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Performance of advanced glazing systems based on detailed and integrated simulation

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ABSTRACT

This article summarises the performance of buildings and building designs where advanced glazing systems (AGS) resulting from the EC's IMAGE (IMplementation of Advanced Glazing in Europe) project were incorporated. To improve the assessment of building performance, a dynamic thermal/daylighting coupling was implemented between two advanced simulation environments. Based on these developments, detailed simulations of public and office buildings have been undertaken and the corresponding results have been analysed to estimate the impacts related to the AGS.

ZUSAMMENFASSUNG

Dieser Artikel faßt die Leistungen bestehender oder geplanter Gebäude zusammen, welche Hochleistungsverglasungen benutzen, wie diese im Projekt EU IMAGE analysiert wurden (Implementierung von Hochleistungsverglasungen in Europa). Um die geschätzten Werte der Leistungen zu verbessern, wurde eine dynamische Kupplung thermische/Licht zwischen zwei leistungsfähigen Werkzeugen verwirklicht. Anhand dieser Entwicklungen wurden detaillierte Simulationen auf öffentlichen und administrativen Gebäuden durchgeführt. Die erhaltenen Ergebnisse wurden schlussendlich zusammengefaßt, und erlauben nun, die Auswirkungen der benutzten Verglasungen besser zu schätzen.

RÉSUMÉ

Cet article résume les performances de bâtiments, existants ou projetés, qui utilisent des vitrages performants tel qu'analysé dans le projet EU IMAGE (IMplémentation de vitrAGes performants en Europe). Afin d'améliorer l'estimation des performances des bâtiments, un couplage dynamique thermique/lumière fut réalisé entre deux outils performants. A partir de ces développements, des simulations détaillées furent effectuées sur des bâtiments publics et administratifs. Finalement, les résultats ainsi obtenus ont été synthétisés pour permettre d'estimer les impacts des vitrages utilisés.

1. INTRODUCTION

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 and visual discomfort, while its benefits include passive solar heat gain, daylighting and view. For an overall assessment of the glazing performance based on computer simulation, it is important to sharply model the physical processes related to the glazed component in a building.

In the framework of the European project IMAGE, which was set up to encourage appropriate applications of advanced glazing to raise awareness of products amongst designers, a major effort was made to improve aspects related to the calculation of the interaction between thermal and daylight simulation. The European Commission DG XII and the Swiss Federal Office for Education and Sciences (OFES/BBW) funded the IMAGE project, which took place between 1996 and 1999. The project involved glass manufactures (Glaverbel glass (Belgium), Pilkington Glass Products Ltd (England) and Saint-Roch (Belgium)), consultants (Halcrow Gilbert Associates (England)), and research organisations (Belgian Building Research Institute (Belgium), Building Research Establishment (Scotland), Fraunhofer Institut fur Solar Energy Systems (Germany) and the Solar Energy and Building Physics Laboratory (Switzerland)).

2. INTEGRATION: THE KEY ISSUE

Within the IMAGE project, ESP-r [1], an advanced transient building/plant environment and RADIANCE [2], an advanced lighting simulation program, have been *dynamically* coupled [3] [4] in order to achieve a high quality simulation for complex building systems as shown in Figure 1.

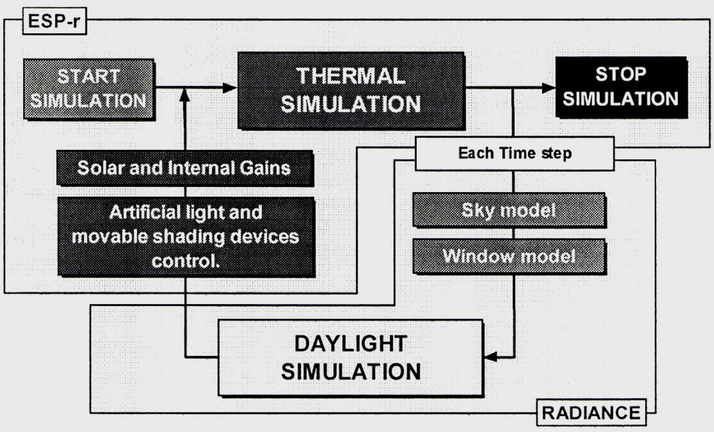

Figure 1 ESP-r/Radiance dynamical coupling

This ESP-r/Radiance coupling has improved the evaluation of:

- Solar and internal heat gains
- Daylight availability
- Blind control
- Energy, cooling and artificial light consumption
- Thermal and visual comfort

This "time step integration" of daylight calculation into thermal dynamic simulation provides an improvement of simulation results but is more time consuming due to the use of a nodal network for thermal algorithms and ray-tracing for daylight algorithms. This methodology is particularly appropriate for complex glazing systems that can not be simulated with simplified methods.
Comparing transient measurements of several advanced glazing systems placed on test cells has validated the coupling. A good agreement between measurements and predictions was observed .

