Design Tools 6.

Introduction 6.1.

Daylighting design is a creative process. It aims to generate appropriate architectural and/or technical solutions to achieve an enjoyable and productive built environment while simultaneously reducing the energy consumption of buildings through the substitution of daylight for electric light.

Daylighting design is both an art and a science. Qualitative information and visual feedback on a given daylighting concept are usually as important for the building designer as the quantitative figures that reflect the engineering aspect of daylighting design.

Design tools are intended to help designers with the qualitative and quantitative elements of daylighting design through features that commonly include:

- visualisation of the luminous environment of a given daylighting design;
- prediction of daylight factors in a space lit by diffuse daylight;
- identification of potential glare sources and evaluation of visual comfort indices;
- prediction of potential energy savings achievable through daylighting;
- control of the penetration of the sun's rays and visualisation of the dynamic behaviour of sunlight.

By providing all information of this type, design tools play a significant role in the decision-making process that characterises daylighting design. These tools support designers throughout the sequence of decisions, from formulation of the daylighting concepts to final implementation of daylighting strategies and innovative techniques in real buildings.

Design tools must therefore fit the significant phases of architectural projects during which important decisions regarding daylighting strategies are made. These tools must suggest appropriate architectural solutions that meet the architectural objectives of the project. The capability of design tools to analyse a given daylighting scenario, based on a detailed physical description of the project, are especially significant when advanced daylighting systems are considered.

This chapter gives an overview of the state of the art of daylighting design tools. Special emphasis is placed on tools that address the advanced daylighting systems investigated by IEA SHCP Task 21.

6.2. Simple Tools

Simple design tools give a designer clues about basic design decisions without requiring extensive time or detail. These tools are normally used to check performance or estimate the impact of specific design elements on daylight performance in an early design stage. They do not require advanced equipment or knowledge and thus non-experts can use them. Simple tools cannot model complex daylighting strategies and therefore are not suitable for fine-tuning daylighting designs.

Many traditional simple tools focus on the daylight factor as a design criterion; these tools should only be used in predominantly cloudy climates. A new generation of "simple" computer tools embodies complex evaluation models, though these tools are nonetheless simple from the user's point of view. A common characteristic of all simple daylighting design tools is the restriction of input parameters to key design properties such as interior

Table 6-1: Survey of simple design tools carried out as part of IEA Task 21 [de Boer and Erhorn 1998]

TYPE	SUBJECT								TOOL
	Daylight Factor for Sidelit Rooms	Daylight Factor for Rooflit Rooms	Window Design	Rooflight Design	Atria Design	Energetic Behaviour / Daylight Autonomy	Shadow and Reflection Analysis / Sunshine Duration	Visual Comfort	
1. Formulae		■		■					2.1.1
	■	■	■	■					2.1.2
2. Tables	■		■						2.2.1
		■		■					2.2.2
3. Nomograms	■	■	■	■	■				2.3.1
	■				■				2.3.2
4. Diagrams	■	■	■	■		■	■	■	2.4.1
	■		■						2.4.2
						■			2.4.3
						■			2.4.4
5. Protractors	■	■	■	■					2.5.1
6. Computer Tools	■	■	■	■		■	■		2.6.1
							■		2.6.2
							■		2.6.3
						■			2.6.4
	■	■	■	■		■			2.6.5
7. Typology	■	■	■	■			■	■	2.7.1
8. Scale Models	■	■	■	■	■		■	■	2.8.1

reflectance, the size and the location of windows and skylights, and the proportions of the space and exterior obstructions.

Several surveys have been carried out during the past few years to identify the simple design tools available to practitioners and to estimate the market impact of these tools [Baker et al. 1993, McNicholl and Lewis 1994, Kenny and Lewis 1995, Aizlewood and Littlefair 1996]. Table 6-1 gives the results of one such survey, conducted recently as part of IEA Task 21 [de Boer and Erhorn 1998].

Most of the tools listed in Table 6-1 are based on practical experience or simple calculation methods, e.g., the lumen input method or the split-flux method [CIBSE 1987]. Although older tools, such as empirical equations, tables, nomograms, diagrams, and protractors, reflect historical conditions when computer technology was not available, new simple design tools are typically computer-based.

Another category of simple tools is dedicated to estimating the impact of obstructions on daylight availability at a construction site or on a facade. These tools generally provide a method of superimposing a sun chart or daylight availability chart on a representation of obstructions. Several instruments have been developed specifically for this purpose, but none of them has had great success.

A fisheye lens with an equidistant projection offers a quick means of analysing obstructions. When the camera is positioned at the location in question and the lens is pointed at the sky's zenith, the photograph is a circular representation of the sky hemisphere including all obstructions. This photograph can be superimposed on a sun chart either manually or by using a computer. Attention should be paid to precisely positioning the sun chart to the true north of the location. The fisheye representation of the surroundings can also be generated by using a computer-aided design (CAD) system rather than a camera. In this case, all obstructions need to be included in the model.

Because decisions in the early stages of building design have a large impact on a building's daylight performance, simple design tools are essential to help designers navigate this phase. Simple tools offer hints about key design parameters but cannot be used to evaluate a strategy in detail or to model advanced systems.

Computer-Based Tools 6.3.

With the advent of personal computers (PCs), powerful processors that can handle complex calculation algorithms and lighting simulation techniques are available to nearly all practitioners. In addition to the first generation of simple design tools, which were translated into numerical programmes, several new pieces of software have been developed since the 1980s to address the complexity of light propagation into building spaces.

Many of these pieces of more complex software were developed by researchers for mainframe computers: They have fewer limitations than simple tools in their ability to address the geometry and the photometry of the modeled architectural space and they offer more and richer graphic output options (e.g., illuminance contours and mapping). Image-based daylighting computer tools have improved these output features by providing synthetic imaging of modeled spaces.

