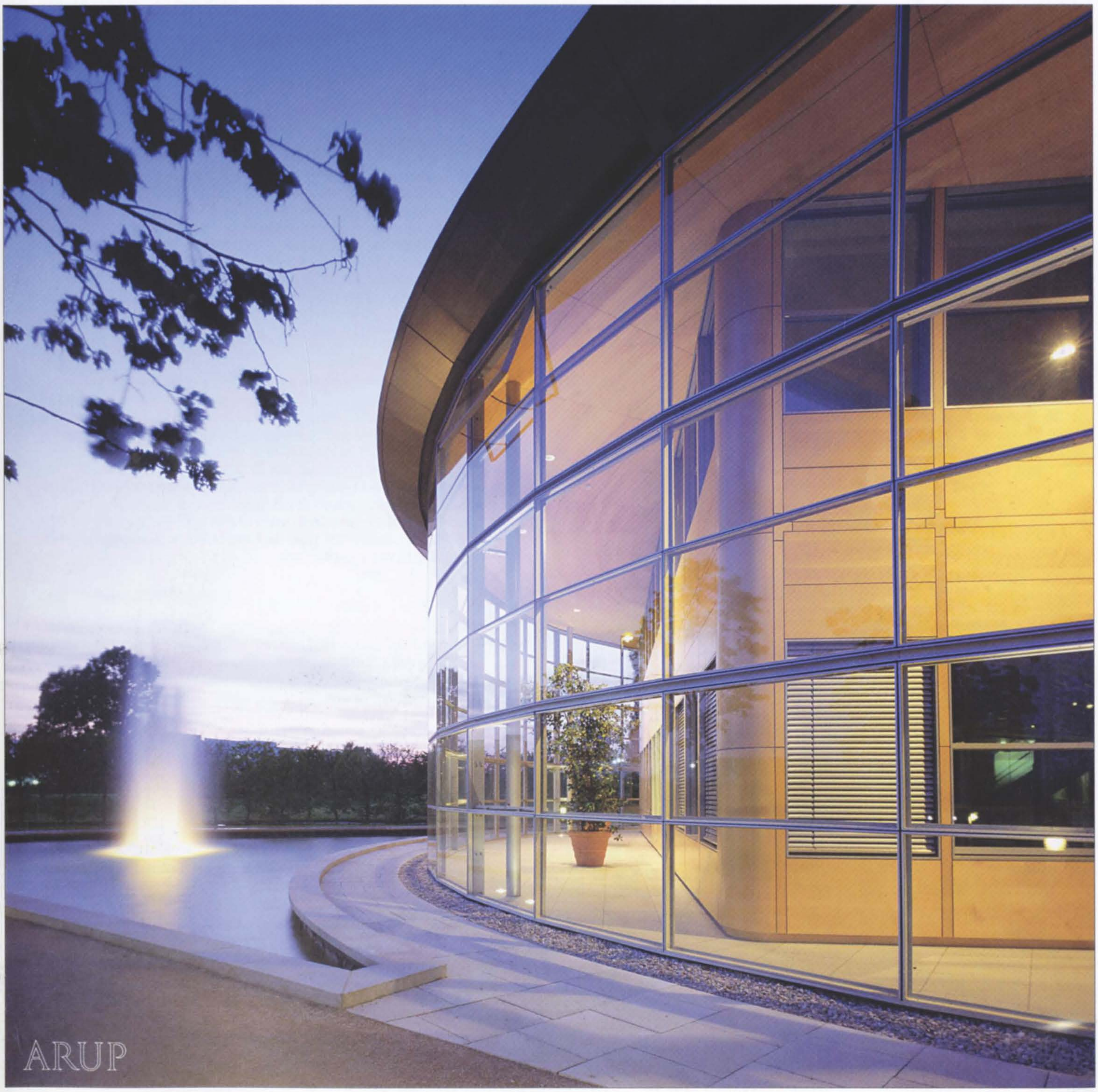
THE ARUP JOURNAL

3/1998



THE ARUP JOURNAL

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Front cover:
No 2 The Square, Stockley Park (Photo: Andrew Putler)
Back cover:
VPRO headquarters, Hilversum (Peter Mackinven)

Alan Williams

Arup's involvement with Stockley Park in West London, which began with the original masterplanning by Arup Associates and site investigation by Ove Arup & Partners in the early 1980s, continues with a 'new generation' of office buildings designed by Arup Associates. These projects are characterised by their unusual response to the office park building - high quality natural materials and options for the tenants' internal environments.

Peter Mackinven

A major example of the rapidly growing range of projects in The Netherlands which which Arup is involved is this new headquarters building for the VPRO broadcasting organisation. Together with the architectural practice MVRDV, Ove Arup & Partners led the design team's efforts to give the client new premises that retained the desired characteristics of their former 'villa' accommodation. An innovative approach to the structural design and services allowed the creation of continuous internal spaces across the deep floor plan, generously penetrated by natural air and light routes.

David J Brown

This 56-apartment block in eastern Berlin is the first low energy building in Germany whose architecture, orientation, and construction have been determined by the engineering design. Arup GmbH's concept includes thermal zoning, controlled ventilation in winter, and automatic controls to eliminate simultaneous use of mechanical and natural systems. The building incorporates a computerised building management system to control and monitor its energy comsumption, and data from this is being analysed by Arup GmbH to determine how well the building's energy-saving concepts work in practice.

Bristol City Council

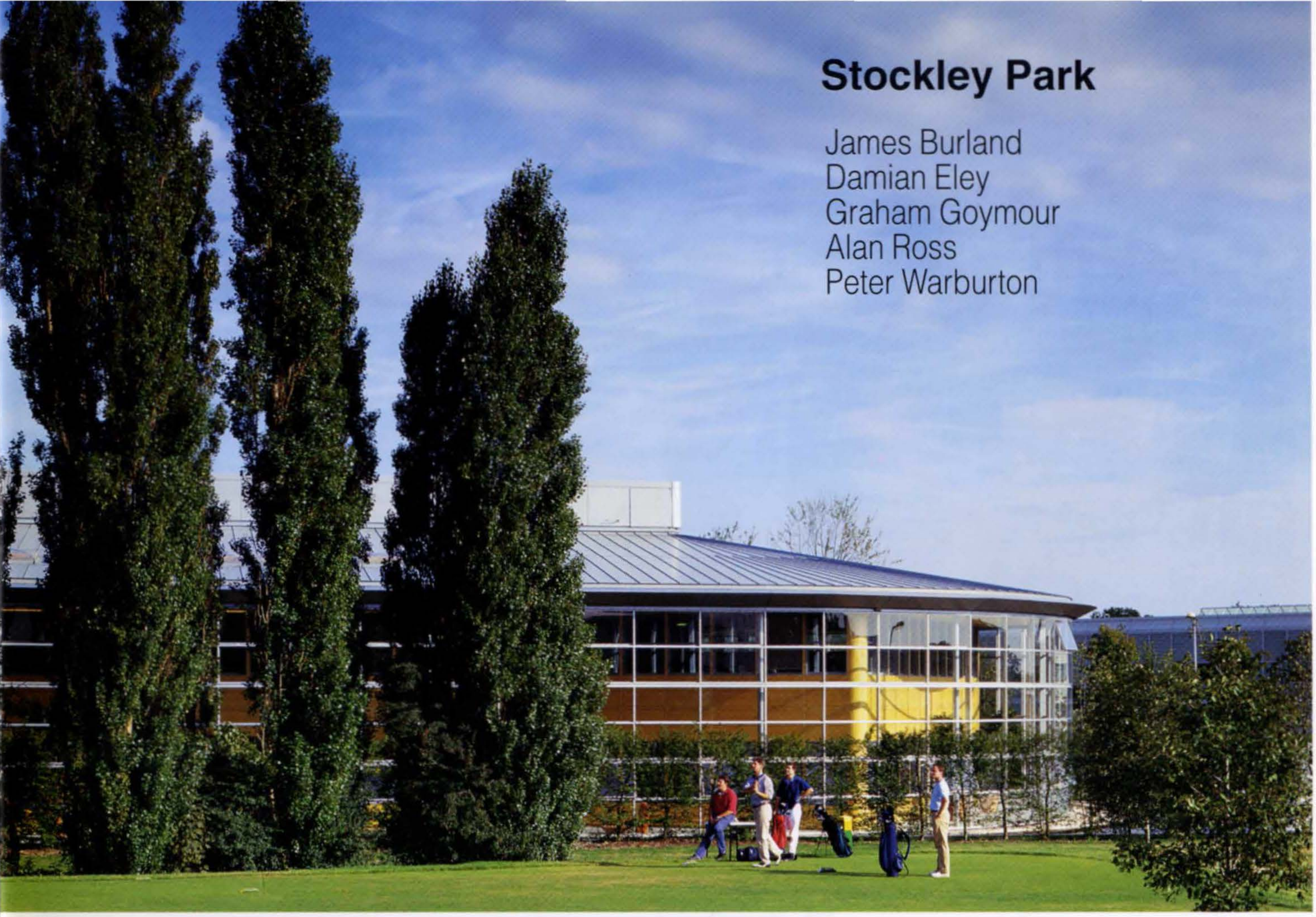
Arup Transportation was asked by Avon City Council (now Bristol City Council) to examine the effectiveness of road pricing as a traffic restraint measure for the region. As well as using computerised analysis models to gauge the effectiveness of various 'packages' of restraint measures, the study involved commissioned market research interviews with motorists in the area.

Peter Mackinven

Since the early 1990s Arup has been involved in the appraisal of the structural design of commercial buildings for blast resistance, and the reinstatement of some that have fallen victim to terrorist bombs. This article discusses in broad terms how building structures and other building elements respond to blast loading, and outlines some measures to mitigate these effects in designing new buildings and enhancing existing ones.

Stockley Park

James Burland
Damian Eley
Graham Goymour
Alan Ross
Peter Warburton



1.
Nº 2 The Square, Stockley Park: the building responds to its setting in the park, allowing occupants to look through the conservatories to the mature landscape beyond - a key element of the project brief.

Development of an office type

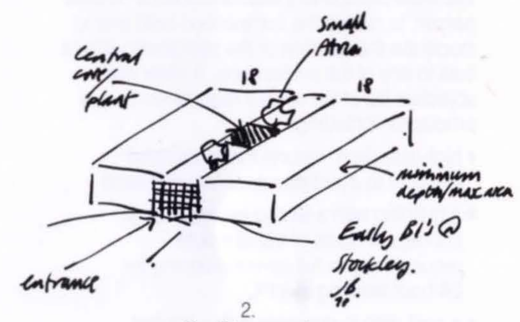
At Phase 2 of the Stockley Park development in West London[1], five Arup Associates' projects are in varying states of completion. Their building pattern was conceived in an architectural competition organised by the developers, Stanhope Properties, who were seeking a new idea to keep them at the forefront of office park design.

Stanhope and Arup Associates developed the original B1 office model at Stockley Park[2].

Typified by its rigorous arrangement of twin 18m-deep floors with services in a linking spine, the B1 type is landscaped to its ground-floor cills, thus reducing its apparent height and disguising the higher ground-floor ceilings for light manufacturing space (virtually the same specification as a standard office floor). Tightly-planned but highly-specified entrances and atria are finished in hardwoods and marble, in keeping with the 'lean and mean and add-back' philosophy of Stanhope's inspirational founder, Stuart Lipton.

