A REVIEW OF METHODS FOR THE EVALUATION OF THE ENERGY CONTRIBUTION OF DAYLIGHT IN BUILDINGS

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EXECUTIVE SUMMARY

A review has been undertaken of energy prediction methods and daylight calculation methods currently in use in the UK. This was based on a literature review and discussions with large engineering practices and academics involved in the areas of daylighting and energy simulation research.

The aim of this review was to identify manual methods or computer programs that are capable of determining energy use in non-domestic buildings and of taking into account the energy savings resulting from daylighting.

One potential application for these methods is in supporting anticipated energy targets for non-domestic buildings within Building Regulations and other energy labelling schemes.

The review has identified a range of methods which are capable of predicting overall energy use while accounting for daylight. These vary in complexity from empirical methods such as ESICHECK and the CIBSE Energy Code through to dynamic energy simulation models such as DOE 2 and ESP.

For each of the methods identified a brief assessment has been made of their technical capabilities, ease of use and availability. These assessments have been based on discussions with users and program developers. Descriptions of the various methods are given in sections 6,7,8 and 9 and summary tables are included as Appendix 1.

The suitability of the models identified, depends upon the application to which they are to be put. Simple buildings with simple glazing and shading strategies can be assessed using simple models. Where special attention is being paid to daylight design, for example with the use of light shelves and complex shading strategies, a more complex and hence costly assessment may be justified.

Without knowing the exact form that Building Regulations energy targets will take, no attempt has been made to rank the suitability of the methods. However, the potential advantages and disadvantages of each method are discussed.

The possible directions that Building Regulations energy targets might take are discussed in section 3 along with the implications these would have for assessment methods.

Ease of use is an essential consideration for energy models and future developments need to focus on methods which will be easy to use and hence attractive to design teams. Those which are complex or which do not have user friendly front ends, are unlikely to be adopted on a wide scale, however, this does not mean they do not have a role.

Much of the building energy analysis undertaken at present is done by academics and consultants who, by specialising in this area, are able draw on the full potential of complex methods to inform the design process. It may be unreasonable to expect architects and engineers to take on this role.

1.0 INTRODUCTION

1.1 BACKGROUND

Under the European Directive 93/76/EEC[1] member states are required to draw up and implement programmes on the energy certification of buildings. The certification process is intended to consist of a description of building energy characteristics and must provide information for users on a building's energy efficiency. While the Government's Standard Assessment Procedure (SAP) has been introduced and endorsed for dwellings there is no similar method for non-domestic buildings.

Approved Document L of the Building Regulations provides an Energy Use method for demonstrating compliance for non-domestic buildings. The Energy Use Method is a calculation method that takes account of useful solar gains and internal gains. The requirement of the regulations is met if the calculated energy use of the proposed building is less than the calculated annual energy use of a similar building designed to comply with the Elemental Method. This approach appears to cover space heating only and no account is taken of the energy contribution of daylight which can displace the energy used for artificial lighting.
The present daylight contribution to UK energy demand has been estimated to be 143 PJ per year which amounts to 27% of the passive solar contribution to UK building energy requirements.

In November 1993 a consultation document was issued as part of the revision process for the non-domestic section of Part L of the Building Regulations. A number of approaches were suggested which included the possibility of setting an overall target for the predicted carbon dioxide emissions from buildings. This target would cover all aspects of energy use including: space heating; hot water; fans; refrigeration and lighting. A similar option is likely to be included in the latest round of consultation which was due to be published in early 1996.

In order for such a target to be implemented, an agreed method must be available for predicting overall energy use and hence carbon dioxide emissions. It is important that this method takes account of the contribution that daylight can make in offsetting energy use for artificial lighting.

For these reasons ETSU commissioned ECD Energy & Environment Ltd to undertake a review of energy prediction methods which can take account of energy savings resulting from daylighting. Additional input has been provided by Cambridge Architectural Research, drawing on experience gained as part of an earlier review of daylight calculation procedures[2].

1.2 OBJECTIVES

The main objectives of this study were:

- To review the available energy computational methods to identify those which give due weight to daylight in terms of displaced energy use for artificial lighting.
- To assess the convenience and use of these methods and to establish whether they could be used in support of Building Regulations energy use targets.

1.3 METHODOLOGY

An initial review was undertaken to identify the main building energy prediction methods currently in use for non-domestic buildings in the UK. This was based on a literature review and telephone discussions with consultants, engineering practices and academics involved in the areas of daylighting and energy simulation research. A list of those people who provided information is included in section 13.

Those responsible for developing the methods identified, were asked to confirm whether the method was capable of predicting energy contributions from daylighting. Where it was, the developers were asked to provide further details relating to the following aspects:

- the technical capabilities of the method
- the cost, availability and ease of use of the method
- its reliability and reputation

A set of questions was drawn up to act as a prompt in these discussions and this is included as Appendix 2. Information was also obtained from user manuals and other published literature and references are given to these sources.

A shortlist was prepared of the most promising methods and these are the subject of this report. Detailed descriptions of the methods identified are provided in sections 6, 7, 8 and 9 and summary tables allowing comparison of the methods are provided in Appendix 1.

1.4 SCOPE

Worldwide there are numerous methods for predicting energy use and daylighting and these are constantly being modified, updated and improved.

This review has focused on computer based energy prediction methods currently in use in the UK. Some of these have been developed elsewhere in Europe and in the United States.

While there are many programs available for predicting overall energy demand in buildings, only those which can currently assess the energy contribution of daylight have been included in this study.

A number of the program developers mentioned that while they did not take account of daylight at present, they were in the process of developing daylighting modules. Where these were of particular relevance to this study they have been described in section 9.

The methods examined fall into the following categories:

- Dynamic energy simulation programs
- Simple energy prediction methods based on empirical algorithms
- Methods for predicting daylight factors and internal illuminance levels

While there are numerous methods available which fall into this last category, these are not the main focus of this study as they do not predict overall energy use. For this reason only a small sample of those which are in wide use or which have been specifically linked to energy simulation programs have been included.

The review has been based on discussions with model developers and on published literature, no copies of the models investigated were obtained and this review is not based on hands on experience of using the models.

While we have consulted widely to identify suitable methods, it may be that there are other methods currently in use in the UK that have been missed.

2.0 REQUIREMENTS FOR DAYLIGHTING ENERGY PREDICTION METHODS

This section discusses the issues that need to be considered when assessing the different methodologies.

2.1 ESSENTIAL REQUIREMENTS

A calculation method is required which takes account of energy use for lighting, while at the same time considering heat gains and losses from windows and luminaires. If for example a model only considers the energy use for lighting, it would give the false impression that the optimum solution is 100% glazing.

The method must therefore provide a breakdown of heating, cooling and lighting energy use, to allow the effect on overall energy demand to be assessed. These should ideally be assessed in terms of primary energy or CO_2 emissions rather than kWh delivered. If delivered energy is used as the measurement it ignores the energy lost in converting fossil fuels into electricity, thus underestimating the contribution of daylight. For example with the current mix of fuel generation in the UK, a KWh of electricity delivered to the building, will result in three times the CO_2 emission of a similar unit of gas.

A further requirement of the method is to ensure that where no artificial cooling is to be provided, the building is capable of maintaining acceptable comfort conditions. The optimum daylighting energy solution might result in a building which overheats and is thus unacceptable to its occupants. Comfort analysis is therefore an important part of any model.

If the method is to be used to predict an overall energy demand target, the method would also need to have the capability to model the energy requirements of different air-conditioning systems and other end uses of energy.

These are the most important requirements for the models described in this report, however, there are other desirable requirements which can be covered broadly by the following headings:

- Technical capabilities
- Ease of use
- Availability and reputation

2.2 TECHNICAL CAPABILITIES

Where the design team are committed to providing a well daylit building, and to demonstrating the energy savings this will achieve, the model will need to have the capability to accurately model a wide range of glazing and shading options.

An earlier survey of the use of daylight prediction methods undertaken by BRE for ETSU[3], asked respondents to list features they felt were important to include in daylighting prediction methods, these included the following technical capabilities:

- ability to model complex, non-rectangular rooms
- ability to model sunlight or real sky conditions in addition to overcast skies
- ability to model complex obstructions (both internal and external)
- ability to model complex shading systems such as light shelves
- ability to model sloped as well as vertical glazing
- plots of illuminance values and 3D isolux diagrams
- visualisation of interiors

2.3 EASE OF USE

The same BRE survey[3] also listed ease of use as being high on respondents agenda.

The main factor affecting ease of use is the "front end" or user "interface". At the worst end of the spectrum data may be input in the form of numeric values on a line editor. This is the system currently used for the SeriRes PC program described in section 6.4. When using this system it is difficult to identify errors in the data input. It is also difficult for the novice to learn their way into the program.

Windows systems with pull down menus are becoming increasingly popular and help to improve ease of data input.

The front end is further improved where a visual representation of the data entry is provided. This makes it easy to identify errors, for example where walls or floors have been missed out or where they do not properly align. This is a feature of the PowerDOE model discussed in section 6.2. This approach is likely to prove popular with designers who are used to visualising problems in graphic form.

Perhaps the most desirable solution is where the program has a direct link to a CAD package, allowing the architect or engineer to import data which is already required as part of the normal design process. This is a feature of a number of the methods and which is being developed as part of the ADELINE program described in section 9.1.

The other factor affecting ease of use is the number of data entries that are required. Simple models such as ESICHECK are very easy to use, as the program makes assumptions on the efficiency of whole building services systems, these being chosen from a menu. In thermodynamic models the characteristics of an air-conditioning system may need to be built up from its component parts. The more data entries required, the greater the risk of error.

PowerDOE and Energy 10 (see sections 6.2 and 9.2) seek to address this problem by building in default values for much of the data input. The user can decide whether they wish to use the default values or to input their own specific information.

Another aspect of ease of use is the form in which the output is presented. It is helpful to be able to plot graphs and tables of key information, rather than simply being presented with a long list of numbers.

The level of training is also a factor. This is linked to the technical capabilities of the program and how user friendly the front end is.

2.4 AVAILABILITY AND REPUTATION

In order for a model to become widely used and hence accepted by the industry it needs to be available at low cost to anyone who is interested in using it. The methods identified in this report vary in cost from hundreds to thousands of pounds. This issue would be particularly important if the use of a method became compulsory under Building Regulations, if energy targets are suggested as an alternative method of demonstrating compliance, it is less significant.

A further factor affecting cost and availability is the platform on which the program will run. For example ESP requires a UNIX workstation, which would be a costly acquisition for organisations who do not already have one. At the other end of the scale versions of DOE 2.1 are available on all commonly used platforms including MS DOS, Apple Mac and Windows and could thus be loaded onto a companies existing systems.

The reputation of a program is likely to be influenced by a number of factors including: the length of time it has been available; the number and type of users; the credibility of the organisation that developed it and the results of technical validation.

Most validation studies such as the IEA Task 12 Annex21 and BEST Test , have focused on the thermal characteristics of energy simulation models, however, some validation of daylight models has recently been undertaken by BRE[4] and De Montfort University[5,6].

3.0 POTENTIAL ENERGY PERFORMANCE TARGETS FOR BUILDING REGULATIONS

In assessing the methods identified, consideration must be given to the applications to which they might be put. For example if the use of the program is to be voluntary the cost of the program is less sensitive, than if the use of the program is compulsory.

One of the key objectives in undertaking this study was to review daylighting energy prediction methods suitable for supporting overall energy targets for building regulations. While the exact form of these targets is currently unknown, this section sets out the main possibilities being considered.

An earlier review of energy targeting methodologies undertaken by ECD for BRE[7], revealed that there are two main approaches for setting targets against which a building's overall energy performance can be compared.

- Comparison against a benchmark
- Comparison against a reference building

Each of these has its own benefits and disadvantages and both have been considered for use in UK building regulations.

3.1 COMPARISON AGAINST A BENCHMARK

The BREEAM[25] scheme in the UK and a number of proposed methodologies for predicting overall energy consumption in European countries, use a benchmarking approach.

The building's energy use is calculated using a standard procedure or computer model and compared against a published benchmark figure or target.

In November 1993 a consultation document was issued as part of the revision process for the non-domestic section of Part L of the Building Regulations. A number of approaches were suggested which included the possibility of setting an overall target for the predicted carbon dioxide emissions from the building.

In order to comply design teams would have needed to present calculations in accordance with the calculation procedure for CO_2 emissions given in the BRE report BREEAM 1/93[25], and to demonstrate that the predicted emissions would not exceed 80kg/m^2/year of carbon dioxide. This method would have required the use of the ESICHECK program described in section 7.2.

