AN ADVANCED GLAZING CASE STUDY FROM THE IMAGE PROJECT

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ABSTRACT

The IMAGE project aims to generate new performance information for advanced glazing and identify opportunities for applications. There are two main research activities in support of these aims: the laboratory and outdoor test cell monitoring of alternative systems; and the use of simulations to determine the cost-benefit of application to different building types when placed in different climate contexts. This paper describes the application of computer simulation as part of a cost-benefit analysis applied to a live building design project for a major office building in Birmingham. The results shows that, starting from a good standard in the base case, the addition of advanced glazing has significant energy and environmental benefits that do not necessarily increase the overall capital cost of the building.

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. Advanced glazing types (e.g. electrochromic, aerogel and low emissivity products) and window systems (e.g. evacuated glazing) therefore aim to accentuate these benefits while eliminating the disadvantages.

The IMAGE project aims to generate new performance information for advanced glazing and identify opportunities for applications. There are two main research activities in support of these aims: the laboratory and outdoor test cell monitoring of alternative systems; and the use of simulations to determine the cost-benefit of application to different building types when placed in different climate contexts.

The simulation work adheres to a standard performance assessment method (Clarke et al 1996) whereby computer modelling is used to determine the thermal and visual performance of the building against a corresponding base case with no advanced glazing. In this way, the contribution of the advanced glazing may be quantified. For cases where advanced glazing offers an improvement to the cost/performance ratio, parametric analyses are undertaken to examine the prospects for optimisation with respect to glazing system design and artificial light control.

Finally, the base case (as-built or as-intended) and reference models are contained within an electronic ‘design manager’ which allows 3D browsing, model exporting to CAD, and further exploratory thermal and/or lighting analysis.

This paper relates to a development in Birmingham. It summarises the computer representation of the building and its related advanced glazing reference designs, and presents the simulation results from the ESP-r and RADIANCE systems in the form of an *Integrated Performance View* (IPV) for each case studied. Complete details of the computer model and performance results are available on-line within the ESP-r system.

COMPUTER REPRESENTATION

The office building is located in Birmingham and forms the north-west edge of a central square in a new development. It comprises 7 storeys of offices, 14m wide on either side of central atrium which is 10-12m wide. The architect wishes the south-east elevation, facing the square, to be extensively glazed with full height windows to take advantage of the view and to provide good contact with the outside activities. This elevation has horizontal shading which projects 0.4m at 0.8m vertical intervals running the entire length of the full height glazing. A range of HVAC systems are proposed from which prospective tenants may chose a conventional air-conditioning system using fan-coils, displacement ventilation with chilled ceilings or displacement ventilation alone.

Model Geometry

When analysing the performance of a large building to assess the benefits of advanced glazing there is little point attempting to represent the whole building. To do so only produces large quantities of redundant data.

The model geometry chosen for this study comprises the central atrium, and 10 zones representing typical south-east and north-west facing offices when equipped with alternative environmental control systems: 2 and 4 pipe fan coil, displacement ventilation with chilled ceiling and displacement ventilation only. The offices have a floor area of 90 m² and a volume of 288 m². A central atrium is represented by three thermal zones, i.e. atrium-low (representing the lower three floors), atrium-mid (representing one floor) and atrium-up (representing the upper three floors). Additional details have been added to complete the building shape and represent the surrounding buildings.

Glazing Options

Recognising the thermal and visual focus of the project, the glazing layers are represented explicitly so that the intra-pane temperature and radiation processes are modelled in detail. Four glazing products have been applied to the office facades for assessment:

- In the base case simulation, a double glazed unit with a low-e coating (e = 0.176) applied to surface 3, with an air filling.
- In the reference 1 simulation, a double glazed unit with a low-e coating (e = 0.04) applied to surface 2 (inward-facing side of the external pane), with argon filling.
- In the reference 2 simulation, a double glazed unit with a low-e coating (e = 0.04) applied to surface 2, with an air filling.
- In the reference 3 simulation, a double glazed unit with a low-e coating (e = 0.04) applied to surface 2, with an air filling. This unit has a slightly lower visible transmission and a slightly higher solar transmission than reference 2 but is considerably less expensive.