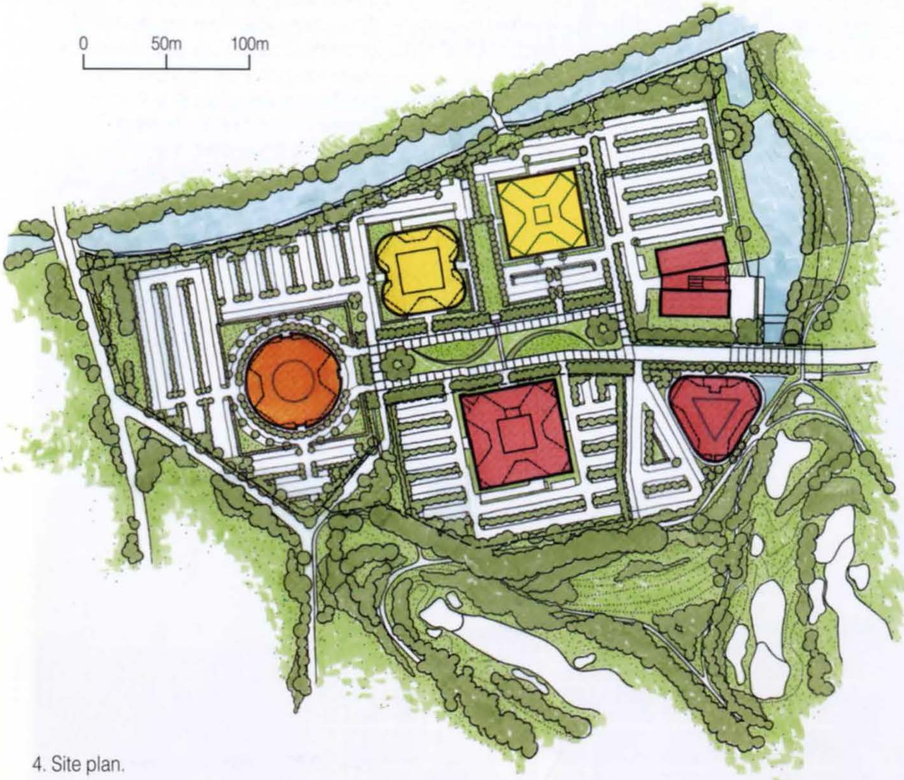
The early prototype was adopted and developed by subsequent architects including the then Foster Associates, Troughton McAslan (now John McAslan & Partners) and Eric Parry Associates[3].

It was time for a change.



2.
The B1 concept.

3.
Left to right: Nº 4 The Square (under construction); Nº 3 The Square: Nº 2 The Square (foreground); B1 concept building [architect: Eric Parry Associates] (behind). In the rear centre the site is being prepared for two further blocks - see Fig 4: site plan overleaf.

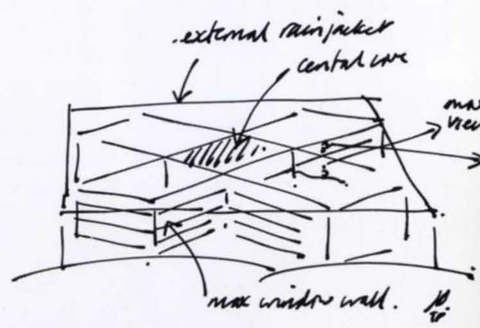


4. Site plan.

Nº 2 The Square

Design concept

Arup Associates' new generation of offices at The Square invert the commonly-used central atrium or U-shaped office plan. Floor plates are planned with a central core similar to a typical high-rise building. Each plan is developed from a cruciform shape which generates a long external window wall for maximum views to the park. This increases the wall-to-floor ratio, raising costs and increasing materials needed for the same gross area. To solve these problems, the 'umbrella' or 'rain jacket' component of an external wall is separated out in a single-glazed square skin surrounding the cruciform inner building.



5. Basic concept for the 'new generation' at Stockley Park.

Andrew van der Meersch (still working for Stanhope but soon to become Chief Executive of Stockley Park) met Arup Associates for the first briefing. The multi-disciplinary team included a 'neutral person' to record the competition brief and to moderate the reaction of the designers without bias to any of the professions. A clear and objective list of the client's requirements was produced, including:

- high-standard, natural materials used sensibly to avoid maintenance problems
- a building with a strong environmental concept, in spite of the absolute requirement for full air-conditioning for 24-hour working at 21°C
- a cost plan to compete with a normal air-conditioned box
- maximum windows to the landscape
- 90% tenant efficiency (ie 10% of the net is tenant circulation areas).

Arup Associates was determined that this new building type could be strongly defined by ideas of landscape, climate, and materials:

Landscape: in a wide sense, from the internal office landscape to the park and the golf course

Climate: not just environmental wizardry, with 'layers' and 'double walls', but an approach so simple, understandable, and inevitable that even the most cautious institution or occupier would be able to perceive clearly its benefits.

Materials: warm glowing timbers and richly patterned stone - usually impossible with this kind of budget but nevertheless affordable though a lateral idea about construction. Could an architect, environmental engineer, and structural engineer together produce a new idea within the standard business park brief at an acceptable price?

6 below:
The design for Nº 2 The Square creates three small corner conservatory spaces. The transparency of the outer screen, with its aluminium glazing elements supported on a lightweight steel frame, allows for the layered construction, creating depth and architectural interest. The maple-clad office sits independently within the outer screen and incorporates all the thermal performance requirements of the building. The double wall construction creates interstitial spaces which act as environmental buffers and encourage natural ventilation of the building.

As the second and most recently-completed building of the five - Nº 2 The Square - demonstrates, this design concept meets the requirements of the brief. The site is an awkward corner of the park and best developed with a three-sided building, generating efficient parking space and a consolidated area for landscaping. The plan of three wings with a central core increases efficiency by reducing the conservatory spaces from four to three. This helped balance costs against the increase caused by a reduction from four to two storeys.

External façade: glazed rain screen

The outer glazed screen needed to be as simple as possible for both economy and to minimise obstruction of the views out to the park. Its performance criteria were limited to keeping rain out and letting air in.

The glazed elements are approximately 1.1m high and 2m wide, held within a 12mm wide, natural anodised aluminium frame of a modified proprietary glazing system. These are supported by welded steel frames, in larger modular units each approximately 2.2m high and 6m or 7.5m wide, holding six or eight glazing panels respectively. Each steel frame unit is a welded assembly of steel flats, angles and tees of overall depth 150mm.

The façade steelwork was brought to site as separate frames which were then bolted to their neighbours and connected to the tubular roof support columns behind. The frames carry the wind loads horizontally to these columns. The connection between the frames and the columns is via machined steel link rods, which are designed to allow careful final adjustment of the frame positions.

The glass screen incorporates opening lights at high and low levels, which are automatically activated and linked via sensors to a building management system.

Internal façade

The internal façade enclosing the office space meets the thermal insulation and air-permeability performance criteria for the building.

This façade is constructed from storey-height steel ladder frames overclad with timber linings and prefabricated maple-veneered spandrels which incorporate thermal insulation, vapour barriers and fixings for internal radiator panels. Vertical sliding sash windows are aluminium-framed double-glazed units. At window head level, the spandrel conceals a retractable, external quality Venetian blind, which is operable from within the office and acts to reduce both solar glare and heat gain.

Conservatory spaces

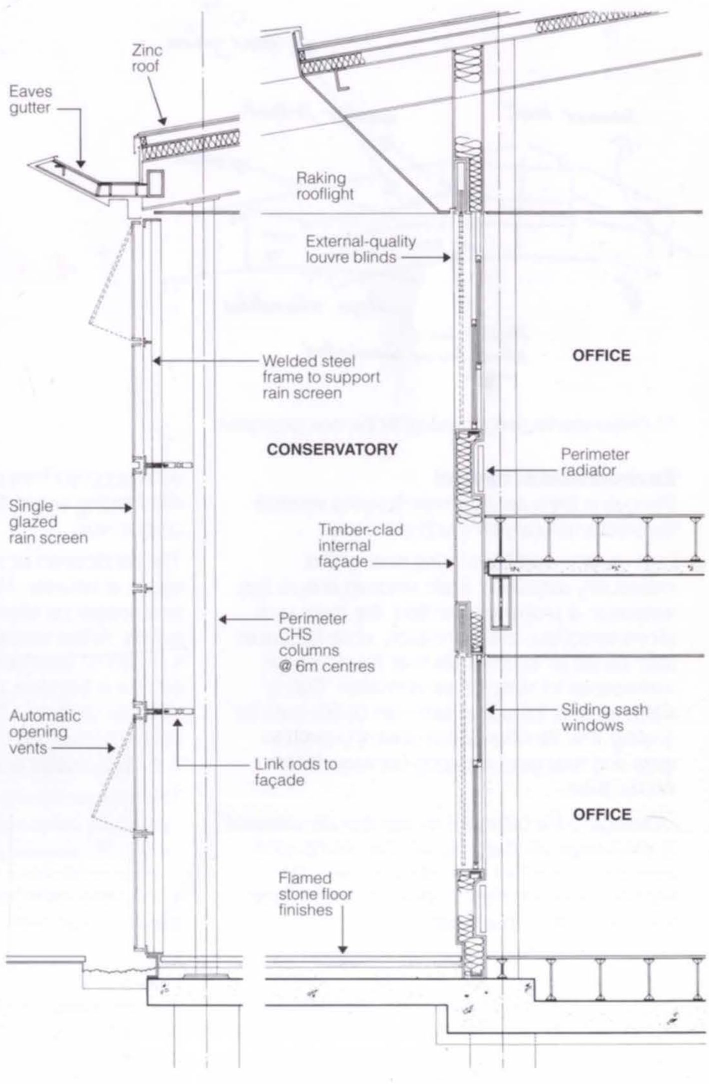
The conservatory spaces have the particular benefit of not being considered part of the planning consent development area, so the developer is not penalised by the conservatories causing a reduction in net lettable space.

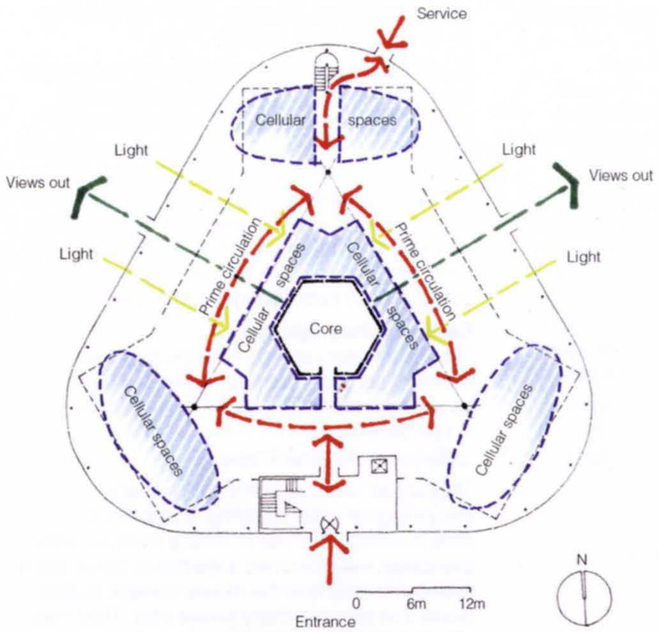
They are architecturally interesting spaces, exceeding the usual cladding façade depth of other buildings. The use of natural materials within this construction provides a warmth of colour that is a welcome relief from the monochromatic sealed boxes that populate many similar sites. Their cost-effective and low-maintenance construction also provides adequate protection from the elements.