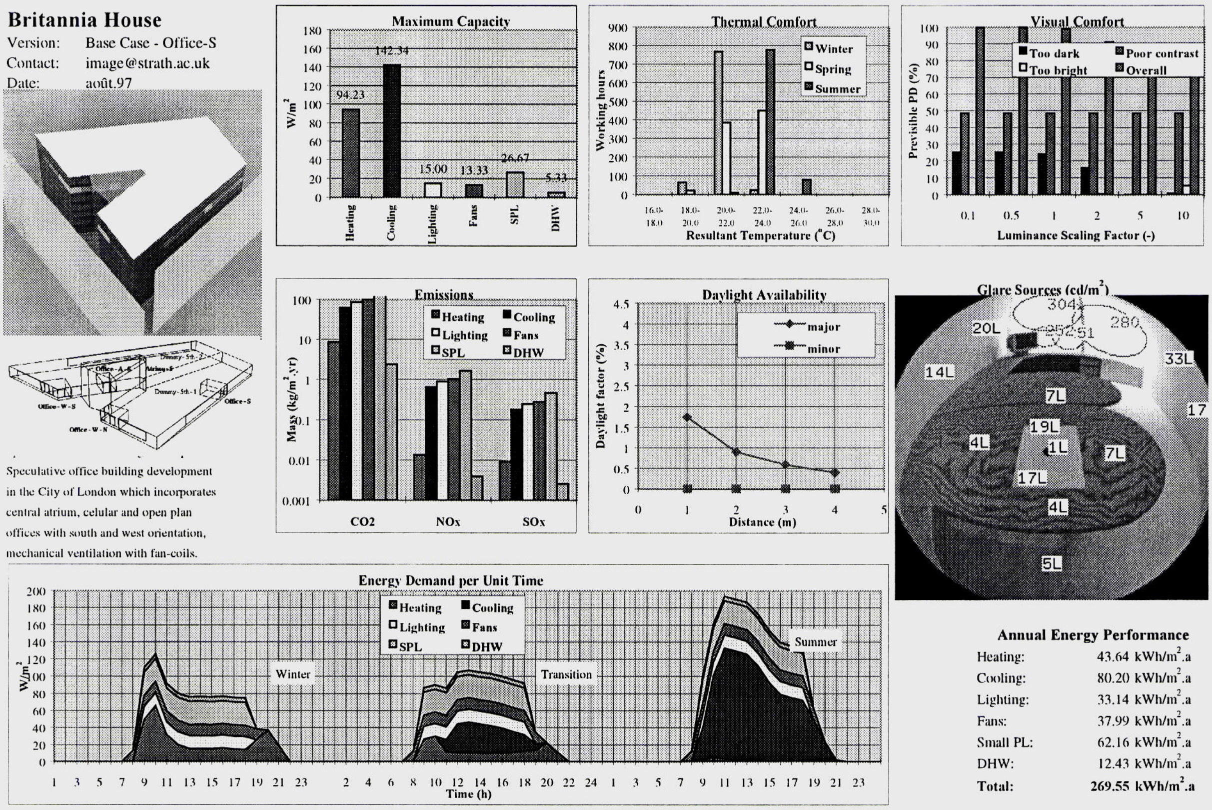

Figure 2 Example Integrated Performance View.

3. INTEGRATED PERFORMANCE VIEW

The performance assessment of an advanced glazing system (AGS) was analysed based on an *integrated performance view* (IPV) as proposed by Clarke [5]. An IPV is a collection of relevant performance metrics for energy consumption, thermal and visual comfort, and environmental impacts due to energy consumption as shown in Figure 2
Comparison between IPVs based on different advanced glazing systems used in the same building allows an estimation of the performance of alternative designs. In order to generalise the impacts related to the AGS, the nine different buildings listed in Table 1 were analysed
The building description, the AGS properties and simulation outcomes for each case/design study can be found in the technical report of the IMAGE project [6]. What follows is a summary of the impacts of advanced glazings on each performance category as judged by comparing the reference and base case models .