Having consulted with BRE it appears that this approach has not been ruled out and is likely to be included in the next round of consultations. As well as the BREEAM calculation procedure, the forthcoming CIBSE 2c method is also being considered (see section 7.1).
In the Netherlands building regulations are based on a numerical Energy Performance Coefficient. This is based on the calculated total primary energy use for heating, fans, pumps, lighting, comfort cooling, humidification and the production of domestic hot water[8]. The calculation method is based on the NPR 2917 model described in section 7.4.

3.1.1 Advantages of Benchmarks

Using a benchmark method, where the method of calculation is the same in all cases, allows meaningful comparison between one building and another, this is essential in order to develop a non-domestic energy label.

By building default values into the calculation procedure, the method is less open to input error or deliberate attempts to mislead a building control officer.

3.1.2 Disadvantages of Benchmarks

Where a benchmark is being used for energy targeting, a standard set of assumptions must be agreed and defined to cover occupancy factors, such as equipment loads, hours of use, occupancy density etc. A single agreed and well documented model is also required to compare a building's performance against the target. This must be freely available and not entail the user in excessive cost.

Difficulties may arise in dealing with differing daylight availability in different parts of the country.

A range of benchmark figures must be developed to cover the various building types to which the targeting method is to apply. This may require the collection of considerable monitored data or the use of computer simulation models to predict energy consumption figures over a range of building types. An agreed method of building classification is also required.

3.2 COMPARISON AGAINST A REFERENCE BUILDING

The ASHRAE 90.1[9] standard sets out a Building Energy Cost Budget Method, where energy running costs for the building design are compared to a prototype or reference building. The prototype building is essentially a building of a similar size to the design building which complies with the prescriptive and sub-system performance standards set out elsewhere in the ASHRAE 90.1 code. The sub-system performance standards cover, heat loss, lighting energy use, HVAC systems and hot water.

This is a similar approach to the less comprehensive Energy Use method described in section 2.17 of Part L of the current Building Regulations. Under the Energy Use method, the designers must demonstrate that "the calculated annual energy use of the proposed building is less than the calculated energy use of a similar building designed to comply with the Elemental method". As the elemental criteria currently apply to fabric heat loss measures only, such as U-values and glazing areas, this method only covers space heating.

For daylighting to be considered in such a method, lighting performance criteria would need to be included in the Elemental method. Possible criteria that might be considered include: minimum daylight factors to be achieved; maximum requirements for installed power load in $W/m^2/100$ lux; maximum room depths or requirements for optimum glazing areas dependent on orientation and expected internal gains.

3.2.1 Advantages of the Reference Building Method

Comparison against a reference building does not rely on a single method for calculating performance. A range of existing programs may be used provided that both the design and reference building are modelled using the same method. This allows the design team or their consultants to select simple models for simple buildings or more complex models to deal with innovative daylighting design solutions.

The performance of the reference building must be defined using prescriptive or sub-system targets, this makes it suitable as an alternative method of compliance, where these prescriptive standards are also being proposed. Sub-system performance targets are useful in themselves for arriving at an energy efficient solution.

Assumptions about occupancy may be varied, provided that both the reference building and design use the same values.

No absolute target figures are required and thus the cost of researching target figures is avoided.

3.2.2 Disadvantages of the Reference Building Method

Where different models and different assumptions have been used, it may not be possible to compare the performance of one building against another, and this may be seen as failing the objectives of the EC 93/76/EEC directive on energy labelling[1] .

When looking at the predicted performance of a building, it may not be clear what assumptions have been used, where they have been allowed to vary.

4.0 ACCOUNTING FOR DAYLIGHT CONTRIBUTION IN ENERGY MODELS

4.1 INTRODUCTION

In order to calculate the energy contribution from daylighting the following steps should ideally be followed:

- Determine the interior illuminance levels at a chosen location based on: the geometry of the room; its glazing and shading characteristics; internal and external obstructions and the assumed external illuminance of the sky (based on either CIE standard overcast sky, average sky data or real or measured sky data)

- Describe the switching criteria for the lighting in the chosen location for example manual switching, continuous dimming linked to a photosensor, stepped switch off in response to a photosensor, etc.

- Set the target illuminance level for the chosen location, for example 300 lux at the working plane, or at a photoelectric control sensor.

- Describe the characteristics of the proposed artificial lighting system, for example the installed circuit load (W/m^2), the lamp efficacy (lumens/W), task or uniform lighting, etc.

- Use this information to decide for a given time period whether the light will be on, off or dimmed and calculate the lighting power consumption over the time period and the heat gains to the space.

- Calculate the overall energy demand for the lighting circuit, heating and refrigeration.

A simplified approach is to use empirical data to relate overall energy use to a number of key parameters such as glazing area, room depth, daylight factor or effectiveness of controls and installed power load. This is the approach adopted in ESICHECK, the CIBSE Energy Code Part 2c and the Dutch NPR 2917 method.

A similar approach is that used in the LT method, where dynamic energy analysis has been used to relate overall energy use for space heating, cooling and lighting, to key parameters such as glazing area, orientation, and internal gains.

4.2 DETERMINING INTERIOR ILLUMINANCE LEVELS

There are a number of ways to determine interior illuminance levels each with their own key characteristics. These can be summed up by two generic approaches:

- Daylight Factor / CIE Overcast Sky
- Dynamic Daylight Illuminance

4.2.1 Daylight Factor / CIE Overcast Sky

Most of the methods examined use the well-established technique of daylight factor calculations. The daylight factor being the ratio of the illuminance level at a point indoors (usually the working plane or the sensor of a lighting control system) to the external illuminance level. Some methods contain an integral module for determining daylight factors, in others these must be calculated separately and entered as part of the input data.

External illuminance data is usually based on the CIE standard or uniform overcast sky which takes account of diffuse radiation only. No consideration is given to the direct beam or sunny component. In some cases this data is adjusted according to orientation to allow for brighter conditions in the southern sky.

As overcast conditions are predominant in the UK this is a reasonable approximation. Previous work has shown[10] that where rooms are well daylit the fraction of the time that daylight provides sufficient illumination is relatively insensitive to the inclusion or exclusion of direct beam radiation in the calculation.

In climates which have a significantly lower incidence of overcast skies the daylight factor method is unsuitable for designing or evaluating daylighting, and other techniques must be adopted.

Daylight factors are usually calculated using the methods published by BRE. The sky component and externally reflected component are usually calculated using the methods described in BRE digest 309[11], while the internally reflected component is commonly determined using Hopkinson's split flux method as described in BRE digest 310[12].

In general models based on this method are not good at dealing with complex shading systems in particular those with a strongly reflective component such as light shelves or Venetian blinds.

Shading devices are normerly taken into account by applying an adjustment factor to the transmission value for the window, this is acceptable for diffuse shading devices such as roll down cloth blinds but is not good at representing directional devices, such as louvres, light shelves and horizontal Venetian blinds.

4.2.2 Dynamic Daylight Illuminance

This provides a more detailed approach. As well as the standard CIE overcast sky, these methods can use average data for clear skies and direct sunlight and may also model real skies using measured data.

They also allow more complex room shapes, obstructions, glazing types and shading strategies to be modelled.

Internal illuminance levels may be determined on an hourly basis or on a smaller time step and this data used as input to dynamic simulation programs.

Two main approaches have been identified in this review:

- Radiosity Algorithms
- Backward Ray Tracing

Radiosity Algorithms

These are based on the Monte Carlo method and finite integration method for sky component calculation and recursive iteration method for reflective component calculation. This is the method used by the SUPERLITE program discussed in section 8.4. This method is only suitable for rooms with large diffuse surfaces rather than many specular surfaces.

Backward Ray Tracing

This method can be used to provide extremely accurate assessment of internal illuminance levels allowing visual rendering of a space.

The calculation requires a description of the 3-dimensional surface geometry, materials, and light sources in the room or scene. In order to produce visual images the view point, direction and angle of view must also be specified.

The method used in RADIANCE (see section 8.3) uses a hybrid approach of Monte Carlo and deterministic ray tracing to achieve a sufficiently accurate result in a reasonable time. The method starts by establishing a measurement point, this might either be a view or the sensor of a lighting control system. The method traces rays of light backwards to their source, ie artificial lighting or glazing. The calculation is divided into three main components.

- the direct component
- the specular indirect component
- the diffuse indirect component

The direct component consists of light arriving at a surface directly from a light source or via one or more perfectly specular transfers from other surfaces.

The specular indirect component consists of light arriving at a surface from other surfaces and being reflected off or transmitted through in a directional manner. Perfectly specular surfaces are handled by simply redirecting the ray in the appropriate transmitted or reflected direction. Rough specular transfers are modelled with Monte Carlo sampling of the reflected and/or transmitted direction.

The diffuse indirect component consists of light arriving at a surface and being reflected or transmitted with no directional preference. The nature of this component requires that hundreds of directions be examined in order to make a reasonable Monte Carlo estimate. As the diffuse indirect component changes slowly over surfaces, a few values are calculated at reasonably spaced intervals and interpolated at the points in between.

The user is able to define the number of reflections or "ambient bounces" that are considered in the calculation. The more bounces the longer the calculation but the greater the accuracy.

Raytracing calculations allow more accurate prediction of internal illuminance levels and can take account of diffuse as well as sunny conditions.

The more accurate/complex a model becomes the greater the predicted contribution of daylighting. This is because simple daylight models do not adequately account for the repeated surface reflections within a space. If for example a model is required to assess the daylight contribution of a deep atrium to offices on the ground floor, RADIANCE would predict higher daylight levels than a simple daylight factor model such as DAYLIGHT (see section 8.1).

4.3 ASSESSMENT OF SWITCHING STRATEGIES

However accurate the prediction of internal illuminance may be, the greatest factor affecting the predicted energy contribution, is the assumptions made regarding switching.

Having determined the internal illuminance level at a given time step, a method is required to determine whether the lights are likely to be switched on, off, or dimmed in response to the daylight available and to determine what effect this has on the power consumed by the lighting circuit. There are a number of published papers relating to this subject [13,14].

Most of the methods reviewed in section 6 allow the following switching arrangements to be modelled:

- Preset manual switching schedules based on hours of occupancy. These take no account of daylight.
- Manual switching methods, linked to the probability of the lights being switched on or off for a given daylight level.
- Ideal dimming systems where the lights are automatically dimmed directly in proportion to the illuminance level measured at a sensor (either internal or external)
- Stepped dimming systems, where a proportion of the lights are switched off when daylight levels exceed a preset level or are switched on when they drop below a separately defined level. The illuminance levels must be determined at the position of the photosensor control.

By specifying one of these assumptions dynamic models are able to decide at the start of a time step whether the lighting system will be switched on or off and hence what the power consumption for lighting will be for that hour. They can also predict what the heat gains will be to the space and hence the cooling demand on hot days.

The accuracy with which switching arrangements can be modelled is dependent on the number of switching zones that can be specified. For example some models will only allow a single switching strategy to be specified for a room, while others will allow the room to be divided into zones. This latter arrangement is for example useful when a bank of perimeter lights are to be controlled separately from those at the core.

The power savings relating to dimmed switching assumptions are relatively simple to calculate, however, a correlation needs to be made between the degree of dimming and its effect on the circuit load. For example dimming the light output from a fluorescent tube by 30% might only result in a power saving of 20% and algorithms are required to take this into account.

The greatest difficulty arises where assumptions must be made in relation to the occupants use of manual switching. APACHE, ESP and SERI RES all use assumptions based on Hunt's method[13]. Field studies of switching patterns undertaken by Hunt and others at BRE resulted in three conclusions:

- In each room usually all or none of the lighting was in use.
- On entering an empty room people would decide whether to switch the lights on . Once on the lights were rarely switched off until the room became completely empty again.
- The probability of people switching the lights on was most closely related to the minimum daylight illuminance on the working plane.

Hunt derived a series of curves[13] which related the minimum illuminance level in the room to the probability of someone switching on the lights at the start of the occupancy period. These probability assumptions can be used to determine whether lights will be on or off at each time step in a dynamic daylight analysis. Haves and Littlefair[10] have described how this method was adapted for use in the SERI-RES dynamic simulation model and Lynes and Littlefair[15] describe how it can be adapted to relate to average daylight factors.

As part of the review, one user of the SERI-RES program expressed concern that the Hunt method underestimated the energy use for lighting. Energy use was consistently lower using the Hunt method than it was using photo-electric dimming controls.

This may be because the Hunt method assumes people will work at much lower levels of daylighting than would be pre-set using an automatic system. The Hunt method is also unable to account for the number and location of switches.