As well as acting as environmental buffers, the conservatories form the entrance foyer and spill-over from the ground floor restaurant and offices. Functions and presentations can also be easily accommodated.

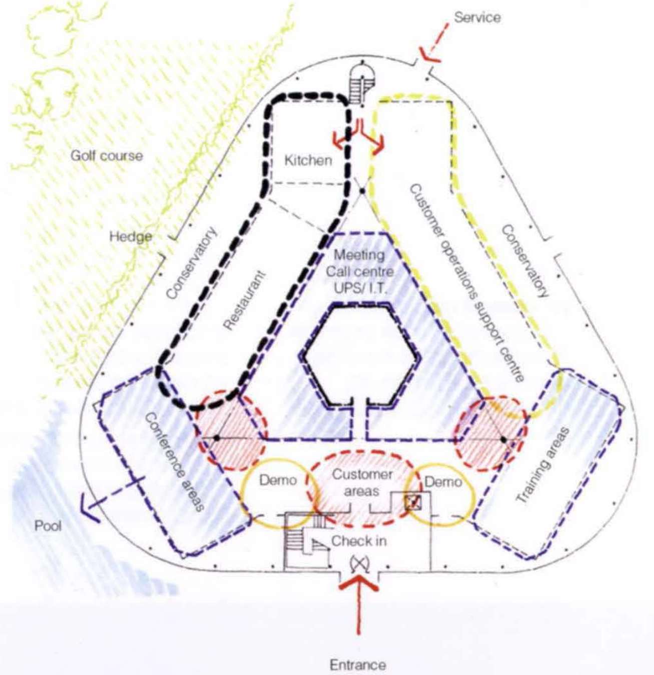
7.
The entrance foyer is housed in one of the three main conservatory spaces which provides a transitionary area from outside to inside. This space, which also contains the main stair, lift and link bridge, allows clear views into adjoining spaces and out into the landscape.

8 below:
Section through double wall at Nº 2 The Square.

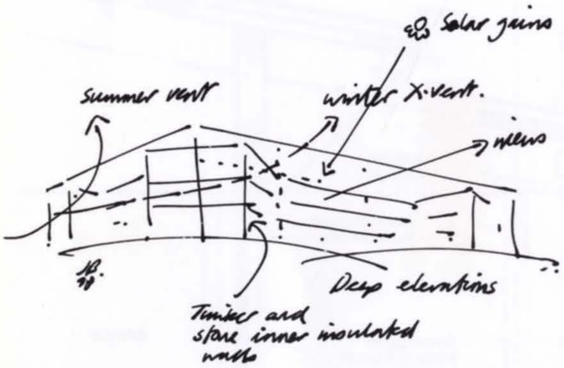




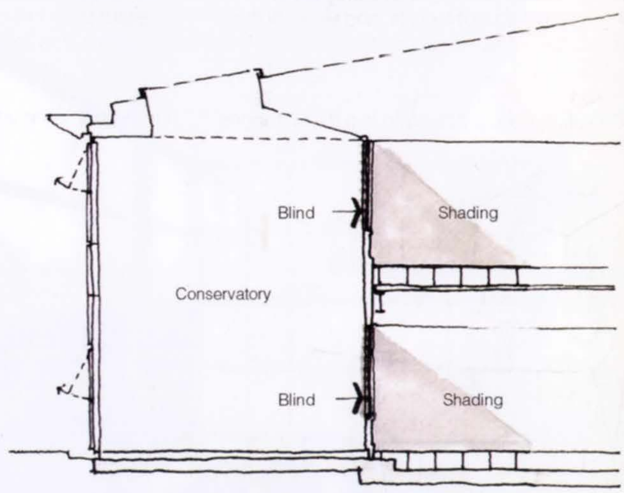
9. Nº 2 The Square: ground floor circulation strategy.



10. Nº 2 The Square: ground floor usage strategy.



13. Environmental design concept for the 'new generation'.



14. Shading the building.

Environmental control

Devices in the outer and inner façades ventilate the offices naturally for much of the year.

Each window and blind in the inner wall is individually controlled. Sash windows ensure that ventilation is properly controlled: the lower sash allows direct low-level ventilation, while the upper sash allows air to penetrate over the perimeter workspaces for deep cross-ventilation. During warm weather the upper sash can be left open for cooling. The Venetian blinds control both solar glare and heat gain, negating the need for an interior blind.

Openings in the outer rain screen can be operated to encourage cross-ventilation: the natural wind-assisted stack effect created by hot air in the warmer conservatories draws air through offices from the cooler conservatories.

The degree to which natural ventilation of this building can be relied on will depend on the limiting conditions which occupants consider acceptable before air- conditioning is required. For days when natural ventilation is inadequate, an under-floor plenum air-conditioning system is provided.

Air is supplied from a central rooftop air plant discharging air into the office's raised-floor plenum void.

The conditioned air is supplied into the office space at between 18°C and 22°C - depending on seasonable variations - through twist type floor air outlets. At this temperature range, the air is close to the comfort conditions required by the occupants. Air flow is therefore directed upwards, producing rising air patterns which work in conjunction with natural convection currents generated by people and office equipment.

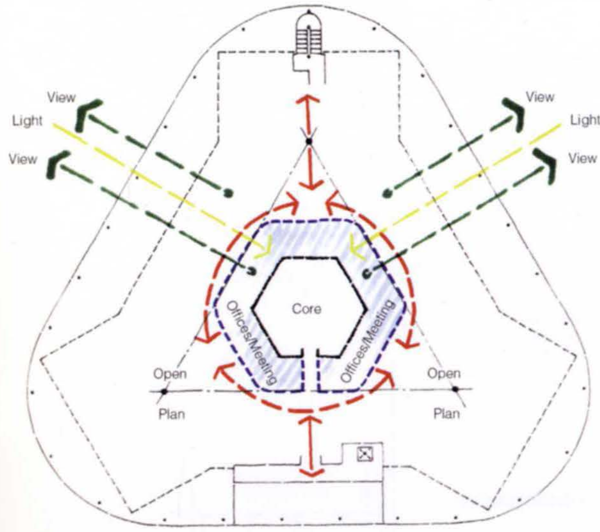
This approach makes the best possible use of outside air, discouraging mixing at high level and dilution of the supply air with the contaminated air already in the room. Air is extracted from the office space via a ceiling plenum void and distributed back to the air plant.

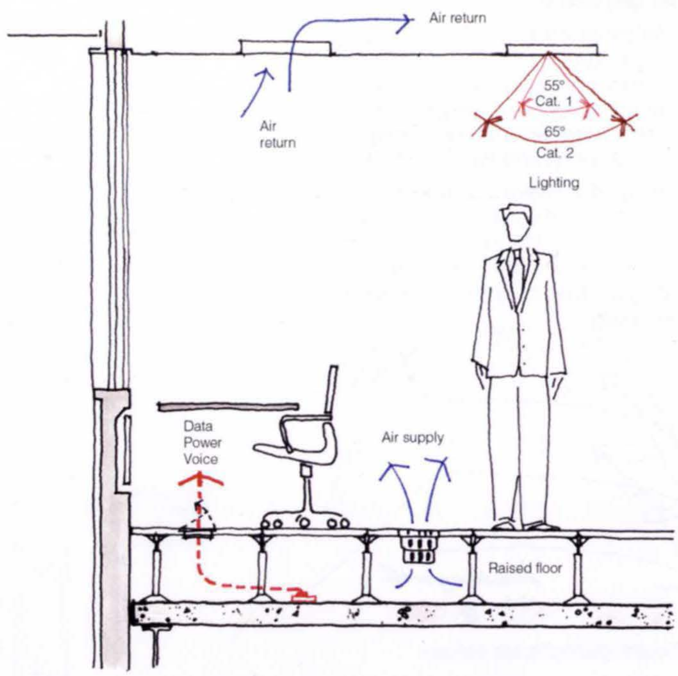
The air-cooled, low-ozone depletion chillers that provide chilled water for the air plant are located in a landscaped enclosure in the chiller car park. A low pressure, low NO_x gas-fired boiler plant provides the heating to the building through a perimeter radiator system.

Building structure

The building structure is a steel framework of beams and columns with a composite slab. The structural grid is a combination of 9m x 9m square grids and some longer spans of up to 12.5m, arranged around a hexagonal central core. This arrangement enables the number of 'exposed' columns to be reduced to only three, all of the others being integral with either the core, the internal façade, or the rain screen.

The building is braced by the central core acting in combination with some wind-moment frames in the internal façade.





11. Nº 2 The Square: planning strategy for first floor.

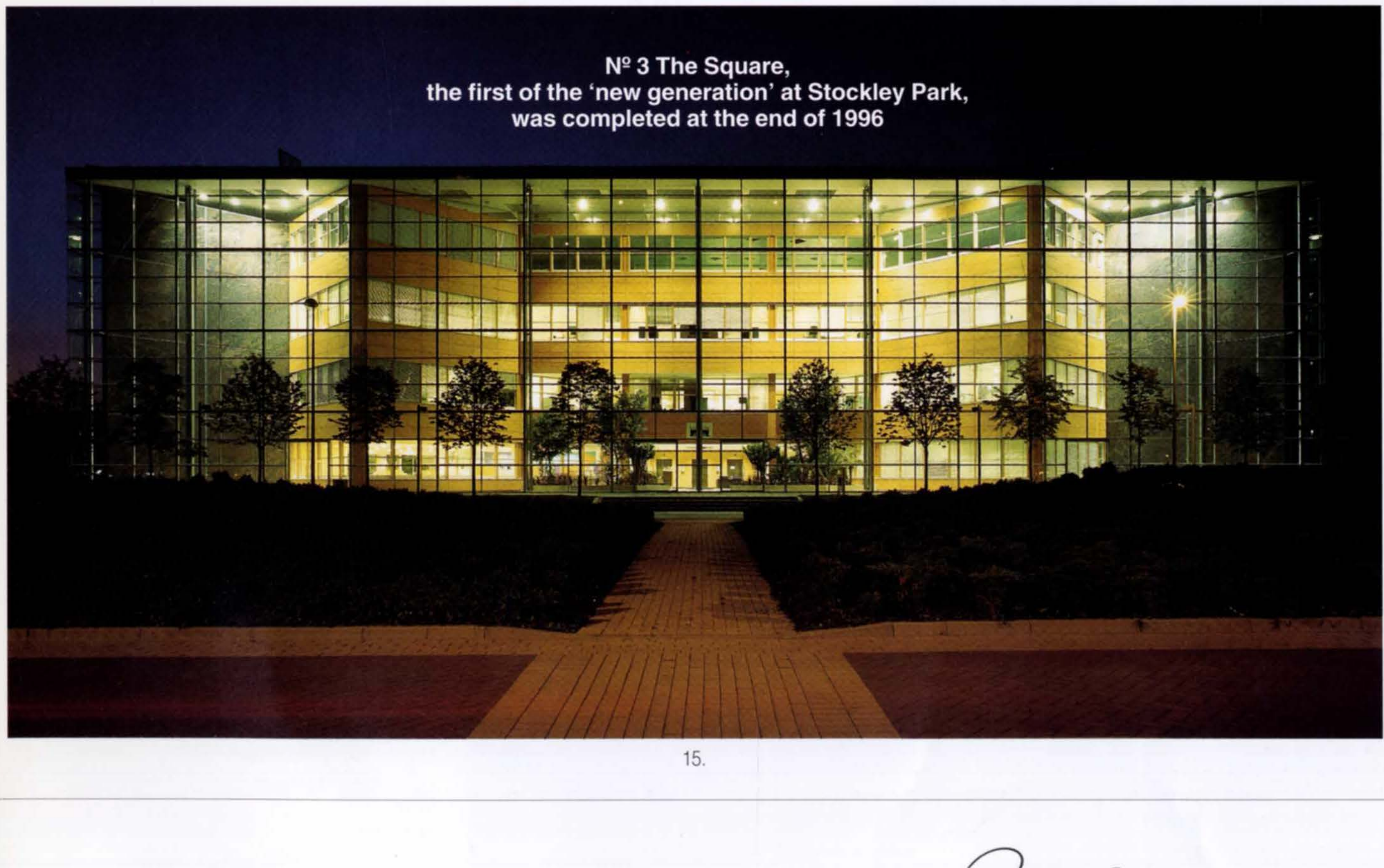
12. Office fit-out.

