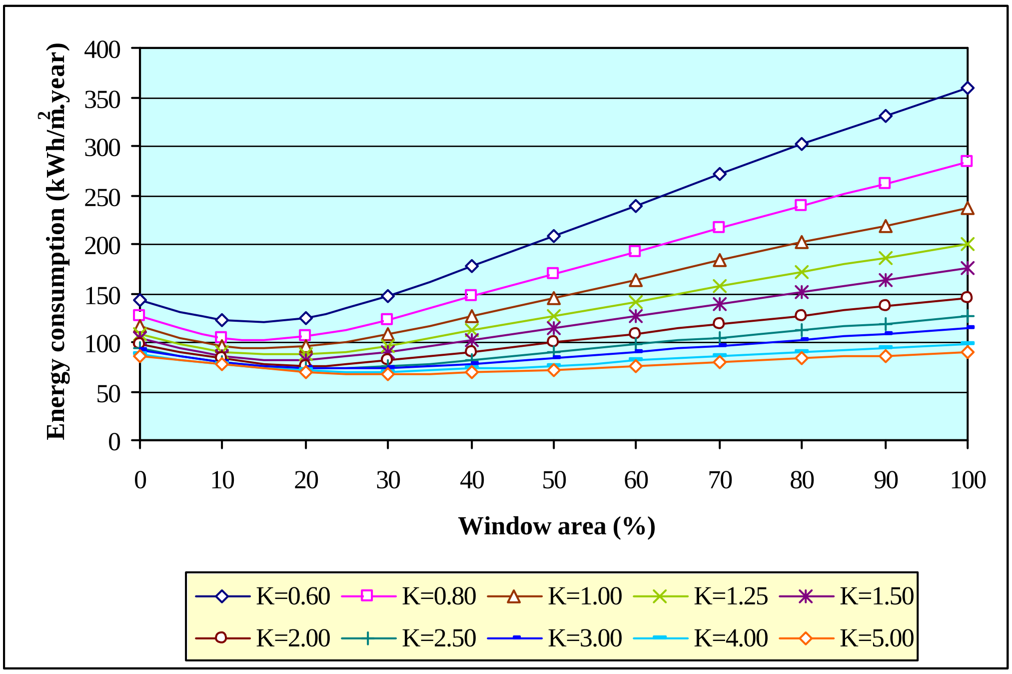

Figure D.18. Energy consumption for Curitiba, room ratio of 2:1, East orientation.

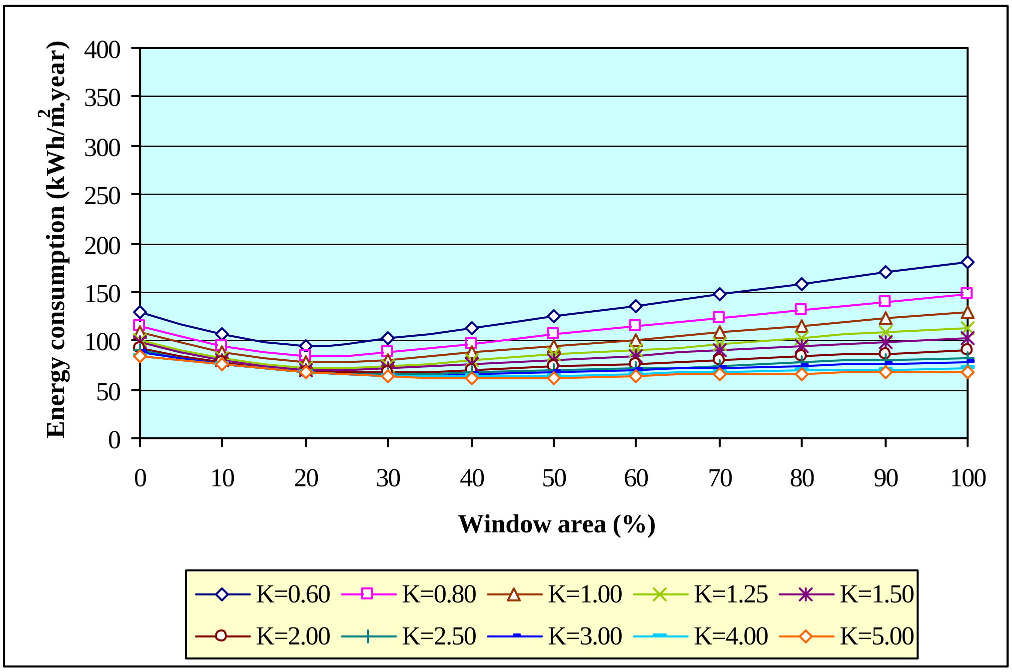

Figure D.19. Energy consumption for Curitiba, room ratio of 2:1, South orientation.

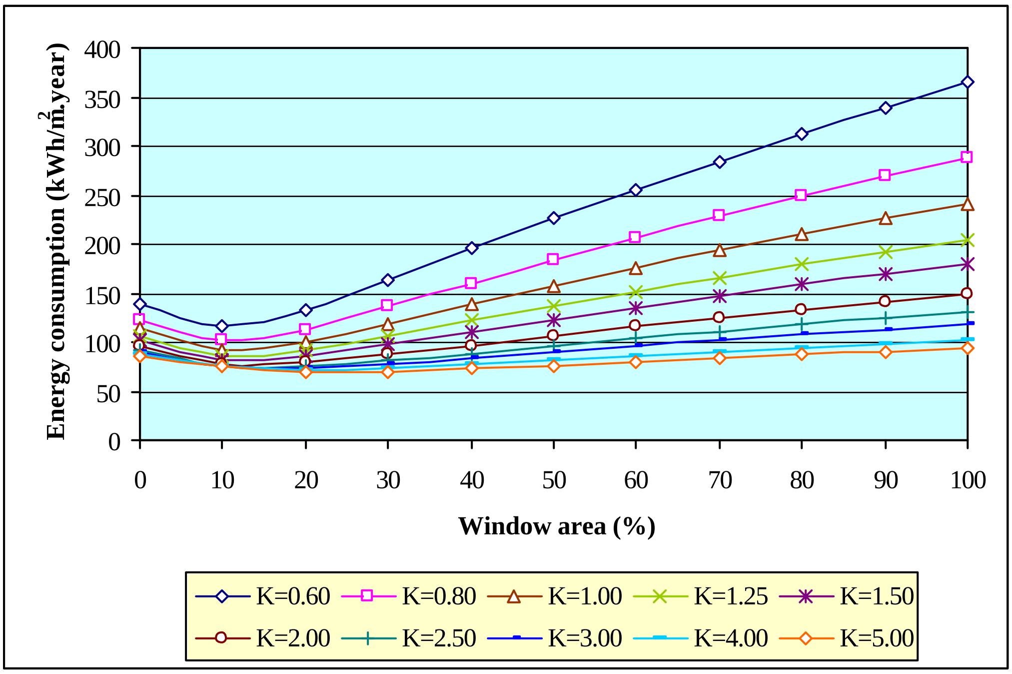

Figure D.20. Energy consumption for Curitiba, room ratio of 2:1, West orientation.

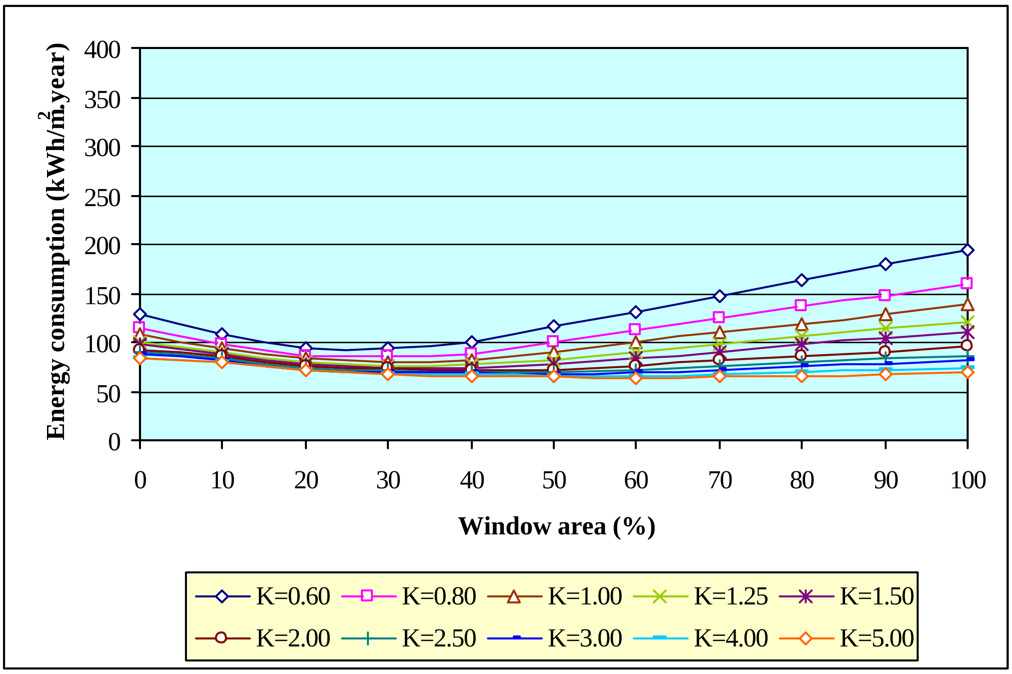

Figure D.21. Energy consumption for Curitiba, room ratio of 1:2, North orientation.

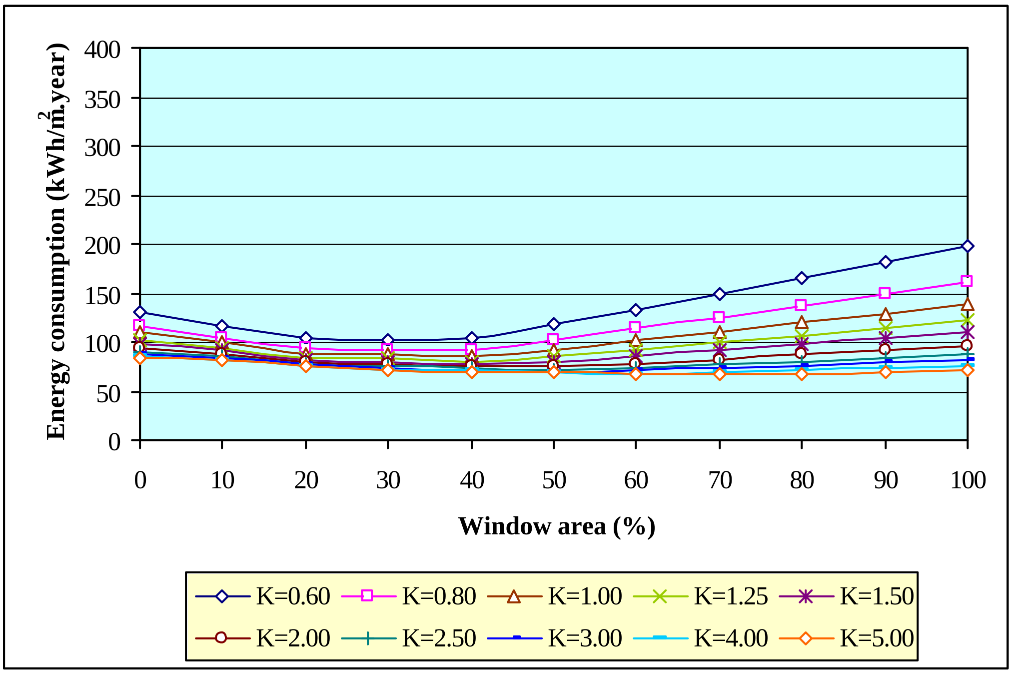

Figure D.22. Energy consumption for Curitiba, room ratio of 1:2, East orientation.

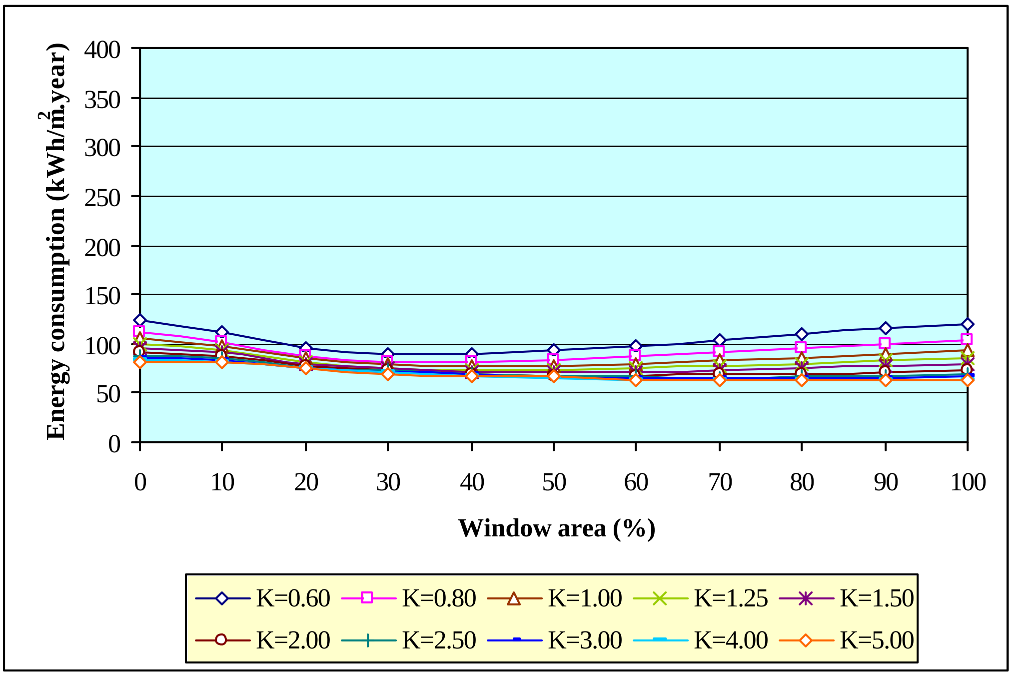

Figure D.23. Energy consumption for Curitiba, room ratio of 1:2, South orientation.

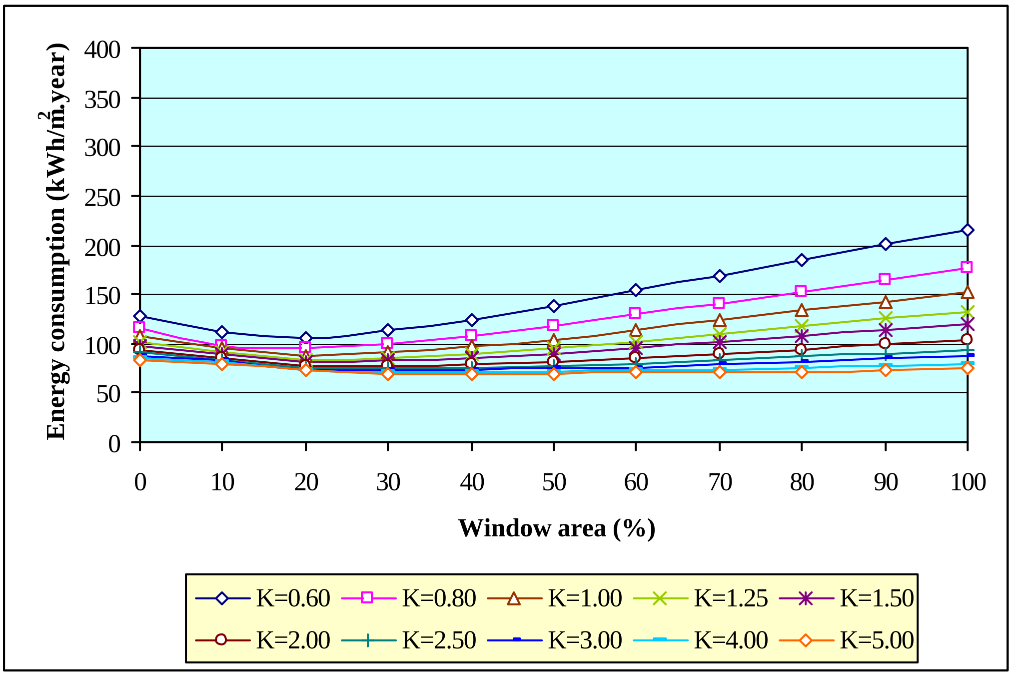

Figure D.24. Energy consumption for Curitiba, room ratio of 1:2, West orientation.

4. Energy consumption for Florianópolis

Figures D.25 to D.28 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.29 to D.32 show the same information for room ratio of 1:2.

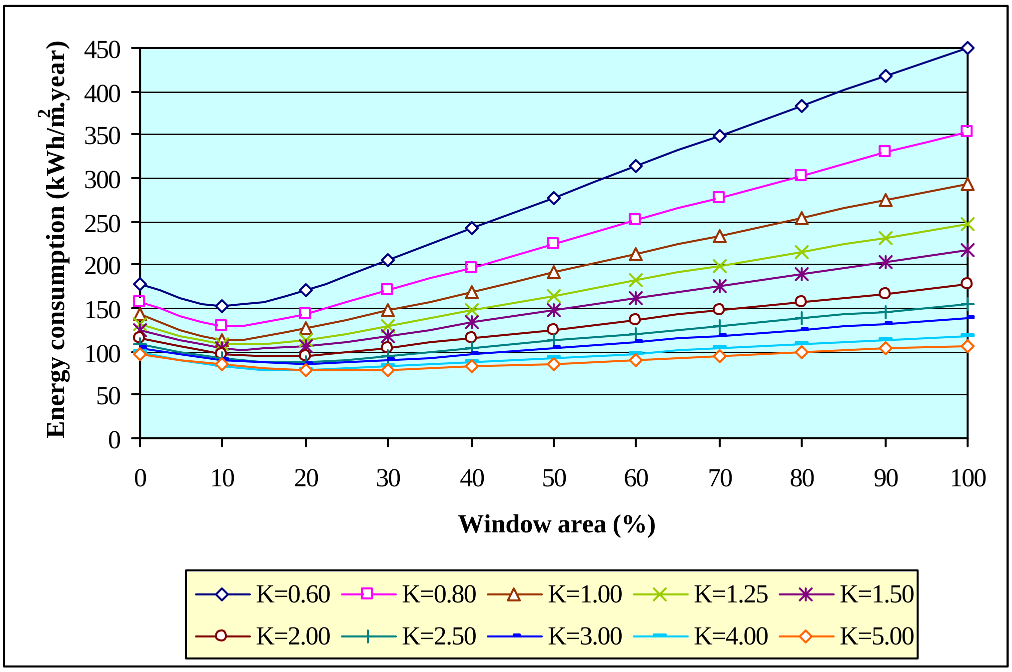

Figure D.25. Energy consumption for Florianópolis, room ratio of 2:1, North orientation.

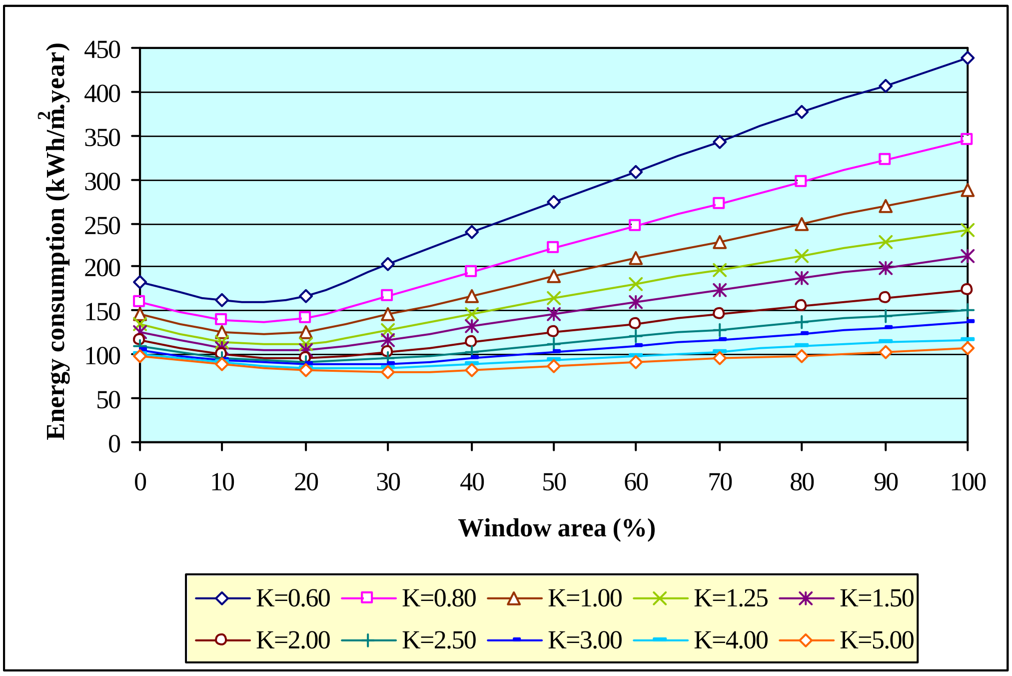

Figure D.26. Energy consumption for Florianópolis, room ratio of 2:1, East orientation.

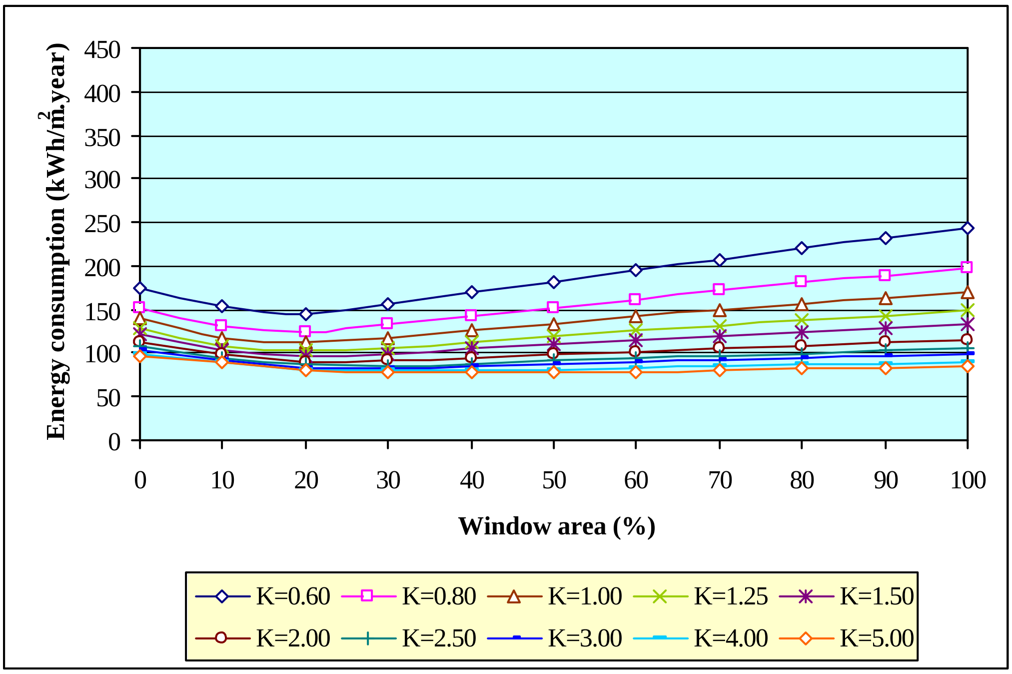

Figure D.27. Energy consumption for Florianópolis, room ratio of 2:1, South orientation.

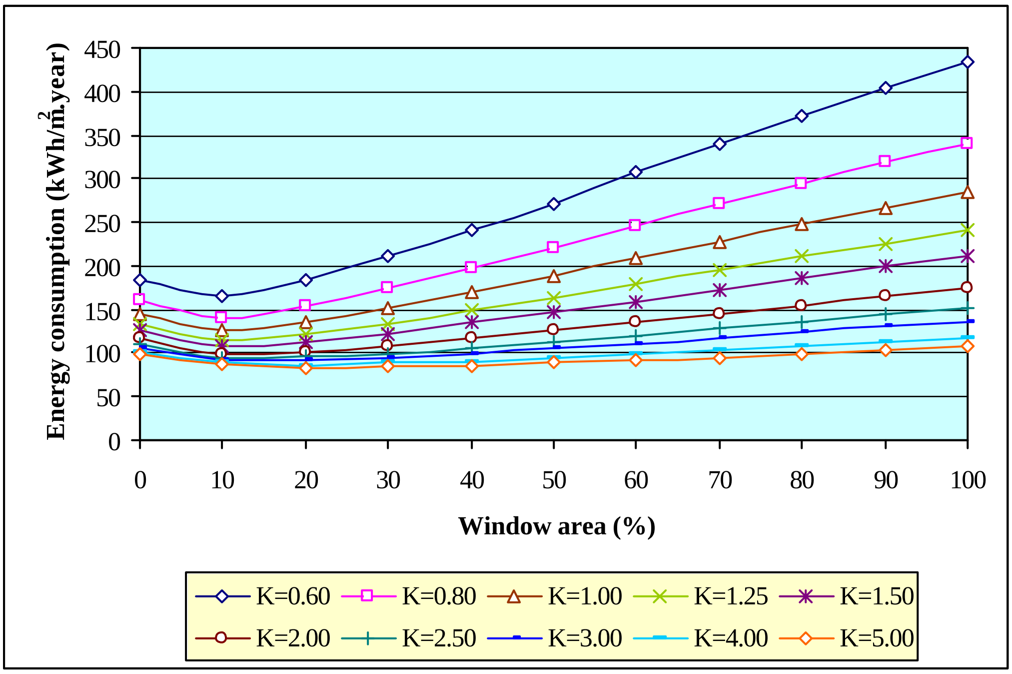

Figure D.28. Energy consumption for Florianópolis, room ratio of 2:1, West orientation.

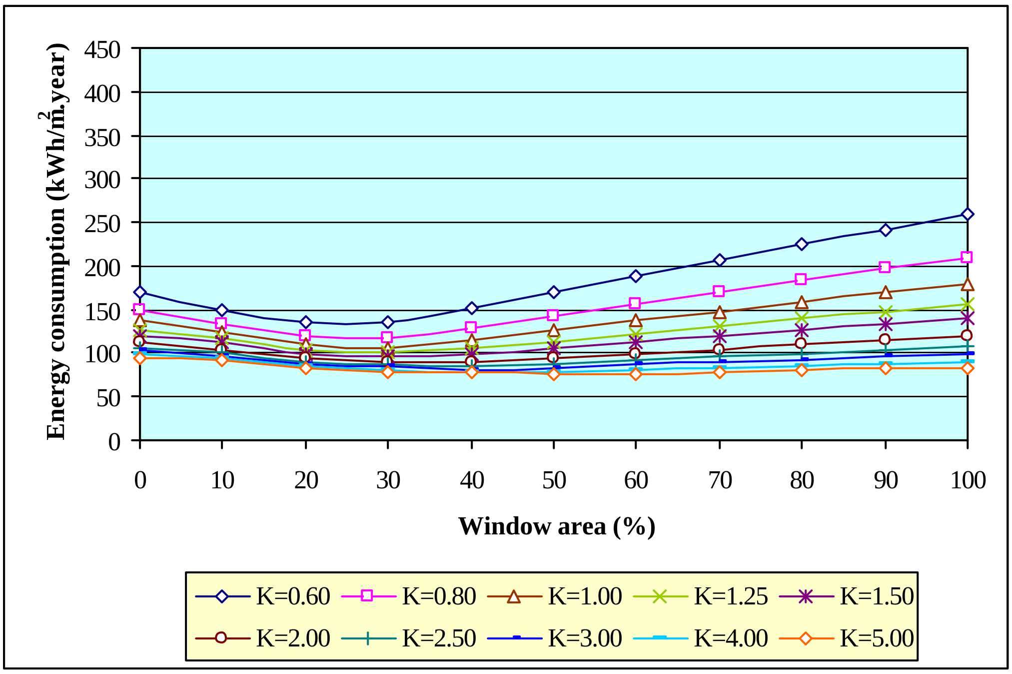

Figure D.29. Energy consumption for Florianópolis, room ratio of 1:2, North orientation.

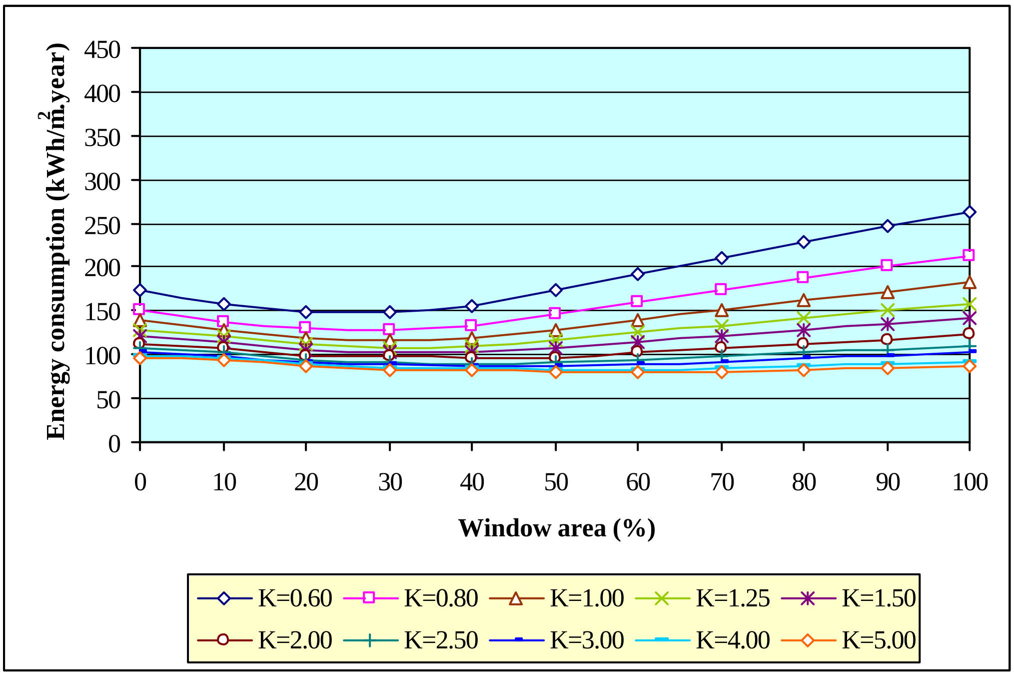

Figure D.30. Energy consumption for Florianópolis, room ratio of 1:2, East orientation.