A control mechanism which is increasingly common, is the use of occupancy sensors for example in meeting rooms, private offices, classrooms, sports halls etc. These are sometimes linked to photosensor dimming. Such systems do not appear to be adequately addressed at present in simulation models, and algorithms could be developed to link the probability of these being in their on or off or dimmed modes.

In a real lighting system the location and accuracy of light sensors will have a significant effect on the success of the system. Sensors need to be carefully located to avoid being obstructed by office activities. Commissioning and calibration will be important in ensuring the schemes success and making the best use of available light.

Most of the validation of lighting models, appears to relate to how well they predict illuminance levels. There appears to be little work on how accurately they predict overall lighting consumption in relation to observed manual and automatic switching patterns.

Validation of manual and automatic switching assumptions against measured data, might provide useful feedback on this issue.

5.0 THE METHODS REVIEWED

The programs reviewed each fall into one of the following categories:

a) Dynamic energy simulation programs which calculate daylight factors, illuminance levels, and determine the effect of daylighting on overall energy use.

b) Dynamic energy simulation programs which take account of the effect of daylighting on energy use, but which require daylight factors to be calculated by a separate method and entered as input.

c) Simple energy prediction methods based on empirical algorithms or predicted data, where adjustments are applied to the energy consumption for lighting, for example in relation to average daylight factors, room depth, type of lighting controls, etc.

d) Methods for calculating daylight factors and or illuminance levels alone with no energy calculation.

Methods falling into categories a) and b) are described in section 6, methods in category c) are described in section 7 and daylight calculation methods are described in section 8.

Summary tables to allow comparison between the methods are included in Appendix 1.

6.0 DYNAMIC ENERGY SIMULATION PROGRAMS

This section covers dynamic energy simulation models which are capable of predicting overall energy consumption for lighting, heating, and cooling and which also allow the energy contribution from daylighting to be considered.

6.1 APACHE

6.1.1 Description

The APACHE program has been developed by Oscar Faber Applied Research. The program has two functions: design and simulation. The design part aids in the design and sizing of services systems, while the simulation program allows the energy use of a given design to be predicted. The two programs can be used together or purchased and operated completely independently from one another. In this report we discuss the simulation program.

The simulation program is capable of assessing the effect of daylighting on overall energy consumption. It can also be used for predicting the likely comfort conditions.

The latest version of APACHE includes a daylighting module which was developed with assistance from Paul Ruyssevelt at HGa. It has been based on the method used in SERI RES[10] which HGa used for assessing the energy performance of non-domestic buildings under the Department of Trade & Industry's Passive Solar Programme.

The technical development of the program is being undertaken by Andrew Tindale at Oscar Faber Applied Research.

6.1.2 Calculation Procedure

Prediction of Illuminance Levels

APACHE uses the standard CIE overcast sky and average luminous efficacies to predict the exterior daylight from diffuse insolation. This is an acceptable method in the UK where the contribution from direct sunlight is small, but is not so satisfactory for sunnier climates.

The program predicts the interior illuminance level using a vertical illuminance method, which takes account of the beam, sky and ground reflected diffuse radiation. This is described in the program manual section A.4.6.2.1.

The user must input the standard CIE average daylight factor for the given zone. Facet have developed a separate daylighting program which will predict daylight factors and which can take account of unusual glazing types and shading systems.

Prediction of Lighting Energy Use

There are three control methods which can be modelled in APACHE:

- Continuous linear: where the target illuminance is met exactly by idealised modulation of light output.

- Stepped control: where illumination can be varied only in steps. This mimics the switching in and out of individual lamps or banks of lights. Each step has its own illuminance upper and lower set points and the control algorithm accounts for hysteresis in the lighting control.

- Manual Control: APACHE's manual control algorithm is based on the method developed by Hunt[13] to predict the behaviour of a typical set of occupants when faced with the decision as to whether or not to switch on lights. The lights can be switched off by a timer and each time the lights switch off, the control law decides the proportion of occupants that would switch the lights back on. The proportion is adjusted according to the number of manual switches available to occupants - the more switches, the greater the degree of local control.

Capabilities

APACHE describes different sections of a building as rooms, up to twenty rooms may be described for a single building. For each room five daylighting zones may be modelled. For each daylighting zone the following information can be provided:

- Proportion of room floor area
- Light type
- Lighting controller
- Maximum lighting output (W/m^2)
- The daylight factor for the zone
- The target illumination levels in the zone (lux).

The program can model rooms of different geometries by making approximations to rectangular rooms.

The program uses window data which is input as part of the standard construction build up, this includes information on glazing type, type of blinds/shutters, overhangs, reveals, etc. External obstructions can be dealt with in the main APACHE model.

The program can model sloped glazing. Internal windows can be modelled but only one layer of window between the inside and the outside is allowed.

Analysis of complex systems such as light shelves, would need to be accounted for as part of the daylight factor calculation, and the ability to do this would depend on the capability of the supporting daylight model chosen.

Program Output

The program will give a breakdown of energy use by fuel type. It will give a further breakdown by fuel and end use, for example lights, cooling, space heating etc.

It will also predict internal air and surface temperatures for the analysis of comfort conditions, including assessment of the proportion of hours that will exceed set point temperatures.

6.1.3 Availability and Use

Copyright for the programs is owned by the Oscar Faber Group Ltd. The program is under continuing development on a commercial basis, development being funded from sales and user support costs.

The program is available for sale to anyone. It can be obtained from Oscar Faber directly or from a number of agents working on Oscar Faber's behalf.

At present there are approximately 100 organisations using the program, some of which may be licensed for more than one terminal. The program is not used by architects, it is mainly used by consulting engineers and researchers. While the number of commercial users exceeds research organisations, the researchers use it more frequently.

The initial cost of the simulation program is approximately £3500. The application program to link it to a CAD system would cost a further £1200.

The program is designed for MS DOS and will run on a 386 PC, however, they recommend a 486 or better. A UNIX version is available and a Windows version is being developed for release in October 1996.

The program can be linked to both AutoCAD and MicroStation CAD packages. This requires the user of either the CAD or APACHE simulation program to buy an applications program which links the CAD system with APACHE. Oscar Faber produce an application program for the MicroStation package and a company called *Estimation* produce an application program for AutoCAD. The building description on the CAD system can be entered into the simulation program avoiding the need to re-enter the building's geometry.

Training

For an experienced user it would take around one or two days to fully input a typical office building and begin to obtain results. This process can be speeded up where it is linked to a CAD system.

Oscar Faber provide a two day training course for new program users. This would typically cost £800. User support is provided for an annual fee which includes program updates and free telephone support lines.

The program contains error messages which will point out when the entered values differ from the expected range.

Validation

The program formed part of the IEA Task 12 validation studies[16], where building simulation programs were used to predict internal conditions for a standard test cell in which measurements of actual conditions had been undertaken. The accuracy of the APACHE model was ranked highly on the list of models assessed, however, the IEA studies did not examine daylight.

The program is currently being examined as part of diagnostic tests being carried out by BRE under the BEST tests research program. This is being undertaken by Elizabeth Silver at BRE. The aims of the diagnostic tests are to determine bugs in the program and to test the effectiveness of the different component algorithms. The BEST test validation will not examine daylighting capabilities

The program can be used for any building type.

Future Development

Oscar Faber were asked whether there were any real barriers to making the APACHE model available at low cost to a very wide set of users. While clearly Oscar Faber would need to be compensated financially for their development costs and loss of future sales, this was not the biggest hurdle, the main concern was the need to provide user support for a model which does require a reasonable level of skill to operate. Users would need to be trained and there would need to be a support service. This would require considerable planning and resources.

One suggestion was the possibility that a separate Building Regulations version would be developed, which performed the same functions as APACHE but which had default values built in for certain parameters to reduce user input, thus improving ease of use and risk of user error.

When asked why they do not combine a daylight factor calculation module within the simulation tool, the main reason was the difficulties that arise from preserving backwards compatibility. It is important that users are able to run old data files on new updates. These problems can be overcome but they are a consideration. A further reason that the simulation tools and daylight programs have developed separately, is that they serve two distinct demands from users.

6.1.4 Relative Strengths

- It can be linked to AutoCAD and MicroStation
- It runs on MS DOS and will soon be available on Windows
- It has good user support and ongoing development
- It is widely used in the UK
- Detailed modelling of zones within rooms
- Can assess thermal comfort
- Uses published and well validated daylight calculation procedures
- Provides a good range of switching options

6.1.5 Relative Weaknesses

- Daylight factors must be calculated separately
- Based on overcast conditions only
- Software cost is at the higher end for the methods reviewed

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Information

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6.2 DOE 2.1 / PowerDOE

6.2.1 Description

DOE 2 (present version 2.1E) is one of the most widely used energy simulation tools. It was developed and continues to be developed by the Lawrence Berkeley Laboratory (LBL) in the United States.

DOE 2.1 takes full account of energy savings from daylighting. The program predicts cooling requirements and lighting energy requirements for a given lighting installation and window geometries. It calculates daylight levels based on CIE standard clear and overcast skys using the split flux method. Energy use is calculated from the installed loads and switching regimes. It can either model stepped switching regimes or include a random probability model which will predict whether the occupants would have switched off the lights or not.

PowerDOE is an enhanced version which is being sponsored by the USA's Department of Energy and Electric Power Research Institute. This will feature a graphical user interface running under Microsoft Windows and has been developed specifically to allow greater ease of data input. A beta test version of the program was due to be issued in February 1996 and the full version is expected in June or July 1996.

PowerDOE will use the same daylight calculation methods as the DOE 2.1 model.

6.2.2 Calculation Procedure

Prediction of Illuminance Levels

A preprocessor calculates in detail a set of daylight factors for later use in hourly loads calculations. The user specifies the coordinates in one or two reference points in the space. DOE 2.1 then integrates over the area of each window to obtain the contribution of direct light from the window to the illuminance at the reference points, and the contribution of light from sky and ground which enters the window and reflects from the walls, floor and ceiling before reaching the reference points. The calculation takes account of window size, orientation, glass transmittance, inside surface reflectance of the space, shading devices such as blinds and overhangs, and the luminance distribution of the sky. Since this distribution depends on the position of the sun and cloudiness of the sky, the calculation is carried out for standard clear and overcast sky conditions for a series of 20 different solar altitude and azimuth values, these covering the annual range of sun positions. A separate set of modified values are also calculated for use in calculations where it can be assumed that the occupants will lower blinds in the case of glare.

An hourly illuminance and glare calculation is performed. The illuminance contribution from each window is found by interpolating the stored daylight factors using the current-hour sun position and cloud cover, then multiplying by the current hour exterior horizontal illuminance obtained from measured horizontal solar radiation.

Ideally weather files with measured solar radiation (such as TMY and WYEC files) should be used as these allow a more accurate prediction of the hour by hour daylight availability as the sky conditions change. Non-solar weather files (such as TRY) may be used but the calculation will not be as accurate.

If the glare control option has been specified, the program will automatically close window blinds in order to decrease the glare below a pre-defined comfort level. (A similar option is available to use window shading devices to automatically control solar gain). Adding the illuminance contributions from all the windows then gives the total illuminance level at the particular reference point.

Prediction of Lighting Energy Use

Stepped and continuously dimming control systems are simulated to determine the electrical lighting energy needed to make up the difference, if any, between the predicted daylight level and the target illuminance. The zone electrical lighting requirements are then passed to the DOE 2.1 thermal loads calculation.

Where the manual switching is used, a random probability can be applied to predict whether the occupants would have switched on or off the lights for a given hour.

For each thermal zone (room) in the model two daylighting zones may be specified.

The daylighting program accounts for the presence of overhangs and other shading surfaces which affect the amount of solar radiation and visible light that strikes the windows. The program can take account of external obstructions, blinds and shading devices, reveals and overhangs and different glazing types. The program cannot accurately model light shelves.

The operation of blinds can be simulated by entering the shading device operating schedules.

In the daylighting calculation, shading devices are modelled as perfect diffusers with a daylight transmittance which is independent of angle of incidence. For this reason the program is not good at modelling interior or exterior light shelves, skylights with deep wells, rooms with internal obstructions that block light from the windows, windows with Venetian blinds or other slatted devices that are highly directional. In these cases, the recommended procedure is to determine the daylight factors from a physical scale model using measurements under real or artificial skies, or from detailed illuminance calculation such as RADIANCE or SUPERLITE. These can then be read into DOE 2.1 in place of the built in daylight factor calculation. This is the basis of the ADELINE program which is described in section 9.1.