Most of these tools have now been ported to the PC world, mainly for Microsoft Windows operating systems. Some of them have also been linked to commonly used architectural CAD programmes, whose graphical means for entering geometric data are much easier to handle than the conventional numerical input for xyz-coordinate systems used in most of the older stand-alone daylighting tools. Some tools offer more elaborate graphical user interfaces which significantly facilitate and speed up the daylighting design and

Table 6-2: Overview of daylighting computer design tools [Lighting Design and Application 1996]

		IEA ECBCS/ SHC ADELINE 3.0	**Lawrence Berkeley Lab RADIANCE 2.4**	**Lawrence Berkeley Lab SUPERLITE 2.0**	**Electric Power Research Institute BEEM 1.01**	**Electric Power Research Institute LIGHTCAD 1.0**	**Cooper Lighting LUXICON 1.1**	**Lighting Technologies Inc. LUMEN-MICRO 6.0**
General Applications	Indoor	X	X	X	X	X	X	X
	Outdoor	X	X				X	
Hardware	Operating System	Windows 95 & NT	UNIX	DOS	DOS	DOS	WINDOWS	DOS
	Operates Inside AUTOCAD							
	System Memory Required					X		
	Hard Disk Space Required							
	Minimum/Recommended Processor	32MB	16M	600K	512K	4M	8M	565K
		50-80MB Pentium	30M ANY 32-BIT RISC	1M 8086/368-387	500K 8088/386	3.5M 386-387/486	26M 486/ Pentium	8M 386/486
Type of Analysis	Horizontal Point-by-Point Illumination	X	X	X			X	X
	Vertical Point-by-Point Illumination	X	X	X			X	X
	Interreflected Calculations	X	X	X			X	X
	Direct Calculations	X	X	X			X	X
	Room Surface Luminance or Exit	X	X	X			X	X
	Analysis Plane Can be Titled	X	X	X			X	
	Lightmeters Can Be Titled	X	X					
	Avg. Indoor Illuminance (zonal cavity)				X	X	X	X
	Avg. Outdoor Illuminance (lumen method)							
	Daylighting	X	X	X	X	X	X	X
	Visual Comfort Probability	X	X				X	X
	Relative Visual Performance						X	X
	Economic Analysis				X	X	X	X
	Unit Power Density	A			X	X	X	A
	Advanced Statistical Analysis						X	
	Image Synthesis	X	X				X	X
	Walk-thru Image Synthesis							SLIDE
Special Features	Automatic Layout					X	X	X
	Generate Schedules					X	X	
	CAD Interface	X	X		X	X	X	X
	Building Shadowing	X	X	X			X	X
	Interior Obstructions	X	X	X			X	X
	Shape of Room (plan view)	ANY	ANY	ANY		X	ORTH	ORTH
	Shape of Room (section view)	ANY	ANY	ANY		X	ORTH	ORTH
	Batch Processing		X				X	X
	Max. Number of Calculation Areas	Unlimited	Unlimited	3	100		Unlimited	5
	Max. Luminaire Types per Run	Unlimited	Unlimited	10		100	Unlimited	8
User Interaction	Tabular Entry	X			X	X	X	X
	Graphical Entry	X				X	X	X
	Metric Input and Output	X	X	X			X	X
	Input Device	KM	KM	K	KM	KM	KM	KM
	Context-Sensitive Help Screens	X	X		X		X	X
Types of Output	Point-by-Point	X	X	X			X	X
	Iso-Contours	X	X				X	X
	Scaled Output	X	X			X	X	X
	Templates	X	X					X
	3D Model View	X	X			X	X	X
	Plotter Output					X	X	
	Color Output	X	X			X	X	
	Graphics Printer as Plotter	X	X			X	X	X
	Shaded Printout	X	X				X	X
	Any Shape Printout or Masking					X	X	
International	Language Calculations			X				
Photometric Database	Photometric Data Manager					Within	Within	Within/Ext.
	Photometric Graphic Viewer						X	X
	Photometric Format	IESNA Eulumdat	IESNA			IESNA	IESNA, Other	All&LTL-1

analysis process. Pre- and post-processors extend the capabilities of the core lighting algorithms — for instance enabling one to link daylighting analysis with the building energy simulation.

Recent surveys have shown that these tools are increasing in number and use for architectural design. Table 6-2 gives an overview of the existing daylighting computer design tools in the more complex category. More recent overviews can be found in the IES publication, *Lighting Design and Application,* and in other publications.

Two main categories of computer-based tools can be distinguished based on the calculation methods they use: the radiosity technique and the ray-tracing technique.

6.3.1. Radiosity Method

The radiosity method is probably one of the first lighting calculation techniques applicable to the evaluation of the interchange of light among all the surfaces defining an architectural space. This method has a significant advantage over former analytical techniques because it allows for light inter-reflections between surface walls.

Originally developed for energy calculations, the radiosity method was used to determine the energy balance of a set of surfaces exchanging radiant energy (Figure 6-1). Some of its basic hypotheses and limitations are that:

- wall surfaces must be subdivided into small finite elements characterised by homogeneous photometric properties (e.g., reflection coefficient);
- all elements must be perfect diffusers (Lambert's law);
- similar hypotheses must be applied to all of the external obstructions situated in front of windows and openings.

The radiosity method is used to determine the illuminance and luminance of a set of points located at the centres of different surface elements. This determination can be made independent of view, before any surface rendering is made from a desired viewpoint.