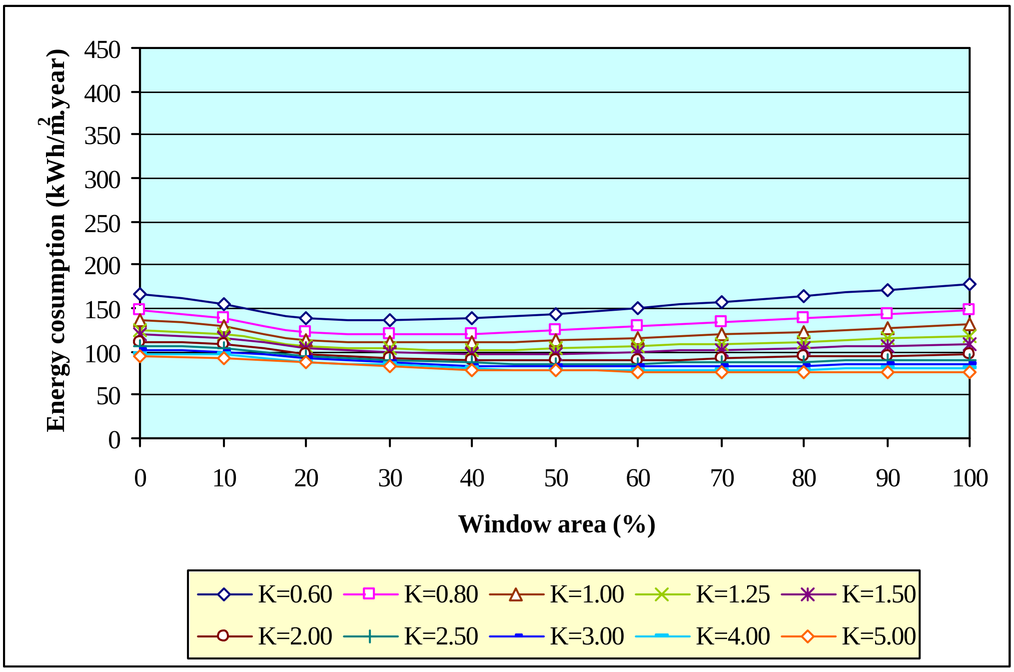

Figure D.31. Energy consumption for Florianópolis, room ratio of 1:2, South orientation.

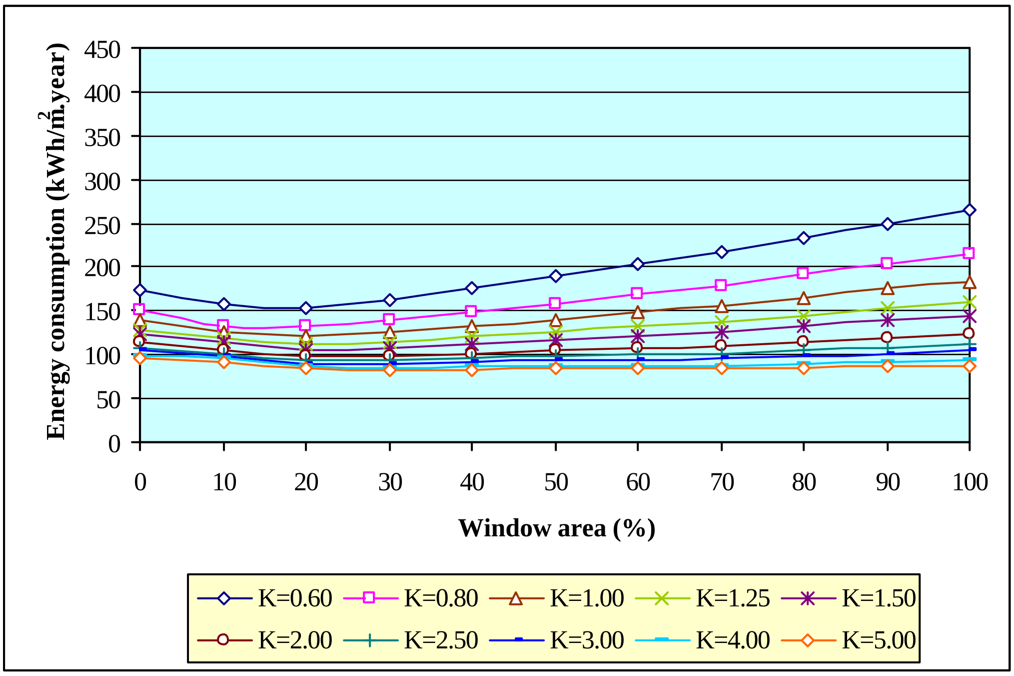

Figure D.32. Energy consumption for Florianópolis, room ratio of 1:2, West orientation.

5. Energy consumption for Leeds

Figures D.33 to D.36 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.37 to D.40 show the same information for room ratio of 1:2.

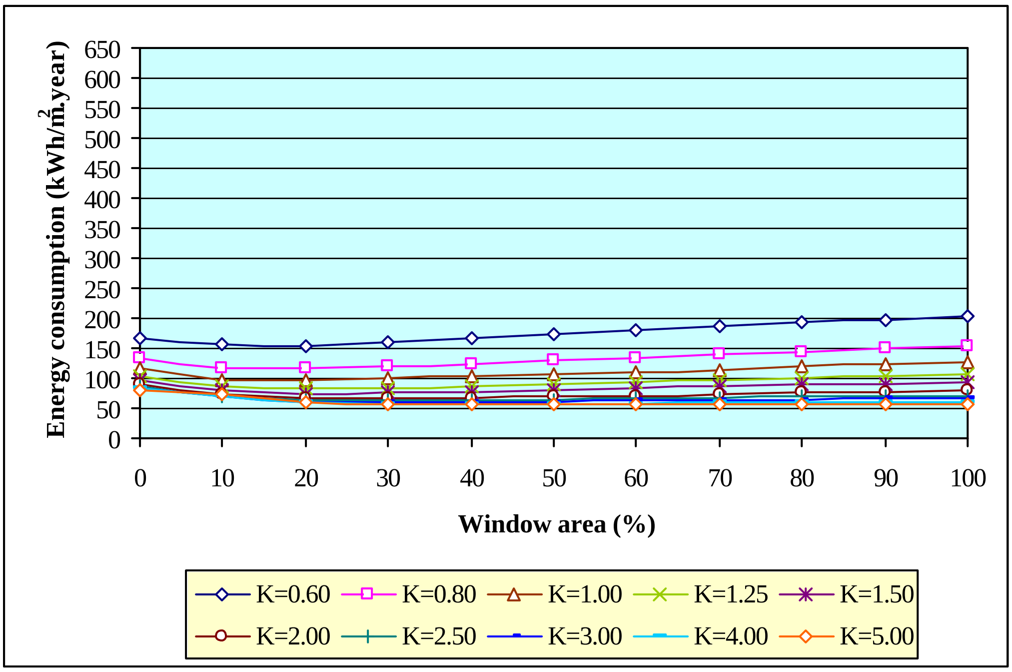

Figure D.33. Energy consumption for Leeds, room ratio of 2:1, North orientation.

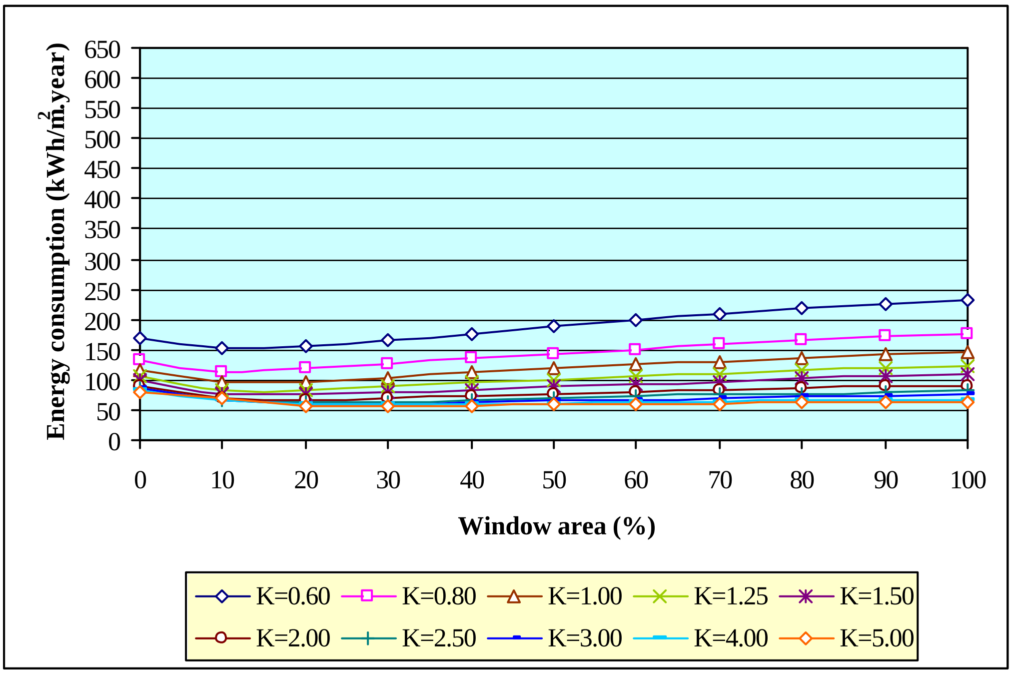

Figure D.34. Energy consumption for Leeds, room ratio of 2:1, East orientation.

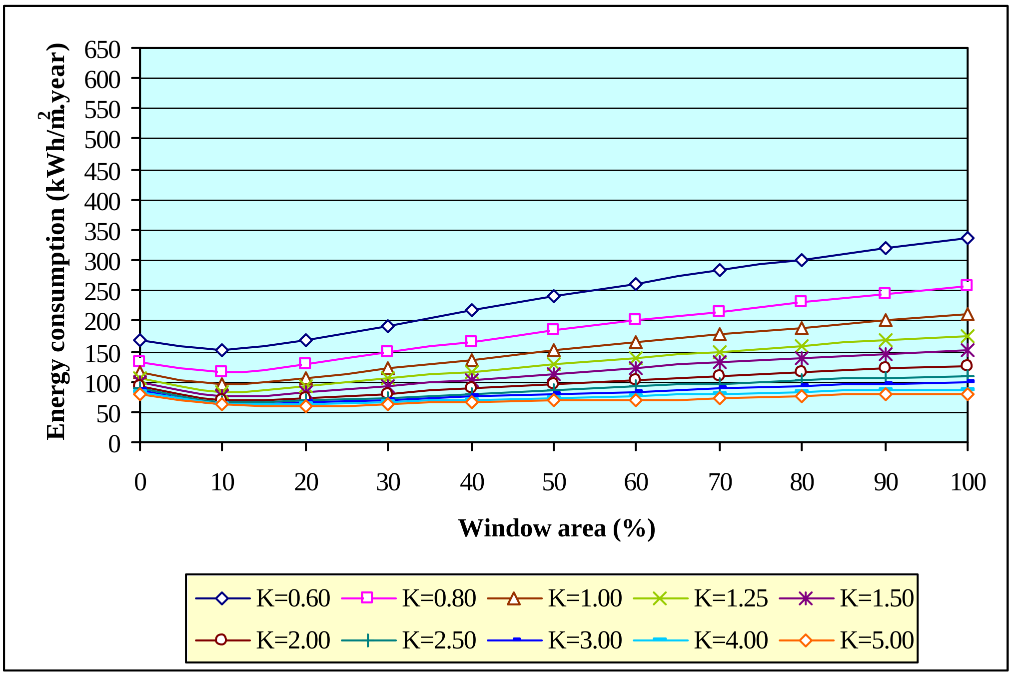

Figure D.35. Energy consumption for Leeds, room ratio of 2:1, South orientation.

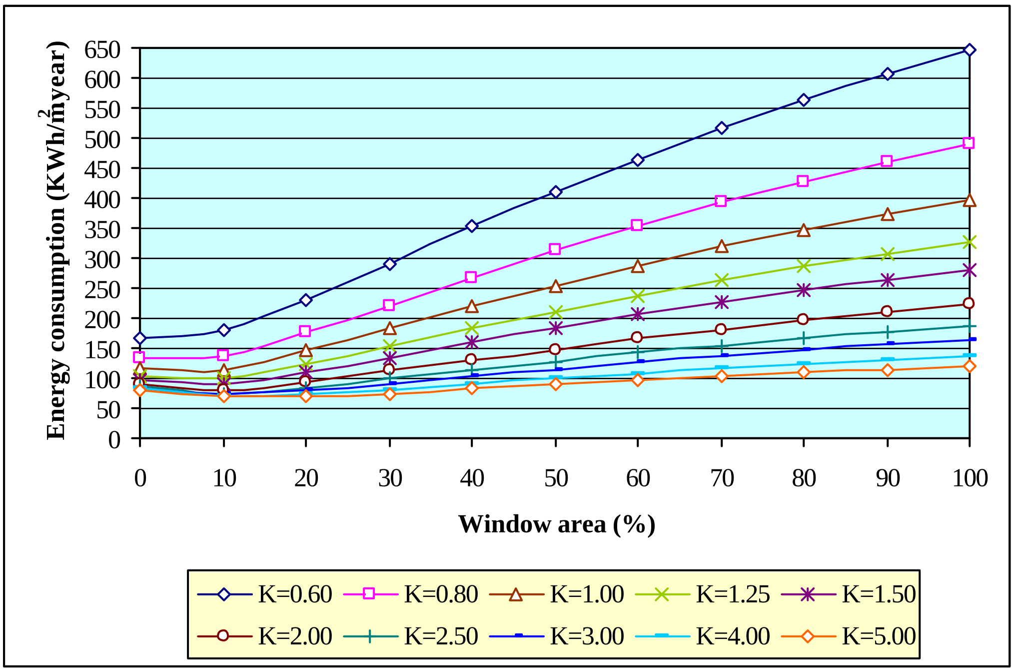

Figure D.36. Energy consumption for Leeds, room ratio of 2:1, West orientation.

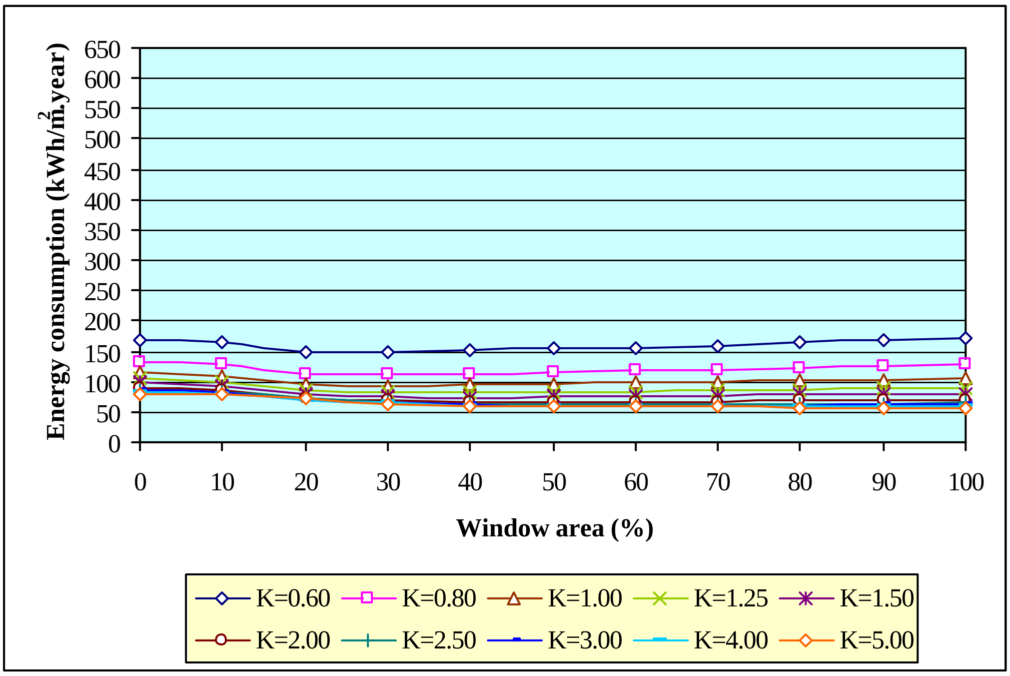

Figure D.37. Energy consumption for Leeds, room ratio of 1:2, North orientation.

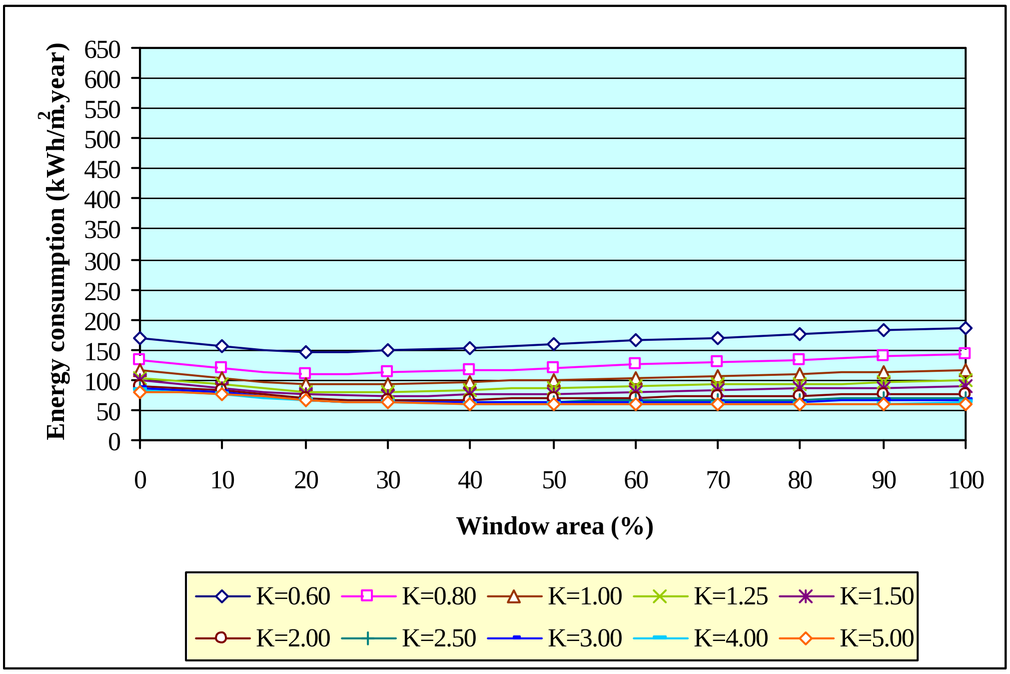

Figure D.38. Energy consumption for Leeds, room ratio of 1:2, East orientation.

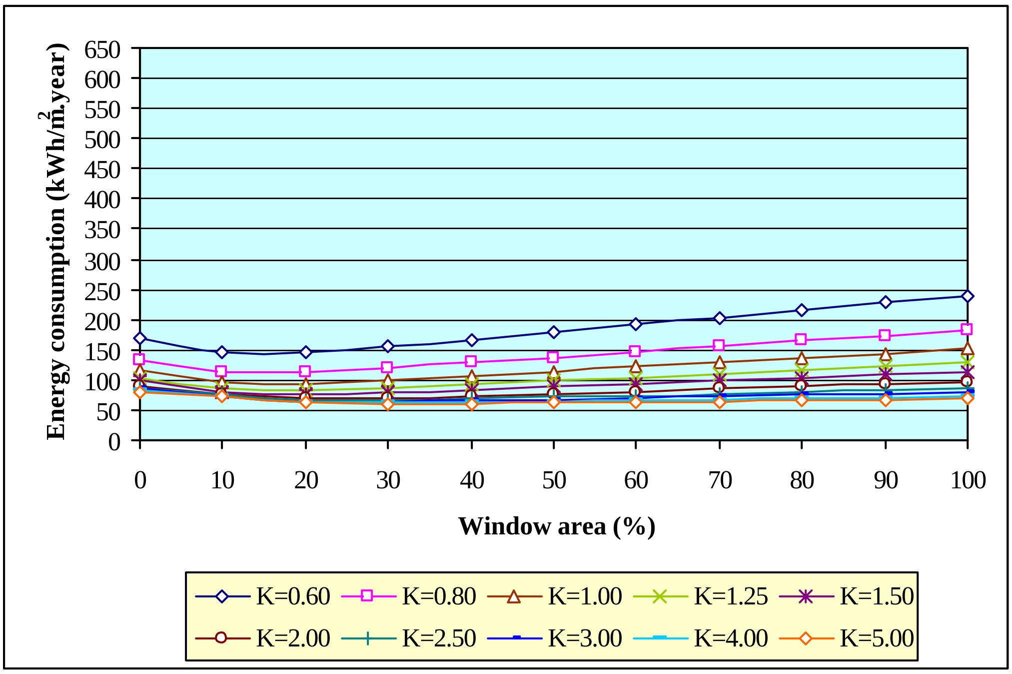

Figure D.39. Energy consumption for Leeds, room ratio of 1:2, South orientation.

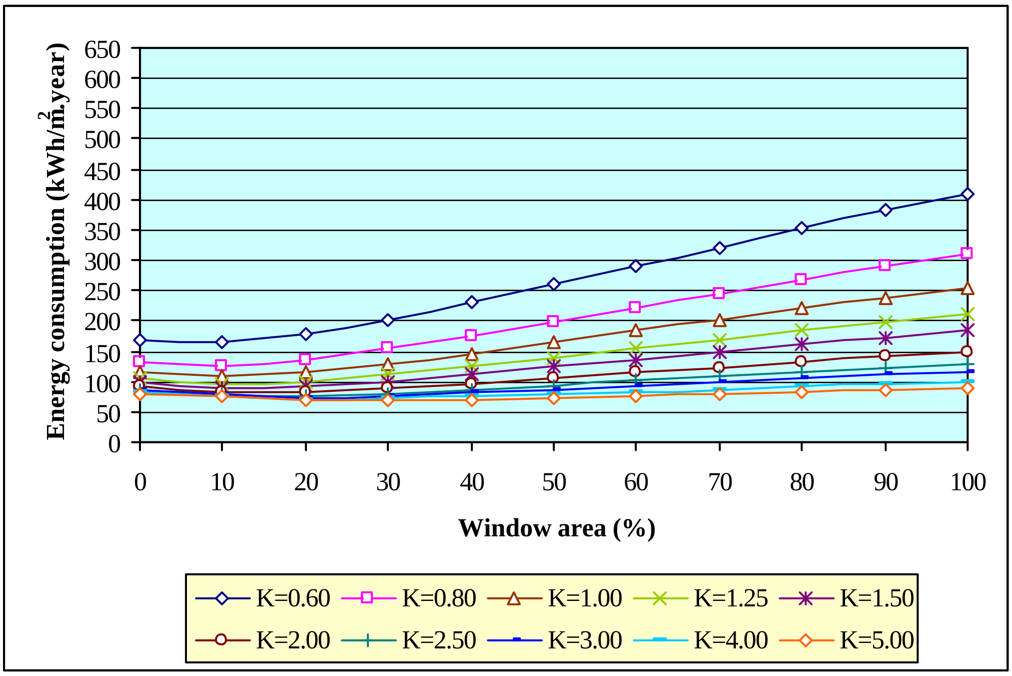

Figure D.40. Energy consumption for Leeds, room ratio of 1:2, West orientation.

6. Energy consumption for Natal

Figures D.41 to D.44 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.45 to D.48 show the same information for room ratio of 1:2.

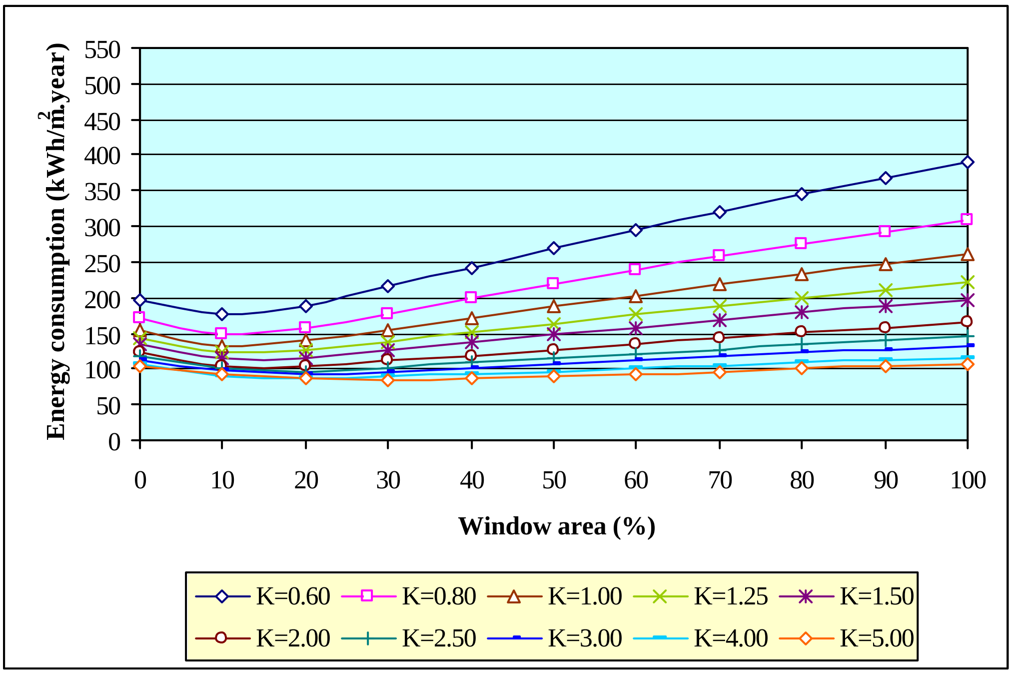

Figure D.41. Energy consumption for Natal, room ratio of 2:1, North orientation.

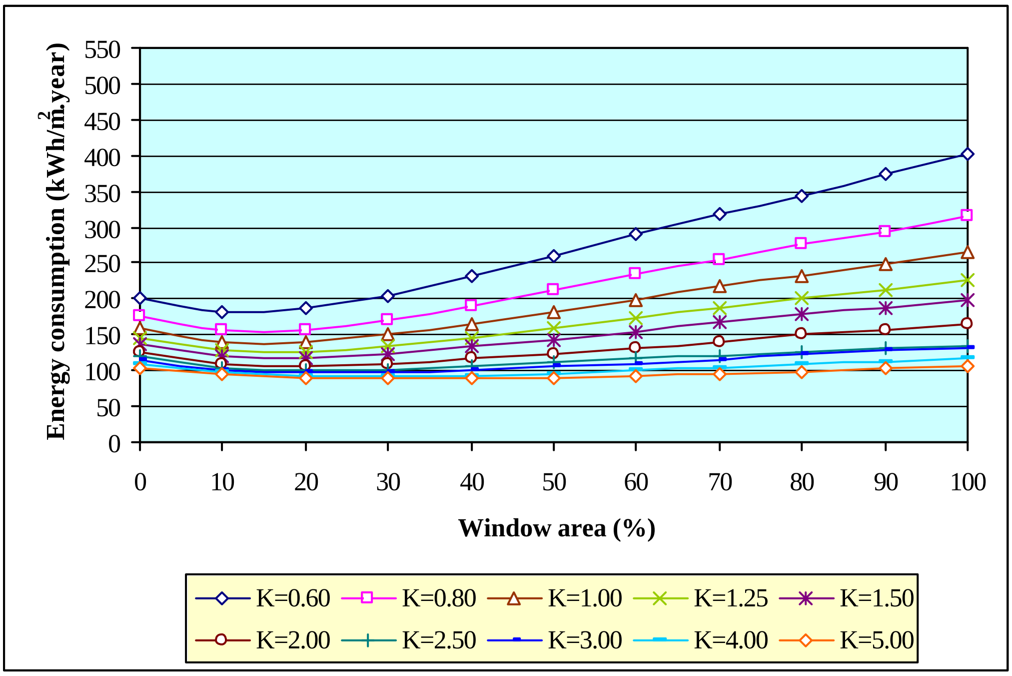

Figure D.42. Energy consumption for Natal, room ratio of 2:1, East orientation.

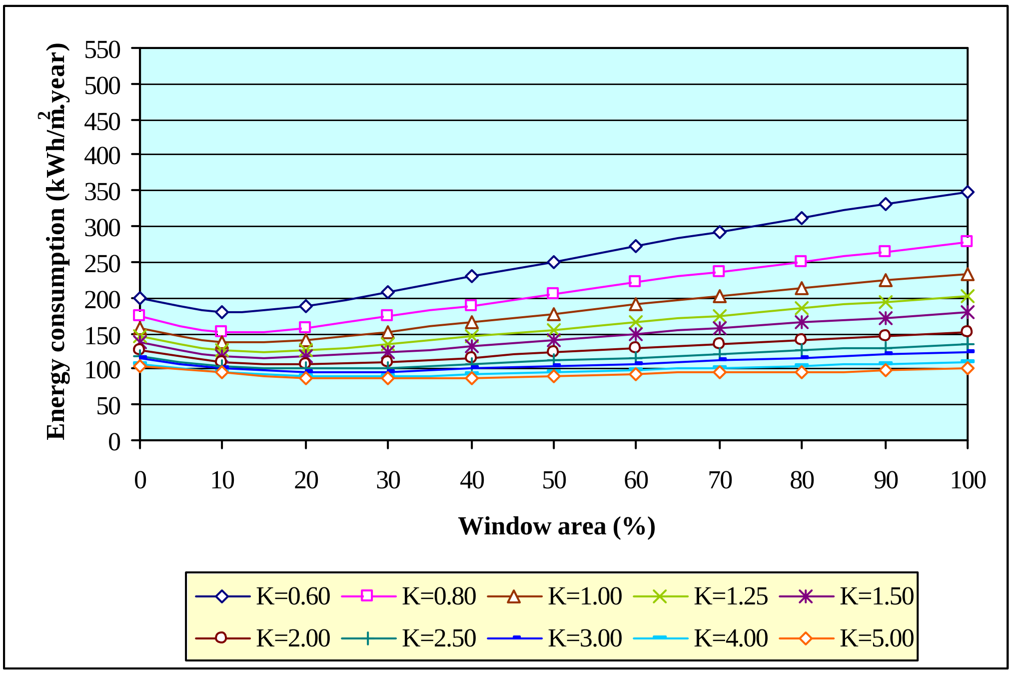

Figure D.43. Energy consumption for Natal, room ratio of 2:1, South orientation.

