# IMAGE

## Implementation of Advanced Glazing in Europe

Robert Cohen, Jonathan Bates

**Halcrow Gilbert Associates**
Burderop Park
Swindon, Wiltshire
SN4 0QD
United Kingdom
Tel: +44 1793 814756
Fax: +44 1793 815020
e-mail: hga@hga.co.uk

Performance Optimisation of Advanced Glazing Systems in Practical Applications
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# CONTENTS

# IMAGE

(Implementation of Advanced Glazing in Europe)

# Performance Optimisation of Advanced Glazing Systems in Practical Applications


## ABSTRACT

From an energy and environment viewpoint, the glazed component of a building is, at the same time, the weakest and strongest element. Its disadvantages are associated with heat loss, thermal discomfort and visual discomfort (glare); its benefits include passive solar heat gain, electric lighting power reduction and view. Previous research has therefore sought to assist the industry in accentuating the benefits while eliminating the disadvantages. By focusing on specific technologies, such research has brought about significant developments in both the glazing itself and window systems. However, actual benefits will depend critically not only on the technical capabilities of the glazing but also on the interactions with other building sub-systems.

The IMAGE project set out to encourage appropriate applications of advanced glazing, to raise awareness of products amongst designers and to give impetus to market penetration. The project comprised two complementary activities: the testing of representative advanced glazing systems in laboratories and outdoor test cells; and the use of computer simulations to determine the overall behaviour of these glazing systems when applied to different building types operating in different climates.

Standard test procedures were developed for the assessment of the performance of advanced glazing systems in the laboratory and outdoors. A whole range of glazing and window systems, from high-technology glazings to more ordinary framing systems, were tested and have been studied by means of numerical simulation. A good agreement was found between the outdoor and laboratory tests.

The project developed better computer simulation techniques for representing the performance of glazing in buildings. A new software product - the GDST (Glazing Design Support Tool) - has been established to enable glazing manufacturers to subject their products to a multi-variate performance appraisal.

Design integration studies were undertaken to involve building industry professionals in advanced glazing and to obtain the feedback which is necessary for manufacturers to understand market forces and constraints.

Last but not least a marketplace study was carried out to evaluate exploitation potential. This included a market survey of some 300 building industry professionals in 4 countries and an environmental impact study, which involved the development of a software package to determine the environmental life cycle cost/benefit of any glazing system.

**PARTNERSHIP**

| | |
|---|---|
| **Organisation** | Belgian Building Research Institute |
| **Address** | Avenue P Hollofe 21<br>Limelette  B-1342, Belgium |
| **Contact** | Mr Serge Martin |
| **Telephone** | 00 32 2 655 7810 |
| **Fax** | 00 32 2 653 0729 |
| **e-mail** | serge.martin@bbri.be |

| | |
|---|---|
| **Organisation** | BRE Scotlab |
| **Address** | Kelvin Road<br>East Kilbride, Lanarkshire  G75 0RZ, UK |
| **Contact** | Dr Paul Baker |
| **Telephone** | 00 44 13552 33001 x 5234 |
| **Fax** | 00 44 1355 241895 |
| **e-mail** | bakerp@bre.co.uk |

| | |
|---|---|
| **Organisation** | ESRU |
| **Address** | Dept of Mechanical Engineering<br>University of Strathclyde<br>James Weir Building, Montrose Street<br>Glasgow  G1 1XJ, UK |
| **Contact** | Professor Joe Clarke |
| **Telephone** | 00 44 141 552 4400 x 3986 |
| **Fax** | 00 44 141 552 8513 |
| **e-mail** | joe@esru.strath.ac.uk |

| | |
|---|---|
| **Organisation** | Fraunhofer Institut für Solar Energiesysteme |
| **Address** | Oltmannstrasse 5<br>Frieburg 79100<br>Germany |
| **Contact** | Dr Werner Platzer |
| **Telephone** | 00 49 761 458 8131 |
| **Fax** | 00 49 761 458 8132 |
| **e-mail** | platzer@ise.fhg.de |

| | |
|---|---|
| **Organisation** | Glaceries de Saint-Roch S.A |
| **Address** | Service Recherche et Développement<br>Rue des Glaces Nationales 169<br>Sambreville  B-5060, Belgium |
| **Contact** | Dr Nicolas Vanandruel |
| **Telephone** | 00 32 71 26 12 86 |
| **Fax** | 00 32 71 261 697 |
| **e-mail** | Nicolas.Vanandruel@saint-roch.be |