Table 1 lists the thermal and optical characteristics for these glazing systems. The physical characteristics are based on data supplied by the glazing manufacturers, while the angle-dependent OVT and OST values were determined from the Window 4.1 program (Finlayston et al 1993).

Three system types were applied to the atrium roof:

- In the base case simulation, a double glazed unit with low-e coating (e = 0.176) applied to surface 3 (laminated glass) with air filling.
- In the reference 1 simulation, a double glazed laminated unit with low-e coating (e = 0.04) applied to surface 2 with air filling.
- In the reference 2 simulation, a double glazed laminated unit with low-e coating (e = 0.04) applied to surface 2 with air filling. This unit has a slightly lower visible transmission and a slightly higher solar transmission than reference 2 but is considerably less expensive.

Table 2 lists the thermal and optical characteristics for these glazing systems.

It is important to note that the base case glazing already represents an advanced glazing option, with a relatively low U-value and near optimal visible-to-solar transmittance ratio for solar control glazing. This glazing was specified by the design team prior to the involvement of the IMAGE project.

Usage and Environmental Systems

The following data were supplied by the design team or assumed to define the patterns of internal heat gain.

Occupants and Appliances

The occupied spaces have a loading of one person per 10m² or 7.5W/m² during the period 8:00 to 18:00 during weekdays. It is assumed that the building is not normally occupied at weekends. The small power loads of 20W/m² and are assumed to be on from 8;00 to 18:00 during weekdays.

Lighting and Control

Lighting heat gain is equivalent to 12W/m² in the offices and is assumed to be on from 8:00 to 18:00 during weekdays. The lighting is controlled by dimming (range 100% - 10%) on the basis of the prevailing daylight levels. Table 3 lists the calculated daylight factors for the base case which were used in the lighting control simulation. In the reference simulations the daylight factors were adjusted to account for a change in the glazing visual transmittance.

Heating, Cooling and Ventilation Systems

All office modules are heated by a perimeter convective radiator system with a set-point of 20°C (dry resultant) from 8:00 to 18:00 during weekdays, with a set-back to 15°C at night and at weekends. Fresh air is supplied at the rate of 16 l/s.person (1.8 ac/h) during working hours in the case of the fan coil and chilled ceiling systems. The rate of 2.5 ac/h is applied for the displacement ventilation system. As the office space is maintained at positive pressure relative to the outside, infiltration rates were set to zero. The fresh air is preconditioned against a heating set-point of 18°C and a cooling set-point of 19°C (dry bulb).

The environmental control systems were modelled as follows. The 2 and 4 pipe fan coil systems were modelled as fully mixed ventilation, with convective cooling of the office against a set-point of 22°C (dry resultant) during working hours. The displacement ventilation system applies cooling directly to the fresh air supply down to a minimum supply temperature of 19°C (dry bulb). In the case of static cooling, displacement ventilation is modelled in the same way and the chilled ceiling/ beam systems are modelled by an injection of cooling flux to the suspended ceiling layer with the maximum capacity set at a value which will avoid surface condensation. The set-point for the air temperature was defined as 24°C in order to achieve a comparable resultant temperature to the fan coil systems. The atrium has a displacement ventilation system at the ground floor level delivering 2.5 ac/h (related to the atrium ground floor volume). The fresh air is preconditioned with a heating set-point of 18°C or cooling set-point of 19°C (dry bulb) from 8:00 to 18:00 during weekdays. It is assumed that an equivalent air flow rate passes up the atrium and is extracted at the roof level. There is no additional heating or cooling applied to the central atrium.

Boundary Conditions

Table 4 gives the average and extreme monthly temperatures for the standard UK reference year as used in the study. All simulations were annual.

Simulation Results

Tables 5 summarises the total peak capacities and energy consumptions (office and fresh air conditioning) respectively for the south-east and north-west offices with different environmental control systems after normalisation by floor area.

Figure 1 gives the frequency distribution of the average zone resultant temperature for displacement ventilation and for each case study. The reference 1, 2 and 3 simulations show that the more advanced glazings will result in a reduction in the cooling load. However, displacement ventilation will still be unable to maintain resultant temperatures below 26°C.