Tenant fit-out

The fit-out plan for both levels was guided by the necessity to preserve the spatial clarity of the building, internal daylight levels, and views of the landscape. Most office seating on the first floor is open plan around the perimeter, with 12 cellular offices arranged around the central core. Glazed partitions allow light to penetrate into these spaces.

The ground floor of the building is occupied by a wide range of uses: conference and training rooms; a restaurant; a call centre and other visitor spaces. Each main area links to one of the conservatories. A simple and restrained palette of internal materials suited budgetary constraints: timber joinery, glass and plasterboard wall finishes.

Construction started in July 1997 and the fitted-out building was occupied by March in 1998 by present tenants, Aspect Telecommunications. The building provides accommodation for up to 275 people with 2760m^2 of net lettable area. Total construction costs for shell and core works were approximately £4M.



15.

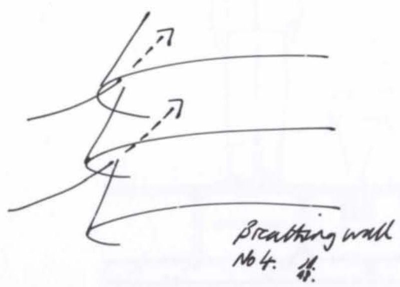
Towards Nº 4 The Square, overleaf: 16.

Full stop!

Nº 4 The Square

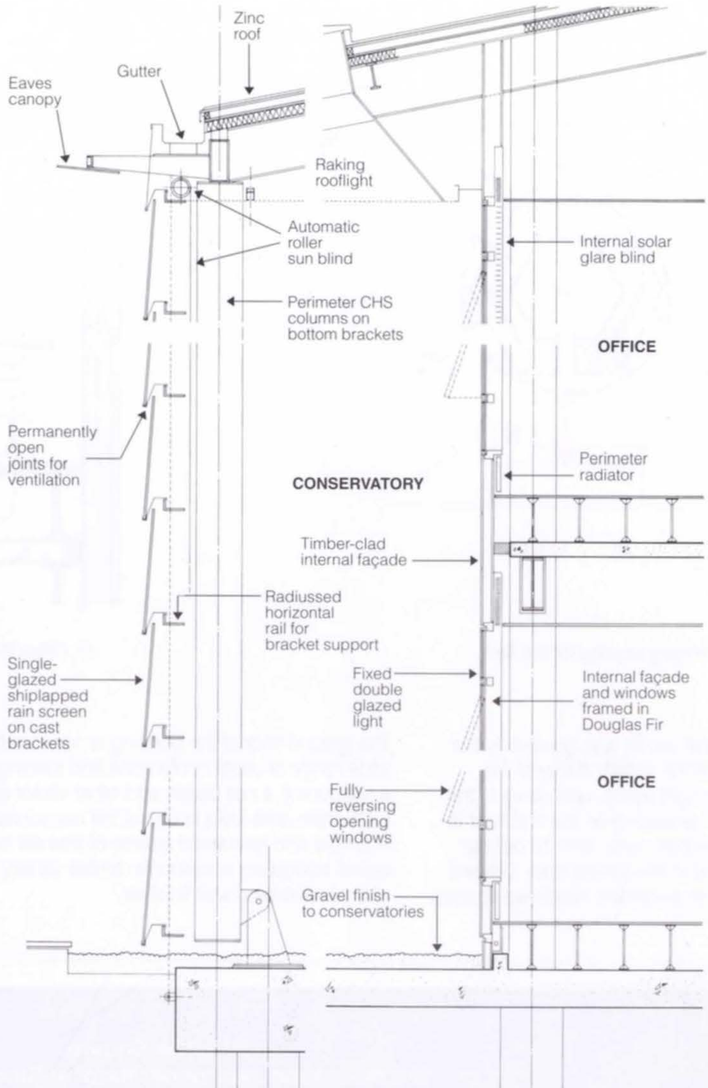
Currently under construction, Nº 4 The Square develops this new building type. The outer glass screen is simplified: opening windows are replaced by an arrangement of vertically overlapping glass panels which shed water while allowing for the full ventilation of conservatory spaces.

The conservatories are protected against solar heat gain by automatic retractable blinds inside the overlapping glass panels. The internal façade is built entirely in Douglas fir and incorporates outward pivoting windows for optimum ventilation and maximum daylight .



17. Nº 4 The Square: glazing/façade concept.

18 left:
Nº 4 The Square:
double wall under construction.



20 above:
Nº 4 The Square:
section through double wall.

19 below:
The circular design for Nº 4 The Square further develops the double wall theme with a shiplapped outer glass screen.

References

(1) STOCKLEY PARK. *The Arup Journal, 22*(1), pp4-7, Spring 1987.

(2) ARUP ASSOCIATES GROUP 3. Hasbro Inc, Stockley Park, *The Arup Journal, 24*(2), pp22-23, Summer 1989.

(3) GLOVER, M. The 'other buildings' at Stockley Park. *The Arup Journal, 25*(1), pp38-42, Spring 1990.

Credits

Clients:
Stockley Park Consortium Ltd

Architects, structural engineers, and building services engineers:
Arup Associates Federica Boiani, Clare Bolt, James Burland, John Edgar, Damian Eley, Frank Ghaidan, Graham Goymour, David Hymas, Sean Macintosh, Terry Moody, Terry Raggett, Marcel Ridyard, Jonathan Rose, George Scott, Gopi Shan , Charles Stanton, Peter Warburton

Quantity surveyors:
Davis Langdon & Everest

Landscape architects:
Charles Funke Associates

Construction manager:
Schal

Illustrations:
1, 18, 19: Grant Smith
2, 5, 13, 16, 17: James Burland
3: Marcus Taylor
4, 8, 14, 20: Arup Associates
6, 7, 15: Andrew Putler
9-12: Arup Associates/Tom Graham

VPRO headquarters, Hilversum, The Netherlands

Rory McGowan

1. East façade: the front of the building.

Introduction

The VPRO TV and Radio Company enjoys a reputation for quality broadcasting in The Netherlands. It is funded by voluntary subscriptions, and its popularity - gauged by the increasing number of subscribers - led it in 1993 to decide to relocate to a purpose-built headquarters on a greenfield site within the grounds of the National Broadcasting Authority Centre in Hilversum.

Ove Arup & Partners International Ltd were invited to team up with the architects MVRDV and subsequently were appointed to carry out the structural and services design and site supervision, following an interview. Following this, Arup and MVRDV appointed a number of local consultants and established the design team that was to see the project through to completion. The client was represented by a professional client representative, as is customary in The Netherlands.

The principal activities of the staff are programme research and design, radio broadcasting, programme editing, central archiving, and customer and staff services. The brief was for 5300 m^2 of flexible office space, 2000m^2 of meeting / conference / workshop areas, and 2000m^2 of studios and editing rooms, with 90 car parking spaces internally and externally. The building started on site in spring 1995 and was formally opened in September 1997 within the overall project budget of Dfl40M, Dfl24M of this being the building cost.

The brief

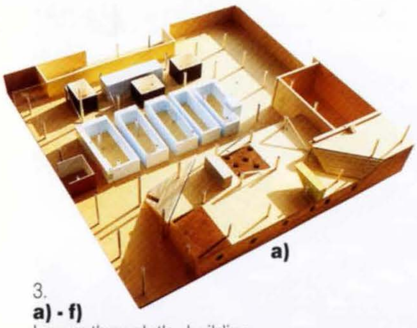
The decision to relocate to a new purpose-designed building was a difficult one for the staff and director of the VPRO. They enjoyed the many positive aspects of their existing accommodation, seven villas in close proximity to one another, with the autonomy of independent operational units but within an overall community, the uniqueness of each villa, the different room types, the absence of long corridors, and the physical and visual connection with the gardens outside.

However, the expanding nature of the organisation continually compromised the benefits, so the decision to build was made.

At this point the design team was presented with a traditional office brief. The concept eventually presented to the client was based on an holistic approach to the situation and the first step in that process was to persuade the client to have a pre-design phase to allow the brief to be tested and developed.

The brief was examined thoroughly by MVRDV and extensive discussions were carried out with the VPRO staff individuals and representatives, operational groups, and management. Strict height and density planning restrictions also applied, as well as regulations covering the working environment. The concept finally presented to the client captured the villa feel and provided additional benefits within a 9000m^2, five-storey building with the deepest office plan in the Netherlands, 56m x 56m on plan.

2. Architectural concept for office space.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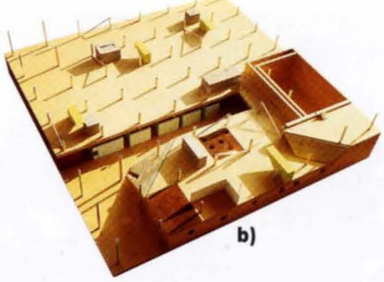
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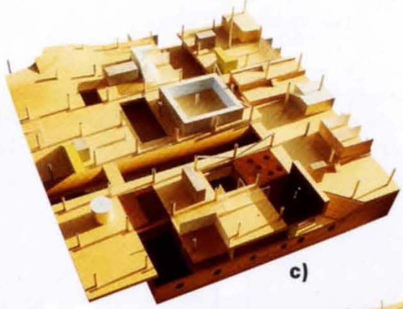
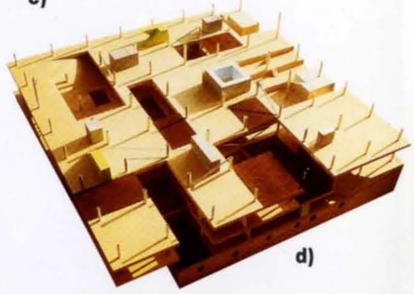

c)

3.
a) - f)
Layers through the building.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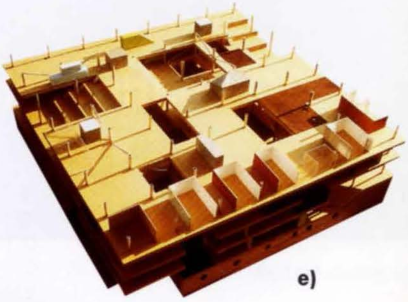
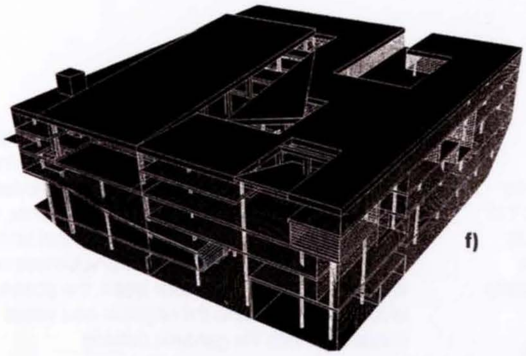

e)

Building design concept

The square building is partially recessed into its hilly site to stay within height restrictions, and is accessed at the first floor by the sloped landscaped car park which continues as the first floor slab into the building and then folds back on itself to form the second floor. This introduces a concept whereby the spaces form a relatively continuous interior through the use of folding plates, a hill, steps, terraced floors, and amusing links such as the stair suspended on invisible wires, and the picture gallery fire escape routes which worm through the building.