6.2.3 Availability and Use

The original version was developed in 1976 and there are now 1200 users world wide with 11 in the UK. Of these users around 70% are engineers, 20% academics and 10% architects.

Since the model was first created versions have been developed to run on all the main computer platforms, including mainframes, MS DOS, Windows, UNIX and Apple Mac. LBL produce a user newsletter which provides details of the latest developments relating to DOE-2 and PowerDOE. This provides details of the worldwide network of organisations who supply the program software and offer user support.

There are no off the shelf links to CAD packages at present, however, PowerDOE is part of an "Alliance for Interoperability" which aims to develop these links.

The program has been connected to detailed lighting simulation programs as part of ADELINE (See section 9.1)

Commercial Issues

LBL own the copyright for the DOE 2 model and the Electric Power Research Institute will own the copyright to PowerDOE.

The DOE 2.1 program is available for sale to anyone. The initial cost of a version varies between $300 (£200) to $1200 (£800) depending on the platform it is to run on. PowerDOE is likely to cost around $1000 (£670).

Three day training courses are offered by private user support companies, these courses cost in the region of $500 (£330).

LBL provides free user support for DOE 2.1 and it is likely that user support will be included in the purchase cost of PowerDOE.

6.2.4 Relative Strengths

- Very widely known and used worldwide with good support network
- Calculates its own daylight factors or can import from other packages
- Able to run on any platform
- At the lower range of costs for software
- Can model diffuse and clear skies
- Can assess thermal comfort
- Provides a good range of switching options
- Can import detailed illuminance data from models such as RADIANCE
- PowerDOE will have a good user interface

6.2.5 Relative Weaknesses

- No commercially available links to CAD
- Few users in the UK

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This information has been based on conversations with Frederick Winkelmann at LBL, on extracts from the PowerDOE working papers, on published papers [17,18] and on the User Newsletter.

6.3 ESP-r

6.3.1 Description

ESP is a three dimensional dynamic thermal simulation model. It has been developed by the Energy Systems Research Unit (ESRU) at the University of Strathclyde over the last 20 years. The program is modular, enabling analysis of a choice of aspects at the relevant level of detail.

Daylighting can be modelled at two levels, either using a simple daylight factor calculation based on the BRE's Hopkinson split-flux[12] method or using a full RADIANCE analysis at each time step (see section 8.3).

ESP was primarily developed as a research tool and provides flexibility to carry out a number of different analysis on a whole or part of a building.

Building data can be entered as geometrical co-ordinates or imported from CAD packages such as AutoCAD and ZIP. There are few restrictions on building form, requiring neither orthogonal walls nor roofs. Openings can be inserted where required and can link different zones. The model can represent a complete building or part of a building and be divided into a number of zones.

Plant is modelled by schematic system description, allowing heating and cooling elements and control points within the building. The plant is able to respond to changing simulated conditions, generating plant operating cycles and enabling comparison of control strategies.

The thermal model uses datasets of real or typical weather, including temperatures, windspeed and radiation for hourly intervals.

6.3.2 Calculation Procedures

ESP models the building over discrete time steps, with simulation of the influence of the environmental conditions, building use and plant controls. Within this environment there are a number of options for including daylight.

Daylight Factors

ESP includes a model to calculate Daylight Factors for the working plane in a space. The module uses the BRE split flux approach, accounting for external obstructions and the direct and internally reflected component. The Daylight Factors are then used with overcast sky illumination levels to predict illumination levels for each time step which in turn can drive the lighting control simulation.

This method is acceptable for simple vertical geometries and where there is limited information available about the properties of the internal surfaces. It is based on the CIE standard overcast sky and thus only considers diffuse daylighting.

Connection to RADIANCE

A more accurate simulation can be generated using RADIANCE to predict either the daylight factors for the working plane and at the control points or by calling RADIANCE at particular times in the simulation to calculate the predicted illumination levels.

RADIANCE is itself a modular based package developed by the Lawrence Berkeley Laboratory which can be operated at a range of levels of sophistication. It allows for complex building geometries and models a range of multi-layered glazing and solar control systems. It can employ sky data incorporating luminosity over grid as well as direct sunlight.

RADIANCE is a ray tracing method, tracking packages of light as they pass through openings and reflect off surfaces. Simple spaces can be modelled quickly while more complex problems can be analysed in more detail to give realistic image and accurate values for illumination levels (see section 8.3).

The information generated by RADIANCE is used to provide input to the thermal simulation as well as provide pictorial representation of the spaces or calculated glare indices.

Lighting Energy Calculation

The illumination levels provided to ESP drive the artificial lighting model. The ability of RADIANCE to accurately model the levels means that more sophisticated lighting control strategies can be compared.

The program can model most lighting control strategies, including photo sensor dimming, stepped controls or manual switching.

The predicted illuminance levels are picked up by a range of sensors which can be selected and positioned to simulate a real control strategy. For example a photocell on an external wall linked to dimmable fluorescent lighting. These then decide whether the lights are on, off or dimmed at a given time step and the energy use is calculated.

For simple on off switching arrangements, where light switching is down to the occupants, the model uses the BRE's Hunt method[13]. This uses probability function tables to decide at each time step, whether lights would be switched on or off, according to the daylight levels at that time and the switching arrangements for the previous time step.

Separate lighting types and switching arrangements can be applied for different zones in a room.

ESP measures the electrical requirement for lighting as well as taking lighting information as an input to the thermal model, contributing to the heating or cooling loads, enabling the incidental benefits of daylight to be evaluated.

Program Output

ESP can generate a wide range of output data, which can be displayed by the program or exported as text files to other packages for further analysis. It should be noted that the current versions of ESP run on UNIX, so direct export to Macintosh or Windows applications is not relevant, although most networks allow data to be passed from one platform to another.

Heating, cooling and lighting loads can be plotted or summarised and the temperatures can be displayed in time series or as hours exceeded.

The program will provide a graphic representation of the illuminance levels within the room. It will also visualise the lighting patterns within the room.

The program can be used to predict whether overheating is likely to be a problem.

6.3.3 Availability and Use

ESP is primarily a research tool and an analysis package for novel building forms. The package runs on a UNIX based microcomputer (SUN, Silicon Graphics etc). ESRU makes the program code available free to researchers to enable validation, development or customisation.

Although the program currently runs on a UNIX, there is felt to be good near-term PC potential. ESRU are willing to develop simpler versions for PC based systems, incorporating existing methods and simplifying procedures based on research carried out on ESP. It would be possible to make the program widely available at low cost.

As a commercial design package it is currently one of the larger, more expensive and complex available requiring specialist users. It provides detailed analysis of sophisticated buildings, but can also be used to generate sensitive analysis of changing parameters.

The program or its source code can be bought by anyone and is available from ESRU. Where the program is for commercial use the cost is £1500, where it is to be used for research, it is made available under licence at no cost. ESRU own the copyright and funds from sales go to the University of Strathclyde to support further research and development.

User support facilities include a World Wide Web site, E-mail list and training courses. A simple problem can be analysed in half a day. A detailed problem or building would take more than two days to examine. ESRU provide three day training courses for a cost of £500.

At present ongoing development of the program is well supported. There are around 50 users in the UK and 150 world wide.

Most of the users are researchers, however, architects and engineers have access to the program through approved consultants for the Energy Design Advice Scheme (EDAS).

Validation

The program was part of the IEA Task 12 Annex 21 validation. It has also been validated by EU, EPSRC and through industry projects. ESRU have a policy to participate in or support all validation projects.

6.3.4 Relative Strengths

- It can be linked to CAD packages including AutoCAD
- It has good support for continued development
- With a connection to RADIANCE it can model the most complex problems and will provide accurate results
- Can assess thermal comfort
- Provides a good range of switching regimes
- Available free to researchers

6.3.5 Relative Weaknesses

- It can only run on a UNIX workstation
- The software cost is high for commercial users
- It is a complex model requiring specialist knowledge to use

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6.4 SERI-RES PC VERSION

6.4.1 Description

SERI RES was originally developed at SERI in California, now the National Renewable Energy Laboratory (ENREL). SUNCODE was the commercial version in the USA. Phil Haves sells an MS DOS PC version, this carries out the same functions as the main frame version developed for ETSU in the late 1980's (ETSU have the code for this).

The model was originally developed for domestic buildings (the RES stands for residential), but is suited to simple non-domestic buildings as well.

SERI RES uses daylight factors which must be calculated separately and entered into the program. To calculate illuminance levels SERI RES uses a slightly more sophisticated sky model than the average overcast sky method. This takes account of orientation and circumsolar but does not take account of direct solar gain. It allows window openings on three façades, ie two walls and rooflights.

6.4.2 Calculation Procedure

Prediction of Internal Illuminance Levels

A description of the SERI RES daylight calculation method is given in reference 10.

SERI RES uses luminous efficacy algorithms to predict external illuminances. Where photoelectrically controlled systems are being modelled a modification is made to take account of the direct beam insolation by splitting each hour into a sunny fraction and cloudy fraction. The diffuse component remains constant throughout the hour, but the direct beam component is added for the fraction of the hour considered sunny. This provides a more realistic prediction of illuminance levels for higher direct beam insolations.

The program predicts the interior illuminance level using a vertical illuminance method. This is felt to be better than methods based on the measurement of radiation on a horizontal plane, as these do not take satisfactory account of orientation effects.

The program uses the solar gain procedure to predict the insolation on the plane of the window, the daylight component is predicted from the luminous efficacy of the radiation and then converted to internal illuminance using a modified daylight factor.

The user must input the standard CIE daylight factor for the zone being examined.

Lighting Energy Calculation

Different switching options can be entered. Manual switching is modelled using the BRE's Hunt method[13]. This uses the probability of different lights being switched on or off at each time step given the illuminance level calculated and the switching pattern for the previous hour.

Photosensing can be modelled using a variable dimmer, down to 20% of full light output and a corresponding 30% of full load. Timed switching of banks or perimeter lighting can also be modelled by scheduling the on off times according to illuminance levels.

Power consumption is measured at each time step according to the load that is switched on. Heat gains are determined in a similar way, and if the building were air-conditioned, a chiller COP could be used to determine the cooling load.

6.4.3 Availability and Use

The main draw back with SERI RES is the editor, which is more basic than a spreadsheet and therefore difficult to use. Work is currently being undertaken at ENREL to address this problem.

One user commented about the lack of feedback when errors have been made in the input, and the difficulty in locating the error.

A further drawback is that it does not include libraries of services equipment such as air-conditioning components. It merely predicts the cooling demand and other assumptions need to be made about how this cooling will be met.

Phil Haves sells the PC version for £100.

Future Development

The editor for the model is being upgraded by Ron Judkoff at ENREL. Phil Haves also mentioned the Energy 10 model which is being developed by Doug Balcomb at ENREL, which has a very user friendly front end, this is described in section 9.2

6.4.4 Relative Strengths

- It uses a published and tried and tested daylight calculation procedure
- The model is available at low cost
- It can assess thermal comfort
- It runs on a PC
- A wide range of switching options may be modelled

6.4.5 Relative Weaknesses

- The user interface is poor
- It is not good at modelling overall energy use for large complex buildings

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Information

The information has been based on conversations with Dr Phil Haves at Loughborough University, Paul Russevelt at HGa, on conversations with users and on published literature[10].

6.5 TSBI3 (Thermal Simulation of Buildings and Systems version 3)

6.5.1 Description

TSBI3 is the Danish Building Research Institute's (SBI) dynamic simulation program. It is used as the standard analysis package by engineers in Denmark. It has primarily been developed to simulate commercial and institutional buildings.

TSBI3 has its own menu driven user interface. The building model can be divided into a number of zones and material properties specified. HVAC systems can also be specified, along with their individual control strategies and operation schedules. The program will provide a breakdown of energy use as well as determining the likely comfort conditions within a zone.

6.5.2 Calculation Procedure

Daylight Calculation

Daylight is modelled in a similar way to the BRE split flux method, except a further factor for the effect of internally reflected direct sunlight is added. The daylight components (sky, external, internal and "direct sun") are calculated for each zone and stored as separate "solar light factors" SF1 to SF4.

Multi layer and special glazing systems and other devices are allowed for by the use of variable transmission factors for the opening.

During the simulation the diffuse and direct radiation data for each period are converted to illuminance by constant factors and the internal illumination calculated from the SFs.

Lighting Energy Calculation

TSBI3 allows for luminaire switching (in up to 4 stages) and dimming based on the calculated daylight level. It accounts for manual switching by assuming the lights will be turned on when the daylight level drops below a set level and then remain on.

In the case where photosensitive control is installed, the position of the sensor is input and the program calculates whether the lights will be on or off in the space every hour. It thus builds up a pattern for energy use throughout the year.