| | |
|---|---|
| **Organisation** | Glaverbel S.A |
| **Address** | Centre de Recherche et Développement<br>Rue de l'Aurore 2<br>B-6040 Jumet<br>Belgium |
| **Contact** | Ir Vincent Lieffrig |
| **Telephone** | 00 32 71 28 02 47 |
| **Fax** | 00 32 71 422 355 |
| **e-mail** | Vincent.Lieffrig@crd.glaverbel.be |

| | |
|---|---|
| **Organisation** | Halcrow Gilbert Associates |
| **Address** | Burderop Park<br>Swindon<br>SN4 0QD, UK |
| **Contact** | Dr Robert Cohen |
| **Telephone** | 00 44 1793 814756 |
| **Fax** | 00 44 1793 815020 |
| **e-mail** | rrc@hga.co.uk |

| | |
|---|---|
| **Organisation** | LESO-PB |
| **Address** | École Polytechnique Fédérale de Lausanne<br>Lausanne 1015<br>Switzerland |
| **Contact** | Mr Stéphane Citherlet |
| **Telephone** | 00 41 21 693 5556 |
| **Fax** | 00 41 21 693 5550 |
| **e-mail** | Stephane.Citherlet@epfl.ch |

| | |
|---|---|
| **Organisation** | Pilkington Technology Centre |
| **Address** | Hall Lane<br>Lathom<br>Ormskirk  L40 5UF<br>UK |
| **Contact** | Mr Brian Pye |
| **Telephone** | 00 44 1695 54463 |
| **Fax** | 00 44 1695 54866 |
| **e-mail** | pyeb@ptc.pilkington.co.uk |

# 1 OBJECTIVES

This project sought to tackle the four most significant barriers to the effective uptake of advanced glazing systems:

1. In the area of product performance, the project aimed to generate reliable information on how advanced window systems behave when placed within different types of buildings, in different climates and with different occupancy regimes and intensities.
2. In the area of product characterisation, the project aimed to provide standard test procedures for fully assessing the practical performance of advanced glazing systems.
3. In the area of product design, the project aimed to create an integrated performance assessment tool which could be used by glazing manufacturers to assess the overall performance (comfort, energy and environmental impact) of advanced glazing/framing systems when incorporated in realistic design contexts.
4. In the area of design integration, the project aimed to expand knowledge on how to incorporate advanced glazing systems within existing buildings, taking into account buildability, aesthetics and cost.

# 2 TECHNICAL DESCRIPTION

## 2.1 Introduction

From an energy and environment viewpoint, it is well understood that the glazed component of a building is, at the same time, the weakest and strongest element. Its disadvantages are associated with heat loss, discomfort (radiant exchange and down-draughts) and visual glare; its benefits include passive solar heat gain, electric lighting power reduction and view. Previous research has therefore sought to assist the industry in accentuating the benefits while eliminating the disadvantages. By focusing on specific technologies, such research has brought about significant developments in advanced glazing systems in the form of new glazing types and window system encapsulations - low emissivity and electrochromic products being examples of the former; multiple glazing assemblies, low conductivity frames and noble gas fills of the latter. While the potential of advanced window systems is high, little has existed in the literature to help manufacturers and designers to quantify performance in realistic situations; and there has been a lack of knowledge about which of the advanced glazing technologies are most likely to have wide-scale application. Thus there was little incentive for window system manufacturers to progress innovative and advanced features.

The Image project addressed these barriers by two main activities: the use of computer simulations to determine the effects of various advanced glazing components in different building types in different climates; and the laboratory and outdoor testing of advanced glazing systems in order to measure thermal and optical properties and to generate data sets which could be used to calibrate the computer simulation models.

The project had 6 work packages as follows:

| Work Package | Description |
|---|---|
| WP 1. | standard test procedures |
| WP 2. | performance data capture |
| WP 3. | design integration studies |
| WP 4. | performance assessment method |
| WP 5. | integrated performance modelling |
| WP 6. | marketplace study |

The relationships between these work packages and the barriers elaborated above are summarised in Figure 1.