This continuous revealing of the building offers numerous spatial experiences and unique rooms echoing the villas. Combined with the discrete island and peninsula floor plates created by the voids routed through the building, this has allowed the staff to customise their working group area as before, while benefiting from the shared facilities - including a restaurant and grassed roof garden - and the atmosphere of the building. The stark finish of the solid raised floor and concrete flat slab soffits is offset by peronal touches, from Persian rugs to basketball nets.

Nearly every office has access to a patio, garden, terrace, or balcony via a door, which makes for a very pleasant working environment in which the difference between inside and outside is played down. The mass of the building is extensively penetrated by air and light routes which enter at the façade and roof and sometimes re-emerge elsewhere. The voids thus formed help satisfy the strict Dutch regulations for offices spaces regarding natural lighting and the requirement for all stations to be within 5m of a view (not defined), and provide opportunities to mute the difference between interior and exterior spaces and provide alternative working possibilities.


f)

4.
Entrance 'hill'.

Achieving the concept

Extensive environmental studies by Arup and DGMR covering natural lighting, façade heat gains and losses, internal and external shading, and acoustics, helped establish the nature and geometry of the voids in an iterative process. Both physical and computational models were used to arrive at the final forms.

The wide variety of spaces created required Arup to develop flexible building services routing and a number of servicing approaches which could also deal with the varied programme in the building. A key goal for the design was to minimise the impact of services in the building, avoiding false ceilings, duct runs, and services routing that looked like an afterthought. The aim was to end up with a solid concrete ceiling and floor finish. The solution adopted located the plant in the basement and on the roof in a conventional manner, with some dedicated mechanical plant located locally for areas such as the kitchens.

The design maximised the ability to use natural ventilation in the spaces, complemented by a raised floor plenum which delivers conditioned air to the majority of the floor area. Certain areas, such as the restaurant and studios, have dedicated AHUs to deal with the high loads, whilst other rooms like the dedicated editing suites incorporated chilled beams to supplement the minimum fresh air from the main building AHUs.

The raised floor, a pedestal system with a solid screed finish, was also used for routing power and communications. Given the irregular floor patterns with voids and islands, discontinuity and distance were concerns in developing the services strategy. Six principal risers, often enclosed in glass, distributed in plan, and linked at basement level, deliver the services to all areas of the building, thus keeping services runs and dimensions to a minimum. This was particularly important in sizing the raised floor.

The largely glazed façade uses 35 types and colours of glass in order to deal with, among other things, heat gains. Extensive use is also made of fixed shading, external curtains, balcony overhangs, internal curtains, blinds and plants, to control the gains. These, combined with the façade orientation and the void geometry, create a dynamic faceted mosaic echoing the excitement of the interior.

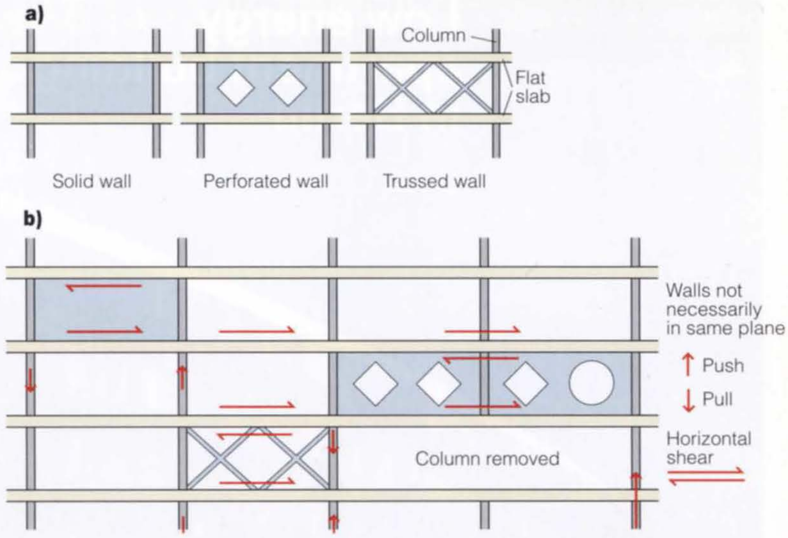
Arup developed a drainage strategy for the unusual geometry and used chains for some of the vertical routing of rainwater to minimise the system's impact.

5. 'Urban landscape' - on the roof.

6 above:
Stepped restaurant.

7. North façade.

8. Circulation space.



9 above:
Structural concepts.
a) Wall types
b) Possible stability load path

10 left:
The voided block.

The structure

The building structure proposed by Arup is principally of reinforced concrete flat slab construction on a regular grid. This system was chosen as it offered maximum flexibility in terms of creating voids, and deforming and stopping plates economically. Maximum use was made of the slab's ability by spanning in two directions and cantilevering to be cut, slotted, and folded without using beam elements. The result gives a clean, smooth concrete floor profile which can be read internally and externally. Beams were used in rooms like the stepping restaurant but here the vertical part of the folded plate acted as a beam as well as wall.

Use was made of steel cruciform shear heads embedded within the slab, and of upstand shear heads, to minimise the thickness of structure as part of an overall strategy to minimise floor-to-floor heights and flatten the building proportions.

No column was allowed to pass through any void created and this, combined with some double grid width voids, led to the incorporation of two deep transfer beams as part of the roofscape. The columns were replaced with steel bars and thus floors were suspended from the transfer beam. The columns are predominantly founded on pads with some piled foundations required in one area of the site; the locally appointed structural consultants Pieters Bouwtechniek had a major role in this part of the design.

The absence of traditional stability cores from the building design, the low height of the building, and the nature of the floor geometries, led to the development of a seemingly random distribution by Arup of structural steel tube stability braces around the building. Several braces, distributed in plan and direction on each floor, transfer wind loads from one floor plate to the next.

The floor plate then distributes these forces to the next layer of braces distributed in a different pattern on the level below. This resulted in a large degree of freedom to scatter the visible bracing around the building so as to create certain moments of harmony or symbolism or collision as desired.

Conclusion

The project was a successful collaboration between Arup and the other consultants, whose role increased in the latter phases. The VPRO building was given listed status before it was even completed and has won several prizes since, including the top concrete building prize in the Netherlands: Betonprijs 1997. The building is among the first major building projects for Arup in the Netherlands and has demonstrated the contribution the firm can make to the built environment in this cost- and design-conscious market.

Credits:

Client:
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Client representative:
Heidemij Advies BV, Arnhem

Architect:
MVRDV, Rotterdam

Engineers:
Ove Arup & Partners International Ltd
Colin Darlington, Alan Foster, Peter Hartigan, Rory McGowan, Clare Murphy, Alan Rowell

Local consultants:
Pieters Bouwtechniek, Haarlem (Structure)
Ketel R I, Delft (Service)
Centrum Bouwonderzoek TNO-TU, Eindhoven (Acoustics)
DGMR, Arnhem (Building physics)

Illustrations:
1, 7, 10: Hans Werlemann
2-3: The architects
4, 6, 8, 11: Peter Mackinven
5: Rory McGowan
9: Rory McGowan/Denis Kirtley

11. South and east façades.

Low energy apartment building in Berlin

Brian Cody

Introduction

A noteworthy low energy building was recently completed in the Marzahn district of eastern Berlin - noteworthy in that it is the first low energy building in Germany whose architecture has been derived directly from engineering principles. Its form, construction, façade appearance, orientation, and room organisation were largely determined by the engineer before the architect put pen to paper. The engineer was Arup GmbH, the architect Assmann Salomon und Scheidt in Berlin.

Marzahn boasts [sic] the largest area of prefabricated buildings - East German style - in Germany. The client, a housing association named Wohnungsbaugesellschaft Marzahn mbH, had signed a contract with the Senate for Building and Housing whereby they were required to meet a target of 20% below the (at that time new) energy regulation requirement, so as to receive additional funding for the project. On top of this legal requirement they wanted to make a 'low energy statement' with the building - to show, as one of the largest housing associations in Berlin, that they were ecologically aware and designing buildings for the future. By the time Arup GmbH were approached in autumn 1994, they had already seen many experts and engineers in the field of low energy residential buildings and been repeatedly told (at least between the lines): 'Get the architect to do a preliminary design and we'll make it work. Let the architect be as creative as he wants; we'll throw thermal insulation at it until it works, stick a couple of solar cells on the roof, and - hey presto - you've got a low energy building!'

Impressed with the Arup thesis that exactly the reverse was required - that the engineer should be the prime determiner of the building form, and that its construction should be inherently energy-efficient and so need less technology in the form of insulation or solar cells - the client promptly contracted Arup GmbH to carry out the complete engineering duties - structure and building services - as well as act as energy consultant.

1 above: South elevation.

2. East elevation.

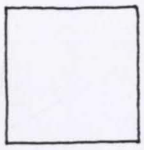
Arup analysis, calculations, and studies were thus the generating force for the energy-efficient architecture of this seven-storey, 56-apartment building. Complemented by an intelligent building management system (BMS), the finished product is predicted to perform much better than the original target set in the contract between the client and the Senate. Arup GmbH is now implementing a survey to compare the actual with the predicted performance. That the client is prepared to pay for this type of work - over a two-year period - marks a new direction for building design in Germany.

Building form

The heat energy demand of a building is influenced in no small part by the relationship of the external envelope available for heating transfer (A) to the volume (V) enclosed by this envelope. Generally, for a constant building volume the less external area a building has, the lower the heat energy demand. One of the goals for a low energy building is therefore that the A/V ratio be as low as possible. The building orientation and the façade construction, in particular the size and location of the transparent portion, can however play an even more important role.

A study was undertaken whereby various basic building forms were examined and compared. All were six storeys high and had a gross floor area of 6000m².

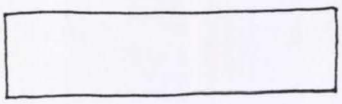
The first form (a) considered was a square footprint.



a

The A/V ratio was calculated at 0.24 and the annual heat energy demand at 41kWh/m². Conventional U-values were assumed for these calculations.

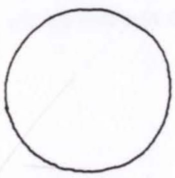
The second form (b) was a longer, slimmer footprint, with the longer sides orientated north and south.



b

The A/V ratio for this alternative is approximately 17% worse and the calculated heat energy demand some 11% higher. The poorer performance of this form is caused by the larger heat transfer area of the external envelope.

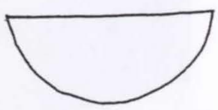
Next to be considered (c) was a cylinder shape.



c

Although the useful passive solar gains associated with this form are lower than in (a) and (b), the calculated heat energy demand is - due to improved A/V ratio (0.22) - much better (35kWh/m² pa).