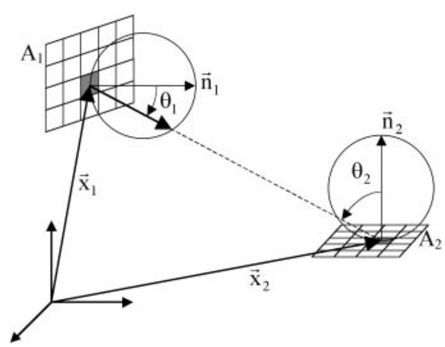


Figure 6-1: Surface elements exchanging light (or radiant energy) in the radiosity method

The SUPERLITE programme was one of the first widely available daylighting computer tools based on the radiosity method. The current version can handle both daylighting and electric lighting as well as rather complex room geometries (e.g., L-shaped rooms). Only perfectly diffusing surfaces can be considered; glazings can be transparent or diffusing, and windows can have shades.

Figure 6-2 gives an example of a visualisation of a daylighting calculation created using the radiosity method (SUPERLITE programme): Surface finite elements are visible in the picture.

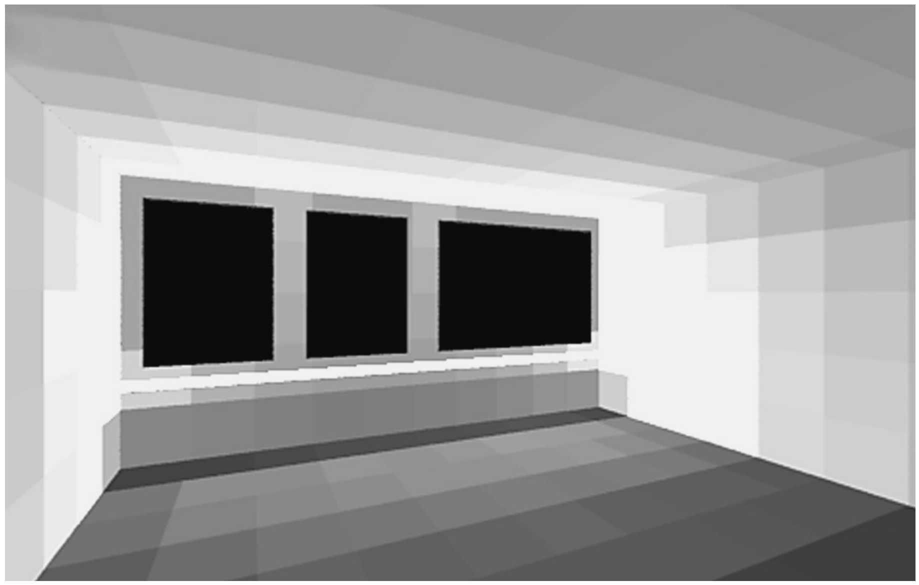


Figure 6-2: Visualization of a daylighting calculation made using a program that relies on the radiosity method [Compagnon 1993]

In spite of its weaknesses, the radiosity method has some advantages compared to the other well-known image rendering method, the ray-tracing technique. These include the radiosity method's view-independent calculation and the pre-eminence of major light sources in the images it renders.

6.3.2. Ray-Tracing Techniques

The ray-tracing technique determines the visibility of surfaces by tracing imaginary rays of light from a viewer's eye to the objects of a rendered scene. A centre of projection (the viewer's eye) and an arbitrary view plane are selected to render the scene on a picture plane. Thanks to the power of novel computer algorithms and processors, millions of light rays can be traced to achieve a high-resolution rendered picture.

Originally developed for imaging purposes, some ray-tracing programmes (e.g., RADIANCE, GENELUX, and PASSPORT) were adapted and optimised for calculation of daylighting within building spaces [Ward and Rubinstein 1988]. In this case, light rays are traced until they reach the main daylight source, which is usually the sun position (clear and intermediate skies) or the sky vault (cloudy skies). Figure 6-3 illustrates the principle of ray tracing, showing the viewpoint (P) and view direction of the observer as well as the main light source, represented by the sun.

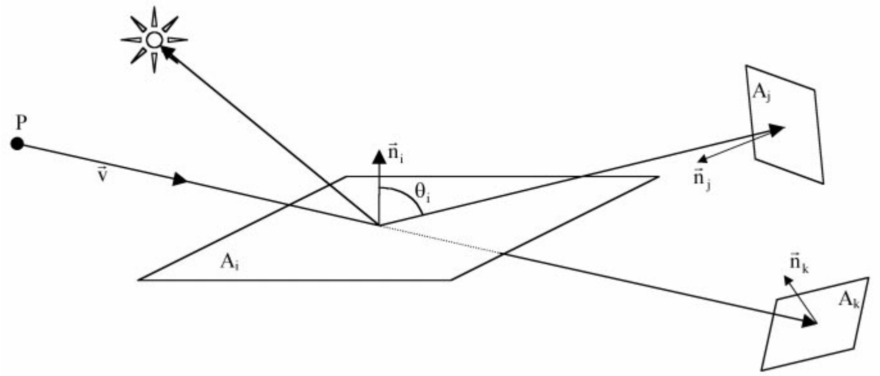


Figure 6-3: Tracing light rays from the viewpoint, P, to different surfaces and to the main light source (the sun)