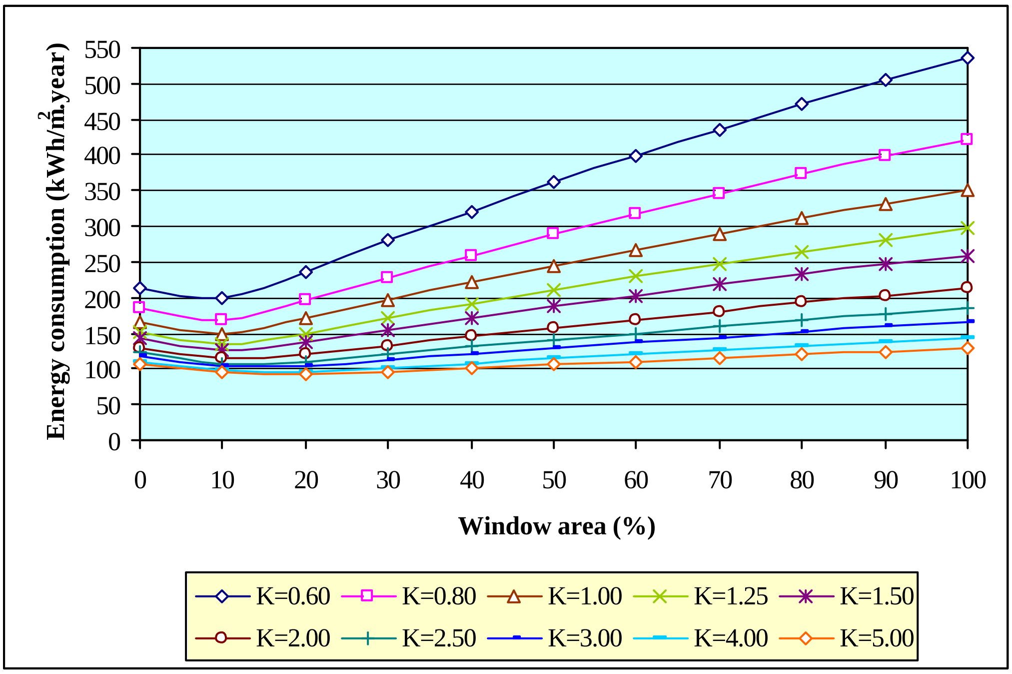

Figure D.44. Energy consumption for Natal, room ratio of 2:1, West orientation.

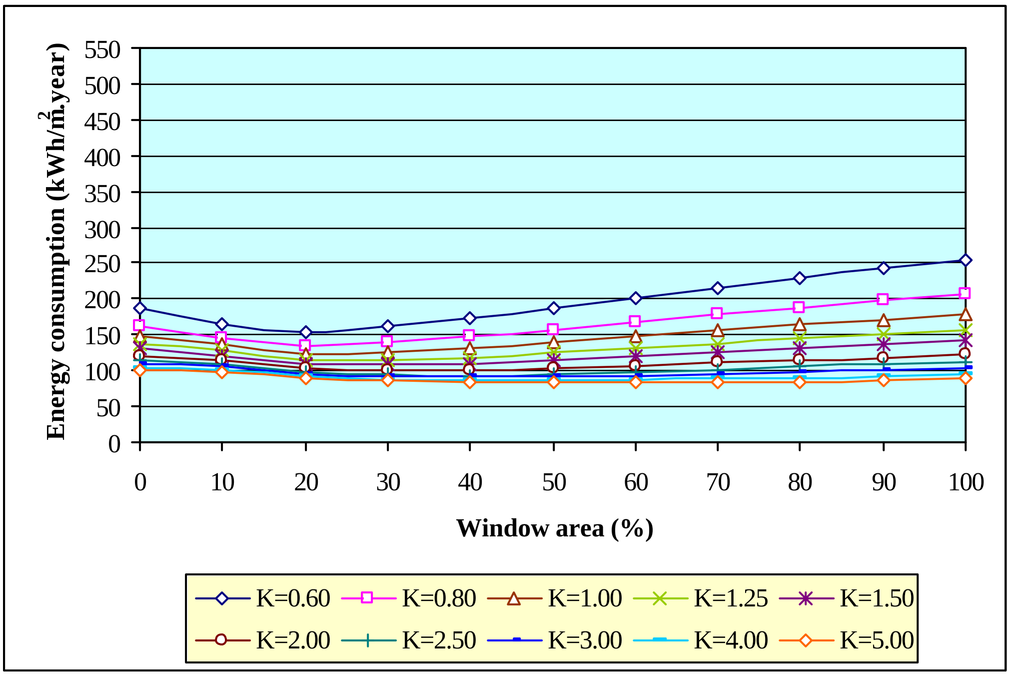

Figure D.45. Energy consumption for Natal, room ratio of 1:2, North orientation.

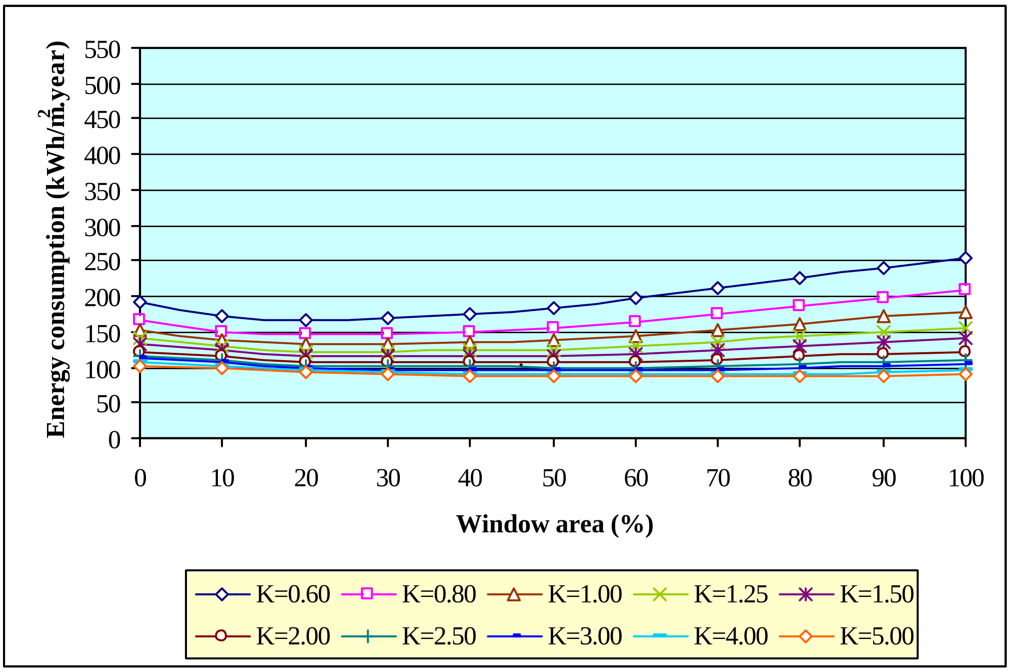

Figure D.46. Energy consumption for Natal, room ratio of 1:2, East orientation.

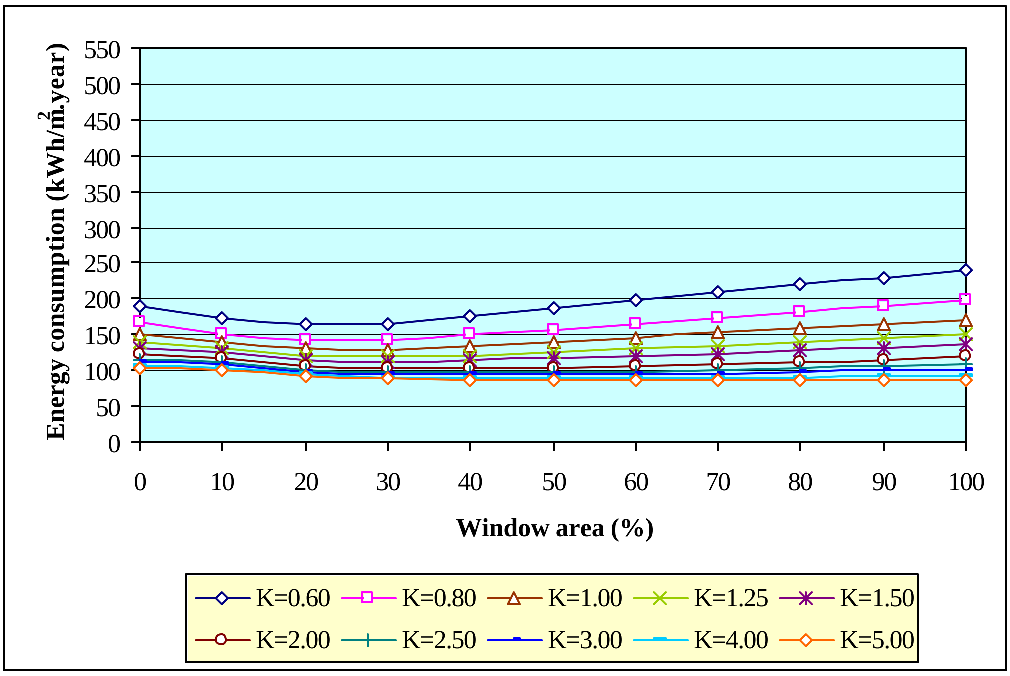

Figure D.47. Energy consumption for Natal, room ratio of 1:2, South orientation.

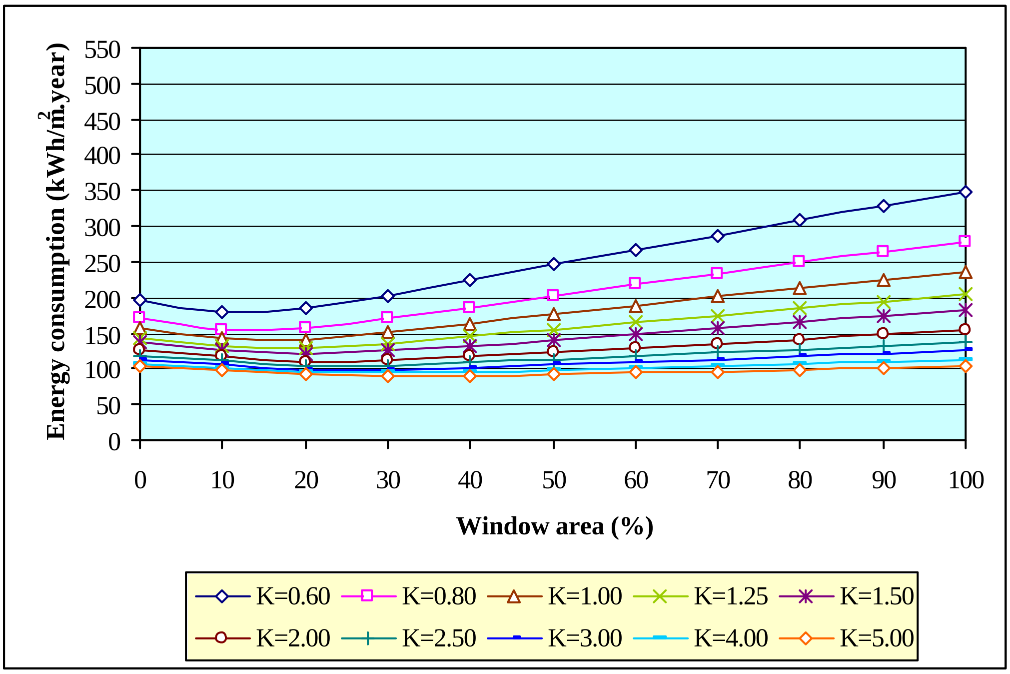

Figure D.48. Energy consumption for Natal, room ratio of 1:2, West orientation.

7. Energy consumption for Rio de Janeiro

Figures D.49 to D.52 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.53 to D.56 show the same information for room ratio of 1:2.

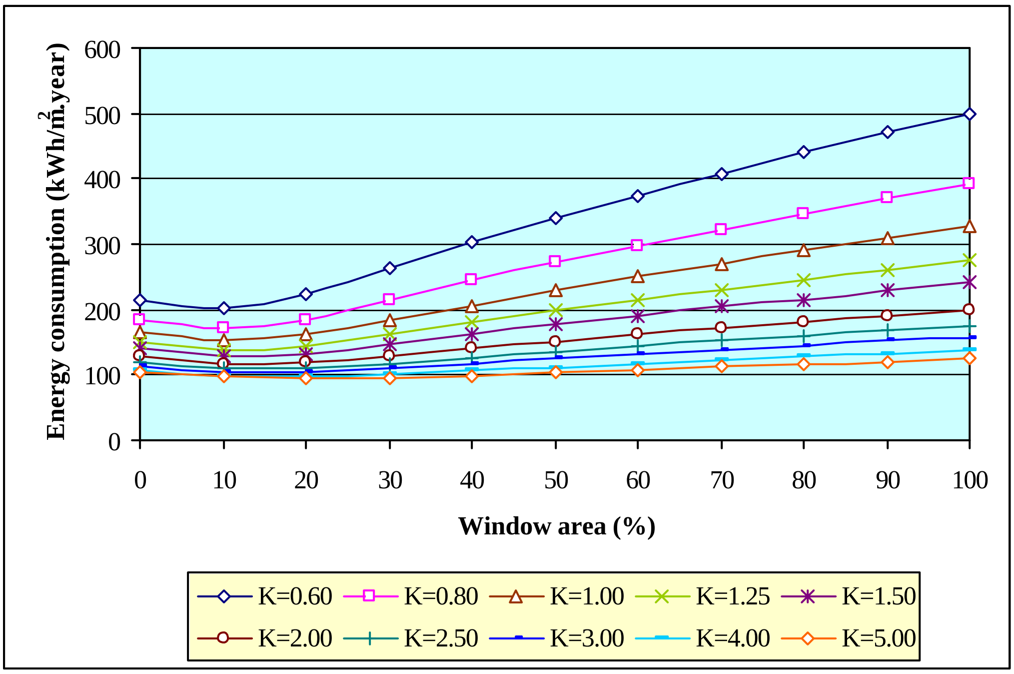

Figure D.49. Energy consumption for Rio de Janeiro, room ratio of 2:1, North orientation.

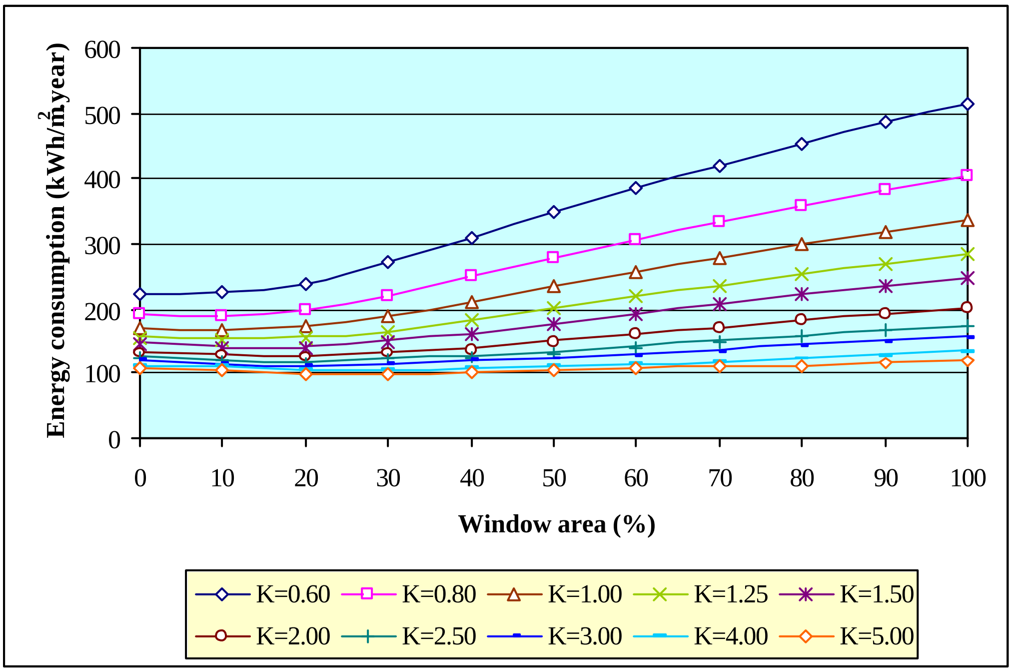

Figure D.50. Energy consumption for Rio de Janeiro, room ratio of 2:1, East orientation.

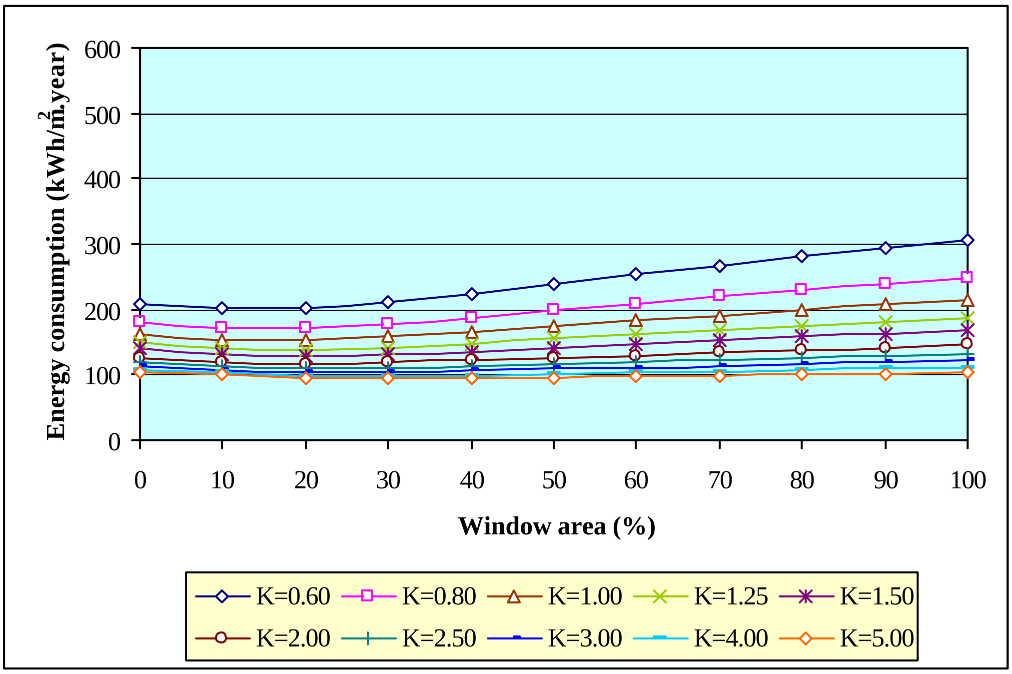

Figure D.51. Energy consumption for Rio de Janeiro, room ratio of 2:1, South orientation.

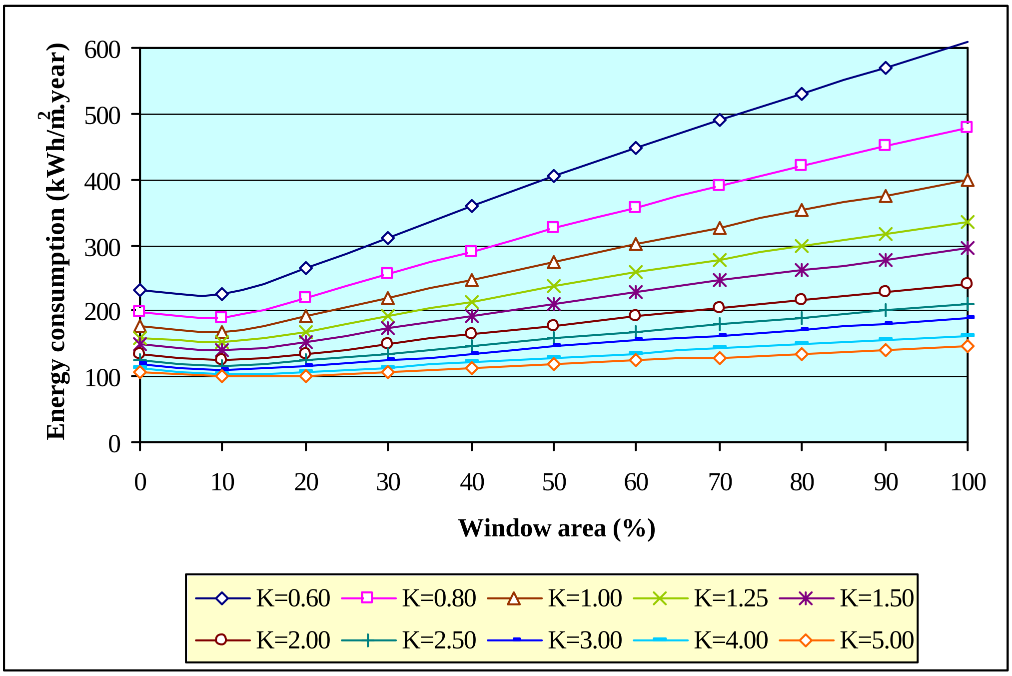

Figure D.52. Energy consumption for Rio de Janeiro, room ratio of 2:1, West orientation.

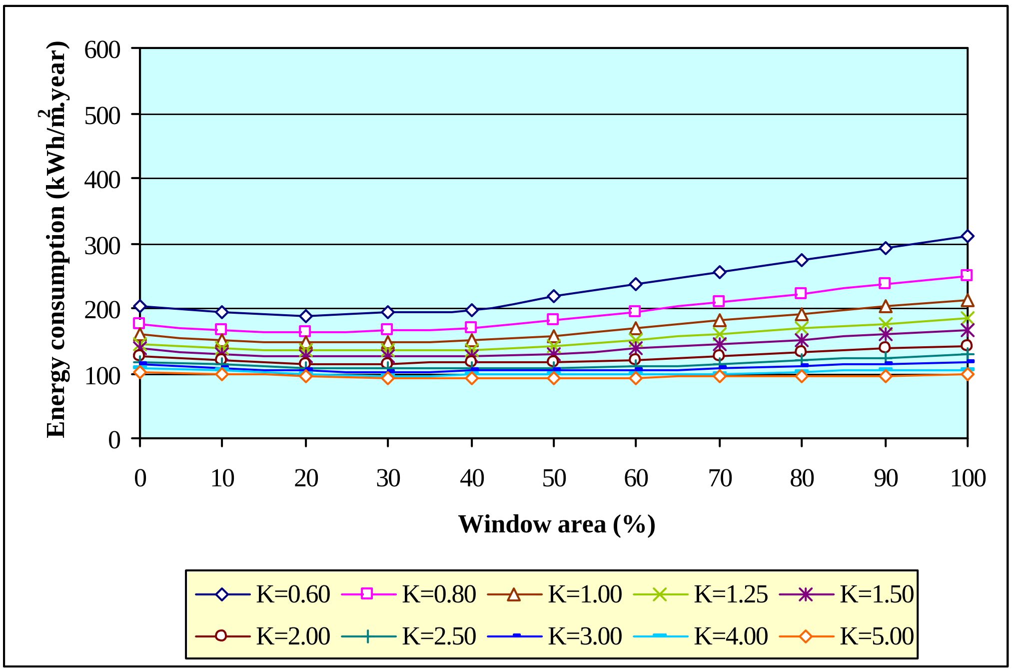

Figure D.53. Energy consumption for Rio de Janeiro, room ratio of 1:2, North orientation.

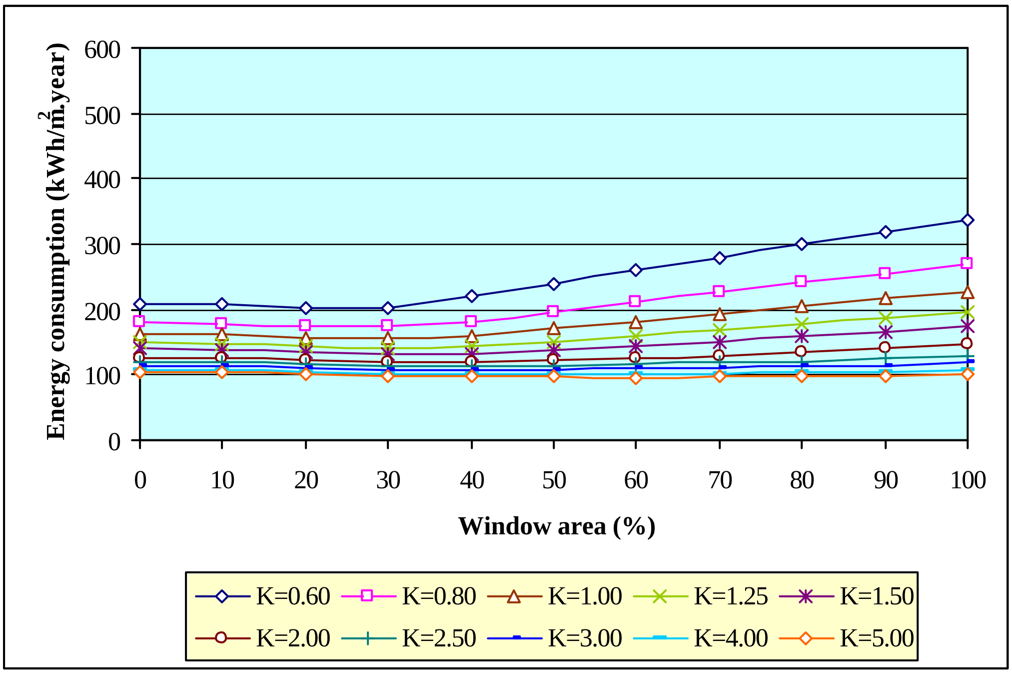

Figure D.54. Energy consumption for Rio de Janeiro, room ratio of 1:2, East orientation.

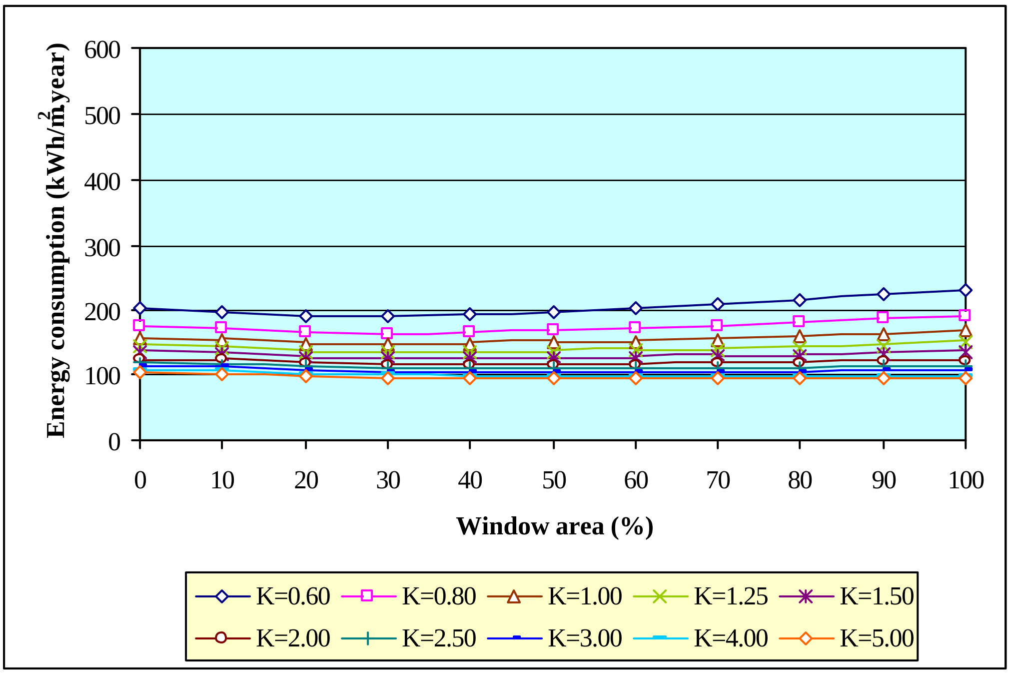

Figure D.55. Energy consumption for Rio de Janeiro, room ratio of 1:2, South orientation.

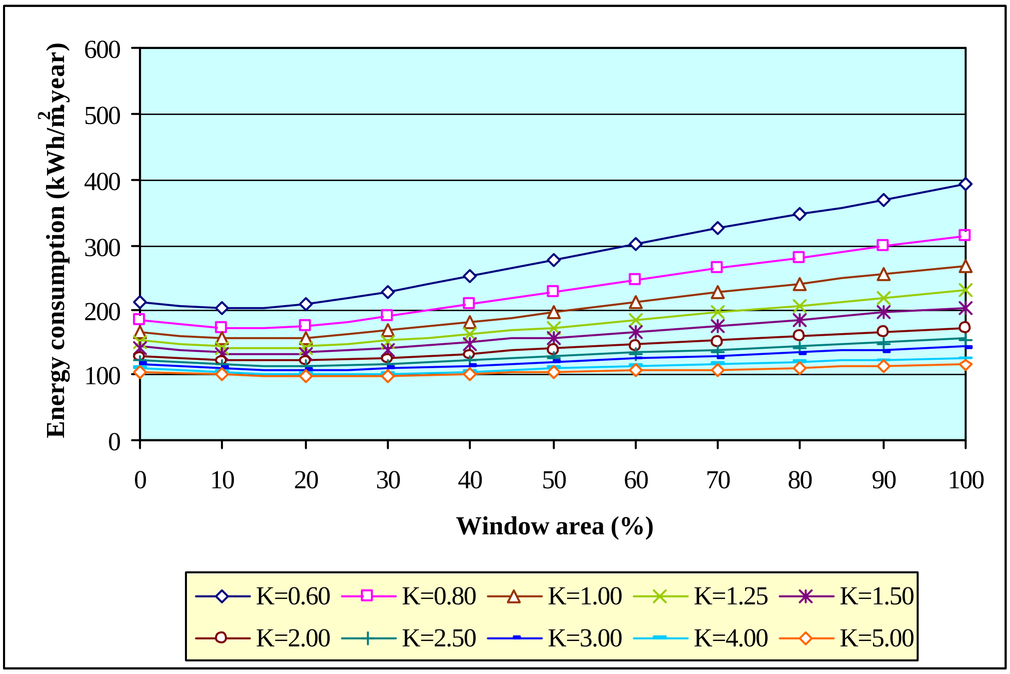

Figure D.56. Energy consumption for Rio de Janeiro, room ratio of 1:2, West orientation.

8. Energy consumption for Salvador

Figures D.57 to D.60 show the energy consumption for the 10 room sizes as a function of the window area, for room ratio of 2:1, and for the four orientations, respectively. Figures D.61 to D.64 show the same information for room ratio of 1:2.

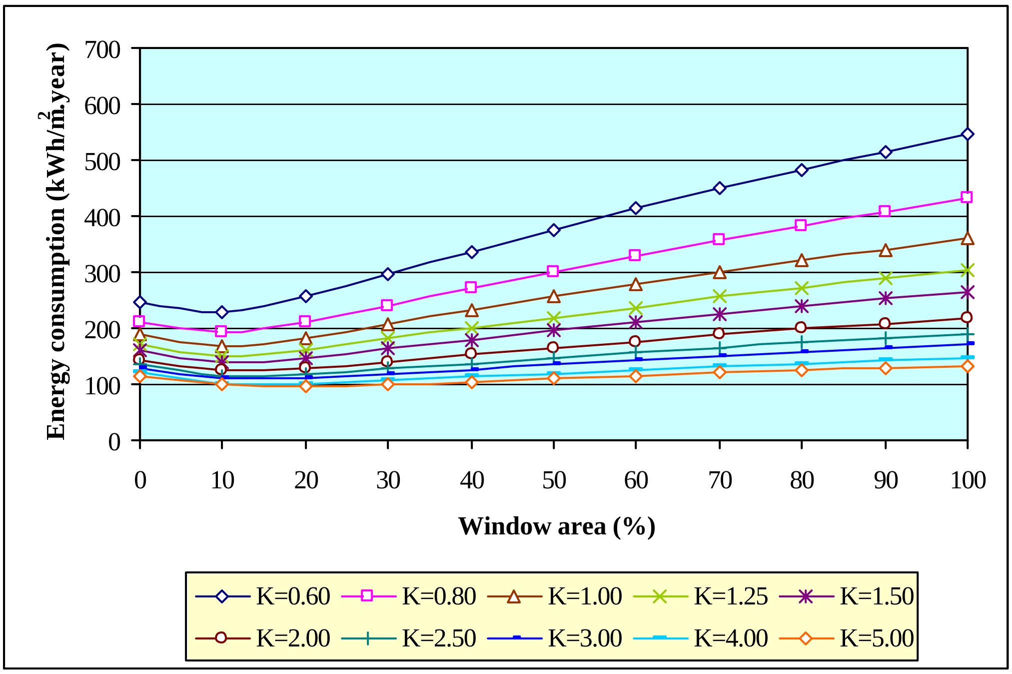

Figure D.57. Energy consumption for Salvador, room ratio of 2:1, North orientation.