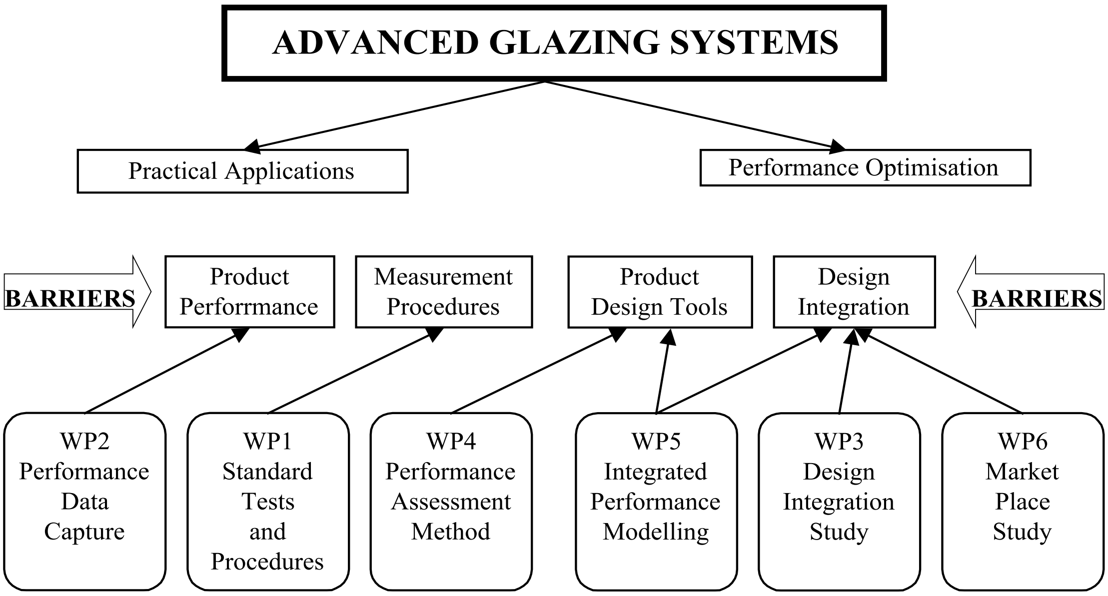



Figure 1: Relationship between work packages and perceived barriers.

## 2.2 Standard Test Procedures

The Image project has developed standard test procedures for the performance assessment of advanced glazing systems in two types of testing environment: the laboratory and outdoors. For the laboratory environment, the physical parameters to be measured have been identified and state-of-the-art measurement techniques have been summarised in principle. For the outdoor testing, a standard test procedure tailored to advanced glazing systems has been defined, based on experience from previous EC (Passys-related) projects.

Both laboratory and outdoor standard test procedures aim not only to determine the physical characteristics of the tested components but also to generate high quality datasets that enable confidence to be gained in component computer modelling.

## 2.3 Performance Data Capture

During the Image project, a whole range of glazing and window systems, from high-technology glazings to more ordinary framing systems, have been tested in various environments and have been studied by means of numerical simulation. A good agreement has been found between the measurements that have been obtained using outdoor and laboratory tests. The results obtained by different experimental methods are consistent which means that the choice of one experimental route rather than another is not likely to lead to different conclusions when assessing the overall performance of a component.

Numerical simulation tools have also proved to be a reliable way to assess the window component's performance. For geometrically simple components, a limited amount of testing supported by simulation activities has been shown to be sufficient to obtain an accurate picture of overall performance. In the case of more advanced or complex components, experimental testing is the most appropriate means to assess overall performance and modelling should come as a secondary step. In these cases, accurate datasets from the experimental testing should be used to ensure the reliability of a numerical model before it is employed for more wide-ranging analysis of a window component's performance.

## 2.4 Design Integration Studies

In order for advanced glazing technologies and components to enter the building design marketplace as a technically and economically viable proposition, it is essential to gain the interest of leading architects, and their clients, and so to understand the practical and aesthetic considerations which determine whether such technology is specified for individual building projects. Design integration studies were undertaken to involve building industry professionals in advanced glazing and to obtain the feedback which is necessary for manufacturers to understand market forces and constraints.

Each design study involved a real building project, potentially suitable for the application of advanced glazings. The IMAGE analysis team worked closely with the design teams to assess the potential for different advanced glazing systems as the design process progressed. The aim was to provide a holistic appraisal package, incorporating energy performance, indoor air quality, environmental impact, amenity and cost assessments.