In cases where photosensitive control is not present, a figure is fed in to the program by the user to define the illumination level at which the lights will be turned off. Once the figure is input the program works out the length of time that the lights will be on to give overall energy consumption.

The heat generated by the lighting is included in the thermal simulation as an additional incidental gain or as an additional cooling load.

Only one lighting controller may be specified in a given room or "zone". Dividing rooms into two zones does not overcome this as you cannot account for transfer of daylight between the zones.

The program is only applicable to buildings with simple lighting control and glazing. It does not model the availability of daylight from atria and other more complex spaces. It does not model solar shading such as blinds and overhangs.

The simulation uses hourly datasets of environmental information, such as the Standard Reference Year datasets.

The program can present output in both tabular and graphical form. There is a choice of several hundred parameters including the internal environmental conditions, energy flows, plant conditions and energy consumption. A selection of these can be plotted, listed or analysed. The graphical output can also be saved as HGPGL files for use by other applications.

6.5.3 Availability and Use

The package is marketed commercially at 30,000DK (~£3,500) and 10,000DK (~£1,200) to educational institutions. There are around 100 users world wide with 2 or 3 in the UK.

The program runs on an MS DOS PC, and is not available in other formats.

Data input is by menus with a hierarchical structure. The user navigates around the menus using a mouse or keyboard control keys. It may take up to two days to fully input a building and obtain results.

The TSBI3 model does not provide a visual representation of the building at present. While it can import data from AutoCAD DXF files, SBI believe there is little advantage at present as the CAD information is only a small amount of what is required to complete the building description.

Training courses and support are provided by a third party in Denmark. These include a hot line service.

SBI are aiming to develop an Integrated Building Design System (IBDS) in due course. This would contain a new thermal analysis tool that would ideally include a visual interpretation of the building and would link this to complex daylighting programs such as RADIANCE. This follows on from work undertaken as part of the EC DG12 COMBINE 2 programme[19].

SBI were responsible for developing the MS DOS version of RADIANCE used in the ADELINE package (see section 9.1).
SBI will be involved in the continued development of ADELINE under Daylight in Design Tools a sub task of the IEA's task 21.

6.5.4 Relative Strengths

- The daylight calculation procedure and algorithms are well documented
- The program runs on MS DOS
- Can assess overall energy use and thermal comfort

6.5.5 Relative Weaknesses

- It can only model one lighting control strategy per room
- It cannot deal with complex room shapes or shading systems
- There are few users in the UK
- Software cost is at the high end of methods reviewed

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Information

This information is based on conversations with Kjeld Johnsen at the Danish Building Research Institute, and on papers describing the daylight calculation procedure[20,21,22,23].

7.0 OTHER ENERGY PREDICTION PROGRAMS

This section covers energy prediction methods which do not fall into the category of dynamic simulation models. In general the methods described are simpler in their approach requiring fewer inputs and hence less time to reach a solution. The extent to which they address daylighting varies in each case.

While the CIBSE 2c method is not yet available it has been included in this review as it is one of the main methods being considered in connection with UK Building Regulations. It has not been possible to obtain a detailed description of the proposed method at this stage.

The Dutch NPR 2917 method is not used in the UK and also uses a very crude method for dealing with daylight. In addition it is at present not available in English. The reason for including it is that it is currently the only method we are aware of which has been used in support of compulsory overall energy targets for non-domestic buildings.

7.1 CIBSE ENERGY CODE PART 2c

7.1.1 Description

The proposed CIBSE Energy Code 2c for air conditioned buildings and mechanically ventilated buildings will follow the CIBSE Energy Code 2a for naturally ventilated buildings, originally published in 1981. It is due for release in September 1996. It will take the form of a manual with an accompanying computer program. The program will be a basic executable DOS based program with no front end as such, but which will have an input data file.

As the code has not yet been published only the treatment of daylighting is discussed here.

CIBSE Energy Code 2c takes account of daylighting by relating daylight factors to a figure called the diversity factor. This diversity factor is applied to the total installed lighting load to give a figure for the predicted energy use associated with lighting.

The graphs and equations from which the diversity factor is derived were developed by the BRE. There are two graphs in the code, one for a 3m wide façade and one for a 20m wide façade. The graphs relate room depth, percentage glazing, required illuminance and daylight factor to give a figure for the diversity factor.

The code also makes an allowance for the heating energy which the lighting provides, but this assumes the lights are switched on throughout the winter months.

The main advantage of the CIBSE Energy Code 2c could be that it will be widely available at low cost.

It is being considered as a possible method to be used in support of energy targets within the building regulations.

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Information
The above is based on telephone conversations with Dr Butcher and Barry Copping at CIBSE and with reference to CIBSE Building Energy Code Part 2 [24].

7.2 ESICHECK

7.2.1 Description

ESICHECK is a semi-empirical computer program. It was originally developed by the Electricity Association (formerly the Electricity Council) and is based on algorithms developed from data obtained from a large sample of monitored buildings.

The ESICHECK program is menu driven with multiple choice answers. Input data is collated on a standard proforma. The proforma covers the building's principle dimensions, fabric construction, type of HVAC plant, lighting systems and controls and occupancy data. Most of the information can be obtained by a short discussion with the building designers, however, measurements of the building geometry have to be taken from drawings. These measurements can take between half and two days depending on the building's complexity.

The program predicts a building's delivered energy consumption by fuel type, for a variety of different types of buildings. Energy consumption is expressed in kWh/m²/annum of delivered energy.

The program has historically been used by regional Electricity Boards to provide advice to their clients on the energy implications of services systems. It has also been adopted as the standard method for predicting CO_2 emissions within BREEAM[25]

Daylighting is taken into account by considering the amount of glazing on each orientation. There are tables of equivalent hours of lighting at full load as function of plan type (deep/narrow), lux level, hours of occupancy and *percentage glazing*. These tables are then modified by glazing type, start time, building type and light control (low/normal/ high) all using factors from tables. These figures are therefore derived using a purely empirical approach, from data collected from a set of buildings surveyed.

7.2.2 Relative Strengths

- simple to use
- little training required
- input data easily obtained
- Collecting the data and running the program can take between one and two days depending on the complexity of the building. The largest part of this time is spent in measuring the building's areas from drawings.
- Once the data has been entered into the program it is very simple to explore the effect on performance of making changes to the building's, lighting, HVAC and fabric specification.
- useful breakdown of the energy consumption in terms of space heating, hot water, lighting, refrigeration, fans and pumps, lifts, humidification and equipment loads.
- delivered energy consumption is calculated by fuel type, the data can easily be converted into other units of performance, for example primary energy, cost or pollution emissions.

7.2.3 Relative Weaknesses

- the main drawback is that the program is not available for sale commercially. There is a possibility that it will be released on to the open market, though it will need further development if this is to happen. However funding for the program is currently being cut back which makes this development doubtful.
- The program is an empirical model based on extensive monitored data. This presents a problem when attempting to model innovative HVAC systems which have not yet been added to the ESICHECK menu.
- The algorithms used in ESICHECK are not well documented.

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Information
Based on information supplied by fax and telephone by Andrew Wright of the Electricity Association.

7.3 LT METHOD

7.3.1 Description

The LT method was and continues to be developed by Cambridge Architectural Research Ltd from research carried out at the University of Cambridge. The computer program was developed in order to produce a simple manual energy design tool, known as the LT Method. Various versions of the method have been produced addressing a range of climates and building types, with the version 2 being dedicated to non-domestic buildings in the UK.

The computer program is currently being validated by the BRE. It is based on a computer spreadsheet format, which allows relatively easy alterations and adjustments to be made to individual algorithms to increase the sophistication or to simplify calculations as appropriate to the research task in hand.

The program integrates heating, cooling, mechanical ventilation and lighting primary energy of representative zones of a building design. The daylight contribution thus affects artificial lighting requirements, which in turn will influence internal gains and thus heating and cooling loads. It is the establishment of these interrelationships and its relatively simple use that are the particular strengths of the program.

7.3.2 Calculation Procedure

LT determines heating and cooling loads on a monthly basis, but daylighting on an hourly basis, Daylight factors for the back and front half of a zone are calculated using the standard Hopkinson[13] equations, but adding an empirically derived equation for the effect of interreflected externally reflected component. This allows a more detailed investigation of the effects of external street cavity geometry and reflectance. Although the CIE overcast sky condition is assumed, this has been refined to allow for the fact that sky to the south is brighter than the north. Hourly daylight availability is derived from the daily diffuse solar radiation data using algorithms developed by Page[26].

Light switching in the original program is assumed to be "ideal stepped", although any alternative algorithms could be inserted to represent dimming or manual switching probability. Thus currently when one of the two reference points in the zone reaches the datum lighting value, artificial lighting is turned off for that half of the zone.

7.3.3 Availability and Use

The LT Spreadsheet Model is not in general circulation, though many research groups have the model. However, the various manual LT Methods that are published have been widely disseminated to the building profession throughout the UK and Europe as a whole. This has been achieved through seminars in the UK organised by the BRE, and as design competition material throughout Europe.
The manual methods are easy to use, taking from 30 minutes to a few hours to reach an answer, depending on the complexity of the building. The method can be taught to designers in less than a day. The methods are aimed at the early design stage and should be used as strategic design tools (simplification of the paper method has meant the need for default values).

The manual method allows for the use of atria or sunspaces. The output is total primary energy use for heating, lighting and cooling, and CO_2 emissions. The program can provide monthly energy use and hourly lighting energy use.

The LT Method version 2[27] is available free from BRECSU.

7.3.4 Relative Strengths

- The method is well documented.
- Validation is taking place.
- Overall energy use is calculated.
- It is simple to use and simple to assess different design options (particularly on the spreadsheet version of the program).
- The method is widely available.

7.3.5 Relative Weaknesses

- The types of services systems and lighting systems are limited.
- It is intended as a design tool and not as an accurate method for predicting energy use.
- It is based on ideal assumptions about the contribution of daylight and less effective switching assumptions cannot be assessed.
- The method does not at present assess overheating.

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Information

This information has been based on conversations with and faxes from Koen Steemers at CAR and a meeting with Bob Everett at BRE and on published papers literature [27,28].

7.4 NETHERLANDS NPR 2917

7.4.1 Description

NEN 2916 is an energy performance analysis method which has been developed in the Netherlands, for commercial buildings. The method sets energy performance (EP) values for new buildings[29]. These energy performance targets have been a statutory requirement as part of the building regulations since 15 December 1995. NPR 2917 is the computer program which accompanies this method and is used to demonstrate compliance with the regulations.

7.4.2 Calculation procedure for lighting energy

Energy consumption for lighting can be determined in two different ways in the method:

1. On the basis of the installed lighting load per m^2 and the total hours of occupancy with a set reduction for the type of lighting control system (lighting usage factor). The lighting usage factors for different systems were derived from empirical data. No account is taken of any reduction in the number of hours of use as a result of daylighting.

2. The same as the method described in section 1 however it is possible to make an allowance for zones adjacent to windows, where there is a lot of daylight illumination.

The daylight factor is calculated by the user for each zone where a daylighting benefit is envisaged. A factor for the reduction of energy use is then applied to zones which have an average daylight factor greater than 3%. The adjustment factor is fixed and does not take into account the degree to which the daylight factor is better than 3%.

The lower of these two values can be used when working out the overall energy performance.

Program output

NPR 2917 does not predict illuminance levels. It does give a value of overall energy performance in the form of an EP (Energy Performance) value. It also gives a figure for energy consumption in terms of primary energy consumption. It will not tell you if there is an overheating problem.

Energy calculation input data

It does allow for the artificial lighting to be zoned.

The following types of lighting control system can be represented in the calculation:

- central timed
- photo-cell based
- central timed & photo-cell
- central on/off
- room switches
- dimmer

The factors used to generate the energy consumption for each system are based on empirical data from existing buildings with a variety of control system.

7.4.3 Availability and Use

The code is available from the Netherlands Institute of Standardisation at a cost of £100. Though this is only available at present in Dutch, a translation would be provided by the European Commission if requested.

The program is widely used by architects, designers and engineers. The program is well supported by the developers of the program who also gave extensive training programs on the system. It takes less than half a day to input a building in to the program which can be run on a PC.

7.4.4 Relative Strengths

- The model is simple, easy to use and is the only model which has been identified which is used to support compulsory energy targets for non-domestic buildings.
- All types of buildings can be modelled.
- Glazing types other than clear glass, external obstruction and atrium can be modelled indirectly in the calculation of the daylight factor, but the adjustment is a crude one.
- Different types of lighting control system can be modelled

7.4.5 Relative weaknesses

- The method for allowing for daylight is very crude.
- Complex room shapes cannot be modelled.
- It can not be linked to existing CAD packages.
- The model is not well validated

- It is used to obtain comparative figures for energy use, not absolute values.