Building	• Advanced Glazing Technology
College La Vanoise *Function*: School *Location*: Modane, France.	• *Base case*: double glazed unit with air filling and translucent plastic atrium roof. • *Variant 1*: triple glazing with low emissivity (low-e) coated (3/5) and argon.
Victoria Quay *Function*: Office Complex *Location*: Edinburgh, Scotland.	• *Base case*: double glazed unit with air filling. • *Variant 1*: as base case but with a low-e coating (surface 2). • *Variant 2*: as reference 1 but with argon filling. • *Variant 3*: as reference 2 but with reduced low-e coating. • *Variant 4*: low-e coated (surfaces 3 and 5) triple glazed unit with krypton.
Brundtland Centre *Function*: Exhibition and Conference Facility *Location*: Toftlund, Denmark.	• *Base case*: low-e double glazed facade with light directing blinds, linked control of blinds and luminaries, central atrium with low-e double glazed roof with integral PV modules. • *Variant 1*: as base case but with the advanced glazing/ blinds removed and luminaries' control deactivated.
Passive Solar Housing *Function*: Residential *Location*: Linford, England.	• *Base case*: clear float double glazed unit with air filling. • Reference 1: low-e coated (surface 3) double-glazed unit with air filling. • *Variant 2*: low-e coated (3 and 5) triple glazed unit with argon filling. • *Variant 3*: solar control low-e coated (surface 2) double glazed unit with argon filling.
Brindley place *Function*: Office Complex *Location*: Birmingham, England.	• *Base case*: hard low-e coated (3) double-glazed unit with air filling. • *Variant 1*: soft low-e coated (2) double glazed unit with argon filling. • *Variant 2*: soft low-e coated (2) double glazed unit with air filling. • *Variant 3*: soft low-e coated (2) double glazed unit with air filling (≠*Var. 2*)
Britannia House *Function*: Office Complex *Location*: London, England.	• *Base case*: hard low-e coated (3) double-glazed unit with air filling and an internal venetian blind. • *Variant 1*: hard low-e coated (3) double-glazed unit with air filling and a mid-pane venetian blind. • *Variant 2*: soft low-e selective coated (2) double-glazed unit with air filling and an internal venetian blind. • *Variant 3*: soft low-e selective coated (2) double glazed unit with air filling, mid-pane venetian blind and single pane float glass. • *Variant 4*: soft low-e selective coated (2) double-glazed unit with air filling and a mid-pane venetian blind.
Hyndburn *Function*: Office Complex *Location*: London, England.	• *Base Case*: vertical facade, fully glazed, with atrium north light. • *Variant 1*: as base case but without atrium north light. • *Variant 2*: as base case but with light-shelf and opaque windowsill to 800*mm*. • *Variant 3*: as reference 2 but with a stepped floor plate. • *Variant 4*: as base case but with opaque windowsill, reduced glazed area and prismatic glazing. • *Variant 5*: as base case but with modified atrium north light.
Glasgow Lighthouse *Function*: Retail and Demonstration *Location*: Glasgow, Scotland.	• *Base case*: doubled glazed unit with air filling. • *Variant 1*: low-e coated (surfaces 3 and 5) triple glazed unit with argon filling. • *Variant 2*: as reference 1 but with daylight-related luminary control
Glenview *Function*: Hospital *Location*: Inverness, Scotland.	• *Base case*: clear float double glazed unit with air filling. • *Variant 1*: double glazed unit with a tint-coated external pane (2), laminated clear float internal pane and air filling. • *Variant 2*: double glazed unit with a tint-coated external pane (2), a hard low-e coated (surface), laminated internal pane and air filling. • *Variant 3*: double glazed unit with a tint-coated external pane (2), a hard low-e coated (3), laminated internal pane and air filling.

Table 1 Buildings simulated within the IMAGE project.

4. PERFORMANCE

The impact of advanced glazing systems on the following performance parameters was observed:

Installed capacity

Heating Capacity: Moderate Impact

A moderate impact on maximum heating capacity was observed in some cases, with reductions of the order of 5% to 8% noted:

- in offices where the peak heating capacity is dominated by ventilation air preheating;
- in office spaces with high casual heat gains, and therefore low heat demand'
- in buildings such as schools and offices where the dominant heat loss paths are infiltration and/or opaque fabric conduction.