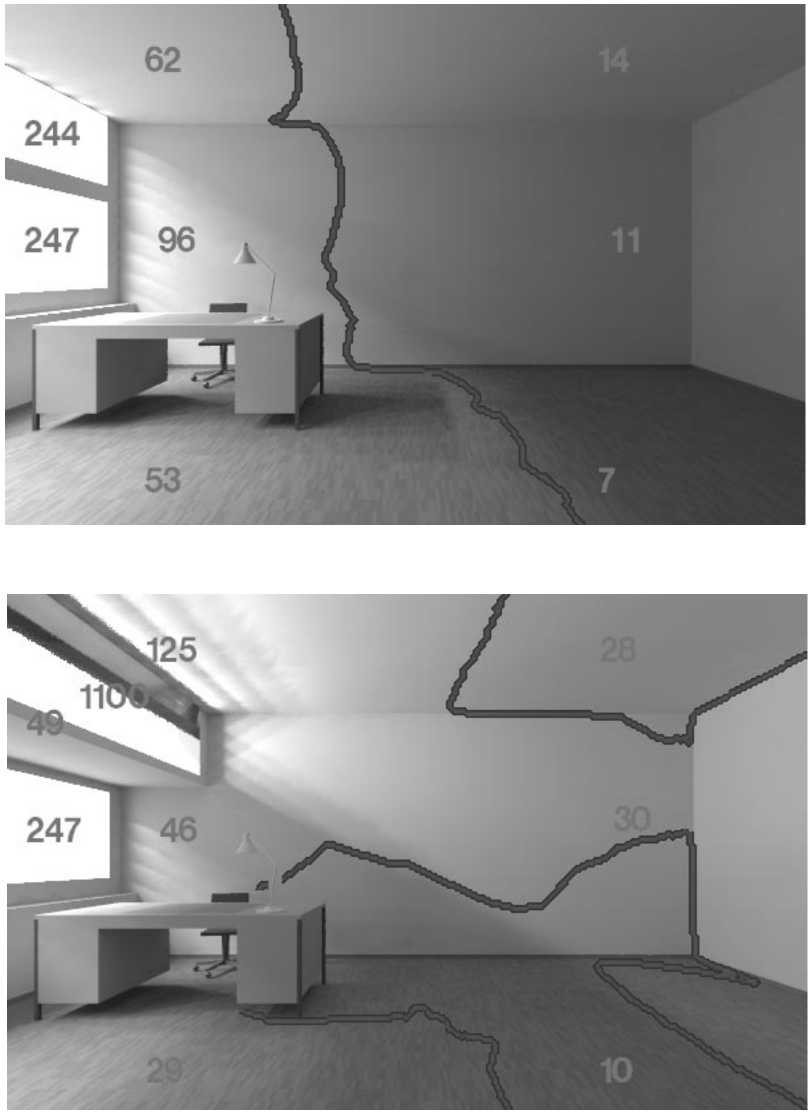
Most daylighting and electric lighting calculation programmes currently use this backward ray-tracing technique (from the viewpoint to the source). A slightly different technique is used by some software to improve daylighting calculations, especially for clear sky conditions (with sun). A forward rather than backward ray-tracing technique is used by the GENELUX programme to follow rays from the light source to a scene.

The principal features of the ray-tracing technique for all types of light calculations are the following:

- the method accounts for every optical phenomenon that can be analytically expressed by physical equations;
- the method can consider specular materials, like window panes and glossy surfaces;
- the method can effectively simulate non-homogeneous textures and surface points.

Thanks to their large range of applications, ray-tracing techniques play a significant role in the design and simulation of advanced daylighting systems. Figure 6-4 shows the numerical simulation of a room equipped with two different daylighting systems (a conventional window pane and a zenithal anidolic collector) created by a programme using a backward ray-tracing technique (RADIANCE); this simulation allows comparison of the luminous performance of the two daylighting systems.

Figure 6-4:
Computer simulation and image of an office space created using a ray-tracing technique.
Top: Reference room with double-pane window
Bottom: Anidolic zenithal collector



Several validations of ray-tracing programmes have demonstrated their reliability for daylighting performance assessment and advanced systems design [Compagnon 1993, Fontoynont 1999].

6.3.3. Integrated Software Environments

The use of daylighting and artificial lighting simulation programmes to calculate complex systems and models in the design practise often is impeded by the fact that the operation of these programmes, especially the model input, is extremely complicated and time-consuming. Programmes that are easier to use generally do not have the calculation capabilities required in practise. A second obstacle arises as the lighting calculations often do not allow any statements regarding the interactions with the energy and thermal building performance.

Both problems are mainly due to a lack of integration of the design tools of other building design practitioners as well as to insufficient user interfaces. The programme package ADELINE (Advanced Daylight and Electric Lighting Integrated New Environment) [Erhorn and Dirksmöller 2000] which has been further developed in the scope of IEA SHC Task 21 presents a promising approach to solving these problems.

The objective was to develop an integrated lighting analysis tool for building design purposes which is intended to assist the building designer and consultant in all issues associated with daylighting and electric lighting design. The general structure of the integrated programme system is depicted in Figure 6-5. The lighting calculations are executed using the algorithms of Superlite and Radiance. Several different pre- and post-processors around these core algorithms facilitate daylighting design and analysis during different design stages:

Simple Input

Early design phases account for the basic and often irreversible decisions concerning the daylight supply. The general floor layout, size and position of daylight openings decide whether daylight supply is sufficient or not. A tool to be used at this stage thus should allow for fast handling and quick access to the requested information while avoiding complex geometric modeling. ADELINE supports, as shown in Figure 6-6, a set of simple floor plan layouts which rely only on parametric input. Daylighting studies and design parameter variations can be performed in a fraction of the time usually required when applying CAD tools. The parametrically defined layouts can be used within ADELINE as starting point for more complex models.

Graphical Scene Editor

The graphical scene editor, depicted in Figure 6-7, allows for an interactive graphical composition of models made up of different predefined objects. Single objects or groups of objects can be copied, translated, rotated, and scaled. The graphical representation is based on a wire frame representation with hidden line removal. The scene editor gives direct access to libraries of furniture, materials, and luminaires. Views which will later be rendered can be defined — camera-like — directly in the wire frame representation.