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8.0 DAYLIGHTING PROGRAMMES

There are many programs available for predicting daylight factors and internal illuminance levels which are not linked to overall energy calculation procedures. While these are not strictly the subject of this review, they are sometimes used to provide input data to programs which can predict overall energy consumption. For this reason we have included a small sample to illustrate the range of capabilities available.

A survey of the use of daylight prediction methods undertaken for ETSU by BRE in 1994[3], found that the most commonly used daylight prediction methods at the time were DAYLIGHT and HEVACOMP.

To these we have added RADIANCE and SUPERLITE which are more powerful daylight prediction methods developed for use in research and which have been used in conjunction with a number of the energy prediction methods discussed in section 6.

8.1 DAYLIGHT

8.1.1 Description

"Daylight" models distribution of natural daylight within single rooms. The dimensions of the room are input into the model (one simplification at this level is that the room is assumed to be rectilinear). The window-rooflights are input by specifying the distance from the left hand side of the wall and the dimensions are input as running lengths. Overhangs and obstructions are input in a similar manner. Room reflectance's and glazing transmittances can then be adjusted.

When the initial input is complete the daylighting performance is simulated. This is based on algorithms developed by the BRE assuming a CIE standard overcast sky for the externally reflected and sky components of natural light and Hopkinson's split flux method for the internally reflected component. The results are given in the form of daylight factor contour plots for the room plan. Daylight factors are also shown graphically as a function of room depth. Lux levels are derived from the daylight factors and may also be plotted

The program will not provide a visual representation of the daylighting in the room.

It does not assess the risk of overheating.

8.1.2 Capabilities

The program can be used to model any building type as it looks at individual rooms. It cannot model curved rooms, but it can model L shaped or other rooms with bends or recesses, provided they can be divided into component rectangles.

Different glazing types may be modelled by specifying their transmittance.

It will not model shading devices such as light shelves or mirrored blinds that have a directional component. It can model shading devices that act in a diffusing way such as a material blind. These would be modelled by adjusting transmittance. It would be possible to develop the model to deal with these aspects.

It can model rooms adjacent to an atrium by specifying the surface reflectance of the atrium. It will not however deal with ray tracing to model successive reflections down the atrium.

External obstructions can be taken into account provided they can be approximated to rectangles. These are entered as blocks on a plan and the available skylight adjusted.

The program does not at present have any links to CAD systems, however, APU are considering this as a future development option.

The program will not predict energy savings from daylighting, and will not allow switching methods to be calculated. This function could be added to the model relatively simply, but would entail some development cost.

8.1.3 Commercial Issues

The program can be bought by anyone. The standard cost of the program is £400, however, there is a 50% reduction for research organisations and academics.

The cost of the program includes user support, however, the program is very easy to use and APU receive only three or four calls a year from the 100 or so users.

No training is required and daylight calculations can be undertaken in a few minutes.

The program is available for DOS systems only and will run on a standard PC.

The program was last updated in 1992, further development could take place if new applications were identified and a source of funding made available. APU would not be able to fund development costs from sales alone.

At present there are around 100 users. 70% in the UK. Of these approximately 50% are research organisations, 25% architects and 25% services consultants.

A market survey undertaken by BRE for ETSU[3] found that Daylight was one of the two most commonly used programs among those surveyed. The other being HEVACOMP.

Validation

The program is based on algorithms developed by BRE.

Future Development

It would be possible to make the program widely available at low cost. Consideration would need to be given to technical support to the much larger group of users, but some form of agreement could be reached. An arrangement could be reached with DOE regarding the cost of the program and royalties.

The program is already used by some researchers to determine daylight factors for use in the daylighting algorithms of thermal simulation programs. It might be possible to develop a direct link with these models.

An energy calculation procedure could be developed to determine lighting energy loads for different daylight configurations.

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Information
Information supplied by Ian Frame in addition to the User Manual.

8.2 HEVACOMP

8.2.1 Description

HEVACOMP has been developed as design software for the building services industry. The packages are designed to provide easy to use programs for engineers and technicians to carry out calculations for design and specification of engineering systems. The package draws heavily on the design guides of the Chartered Institute of Building Services Engineers, although it also makes use of Carrier and ASHRAE methods. In general the package implements the design methods that might otherwise be carried out by hand.

There is not one single energy program but a suite of programs to calculate each service aspect of a building, ie Heating, cooling and lighting. Common building data is used by each program. The package has been linked to AUTOCAD and there is a custom built CAD program, HevaCAD.

8.2.2 Operation

Building data can be input numerically or graphically in the Windows environment or imported from CAD packages such as AutoCAD. Building data is collected into a common building database and used by each program module.

Nimbus calculates daylight factors from the geometrical data, by the BRE split flux approach, accounting for external obstacles, where entered, and direct and internally reflected illumination. The standard CIE overcast sky is assumed.

Transmission and shade factors are applied to model different glazing and shading devices. No account can be taken of novel devices such as light shelves.

The output data from this program can provide the input to LEN, an artificial lighting energy program. This also receives data from the lighting design package and calculates the energy required over any period, simulating a number of switching strategies, including a manual control mode, where the lighting is switched on when required and left on until the end of the day.

In its turn the lighting energy can be passed as input to the heating and cooling packages, for inclusion as incidental gain or load. This package sizes plant according to CIBSE procedures and estimates energy requirements by degree day and admittance methods.

Output is plotted as graphs of energy use or tabulated figures that can be passed to other packages.

8.2.3 Availability and Use

The program is sold commercially as a designers package for £2250. Regular updates are provided and training is available, although the programs come with a tutorial pack. The package is quickly learned and can be used in less than a day.

It is designed to be used by engineers.

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8.3 RADIANCE

8.3.1 Description

RADIANCE is a collection of programs for the graphical simulation and analysis of lighting. The system was developed by Greg Ward at the Lawrence Berkeley Laboratory with funding from the US Department of Energy. Additional funding for further development has been provided by the Technical Research Group at Apple Computer Corporation and by the Swiss National Energy Research Fund (NEFF) as part of the LUMEN project directed by Jean-Louis Scartezzini at the Ecole Polytechnique Federate de Lausanne (EPFL) in Switzerland.

Using backward ray tracing RADIANCE is capable of accurately predicting illuminance levels and daylight factors in the most complex of rooms. It is capable of dealing with transmission through different glazing types, including internal glazed partitions, such as windows onto an atrium. It can also model any light source including diffuse daylight, sunlight and artificial lighting.

These are features which set RADIANCE apart from all the other programs described in this review. The main drawback of the program is that it is a very complex program which can take a considerable time learn to use become familiar with and operate. It is used mainly by industry for rendering graphic images, which is the original reason for its development[32].

8.3.2 Calculation Procedure

The input required for the simulation is a description of the 3-dimensional surface geometry, materials, and light sources in the room or scene. In order to produce visual images the view point, direction and angle of view must also be specified.

The lighting simulation engine of RADIANCE uses a hybrid approach of Monte Carlo and deterministic ray tracing to achieve a reasonably accurate result in a reasonable time. The method starts by establishing a measurement point, this might either be a view or the sensor of a lighting control system. The method traces rays of light backwards to their source, ie artificial lighting or glazing. The calculation is divided into three main components.

- the direct component
- the specular indirect component
- the diffuse indirect component

The direct component consists of light arriving at a surface directly from a light source or via one or more perfectly specular transfers from other surfaces.

The specular indirect component consists of light arriving at a surface from other surfaces and being reflected off or transmitted through in a directional manner. Perfectly specular surfaces are handled by simply redirecting the ray in the appropriate transmitted or reflected direction. Rough specular transfers are modelled with Monte Carlo sampling of the reflected and/or transmitted direction.
The diffuse indirect component consists of light arriving at a surface and being reflected or transmitted with no directional preference. The nature of this component requires that hundreds of directions be examined in order to make a reasonable Monte Carlo estimate. As the diffuse indirect component changes slowly over surfaces, a few values are calculated at reasonably spaced intervals and interpolated at the points in between. This is the basis of the "radiosity" method used for the SUPERLITE model (see section 8.4), however, unlike RADIANCE the radiosity method is only designed to deal with simple geometries and diffuse surfaces[30].

The user is able to define the number of reflections or "ambient bounces" that are considered in the calculation. The more bounces the longer the calculation but the greater the accuracy.

The user can define a grid of reference points (usually across the working plane). At each point the illuminance levels and daylight factors can be determined and plotted. These predicted results can either be used as manual input to overall energy simulation models such as APACHE or SERI RES, or can automatically be calculated at hourly intervals as dynamic input to programs such as DOE 2.1, TSBI3 and ESP.

Kevin Lomas at the School of the Built Environment at De Montfort University, has been undertaking a number of validation studies to compare the results produced by RADIANCE with those of other models. He has found that RADIANCE will predict higher values for daylighting than simpler models such as DAYLIGHT. This is due to the ability of RADIANCE to accurately model internal reflections. This is particularly relevant when modelling the daylight contribution from deep atria.

De Montfort have also validated RADIANCE against measured daylight data for a simple room and for a room with light shelves[5]. The daylight measurements were undertaken by BRE as part of the International Daylight Monitoring Programme. The conclusion from this work was that the RADIANCE system "can predict internal illuminance to higher degree of accuracy for a range of realistic sky conditions for clear glazing and diffuse and specular light shelves" [5].

Work undertaken at De Montfort has indicated that the results produced using RADIANCE may be more accurate than those produced using scale models, because scale models cannot accurately take account of rebates and reveals due to the thicknesses of the materials used to build the scale models. This combined with the ability to quickly make changes to the parameters being modelled, make RADIANCE a potentially attractive tool for designers.

RADIANCE is continuing to be developed both at LBL and EPFL.

8.3.3 Availability and Use

RADIANCE has been in use for about 5 years by designers and researchers at universities and private firms. The software has been thoroughly tested and debugged and is in its eighth official release, version 2.3.

It is designed for use on the UNIX platform, however, an MS-DOS version has been developed for use with the ADELINE package (see section 9.1).

Joe Clarke at the University of Strathclyde has been using the program in conjunction with ESP as described in section 6.3.

AutoCAD files in the DXF format (version 10) can be translated into RADIANCE input files using software which is included with the RADIANCE program distribution. Raphael Compagnon at EDFL has developed an interface between RADIANCE and the CAD program ScribeModeller. However this CAD system is not widely used commercially.

The program developers describe the package as being "well-suited to programmers and people with a high degree of computer proficiency. The interface is command-based in a fashion that is familiar to UNIX users, but uncomfortable for many who are used to the menus and point-and-click interfaces of modern software."

When undertaking the illuminance levels and daylight factors required for lighting energy calculations results are obtained almost instantaneously, however, if visual images are required the process is much slower. It may take between 1 hour and 20 hours to produce a high resolution visual image, depending on the complexity of the room being modelled and the speed of the processor.

RADIANCE is available free but is under copyright so that it cannot be sold for commercial gain. It is available on disk or can be imported directly via the RADIANCE World Wide Web Site.

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The LBL World-Wide-Web site for RADIANCE is at:
http://radsite.lbl.gov/radiance/HOME.html

The EPFL World Wide Web site is at:
http://lesowww.epfl.ch/radiance/radiance.html

Information

This section has been based on published papers [5,6,30,31,32] and on a discussion with Kevin Lomas at De Montfort University and Joe Clark at the University of Strathclyde.

8.4 SUPERLITE

8.4.1 Description

SUPERLITE (latest version is number 2.0) is a powerful lighting analysis program designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems. It enables a user to model interior daylight for any sun and sky condition in spaces having windows, rooflights or other standard glazing system. The major innovation of the latest version is that it provides the capability to calculate electric lighting levels in addition to the daylighting prediction thus allowing lighting performance simulation for integrated lighting systems. The program calculates lighting levels on all interior surfaces, as well as on planes that can be arbitrarily positioned to represent work surfaces or other locations of interest to the user.

SUPERLITE 2.0 is aimed at researchers and lighting designers, who require detailed analysis of the illuminance distribution in architecturally complex spaces.

SUPERLITE 2.0 operates on IBM-PC compatible computers in DOS. A minimum of 600 kilobytes of RAM and a maths coprocessor are required.

Whilst there is no telephone support for SUPERLITE as such, there are limited support facilities by fax and phone.