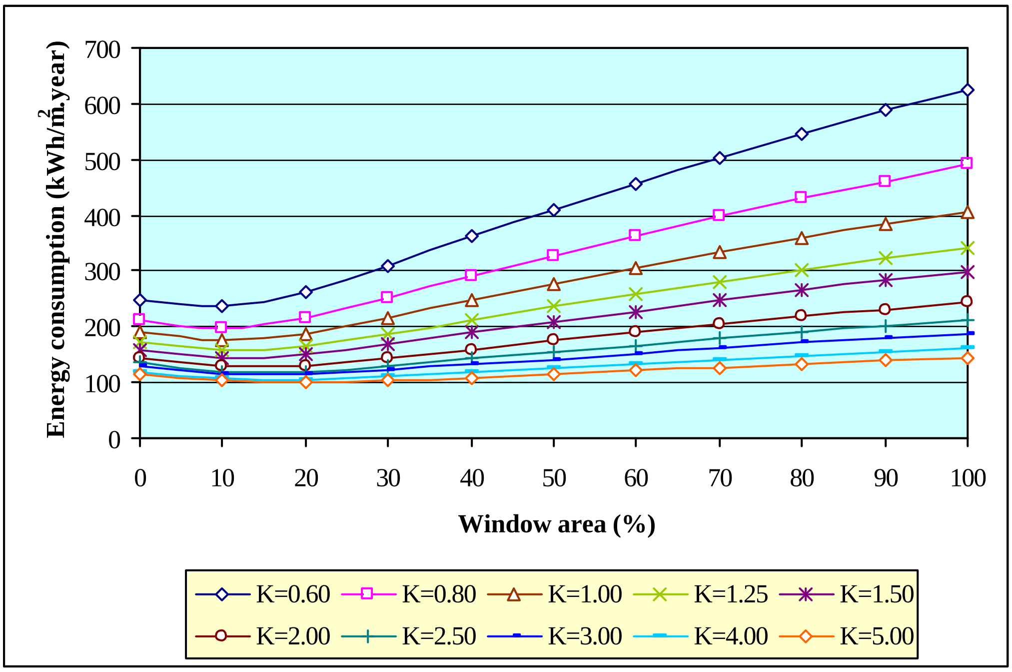

Figure D.58. Energy consumption for Salvador, room ratio of 2:1, East orientation.

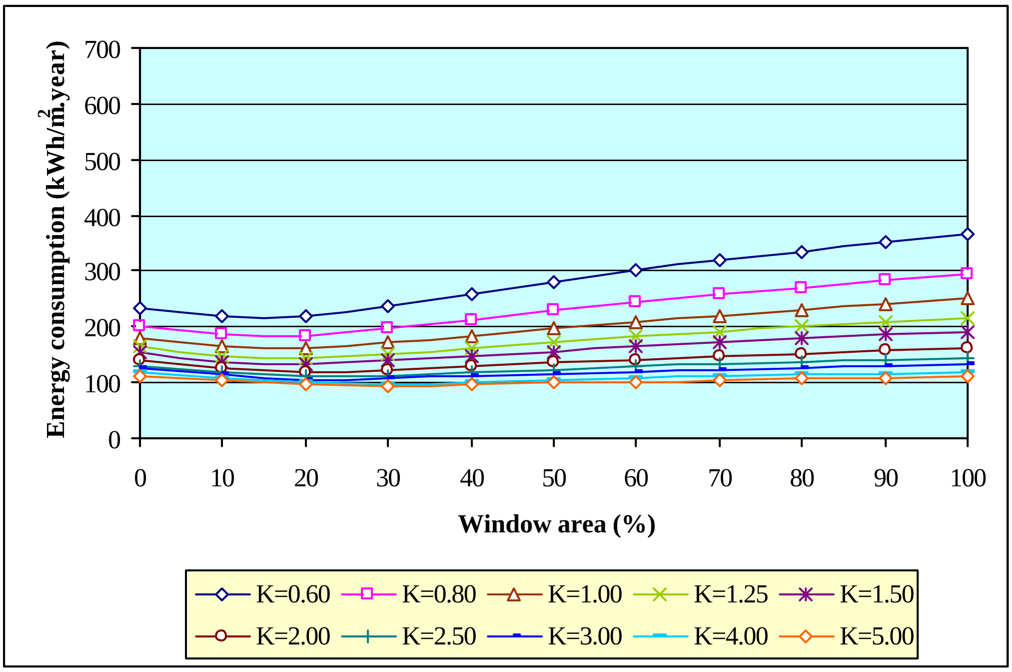

Figure D.59. Energy consumption for Salvador, room ratio of 2:1, South orientation.

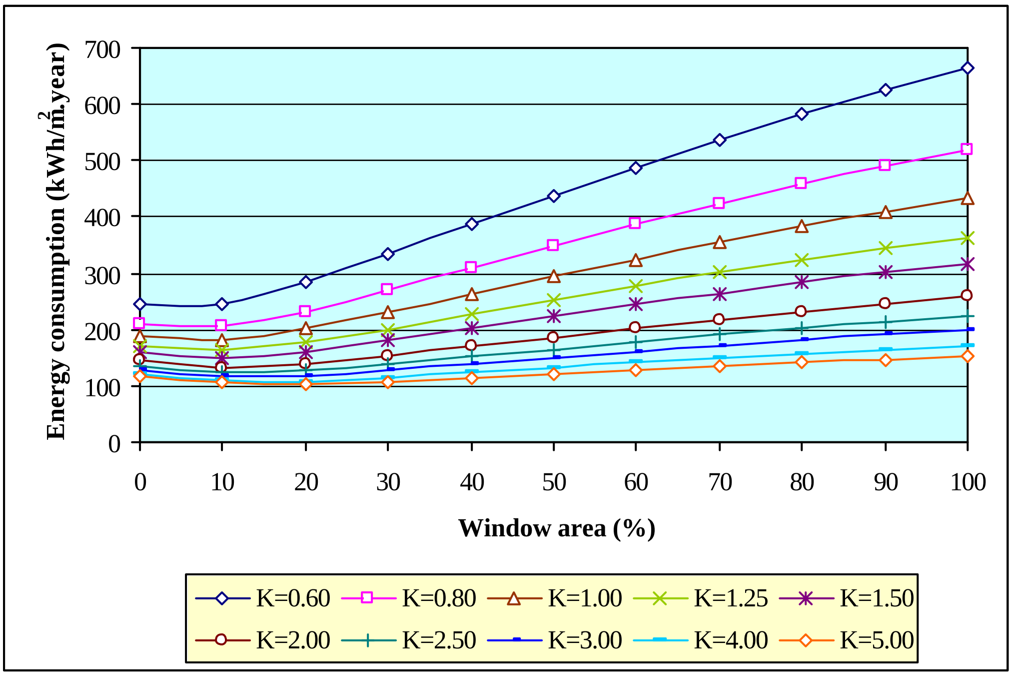

Figure D.60. Energy consumption for Salvador, room ratio of 2:1, West orientation.

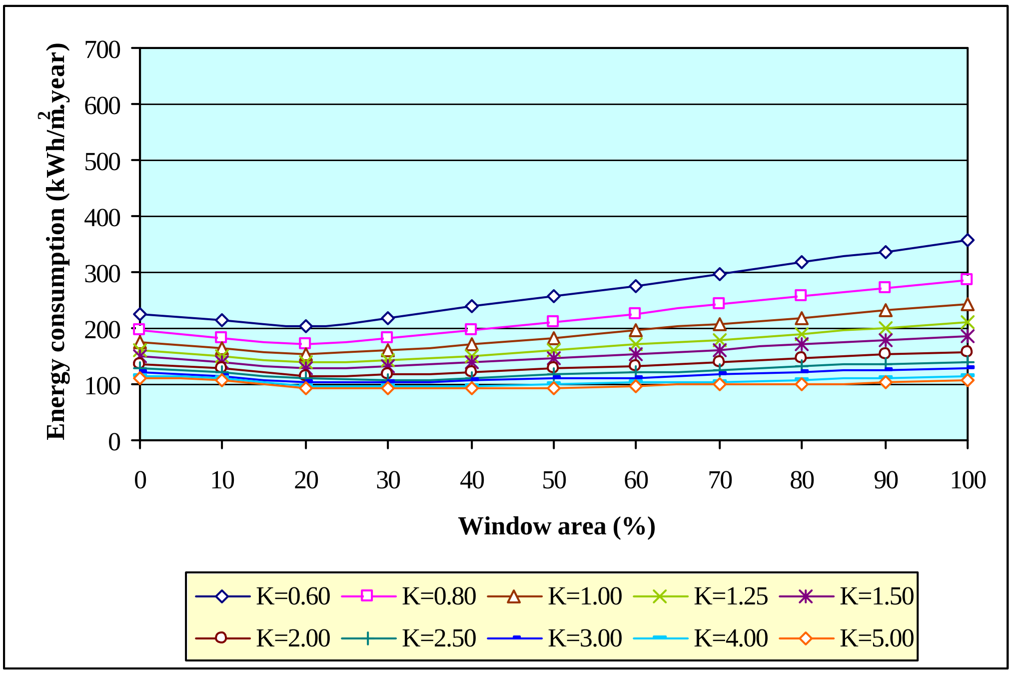

Figure D.61. Energy consumption for Salvador, room ratio of 1:2, North orientation.

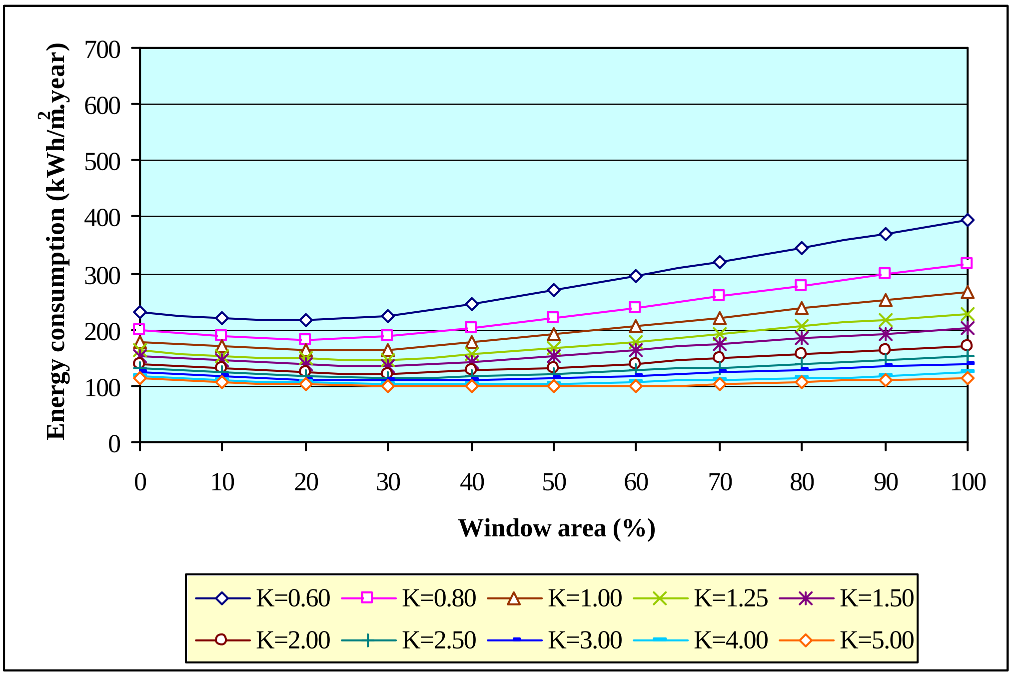

Figure D.62. Energy consumption for Salvador, room ratio of 1:2, East orientation.

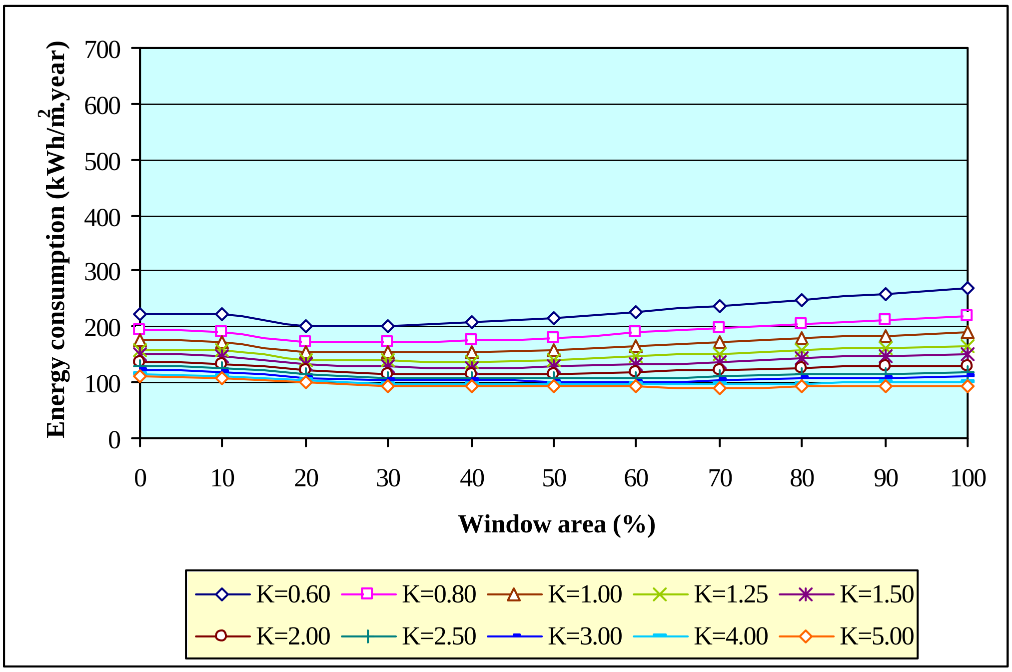

Figure D.63. Energy consumption for Salvador, room ratio of 1:2, South orientation.

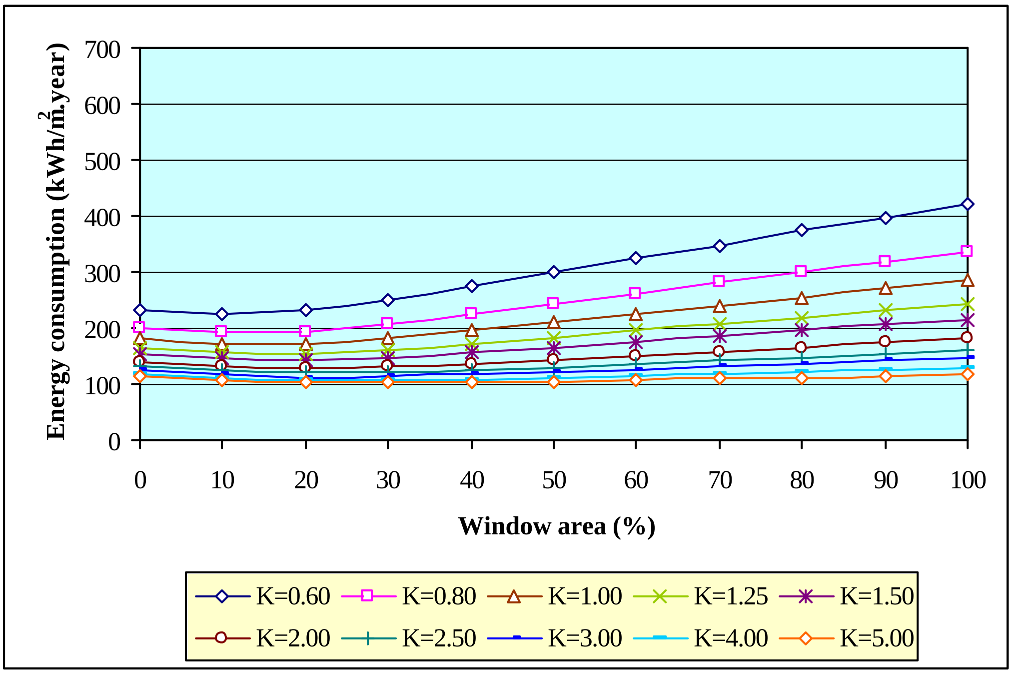

Figure D.64. Energy consumption for Salvador, room ratio of 1:2, West orientation.