Four design integration studies were completed. All involved prestigious, high profile buildings designed by leading architects. Three of the buildings were offices located in the UK (one in London, one in Birmingham and the third in Accrington, near Manchester) and the fourth was a foyer for an auditorium in Belgium. The office buildings in London and Birmingham were large, relatively deep plan, medium-rise structures for which air conditioning was effectively unavoidable. For these two buildings, the objective of the advanced glazing options was to enhance thermal comfort, avoid glare and minimise cooling plant capacity and energy consumption. The third office building and the auditorium foyer had a much stronger emphasis on energy saving in their briefs, and the clients were prepared to accept a wider tolerance on the internal temperature in summer, thereby allowing the design teams to consider complete avoidance of the use of mechanical cooling. For these two buildings, the primary aim for the advanced glazing was to provide acceptable thermal comfort in summer, whilst maintaining good daylighting and low heat loss in winter.

Technically, the predicted performance of the advanced glazing options was very encouraging, yielding reductions in $CO_2$ emissions of up to 25%, savings in cooling plant capacity of 11% and significant improvements in thermal comfort. Furthermore, it was shown that advanced glazing can be economically viable where its extra cost is balanced by savings in the installed cooling plant capacity. Even where the extra cost of advanced glazing is unlikely to be economically justified by energy savings, it was found that it may still be chosen by a client after taking into account potential savings in maintenance costs and any thermal comfort benefits.

## 2.5 Performance Assessment Using Computer Simulation

A major part of the project was devoted to the development of better computer simulation techniques for representing the performance of glazed elements of buildings. The simulation methods used were applied to four existing and five proposed buildings. For each case studied, performance was assessed in terms of HVAC and electrical system capacities, fuel consumptions, environmental emissions, thermal and visual comfort and glare sources. A significant deliverable from the computer simulation activity was a new software product - the GDST (Glazing Design Support Tool) - which has been established to allow the project's industrial partners to subject their products to a multi-variate performance appraisal.

## 2.6 The Marketplace Study

The primary objective of this task was to carry out appropriate technical, economic and marketing assessments of advanced glazing systems and their capabilities with a view to evaluating potentials for exploitation in the market place. The main activity undertaken to meet this objective was a market survey; four subsidiary studies were also initiated addressing seal integrity, ageing of coatings, adjustable shading, and environmental impact.

The study on seal integrity and ageing produced a state of the art review by the manufacturers involved in the project. The study of adjustable shading devices used in tandem with advanced glazing focused on their durability in real applications and was based on case studies of 10 buildings. The results highlighted the importance of achieving a satisfactory technical performance (energy and comfort), producing an aesthetic architectural harmony with the building, creating an ergonomic design which the occupants understand how to operate and ensuring long term performance by using robust components and effective maintenance. The study found that adjustable shading device technology has improved substantially in the last decade. However robust and reliable devices are expensive and there is still a gap between actual and ideal performance. This can be due to either shortcomings in the design of the shading device or less than optimum operation of the device by occupants or, if applicable, an automatic control system.

The key objectives of the marketplace study were to learn more about the industry’s awareness of different advanced glazing products and barriers preventing their more widespread use. This was successfully achieved by a survey of some 300 building industry professionals in 4 countries. The results of the survey confirmed that most professionals are aware of the full range of commercially available advanced glazing products. Not surprisingly, awareness was more patchy for products still at the research stage such as electrochromic and vacuum glazing.

With regard to use of advanced glazing, only solar control coating was widely and regularly used by the respondents. The reason for the lack of market penetration by other advanced glazing technologies is primarily their extra cost over standard double glazing. Durability was also mentioned as a major concern. Nevertheless, respondents’ replies gave some grounds for optimism about future use of advanced glazing, particularly technologies already being used by ‘pioneers’, such as triple glazing with low e and argon fill, double glazing with mid-pane blinds, double skin with solar protection and improved thermal frames.

The environmental impact study involved the development of a software package to determine the environmental life cycle cost/benefit of a window. The environmental impact (global warming, acidification potential, photosmog emissions and waste production) of the main components of a window, during their production and disposal phases, has been combined with the window's impact on a building's energy consumption for the lifetime of the building (calculated by a separate software package). The software enables this 'ecobalance' to be calculated for any window whose components are included in the software's extensive databases.

# 3 RESULTS AND CONCLUSIONS

## Experimental Results

Standard test procedures for the performance assessment of advanced glazing systems have been extensively applied within the framework of the Image project and have been shown to supply valuable information.