As displacement ventilation does not represent a feasible option, even with the application of the advanced solar control glazing, and there is very little difference between the fan coil and chilled ceiling systems, only the fan coil system is further analysed.

Advanced Glazing - Integrated Performance View

A shading/insolation analysis revealed that the north-west facade will receive a significant amount of direct sun during summer but little during the winter. For this reason it was decided to apply advanced glazing systems with a high visible transmittance and solar control to both facades.

This section summarises the overall performance results as obtained from the annual simulations. The results are given in the form of an Integrated Performance View (IPV), which presents several performance criteria across a range of performance types. The IPVs have been produced for a south-east office with a fan coil system and most of the parameters are normalised by floor area.

Figure 2 the IPV for the base case and and Figure 3 shows the reference 3 case. An inter-comparison of the performance entities contained within the IPVs gives rise to the following conclusions.

Maximum Capacity

The diversified total of peak capacities (W/m²) represent critical plant sizes and hence capital costs. Table 6 summaries the results from IPVs and shows the relative reduction in plant peak capacities relative to the base case scenario.

As can be seen , the reference 1 case delivers the greatest reduction in heating capacity - 4.5% when compared to the base case. Reference 2 delivers the greatest reduction in cooling capacity - 10.9% when compared to the base case.

Annual Energy Performance Indicators

The Normalised Performance Indicator (NPI) for the base case is 139.7 kWh/m²yr, while the reference cases are 133.9 kWh/m²yr, 132.0 kWh/m²yr and 132.6 kWh/m²yr respectively.

The reference 2 case delivers the largest energy consumption reduction (6%) relative to the base case, closely followed by the reference 3 case. Table 7 summarises the reduction in energy consumptions relative to the base case.

Based on these data it can be concluded that reference 3 provides the highest cooling energy savings (14%) but there are almost no heating energy savings with any glazing scenario. This latter finding may be attributed to the fact that it is fresh air heating which represents the majority of the energy consumption. There is also a small penalty from application of the advanced glazing scenarios in terms of increased artificial lighting consumption.

Typical Seasonal Energy Demand Profiles

The delivered energy data are expressed as cumulative daily profiles for each season. Regardless of the glazing scenario applied, the building will require cooling, even during cold winter days, and will require artificial lighting, even during sunny spring and summer days. This is typical for fully air conditioned, deep plan office buildings.

Environmental Emissions

The annual energy performance indicators have been converted to equivalent gaseous emissions based on the conversion factors given in Table 8.

The electricity consuming items - cooling systems, fans and artificial lights - are responsible for the largest portion of the gaseous emissions in all categories. The reduction in emissions for the reference models follows the energy consumption trends.

Thermal Comfort

The IPVs give the annual frequency of occurrence of the resultant temperatures within the south-east office space and the upper atrium zone. As can be seen, the office thermal comfort is not significantly affected by the different glazing scenarios. On the other hand, the local thermal comfort (i.e. radiant asymmetry and cold down-draught) is improved by the application of advanced glazings with a lower U-value.

The central atrium is conditioned by the displacement ventilation system located at the ground floor level. Simulations show that temperature stratification will be established and the upper three atrium floors will experience resultant temperatures in excess of 26°C. The application of advanced glazing to the atrium roof reduces significantly the number of hours of thermal discomfort in the upper atrium. The rank ordering of the glazing scenarios is: reference 1 with 37 hours above 26°C, followed by reference 2 with 51 hours above 26°C. The base case glazing scenario results in 682 hours when an average resultant temperature of 26°C is exceeded.

Daylight Availability

The daylight factor is a common metric which is well understood by the design community. The level and distribution of daylight factors is a reasonable indicator of artificial lighting requirements.

As shown on the IPVs, there is a slight reduction in the daylight factors: 3% for reference 1 and reference 2 and 9% for reference 3.

Visual Comfort and Glare

These performance outputs give the visual comfort probability for different viewing directions and highlight potential glare sources within a 3D colour picture (circled red). The results show insignificant variations in these parameters from application of the advanced glazings. This is because of the relatively small decrease in visible transmittance relative to the base case.