Appendix E. Sample of VisualDOE Input & Output Files

```
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Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LV-A  GENERAL PROJECT AND BUILDING INPUT                                            WEATHER FILE- Florianopolis -TRY
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PERIOD OF STUDY

    STARTING DATE    ENDING DATE    NUMBER OF DAYS

       1 JAN 1995    31 DEC 1995              365

SITE CHARACTERISTIC DATA
                                                                  BUILDING
    STATION           LATITUDE  LONGITUDE   ALTITUDE      TIME     AZIMUTH
    NAME                 (DEG)      (DEG)       ( M)      ZONE       (DEG)

Florianopolis -TRY       -27.4       48.3         0.    3            180.0

_VisualDOE                                                                        DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LV-B  SUMMARY OF SPACES OCCURRING IN THE PROJECT                                    WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------


NUMBER OF SPACES    1          EXTERIOR    1     INTERIOR    0

                                         LIGHTING              EQUIP
            SPACE*FLOOR  SPACE           (WATT /              (WATT /  INFILTRATION  AIR CHANGES          AREA         VOLUME
SPACE        MULTIPLIER   TYPE  AZIMUTH    M2  )     PEOPLE     M2  )        METHOD     PER HOUR        ( M2  )        ( M3  )

1Single_Zone_C     10.0    EXT       0.0    18.90       0.7     15.00    AIR-CHANGE         0.20          10.80          30.10
                                                    --------                                          ---------     ----------
BUILDING TOTALS                                          7.2                                             108.00         301.00
```

```
_VisualDOE                                                                        DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LV-C DETAILS OF SPACE                               1Single_Zone_C                  WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

DATA FOR SPACE    1Single_Zone_C

LOCATION OF ORIGIN IN
BUILDING COORDINATES               SPACE
                                 AZIMUTH         SPACE*FLOOR              HEIGHT                AREA              VOLUME
 XB ( M)  YB ( M)  ZB ( M)         (DEG)          MULTIPLIER                ( M)             ( M2  )             ( M3  )
    0.00     0.00     0.00          0.00                10.0                2.79               10.80               30.10

      TOTAL    NUMBER OF    NUMBER OF      NUMBER OF
     NUMBER     EXTERIOR     INTERIOR    UNDERGROUND
OF SURFACES     SURFACES     SURFACES       SURFACES          DAYLIGHTING    SUNSPACE
          6            6            0              0                  YES        NO

NUMBER OF SUBSURFACES

         EXTERIOR           INTERIOR
TOTAL    WINDOWS    DOORS    WINDOWS
     1         1        0          0

                             CALCULATION
FLOOR WEIGHT                 TEMPERATURE
 (KG/M2     )                    (C     )
         0.0                        24.0

INFILTRATION
                            INFILTRATION                                                   HEIGHT TO
                            CALCULATION            FLOW RATE        AIR CHANGES        NEUTRAL ZONE
    SCHEDULE                METHOD                (M3/H-M2 )            PER HOUR                ( M)
    SCH53                   AIR-CHANGE                  0.00                0.20                 0.0

PEOPLE

                                                    AREA PER              PEOPLE              PEOPLE              PEOPLE
                                                      PERSON            ACTIVITY            SENSIBLE              LATENT
    SCHEDULE                      NUMBER             ( M2  )            (WATT    )           (WATT    )           (WATT    )
    SCH156                           0.7                15.0                 0.0                67.4                55.7
```

```
_VisualDOE                                                              DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LV-C DETAILS OF SPACE                               1Single_Zone_C                  WEATHER FILE- Florianopolis -TRY
--------------------------------------------------------------------------------------------------------------(CONTINUED)--------

LIGHTING
                                                        LOAD                                FRACTION
                                LIGHTING             (WATTS/                LOAD             OF LOAD
    SCHEDULE                    TYPE                   M2  )                (KW)            TO SPACE
    SCH156                      REC-FLUOR-NV           18.90                0.00                0.90

ELECTRICAL EQUIPMENT
                               ELEC LOAD                ELEC             FRACTION OF LOAD TO SPACE
                                 (WATTS/                LOAD
    SCHEDULE                       M2  )                (KW)            SENSIBLE              LATENT
    SCH156                         15.00                0.00                1.00                0.00

EXTERIOR SURFACES (U-VALUE EXCLUDES OUTSIDE AIR FILM)
                                                                                                  U-VALUE
                                         AREA       WIDTH   HEIGHT                                            SURFACE
    SURFACE           MULTIPLIER      ( M2  )       ( M)      ( M)          CONSTRUCTION     (W/M2-K       )   TYPE
    Wall1                    1.0         9.18        3.28     2.80          Asm121                  1.910     DELAYED
    Wall2                    1.0         9.18        3.28     2.80          Asm121                  1.910     DELAYED
    Wall3                    1.0         9.18        3.28     2.80          Asm121                  1.910     DELAYED
    Wall4                    1.0         9.18        3.28     2.80          Asm121                  1.910     DELAYED
    Roof5                    0.1        10.76        3.28     3.28          Asm137                  2.226     DELAYED
    Floor6                   0.1        10.76        3.28     3.28          Asm140                  4.533     DELAYED

                                                  LOCATION OF ORIGIN IN                   LOCATION OF ORIGIN IN
                                                  BUILDING COORDINATES                    SPACE COORDINATES
                         AZIMUTH     TILT
    SURFACE                (DEG)    (DEG)          XB ( M)  YB ( M)  ZB ( M)               X ( M)   Y ( M)   Z ( M)
    Wall1                  270.0     90.0             0.00     3.28     0.00                 0.00     3.28     0.00
    Wall2                    0.0     90.0             3.28     3.28     0.00                 3.28     3.28     0.00
    Wall3                   90.0     90.0             3.28     0.00     0.00                 3.28     0.00     0.00
    Wall4                  180.0     90.0             0.00     0.00     0.00                 0.00     0.00     0.00
    Roof5                  180.0      0.0             0.00     0.00     2.80                 0.00     0.00     2.80
    Floor6                   0.0    180.0             3.28     0.00     0.00                 3.28     0.00     0.00

EXTERIOR WINDOWS (U-VALUE INCLUDES OUTSIDE AIR FILM)
                                        GLASS      GLASS  NUMBER  GLASS    SET-  GLASS  GLASS      CENTER-OF-      GLASS
                                         AREA    SHADING      OF   TYPE    BACK  WIDTH HEIGHT   GLASS U-VALUE   VISIBLE
    WINDOW            MULTIPLIER       ( M2  )     COEFF   PANES   CODE    ( M)   ( M)    ( M) (W/M2-K      )     TRANS
    Window1                  1.0         4.13       0.95       1   1001    0.00   3.18   1.30           5.580     0.881
```

```
_VisualDOE                                                             DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                         080.GPH                             VisualDOE Graphic Editor
REPORT- LV-D  DETAILS OF EXTERIOR SURFACES IN THE PROJECT                         WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------

NUMBER OF EXTERIOR SURFACES   6          RECTANGULAR   6     OTHER   0
(U-VALUE INCLUDES OUTSIDE AIR FILM; WINDOW INCLUDES FRAME, IF DEFINED)

                                   - - - W I N D O W S - - -    - - - - W A L L - - - -   -W A L L + W I N D O W S-
SURFACE            SPACE               U-VALUE         AREA      U-VALUE          AREA     U-VALUE          AREA     AZIMUTH
                                   (W/M2-K        )    ( M2 )  (W/M2-K       )    ( M2 )  (W/M2-K       )    ( M2 )
Wall4              1Single_Zone_C       5.350          46.01       1.684          45.83      3.520          91.84    NORTH
Wall1              1Single_Zone_C       0.000           0.00       1.684          91.84      1.684          91.84    EAST
Wall2              1Single_Zone_C       0.000           0.00       1.684          91.84      1.684          91.84    SOUTH
Wall3              1Single_Zone_C       0.000           0.00       1.684          91.84      1.684          91.84    WEST
Floor6             1Single_Zone_C       0.000           0.00       3.435          10.76      3.435          10.76    FLOOR
Roof5              1Single_Zone_C       0.000           0.00       1.924          10.76      1.924          10.76    ROOF

_VisualDOE                                                             DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                         080.GPH                             VisualDOE Graphic Editor
REPORT- LV-D  DETAILS OF EXTERIOR SURFACES IN THE PROJECT                         WEATHER FILE- Florianopolis -TRY
--------------------------------------------------------------------------------------------------------(CONTINUED)--------

                        AVERAGE            AVERAGE          AVERAGE U-VALUE       WINDOW         WALL          WINDOW+WALL
                   U-VALUE/WINDOWS    U-VALUE/WALLS        WALLS+WINDOWS         AREA           AREA             AREA
                   (W/M2-K        )   (W/M2-K        )    (W/M2-K        )      ( M2 )         ( M2 )           ( M2 )
NORTH                    5.350              1.684              3.520            46.01          45.83            91.84
EAST                     0.000              1.684              1.684             0.00          91.84            91.84
SOUTH                    0.000              1.684              1.684             0.00          91.84            91.84
WEST                     0.000              1.684              1.684             0.00          91.84            91.84
FLOOR                    0.000              3.435              3.435             0.00          10.76            10.76
ROOF                     0.000              1.924              1.924             0.00          10.76            10.76
ALL WALLS                5.350              1.684              2.143            46.01         321.35           367.36
    WALLS+ROOFS          5.350              1.691              2.137            46.01         332.10           378.12
BUILDING                 5.350              1.746              2.172            46.01         342.86           388.88
```

```
_VisualDOE                                                                DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                                080.GPH                        VisualDOE Graphic Editor
REPORT- LV-H  DETAILS OF WINDOWS OCCURRING IN THE PROJECT                           WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

NUMBER OF WINDOWS    1           RECTANGULAR   1      OTHER   0

    RECTANGULAR WINDOWS (U-VALUES INCLUDE OUTSIDE AIR FILM)
                                                                          LOCATION OF ORIGIN
                                              GLASS        GLASS  GLASS         IN SURFACE     FRAME          FRAME
        WINDOW                                 AREA       HEIGHT  WIDTH        COORDINATES      AREA         U-VALUE
        NAME                MULTIPLIER      ( M2  )        ( M)    ( M)      X ( M)   Y ( M)  ( M2  ) (W/M2-K        )
        Window1                    1.0         4.13         1.30    3.18       0.10     1.50    5.03          1.592

                                                     GLASS    NUMBER    GLASS   INFILTRATION    CENTER-OF-      GLASS
        WINDOW              SETBACK                SHADING        OF     TYPE           FLOW   GLASS U-VALUE   VISIBLE
        NAME                  ( M)   X-DIVISIONS     COEFF     PANES     CODE          COEFF  (W/M2-K      )     TRANS
        Window1               0.00            10      0.95         1     1001            0.0           5.580     0.881

_VisualDOE                                                                DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                                080.GPH                        VisualDOE Graphic Editor
REPORT- LV-I  DETAILS OF CONSTRUCTIONS OCCURRING IN THE PROJECT                     WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

NUMBER OF CONSTRUCTIONS    3          DELAYED   3      QUICK    0

                               U-VALUE                 SURFACE                 NUMBER OF
    CONSTRUCTION                             SURFACE  ROUGHNESS    SURFACE     RESPONSE
    NAME                (W/M2-K        )  ABSORPTANCE     INDEX    TYPE         FACTORS
    Asm121                        1.910         0.70          3    DELAYED           10
    Asm137                        2.226         0.70          3    DELAYED            4
    Asm140                        4.533         0.70          3    DELAYED            6


_VisualDOE                                                                DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                                080.GPH                        VisualDOE Graphic Editor
REPORT- LS-A SPACE PEAK LOADS SUMMARY                                               WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

                    MULTIPLIER   COOLING LOAD          TIME OF    DRY-  WET-     HEATING LOAD         TIME OF    DRY-  WET-
SPACE NAME         SPACE  FLOOR    (KW       )            PEAK    BULB  BULB      (KW       )            PEAK    BULB  BULB
1Single_Zone_C      1.     10.        1.424   MAY  2  4 PM    26.C  22.C        -0.879    AUG  6  8 AM     2.C   2.C
                                  ---------                                    ---------
SUM                                  14.238                                    -8.789
BUILDING PEAK                        14.238   MAY  2  4 PM    26.C  22.C        -8.789    AUG  6  8 AM     2.C   2.C
```

```
_VisualDOE                                                                        DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LS-C BUILDING PEAK LOAD COMPONENTS                                                  WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

*** BUILDING ***

                    FLOOR  AREA      1163  SQFT       108   M2
                    VOLUME          10630  CUFT       301   M3

                                          COOLING  LOAD                               HEATING  LOAD
                                     ==========================                ==========================
    TIME                                    MAY  2  4PM                                AUG  6  8AM

    DRY-BULB TEMP                      79 F             26 C                     36 F              2 C
    WET-BULB TEMP                      71 F             22 C                     35 F              2 C
    TOT HORIZONTAL SOLAR RAD          178 BTU/H.SQFT   560 W/M2                   0 BTU/H.SQFT     0 W M2
    WINDSPEED AT SPACE                3.9 KTS          2.0 M/S                0.0 KTS          0.0 M S
    CLOUD AMOUNT 0(CLEAR)-10            0                                         1

                                  SENSIBLE            LATENT                              SENSIBLE
                            (KBTU/H)    ( KW )  (KBTU/H)  ( KW )                     (KBTU/H)   ( KW )
                            --------    ------  --------  ------                     --------  --------
     WALL CONDUCTION           4.895     1.434     0.000   0.000                      -20.144    -5.902
     ROOF CONDUCTION           0.984     0.288     0.000   0.000                       -0.882    -0.258
     WINDOW GLASS+FRM COND     6.587     1.930     0.000   0.000                       -9.657    -2.830
     WINDOW GLASS SOLAR       32.324     9.471     0.000   0.000                        0.687     0.201
     DOOR CONDUCTION           0.000     0.000     0.000   0.000                        0.000     0.000
     INTERNAL SURFACE COND     0.000     0.000     0.000   0.000                        0.000     0.000
     UNDERGROUND SURF COND     0.000     0.000     0.000   0.000                        0.000     0.000
     OCCUPANTS TO SPACE        0.877     0.257     1.369   0.401                        0.000     0.000
     LIGHT     TO SPACE        0.000     0.000     0.000   0.000                        0.000     0.000
     EQUIPMENT TO SPACE        2.928     0.858     0.000   0.000                        0.000     0.000
     PROCESS   TO SPACE        0.000     0.000     0.000   0.000                        0.000     0.000
     INFILTRATION              0.000     0.000     0.000   0.000                        0.000     0.000
                            --------   -------   -------  ------                     --------  --------
     TOTAL                    48.595    14.238     1.369   0.401                      -29.995    -8.789
     TOTAL / AREA              0.042     0.132     0.001   0.004                       -0.026    -0.081

     TOTAL LOAD               49.963 KBTU/H       14.639  KW                 -29.995 KBTU/H       -8.789  KW
     TOTAL LOAD / AREA        42.98   BTU/H.SQFT 135.549  W/M2                25.802 BTU/H.SQFT   81.375  W M2
```

```
_VisualDOE                                                                        DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                               080.GPH                                 VisualDOE Graphic Editor
REPORT- LS-D BUILDING MONTHLY LOADS SUMMARY                                                 WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------------------

       - - - - - - - - C O O L I N G - - - - - - - -      - - - - - - - - H E A T I N G - - - - - - - -      - - - E L E C - - -

                                             MAXIMUM                                            MAXIMUM         ELEC-    MAXIMUM
         COOLING     TIME  DRY-  WET-        COOLING        HEATING     TIME  DRY-  WET-        HEATING        TRICAL       ELEC
          ENERGY   OF MAX  BULB  BULB           LOAD         ENERGY   OF MAX  BULB  BULB           LOAD        ENERGY       LOAD
MONTH     ( MWH)   DY  HR  TEMP  TEMP     (KW      )         ( MWH)   DY  HR  TEMP  TEMP      (KW      )        (KWH)       (KW)

JAN      2.22066   27  16   33.C  31.C        10.402         -0.081   12   6   19.C  18.C        -2.526          286.      2.300

FEB      1.91247   19  15   34.C  28.C         9.399         -0.068   21   7   18.C  17.C        -1.934          259.      1.620

MAR      2.26253   13  15   34.C  27.C        11.868         -0.120   30   6   18.C  17.C        -2.684          301.      2.300

APR      2.27541   24  15   28.C  22.C        13.807         -0.308   17   7   13.C  12.C        -4.264          259.      1.620

MAY      1.54463    2  15   26.C  22.C        14.238         -0.815   19   7   12.C  12.C        -5.585          309.      2.981

JUN      1.26685   30  14   29.C  21.C        13.191         -1.254   21   7    4.C   3.C        -7.721          316.      3.661

JUL      0.97176   12  15   27.C  22.C        13.950         -1.392   23   6    7.C   6.C        -8.720          303.      3.661

AUG      0.70555    3  16   22.C  18.C        11.020         -1.423    6   7    2.C   2.C        -8.789          307.      2.981

SEP      0.72704   18  15   27.C  18.C         9.750         -0.885   13   4   14.C  13.C        -5.707          272.      1.620

OCT      0.75705   26  15   27.C  23.C         7.114         -0.834    1   6   13.C  11.C        -6.440          285.      1.620

NOV      0.99622   30  15   29.C  25.C         7.332         -0.455   22   6   13.C  12.C        -4.495          286.      2.981

DEC      1.42395    1  15   24.C  22.C         6.935         -0.290   20   5   17.C  15.C        -3.711          276.      2.981
       ---------                          ----------      ---------                          ----------      --------    -------

TOTAL     17.064                                             -7.926                                             3460.

MAX                                           14.238                                         -8.789                    3.661
```

```
_VisualDOE                                                          DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                                 080.GPH                 VisualDOE Graphic Editor
REPORT- LS-G  SPACE DAYLIGHTING SUMMARY                                       WEATHER FILE- Florianopolis -TRY
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SPACE   1Single_Zone_C

                                                                  ----------------REPORT SCHEDULE HOURS WITH SUN UP----------------

              PERCENT LIGHTING          PERCENT LIGHTING              AVERAGE      PERCENT HOURS
              ENERGY REDUCTION          ENERGY REDUCTION             DAYLIGHT         DAYLIGHT
                BY DAYLIGHTING            BY DAYLIGHTING          ILLUMINANCE      ILLUMINANCE            AVERAGE      PERCENT HOURS
                   (ALL HOURS)    (REPORT SCHEDULE HOURS)        ( LUX        )  ABOVE SETPOINT       GLARE INDEX    GLARE TOO HIGH
         ---------------------  -----------------------       --------------   --------------    --------------   --------------
          TOTAL  REF PT  REF PT     TOTAL  REF PT  REF PT       REF PT  REF PT   REF PT  REF PT    REF PT  REF PT   REF PT  REF PT
MONTH      ZONE       1       2      ZONE       1       2            1       2        1       2         1       2        1       2
-----     -----  ------  ------     -----  ------  ------       ------  ------   ------  ------    ------  ------   ------  ------

JAN        99.8    99.8     0.0      99.8    99.8     0.0       3442.3     0.0     76.8     0.0       6.5     0.0      0.0     0.0

FEB       100.0   100.0     0.0     100.0   100.0     0.0       3783.0     0.0     80.5     0.0       6.8     0.0      0.0     0.0

MAR        99.1    99.1     0.0      99.1    99.1     0.0       3591.4     0.0     83.4     0.0       6.2     0.0      0.0     0.0

APR       100.0   100.0     0.0     100.0   100.0     0.0       7491.8     0.0     82.1     0.0       3.4     0.0      0.0     0.0

MAY        97.1    97.1     0.0      97.1    97.1     0.0       8410.1     0.0     79.3     0.0       2.7     0.0      0.0     0.0

JUN        91.4    91.4     0.0      91.4    91.4     0.0       9881.6     0.0     81.6     0.0       2.4     0.0      0.0     0.0

JUL        91.1    91.1     0.0      91.1    91.1     0.0       7207.4     0.0     81.3     0.0       3.2     0.0      0.0     0.0

AUG        97.6    97.6     0.0      97.6    97.6     0.0       5562.0     0.0     79.6     0.0       4.3     0.0      0.0     0.0

SEP       100.0   100.0     0.0     100.0   100.0     0.0       3403.0     0.0     79.2     0.0       5.8     0.0      0.0     0.0

OCT       100.0   100.0     0.0     100.0   100.0     0.0       3187.7     0.0     78.1     0.0       6.5     0.0      0.0     0.0

NOV        99.6    99.6     0.0      99.6    99.6     0.0       3272.8     0.0     85.0     0.0       6.9     0.0      0.0     0.0

DEC        98.8    98.8     0.0      98.8    98.8     0.0       3435.0     0.0     80.4     0.0       6.8     0.0      0.0     0.0
          -----  ------  ------     -----  ------  ------       ------  ------   ------  ------    ------  ------   ------  ------

ANNUAL     97.9    97.9     0.0      97.9    97.9     0.0       5037.7     0.0     80.5     0.0       5.3     0.0      0.0     0.0
```

```
_VisualDOE                                                      DOE-2.1E-W83   1/12/2001    15: 2: 8  LDL RUN  1
Base Case                              080.GPH                VisualDOE Graphic Editor
REPORT- LS-I PERCENT LIGHTING ENERGY REDUCTION BY DAYLIGHT                  WEATHER FILE- Florianopolis -TRY
------------------------------------------------------------------------------------------------------------------


*** BUILDING ***


                                         HOUR OF DAY
                                                                                                              ALL
MONTH     1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24  HOURS
-----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  -----

JAN       0    0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100   98    0    0    0    0    0    0    100

FEB       0    0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100  100    0    0    0    0    0    0    100

MAR       0    0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100   93    0    0    0    0    0    0     99

APR       0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100  100    0    0    0    0    0    0    0    100

MAY       0    0    0    0    0    0    0   80  100  100  100    0    0  100  100  100   97    0    0    0    0    0    0    0     97

JUN       0    0    0    0    0    0    0   37  100  100  100    0    0  100  100  100   94    0    0    0    0    0    0    0     91

JUL       0    0    0    0    0    0    0   34  100  100  100    0    0  100  100  100   95    0    0    0    0    0    0    0     91

AUG       0    0    0    0    0    0    0   81  100  100  100    0    0  100  100  100  100    0    0    0    0    0    0    0     98

SEP       0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100  100    0    0    0    0    0    0    0    100

OCT       0    0    0    0    0    0    0  100  100  100  100  100    0  100  100  100  100  100    0    0    0    0    0    0    100

NOV       0    0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100   97    0    0    0    0    0    0    100

DEC       0    0    0    0    0    0    0    0  100  100  100  100    0    0  100  100  100   90    0    0    0    0    0    0     99
        ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  -----

ANNUAL    0    0    0    0    0    0    0   76  100  100  100  100    0  100  100  100   99   96    0    0    0    0    0    0     98
```

```
_VisualDOE                                                           DOE-2.1E-W83   1/12/2001    15: 2: 8  PDL RUN  1
Base Case                               080.GPH                    VisualDOE Graphic Editor
REPORT- PS-E  MONTHLY ENERGY END-USE SUMMARY                                   WEATHER FILE- Florianopolis -TRY
---------------------------------------------------------------------------------------------------------------------

ELECTRICAL END-USES IN KWH

                 JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC     TOTAL
               -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------

 AREA LIGHTS        1.       0.       3.       0.      11.      31.      30.       9.       0.       0.       1.       4.      91.
      MAX KW       0.7      0.0      0.7      0.0      1.4      2.0      2.0      1.4      0.0      0.0      1.4      1.4      2.0
      DAY/HR      6/18     0/ 0    22/18     0/ 0    12/ 9     7/ 9     3/ 9     2/ 9     0/ 0     0/ 0    21/18    12/18

MISC EQUIPMT      285.     259.     298.     259.     298.     285.     272.     298.     272.     285.     285.     272.    3370.
      MAX KW       1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6      1.6
      DAY/HR      2/ 9     1/ 9     1/ 9     3/ 9     1/ 9     1/ 9     3/ 9     1/ 9     1/ 9     2/ 9     1/ 9     1/ 9

  SPACE COOL        4.       0.       5.      13.       6.       0.       0.       0.       0.       0.       0.       0.      27.
      MAX KW       1.3      0.0      1.7      2.0      1.8      0.0      0.0      0.0      0.0      0.0      0.0      0.0      2.0
      DAY/HR     28/16     0/ 0    18/15    22/17    27/17     0/ 0     0/ 0     0/ 0     0/ 0     0/ 0     0/ 0     0/ 0

   VENT FANS       76.      76.      76.      94.      76.      76.      94.      76.      94.      76.      76.      94.     982.
      MAX KW       2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4      2.4
      DAY/HR      7/ 9     4/ 9     4/ 9     1/ 9     6/ 9     3/ 9     1/ 9     5/ 9     2/ 9     7/ 9     4/ 9     2/ 9
               =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  ========

   TOTAL KWH      365.     335.     382.     367.     390.     391.     397.     382.     367.     361.     362.     371.    4469.

FUEL END-USES IN  MWH

                 JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC     TOTAL
               -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------

DOMHOT WATER       2.0      1.9      2.1      2.1      2.4      2.4      2.4      2.5      2.2      2.3      2.2      2.1     26.5
    MAX  MWH     0.008    0.008    0.008    0.009    0.009    0.010    0.010    0.010    0.009    0.009    0.009    0.009    0.010
      DAY/HR      2/13     1/13     1/13     3/13     1/13     1/13     3/13     1/13     1/13     2/13     1/13     1/13
               =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  =======  ========

  TOTAL  MWH       2.0      1.9      2.1      2.1      2.4      2.4      2.4      2.5      2.2      2.3      2.2      2.1     26.5
```

```
_VisualDOE                                                                         DOE-2.1E-W83   1/12/2001    15: 2: 8  PDL RUN  1
Base Case                                080.GPH                                 VisualDOE Graphic Editor
REPORT- PS-F  ENERGY-RESOURCE PEAK BREAKDOWN BY END-USE                                      WEATHER FILE- Florianopolis -TRY
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ENERGY-RESOURCE:  ELECTRICITY
          UNITS:  KWH

                  JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC
               -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------  -------

 PEAK DEMAND:       3.7      2.4      4.0      4.3      4.1      3.7      3.7      3.0      2.4      2.4      3.0      3.0
      DAY/HR:     28/16     4/ 9    18/15    22/17    27/17     7/ 9     3/ 9     2/ 9     2/ 9     7/ 9    21/18    12/18

BREAKDOWN
-------------

 AREA LIGHTS:      0.00     0.00     0.00     0.00     0.00     2.04     2.04     1.36     0.00     0.00     1.36     1.36
         (%):      0.00     0.00     0.00     0.00     0.00    55.75    55.75    45.65     0.00     0.00    45.65    45.65

MISC EQUIPMT:      0.00     0.00     0.00     0.00     0.00     1.62     1.62     1.62     0.00     0.00     1.62     1.62
         (%):      0.00     0.00     0.00     0.00     0.00    44.25    44.25    54.35     0.00     0.00    54.35    54.35

  SPACE COOL:      1.32     0.00     1.67     1.96     1.75     0.00     0.00     0.00     0.00     0.00     0.00     0.00
         (%):     35.88     0.00    41.46    45.32    42.64     0.00     0.00     0.00     0.00     0.00     0.00     0.00

   VENT FANS:      2.36     2.36     2.36     2.36     2.36     0.00     0.00     0.00     2.36     2.36     0.00     0.00
         (%):     64.12   100.00    58.54    54.68    57.36     0.00     0.00     0.00   100.00   100.00     0.00     0.00

DOMHOT WATER:      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
         (%):      0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
```

```
_VisualDOE                                                                  DOE-2.1E-W83   1/12/2001    15: 2: 8  PDL RUN  1
Base Case                                  080.GPH                        VisualDOE Graphic Editor
REPORT- BEPU  BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)                     WEATHER FILE- Florianopolis -TRY
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                                ENERGY TYPE:  ELECTRICITY  NATURAL-GAS
                                 SITE UNITS:      KWH           Mj

                             CATEGORY OF USE
                             ---------------
                                AREA LIGHTS         91.           0.
                               MISC EQUIPMT       3370.           0.
                                 SPACE COOL         27.           0.
                                  VENT FANS        982.           0.
                                             ----------   ----------
                                      TOTAL       4469.           0.

           TOTAL ELECTRICITY      4469. KWH          0.357 KWH     / M2 -YR GROSS-AREA    0.357 KWH     / M2 -YR NET-AREA
           TOTAL NATURAL-GAS        27. Mj           0.002 Mj      / M2 -YR GROSS-AREA    0.002 Mj      / M2 -YR NET-AREA

                   PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE =  0.0
                   PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED                =  0.0

                   NOTE:  ENERGY IS APPORTIONED HOURLY TO ALL END-USE CATEGORIES.
```

Appendix F. Equations for the Ideal Window Area

Tables F.1 to F.8 show the equations used to determine the Ideal Window Area of rooms as a function of the room index (K). The equations are presented for each of the eight cities studied in this work – Belém, Brasília, Curitiba, Florianópolis, Leeds, Natal, Rio de Janeiro, and Salvador – five room ratios and four orientations.

Table F.1. Equations for the Ideal Window Area in Belém.

Room ratio		North	East	South	West
2:1	IWA=	2.49K + 9.93	6.11K + 7.61	3.56K + 12.13	3.56K + 8.12
	R^2 =	0.9849	0.9811	0.9856	0.9861
1.5:1	IWA=	3.12K + 10.44	8.46K + 4.86	4.82K + 11.58	4.33K + 8.29
	R^2 =	0.9810	0.9760	0.9863	0.9803
1:1	IWA=	3.87K + 11.60	8.72K + 6.65	6.46K + 13.46	3.23K + 9.08
	R^2 =	0.9881	0.9820	0.9865	0.9972
1:1.5	IWA=	4.00K + 15.79	12.10K + 8.68	7.96K + 17.42	5.99K + 10.40
	R^2 =	0.9939	0.9841	0.9933	0.9819
1:2	IWA=	6.80K + 15.20	14.42K + 9.21	9.91K + 20.37	7.01K + 13.83
	R^2 =	0.9973	0.9834	0.9981	0.9904

Table F.2. Equations for the Ideal Window Area in Brasília.

Room ratio		North	East	South	West
2:1	IWA=	3.05K + 10.34	4.54K + 13.51	5.04K + 16.78	2.57K + 8.89
	R^2 =	0.9812	0.9967	0.9965	0.9901
1.5:1	IWA=	3.15K + 13.02	5.66K + 12.45	6.56K + 17.34	3.60K + 8.41
	R^2 =	0.9929	0.9942	0.9945	0.9931
1:1	IWA=	4.24K + 14.53	8.14K + 14.57	7.57K + 22.89	4.38K + 10.57
	R^2 =	0.9865	0.9880	0.9921	0.9862
1:1.5	IWA=	6.83K + 15.57	9.49K + 20.05	11.72K + 24.39	3.55K + 14.69
	R^2 =	0.9962	0.9899	0.9920	0.9814
1:2	IWA=	8.57K + 18.86	12.27K + 23.06	11.35K + 34.59	4.46K + 16.60
	R^2 =	0.9864	0.9749	0.9910	0.9883

Table F.3. Equations for the Ideal Window Area in Curitiba.

Room ratio		North	East	South	West
2:1	IWA=	3.65K + 10.16	4.25K + 11.03	6.30K + 14.18	2.79K + 8.72
	R^2 =	0.9909	0.9914	0.9946	0.9806
1.5:1	IWA=	3.50K + 13.22	3.80K + 15.00	7.02K + 15.54	2.51K + 9.03
	R^2 =	0.9904	0.9964	0.9890	0.9778
1:1	IWA=	5.08K + 14.45	4.75K + 17.33	7.80K + 19.50	4.45K + 9.04
	R^2 =	0.9940	0.9960	0.9890	0.9814
1:1.5	IWA=	6.44K + 19.07	6.64K + 22.19	10.73K + 25.48	3.80K + 13.52
	R^2 =	0.9918	0.9803	0.9880	0.9644
1:2	IWA=	7.92K + 24.60	8.55K + 26.51	10.86K + 36.76	3.22K + 16.79
	R^2 =	0.9824	0.9861	0.9921	0.9932

Table F.4. Equations for the Ideal Window Area in Florianópolis.

Room ratio		North	East	South	West
2:1	IWA=	2.90K + 9.15	3.57K + 12.37	3.32K + 16.30	2.62K + 8.46
	R^2 =	0.9814	0.9960	0.9916	0.9815
1.5:1	IWA=	4.25K + 8.81	3.55K + 13.36	4.26K + 17.52	3.14K + 8.33
	R^2 =	0.9947	0.9960	0.9883	0.9915
1:1	IWA=	3.73K + 14.04	3.98K+16.20	6.34K+17.30	3.06K + 9.98
	R^2 =	0.9830	0.9806	0.9824	0.9813
1:1.5	IWA=	5.02K + 17.27	4.75K + 21.93	7.86K + 20.10	3.41K + 13.19
	R^2 =	0.9905	0.9919	0.9844	0.9850
1:2	IWA=	5.90K + 21.89	7.18K + 21.66	11.24K + 24.41	3.22K + 16.58
	R^2 =	0.9903	0.9848	0.9727	0.9890

Table F.5. Equations for the Ideal Window Area in Leeds.

Room ratio		North	East	South	West
2:1	IWA=	7.33K + 12.05	3.03K + 9.60	1.74K + 9.18	1.93K + 5.95
	R^2 =	0.9926	0.9910	0.9823	0.9832
1.5:1	IWA=	6.28K + 15.09	4.54K + 9.49	1.37K + 10.24	2.19K + 5.65
	R^2 =	0.9844	0.9892	0.9735	0.9874
1:1	IWA=	10.89K + 9.54	4.42K + 12.97	2.87K + 9.44	3.17K + 4.92
	R^2 =	0.9859	0.9845	0.9872	0.9835
1:1.5	IWA=	13.91K + 9.67	5.80K + 16.60	4.61K + 8.63	3.67K + 6.22
	R^2 =	0.9952	0.9847	0.9835	0.9927
1:2	IWA=	14.49K + 14.08	7.98K + 14.78	4.65K + 10.75	4.53K + 6.29
	R^2 =	0.9855	0.9907	0.9818	0.9919

Table F.6. Equations for the Ideal Window Area in Natal.

Room ratio		North	East	South	West
2:1	IWA=	3.99K + 8.44	5.01K + 8.85	4.13K + 8.91	2.77K + 7.11
	R^2 =	0.9937	0.9815	0.9973	0.9762
1.5:1	IWA=	4.01K + 9.40	6.29K + 8.39	3.86K + 11.40	2.75K + 7.27
	R^2 =	0.9950	0.9884	0.9865	0.9833
1:1	IWA=	5.98K + 9.80	8.43K + 7.07	5.65K + 11.92	3.61K + 7.26
	R^2 =	0.993	0.9979	0.9928	0.9763
1:1.5	IWA=	7.45K + 13.03	10.81K + 9.26	6.60K + 15.17	5.23K + 8.06
	R^2 =	0.9961	0.9848	0.9824	0.9785
1:2	IWA=	8.92K + 15.00	11.66K + 9.27	9.11K + 12.73	1.87K + 17.11
	R^2 =	0.9906	0.9818	0.9853	0.9825

Table F.7. Equations for the Ideal Window Area in Rio de Janeiro.

Room ratio		North	East	South	West
2:1	IWA=	2.89K + 7.34	3.94K + 6.18	2.56K + 16.08	1.17K + 7.26
	R^2 =	0.9950	0.9889	0.9841	0.9863
1.5:1	IWA=	4.70K + 6.72	4.59K + 7.77	4.39K + 13.24	1.23K + 7.89
	R^2 =	0.9902	0.9804	0.9865	0.9886
1:1	IWA=	2.79K + 11.91	5.13K + 11.02	5.81K + 16.16	2.19K + 7.59
	R^2 =	0.9735	0.9897	0.9970	0.9885
1:1.5	IWA=	3.31K + 14.10	6.94K + 14.01	8.58K + 17.33	3.85K + 7.99
	R^2 =	0.9748	0.9909	0.9924	0.9911
1:2	IWA=	4.49K + 17.07	7.64K + 21.76	9.18K + 23.59	3.06K + 10.73
	R^2 =	0.9840	0.9875	0.9948	0.9666

Table F.8. Equations for the Ideal Window Area in Salvador.

Room ratio		North	East	South	West
2:1	IWA=	2.35K + 8.18	2.61K + 7.84	3.71K + 13.93	2.81K + 5.65
	R^2 =	0.9925	0.9929	0.9815	0.9903
1.5:1	IWA=	2.72K + 8.21	2.78K + 8.98	4.00K + 15.48	2.84K + 5.96
	R^2 =	0.9811	0.9725	0.9791	0.9912
1:1	IWA=	3.67K + 9.18	2.52K + 14.14	5.02K + 16.80	3.79K + 6.70
	R^2 =	0.9927	0.9659	0.9940	0.9752
1:1.5	IWA=	2.82K + 13.82	3.72K + 15.13	8.24K + 18.12	4.60K + 7.70
	R^2 =	0.9898	0.9964	0.9944	0.9812
1:2	IWA=	2.71K + 18.09	6.16K + 16.96	9.18K + 23.99	5.74K + 7.42
	R^2 =	0.9845	0.9825	0.9820	0.9962

Appendix G. Energy Consumption versus Window Area

Tables G.1 to G.16 show the percentage of the energy consumption increase for window areas different than the Ideal Window Area for the eight cities studied in this work, for room ratios of 2:1 and 1:2.

Table G.1. Percentage of the energy consumption increase for window areas different than the IWA for Belém, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	14.1	0.3	7.2	21.4	36.2	50.5	64.5	78.0	91.0	103.3	114.8
	East	13.0	0.7	3.4	18.8	37.9	58.7	78.8	98.3	116.9	134.5	151.3
	South	11.4	1.0	2.3	12.7	26.1	39.1	51.7	65.1	77.9	89.9	101.1
	West	6.4	0.0	7.8	23.6	41.6	60.0	77.8	95.1	111.5	127.1	142.3
0.80	North	17.1	0.6	6.4	19.0	32.3	45.1	57.5	69.7	81.4	92.4	102.7
	East	15.6	1.2	3.2	15.9	33.3	51.2	69.3	86.7	103.4	119.1	134.1
	South	14.6	1.1	2.2	11.0	23.0	34.6	45.8	57.0	68.0	78.6	88.7
	West	8.8	0.0	5.9	19.9	33.9	50.3	66.1	81.6	96.1	110.0	123.5
1.00	North	22.4	0.5	8.4	19.8	32.0	43.8	58.4	66.7	77.5	87.8	97.4
	East	17.0	1.0	2.7	12.8	28.4	44.3	60.5	76.2	91.3	105.5	119.1
	South	16.7	1.8	0.9	9.2	19.9	30.4	40.6	50.7	60.6	69.9	78.5
	West	12.4	0.0	6.0	18.6	31.6	44.6	59.1	73.2	86.6	99.3	111.6
1.25	North	20.0	0.8	4.0	13.7	24.1	34.3	44.2	54.0	63.3	72.3	80.7
	East	17.8	1.2	2.0	9.8	23.5	37.2	51.7	65.6	79.1	91.8	103.9
	South	18.5	2.8	0.7	8.1	17.0	26.3	35.4	44.5	53.3	61.6	69.5
	West	14.1	0.6	4.8	15.9	27.2	38.8	49.8	62.4	74.4	85.9	96.9
1.50	North	21.4	1.3	3.3	11.7	21.1	30.2	39.2	48.0	56.4	64.6	72.2
	East	17.9	1.1	1.0	6.6	18.5	31.4	43.7	56.2	68.3	79.7	90.6
	South	19.7	3.5	0.3	6.6	14.2	22.5	30.6	38.9	46.9	54.4	61.5
	West	13.5	0.8	1.8	11.5	21.5	31.6	41.5	50.8	61.5	71.7	81.6
2.00	North	21.2	2.8	1.0	7.5	15.1	22.5	29.9	37.2	44.2	51.0	57.5
	East	18.4	1.3	0.8	2.9	12.7	23.4	33.1	43.5	53.7	63.4	72.5
	South	21.0	4.7	0.0	4.4	10.2	17.0	23.8	30.6	37.4	43.8	49.8
	West	15.2	1.7	0.8	8.4	16.4	24.8	33.0	41.1	48.9	56.3	64.2
2.50	North	21.2	3.0	0.0	4.8	11.2	17.5	23.8	30.0	36.1	41.9	47.5
	East	18.1	2.1	0.0	1.5	7.9	16.8	25.5	33.7	42.3	50.7	58.5
	South	21.4	5.5	0.0	2.7	7.2	12.9	18.6	24.5	30.1	35.8	41.1
	West	16.2	2.6	0.4	6.0	12.9	19.9	26.9	33.9	40.6	47.0	53.3
3.00	North	21.7	3.7	0.0	3.4	9.0	14.5	19.9	25.6	30.9	36.0	41.0
	East	18.1	2.6	0.0	0.8	4.8	12.6	20.3	27.2	34.7	42.1	49.0
	South	22.3	9.0	0.6	2.2	5.7	10.6	15.7	20.8	25.8	30.9	35.5
	West	16.5	3.3	0.0	4.3	10.3	16.2	22.4	28.5	34.3	40.0	45.5
4.00	North	23.0	2.3	0.0	2.6	6.6	11.1	15.4	19.9	24.4	28.7	32.7
	East	18.2	4.6	0.4	0.0	0.7	7.1	13.2	19.3	25.1	30.4	36.1
	South	18.9	8.4	0.0	0.3	0.6	3.7	7.5	11.5	15.5	19.5	23.2
	West	15.5	3.9	0.0	0.9	5.2	9.9	14.7	19.5	24.2	28.7	33.2
5.00	North	22.0	8.1	0.0	1.1	3.7	7.3	10.9	14.7	18.3	21.9	25.5
	East	20.3	8.0	2.5	1.6	0.0	4.7	10.6	15.8	20.8	25.7	29.8
	South	21.7	12.3	3.2	0.0	1.6	3.6	6.9	10.3	13.6	17.0	20.4
	West	17.5	7.0	0.0	1.3	4.5	8.5	12.5	16.6	20.6	24.5	28.2

Table G.2. Percentage of the energy consumption increase for window areas different than the IWA for Belém, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	18.3	7.5	0.0	4.4	10.8	19.5	28.2	36.7	45.0	53.1	61.1
	East	16.9	4.5	0.0	2.2	4.3	14.0	24.9	36.1	48.0	59.7	70.9
	South	15.0	7.3	0.8	0.3	4.1	10.8	18.6	26.1	33.6	41.0	48.1
	West	10.7	2.0	0.3	4.6	13.0	21.7	30.8	41.2	51.4	61.6	71.5
0.80	North	19.8	8.9	0.1	3.3	8.7	16.1	23.4	30.8	38.1	45.1	52.0
	East	17.5	3.8	0.3	1.6	3.2	10.0	19.3	28.6	39.0	49.1	58.8
	South	16.5	9.0	1.6	0.0	3.1	8.1	14.6	21.1	27.7	34.1	40.2
	West	12.4	0.9	0.3	3.0	10.3	17.8	25.5	33.3	41.3	50.2	58.8
1.00	North	20.3	10.2	0.3	2.3	6.6	12.7	19.3	25.7	32.0	38.2	44.3
	East	17.4	6.1	0.4	1.1	2.2	6.6	14.4	23.4	31.7	40.6	49.2
	South	17.9	10.9	2.3	0.0	2.1	5.7	11.5	17.2	22.9	28.5	34.0
	West	13.0	4.6	0.5	2.0	7.7	14.1	21.0	27.7	34.4	41.2	48.3
1.25	North	21.2	13.9	0.7	2.1	5.3	10.2	16.0	21.6	27.1	32.4	37.7
	East	16.9	7.0	0.3	0.6	1.2	3.3	9.9	17.7	24.5	32.1	39.6
	South	17.2	12.0	1.8	0.0	0.2	3.1	7.3	12.3	17.1	21.9	26.5
	West	14.2	7.0	0.7	1.7	6.2	11.6	17.4	23.5	29.3	35.0	40.8
1.50	North	33.8	26.9	10.8	11.8	14.5	18.8	24.2	29.7	35.1	40.3	45.4
	East	16.2	7.2	0.0	0.1	0.1	0.5	6.1	12.8	19.4	25.3	31.7
	South	18.0	13.3	2.5	0.4	0.0	1.9	5.0	9.4	13.7	18.0	22.0
	West	14.4	7.8	0.5	0.8	4.3	8.7	13.7	19.0	24.1	29.2	34.2
2.00	North	22.0	17.3	1.8	1.3	2.6	5.2	8.9	12.9	16.9	20.7	24.6
	East	16.1	8.0	0.7	0.1	0.1	0.0	2.1	7.3	12.5	17.9	22.4
	South	18.9	15.2	3.1	1.7	0.0	0.6	2.1	5.5	9.1	12.5	15.9
	West	15.1	9.5	0.5	2.0	2.1	5.7	9.4	13.6	17.8	22.0	26.2
2.50	North	22.4	17.6	4.1	0.2	1.2	2.8	5.7	9.0	12.2	15.5	18.7
	East	17.6	9.9	1.9	0.8	1.0	0.0	0.6	4.5	9.3	13.9	18.3
	South	19.6	16.7	4.0	2.0	1.3	0.0	1.2	3.1	6.0	9.0	11.8
	West	17.4	11.9	2.2	0.0	2.2	5.2	8.1	11.5	15.1	18.7	22.2
3.00	North	21.8	17.5	4.2	0.3	0.0	1.0	3.5	6.0	8.8	11.6	14.4
	East	17.2	9.6	1.3	0.5	0.5	0.1	0.0	1.2	5.4	9.2	13.0
	South	20.4	17.9	5.4	2.7	1.9	0.0	0.9	1.8	4.3	6.8	9.4
	West	21.0	15.6	1.3	2.4	4.5	6.7	9.5	12.2	15.3	18.4	21.6
4.00	North	22.8	19.1	5.9	1.3	0.0	0.4	1.9	3.9	5.9	8.2	10.3
	East	18.8	12.0	4.2	2.1	1.3	0.9	0.0	1.0	1.7	5.3	8.3
	South	20.8	18.5	8.9	2.9	2.2	0.7	0.0	0.8	1.6	3.5	5.4
	West	16.4	12.1	4.3	0.9	0.0	0.6	2.7	4.5	6.7	9.0	11.3
5.00	North	23.1	19.7	7.3	2.7	1.3	0.0	0.8	2.4	4.0	5.7	7.5
	East	19.9	14.1	6.2	3.2	2.0	1.7	1.6	1.5	0.0	2.3	5.5
	South	21.6	19.7	10.8	3.9	3.0	2.3	0.0	0.3	1.3	1.9	3.5
	West	16.7	13.2	5.0	0.9	1.2	0.0	1.0	2.8	4.5	6.2	8.2