A good agreement has been found between the measurements that have been obtained using outdoor and laboratory tests. Each experimental route has its own advantages and limitations and should be selected according to the pursued objective. For detailed measurement of a component's characteristics, laboratory tests are best while for a component for which, for example, size and climate may be significant, outdoor tests are more appropriate.

The results obtained by different experimental techniques are consistent and the choice of one experimental route rather than another is not likely to lead to different conclusions when assessing the overall performance of a component.

Experimental and simulation results are consistent and in good agreement with each other. The level of detail in a model has of course to be chosen judiciously. It has been shown that in certain cases simplified models can provide valuable performance information for a limited amount of effort.

It is evident that the use of simulation tools is increasingly one of the most cost effective ways to determine the characteristics of glazed components. For multi-glazed systems, measurement of the material characteristics and numerical simulations produce results which are as reliable and sometimes more accurate than intensive laboratory testing of complete elements. On the other hand, component testing is still the most appropriate method for overall performance assessment when dealing with more complex components like variable transmittance glazing or multi-functional windows.

## Computer Simulation

A methodology has been developed for the detailed appraisal of advanced glazing systems when applied to existing or proposed designs. The method includes the notion of an Integrated Performance View (IPV) by which the benefits associated with a particular glazing component can be ascertained across a range of criteria. The method has been applied to 4 existing and 5 proposed buildings in order to test the applicability of advanced glazing systems across a range of design types and climates and under realistic marketplace constraints. The following conclusions have been drawn:-

On design integration:

- There are no simple paradigms for the application of advanced glazings to buildings. Relatively large differences in attainable performance have been observed for the different building/location combinations included within the project.

- Advanced glazings are capable of reducing the installed heating capacity by up to 20% and the installed cooling capacity by up to 60%. In such cases the capital cost savings associated with boiler and chiller plant should be used to ensure advanced glazing cost effectiveness.
- Advanced glazings are capable of reducing heating energy consumption by up to 18% and cooling energy consumption by up to 70%. Such reductions translate to significant savings in running costs and gaseous emissions.
- In many cases advanced glazings will marginally increase the energy consumed by artificial lighting because of the generally lower visible transmittance.
- Advanced glazings will significantly improve the local thermal comfort in winter and summer resulting in a positive effect on occupant satisfaction and productivity.
- Special light redirecting/diffusing advanced glazings will significantly improve visual comfort.
- Advanced glazings have the potential to significantly reduce energy demand (but not the demand profile shape) and thereby facilitate the introduction of building-integrated renewable energy technologies (e.g. PV-integrated facades).

On integrated performance modelling:

- A performance assessment methodology has been developed and tested for advanced glazing design integration appraisal.
- The project has resulted in improved methods for the integrated modelling of buildings with advanced glazings and daylight responsive luminaire control under realistic skies.
- An industry-oriented glazing design support tool (GDST) has been developed for a PC platform. This offers two modes of operation: a marketing support mode where IPVs for pre-formed building/climate/glazing combinations can be viewed, and an R&D mode where new combinations can be defined and sent to ESP-r for IPV production.

On the link between simulation and experimental testing:

- Procedures have been established for the calibration of advanced glazing simulation models against experimental data collected from the PASLINK test cell.
- The calibration procedure has been successfully applied to several advanced glazings.

## Design Integration Studies

Four design integration studies have been completed. All four involved prestigious, high profile buildings designed by leading architects. Three of the buildings were offices located in the UK (one in London, one in Birmingham and the third in Accrington, near Manchester) and the fourth was a large foyer space for a 1,400 seat auditorium in Belgium. Technically, the predicted performance of the advanced glazing options was very encouraging, yielding reductions in $CO_2$ emissions of up to 25%, savings in cooling plant capacity of 11% and significant improvements in thermal comfort.

Generally, advanced glazing can be economically viable where its extra cost is balanced by savings in the installed cooling plant capacity, as was demonstrated in design integration study 1. However, the significant extra cost of a mid-pane blind compared with an internal blind is unlikely to be economically justified by energy savings. Nevertheless, the decision about mid-pane blinds should also take into account possible cooling plant capacity reductions, the considerable savings in window and blind cleaning costs and the undoubted thermal comfort benefits.

On the other hand, the opposite applies when comparing integrated mid-pane blinds with a ventilated double skin: the annual energy is higher but the capital costs are significantly lower. The pay-back time for a ventilated double skin on the basis of energy savings will therefore typically be longer than several decades. However other considerations must be taken into account, such as the double skin has a lower 'U' value and thus produces higher surface temperatures in winter, enhancing thermal comfort. Also, at the present time, the maintainability of the shading in the double skin is better proven due to its accessibility.