It is likely that the vertical facades will give rise to glare problems - as can be seen on the IPVs for the south-east office. The simulations indicate a 40% visual comfort probability for the given viewing directions. This situation is not uncommon in deep plan offices where daylight can contribute to the internal illuminances only up to about 5m from the facade. The resulting low ratio of core to perimeter brightness then gives rise to visual discomfort. This can result in the continuous usage of artificial lighting in order to counteract the brightness contrasts.

A possible improvement would be to install light redirecting glazing to the upper facade window (aimed towards the ceiling), with a high visible transmittance and good solar control. A simpler solution which is likely to be adopted is to use fritted or etched glass in the upper window which will reduce glare without significantly reducing daylight transmission. As can be seen from the IPVs, this is the facade portion which gives rise to the glare problem.

FINANCIAL BENEFITS

An analysis by the project quantity surveyor reveals that the additional cost of employing the reference 3 advanced glazing (including fritted glass to the upper windows) was estimated to be £103,000. Since the main impact of this glazing is on the cooling load and cooling demand the M&E engineers were asked to examine the effect on the HVAC system. The reduction in cost of items such as chillers, pumps, pipework, etc. was estimated to be £110,000. Within the accuracy of such estimates it is difficult to claim that the application of the advanced glazing (reference 3) results in a capital cost saving but it is unlikely to add to the overall cost of the building if the HVAC plant is appropriately sized.

In addition to the capital cost benefit there will be a financial saving associated with reduced energy consumption of the HVAC system.

CONCLUSIONS

Based on the IPV performance indicators for the base and reference cases, the following conclusions can be drawn.

- Advanced glazing offers a 4.5% reduction in the maximum heating capacity and a 10.9% reduction in maximum cooling capacity;
- Advanced glazing offers a 6% reduction in total energy consumption, a 14% reduction in cooling energy consumption and a marginal reduction/ increase in heating/ lighting energy consumption;
- The application of advanced glazing to the atrium roof offers a significant improvement in thermal comfort and reduces summer overheating to acceptable levels. The local comfort conditions close to the perimeter facade will also improve;
- Advanced glazing will insignificantly decrease daylight availability and will not change its characteristic distribution;
- Advanced glazing will not influence the visual comfort and glare source distribution;
- The additional of advanced glazing need not add to the overall cost of the building if the HVAC systems are appropriately sized.

REFERENCES

Clarke J A, Hand J W, Hensen J L H, Johnsen K, Wittchen K, Madsen C and Compagnon R (1996) `Integrated Performance Appraisal of Daylight-Europe Case Study Buildings' *Proc. 4th European Conference on Solar Energy in Architecture and Urban Planning* Berlin, March.

Finlayston E U, Arasthe D K, Huizenga C, Rubin M D, Reilly M S (1993) `Window 4.1 Manual' Building Technologies Group, Energy and Environment Division, Lawrence Berkeley Laboratory.

Table 1: Optical and thermal properties of perimeter facade glazing.

Glazing	LT	GF	LEP	CE	GE	OVT	OST	U
Base Case	6/12/6	Air	3	0.176	0.84	0.671	0.495	1.93
Reference 1	6/12/6	Argon	2	0.04	0.84	0.65	0.33	1.28
Reference 2	6/12/6	Air	2	0.04	0.84	0.65	0.33	1.68
Reference 3	6/12/6	Air	2	0.04	0.84	0.61	0.36	1.78

LT: Layer thickness (mm).
GF: Gas filling.
LEP: Low emissivity coating position (2 means innermost surface of the external pane).
CE: Coating emissivity.
GE: Glass emissivity.
OVT: Overall, normal incidence visible transmittance.
OST: Overall, normal incidence solar transmittance.
U: Overall thermal transmittance (W/m²K).

Table 2: Optical and thermal properties of atrium roof glazing.

Glazing	LT	GF	LEP	CE	GE	OVT	OST	U
Base Case	6/12/4-2-4	Air	3	0.176	0.84	0.646	0.428	1.91
Reference 1	6/12/4-2-4	Air	2	0.04	0.84	0.63	0.30	1.68
Reference 2	6/12/4-2-4	Air	2	0.04	0.84	0.63	0.30	1.68
Reference 3	6/12/4-2-4	Air	2	0.04	0.84	0.59	0.36	1.78

LT: Layer thickness (mm).
GF: Gas filling.
LEP: Low emissivity coating position (2 means innermost surface of the external pane).
CE: Coating emissivity.
GE: Glass emissivity.
OVT: Overall, normal incidence visible transmittance.
OST: Overall, normal incidence solar transmittance.
U: Overall thermal transmittance (W/m²K).