Object Libraries

A material database with numerous opaque and transparent or translucent materials is included. Access to luminaire databases is provided. Using furniture in simulations enables more realistic and representative visualisations. Individual libraries can be established or existing ones can be used. More than 350 objects such as tables, chairs, and office equipment, Figure 6-8, can be selected from a furniture library to allow for representative visualisations. Selection and preview dialogues allow the convenient placement and arrangement of objects within the graphical scene editor.

Comprehensive Graphical Output

Light distributions can be displayed through either two- or three-dimensional graphics, and results are given as iso-lux or iso-daylight-factors curves as depicted in Figure 6-9. Light penetration can be analysed through two-dimensional sections of the building. This is very powerful for estimating the impact of each opening. Radiance renderings allow for detailed illuminance and luminance analysis as shown in Figure 6-12.

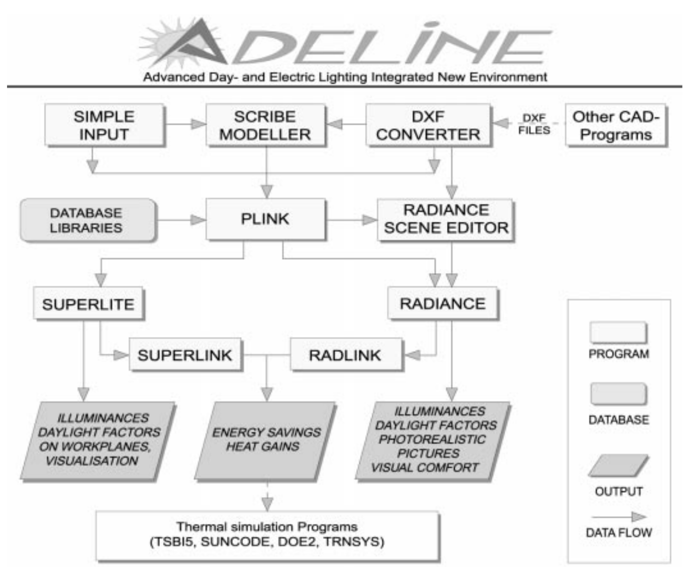
Integrated Energy Approach

SUPERLINK and RADLINK are programmes used to obtain estimates of the interaction between daylighting, artificial lighting, and the dynamic thermal building performance. The simulation is based on daylighting calculations with SUPERLITE or RADIANCE. SUPERLINK and RADLINK produce hourly values for additional artificial lighting input into a building over a complete year, taking into account:

- several lighting control strategies,
- different lamp types,
- desired work surface illuminance,
- user-defined work schedule,
- hourly sunshine probability.

A typical outcome of this calculation is shown in Figure 6-10. The hourly lighting energy input can be used to perform hourly thermal simulation with dynamic building simulation programs such as tsbi5, SUNCODE, DOE2, or TRNSYS.