Heating Capacity: High Impact

A high impact on maximum heating capacity was observed in some cases, with reductions up to 20% noted in highly glazed spaces with low infiltration rates.

Cooling Capacity: Moderate Impact

A moderate impact on the maximum cooling capacity was observed in some cases, with reductions of the order of 11% noted in offices with effective structural solar shading.

Cooling Capacity: High Impact

A high impact on the maximum cooling capacity was observed in some cases, with reductions of the order of 30% to 60% noted:

- in highly glazed spaces where a major component of the heat gain is due to direct and indirect solar gain;
- in mid-European coastal climates where the central ventilation plant cooling loads are moderate due to the lower ambient summer temperatures in summer. Note that in such climates the lower U-Value of solar control glazing will tend to increase the peak cooling capacity (e.g. by up to 5%) because of the reduction in the heat loss, which may not occur in warmer climates.

Annual Energy Requirements

The impact of advanced glazing on annual energy requirements was observed to depend on the context as follows.

Heating Energy: Low Impact

A low heating energy saving, of the order of 0.6% to 9%, was observed in the same cases as listed above under Heating Capacity: Moderate Impact.

Heating Energy: Moderate Impact

A moderate heating energy saving, of the order of 10% - 18%, was observed in the following cases:

- -in buildings with low U-value triple glazed system;
- -in highly glazed spaces with low U-value, solar control glazing to strike an effective balance between thermal and solar control.

Cooling Energy: Moderate Impact

A moderate cooling energy saving, of the order of 10% - 14%, was observed in buildings where effective structural solar shading is applied.
In mid-European coastal climates, low U-value, solar control glazing tends to increase the cooling energy requirement (e.g. by up to 11%) because of the reduced heat loss.

Cooling Energy: High Impact

A high cooling energy saving, of the order of 51% - 74%, was observed in buildings where the principal cooling load component is due to the solar gain through the glazing. In such cases, solar control glazings therefore have the potential to deliver significant energy savings.

Lighting Energy

Lighting energy was reduced by up to 7%, and increased by up to 10%, depending on degree to which the advanced glazing component changed the visible transmittance.

On Thermal Comfort

The impact of advanced glazing on thermal comfort was observed to depend on the context as follows.

- Low U-value glazing delivers significant increases resultant temperatures during in winter, generally maintaining temperatures within the comfort zone.
- Low U-value glazing causes moderate increases in resultant temperatures during summer, generally increasing the overheating tendency.
- Solar control glazing significantly decreases the resultant temperature in summer, generally maintaining temperatures within the comfort zone.

On Daylight Availability

All advanced glazing systems had god visible transmittance and therefore only marginally decreased in the daylight availability was pointed out.

On Visual Comfort

Light redirecting and diffusing systems were observed to significantly improve visual comfort. The optimum arrangement will offer distinct redirecting or diffusing properties while maintaining high visible transmittance and allowing dynamic solar control.

Glare control through the use of low visible transmittance glazing must be balanced by occupant viewing requirement.

5. ENVIRONMENTAL IMPACTS

The use of the ecobalance to determine the 'environmental cost' of a window has been analysed for various AGS. In order to estimate the global environmental impact of the windows, the study has analysed not only the ecobalance data during the whole life time of the unit but also the energy consumption during its utilisation stage. A typical Swiss office and classroom have been used to which the climates of Glasgow, Lausanne, and Rome have been applied.

The detailed analysis [7] has shown, that even if the *ecological cost* of an advanced glazing system is greater than a that of a standard window during unit construction, maintenance and deconstruction, the energy consumption during the utilisation phase rapidly decreases due to the improvement of the windows' performance. Within about 5 years, depending on the AGS, the typology and the climate, the use of AGS produces less environmental impacts.

6. CONCLUSION

The simulation of design and case studies undertaken in the framework of the European project IMAGE has shown the advantage of using advanced glazing systems. Due to the improvement of the window performance (lower U and g-value for almost the same visible transmittance), the energy consumption can be significantly reduced depending on the climate and the AGS used.

Furthermore, a detailed study of the environmental impacts of AGS's has shown that over the component life time the loads are reduced compare to more conventional glazing.

The project has demonstrated a need for smart glazing systems that facilitate a dynamic thermal/visible transmittance adaptation as a function of the prevailing heating/cooling demands, thermal and visual comfort and daylight penetration requirements. Just as control strategies to manage the complex and dynamic interactions between the window, shading and lighting systems.

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