Another option investigated was a double skin with integrated mid-pane blinds in the outer skin compared with a ventilated double skin incorporating solar shading. It was found that these systems have a very similar technical performance but the cost of the integrated mid-pane blinds option was significantly higher.

## Marketplace Study

The industry's awareness of different advanced glazing products and barriers preventing their more widespread use were successfully analysed by a survey of some 300 building industry professionals in 4 countries.

The results of the survey confirmed that most professionals are aware of the full range of commercially available advanced glazing products. Not surprisingly, awareness was more patchy for products still at the research stage such as electrochromic and vacuum glazing.

However, the respondents regularly used only one advanced glazing technology, solar control coating. Price was by far the most important commercial disadvantage named by respondents, although durability was also a major concern.

Nevertheless, respondents replies gave some grounds for optimism about future use of advanced glazing, particularly technologies already being used by 'pioneers', such as double or triple glazing with low e and argon fill, double glazing with mid-pane blinds, double skin with solar protection and improved thermal frames.

A software package has been developed to determine the environmental life cycle cost/benefit of a window. In order to perform this calculation, the window has been broken down into its constituent components and their global environmental impact during their production and disposal phases has been combined with the window's impact on the building's energy consumption for the lifetime of the building.

A spreadsheet has been developed which allows the calculation of this ecobalance for any combination of the window elements considered. For a given window, the spreadsheet will calculate the non-renewable energy consumption, the global warming and the acidification potential, the photosmog emissions and the waste production.

# 4 EXPLOITATION PLANS AND ANTICIPATED BENEFITS

The project has generated 3 main deliverables which can be exploited further:

1. Standard Test Procedures

The project has produced proposed Standard Test Procedures. These will now need to be reviewed by third parties to confirm their acceptability. The first step should be a peer review of the proposed procedures by interested parties such as other research organisations and glazing manufacturers. If a consensus can be reached, the next step would be to pursue the development of a European Standard. This program would require support from the EC and might be completed within 3 years.

The main innovative feature of the proposed Standard Test Procedures is the ability to prove the performance of glazed elements for buildings under real climate conditions. Glazing manufacturers seeking to develop new products for improving the performance of glazing in buildings will need to test or prove these new products using test facilities compliant with accepted (eg European or ISO) standards. Organisations able to offer compliant facilities as a service to manufacturers will be able to run such a facility commercially.

2. The Integrated Performance View (IPV)

The performance of advanced glazing products have previously been characterized by basic parameters such as U-value, solar and visible transmittance, etc. which do not readily translate to an IPV. The overall performance of the glazing has been difficult to summarise. Within the IMAGE project, the ESP-r and Radiance programs, for thermal and lighting simulation respectively, have been placed within an application framework whereby the results from simulations are collated to provide a succinct summary of overall performance, called an IPV. The IPV is a collection of representative performance metrics which quantify building fuel use, equivalent environmental impact and room level comfort in a way which supports comparisons between alternative designs.

The main innovative feature is the combining of the outputs from thermal simulation with the outputs from detailed lighting analysis, hence addressing simultaneously thermal and visual comfort. Third parties wishing to use ESP-r and having a license to do so will benefit from the additional capability afforded by the automatic generation of IPVs.

3. Glazing Design Support Tool (GDST)

The GDST is a software tool which will indicate the performance of a given advanced glazing system in a specific building under given climatic conditions. This is achieved either by accessing a library of pre-processed buildings, glazings and locations or by operating a short-cut, user-friendly version of the thermal simulation programme ESP-r.

Glazing manufacturers and their agents currently have no reliable means to predict the performance of their advanced glazing products when applied in specific buildings or climates. They can only demonstrate their appearance and provide data from steady state laboratory tests ('U' value, transmissivity, etc.). The GDST will enable glazing manufacturers to predict the beneficial effects of advanced glazing in new designs, and thereby promote them to designers and clients. The main innovation is an ability for the manufacturers' sales representatives or marketing staff to predict very quickly the potential benefits of using different advanced glazing products in a particular new building or building refurbishment, just at the time when decisions about the glazing to be used in that building are being made. Such an enhancement to the service glazing manufacturers are able to provide their customers will greatly improve the chances of new advanced glazing products penetrating the market.