Table G.3. Percentage of the energy consumption increase for window areas different than the IWA for Brasília, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	23.8	0.3	9.7	36.5	62.6	87.2	110.0	134.3	157.9	180.3	202.0
	East	21.7	2.7	1.0	19.4	42.7	67.2	90.9	113.7	135.8	157.2	177.7
	South	24.2	7.9	0.0	4.5	13.4	24.4	35.7	46.5	56.7	66.5	75.8
	West	12.9	0.0	12.4	37.1	62.6	87.3	111.3	134.7	156.9	178.6	199.5
0.80	North	27.8	1.5	8.2	32.0	54.8	76.4	96.1	117.4	138.0	157.7	176.6
	East	25.1	4.0	1.2	16.6	37.2	58.3	79.3	99.3	118.9	137.7	155.9
	South	26.8	8.4	0.0	3.4	11.0	20.3	30.0	39.3	48.2	56.6	64.7
	West	16.0	0.0	7.8	29.4	51.7	73.3	94.4	114.9	134.5	153.4	171.7
1.00	North	36.1	0.7	11.7	33.5	54.6	74.5	93.4	112.3	131.3	149.5	167.2
	East	26.2	4.1	0.6	12.9	31.1	49.3	67.8	85.6	102.8	119.5	135.6
	South	29.1	7.2	0.2	2.6	9.3	17.1	25.6	33.8	41.7	49.2	56.3
	West	18.8	0.6	6.5	23.8	43.6	62.8	81.6	100.0	117.4	134.4	150.7
1.25	North	29.6	1.6	3.5	21.3	38.6	55.0	70.5	85.8	101.4	116.5	131.0
	East	26.4	4.3	0.0	9.2	25.0	40.3	56.5	72.0	87.0	101.6	115.5
	South	31.0	9.0	0.9	2.2	7.9	14.3	21.7	28.9	35.8	42.4	48.6
	West	19.9	0.7	4.6	17.6	34.5	51.3	67.7	83.7	99.0	113.9	128.1
1.50	North	30.4	2.3	1.9	17.4	32.6	47.0	60.8	74.0	87.8	101.0	113.9
	East	27.3	5.0	0.0	6.7	20.5	33.6	48.0	61.7	75.1	88.0	100.5
	South	30.9	9.0	0.1	0.5	5.2	10.4	17.0	23.2	29.2	34.9	40.4
	West	21.1	0.9	3.2	14.3	28.8	43.0	56.9	70.9	84.6	97.7	110.4
2.00	North	31.8	4.5	0.7	12.8	25.0	36.8	48.0	58.4	69.7	80.7	91.3
	East	27.4	6.3	0.2	3.1	14.0	24.7	35.5	46.8	57.7	68.3	78.6
	South	32.9	14.5	1.6	0.6	4.0	7.8	13.0	18.1	23.0	27.7	32.2
	West	21.1	1.1	1.0	8.7	20.2	31.6	42.9	53.8	64.5	74.9	84.8
2.50	North	32.3	8.0	0.0	9.5	19.8	29.6	39.0	47.5	57.1	66.4	75.3
	East	25.6	5.7	0.6	0.4	8.2	16.9	25.3	34.8	43.8	52.7	61.3
	South	33.2	15.7	2.8	0.0	2.8	5.5	9.6	13.9	17.9	21.9	25.6
	West	22.3	2.0	0.6	6.2	15.9	25.3	34.8	44.2	53.3	62.0	70.5
3.00	North	31.3	8.7	0.0	6.3	15.0	23.4	31.5	38.6	46.9	54.9	62.6
	East	25.4	6.9	1.1	0.2	5.3	12.8	20.2	27.7	35.7	43.4	50.9
	South	32.7	17.3	3.7	0.0	1.7	3.9	7.1	10.7	14.2	17.6	20.8
	West	22.2	2.9	0.3	4.5	12.2	20.3	28.4	36.5	44.3	52.0	59.3
4.00	North	32.1	4.3	0.0	3.7	10.6	17.2	23.7	29.8	35.4	41.8	48.1
	East	24.7	9.1	2.2	0.0	1.2	6.9	12.7	18.3	24.1	30.2	36.2
	South	31.5	19.5	6.9	1.4	0.0	1.6	3.5	6.2	8.8	11.5	14.0
	West	22.5	6.9	0.4	2.4	7.7	14.0	20.4	26.7	32.9	39.0	44.9
5.00	North	30.1	12.2	1.8	1.1	6.1	11.2	16.5	21.6	25.8	31.0	36.2
	East	24.9	11.6	2.9	0.7	0.8	3.7	8.5	13.3	17.8	22.5	27.5
	South	31.3	21.7	8.1	2.1	0.1	0.7	2.0	4.0	6.2	8.3	10.4
	West	23.5	9.6	0.8	2.0	5.7	10.8	16.0	21.3	26.5	31.6	36.5

Table G.4. Percentage of the energy consumption increase for window areas different than the IWA for Brasília, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	33.5	12.9	1.3	2.6	13.5	29.6	45.6	61.2	76.4	91.2	105.5
	East	25.1	9.1	0.9	1.0	1.3	9.6	23.9	38.4	52.8	66.8	80.3
	South	26.3	14.5	2.9	0.7	0.0	1.1	5.7	10.7	15.6	22.1	28.3
	West	17.9	4.9	0.0	6.2	18.0	32.6	47.1	61.7	76.0	90.0	103.7
0.80	North	32.1	13.2	1.3	0.9	8.4	21.9	35.0	47.9	60.5	72.7	84.5
	East	25.1	8.1	1.3	0.7	0.0	5.6	17.0	29.1	41.2	53.0	64.4
	South	27.7	17.0	4.7	1.6	0.0	0.3	3.9	7.9	12.1	17.0	22.2
	West	20.0	4.4	0.0	5.0	12.6	24.4	36.8	49.2	61.4	73.4	85.0
1.00	North	32.8	15.8	2.5	0.6	6.3	17.3	28.7	39.8	50.6	61.1	71.3
	East	25.4	11.9	2.4	0.9	0.0	2.9	12.7	22.9	33.2	43.4	53.3
	South	29.8	21.0	7.3	3.7	1.1	0.5	3.5	7.0	10.3	14.2	18.7
	West	20.7	8.8	0.0	3.7	9.9	17.5	28.3	39.0	49.6	60.0	70.1
1.25	North	31.0	16.7	2.5	0.0	2.9	11.7	21.1	30.4	39.5	48.4	56.8
	East	25.8	14.2	3.5	2.2	0.0	1.9	9.0	17.3	26.2	35.0	43.3
	South	28.7	22.1	7.5	3.6	0.3	0.0	1.1	3.8	6.8	9.6	13.1
	West	21.1	10.7	0.0	3.0	7.4	13.5	21.3	29.9	38.3	47.4	56.0
1.50	North	30.1	17.4	2.6	0.0	1.0	7.7	15.8	23.7	31.5	39.1	46.5
	East	25.9	15.7	4.1	2.7	0.0	1.4	6.1	13.2	20.5	28.1	35.5
	South	29.1	23.8	8.7	4.9	0.8	0.8	0.3	2.1	4.6	7.1	10.0
	West	19.4	10.3	0.4	0.7	3.9	8.7	15.0	22.1	29.4	36.4	43.4
2.00	North	30.3	20.3	4.4	1.3	0.0	4.2	10.4	16.7	22.9	28.9	34.8
	East	24.8	15.8	4.1	2.4	1.3	0.0	1.6	7.1	12.5	18.0	23.9
	South	30.2	26.2	12.9	7.0	2.5	1.3	0.0	1.2	2.9	4.7	6.6
	West	20.7	12.2	1.3	0.6	2.9	5.9	10.5	15.8	21.5	27.2	32.8
2.50	North	29.6	21.5	4.8	1.5	0.3	1.3	6.1	11.3	16.4	21.3	26.1
	East	25.0	16.7	5.5	2.8	2.4	0.1	0.0	3.8	8.3	12.7	17.1
	South	30.0	26.6	13.8	7.4	5.2	1.3	1.1	0.0	1.1	2.4	3.7
	West	21.3	13.3	1.9	0.0	1.8	4.0	7.5	11.3	16.0	20.7	25.3
3.00	North	29.6	22.5	5.9	2.2	0.6	0.0	4.0	8.2	12.6	16.8	20.9
	East	24.9	17.3	6.1	3.4	2.6	1.3	0.0	1.6	5.4	9.2	12.8
	South	30.6	27.5	15.8	8.7	6.2	2.3	1.6	0.0	0.8	1.7	2.8
	West	23.4	17.7	1.6	1.4	2.7	4.5	7.2	10.5	13.9	17.9	21.9
4.00	North	30.7	25.0	8.8	3.9	2.4	0.0	2.0	5.1	8.5	11.8	15.1
	East	24.9	18.8	8.4	4.3	2.9	1.9	1.1	0.0	1.5	4.4	7.2
	South	30.6	28.1	17.8	10.1	6.9	3.1	1.8	1.5	0.0	0.6	1.1
	West	21.8	17.4	3.6	0.0	0.2	1.7	3.1	5.4	7.9	10.5	13.0
5.00	North	30.3	25.3	10.3	4.6	2.8	1.7	0.0	2.5	4.9	7.7	10.4
	East	24.8	19.8	9.9	4.8	3.3	2.4	1.4	0.1	0.0	1.5	3.8
	South	30.4	28.5	19.2	10.7	7.6	5.6	2.4	1.5	1.3	0.0	0.3
	West	22.1	18.3	6.8	1.6	0.0	1.0	2.1	3.6	5.5	7.6	9.6

Table G.5. Percentage of the energy consumption increase for window areas different than the IWA for Curitiba, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	25.3	0.7	7.3	33.9	63.0	91.6	120.1	148.4	175.5	201.0	225.5
	East	19.4	1.5	3.3	21.9	47.7	73.0	99.4	125.7	151.0	175.3	198.8
	South	36.4	13.3	0.0	7.9	19.3	31.4	43.1	55.1	67.6	79.5	91.1
	West	18.4	0.0	13.3	40.2	67.2	93.7	119.3	144.0	167.8	190.6	212.4
0.80	North	27.9	1.1	5.6	28.8	53.9	78.7	102.6	125.3	148.8	171.0	192.2
	East	23.2	1.3	2.9	18.9	41.8	64.1	87.0	110.2	132.5	153.9	174.5
	South	38.5	13.0	0.0	6.3	16.2	26.6	36.7	46.8	57.5	67.8	77.7
	West	21.9	0.2	11.3	34.9	58.5	81.6	104.0	125.6	146.5	166.3	185.3
1.00	North	33.7	1.1	7.3	28.4	51.0	73.4	95.0	115.8	135.7	155.8	174.8
	East	25.7	2.9	2.5	16.1	36.4	56.3	76.2	96.8	116.7	135.7	154.1
	South	39.9	13.7	0.1	5.0	13.8	22.7	31.5	40.2	49.4	58.5	67.2
	West	23.9	0.4	8.9	29.7	50.6	71.0	90.6	109.8	128.1	145.6	162.4
1.25	North	29.7	2.2	2.1	19.3	38.1	56.9	74.9	92.3	108.6	125.5	141.3
	East	26.7	3.9	1.5	12.7	30.3	47.6	64.9	82.5	99.8	116.5	132.5
	South	40.7	15.0	0.4	3.9	11.7	19.2	26.8	34.3	42.0	49.9	57.5
	West	25.5	1.1	7.7	25.1	43.3	61.1	78.3	94.9	111.0	126.3	140.9
1.50	North	30.6	3.6	1.3	16.0	32.2	48.7	64.7	79.9	94.3	108.9	122.8
	East	26.8	4.5	0.4	9.6	24.6	39.7	55.0	69.9	85.1	99.7	113.9
	South	40.0	15.3	0.0	2.3	8.7	15.1	21.7	28.1	34.5	41.4	47.9
	West	26.2	1.4	6.2	20.9	36.6	52.2	67.3	81.9	96.0	109.5	122.3
2.00	North	31.1	6.4	0.1	11.2	23.7	37.0	49.9	62.3	73.9	85.3	96.6
	East	27.5	8.7	0.0	6.4	17.8	30.0	42.1	53.9	65.9	78.0	89.5
	South	39.8	17.8	3.0	1.3	5.7	11.0	16.2	21.4	26.3	31.2	36.5
	West	24.9	1.2	2.8	13.3	25.7	38.0	50.0	61.7	72.7	83.5	93.6
2.50	North	31.6	8.3	0.0	8.4	18.6	29.4	40.2	50.7	60.5	70.0	79.3
	East	27.7	9.5	0.0	4.2	12.7	22.7	32.8	42.7	52.2	62.3	72.0
	South	38.1	18.2	3.6	0.0	3.1	7.3	11.4	15.7	19.7	23.6	27.4
	West	23.6	1.1	0.9	8.2	18.2	28.2	38.0	47.7	56.9	65.7	74.1
3.00	North	31.3	10.0	0.0	5.7	14.5	23.6	32.9	41.9	50.4	58.6	66.3
	East	26.2	9.6	1.3	1.9	8.2	16.6	25.2	33.5	41.5	49.7	58.1
	South	35.2	17.7	3.3	0.0	0.3	3.8	7.2	10.7	14.1	17.4	20.4
	West	23.5	2.5	0.8	5.8	14.1	22.6	31.0	39.2	47.2	54.8	62.2
4.00	North	28.8	5.3	0.2	1.3	7.7	14.2	21.3	28.2	34.9	41.2	47.3
	East	25.5	12.0	2.2	0.0	4.2	9.6	16.1	22.7	29.0	35.0	41.1
	South	34.2	20.4	7.7	1.0	0.0	1.1	4.0	6.6	9.2	11.6	14.0
	West	22.6	4.8	0.0	2.1	7.9	14.2	20.6	27.0	33.1	39.0	44.8
5.00	North	28.2	12.5	2.7	0.1	4.5	9.5	14.8	20.4	25.9	31.1	35.9
	East	25.8	14.5	3.3	0.0	2.7	6.5	11.3	16.6	21.9	27.0	31.8
	South	33.3	22.8	9.1	1.8	0.1	0.0	2.0	4.0	6.0	8.1	9.8
	West	23.8	8.4	0.9	1.6	5.8	10.7	15.8	21.1	26.2	31.2	35.9

Table G.6. Percentage of the energy consumption increase for window areas different than the IWA for Curitiba, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	37.7	16.8	1.6	1.0	6.7	24.0	41.3	58.7	75.9	92.7	109.2
	East	28.3	13.6	2.4	0.0	2.1	15.9	30.7	45.9	62.2	78.4	94.4
	South	39.4	25.1	7.3	1.0	0.1	3.9	9.9	16.1	22.5	28.9	35.4
	West	21.7	5.0	0.0	6.8	16.8	30.0	44.8	59.8	74.8	89.5	103.8
0.80	North	37.1	17.8	2.6	1.0	4.4	18.6	33.1	47.6	61.7	75.8	89.5
	East	28.9	14.1	3.8	0.5	1.1	12.0	24.5	37.2	50.1	63.8	77.0
	South	38.9	26.3	8.7	1.8	0.0	2.3	7.2	12.2	17.4	22.8	28.1
	West	23.3	2.7	0.8	5.8	14.1	24.4	37.2	49.9	62.5	75.0	87.0
1.00	North	34.6	18.2	4.5	0.0	1.8	13.0	25.2	37.5	49.5	61.5	72.8
	East	28.5	16.6	4.2	2.4	0.0	8.5	19.0	30.1	41.1	52.2	63.5
	South	37.7	27.7	11.6	3.2	1.0	0.9	4.6	9.0	13.4	18.1	22.3
	West	22.3	7.5	0.0	3.9	10.3	18.4	29.3	40.1	50.9	61.5	71.7
1.25	North	32.9	19.3	4.9	0.0	0.9	8.6	18.9	28.9	39.3	49.2	59.0
	East	27.9	18.1	5.3	3.2	0.0	5.7	14.4	23.5	32.8	41.8	51.2
	South	35.1	27.9	12.0	3.3	0.4	0.0	1.8	5.0	8.8	12.5	16.1
	West	22.5	9.8	0.6	3.4	8.3	14.4	23.4	32.5	41.7	50.7	59.5
1.50	North	33.2	21.4	6.6	1.6	1.2	6.6	15.3	24.1	32.9	41.5	50.0
	East	27.3	18.7	5.8	3.4	0.0	3.1	10.5	18.2	26.1	33.8	41.5
	South	34.6	28.5	12.9	4.7	1.1	0.0	0.4	3.3	6.1	9.3	12.3
	West	22.7	10.8	0.5	2.9	6.5	10.8	18.4	26.3	34.1	41.8	49.5
2.00	North	30.5	20.6	6.3	3.0	0.0	1.8	8.3	15.0	21.8	28.4	35.0
	East	25.5	18.2	7.5	3.0	1.8	0.0	5.0	10.7	16.7	22.7	28.6
	South	33.7	29.3	13.7	8.3	2.5	0.5	0.0	0.8	3.0	5.2	7.5
	West	22.5	11.6	0.5	1.8	4.3	7.5	11.9	17.8	24.0	30.1	36.0
2.50	North	30.9	22.5	8.0	3.9	0.7	0.7	5.5	10.9	16.3	21.8	27.3
	East	26.5	19.7	9.3	4.2	3.1	0.0	3.1	7.6	12.4	17.4	22.3
	South	33.3	29.7	15.2	9.7	3.9	1.2	0.2	0.0	1.2	3.0	4.7
	West	22.1	12.4	0.4	0.5	2.6	4.9	7.4	11.9	16.8	21.9	26.8
3.00	North	30.1	22.6	8.2	4.1	2.8	0.0	2.9	7.2	11.8	16.4	21.0
	East	26.6	20.3	10.0	5.1	3.4	0.0	2.1	5.2	9.2	13.3	17.6
	South	33.0	29.7	16.4	11.0	6.6	1.9	0.6	0.0	0.3	1.7	3.2
	West	22.6	14.3	0.8	0.8	1.9	3.7	5.3	9.0	13.1	17.4	21.5
4.00	North	29.7	23.7	10.2	5.0	3.2	0.1	0.3	3.1	6.5	9.9	13.4
	East	25.5	20.6	11.5	4.9	3.3	2.3	0.0	1.7	4.0	7.0	10.0
	South	32.6	29.9	18.3	12.0	8.0	3.5	1.6	0.5	0.0	0.3	1.2
	West	22.0	15.0	3.2	0.0	0.5	1.7	2.9	4.4	7.2	10.3	13.4
5.00	North	29.5	24.4	11.4	5.8	3.7	2.7	0.0	1.1	3.5	6.2	8.9
	East	25.0	20.8	12.5	7.2	3.5	2.3	1.1	0.0	1.5	3.2	5.6
	South	32.1	29.8	20.3	12.8	8.9	6.4	2.3	1.0	0.3	0.0	0.3
	West	22.1	15.9	4.6	0.1	0.1	0.7	1.6	2.0	4.2	6.5	8.9

Table G.7. Percentage of the energy consumption increase for window areas different than the IWA for Florianópolis, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	17.0	0.0	12.9	35.6	59.4	82.6	106.3	129.0	151.9	174.5	195.6
	East	13.5	0.7	3.1	25.0	47.6	69.6	90.3	111.6	132.1	151.7	170.4
	South	19.6	5.7	0.5	7.4	16.6	25.7	34.6	43.3	51.7	59.8	67.9
	West	10.5	0.0	11.1	27.0	45.5	63.8	84.8	104.8	124.0	142.9	160.9
0.80	North	19.9	0.2	10.6	30.5	51.7	72.1	93.0	113.1	133.0	153.0	171.7
	East	16.2	1.7	1.8	21.1	41.1	60.6	78.6	97.5	115.6	133.0	149.7
	South	22.8	4.7	0.5	6.6	14.6	22.6	30.4	38.1	45.6	52.5	59.8
	West	13.5	0.1	9.5	23.3	39.8	55.6	74.3	92.0	109.2	125.6	141.3
1.00	North	27.0	0.4	13.0	31.5	51.1	70.0	89.3	108.2	126.5	145.1	162.7
	East	17.6	1.8	0.5	17.3	35.1	52.5	69.1	85.0	101.2	116.8	131.7
	South	24.1	4.9	0.0	4.9	12.0	19.0	26.0	32.8	39.3	45.5	51.7
	West	15.7	0.3	8.0	20.1	34.8	48.9	65.4	81.2	96.6	111.5	125.5
1.25	North	21.5	0.5	5.4	20.4	36.6	52.4	68.4	84.1	99.2	114.7	129.5
	East	19.8	2.5	0.6	14.8	30.6	46.1	60.9	74.8	89.3	103.2	116.6
	South	25.2	5.8	0.0	3.7	9.7	15.8	21.9	27.8	33.5	38.9	44.2
	West	16.8	0.2	6.3	16.4	29.2	41.7	55.7	69.8	83.5	96.5	109.0
1.50	North	21.8	1.2	3.2	16.1	30.4	44.3	58.4	72.3	85.7	99.2	112.3
	East	21.8	3.8	0.9	12.9	26.9	40.8	54.1	66.4	79.5	92.0	104.1
	South	26.0	6.7	0.1	2.7	7.9	13.1	18.5	23.6	28.7	33.5	38.0
	West	18.6	0.5	5.8	14.1	25.6	36.7	49.0	61.7	74.0	85.7	96.9
2.00	North	22.0	2.8	0.8	10.4	21.6	32.9	44.5	55.9	67.0	77.7	88.5
	East	20.3	4.7	0.0	6.8	17.8	29.0	39.8	50.3	59.8	70.2	80.0
	South	27.0	11.1	1.0	1.9	5.9	9.9	14.1	18.4	22.5	26.4	30.1
	West	18.0	0.9	2.9	8.6	17.7	26.5	36.0	46.5	56.5	66.1	75.3
2.50	North	22.9	4.3	0.0	7.8	16.6	26.3	36.0	45.7	55.1	64.2	73.3
	East	20.3	5.3	0.0	4.0	12.9	22.2	31.3	40.2	48.9	56.7	65.1
	South	26.6	11.8	1.5	1.2	3.8	7.0	10.4	13.8	17.3	20.6	23.7
	West	17.9	0.7	1.7	5.5	12.7	20.1	27.7	36.5	45.0	53.3	61.1
3.00	North	23.6	6.2	0.0	5.4	13.4	21.7	30.1	38.6	46.9	54.9	62.6
	East	20.4	6.4	0.1	2.5	9.8	17.8	25.7	33.5	41.2	47.5	55.0
	South	26.5	13.1	1.4	1.1	3.0	5.4	8.3	11.2	14.2	17.0	19.7
	West	17.0	0.8	0.6	2.6	8.8	15.0	21.1	28.8	36.2	43.3	50.1
4.00	North	26.9	4.6	0.0	4.9	11.2	17.7	24.3	31.3	38.1	44.7	51.0
	East	21.0	9.2	1.1	1.3	6.2	12.2	18.4	24.7	30.8	36.8	41.5
	South	24.3	13.4	2.2	0.0	0.5	2.0	3.9	6.1	8.4	10.5	12.5
	West	18.2	3.9	0.0	3.5	5.8	10.5	16.3	20.8	26.9	32.6	38.2
5.00	North	23.6	10.4	0.4	1.5	5.5	10.7	15.8	21.2	26.7	32.1	37.2
	East	20.7	11.1	2.9	0.0	3.0	7.6	12.6	17.7	22.8	27.8	32.6
	South	24.4	15.8	3.9	0.1	0.5	1.4	2.7	4.3	6.1	7.8	9.5
	West	19.0	6.5	0.3	3.1	4.0	7.8	11.7	15.8	20.9	25.7	30.4

Table G.8. Percentage of the energy consumption increase for window areas different than the IWA for Florianópolis, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	26.2	11.6	1.2	1.0	12.9	26.8	40.5	54.0	67.3	80.3	93.1
	East	16.6	6.1	0.2	0.3	4.6	16.9	29.2	41.6	53.8	66.0	77.6
	South	23.0	14.8	2.5	0.0	1.8	5.8	10.5	15.6	20.7	25.7	30.5
	West	13.5	3.1	0.2	6.8	15.3	24.5	33.9	42.1	53.2	63.7	74.0
0.80	North	27.4	13.6	2.2	0.2	10.4	21.9	33.7	45.3	56.8	68.0	78.9
	East	18.5	7.3	1.7	0.7	3.3	13.7	24.3	35.1	45.6	56.3	65.8
	South	23.8	16.1	3.6	0.1	1.2	4.1	8.0	12.1	16.4	20.7	24.7
	West	15.1	1.0	0.3	5.4	12.6	20.2	28.2	35.1	44.7	53.7	62.1
1.00	North	29.0	16.4	4.0	0.6	9.3	19.0	29.3	39.6	49.7	59.6	69.1
	East	18.3	9.2	1.5	0.0	1.2	9.9	19.0	28.3	37.5	46.8	55.8
	South	24.0	17.9	4.4	0.6	0.9	2.8	5.9	9.4	13.1	16.7	20.2
	West	15.4	5.2	0.0	4.1	9.8	16.5	23.2	29.0	37.4	45.3	52.2
1.25	North	26.9	16.4	3.3	0.0	5.4	13.3	22.0	30.6	39.1	47.4	55.6
	East	19.2	11.4	2.8	0.0	2.0	7.7	15.6	23.5	31.4	39.4	47.2
	South	23.1	18.5	4.6	0.7	0.0	1.1	3.4	6.2	9.1	12.1	15.0
	West	15.7	6.9	0.0	3.3	7.7	13.1	18.9	23.4	29.8	37.3	42.8
1.50	North	26.2	16.8	3.5	0.0	3.4	9.9	17.2	24.7	32.0	39.2	46.3
	East	19.5	12.3	3.5	0.4	1.7	5.5	12.3	19.2	26.0	33.0	39.8
	South	23.1	19.2	6.0	1.4	0.2	0.4	2.1	4.3	6.8	9.3	11.6
	West	16.5	7.9	0.4	3.2	6.6	11.0	15.9	19.5	25.1	31.8	37.4
2.00	North	25.5	17.3	4.8	0.0	1.1	5.6	11.4	17.1	22.9	28.7	34.3
	East	17.8	11.5	3.1	1.8	0.0	1.2	6.3	11.6	17.0	22.4	27.7
	South	22.9	20.0	8.1	2.7	0.8	0.0	0.8	2.1	3.9	5.8	7.6
	West	16.8	8.5	0.5	1.2	4.8	7.7	11.5	13.7	18.1	23.5	28.1
2.50	North	25.5	18.3	6.0	2.1	0.0	3.3	7.8	12.5	17.3	22.1	26.8
	East	19.4	13.3	5.0	1.9	0.0	0.8	4.7	9.1	13.6	18.0	22.5
	South	23.0	20.6	9.1	4.0	1.2	0.2	0.0	0.9	2.3	3.6	5.1
	West	17.3	9.6	0.9	0.7	3.8	5.9	8.7	10.0	13.6	17.3	22.0
3.00	North	26.4	20.1	7.3	3.5	0.0	2.6	6.3	10.3	14.4	18.5	22.6
	East	19.3	13.7	5.2	2.4	0.0	0.9	2.8	6.3	10.1	13.9	17.8
	South	23.0	20.8	10.2	5.2	0.6	0.6	0.0	0.4	1.3	2.4	3.6
	West	18.2	12.2	1.3	1.0	3.6	5.3	7.4	8.1	11.1	14.3	18.4
4.00	North	25.4	20.3	8.1	3.9	0.4	0.3	2.5	5.4	8.5	11.6	14.7
	East	20.3	16.0	8.0	3.9	3.6	0.5	1.3	3.7	6.5	9.4	12.3
	South	24.3	22.5	12.9	7.7	3.0	1.4	0.0	0.8	1.3	1.9	2.6
	West	17.3	12.4	3.0	0.0	1.7	2.8	4.1	3.8	6.0	8.2	11.6
5.00	North	25.0	20.4	9.5	4.2	2.5	0.0	0.5	2.7	5.1	7.6	10.0
	East	20.9	17.2	9.5	5.5	4.3	1.2	0.5	2.2	4.4	6.7	8.9
	South	24.8	23.3	14.7	9.2	4.7	3.0	1.6	0.4	0.0	1.8	2.1
	West	17.0	12.4	4.0	0.4	1.1	1.7	2.5	3.6	3.2	4.9	6.7