Figure 6-5:
ADELINE 3
Programme System



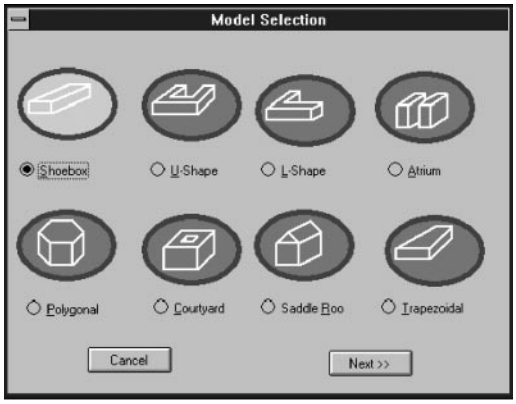


Figure 6-6: Parametrically definable basic geometries of the Simple Input Mode

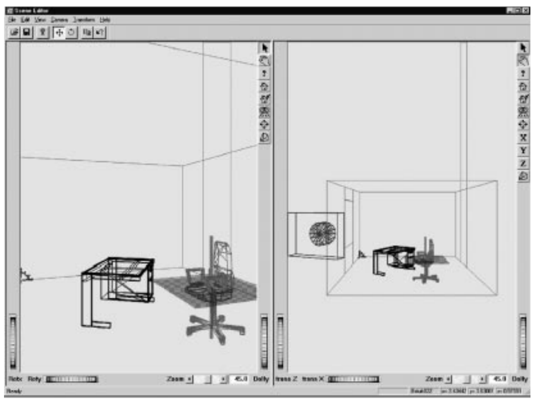


Figure 6-7: Wire Frame representation of Radiance Scene Editor

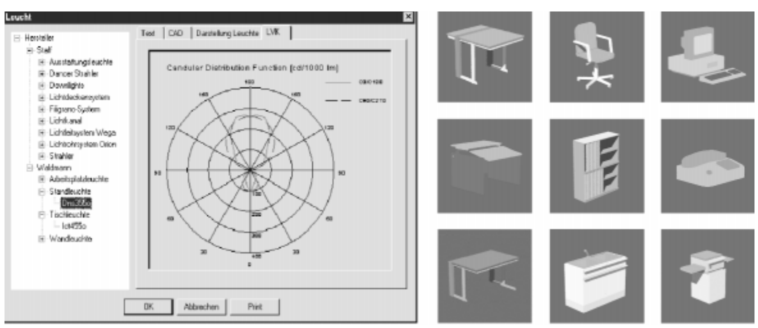


Figure 6-8: Examples from the luminaire and furniture database

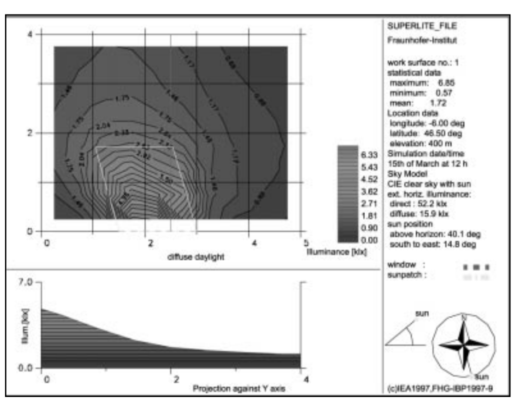
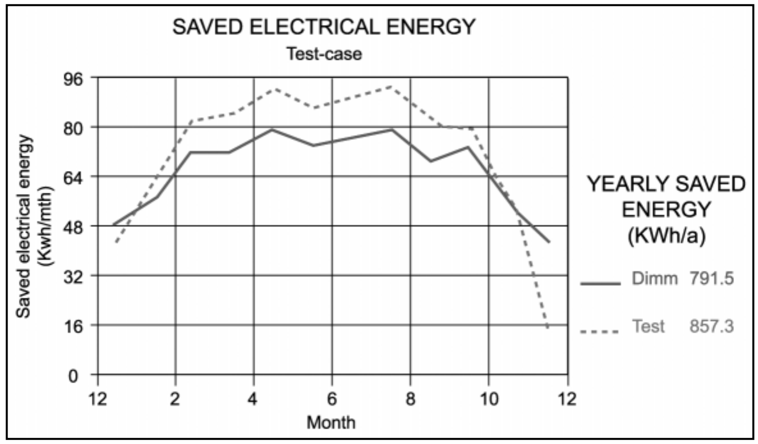


Figure 6-9: Iso-contour line representation of illuminances in a working plan

Figure 6-10:

Annual electrical energy saved as a function of different daylight-dependent artificial lighting control strategies results calculated with SUPERLINK



6.3.4. Simple Computer-Based Calculation Tools

From a user's point of view, the main differences between the advanced computer tools described above and simple computer-based tools are that the latter allow less freedom in the complexity and detail of input, and the results are less accurate. Most simple tools can only handle shoe-box type room geometry, and many permit daylight apertures in only one wall. Input for these programmes may, however, be very easy.

Simple computer-based design tools can only handle calculations for diffuse skylight, CIE or uniform luminance distribution or both. The algorithms commonly used for direct sky and external reflected components are based on the solid angle formulas derived from double integrals [Hopkinson et al. 1966]. Some tools have "computerised" simple manual tools, such as BRS protractors, Waldram diagrams, or other diagrams or tables. For the internal reflected component, these tools will often rely on the BRS split flux or other applications of the integrating sphere theory, sometimes with some sophisticated corrections added.

These programmes can produce highly accurate direct and external reflected component calculations given that the cases to be analysed have very simple geometry. Serious inaccuracies may, however, result in calculation of the internal reflected component. In the critical dark deep zones of a room, this component is a major contributor to the daylight factor. Thus, simple calculation tools have problems with accuracy in this zone.

Although computer design tools can play a substantial role in daylighting design, most are more appropriate for analysis of daylighting performance. An accurate physical description is often required for the device to be analysed (e.g., for ray-tracing simulation) at stages where designers usually need suggestions for appropriate architectural and technical solutions.

To overcome this problem and provide users with optimal support during different design phases, daylighting decision tools were developed based on the theory of information [Paule et al. 1995]. Fuzzy logic was used to offer the possibility of characterising room geometry and photometric properties through linguistic values (fuzzy subsets) (Figure 6-11).

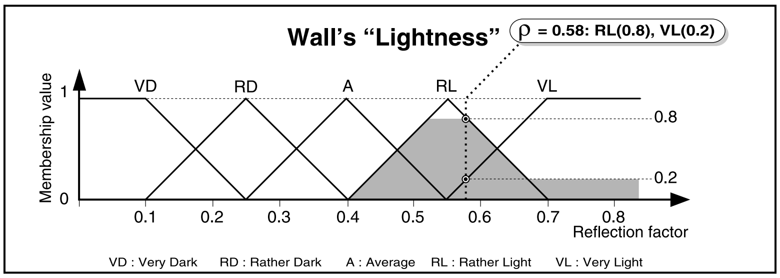


Figure 6-11: Fuzzy characterisation of the brightness of walls using fuzzy subsets

The international version of the program LESODIAL, which was developed as part of IEA Task 21, uses this novel approach. Based on fuzzy logic, this daylighting decision tool, described in Figure 6-12, has the following features:

- it takes into account imprecise parameters, expressed in vague terms, during architectural pre-design phases;
- it facilitates problem description through graphical and linguistic expressions;
- it uses fuzzy inference rules to give daylighting diagnosis and recommendations for a design;
- it compares and outranks architectural reference objects by means of fuzzy outranking relations from a building database.

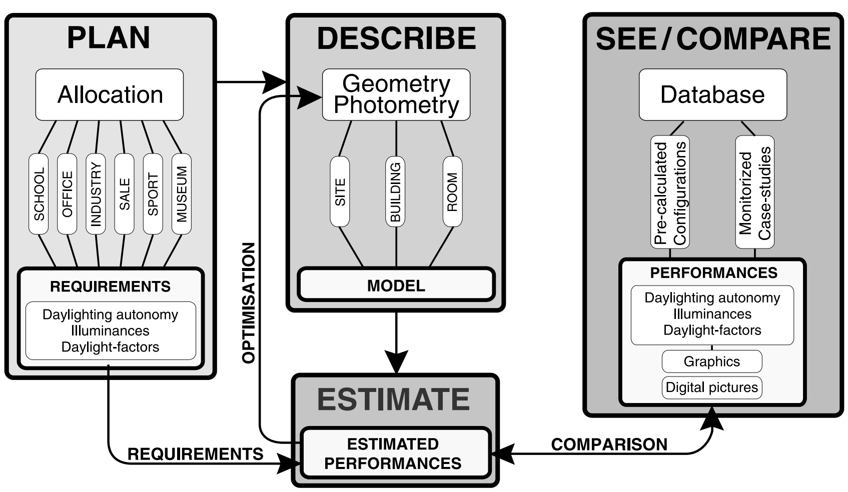


Figure 6-12: Flow chart of a daylighting decision tool based on fuzzy logic

In addition, the programme calculates daylight factors and the percentage of the year when daylight is sufficient by means of an analytical (BRE split-flux) method and statistical climate data. Diagnosis and recommendations to improve the daylighting design are provided in the form of graphics and verbal comments. A vocabulary of lighting terminology helps designers to use the programme with very little tutoring.