The GDST has been developed in two versions:

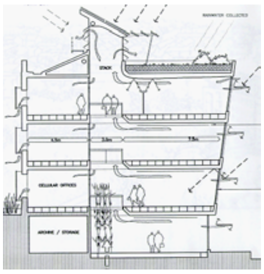
1. The *marketing version,* developed specifically for marketing purposes, requires less input and instantly displays performance results for the given glazing/building/climate combination using a database. This tool only permits the user to select glazing/building/climate combinations that have been previously analysed.
2. The *R & D version* permits the user to examine any combination of the glazing/building/climate datasets incorporated in ESP. It enables the user to run a simulation with ESP-r without knowing how to use the program. The RADIANCE model is not accessible for 'live' runs from the current version of the GDST, but results from previous runs of RADIANCE, stored in the IPV, can be displayed by the GDST.

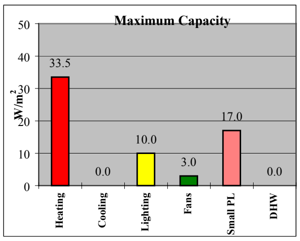
The GDST software is ready for β–testing by the glazing manufacturers participating in Image. In addition to its usability (user-friendliness), one possible barrier to the uptake of the software is the reliability and accuracy of the software: the manufacturers will need to be confident that the software is reliable, as they will be promoting particular glazing products on the basis of the GDST's output. Although the chances of comeback from clients who proceed to use a product and are then unhappy with its performance in practice are very slim, they cannot be altogether discounted.

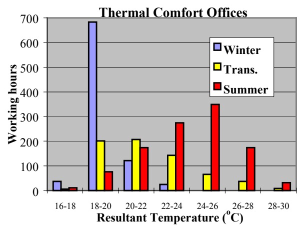
# 6 ILLUSTRATION OF POTENTIAL APPLICATIONS OF THE PROJECT

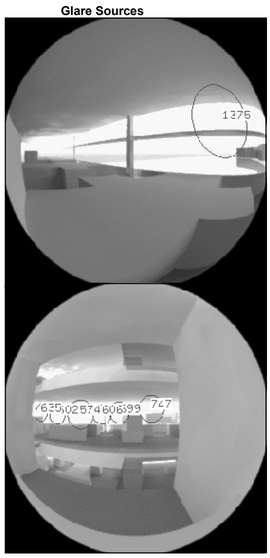
**Hyndburn Zero Energy Office**

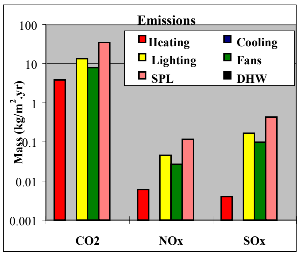
Version: Termodeck Basecase
Contact: mxs@hga.co.uk
Date: Mar-98

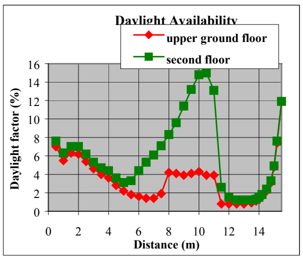




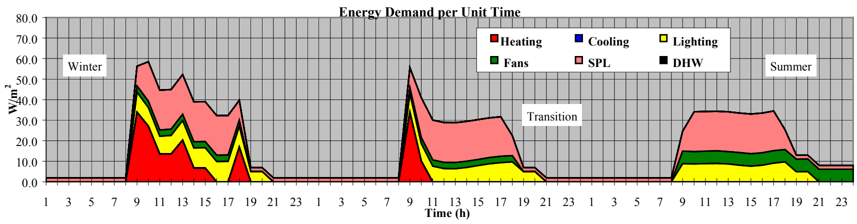




Office and Council Chambers in Accrington UK. Termodeck Base Case - tripple glazing covering 70% of wall, external shading, 2.5 ach (over 19C), occupant load 15 W/m² equipment load 19W/m² (HYNTIMB)




**Annual Energy Performance**

| | |
|---|---|
| Heating: | 20 kWh m2 a |
| Cooling: | 0 kWh m2 a |
| Lighting: | 22 kWh m2 a |
| Fans: | 13 kWh m2 a |
| Small PL: | 57 kWh m2 a |
| DHW: | 0 kWh m2 a |
| **Total:** | **112 kWh m2 a** |

Example Integrated Performance View