Table G.9. Percentage of the energy consumption increase for window areas different than the IWA for Leeds, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	9.3	1.3	0.0	3.1	7.4	12.1	16.5	20.8	25.0	28.9	32.5
	East	11.7	0.5	3.5	10.3	17.5	24.7	31.5	37.9	44.0	49.6	54.6
	South	11.2	0.0	11.7	27.5	43.4	58.8	73.3	86.8	99.4	111.3	122.6
	West	0.0	6.9	36.6	72.8	109.1	144.0	176.1	206.9	235.0	260.7	284.4
0.80	North	15.8	2.2	0.4	3.8	7.5	12.5	17.2	21.7	26.1	30.1	33.8
	East	18.3	1.0	4.2	11.4	18.9	26.3	33.3	40.0	46.2	51.9	57.0
	South	16.6	0.0	12.3	28.4	44.4	59.9	74.5	88.1	100.6	112.5	123.8
	West	0.3	3.1	31.7	66.6	101.5	134.4	165.6	194.7	221.4	246.3	268.8
1.00	North	21.3	2.9	0.0	3.3	7.3	11.2	15.9	20.4	24.7	28.7	32.3
	East	23.7	0.9	3.8	10.8	18.2	25.5	32.3	38.8	44.9	50.5	55.5
	South	21.7	0.0	12.1	27.8	43.4	58.4	72.5	85.6	97.8	109.2	120.2
	West	2.7	1.4	28.5	61.4	94.3	125.4	155.2	182.2	207.5	231.1	252.3
1.25	North	27.4	4.6	0.0	2.9	6.7	10.7	14.2	18.5	22.7	26.5	30.0
	East	29.0	1.5	3.1	9.7	16.8	23.7	30.1	36.3	42.0	47.3	52.1
	South	26.6	0.0	11.3	26.1	40.6	54.7	67.8	80.2	91.5	102.3	112.5
	West	6.5	0.9	25.8	56.5	86.8	115.5	143.1	168.6	192.0	213.8	233.6
1.50	North	32.7	6.8	0.0	2.3	5.8	9.5	12.9	15.9	19.8	23.5	26.9
	East	34.7	3.4	3.0	9.1	15.7	22.0	28.2	33.9	39.3	44.3	48.8
	South	31.3	0.0	10.6	24.2	37.7	50.8	63.0	74.4	85.1	94.9	104.2
	West	10.4	0.8	23.0	51.3	79.2	105.5	130.8	154.1	176.0	196.3	214.6
2.00	North	39.5	11.9	0.9	1.7	4.2	7.2	10.2	13.1	15.9	17.9	20.8
	East	38.0	4.2	0.5	5.0	10.3	15.6	20.9	25.8	30.2	34.4	38.2
	South	36.2	1.5	8.6	20.0	31.4	42.4	52.8	62.5	71.6	80.1	87.8
	West	14.6	0.0	17.7	41.1	64.3	86.7	107.7	127.5	146.1	163.3	179.0
2.50	North	42.9	16.4	1.9	1.2	2.8	4.9	7.3	9.7	12.1	14.3	16.3
	East	40.2	6.8	0.0	2.8	7.0	11.4	15.7	19.8	23.8	27.5	30.5
	South	36.9	1.3	5.7	15.0	24.5	33.7	42.4	50.6	58.3	65.5	72.1
	West	17.0	0.0	13.2	32.7	52.6	71.6	89.6	106.5	122.4	137.1	150.9
3.00	North	42.4	18.7	1.5	0.0	0.6	2.0	3.9	5.8	7.7	9.5	11.3
	East	41.6	10.3	0.3	2.1	5.4	8.9	12.4	16.1	19.4	22.5	25.4
	South	37.3	2.2	4.4	11.9	20.0	27.9	35.3	42.4	49.1	55.3	61.1
	West	18.0	0.2	9.6	26.1	43.1	59.4	75.3	89.9	103.8	117.0	128.9
4.00	North	42.9	22.5	4.1	0.6	0.0	0.4	1.2	2.4	3.7	4.8	6.0
	East	41.6	16.2	0.6	0.6	2.5	4.9	7.4	10.2	12.7	14.9	17.0
	South	37.1	2.7	2.5	7.8	13.8	19.7	25.5	31.1	36.3	41.1	45.6
	West	17.3	0.5	3.3	15.3	28.2	40.7	52.9	64.5	75.5	85.8	95.4
5.00	North	42.8	28.0	6.2	1.8	0.4	0.0	0.3	0.9	1.6	2.4	3.2
	East	40.9	19.3	1.2	0.2	1.2	2.7	4.6	6.4	8.5	10.4	12.1
	South	33.8	5.3	0.0	3.4	7.9	12.5	17.0	21.4	25.6	29.5	33.1
	West	18.1	2.5	1.0	10.1	20.4	30.7	40.8	50.4	59.4	68.1	76.2

Table G.10. Percentage of the energy consumption increase for window areas different than the IWA for Leeds, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	13.2	10.5	0.6	0.6	2.0	3.8	5.8	8.0	10.6	13.1	15.6
	East	14.9	6.9	0.3	2.3	5.4	8.9	12.7	16.5	20.5	24.2	27.9
	South	15.6	0.9	1.7	7.8	15.5	23.8	32.1	40.5	48.8	56.8	64.8
	West	2.3	0.0	7.9	22.6	40.0	58.6	77.4	96.1	114.7	133.0	150.0
0.80	North	19.6	15.0	1.6	1.1	2.4	4.2	6.3	8.5	10.5	13.2	15.8
	East	21.0	9.7	0.6	2.5	5.6	9.4	13.3	17.2	21.3	25.1	28.9
	South	20.9	2.1	1.9	8.2	16.1	24.5	33.0	41.4	49.7	57.9	65.7
	West	5.1	0.0	7.4	21.9	39.1	57.5	75.9	94.3	112.6	130.2	146.6
1.00	North	23.6	17.6	2.3	0.0	1.1	2.7	4.7	6.8	9.0	10.5	13.0
	East	25.9	12.6	0.5	2.0	5.1	8.7	12.5	16.4	20.3	24.0	27.7
	South	24.5	2.8	1.1	7.2	14.9	22.9	31.1	39.1	47.1	54.8	62.3
	West	7.3	0.0	6.1	19.9	36.1	53.2	70.7	88.0	104.9	121.4	137.2
1.25	North	28.3	21.6	3.9	0.1	0.6	1.8	3.5	5.4	7.4	9.5	11.4
	East	30.2	16.1	1.0	1.5	4.0	7.3	10.8	14.4	18.0	21.5	24.8
	South	27.2	3.3	0.0	5.5	12.2	19.7	27.2	34.6	41.9	48.9	55.7
	West	9.6	0.4	4.7	17.1	31.8	47.5	63.2	78.8	94.2	108.9	123.3
1.50	North	32.2	25.2	5.8	0.5	0.1	1.0	2.3	3.9	5.7	7.5	9.2
	East	32.5	18.6	1.2	0.1	2.1	4.8	7.9	11.1	14.3	17.4	20.4
	South	30.3	6.2	0.0	4.6	10.6	17.3	24.2	30.9	37.5	44.0	50.3
	West	11.4	1.0	3.2	14.0	27.1	41.0	55.0	69.2	83.0	96.4	109.3
2.00	North	36.4	29.7	9.8	1.9	0.0	0.0	0.6	1.6	2.8	4.2	5.4
	East	35.8	23.4	3.4	0.0	0.7	2.3	4.7	7.1	9.6	12.2	14.6
	South	33.8	12.6	0.8	3.6	8.4	13.7	19.2	24.9	30.5	35.9	40.9
	West	12.2	1.7	0.4	8.1	18.6	29.6	41.0	52.4	63.4	74.4	84.9
2.50	North	38.6	32.6	13.6	3.8	0.9	0.0	0.1	0.5	1.2	2.0	2.9
	East	37.1	26.2	5.7	0.1	0.0	0.9	2.5	4.4	6.3	8.2	10.1
	South	34.5	15.7	1.0	2.3	5.9	10.0	14.6	19.2	23.7	28.3	32.5
	West	14.4	4.0	0.0	5.7	14.1	23.1	32.6	42.2	51.6	60.9	69.8
3.00	North	39.3	34.1	16.6	6.8	2.1	0.3	0.0	0.1	0.4	0.8	1.2
	East	37.8	28.0	8.2	1.6	0.0	0.5	1.4	2.9	4.4	5.9	7.3
	South	34.9	18.1	1.4	1.8	4.5	7.8	11.6	15.6	19.4	23.2	26.9
	West	15.9	5.9	0.0	4.2	11.0	18.5	26.7	34.9	43.1	51.0	58.7
4.00	North	40.0	36.2	20.0	10.4	3.8	1.9	0.7	0.2	0.1	0.0	0.0
	East	38.0	30.2	13.5	4.1	0.5	0.0	0.4	0.9	1.9	2.9	3.9
	South	34.6	21.7	2.5	1.4	2.7	4.9	7.4	10.3	13.2	16.1	18.8
	West	17.2	10.3	1.1	1.6	6.1	11.7	17.8	24.1	30.4	36.7	42.7
5.00	North	40.3	38.0	24.8	12.5	6.4	3.8	1.8	1.1	0.5	0.3	0.0
	East	37.7	31.8	16.2	6.1	2.5	0.2	0.0	0.3	0.7	1.4	2.0
	South	33.9	23.0	3.1	1.3	1.6	3.0	4.9	6.9	9.2	11.5	13.7
	West	18.0	12.3	2.4	0.4	3.5	7.5	12.3	17.3	22.4	27.4	32.3

Table G.11. Percentage of the energy consumption increase for window areas different than the IWA for Natal, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	12.4	0.2	7.6	22.7	38.1	53.4	68.4	83.1	97.2	110.5	122.9
	East	11.2	0.3	3.5	13.2	28.1	44.1	59.9	75.3	90.2	105.9	122.2
	South	12.3	0.5	5.0	17.1	29.0	40.8	52.3	63.3	74.7	85.6	95.9
	West	7.5	0.4	18.9	40.5	61.4	81.3	100.4	119.1	137.1	153.8	169.7
0.80	North	15.0	0.5	6.0	19.5	33.0	46.6	59.8	72.6	84.9	96.4	107.2
	East	13.5	1.0	2.4	10.9	23.6	37.7	51.8	65.5	78.7	91.1	105.5
	South	14.4	0.6	3.5	14.0	24.6	34.9	45.1	54.9	64.2	73.0	82.1
	West	9.5	0.0	15.6	34.9	53.4	71.1	88.2	104.7	120.8	135.7	150.0
1.00	North	19.8	1.0	7.4	19.6	31.9	44.3	56.4	68.2	79.6	90.2	100.2
	East	15.8	1.3	2.0	9.5	20.3	33.0	45.7	58.0	70.0	81.7	92.7
	South	16.2	0.9	2.3	11.7	21.0	30.3	39.4	48.1	56.5	64.3	71.7
	West	11.2	0.0	13.3	30.5	47.2	63.2	78.6	93.5	108.1	121.6	134.5
1.25	North	17.3	0.5	2.7	13.0	23.5	34.0	44.4	54.6	64.3	73.5	82.2
	East	16.4	2.1	0.9	7.2	16.6	27.2	38.3	49.2	59.9	70.1	80.2
	South	18.0	1.9	2.0	9.8	18.1	26.3	34.4	42.2	49.6	56.6	63.3
	West	12.6	0.0	10.8	26.2	41.1	55.3	69.0	82.3	95.4	107.5	119.0
1.50	North	18.4	1.0	1.6	10.6	19.9	29.3	38.5	47.6	56.4	64.7	72.5
	East	17.2	2.4	0.6	5.3	13.5	22.5	32.4	42.2	51.7	60.9	70.0
	South	17.9	1.7	0.8	6.9	14.1	21.3	28.5	35.4	42.0	48.3	54.2
	West	13.6	0.0	8.7	22.4	35.7	48.5	60.8	72.8	84.7	95.6	106.0
2.00	North	20.3	1.7	0.8	7.9	15.2	23.1	30.9	38.5	45.9	52.9	59.6
	East	17.3	2.6	0.0	2.4	8.7	15.4	23.5	31.6	39.5	47.1	54.6
	South	18.4	2.6	0.2	3.6	9.5	15.3	21.2	26.9	32.3	37.6	42.5
	West	14.5	0.0	5.6	16.6	27.7	38.4	48.7	58.7	68.7	77.9	86.7
2.50	North	21.2	4.8	0.0	5.8	11.8	18.5	25.1	31.6	38.0	44.2	49.8
	East	17.4	3.4	0.0	0.8	5.7	11.7	17.7	24.6	31.3	38.0	44.3
	South	18.8	3.5	0.0	1.5	6.5	11.3	16.2	21.2	25.9	30.4	34.6
	West	14.9	0.3	3.5	12.5	22.0	31.1	39.9	48.6	57.2	65.2	72.7
3.00	North	21.9	6.1	0.0	4.2	9.6	15.4	21.1	26.8	32.5	37.9	43.1
	East	18.4	5.0	1.6	0.6	4.7	9.7	14.6	20.6	26.5	32.3	38.1
	South	18.6	4.0	0.0	0.7	4.1	8.3	12.5	16.8	20.9	24.9	28.7
	West	15.2	0.7	2.4	9.9	18.0	26.0	33.8	41.4	49.1	56.3	62.9
4.00	North	22.8	3.9	0.0	2.2	6.6	10.9	15.5	20.1	24.7	29.2	33.4
	East	18.2	6.3	1.9	0.0	2.2	5.4	9.5	13.3	18.2	22.8	27.4
	South	18.8	6.6	0.4	0.0	1.3	4.5	7.8	11.2	14.6	17.8	20.9
	West	15.4	2.2	0.6	6.0	12.3	18.7	25.0	31.2	37.4	43.3	48.8
5.00	North	21.2	9.1	1.0	0.0	3.2	6.4	10.1	13.8	17.5	21.2	24.8
	East	17.9	7.2	1.7	0.1	0.5	3.0	6.0	9.4	12.6	16.5	20.3
	South	19.2	8.9	1.0	0.0	0.6	2.5	5.1	8.0	10.8	13.6	16.1
	West	15.9	4.0	0.0	4.0	9.2	14.5	19.7	25.0	30.2	35.3	40.0

Table G.12. Percentage of the energy consumption increase for window areas different than the IWA for Natal, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	20.5	7.5	0.0	4.9	12.8	21.0	29.6	38.9	48.0	56.7	65.2
	East	14.0	2.5	0.0	1.3	3.8	8.8	17.1	25.9	34.8	43.5	52.1
	South	16.3	5.5	0.2	1.7	7.9	14.7	21.4	28.1	34.7	41.2	47.5
	West	10.4	0.2	2.8	13.4	25.2	37.2	49.0	60.7	72.1	83.2	94.1
0.80	North	21.7	9.2	0.3	3.7	10.3	17.2	24.6	32.5	40.3	47.9	55.2
	East	14.6	2.1	0.0	0.7	2.6	5.9	12.4	20.1	27.7	35.1	42.5
	South	17.0	6.6	0.3	0.8	5.2	10.8	16.6	22.3	27.9	33.5	38.9
	West	13.4	0.9	3.0	12.2	22.4	32.9	43.3	53.7	63.8	73.6	83.2
1.00	North	21.1	10.1	0.6	1.6	6.6	12.9	19.4	26.1	32.9	39.5	45.8
	East	15.4	5.0	0.6	0.7	2.2	3.8	9.6	16.0	22.7	29.3	35.7
	South	17.5	8.3	0.7	0.5	3.4	8.0	13.0	18.0	23.0	27.8	32.5
	West	12.0	2.4	0.7	7.6	16.4	25.3	34.3	43.3	52.2	60.8	69.1
1.25	North	20.6	11.5	1.5	0.4	3.9	9.3	14.8	20.5	26.3	32.0	37.5
	East	15.1	6.1	0.5	0.3	1.2	1.5	6.3	11.3	17.1	22.8	28.3
	South	17.5	10.5	1.0	0.4	1.5	5.3	9.4	13.7	17.9	22.1	26.2
	West	12.2	3.6	0.0	5.2	12.4	20.1	27.9	35.7	43.4	51.0	58.3
1.50	North	20.1	11.9	1.7	0.0	1.7	6.2	10.9	15.8	20.9	25.8	30.6
	East	15.4	7.2	0.8	0.4	1.0	0.6	4.1	8.5	13.1	18.1	23.1
	South	18.0	11.9	1.5	0.6	1.2	3.5	7.0	10.7	14.4	18.1	21.7
	West	13.1	4.8	0.0	3.9	10.1	16.7	23.5	30.5	37.3	44.0	50.5
2.00	North	21.3	14.7	3.8	0.7	0.7	4.1	7.8	11.6	15.7	19.8	23.7
	East	15.2	8.2	1.0	0.0	0.3	0.9	1.0	4.4	7.9	11.5	15.4
	South	17.4	12.4	1.8	0.0	0.1	0.6	3.0	5.8	8.7	11.6	14.5
	West	13.9	6.7	0.0	1.9	6.6	11.8	17.4	23.1	28.6	34.1	39.4
2.50	North	22.1	16.7	5.0	1.9	0.0	2.6	5.6	8.8	12.2	15.6	18.9
	East	16.1	10.1	2.1	0.8	0.7	0.0	0.2	2.4	5.4	8.3	11.1
	South	18.0	13.5	3.0	0.5	0.1	0.2	1.1	3.3	5.7	8.1	10.5
	West	15.0	8.4	0.6	0.7	5.0	9.1	13.8	18.6	23.3	28.0	32.5
3.00	North	20.5	15.8	4.3	1.0	0.0	0.0	2.4	5.0	7.8	10.8	13.6
	East	16.2	10.8	2.7	0.9	0.7	0.6	0.0	1.1	3.3	5.7	8.3
	South	18.1	14.4	3.7	0.7	0.0	0.0	0.3	1.5	3.6	5.6	7.6
	West	17.1	10.8	0.4	1.5	5.2	8.8	12.7	16.8	21.1	25.2	29.3
4.00	North	20.7	16.7	5.3	1.8	0.6	0.0	0.2	2.1	4.2	6.5	8.7
	East	16.6	12.2	4.2	1.6	1.0	0.4	0.1	0.0	1.0	2.6	4.5
	South	18.6	15.3	5.5	1.7	0.3	0.0	0.0	0.4	1.1	2.6	4.2
	West	14.6	8.7	1.0	0.0	0.8	3.3	6.2	9.2	12.4	15.6	18.7
5.00	North	22.4	18.8	7.9	4.1	2.4	1.5	0.0	1.4	3.1	4.9	6.8
	East	16.8	13.2	5.1	2.3	1.3	0.9	0.8	0.0	0.0	1.0	2.2
	South	19.0	16.2	6.9	2.6	1.0	0.2	0.0	0.0	0.3	0.9	2.1
	West	14.8	9.7	1.9	0.0	0.6	1.7	3.8	6.2	8.9	11.5	14.1

Table G.13. Percentage of the energy consumption increase for window areas different than the IWA for Rio de Janeiro, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	5.5	0.1	11.1	31.0	49.8	68.0	84.4	101.5	117.8	132.9	147.3
	East	0.3	0.6	6.2	21.0	38.6	55.7	72.1	87.7	102.7	116.7	130.0
	South	4.6	0.5	1.0	5.2	12.2	19.4	26.8	33.9	40.7	47.1	53.1
	West	2.6	0.5	18.0	38.7	59.8	79.8	99.2	118.0	136.0	153.4	170.3
0.80	North	6.5	0.0	7.6	25.3	42.1	58.3	72.8	87.9	102.4	116.0	128.7
	East	1.4	0.3	4.3	15.6	31.4	46.7	61.3	75.0	88.5	101.0	112.8
	South	5.5	0.5	0.4	4.1	9.9	16.2	22.6	28.8	34.8	40.4	45.8
	West	4.2	0.6	15.6	34.9	53.6	71.7	89.1	106.0	122.2	137.8	153.0
1.00	North	8.3	0.0	7.0	21.4	36.2	51.6	64.6	78.5	91.6	103.9	115.5
	East	2.3	0.0	2.9	11.6	25.7	39.5	52.6	65.1	77.1	88.5	99.2
	South	6.2	0.7	0.0	3.2	8.0	13.6	19.3	24.7	30.0	35.1	39.9
	West	4.8	0.0	13.3	30.7	47.6	63.9	79.7	94.8	109.6	123.6	137.4
1.25	North	8.4	0.1	4.9	17.4	30.6	43.1	55.4	67.0	78.3	88.1	98.6
	East	2.9	0.0	1.4	7.4	19.9	32.1	43.9	55.0	65.7	75.9	85.5
	South	7.1	1.2	0.0	2.5	6.6	11.5	16.5	21.3	26.0	30.5	34.8
	West	5.5	0.0	11.6	27.2	42.4	56.9	71.1	84.7	98.0	110.6	123.0
1.50	North	9.3	0.3	3.9	15.4	26.9	38.2	49.3	59.9	68.5	78.7	88.2
	East	4.0	0.5	0.8	7.1	15.9	26.9	37.6	47.7	57.5	66.8	75.4
	South	7.9	1.7	0.0	2.0	5.4	9.7	14.2	18.5	22.6	26.7	30.6
	West	6.3	0.0	10.0	24.1	37.8	51.0	63.8	76.1	88.1	99.6	110.9
2.00	North	9.6	0.5	2.7	11.1	20.5	30.0	39.1	48.0	56.4	63.3	71.5
	East	5.5	1.4	0.0	5.0	9.5	19.2	28.2	36.9	45.1	53.0	60.5
	South	8.9	2.8	0.0	1.4	3.7	7.3	11.1	14.7	18.1	21.5	24.7
	West	7.0	0.0	7.6	19.4	30.9	42.1	52.8	63.3	73.3	83.1	92.6
2.50	North	9.8	0.9	1.3	7.9	15.8	23.9	31.8	39.5	46.7	53.2	59.3
	East	6.9	2.7	0.0	3.9	8.7	13.9	21.8	29.4	36.6	43.5	50.1
	South	8.7	3.1	0.0	0.7	2.4	5.3	8.4	11.5	14.4	17.3	20.1
	West	7.4	0.0	5.9	16.0	25.9	35.6	44.9	54.0	62.7	71.2	79.3
3.00	North	10.0	1.4	0.6	5.7	12.4	19.6	26.5	33.3	39.7	46.0	50.6
	East	6.9	2.7	0.0	2.3	6.3	10.3	15.8	22.5	28.9	35.0	40.9
	South	8.6	3.5	0.0	0.2	1.3	3.8	6.5	9.2	11.8	14.3	16.7
	West	7.6	0.0	4.7	13.4	22.2	30.7	39.0	47.0	54.7	62.3	69.6
4.00	North	9.9	0.7	0.1	2.5	7.9	13.4	18.9	24.4	29.7	34.8	39.7
	East	8.2	5.9	0.7	1.4	4.4	7.7	10.8	14.2	19.7	24.8	29.7
	South	9.1	4.9	0.7	0.0	0.8	2.4	4.6	6.7	8.8	10.8	12.8
	West	7.3	0.0	2.6	9.5	16.5	23.4	30.1	36.7	43.0	49.1	55.2
5.00	North	10.2	6.5	0.4	1.7	5.2	9.5	14.3	18.9	23.4	27.8	32.0
	East	8.1	6.1	0.5	0.0	2.2	4.9	7.5	10.0	12.2	16.6	20.8
	South	9.3	11.1	1.0	0.0	0.4	1.5	3.3	5.1	6.8	8.6	10.2
	West	5.9	5.3	0.0	5.7	11.5	17.3	22.8	28.3	33.6	38.7	43.8

Table G.14. Percentage of the energy consumption increase for window areas different than the IWA for Rio de Janeiro, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	7.8	1.9	0.0	1.8	4.8	15.4	25.7	34.9	44.9	54.8	64.4
	East	3.3	2.5	0.5	0.5	8.9	18.8	28.5	38.2	47.8	57.1	66.3
	South	5.9	3.6	0.3	0.1	1.4	3.5	5.9	8.8	12.9	16.9	20.9
	West	5.6	0.4	3.0	12.8	24.8	36.7	48.3	59.8	71.1	82.3	93.2
0.80	North	8.4	2.5	0.0	1.3	3.4	10.6	19.4	27.9	36.1	44.7	53.2
	East	4.2	3.5	0.8	0.3	5.0	13.6	22.1	30.6	39.0	47.2	55.3
	South	6.5	4.5	0.6	0.0	0.9	2.5	4.6	6.6	10.1	13.6	17.0
	West	6.7	0.4	2.7	11.0	21.7	32.1	42.4	52.5	62.5	72.3	82.0
1.00	North	8.7	3.1	0.0	0.9	2.6	7.9	15.7	23.3	30.7	37.9	45.1
	East	4.3	3.7	0.6	0.0	1.5	9.1	16.5	24.1	31.6	38.9	46.0
	South	6.9	5.2	0.9	0.0	0.2	1.8	3.4	5.2	7.8	10.9	14.0
	West	6.7	0.7	1.7	8.7	18.1	27.4	36.5	45.6	54.4	63.1	71.8
1.25	North	8.9	3.4	0.0	0.6	1.9	5.1	12.0	18.7	25.2	31.6	37.8
	East	4.9	4.6	1.1	0.0	1.2	5.3	11.8	18.5	25.1	31.5	37.8
	South	7.8	6.4	1.8	0.6	0.5	1.6	2.8	4.4	6.3	9.0	11.7
	West	6.8	1.1	1.0	6.8	15.0	23.1	31.2	39.1	46.9	54.7	62.3
1.50	North	9.8	4.4	0.6	0.9	2.0	3.5	9.6	15.6	21.5	27.2	32.8
	East	5.6	5.4	1.6	0.5	0.4	3.7	8.2	14.1	20.1	25.8	31.5
	South	7.7	6.7	1.7	0.3	0.1	0.7	1.7	2.9	4.3	6.7	9.0
	West	6.8	1.2	0.4	5.2	12.4	19.6	26.7	33.8	40.8	47.7	54.5
2.00	North	9.9	5.1	0.7	0.6	1.3	2.1	5.5	10.5	15.3	20.1	24.7
	East	5.6	5.9	1.9	0.5	0.0	1.9	4.4	7.4	12.3	17.1	21.8
	South	8.1	7.2	2.1	0.5	0.0	0.0	0.8	1.5	2.6	4.1	6.0
	West	7.1	1.7	0.0	3.4	9.4	15.3	21.1	27.1	32.8	38.6	44.2
2.50	North	10.4	6.1	0.8	0.8	1.3	1.8	3.0	7.3	11.4	15.6	19.5
	East	6.0	6.1	2.2	0.7	0.0	0.7	2.6	4.8	6.8	11.0	15.0
	South	8.6	7.4	2.8	1.0	0.4	0.0	0.2	1.0	1.6	2.6	4.2
	West	7.6	2.4	0.0	2.4	7.6	12.5	17.6	22.6	27.6	32.5	37.4
3.00	North	9.7	5.7	0.4	0.0	0.3	0.7	0.3	3.9	7.6	11.2	14.7
	East	6.5	6.6	2.9	1.2	0.4	0.0	1.8	3.6	5.6	6.8	10.5
	South	8.8	7.7	3.3	1.3	0.5	0.0	0.0	0.6	1.1	1.8	2.9
	West	7.8	2.8	0.0	1.7	6.2	10.5	14.9	19.3	23.7	28.0	32.3
4.00	North	10.1	6.7	1.3	0.0	0.3	0.6	0.9	0.8	3.7	6.6	9.5
	East	7.1	7.2	4.1	1.9	0.7	0.2	0.0	1.9	3.4	4.9	6.5
	South	9.2	8.3	3.9	1.9	0.7	0.3	0.0	0.1	0.3	0.9	1.3
	West	8.0	3.6	0.0	0.8	4.2	7.7	11.2	14.7	18.2	21.7	25.2
5.00	North	10.4	7.3	1.9	0.3	0.0	0.5	0.7	1.1	1.3	3.7	6.1
	East	7.3	8.2	5.3	2.9	1.0	0.3	0.0	0.6	2.0	3.1	4.4
	South	9.5	8.7	4.5	2.3	1.0	0.5	0.1	0.0	0.1	0.3	0.8
	West	9.0	5.0	0.9	0.7	3.8	6.7	9.7	12.6	15.6	18.5	21.5

Table G.15. Percentage of the energy consumption increase for window areas different than the IWA for Salvador, room ratio of 2:1 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	8.3	0.0	11.9	29.3	47.1	64.0	80.6	96.2	110.9	125.0	138.9
	East	4.9	0.0	10.3	30.3	52.4	72.7	93.1	112.3	130.6	147.9	164.3
	South	7.6	0.4	1.4	10.0	19.7	29.1	38.2	46.6	54.5	62.0	69.1
	West	0.3	0.2	15.5	36.2	57.4	78.2	98.2	118.2	136.8	153.6	169.5
0.80	North	10.7	0.0	10.2	25.9	42.0	57.3	72.4	86.4	99.7	112.5	125.0
	East	6.7	0.0	8.2	25.8	46.0	64.4	82.9	100.1	116.7	132.3	147.2
	South	10.2	1.6	0.7	8.4	17.1	25.6	33.9	41.4	48.5	55.3	61.6
	West	3.0	0.4	13.4	32.1	51.5	70.4	88.6	106.9	123.7	139.1	153.5
1.00	North	14.0	0.0	10.1	24.5	39.4	53.6	67.5	80.5	92.9	104.6	116.3
	East	8.1	0.0	6.1	22.0	40.4	57.2	74.0	89.7	104.8	119.0	132.6
	South	12.6	2.8	0.6	7.5	15.4	23.2	30.7	37.6	44.1	50.2	56.0
	West	4.5	0.1	10.9	27.9	45.5	62.8	79.5	96.2	111.5	125.5	138.7
1.25	North	13.7	0.1	6.8	19.6	32.7	45.4	57.2	69.3	80.4	90.7	101.1
	East	9.2	0.0	4.4	18.5	34.9	50.2	65.2	79.3	93.0	105.8	118.1
	South	14.3	3.7	0.0	6.0	12.7	20.1	26.9	33.1	39.0	44.5	49.7
	West	6.0	0.0	8.8	24.0	40.1	55.6	70.7	85.9	99.7	112.3	124.3
1.50	North	15.1	0.4	5.5	17.1	29.0	40.6	51.3	62.3	72.5	81.9	91.3
	East	10.9	0.6	3.5	16.2	31.1	45.1	58.1	71.7	84.1	95.9	107.2
	South	17.0	5.2	0.0	5.8	12.0	18.8	25.0	30.7	36.1	41.1	45.9
	West	7.4	0.0	7.0	20.8	35.5	49.7	63.5	77.4	90.0	101.6	112.5
2.00	North	16.5	0.6	3.2	13.1	23.0	32.9	42.2	51.5	60.2	68.3	76.2
	East	13.5	1.1	2.9	13.5	25.8	38.0	49.2	60.7	71.4	81.8	91.5
	South	18.9	7.2	0.0	4.2	9.5	15.2	20.4	25.3	29.9	34.2	38.4
	West	9.1	0.0	4.4	16.0	28.5	40.5	52.6	64.5	75.3	85.2	94.7
2.50	North	17.6	0.9	1.8	10.3	18.8	27.5	35.6	43.6	51.3	58.4	65.4
	East	14.3	1.6	1.7	10.6	20.7	31.6	41.3	51.3	60.5	69.6	78.2
	South	19.1	7.7	0.0	2.5	6.9	11.9	16.4	20.6	24.5	28.3	31.9
	West	10.2	0.4	2.7	12.5	23.3	33.9	44.6	55.0	64.5	73.3	81.6
3.00	North	18.0	1.3	0.6	8.0	15.6	23.3	30.6	37.2	44.5	50.9	57.1
	East	13.6	2.7	0.3	7.3	16.1	25.4	34.1	42.9	51.0	58.8	66.5
	South	18.7	8.0	0.6	1.0	4.8	9.3	13.2	16.8	20.4	23.7	26.8
	West	11.3	1.0	1.9	10.3	19.9	29.4	39.1	48.5	57.0	64.9	72.4
4.00	North	24.1	1.6	3.2	9.8	16.4	23.0	29.2	35.1	41.0	46.7	52.1
	East	15.4	4.6	0.0	5.3	12.3	20.0	27.1	34.0	41.3	47.7	54.1
	South	19.3	10.0	1.7	0.0	2.8	6.6	9.8	12.7	15.6	18.4	21.0
	West	12.1	2.5	0.1	6.5	14.4	22.3	30.4	38.1	45.1	51.7	58.0
5.00	North	20.3	4.4	0.0	4.2	9.7	14.9	20.1	25.0	29.4	34.5	39.0
	East	14.3	4.1	0.0	2.0	7.7	14.1	19.9	25.6	31.2	37.3	42.6
	South	19.9	11.7	2.5	0.0	1.3	5.2	7.8	10.4	12.9	15.2	17.4
	West	13.6	3.8	0.0	4.8	11.7	18.5	25.6	32.2	38.2	44.0	49.5

Table G.16. Percentage of the energy consumption increase for window areas different than the IWA for Salvador, room ratio of 1:2 (%).