6.4. Physical Models

Scale models of buildings are used all over the world for daylighting design. The main advantages and interest of this approach compared to other design methods are that:

- architects use scale models as design tools to study various aspects of building design and construction;
- it is a "soft technology," well known to and shared by architects and other building professionals;
- when properly constructed, scale models portray the distribution of daylight within the model room almost as exactly as in a full-size room.

All these features are a result of the extremely small size of light wavelengths (380–780 nanometers). Thus, the physical behaviour of light is absolutely the same for a 1 m^2 area in a full-size room as it is for the corresponding 4 cm^2 area of a 1:50 scale model. In other words, even the smallest of scale models can produce very accurate results.

Construction of a model must be preceded by choice of an appropriate scale, which is directly related to the model's particular purpose. Scales ranging from 1:500 to 1:1 can be considered, as shown by the different activities undertaken as part of IEA Task 21. Table 6-3 summarises the possible scale choices.

Table 6-3: Scale choice as a function of daylighting design purpose

Scale	Objectives
1: 200 - 1 : 500	for preliminary design and concept development to provide a gross sense of the massing of the project to study the shadow created by the future building or from a neighbouring building
1 : 200 - 1 : 50	to study direct sunlight penetration into a building (e.g., efficiency of solar protection) to study diffuse daylight in a very big space (e.g., an atrium)
1 : 100 - 1 : 10	to consider detailed refinement of spatial components to have highly detailed inside views (e.g., video or photos) to study accurately diffuse and direct daylight penetration
1 : 10 - 1 : 1	to integrate critical industrial components to consider daylighting devices that cannot be reduced in scale to proceed to final evaluation of advanced daylighting systems through monitoring and user assessment

Common rules must be applied, however, in the construction of any model, whatever its scale. The principal rules are:

Materials

- the walls of the model must be absolutely opaque, and all the joints must be light proof;

- model parts must be movable or replaceable to facilitate comparison of configurations and allow for the placement of sensors and cables;
- Optical properties of internal (walls, ceiling, and floor) and external surfaces must be as close as possible to those of the planned building;
- model glazing materials, i.e., thin sheets of glass or clear plastic, should be used in apertures if the angle of incidence transmissivity of glass is expected to be important for the distribution of daylight in the internal spaces;
- geometry and sizes must be as accurate as necessary to permit consideration of the design questions.

Other Criteria

- the overall dimensions and weight of the model must be such that it can be supported (e.g., on a heliodon) or moved (e.g., movable mock-up rooms);
- the size of the model must be reasonable with regard to the distance to light sources (e.g., 0.6 m in height for a 5-m-diameter sky dome);
- the fixing of the model parts should be strong enough to allow different movements (e.g., mock-up rooms) and even vertical positions (e.g., heliodon);
- access to the model's interior, through apertures or removable parts, must be possible for placing illuminance sensors or imaging devices.

Because of the difficulty in meeting all these requirements, physical modeling generally achieves relative rather than absolute results. The search for relative improvements in performance is thus a more appropriate goal than attempting to obtain accurate quantitative measurements.

These difficulties are even more important when models are placed under real sky conditions and not under sky or sun simulators, for example, in the case of on-site performance assessment and for mock-up room measurements, which depend upon the sky luminance distribution at the site. The use of a reference facade in conjunction with the facade is necessary to overcome this difficulty and produce a relative performance assessment. Indoor and outdoor testing situations will be considered in the following sections.

6.4.1. Sky Simulators

Sky simulators have been used for decades in daylighting design studies. Their main advantage is that they offer reliable and reproducible conditions that simulate daylighting under real skies. To allow comparisons among daylighting design studies carried out on different simulators, normalised sky luminance distributions (so-called "standard skies") are used. Table 6-4 gives an overview of the principal sky simulator configurations.

Table 6-4: Principle sky simulator configurations

Designation	Characteristics	Advantages	Disadvantages
Mirror sky	Most common configuration; mirror enclosure with a lighting ceiling (fluorescent tubes and opal diffuser)	• moderate cost • minimised horizon error	• only CIE overcast sky reproduced • inter-reflection disturbed by the scale model
Sky dome	Diameter between 3 and 9 m; made of white opaque hemisphere illuminated by light sources in a circular groove	• reproduction of different standard sky models (uniform sky overcast or clear CIE sky) possible • very easy scale model access	• hard and tiresome calibration (requires about 1 week) • high electric consumption and frequent maintenance problems
Spotlight sky simulator	Vault made of a multitude of incandescent lamps	• all types of sky reproducible	• calibration and maintenance complicated by different aging patterns of sources • high luminance discontinuity
	Line of 30 lamps mounted in a quarter-circle arc	• all types of sky reproducible • moderate cost	• model cannot be viewed under simulated daylight • slow measurement procedure
Scanning sky simulator	A sixth of the vault is constructed with 25 lamps. The whole hemisphere, based on Tregenza's model of 145 light zones, is rebuilt by a six-step scan. Quantitative (illuminance) and qualitative data (video digitised image) are added at the end of the process.	• a close match to the sky luminance measuring format (IDMP) • can reproduce all existing standard or statistical sky models • can achieve low construction, maintenance, and operation costs	• it is impossible to visualise or to measure instantaneously inside the model

Some proposed new sky simulator configurations are based on a scanning process [Tregenza 1989, Michel et al. 1995]. Of these, one uses a scanning process to rebuild the overall sky hemisphere, starting with a sixth of a hemisphere. This novel apparatus, shown in Figure 6-13, was used in IEA Task 21. Its numerous advantages are summarised in Table 6-4.