8.4.2 Relative Strengths

It gives very accurate values for illumination levels on the working plane. Complex spaces can be modelled, such as L-shaped rooms, trapezoidal surfaces, interior partitions and external obstructions. Window glazing can be clear or translucent. Illuminance data are calculated for points on user specified planes. Electric lighting data is entered in terms of illuminance values.

8.4.3 Relative Weaknesses

Unlike RADIANCE all surface reflection of light is assumed to be perfectly diffuse, specular reflections are not represented directly. Complex window systems such as Venetian blinds and specular light shelves cannot be modelled. Input and output data are accomplished only through ASCII text files. The number of surfaces, windows and nodes can be restrictive for complex surfaces.

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Information
This section is based on published papers [33] and on information contained on the LBL Web Site.

9.0 RELATED INITIATIVES

This section covers a number of calculation methods and research programs which were referred to during our review and which are of interest in relation to daylighting energy analysis in buildings.

While the ADELINE and ENERGY 10 calculation methods are not at present used commercially in the UK, they are important developments and are likely to become more widely known and used in future.

9.1 ADELINE (Advanced Day and Electric Lighting Integrated New Environment)

Description

ADELINE is an integrated lighting design computer tool developed by an international research team within the framework of the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 12.

It is an important development within the context of this study as it links a 3D CAD package with detailed daylighting design programs and whole building energy simulation models. This is a potentially useful tool for architects and engineers as it will allow numerical and visual analysis of daylighting, without the need to input a separate model of the building.

ADELINE contains SCRIBE-MODELLER as the CAD interface, the daylighting tools SUPERLITE and RADIANCE and a link to energy simulation tools is provided by SUPERLINK.

ADELINE and its component programs all run on the MS-DOS platform. The program encompasses an MS-DOS version of RADIANCE 2.3pc which was previously available on UNIX only.

Daylighting Analysis

The first stage in the process is to develop a 3D model of a space using the SCRIBE-MODELLER package. Alternatively AutoCAD DXF files can be converted for this purpose.

ADELINE then generates input files for the SUPERLITE program or RADIANCE. These programs are used to calculate the interior illuminance levels within the space.

SUPERLITE is the simpler of the two methods and results in a shorter calculation time. RADIANCE while taking longer provides extremely detailed results including colour visualisations of the lighting within the space and these may be of particular interest to architects. RADIANCE is also capable of modelling complex glazing and shading systems such as light shelves which means it can be used to assess innovative design solutions. Other simpler daylight prediction programs could also be linked using ADELINE if desired.

SUPERLINK, a modified version of SUPERLITE, is used to model electric lighting system controls in response to the daylight availability predicted by the daylight model. It generates hourly input files which are used as input to whole building energy simulation programs. These provide information on the energy loads for lighting as well as the cooling and heating loads generated by the lighting. Initially links were made to TSBI3 and DOE 2, however, other thermal simulation programs are now being added including SUNCODE, TRNSYS and TAS.

Inputs to SUPERLINK include:

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

Current Use

The ADELINE program is currently used mainly be research organisations and academics. While it has the potential to be used by architects and engineers it does not appear to have reached this market yet.

The SCRIBE modeller CAD package is not widely used by designers and this may not provide a useful link to existing systems.

Future Development of ADELINE

The following organisations have been involved in the development of the design tools:

- Fraunhofer Institute of Building Physics, Germany (Task lead)
- Lawrence Berkeley Laboratory, USA
- Ecole Polytechnique Federale de Lausanne, Switzerland
- Swiss Material Testing Institute EMPA, Switzerland
- Danish Building Research Institute, Denmark

The development of ADELINE continues within the framework of the international ADELINE working group. The main focus of the work is:

- to improve the integration of the different parts of the package
- to enhance the capabilities of SUPERLITE, i.e. to increase the complexity limits of the models and to include algorithms for artificial lighting calculations
- to include SUPERLITE's Simple Input Mode as a simple tool for an early design stage assessment
- to develop RADLINK, i.e. the link between RADIANCE and the thermal simulation, to evaluate the overall energy performance of complex daylighting systems
- to simplify the use of the programs, i.e. especially to improve the user interfaces
- to enhance the graphical output capabilities of the simulation programs
- to improve the CAD interfaces
- to improve the documentation

Further developments are intended under IEA-SHC Task 21.

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Information on ADELINE can be obtained on LBNL's world wide web site at:

http://radsite.lbl.gov/adeline/HOME.html

9.2 ENERGY 10

Description

While not currently available in SI units ENERGY 10 is likely to provide a useful daylighting tool in the future. The program has been developed by the National Renewable Energy Laboratory who were also responsible for the SERI- RES program described in section 6.4.

ENERGY 10 is a PC based building energy simulation program for smaller commercial and institutional buildings. It is designed specifically to allow evaluation of energy efficiency measures at the early stages of design. The aim of the program is to make it easy to evaluate the integration of daylighting, passive solar design, passive cooling, and energy efficient equipment.

The simulation engines perform whole building energy analysis for 8760 hours per year including both daylighting and dynamic thermal analysis. The primary target audience for the program is building designers, especially architects.

The program uses default values to reduce the amount of information necessary to reach an answer. Users can choose whether they want to change these default values to model specific requirements.

The program takes full account of energy savings from daylighting using the same daylighting calculation method as the DOE 2.1 model (see section 6.2). The program predicts cooling requirements and lighting energy requirements for a given lighting installation and window geometries.

The Beta test version of Energy 10 was released in July 1995. The full version 1 is likely to be available in March 1996. It is a public domain model and the cost will be around $200 (£130) to $300 (£200) to cover telephone support.

Potential problems at present are that it is based on imperial units of measurement and the weather data files are specially compacted to speed up its use. A private company called the Berkeley Solar Group, could create suitable weather data files from TMY format.

ENERGY 10 and DOE 2.1 are not good at dealing with complex geometries and shading systems such as light shelves. Version 2 of ENERGY 10 will address this by using the SUPERLITE model being developed at the Lawrence Berkeley Institute.

A Beta test version of the program has been given to Nick Baker and Koen Steemers at the Martin Centre.

Contact

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Information
This information has been based on conversations with Douglas Balcomb at NREL and on published data [34].

9.3 Environmental Design Manual (EDM)

Description

The BRE are currently working on a project called the Environmental Design Manual. Incorporated into this work are plans to produce a user friendly computer program which will calculate average daylight factors, illuminance levels and the energy savings associated with the use of daylight. The calculations will be based on algorithms developed at the BRE. It is currently at the pre-design stage.

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9.4 Daylight Europe

This is a European Union (DGXII) funded research project, with a three and a half year contract, and a score of participants from Europe and beyond. The main aims are to develop design guidelines, design tools, a Daylight Performance Index (DPI) and report on the monitoring results of 80 case study buildings.

The intended monitoring and simulation activities will provide new Information and insights on the lighting performance of buildings and systems, and behavioural responses from occupants.

The project is being co-ordinated by Poul Kristensen of Esbensen.

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10.0 CONCLUSIONS

This review has identified a range of programs which are currently available and which have the capability to assess the contribution of daylighting to savings in overall energy use.

The methods identified vary considerably in the accuracy with which daylighting strategies may be modelled and in their ease of use.

No single model stands out as being better than any other. They each have their own advantages and disadvantages and where important these have been described.

Some methods such as ESICHECK are simple to use but are crude in their assessment of daylighting. Others such as ESP are capable of modelling very complex daylighting solutions but require specialist knowledge in order to operate them.

There is no single method, currently available, which combines sufficient ease of use, availability and daylighting capability to be used as the basis of a compulsory overall energy target within Building Regulations.

If compulsory targets were to be proposed and if daylighting energy contribution was to be fully recognised within them, then further work would be required to adapt an existing method or develop a new one which draws on the best features of those which exist. This should ideally have standard occupancy assumptions built in and be tailored specifically for ease for use.

None of the energy prediction programs identified have the capability to accurately assess complex daylighting strategies such as light shelves in their stand alone mode. ESP and DOE 2.1 are able to do this if linked to the daylighting model RADIANCE.

RADIANCE is an extremely powerful daylight analysis tool and is likely to appeal to designers as it can provide a visual image of the daylit room. However, it is highly complex to use and is thus unlikely to be adopted widely in its present form.

Where daylighting calculation methods have been validated, this validation has focused on their ability to accurately predict internal illuminance levels. While this is an important aspect of the models, this accuracy may have little benefit in energy calculations, unless it is accompanied by similarly accurate assumptions about how the lighting controls will respond to illuminance levels and resulting occupant behaviour.

Modern lighting control strategies which use combinations of presence detectors, photosensor dimming, manual and timed switching, do not appear to be adequately addressed within the methods identified. It may be that these systems are simply too unpredictable to make any reasonable modelling assumptions. If this is the case there may be little point in developing highly accurate illuminance calculations, within energy prediction models for Building Regulations.

The need to consider daylighting within Building Regulations could be addressed by simple "elemental" targets, for example: minimum average daylight factors; maximum room depth criteria; glazing area ranges in relation to orientation and internal loads (based on the LT method), maximum installed lighting loads etc.

These elemental targets would be needed if overall energy targets are to be based on the Energy Use method currently included in the Regulations. This requires the energy use for the proposed building to be compared to a reference which meets the elemental criteria.

If the Energy Use method was to be extended to cover daylighting, a range of permitted calculation methods could be specified for demonstrating compliance. Of the energy prediction methods available at present, the following have the potential to support an Energy Use method:

- APACHE
- DOE 2.1
- ESP
- SERI RES
- TSBI3
- The LT method

The applicability of these methods would be dependent on the elemental criteria set.

Methods which may become available in future include:

- PowerDOE
- Energy10
- CIBSE Energy Code Part 2c

The NPR 2917 and ESICHECK programs have been excluded from this list as their capability to assess daylight is not sufficiently detailed.

Where buildings are to feature complex daylighting strategies designers can select a complex model to demonstrate compliance with Regulations and the savings achieved. Where a simple daylighting strategy is proposed a simpler model could be used.

It is apparent from talking to program developers that few architects use the methods currently available. Assessment of the energy use of buildings is either carried out by specialists in research organisations, by energy consultants and in some cases by building services engineers.

This has two possible implications on the choice of energy prediction methods: either it is accepted that architects will never take on the role of energy consultant in which case the complexity of models becomes less of a concern or alternatively models need to be developed which are simpler to use and hence more attractive to designers.

A number of program developers are attempting to develop models with user friendly interfaces. These include the PowerDOE model described in section 6.2 and the ENERGY 10 model described in section 9.2.

Further development of the methods identified should focus on improving ease of use and on developing simple links between CAD systems, daylight models and energy simulation methods.

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13.0 CONTACTS

The following people and organisations were contacted as part of this review and we very much appreciate their input.

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APPENDIX 1

Summary Tables

THERMAL SIMULATION MODELS WITH DAYLIGHTING CAPABILITY

ASSESSMENT CRITERIA	THERMAL SIMULATION MODELS				
	APACHE	**DOE 2.1**	**ESP-r / RADIANCE**	**SERI RES (PC)**	**TSBI3 (Thermal Simulation of Buildings and Installations**
General Details					
Developer:	Oscar Faber Applied Research Marlborough House Upper Marlborough Road St Albans, HERTS AL1 3UT	Lawrence Berkeley Lab University of California 1 Cyclotron Road Berkeley California, 94720 USA	Energy Systems Research Unit University of Strathclyde	Loughborough University	SBI (Danish Building Research Institute) PO Box 119 Dr Neergaards Vej 15 DK-2970 Horsholm
Contact:	Steve Irving Tel: 0181 784 5729 Fax: 0181 784 5700	Frederick Winkelman Tel: 001 510 4865711 Fax: 001 510 4864089	Professor Joe Clarke Tel: 0141 552 4400 x 3986 Fax: 0141 552 8513	Dr Phil Haves Tel: 01509 222 609 Fax: 01509 610 231	Kjeld Johnsen Tel: 00 45 4286 55 33 Fax: 00 45 4286 7535
Copyright:	Oscar Faber Group Ltd	DoE/LBL	ESRU	ENREL, ETSU, PH	SBI
Availability:	Commercially available	Commercially available	Commercially available	Commercially Available	Commercially Available but not in USA
Cost:	£3500 (£1200 CAD link)	$250-500 approx	£1500 or free to academics	£100	30.000DK
Training:	2 days	1 week	3 days	None	Training courses available
User Support:	telephone and updates	telephone and updates	E-mail, World Wide Web training courses	Not much, trying to resolve this	Hot line (2 hours free)
Hardware:	DOS PC, UNIX Windows in October	VAX, DOS, WINDOWS	UNIX only	DOS PC only	DOS PC only
Links to CAD:	AutoCAD, MicroStation	None at present, will be linked under the Adeline project	AutoCAD and ZIP	None	DXF transfer developed, but a Danish IBDS under development
No of Users:	100 mostly engineers and researchers	1200 worldwide, 11 in the UK	50 UK 150 Worldwide	25 researchers 25 consultants	2-3 In the UK 100 worldwide