Table 3: Calculated daylight factors as used for lighting control.

Point (m)	base case daylight factor (%)	
	south-east	north-west
1	4.4	12.5
2	2.8	5.6
3	1.7	2.7
4	1.1	1.7
5	0.8	1.3
6	0.7	1.0
7	0.6	0.8
8	0.5	0.7
9	0.5	0.6
10	0.5	0.6
11	0.5	0.6
12	0.6	0.6
13	0.9	0.6
14	1.8	1.7

Table 4: Monthly average and extreme temperatures (°C) for the reference year.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
minimum	-2.2	-0.2	0.9	0.0	0.0	6.5	9.7	9.6	5.6	2.8	-0.5	-4.4
average	5.4	6.5	8.1	8.7	11.9	15.4	18.7	16.9	14.6	12.0	6.6	5.2
maximum	13.2	13.3	16.7	20.1	25.1	24.4	28.7	24.7	22.0	20.1	15.0	13.2

Table 5 Peak capacities and energy consumptions for base case simulations

Base Case Results	**South-East Offices**			**North-West Offices**		
	Heating	**Cooling**	**Lighting**	**Heating**	**Cooling**	**Lighting**
Capacity	W/m²	W/m²	W/m²	W/m²	W/m²	W/m²
Fan Coil	46.3	62.4	12	47.2	62.4	12
Chilled Ceiling	48.4	61.7	12	49.2	62.4	12
Displacement Vent	59.6	24.9	12	60.7	24.9	12
Consumption	kWh/m²y	kWh/m²y	kWh/m²y	kWh/m²y	kWh/m²y	kWh/m²y
Fan Coil	31.3	57.4	14	31.3	52.9	14
Chilled Ceiling	31.6	54.2	14	31.7	50.3	14
Displacement Vent	42.8	2.8	14	42.8	2.8	14

Table 6: Reduction in peak capacities for a south-east office with fan coil system.

Case	Capacity reduction (%)			
	Heating	Cooling	Lighting	Fans
Base case	0.0	0.0	0.0	0.0
Reference 1	4.5	10.7	0.0	0.0
Reference 2	2.6	10.9	0.0	0.0
Reference 3	0.4	8.9	0.0	0.0

Table 7: Reduction in energy consumptions for a south-east office with fan coil system.

Case	Consumption reduction (%)			
	Heating	Cooling	Lighting	Fans
Base case	0.0	0.0	0.0	0.0
Reference 1	0.9	10.4	-3.0	0.0
Reference 2	0.6	13.9	-3.0	0.0
Reference 3	0.0	14.1	-9.0	0.0

Table 8: Gaseous emission conversion factors.

Fuel	Emissions (g/kWh)		
	CO_2	NO_x	SO_x
Gas	100	0.2	nil
Electricity	360	3.0	0.57
Oil	160	0.6	2.0