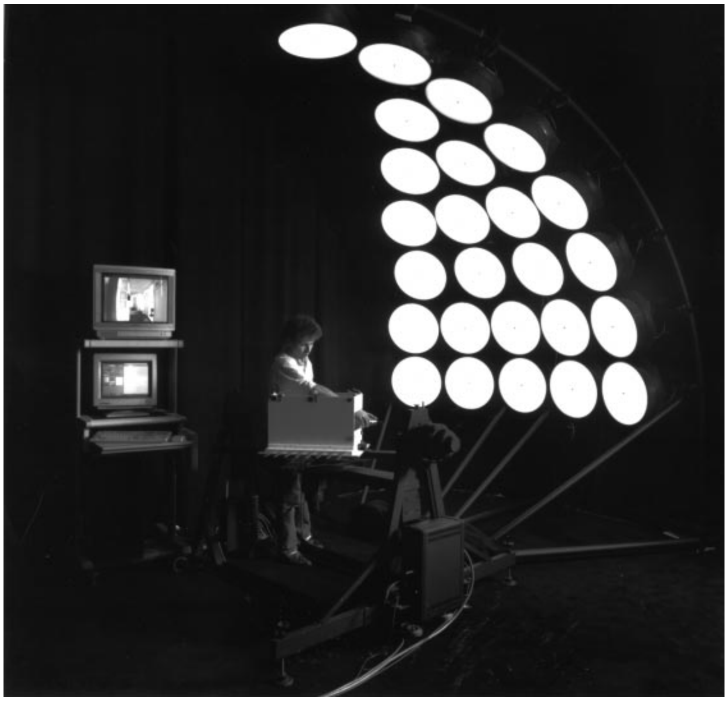


Figure 6-13: View of the EPFL scanning sky simulator (Switzerland), above, and the BRE mirror sky (UK), below

The novel principle on which the scanning sky simulator is based allows accurate reproduction of the luminance distributions of every type of sky. Some of these distributions, standardised by the CIE recommendations, are described by analytical functions. These distributions are used in daylighting studies and, although theoretical, have the important advantage of allowing comparison of results internationally. The main "standard skies" that can be reproduced on the simulator are:

- isotropic (uniform) sky
- CIE overcast sky
- CIE clear sky
- CIE intermediate sky

It is possible to reproduce statistical skies in addition to the different standard skies. Illuminance and luminance distributions of real sky measurements have been made available through the International Daylight Measuring Program (IDMP). The processing of these data allows the development of statistical skies that are representative of the daylight in a particular area. Monthly average skies as well as dynamic daily skies can be reproduced this way.

6.4.2. Full-Scale Test Rooms

Many quantitative daylighting design parameters can be assessed and optimised using scale models and simulators. Daylighting projects, however, have not only quantitative objectives (providing light, saving energy, etc.), but also qualitative requirements (perception of space, visual comfort, etc.). Some of these qualitative requirements can be formally expressed using structured, available scientific knowledge, including:

- perception and visual adaptation (ergo-ophthalmology)
- visual comfort and performance (visual ergonomy)
- light propagation, transmission, and reflection (photometry)

Several "occupancy-dependent" criteria and figures, which can be measured by appropriate physical instruments, can be outlined, which will lead to a relatively objective assessment of the human response to the luminous environment. Table 6-5 summarises the principal quantifiable figures that depend on occupants.

Table 6-5: Principle quantifiable criteria that depend on occupants

Objectives	Associated quantifiable figures
Visual performance	Illuminance (on working surface) Contrast object / background Object size
Visual comfort	Luminance contrast (task / background) Illuminance uniformity Colour temperature

Most of these quantifiable figures cannot, unfortunately, be assessed or measured in scale models because neither the occupants nor some objects that make up the luminous environment can be reduced in size (documents, view out, etc.). Full-scale test rooms in outdoor conditions must be used (see Appendix 8.4).

Because lighting conditions depend on the variable luminance distribution of the sky vault, two modules must generally be constructed:

- one is used as a reference room and equipped with a conventional facade (double glazing);
- the second is used as a test room and features novel daylighting systems.

A designer can optimise a daylighting system and room configuration using the assessment data. Most of the information gained by this procedure can be used to increase user acceptance of the designed system in the real building.

Conclusion 6.5.

Design tools play a significant role in the decision-making process that characterises daylighting design in a building project. These tools support designers through the sequence of decisions that leads from original daylighting concepts to their final implementation in a building.

To be efficient and accepted by practitioners, design tools must fit the most significant phases of the architectural projects where crucial decisions regarding daylighting strategies are made. These tools might even propose appropriate options.

Different types of daylighting design tools are available today for practitioners, providing qualitative and quantitative information. These tools include:

- simple tools, which are most appropriate for early design phases and are best suited for basic design problems;
- computer-based tools, which can handle advanced daylighting systems and provide a vast variety of output (images, visual comfort calculations, etc.);
- physical models, which are well-known and shared by architects and other building professionals.

No design tool will ever replace designers themselves, who must make the choices involved in the daylighting design of a building. However, these tools can accompany the designer in a creative process of devising an enjoyable and productive built environment while saving energy through the use of daylighting.