Validation:	IEA, BRE BEST, EA	!IEA Task 12/A21	IEA Task 12/A21, EU, EPSRU	IEA Task 12/A21	IEA Task 12/A21
Daylight Calculation					
Sky Data	CIE Overcast Sky	Diffuse and clear sky	CIE Overcast Sky or real skies and sunlight via RADIANCE	luminous efficacy algorithms	Diffuse & Direct
Real Sky Capability	No	Hourly data files (TMY, WYEC)	Yes	No	Hourly data (TRY files)
Internal Illuminance Calculation	Vertical Illuminance Method Average Efficacy	Uses current hour sun-position and cloud cover to determine	BRE Split flux method or ray tracing using RADIANCE	Vertical illuminance method Average efficacy	Split flux method
Does illuminance calculation take account of Sky component, reflected component and or Internally reflected component?	Daylight factors calculated separately	All components	All components	Daylight factors calculated separately	All components
Daylight Factor Module Included?	Daylight factors calculated by user and input separately	Illuminance data based on sky model or daylight factors entered separately	Program calculates daylight factors or alternatively illuminance levels calculated by RADIANCE	Daylight factors calculated separately	Illuminance data based on sky model
Lighting Controls	Continuous dimmable Stepped dimmable Manual probability based on Hunt	Continuous dimmable Stepped dimmable Manual probability	Continuous dimmable Stepped dimmable Manual based on Hunt stochastic method	Continuous dimmable Stepped dimmable Manual probability based on Hunt stochastic method	Photo sensor dimmer, stepped switch off, manual switching
Capabilities					
Buildings Modelled	All building types	All building types	All types	Developed for domestic, can be used for other building types	All building types
Non rectangular rooms	Yes, but approximated to rectangular room		any room shape		Simple rooms only
				Can be taken into	

External Obstructions	Yes	yes	yes	account in model	yes self and external
Complex shading systems and light shelves	Can be accounted for separately in the daylight factor calculation	shading systems yes, but light shelves no. Can model separately and input daylight factors	Basic model no. Can model complex shading systems and light shelves by linking to RADIANCE	Can be accounted for separately in the daylight factor calculation	from solar light factors calculated separately
Number of zones in room	can model 5 zones in each of 20 rooms, daylight factor and control type specified for each zone	two reference points in a given room.	Can be divided into zones	2 daylighting zones in each room	single system per zone
Output	Energy use by fuel type and end use. Thermal comfort analysis	Energy use, and environmental conditions	Heating, cooling and lighting loads can be plotted or summarised and temperatures can be displayed as time series or hours exceeded	Energy use for lighting Space heating demand	energy use, environmental conditions

OTHER DAYLIGHTING CALCULATION METHODS

ASSESSMENT CRITERIA	SIMPLE ENERGY MODELS			
	CIBSE 2c	**ESICHECK**	**LT Method**	**NPR 2917**
General Details				
Developer:	CIBSE Delta House 222 Balham High Road London SW12 9BS	EA Technology Ltd, Capenhurst, Chester, CH1 6ES	Cambridge Architectural Research The Eden Centre 47 City Road Cambridge CB1 1DP	dgmr esienhowerlaan 112 2517 Km den Haag The Netherlands
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Copyright:	CIBSE	EA Technology Ltd	Nick Baker	Netherlands Institute
Availability:	Will be commercially available possibly given away free to members or with Building Regs	Available under license only, not sold commercially	Available free from BRECSU	Available Commercially
Cost:	Likely to be free	Not for sale	Free from BRECSU	£100
Training:	Likely to be small	Simple to use half a day	No training required	two day training courses
User Support:	not known	By telephone to developers	N/A none	telephone support
Hardware:	PC	MS DOS, WIndows	Manual Method / Spreadsheet	PC
Links to CAD:	None	None	None	None
Users:	None at present	Electricity Boards and BREEAM	1000 in UK 2000 worldwide	Architects, designers, and engineers.
Validation:	Based on CIBSE guides ?	Based on extensive monitored	No formal validation	Code published
Ease of Use				
Input Editor	not published yet	Menu driven easy to use and quick to explore options	Manual method or Excel spreadsheet	Menu driven
Output	not published yet	Tabular output of annual energy use by fuel type and end use	Read from graphs	Tabular output
Evaluation time	not published yet	0.5 to 1 day to measure up typical building and input data	Half a day	less than half a day
Daylight Calculation				

Description	not published yet	There are tables of equivalent hours of lighting at full load as a function of plan type (deep/narrow), lux level hours occupancy and percentage glazing. Based on empirical data.	The method uses look up tables to determine the likely energy use for lighting, depending on the percentage of glazing and building use factors. These tables were derived using daylight factors based on diffuse sky and split flux method to convert vertical illumination to horizontal sky.	Energy use for lighting is calculated from the installed load and hours of use. A simple adjustment is made to the predicted energy use for those zones where the daylight factor exceeds 3%. The daylight factors must be calculated separately by the user.
Input Data	not published yet	Plan depth, target lux level, hours occupancy, percentage glazing. Energy prediction modified according to start time, glazing type, shading type, and expected usage (low, normal high, based on users own assessment)	Building type, internal gains, desired illuminance level, orientation.	Installed load, and area of zones with increased daylight factor.
Lighting Controls	not published yet	No separate input of control types, user assesses whether controls will result in high, normal or low usage.	Based on stepped control. Not able to model separately.	Different usage factors are applied for different types of lighting control system based on empirical data. Systems are selected from a menu.
Capabilities				
Buildings Modelled	not published yet	Wide range of non-domestic buildings	Offices, Institutional and Schools. method being developed for refurbishment	Most non-domestic buildings
Non rectangular rooms	not published yet	No	N/A	No
External Obstructions	not published yet	No	Yes uses factors for Urban Horizon Angle	No
Complex shading systems	not published yet	No	No	No
Number of zones in room	not published yet	One	2 zones assumed	One
Output	not published yet	Annual energy use by fuel type and end use.	Annual energy use for heating, cooling and lighting	Annual primary energy use.
Overheating	not published yet	Warning given if rooms are likely to	No	No warning of overheating

DAYLIGHTING EVALUATION METHODS

ASSESSMENT CRITERIA	DAYLIGHT CALCULATION METHODS			
	APU Daylight V4.1	**Hevacomp Nimbus & LEN**	**Radiance**	**Superlite**
General Details				
Developer:	Faculty of Built Environment Science and Technology Anglia Polytechnic University Victoria Road South Chelmsford Essex CM1 1LL	Hevacomp 212-218 West Street Sheffield S1 4EU	Lighting Systems Reeearch Group Lawrence Berkeley Laboratory California USA	Lighting Systems Reeearch Group Lawrence Berkeley Laboratory California USA
Contact:	Ian Frame Head of Building Performance Research Unit Tel: 01245 493131 extn 3493 Fax: 01245 358044	Paul Wheeler Tel: 0114 2556680	Greg Ward	
Copyright:	Anglia Polytechnic University	Hevacomp	LBL	LBL
Availability:	Commercially Available	Commercially Available	Available, can be downloaded from Internet	Available, can be downloaded from Internet
Cost:	£400 commercial £200 to academics	Elec designer package £2250	Free under copyright	Free under copyright
Training:	None required	From self help tutorials and courses available	Extensive training needed	Training required, considerably less than Radiance
User Support:	Telephone support included in price	Help line and annual updates	Limited, World wide web	Limited, World wide web
Hardware:	IBM PC	PC	UNIX or PC (MS-DOS)	MS-DOS
Links to CAD:	None at present	AutoCAD link and windows GUI	AutoCad link Link to CAD via Scribe Modeller also exists	AutoCad link Link to CAD via Scribe Modeller also exists
No of Users:	70 UK 30 Europe 50% Academics, 25% Architects, 25% Engineers	1900 worlld wide 1750 UK Mostly engineers		
Validation:	Based on published BRE methods	Based on CIBSE and BRE	Well validated	Well validated
Ease of Use				

Input Editor	Very easy	Menu driven	Very complex	Complex but simpler than RADIANCE
Output	plots of DF and Lux levels	DF calculated and lux levels, can be linked to lighting energy program LEN	Very high resolution graphics in addition to illuminance levels and daylight factors	Illuminance levels at any point and daylight factors
Evaluation time	Quick	Quick	Lenghty	slow, faster than RADIANCE
Daylight Calculation				
Sky Data	CIE Standard Overcast Sky	CIE Standard Overcast Sky	CIE Standard Skies and real sky data + direct sunlight	CIE Standard Skies and real sky data
Real Sky Capability	No	No	Yes	Yes
Internal Illuminance Calculation	BRE's Hopkinson split flux method	BRE's Hopkinson split flux method	Uses Monte Carlo and ray-tracing method	Radiosity
Lighting Controls	Not applicable	Various switching options for the energy calculation	Not applicable	Not applicable
Capabilities				
Buildings Modelled	Any building type but one room only	All	All	All
Non rectangular rooms	Can only model a single rectangular room	No	Yes	Yes
External Obstructions	Can be modelled, but are approximated to rectangles	Yes	Yes	Yes
Complex shading systems	No	No	Yes including lightsehelves	Yes but not lightshelves
Complex window geometries	Can only model vertical glazing	No	Yes	Yes

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APPENDIX 2

ASSESSMENT OF DAYLIGHTING MODELS

The purpose of this questionnaire is to obtain information on those computer simulation tools, models or manual calculation methods that are capable of determining the illuminance levels resulting from daylight and of predicting the likely consequences on energy use of a given combination of daylight design, artificial light sources and associated switching strategies.

Where programs are currently only capable of calculating illuminance levels resulting from daylight design, the intention is to explore whether or not these methods might form the basis for the development of a more complex method that is able to estimate the effect on energy use.

General Details

Your Name:
Your Position:
The Name of Your Organisation:
Name of Program or Method:
Name of organisation that developed it:

Program Output

Which of the following can the model be used for:

a) Predicting the likely illuminance levels from daylight on a given working plane, for a given window and room design.

b) Predicting energy consumption for the lighting circuit, based on predicted illuminance levels and specified artificial light sources and switching strategies.

c) Predicting overall energy use for a given room and window design and artificial lighting strategy, taking into account refrigeration loads. lighting energy use and space heating demand.

Is there a graphic representation of the distribution of illuminance levels?

Is there a visualisation of the lighting patterns within the room?

Will it tell you if overheating is likely to be a problem?

Daylight Input Data

Is the model based on overcast skys only or can direct sunlight be modelled?

What sky data is the model based on, can it use real sky data?

Does the model predict illuminance levels based on sky data or must daylight factors be calculated separately?

Does the illuminance calculation take account of the:

a) Sky Component
b) Reflected Component
c) Internally Reflected Component

What method(s) are used for predicting illuminance?

Building Geometry and Components?

Can the model be linked to existing CAD packages to reduce building input time?

What building types can be modelled?

Can the model investigate complex room shapes, ie other than rectangular or square? How?

Can the model investigate glazing types other than clear glazing?

Can the model investigate innovative window design and shading strategies ie light shelves, window recesses etc? How?

Can it deal with rooms adjoining an atrium?

Can it take account of external obstructions? How?

Can the model take account of internal obstructions? How?

Energy Calculation Input Data

Does it allow artificial lights and switching arrangements to be zoned or will it only model a single system?

What switching methods can be modelled?

a) photosensor dimmer

b)	stepped switch off
c)	manual switching

How is the probability of lights being switched on and off dealt with for manual methods?

Availability and Use

Can anyone buy the program?

Where can copies be obtained?

How much does the program cost? Who receives the money?

Who owns the copyright?

Would it be possible to make the program widely available at low cost?

What user support facilities exist?

What does it run on ie PC, UNIX, Apple Macintosh?

Is further development of the program supported at present and will it be in future?

How many users are there in the UK?

How many users world wide?

How much Is it used by:

a)	architects
b)	engineers
c)	researchers

How long does it take for an experienced user to input a building from scratch and obtain the desired output?

a) less than half a day
b) half to two days
c) more than two days

How much training is required, what are the costs for this training?

Validation

Has the program been the subject of validation against measured data or other simulation programs?

Is future validation planned?

Future Development

Are there any future plans we should know about?