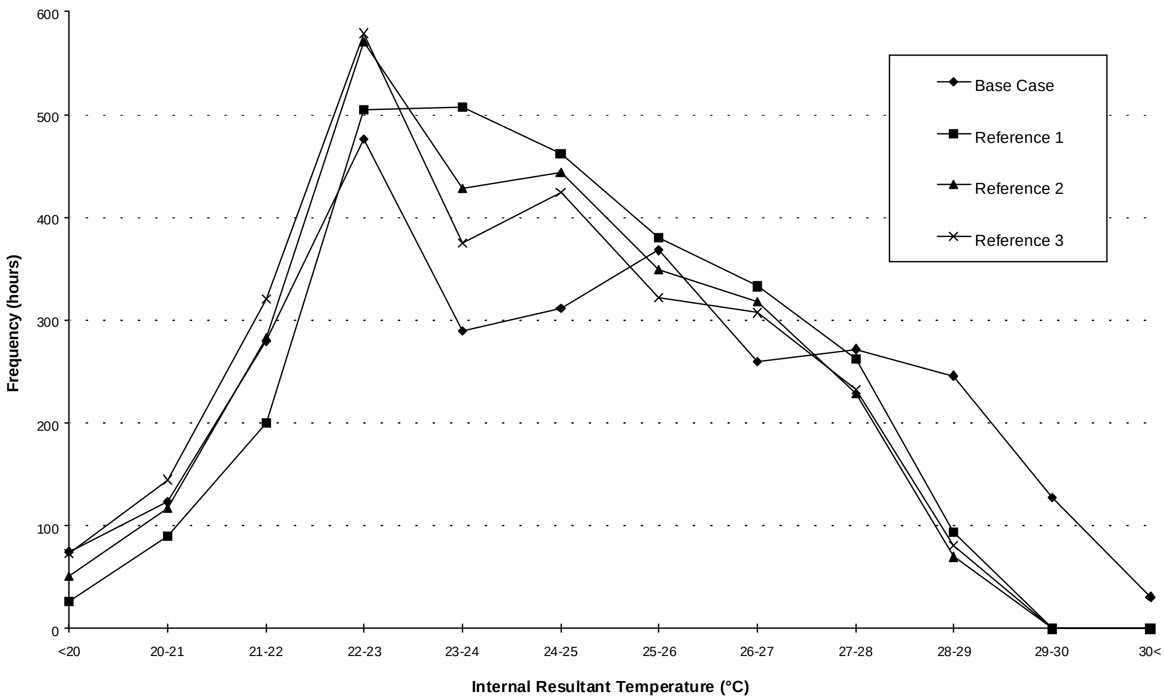

Figure 1 Frequency distribution of internal resultant temperature for displacement ventilation