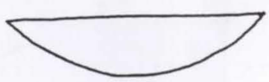
A half-cylindrical shape (d) was considered next.



d

Because of the poorer A/V ratio this form uses more heat energy per m² pa than the cylindrical form.

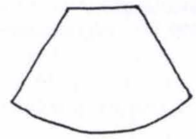
The next alternative (e) was an attempt to make the south-facing façade as large as possible.



e

This building has in effect no east or west sides - just a north side and a larger south side. The increased passive solar gains are, however, more than compensated by the greater transmission losses due to the poor A/V ratio. The calculated energy demand is higher than all previous alternatives.

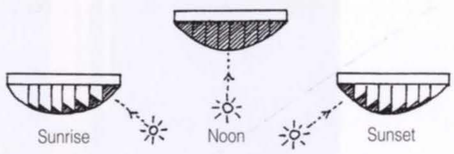
The next alternative (f) proved to be very efficient in terms of heat energy demand.



f

The area of the north façade was kept as small as possible, while the length of the east and west sides were varied until an optimum form was reached. The annual heat energy demand is comparable to that of the cylindrical building form (35kWh/m²). The higher transmission losses due to the greater external envelope area (A/V = 0.23) are compensated by higher solar gains from the larger south-facing façade. The advantage of this compared to the cylindrical alternative is that all apartments can be arranged to face south. That is not possible with the cylinder, so that, depending on the orientation, some apartments will have a greater or lesser heat energy demand and a different quality. The glass portion of the south façade of this building form should be as large as possible - with an appropriate glass construction - while the north, east, and west façades should have a minimum glass area.

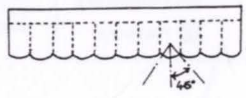
There are, however, other aspects to consider with the curved south façade (g):



g

- At any particular time the apartments receive different amounts of solar energy.
- The heat energy demand varies from apartment to apartment. Some apartments are more energy-efficient than others.

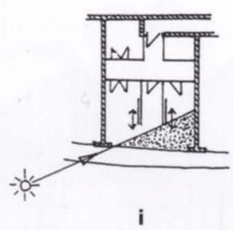
A possible solution to these problems would be a curved south façade for each apartment.



h

The heat energy demand of (h) is, however, approximately 17% more due to the higher A/V ratio.

These problems were partially solved (i) by the use in the apartments of sliding doors, which when pulled back allow the sun to shine into the whole apartment.



i

After long evening discussions with the architects, and intensive days carrying out analysis on Arup computers in Düsseldorf and Berlin, the building form emerged which now stands proudly among the prefabricated buildings of the former GDR.

Deviations from the optimum form can be ascribed to requirements from the town planning authorities and the fact that rooms deeper than c6m cannot be effectively naturally ventilated and lit from one side.

Thermal performance of the building envelope

The next step was to optimise the thermal performance of the individual building elements. The U-values of the chosen constructions are as follows:

Roof	0.15W/m²K	
External walls	0.19W/m²K	
Windows	1.21W/m²K	g = 0.58
Slab above the basement	0.30W/m²K	

The so-called g-value, which determines how much solar energy is transmitted, played an equally important role in selecting the glass.

Thermal zoning

The building was then split up into three separate thermal zones:

- Zone 1: north-facing unheated buffer zone (circulation areas, stairways and lifts)
- Zone 2: internal zone (apartment entrances, hallways and mechanically ventilated bathrooms)
- Zone 3: south-facing occupied zone (living rooms, kitchens and bedrooms).

This zoning concept allows those areas with different environmental conditions to be treated separately and to be orientated in the most favourable direction.

Structure

A crosswall type of construction is used, with the internal walls in the apartments non-loadbearing to allow maximum flexibility in the internal organisation of the rooms. The 200mm thick slabs are constructed with precast hollow prestressed concrete units and span up to 8.6m.

The loadbearing walls are of precast reinforced concrete units.

Ventilation

Sufficient ventilation with removal of harmful substances and moisture vapour is needed for good air quality and healthy living conditions. Insufficient ventilation can cause:

- formation of breeding-grounds for micro-organisms and dust mites
- formation of mould and mildew on interior surfaces
- accumulation of harmful substances and odours in the room air, eg CO_2, cigarette smoke, vapours from paints, plastics, and furniture, etc.

The proportion of the heating energy demand from ventilation in a low energy building with very good thermal insulation can be very high. Conventional natural ventilation during the heating season can lead to very high heat energy consumption. High wind pressures and a large temperature differential between inside and outside can give rise to air change rates much higher than necessary. A system which constantly supplies the minimum amount of fresh air required - and not more - protects the building construction, while reducing heat energy usage.

In the early stages of the project, using decentralised mechanical supply and extract systems with heat recovery was considered but later discarded, due to the high capital costs involved. A compromise was found whereby only mechanical extract is provided. The required fresh air quantity enters through special elements in the façade. With this system, the heat energy cannot of course be recovered from the extract air, but controlled ventilation with a constant fresh air supply can be maintained and the heat energy required to warm the fresh air to room temperature thus reduced.

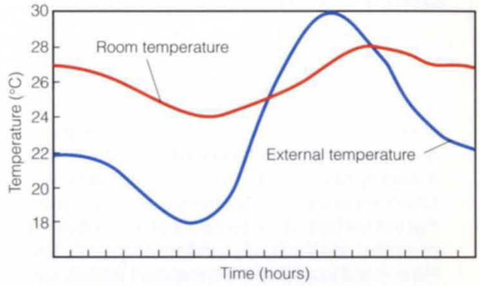
Continued overleaf: ▶

HVAC concept

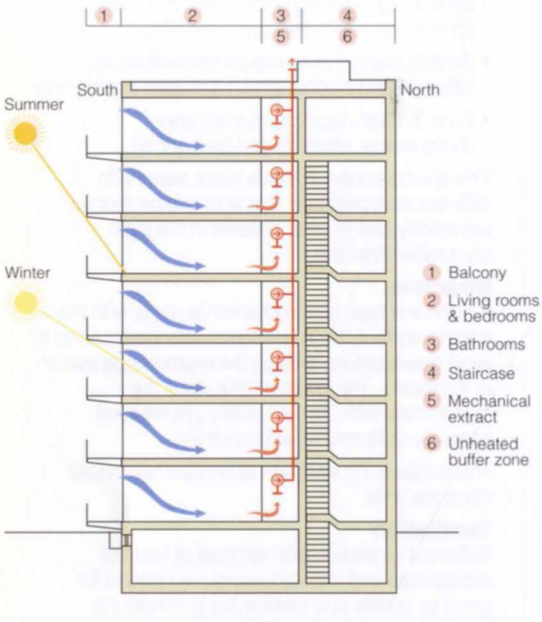
The apartments are heated with a warm water system, connected indirectly via a heat exchanger to the local district heating network.

Each apartment has two extract fans, one in the kitchen and one in the bathroom. These provide the basic ventilation in winter, while the windows remain closed and fresh air enters through special controllable elements integrated into the window frames. The sun, which is low in the sky, shines deep into the apartment and warms the floor and furniture. This heat energy is then transferred by convection to the room air. Radiators provide any necessary additional heating. Only the required amount of fresh air is supplied, thus minimising the heat energy input required to warm this air to room temperature. When visitors or smoking make the fresh air supply insufficient, the window should be fully opened periodically for five minutes at a time to increase the ventilation. Contacts on the windows ensure that the heating and mechanical ventilation systems are switched off - with a time delay - as long as the windows are opened, so that there is no simultaneous use of natural and mechanical systems. This teaches users the correct use of the windows in cold weather. If they leave the window open too long, the temperature sinks and the natural reaction is to close the window again.

In summer the building is ventilated normally using the windows, which can be tilted open (hinged at the bottom), or opened fully (hinged at the side).

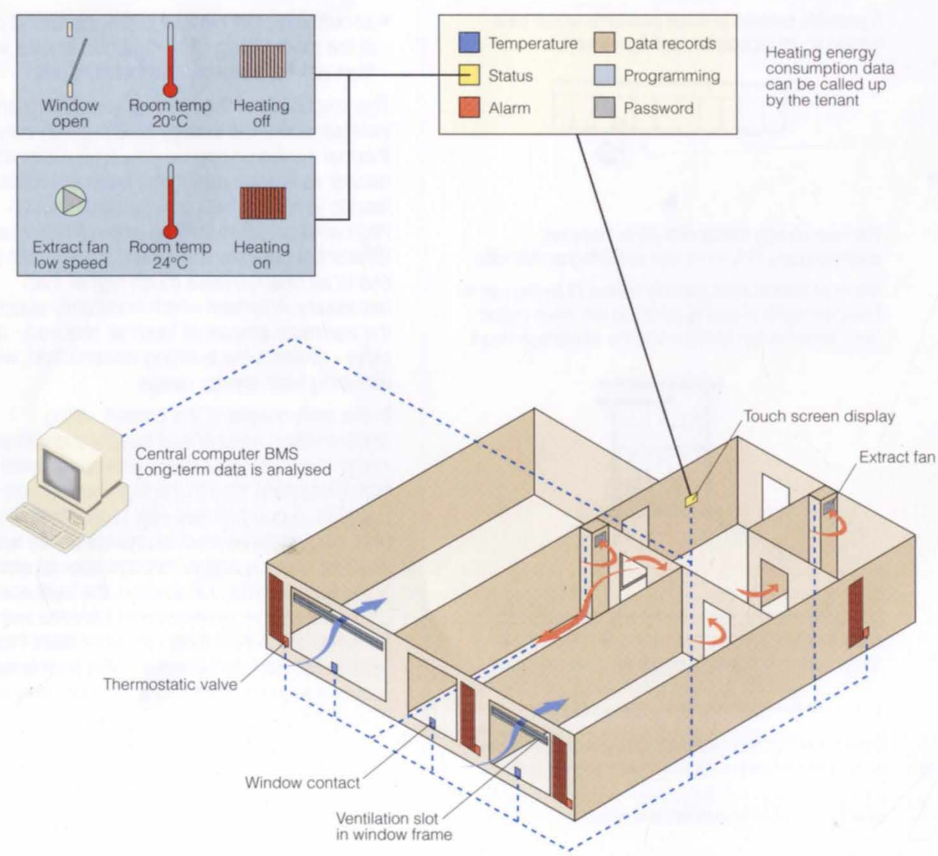


5. Summertime temperatures.



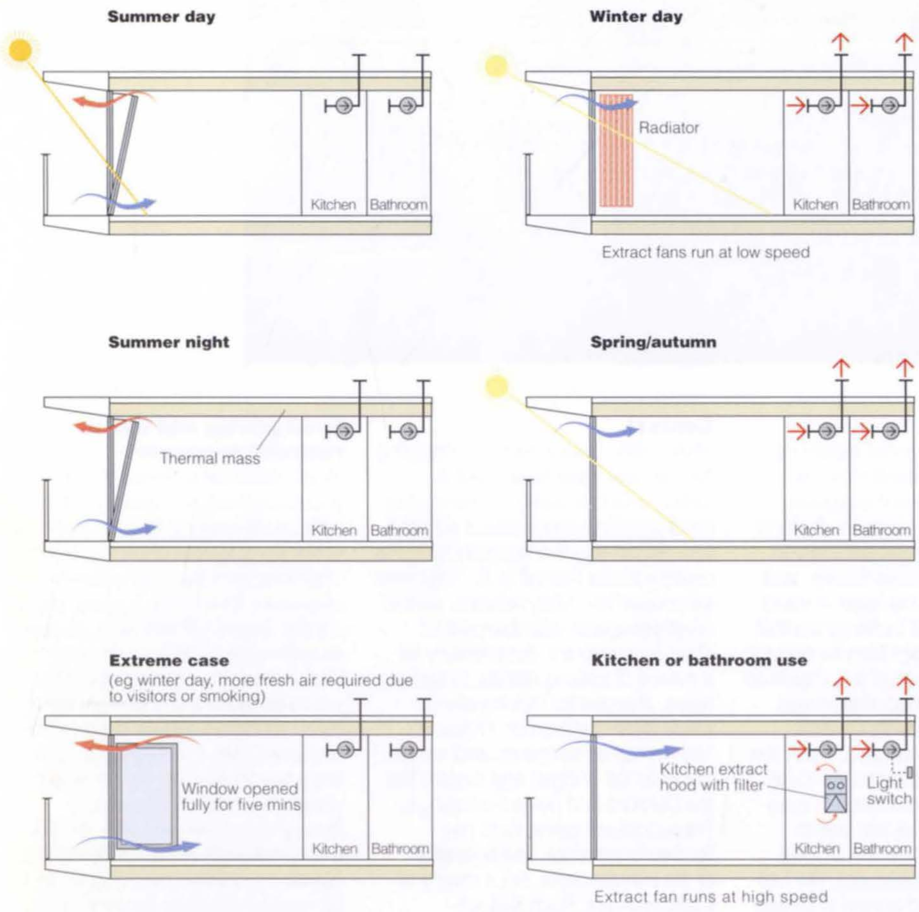
3. Thermal zoning.