K	Orient.	Window area (%)										
		0	10	20	30	40	50	60	70	80	90	100
0.60	North	11.9	6.1	0.0	7.9	17.3	26.8	36.3	46.4	56.2	66.4	76.1
	East	7.4	1.8	0.0	3.2	12.8	24.3	35.8	48.0	59.8	71.2	82.0
	South	12.2	11.1	1.4	0.7	4.0	8.5	13.6	19.2	24.5	29.6	34.7
	West	3.4	0.0	3.1	11.5	21.6	32.6	43.6	54.6	65.8	76.9	87.7
0.80	North	14.3	7.4	0.0	6.7	14.9	23.4	31.9	40.9	49.8	58.7	67.4
	East	9.0	3.4	0.0	2.5	10.7	20.9	31.1	42.1	52.9	63.1	72.8
	South	13.2	11.6	1.2	0.0	2.1	5.9	10.4	14.9	19.9	24.4	28.8
	West	5.1	0.0	1.8	8.9	17.7	27.4	37.0	46.8	56.8	66.7	76.5
1.00	North	16.0	8.5	0.1	5.6	12.8	20.6	28.1	36.3	44.4	52.5	60.4
	East	9.7	3.8	0.1	1.2	8.2	16.9	26.1	36.1	45.9	54.9	63.8
	South	14.2	12.3	1.4	0.0	0.8	4.0	8.0	12.1	16.6	20.6	24.5
	West	6.3	0.4	1.3	6.9	14.7	23.3	32.0	40.8	49.9	58.8	67.7
1.25	North	16.9	9.3	0.0	4.0	10.3	17.1	23.7	31.0	38.2	45.1	52.5
	East	10.7	4.7	0.7	0.3	6.4	13.6	22.0	30.7	39.5	47.7	55.5
	South	15.4	13.5	2.0	0.3	0.0	2.8	6.2	9.7	13.7	17.2	20.7
	West	7.0	1.0	0.6	4.7	11.4	18.8	26.5	34.2	42.3	50.2	58.1
1.50	North	18.7	10.8	0.7	3.5	9.5	15.1	21.1	27.7	34.3	40.5	47.3
	East	12.8	6.6	1.4	0.5	6.1	12.1	19.8	27.7	35.9	43.3	50.5
	South	17.6	15.5	3.5	1.6	0.0	2.7	5.6	8.8	11.9	15.6	18.8
	West	8.0	1.4	0.4	3.2	9.1	15.5	22.5	29.5	36.6	43.7	50.9
2.00	North	19.2	11.3	0.7	1.3	6.3	10.8	15.6	21.2	26.8	32.0	37.2
	East	12.9	6.5	1.7	0.0	3.4	8.0	13.9	20.4	27.2	33.6	39.7
	South	18.0	15.7	5.3	1.2	0.0	0.6	2.8	5.3	7.9	11.0	13.6
	West	9.1	2.1	0.0	1.2	5.6	11.0	16.7	22.6	28.5	34.4	40.5
2.50	North	19.7	11.8	1.6	0.0	4.2	8.4	11.8	16.6	21.4	26.0	30.5
	East	13.1	6.7	1.6	0.0	1.4	5.3	10.0	15.2	21.1	26.7	32.1
	South	19.5	17.1	6.8	2.1	1.6	0.0	2.0	4.0	6.3	8.4	11.2
	West	11.1	3.8	1.0	0.7	4.5	9.1	13.8	19.0	24.2	29.4	34.6
3.00	North	20.3	12.8	1.9	0.0	3.1	6.8	9.4	13.7	18.0	22.2	26.1
	East	13.9	7.5	1.7	0.7	0.0	4.3	8.1	12.5	17.4	22.6	27.5
	South	20.3	17.9	7.8	2.8	2.1	0.0	0.8	3.1	5.0	7.0	9.4
	West	12.8	5.3	0.2	1.1	4.1	8.0	12.1	16.7	21.4	26.0	30.7
4.00	North	21.4	14.8	2.7	0.0	1.8	4.8	7.9	9.9	13.4	16.9	20.2
	East	13.1	7.3	2.6	0.9	0.0	0.9	3.7	7.0	10.5	14.6	18.6
	South	20.6	18.4	9.0	3.2	1.9	1.4	0.0	0.8	2.7	4.2	5.8
	West	11.6	4.7	0.7	0.0	0.6	3.2	6.6	10.0	13.7	17.4	21.3
5.00	North	22.0	15.2	3.1	0.0	0.9	3.3	5.9	8.6	10.1	13.1	16.0
	East	14.2	9.1	3.9	1.8	0.5	0.0	2.7	5.1	8.0	11.2	14.4
	South	20.8	18.7	9.7	3.6	2.0	1.6	1.5	0.0	0.8	1.6	3.8
	West	12.3	5.7	2.0	0.1	0.0	1.7	4.3	7.1	10.3	13.6	16.9

Appendix H. Methods of Economic Analysis

This appendix presents theoretical methods and aspects of economic analysis. The methods usually used to perform economic analysis of investments are the following:

1. Simple payback;
2. Present value;
3. Corrected payback;
4. Internal rate of return.

Further information on economic analysis of investments can be obtained in BUSSEY (1978), BIERMAN JR & SMIDT (1975), or in any other books on economic analysis.

1. Simple payback method

Although being widely used, the simple payback method is not an accurate method because it only takes into account the relationship between the initial investment and the benefits; it does not take into account either monetary depreciation with time or the whole life of the project. Equation H.1 shows how to determine the simple payback period (BUSSEY, 1978).

$$\text{Payback} = \frac{\text{Investment}}{\text{Benefits}} \tag{H.1}$$

Therefore, if a project requires an investment of £1,000.00 and provides monthly benefits of £250.00, the payback period will be 4 months, independent of the life span of the project. It can be easily understood that if two projects provide the same payback, the project that lasts more will be economically more attractive. However, the simple payback method does not show this kind of information and should be only used in connection with more accurate methods.

2. Present value method

This method consists of determining the present value of the cash flow of an investment. If the present value is positive, the project is viable. In case of a comparison amongst different projects, the more viable will be the project with higher present value. Interest rate to be used in this method must be the one in which the investor believes to make profit.

This method consists of bringing all investments and benefits that happen along the life span of the project to the present date, as a function of the interest rate. This rate is incorporated to the calculus through the Discount Factor shown in equation H.2 (BIERMAN JR & SMIDT, 1975).

$$DF_n = \frac{1}{(1+i)^n} \tag{H.2}$$

Where:

DF_n	is the discount factor for the period n (non-dimensional);
i	is the tax (in decimals);
n	is the period in which the tax is applied.

Therefore, the present value for each period will be determined through equation H.3 (BIERMAN JR & SMIDT, 1975).

$$PV_n = DF_n\ (\text{Benefit} - \text{Investment})_n \tag{H.3}$$

Where:

PV_n	is the present value for the period n ($);
DF_n	is the discount factor for the period n (non-dimensional);
Benefit_n	is the benefit within the period n ($);
Investment_n	is the investment within the period n ($).

Consequently, the total present value to the project life will be given by equation H.4 (BIERMAN JR & SMIDT, 1975).

$$PV_{total} = \sum_{n=0}^{n} PV_n \tag{H.4}$$

For the example discussed in section 1 above, for an interest rate of 4% per month, if the project life is 5 months, its present value will be £112.96. However, if the project life is 10 months, its present value will be £1027.72. Therefore, with this method it is possible to notice that two projects with the same simple payback period can be more or less attractive. However, special attention must be paid to the project life because if it is much longer than in a real situation, the present value will not correspond to reality.

3. Corrected payback method

Through the use of the present value method it is possible to determine the corrected payback, which corresponds to a more accurate payback than the simple payback as the monetary depreciation is taken into account. The corrected payback is determined as a function of the accumulated present value, which is calculated through equation H.5 (BUSSEY, 1978).

$$APV_n = PV_n + APV_{n-1} \tag{H.5}$$

Where:

APV_n	is the accumulated present value for the period n ($);
PV_n	is the present value for the period n ($);
APV_{n-1}	is the accumulated present value for the period n-1 ($).

Therefore, there will be a moment in which the accumulated present value changes from a negative to a positive value. This is the moment in which the investor starts to retrieve the money invested, which is the corrected payback period. Figure H.1 exemplifies this situation for the example described in section 1. As it is shown, the corrected payback period is 4.45 months for an interest rate of 4% per month. The simple payback period of 4 months would only be real if the interest rate were zero.

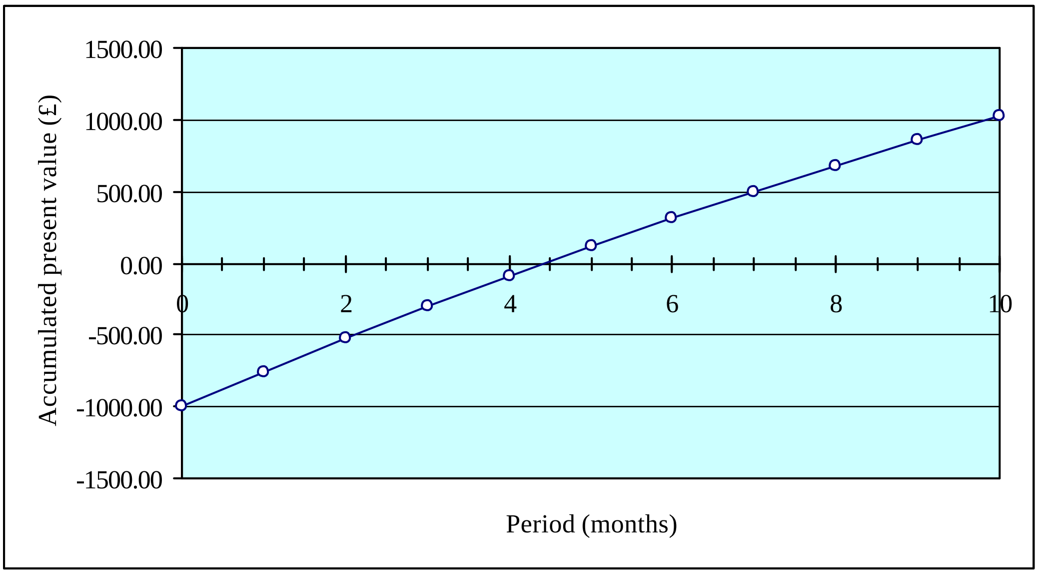

Figure H.1. Corrected payback for a specific example.

4. Internal rate of return method

The internal rate of return (IRR) must be understood as a rate that makes the total present value of an investment be zero. Therefore, an investment will be viable when the internal rate of return is higher than the interest rate.

For the example presented in section 1 the IRR will be 21.4% per month if the project has a life span of 10 months. Figure H.2 presents this example and shows the accumulated present value variation as a function of the interest rate (ir). For interest rate lower than the IRR, the accumulated present value at the end of the period (10 months) will be positive; and the lower the interest rate, the higher the accumulated present value. However, if the interest rate is higher than the IRR, the investment is not viable: the accumulated present value will be negative even at the end of the life span of the project.

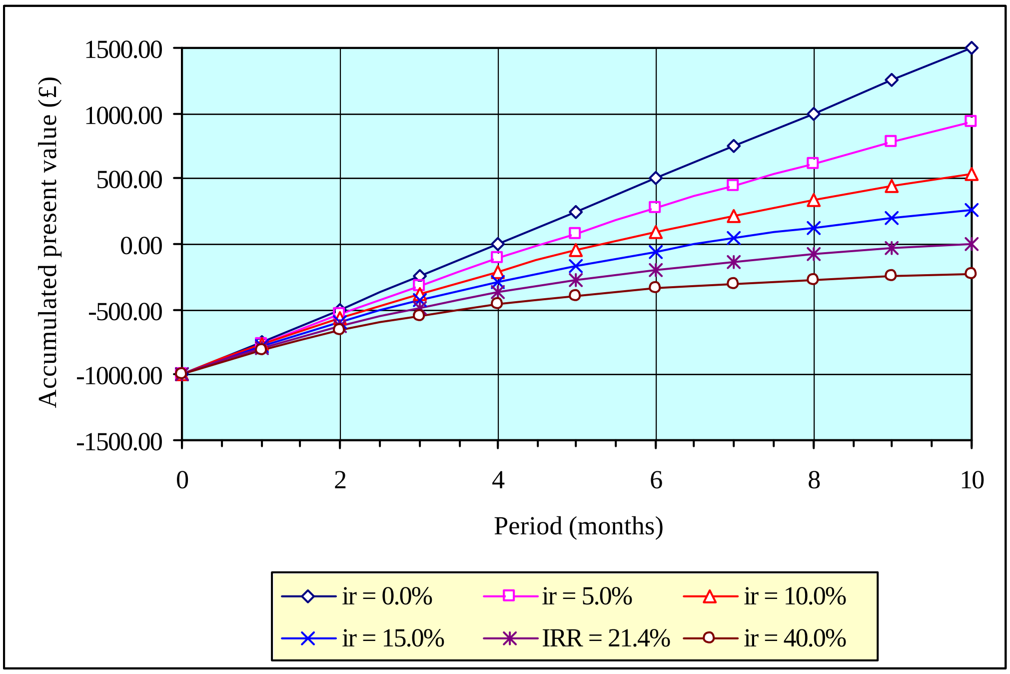

Figure H.2. Accumulated present value as a function of interest rates.

5. Investment versus benefits

Through the assessment of the methods previously described it is possible to note that the three last ones provide accurate and comparable results.

It can also be observed that the corrected payback and the internal rate of return are methods that can be assessed as a function of the ratio of investment to benefits. For instance, a project whose life span is 10 years will have a corrected payback of 5.90 years (for an interest rate of 5.00% a year) and an internal rate of return of 15.50% a year when the investment is £50.00 and the benefits are £10.00 a year. The same results are obtained if the investment is £50,000.00 and the benefits are £10,000.00 a year. The present value, obviously, grows according to investment and benefits increase.

Therefore, through the development of the corrected payback and the internal rate of return methods it is possible to elaborate tables and charts with the corrected payback and the internal rate of return as a function of the ratio between the investment and the benefits.

Figure H.3 presents the corrected payback that can be obtained as a function of ratios between investment and benefits, and as well as a function of interest rates of 5.0%, 10.0%, 15.0% and 20.0% per period. Therefore, if a project needs an investment 5 times higher than the expected monthly benefits, the corrected payback will be 5.90 months for an interest rate of 5.0%. The higher the interest rates, the higher the corrected payback.

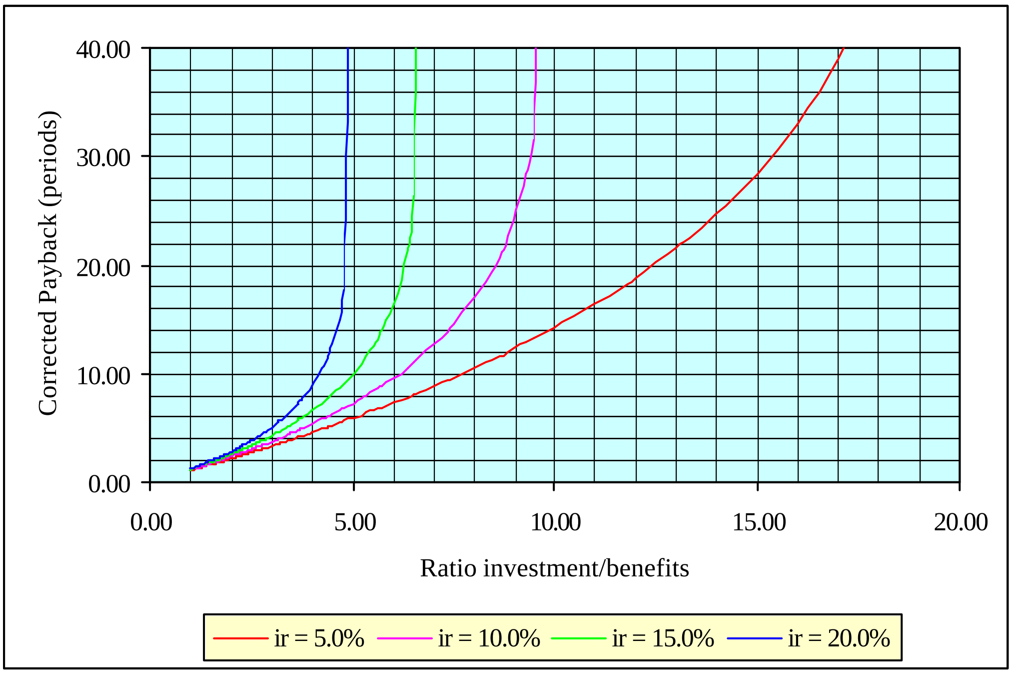

Figure H.3. Corrected payback as a function of investment, benefits and interest rates.

Figure H.4 presents the internal rate of return that can be obtained as a function of ratios between investment and benefits, and as well as a function of project lives of 10, 20 and 30 periods. Therefore, if a project needs an investment 5 times higher than the expected yearly benefits, the internal rate of return will be 15.1% a year for a project life of 10 years. If its life is 20 years, the internal rate of return will be 19.4% a year.

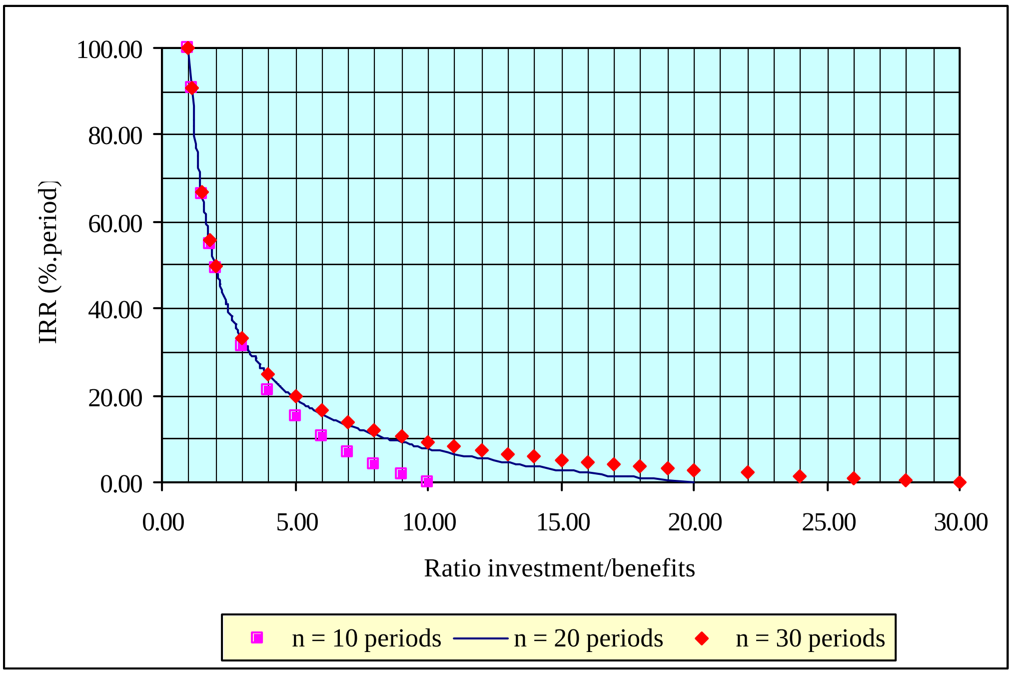

Figure H.4. Internal rate of return as a function of investment, benefits and project life.

Appendix I. Energy Consumption for the Ideal Window Area

Tables I.1 to I.8 show the energy consumption of the rooms over the ten room indices, five room ratios, four orientations and eight cities studied in this work for the situation in which the Ideal Window Area is applied. Such energy consumptions were obtained by computer simulations using the VisualDOE programme as discussed in Chapters 4 and 5.

Table I.1. Energy consumption for the Ideal Window Areas in Belém, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	186	188	191	194	184	183	188	190	177	178	181	184	170	172	175	178	164	168	170	175
0.80	157	159	161	165	156	156	158	162	151	151	152	157	146	149	150	154	142	146	147	151
1.00	136	142	143	145	139	139	141	144	135	136	136	140	131	135	135	139	129	133	133	137
1.25	127	129	129	131	126	126	127	130	123	125	124	129	120	124	123	128	118	123	123	125
1.50	118	121	120	124	118	119	118	122	115	118	116	121	112	117	115	120	101	117	116	118
2.00	108	110	109	112	107	110	108	111	105	108	107	111	103	108	106	109	102	108	106	108
2.50	102	104	102	105	100	104	101	104	99	102	101	104	97	102	100	103	97	101	100	101
3.00	97	100	97	100	95	99	97	101	94	98	97	100	94	98	96	98	94	98	95	94
4.00	91	94	94	96	90	93	91	95	90	93	91	91	89	91	90	90	88	91	90	93
5.00	88	89	89	91	87	91	89	89	87	89	87	88	86	89	87	90	85	88	86	90

Table I.2. Energy consumption for the Ideal Window Areas in Brasília, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	130	139	125	146	128	135	122	145	120	133	119	140	112	125	116	133	109	123	116	130
0.80	112	119	109	126	111	117	106	123	105	115	104	121	100	110	103	116	99	110	103	114
1.00	97	108	99	113	101	106	97	101	96	105	95	99	93	102	94	107	92	101	94	105
1.25	95	100	91	104	93	98	90	102	89	97	89	101	88	95	88	100	88	94	89	98
1.50	90	94	87	98	88	92	85	97	85	92	86	96	84	90	85	94	85	90	85	95
2.00	83	87	80	91	82	87	79	89	80	86	79	89	79	85	79	88	80	85	79	88
2.50	79	84	77	86	78	83	76	86	77	82	76	85	77	82	76	84	77	81	76	84
3.00	77	81	74	83	75	81	74	83	75	80	74	82	75	79	74	82	75	79	74	80
4.00	73	78	72	79	74	77	71	78	73	76	71	78	72	76	71	77	71	76	71	78
5.00	72	75	70	76	71	75	70	76	71	75	69	76	70	74	69	76	70	74	69	75

Table I.3. Energy consumption for the Ideal Window Areas in Curitiba, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	110	120	95	117	107	116	93	114	90	109	92	110	94	104	89	108	93	102	89	106
0.80	96	103	84	101	93	100	82	99	88	95	81	96	84	92	80	95	84	91	81	94
1.00	85	93	77	92	85	91	76	90	81	88	76	89	79	85	76	88	80	85	76	88
1.25	82	86	72	85	79	84	71	84	77	83	72	83	71	80	72	84	76	80	73	83
1.50	78	82	70	81	75	80	69	80	74	79	69	80	74	79	70	81	73	78	71	80
2.00	73	76	66	77	71	76	66	77	71	74	67	77	71	74	67	74	70	75	68	76
2.50	70	73	65	75	69	74	65	75	69	72	66	74	69	72	66	74	68	72	66	74
3.00	68	72	65	73	67	72	64	73	67	70	64	73	67	70	64	72	67	70	65	72
4.00	67	70	63	71	67	69	63	71	66	69	63	70	65	68	63	70	65	68	63	70
5.00	66	68	62	69	65	68	62	69	65	67	62	69	64	67	62	69	64	67	62	69

Table I.4. Energy consumption for the Ideal Window Areas in Florianópolis, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	152	162	145	166	149	160	143	163	145	155	140	159	134	151	136	155	134	148	136	152
0.80	130	138	124	141	128	135	122	138	124	132	120	136	117	130	119	133	117	128	119	132
1.00	112	124	112	126	116	120	110	124	111	119	109	122	107	117	109	120	106	117	109	120
1.25	108	112	103	115	107	109	102	113	101	108	101	111	102	109	101	112	100	108	102	111
1.50	102	104	97	107	100	104	96	106	96	102	96	105	96	103	96	106	95	102	97	105
2.00	94	97	89	99	92	96	89	98	90	94	89	98	89	95	90	98	89	96	90	97
2.50	89	92	85	94	87	90	85	93	86	91	85	93	85	90	86	92	85	90	86	92
3.00	85	88	82	91	82	87	83	90	84	87	83	89	82	87	83	89	81	87	83	88
4.00	79	83	79	85	80	83	79	85	79	82	78	84	79	82	78	85	78	82	78	84
5.00	78	81	77	82	78	80	76	82	77	80	76	82	76	80	76	82	76	79	76	82

Table I.7. Energy consumption for the Ideal Window Areas in Rio de Janeiro, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	202	224	200	225	197	220	199	220	193	212	197	214	191	205	193	207	189	202	192	203
0.80	172	190	171	189	168	187	170	186	165	180	167	181	164	175	166	177	163	173	165	173
1.00	152	169	153	168	150	166	152	165	148	160	150	160	147	157	149	158	147	156	149	156
1.25	138	153	139	151	136	150	138	148	135	145	136	146	135	143	136	143	134	142	135	142
1.50	128	141	129	140	127	138	128	138	126	135	128	135	126	132	127	134	125	132	127	133
2.00	116	126	117	125	115	124	116	124	115	121	116	123	115	120	116	121	114	120	116	121
2.50	109	116	110	117	109	116	109	116	108	114	109	115	108	113	109	113	107	113	108	113
3.00	104	111	105	111	104	110	104	110	103	109	104	109	103	108	104	108	103	107	104	107
4.00	98	103	98	104	97	102	98	103	97	101	98	102	97	101	97	101	97	100	97	101
5.00	94	99	94	101	94	99	94	98	94	97	94	98	93	96	94	97	93	96	94	96

Table I.8. Energy consumption for the Ideal Window Areas in Salvador, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	229	237	217	246	224	232	214	242	217	227	209	236	210	219	204	229	203	217	200	225
0.80	191	198	182	205	188	195	179	202	182	192	176	199	177	186	173	194	171	182	171	191
1.00	166	175	160	181	165	172	158	178	161	168	156	176	156	165	153	173	152	163	153	170
1.25	151	157	143	162	148	154	140	160	145	150	140	159	140	148	137	155	138	147	138	154
1.50	139	144	131	149	136	142	129	147	134	138	130	147	129	137	127	143	127	135	127	143
2.00	124	127	117	133	122	127	116	132	120	124	116	131	116	123	115	129	115	122	115	129
2.50	115	118	110	123	114	117	109	122	111	116	108	121	108	115	107	121	108	115	107	119
3.00	109	113	105	116	107	111	104	116	105	111	102	114	101	110	102	114	102	109	101	112
4.00	97	104	98	108	99	105	97	107	97	103	96	105	96	103	96	105	96	103	95	107
5.00	96	101	94	102	95	100	93	101	93	99	92	101	93	99	92	102	92	98	92	102

Table I.7. Energy consumption for the Ideal Window Areas in Rio de Janeiro, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	202	224	200	225	197	220	199	220	193	212	197	214	191	205	193	207	189	202	192	203
0.80	172	190	171	189	168	187	170	186	165	180	167	181	164	175	166	177	163	173	165	173
1.00	152	169	153	168	150	166	152	165	148	160	150	160	147	157	149	158	147	156	149	156
1.25	138	153	139	151	136	150	138	148	135	145	136	146	135	143	136	143	134	142	135	142
1.50	128	141	129	140	127	138	128	138	126	135	128	135	126	132	127	134	125	132	127	133
2.00	116	126	117	125	115	124	116	124	115	121	116	123	115	120	116	121	114	120	116	121
2.50	109	116	110	117	109	116	109	116	108	114	109	115	108	113	109	113	107	113	108	113
3.00	104	111	105	111	104	110	104	110	103	109	104	109	103	108	104	108	103	107	104	107
4.00	98	103	98	104	97	102	98	103	97	101	98	102	97	101	97	101	97	100	97	101
5.00	94	99	94	101	94	99	94	98	94	97	94	98	93	96	94	97	93	96	94	96

Table I.8. Energy consumption for the Ideal Window Areas in Salvador, Brazil (kWh/m^2.year).

K	2:1				1.5:1				1:1				1:1.5				1:2			
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W
0.60	229	237	217	246	224	232	214	242	217	227	209	236	210	219	204	229	203	217	200	225
0.80	191	198	182	205	188	195	179	202	182	192	176	199	177	186	173	194	171	182	171	191
1.00	166	175	160	181	165	172	158	178	161	168	156	176	156	165	153	173	152	163	153	170
1.25	151	157	143	162	148	154	140	160	145	150	140	159	140	148	137	155	138	147	138	154
1.50	139	144	131	149	136	142	129	147	134	138	130	147	129	137	127	143	127	135	127	143
2.00	124	127	117	133	122	127	116	132	120	124	116	131	116	123	115	129	115	122	115	129
2.50	115	118	110	123	114	117	109	122	111	116	108	121	108	115	107	121	108	115	107	119
3.00	109	113	105	116	107	111	104	116	105	111	102	114	101	110	102	114	102	109	101	112
4.00	97	104	98	108	99	105	97	107	97	103	96	105	96	103	96	105	96	103	95	107
5.00	96	101	94	102	95	100	93	101	93	99	92	101	93	99	92	102	92	98	92	102