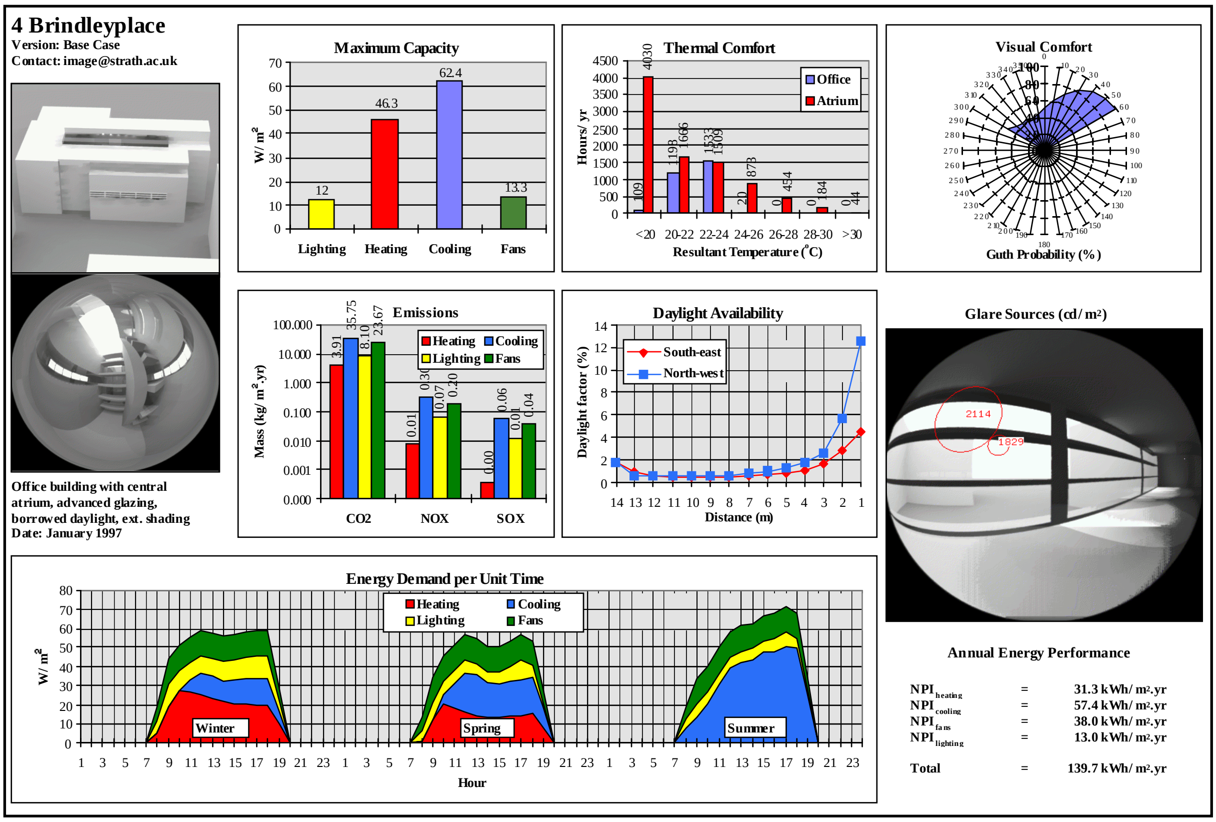

Figure 2 Base Case Integrated Performance View (IPV)

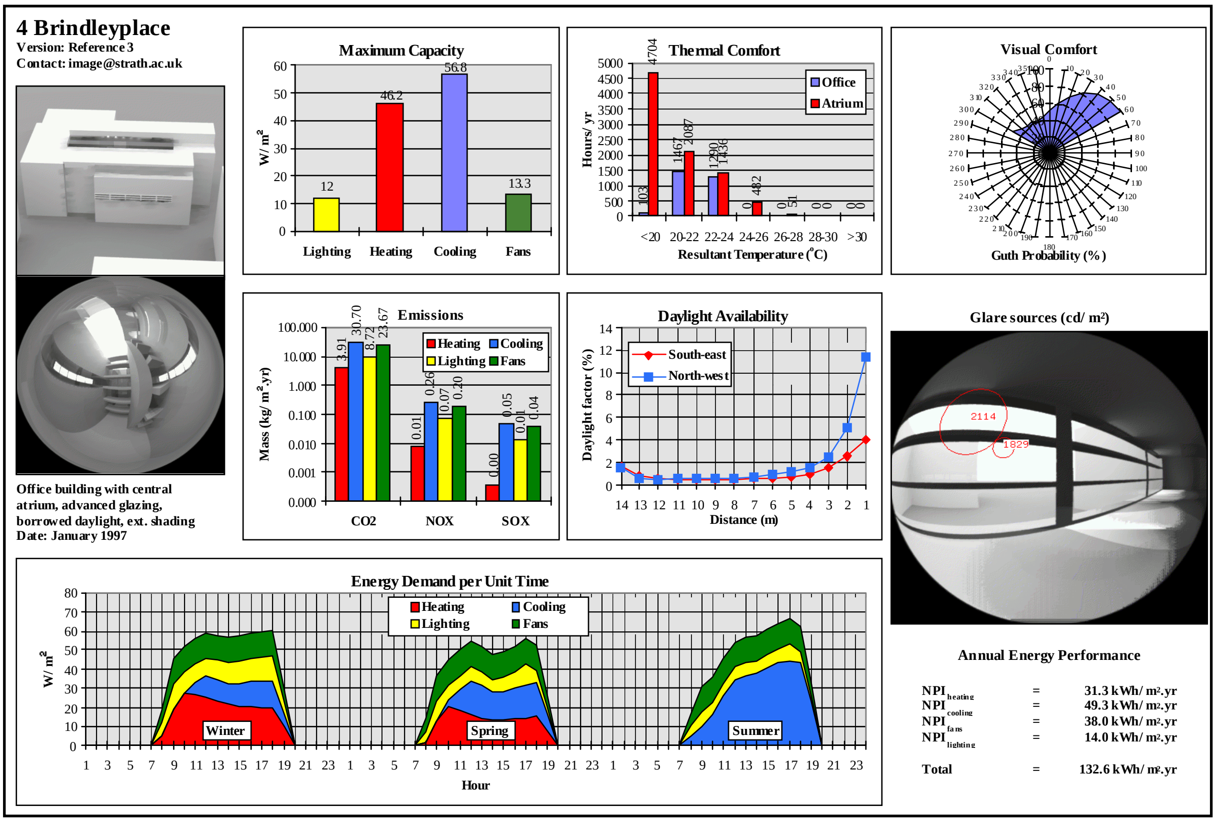

Figure 3 Reference 3 Integrated Performance View (IPV)