6. Apartment balcony.



4. Controlling the apartment environment.

7. Interior of apartment in winter, showing solar penetration.



8. Internal environment at various times of the year.

Solar protection is offered by the surrounding deciduous trees on the south side - which lose their leaves in winter and let the sunlight through - and the overhanging balconies. The depth of these was calculated to allow the direct sunlight into the apartments in winter but almost entirely exclude it in summer, when the sun is higher in the sky. An internal blind for further solar protection is provided.

If the windows remain closed at a temperature whereby it would be more sensible to open them rather than run the extract fans, a visible warning via the BMS (see below) informs the user of this.

In the summer, the windows are left open - probably tilted - at night, to cool down the thermal mass in the room (primarily the exposed concrete slabs) with the cool nighttime air. The 'coolth' stored in this way contributes significantly to maintaining comfortable internal temperatures in the rooms the next day.

When the kitchen is in use, the kitchen extract fan is switched automatically from the first low speed stage - providing basic ventilation - to the second high speed stage. A recirculation fan with a filter in the extract hood over the cooker is also switched on.

The extract fan in the bathroom is coupled with the light switch, so that when the bathroom is used the fan automatically switches from the first stage to the second high speed stage. After the light is switched off, the fan runs for a further five minutes before it returns to the low speed stage.

Building management system

Experience has shown that the energy performance of buildings is largely determined by the way they are used. Even well-designed low energy buildings can have heat energy consumption figures well over the norm if they are incorrectly used. This often happens when users do not fully understand the way the building is supposed to work. The final stage of the energy concept for this building was thus an attempt to increase user awareness of the energy performance, by incorporating the following features into the BMS concept:

- automatic exclusion of simultaneous natural and mechanical system operation (see above).
- Touch screen displays in the apartments allow users to call up information about the heat energy consumption directly in DM. In this way, they can tell how their behaviour influences the heat energy performance of their apartments and react accordingly. Room temperatures and system status as well as alarm reports are also displayed here.
- Long-term data is archived and will be analysed by Arup engineers for two years after completion.

Conclusion

The first tenants have already moved in and the project has been much publicised in Germany, both in the conventional and the architectural press. Arup GmbH has been inundated with inquiries from universities, student organisations, and architectural and consulting engineering associations. Despite the high quality achieved, the construction cost (c 2100DM/m^2) was only 10% higher than the cost of an average non-low energy residential building (c 1900DM/m^2). The collection and analysis over the next two years of data on the energy consumption of the apartments should provide very useful information for future design work.

Credits

Client:
Wohnungsbaugesellschaft Marzahn mbH

Architect:
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Consulting engineers:
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Landscape planning:
Büro Kiefer

Site management:
Büro Lubic

Surveyor:
Büro Dippold

Soil investigation:
Büro Pollak

Proof engineer:
Büro Draheim

Contractors:
Datec, Egokiefer, Ernst Mattern, Rheiner Stahlbau (building envelope)
Stift, Laurenz, Bildau und Bussmann, Rahn, Fliegedo, Udo Dohms, Becker & Söhne Bau (interior finishes)
Marx, Heiztechnik Mühlhausen, Elektro Bunk, Mestronic Steuerungstechnik, Otis (building services)

Illustrations:
1, 6, 7: Willy Engel, Berlin
2: David J Brown
3-5, 8: Brian Cody / Denis Kirtley

Avon traffic restraint

Bernadette Baughan
Hugh Collis
Gordon Henderson

1.
Bristol's traffic problem.

Background

Bristol, like most other cities of its size in the UK, relies heavily on the private motor vehicle to meet its transport needs. Growth in car ownership and use, and more dispersed, low-density development, have combined to produce steadily increasing traffic congestion. Public awareness of the transport problem is continually growing, particularly relating to its environmental effects and the sustainable development debate. The Government's 1998 White Paper on the Future of Transport[1] states: 'Many of our towns and cities face significant levels of congestion and pollution which place a burden on business and result in a poor quality of life for people who live and work there.'

It is predicted that in line with national trends, car travel in the Bristol area will grow by more than a third over the next 20 years. The now familiar problems of congestion and pollution have to be addressed. In recognition of this need for action, a series of targets to control the pattern of increased car usage and decline in the attractiveness of alternatives, including public transport, were set out in the Transport Plan for the Avon Area[2]. These include:

- reductions in car journeys into central Bristol to 40% of peak journeys by 2013
- extensions to parking controls in urban areas
- improved public transport facilities through expanding bus priority measures, Park & Ride services (Fig 2), development of a rapid transit network, and possible implementation of traffic restraint through road pricing.

2.
Park & Ride bus.

It is now accepted that as road capacity in cities cannot expand to meet demand, demand must be managed. A demand management strategy has three elements: firstly to discourage car usage, secondly to encourage use of other modes, and thirdly to minimise the need to travel at all. It is important to recognise that the three methods are complementary. Following submission of a competitive proposal, Arup Transportation was chosen by Avon County Council (now Bristol City Council) to study the likely effects on traffic and the local economy of the introduction of road pricing in Bristol. The aim was to compare the effectiveness of road pricing with other measures, like fuel price increases and control of private parking spaces, as a way to restrain traffic to meet the authority's targets. Arup Transportation was appointed to undertake the study at the beginning of 1995, and it was completed in June 1997.

The Study Brief

The London Congestion Charging Studies programme, commissioned by the Department of Transport (DTp) and published in 1995, had considered the implications of road pricing in London, and the DTp - now Department of the Environment, Transport, and the Regions (DETR) wished to study a major provincial city. Arup's brief was to consider the results of the 1995 London survey and develop a vision of the type of road pricing scheme that would be suitable in Bristol. It was then necessary to specify the modelling requirements; this needed market research to establish likely response to road pricing. Arup was asked to use the model to forecast the effects of different levels of charge, charging at various times of day, and variations in the area to be tolled, and then to apply the model to assess the effects of various restraint measures - road pricing, parking restraint, and fuel duties - in combination to determine the options for meeting traffic restraint targets.

Context

Historically, several forms of charging for road use have been used in Britain. The first parking meters were introduced in London about 40 years ago; Bristol was the second city in the country to use them (Fig 3). They were introduced for policy reasons, so that on-street space was reserved for short-term parkers, not primarily as a means of making money. In earlier times, charges for moving along roads were common on 17th and 18th centuries turnpikes, and remain today on toll bridges and tunnels like the Dartford and Severn crossings. These tolls are primarily to pay for the construction and operation of the infrastructure, not a means of traffic restraint. Such tolls are common throughout the world, including French, Spanish, and Italian motorways.

Charging tolls as a way to restrain traffic in urban areas has been widely considered over almost 30 years. The first scheme was introduced in Singapore, which operates on the basis of a supplementary licence that has to be displayed when entering the central area at peak periods. This is shortly to be replaced by an electronic tolling system. The Norwegian cities Oslo, Trondheim, and Bergen operate pricing schemes on a cordon basis. Some Italian cities restrict access to historic parts of their centres to resident and business permit holders only. In Rome, these permits are enforced using a paper permit in the windscreen, but it is planned to introduce in the near future an electronic system which would charge on length of time spent in the zone. An urban motorway with a tolling system for recovery of revenue is currently under construction in Melbourne.

Road pricing and traffic restraint measures

Arup undertook a review of road pricing techniques, based on world-wide experience, to identify technical feasibility and acceptance. Various characteristics were considered necessary for a tolling system, and a cordon-based scheme was adopted as preferable to time- or distance-based charging options. Motorists would be given the option of paying by an electronic system which either deducted from a stored value card like a telephone card (which would preserve motorists' privacy), or through accounts sent after use, like a telephone bill. An On-Board Unit containing a smart card (Fig 4) would be read by roadside sensors to check validity of payments. This is similar to current systems in auto-toll lanes at toll crossings. It was also considered essential that the tolling system allow normal driving speeds to be maintained at tolling points, and that it should be easy to use for both regular and non-regular users.

3.
Old charging technology.

4.
On-Board Unit comprising 'smart' card and mount.

Road pricing market research

Two major market research exercises were undertaken by Accent Marketing & Research as subconsultant to Arup Transportation.

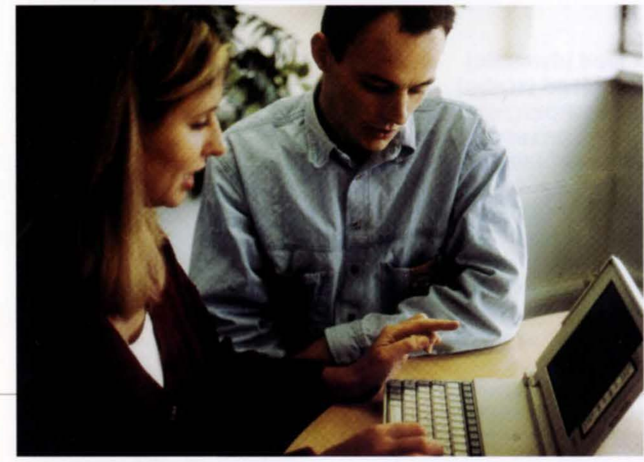
One survey comprised 420 in-depth 'stated preference' interviews (Fig 5) with motorists at five locations in and around Bristol. These examined motorists' responses to various prices and travel choices, including a proposed light rail system, so as to calibrate the model being used for analysis. The survey was divided into five segments:

- motorists who had recently made journeys to work (in three earnings bands)
- education/leisure
- shopping/personal business.

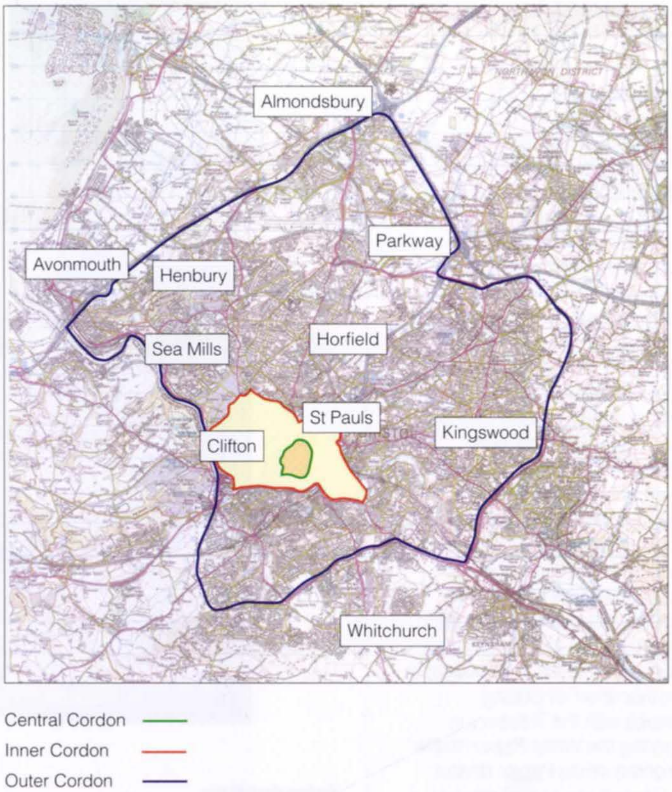
A quota was set for each segment. Respondents were faced with a series of options and asked to choose between travel by car, use of an alternative mode, or not making the trip. Questions were also asked about environmental concerns, using a contingent valuation technique, and this showed air quality improvement to be the greatest concern. It was clear from these surveys that road pricing could only be politically acceptable if the surpluses were used to improve public transport and the environment in Bristol, and it would also be necessary to introduce the public transport improvements before road pricing charges are introduced.

A second set of surveys was undertaken with 200 businesses in and around Bristol to assess how they would respond to road pricing.

Interestingly the firms that would consider relocation to outside the priced area were those already considering moving for other reasons, and, in general, these firms would stay in the Bristol area rather than move to another centre. Some firms would welcome pricing if it reduced congestion[4].

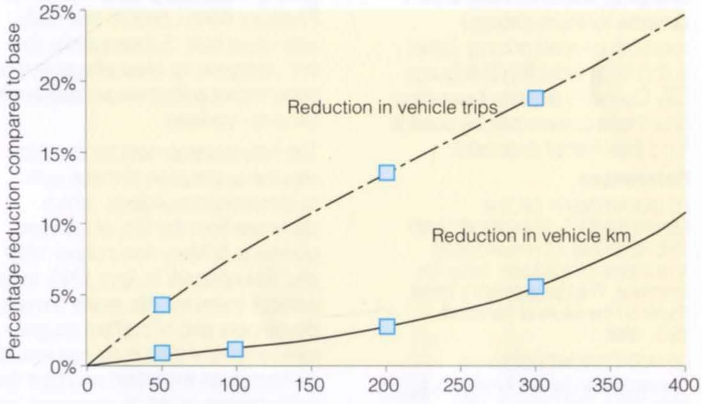


5.
Doing the survey.



6 above:
Cordons proposed for Bristol.

7 below:
Effects of charging on car journeys.



The study evaluated a range of traffic restraint packages and assessed the extent to which they could meet the local authority targets. These packages consisted of:

• ***Pricing scenarios:*** Extensive market research *(see above)* was undertaken for this study to determine the likely reactions of local residents and businesses to a range of road pricing schemes. The results of this research were then used to develop road pricing scenarios - charges on some or all cordons, at various price levels, and either during peak periods only or throughout the day. Three orbital cordons were tested which would impose charges on vehicles driving towards the centre of Bristol, or on both in and out-bound trips.

• ***Parking strategies:*** Varying degrees of parking control were tested, including eliminating contract parking, improving enforcement, increased parking charges, and reduced private non-residential parking.

• ***Fuel surcharges:*** A range of fuel prices and duty levels were tested to determine for future years the extent to which these influence journey patterns and levels.

Traffic model

To evaluate the range of traffic restraint packages, a transportation model was developed to incorporate both highway and public transport networks, and to forecast trips for the year 2013 to allow comparison with targets set out in the Transport Plan for the Avon Area. The TRAM (Traffic Restraint Analysis Model) model covered eight time periods in the day, with road pricing and parking options varying by time period, four trip purposes, three income levels, and two car ownership categories.

The model assumes that planned long-term public transport facilities would be in place before road pricing was implemented, to allow car passengers to switch to public transport. A unique feature of this model is that journeys were modelled as two-way trips (ie tours), instead of the traditional one-way trips, to allow more accurate modelling of home-based trips.

Impact of traffic restraint measures

The study concluded that a charge of £1.20-£1.90 per cordon per day (with a maximum of three cordons (Fig 6) being crossed for a trip inbound to central Bristol) would be necessary to contribute significantly to transport and environmental objectives. Enforcing this charge during any time period would reduce car trips by 14%-20% throughout Bristol. However, this also requires implementation of a wide range of parking restraint measures, and a degree of fuel surcharges imposed by central Government. The study also identified that charges would need to be levied throughout the day, as charges during peak periods led to an increase in car journeys shortly before and after the peak periods rather than an increase in public transport trips. One feature (Fig 7) of the results was that vehicle mileage was not reduced proportionately to the reduction in vehicle trips, as some motorists made longer journeys to avoid tolling points.

Due to the relatively low elasticity of demand relative to price, road pricing can produce very high revenues, and significantly contribute to the objectives and targets in the Avon Area Transport Plan. Parking restraint measures and fuel surcharges imposed by central Government will provide similar, but smaller effects compared to road pricing. However, for road pricing and traffic restraint measures to be acceptable, very significant public transport improvements will be required. The revenue streams could, in principle, allow such improvements to be financed, and a recent Arup discussion paper on this issue that attracted wide attention considered how such a private finance scheme could be applied to fund London Transport[3].

One of the concerns about road pricing schemes is social equity and, while there may be concern over the impact on the personal finances of those at the margins of car ownership, it should be recognised that the higher quality of public transport available should provide a genuine alternative to car use and also benefit existing public transport users. Access to employment and leisure opportunities will thus be much less dependent on car ownership.

Text concludes overleaf ▶

Avon traffic restraint
concluded

Conclusions

The project was part of a programme of research in Bristol and elsewhere supported by DETR, and tested concepts that have been accepted for future legislation in the recent White Paper, which states: 'We will therefore introduce legislation to allow local authorities to charge road users so as to reduce congestion, as part of a package of measures in a local transport plan that would include improving public transport'. The work demonstrated the effectiveness of road pricing and parking restraint in meeting urban traffic and environmental objectives. The finding that the revenues must be spent on local public transport improvements for such a scheme to be acceptable was important for DETR in negotiating 'hypothecation' of pricing revenues with the Treasury in preparing the White Paper. In the light of the White Paper, Bristol City Council are now exploring opportunities for demonstration projects to examine further the issues arising from electronic charging, and to develop a pilot scheme for more detailed research on road pricing. Other authorities, including Edinburgh City Council[5], are also examining how these powers can be used to fund their transit proposals.

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Credits

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Building in blast protection

1 above:
Part of the Manchester city centre explosion, June 1996: façades were destroyed but concrete frame structures remained largely intact.
Arup undertook the comprehensive restoration.

Introduction

In a sense, Arup experience in 'blast engineering' goes right back to World War 2, when Ove himself conceived a substantial underground shelter for Finsbury, north London, that sadly was never built. Subsequently, the firm designed for blast effects in many government and strategic facilities in UK and overseas.

The new development for the '90s was the application of these skills to commercial buildings, which stemmed from the City of London bombs at St Mary Axe in April 1992 and Bishopsgate in April 1993. In the wake of these events, many owners, developers and occupiers sought advice on how their buildings would perform in an explosion and how their performance might be improved, and Arup was variously involved in many of the subsequent appraisals and reinstatements. It has been similarly engaged in Manchester following the June 1996 explosion there (Fig 1), and this year's tragic events in Nairobi, Dar-es-Salaam, and Omagh inevitably generated a new wave of concern about making buildings more secure against this threat.

This article discusses in broad terms how building structures and other building elements respond to blast loading, and outlines some measures to mitigate these effects in designing new buildings and enhancing existing ones.

Blast load (dynamic) v normal load (static)

Structures are designed to resist gravity, wind, and earth pressure where it occurs. Leaving aside tall slender buildings where wind-induced dynamic effects may be important, gravity and wind can be treated as static forces - sustained loads which cause deformation of the structure proportional to their magnitude. Double the load and you double the deformation. The amount a structure deforms depends on its stiffness; the stiffer it is the less it deforms.

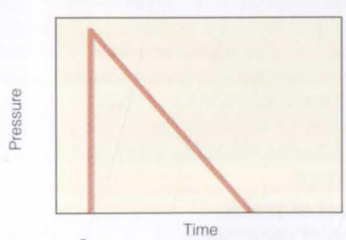
All this is familiar and feels intuitively right, but in fact static loads are just a special case of the whole picture. The total resistance of a structure to an applied force is the sum of various components:

$$m\ddot{x} + c\dot{x} + kx = F$$

inertia damping stiffness applied force

x here signifies a displacement or deflection; $\ddot{x}$ indicates acceleration; $\dot{x}$ indicates velocity.

When there is no motion, or if any movement is very slow, the first two terms in this general expression are zero or insignificant, leaving only stiffness to provide the total resistance to the applied static load. The stiffness term ***alone*** equates to stress and, if large enough, to failure of the element.



2.
Pressure/time graph.

Now consider the case of a dynamic load which ***does*** induce motion into a structure. This time the inertia term may contribute significantly to the total resistance to applied load, to the extent that only a small displacement is needed to balance the equation. The crucial message is that a structure or building element's response to a dynamic load is fundamentally different from the way it responds to a static load.

Bomb blast pressures are characterised by an almost instantaneous rise to peak pressure, followed by rapid decay. In simplified terms the positive pressure phase can be represented as in Fig 2 where pressure may be several hundred kN/m^2 and duration measured in a few thousandths of a second. Compare that to wind loads which are represented for design by pressures of $1\text{-}2kN/m^2$ based on a gust duration of three seconds.

So at what point - over what duration - do we consider an applied force to be dynamic? It depends on the characteristics of the structure and in particular its natural period of vibration (the time the structure would take to complete a full cycle of vibration if you could bend it to one side and let it go). This 'natural period' depends on two properties: stiffness and mass. If you increase stiffness while keeping mass constant the natural period will be shorter. In other words the structure vibrates more rapidly.

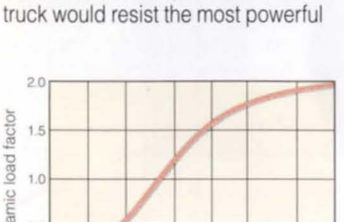
Conversely if you increase mass while keeping stiffness constant the natural period will increase.

To illustrate this, think of how you used to vibrate your ruler on the desk at school. Make it shorter and hence stiffer and you get more rapid vibration. Add a lump of *Blu-tak* to the end to increase the mass but keep the length the same and it vibrates more slowly.

We can show mathematically that the degree to which a structure responds to a short duration load like a bomb blast will largely depend on the relative magnitudes of the natural period of the structure and the duration of the applied blast load. Fig 3 illustrates this effect for a triangular pulse such as that which a bomb explosion might produce. For a structure or element whose natural period is significantly longer than the blast duration, ie T/T_N is small, only a small proportion of the peak blast pressure is 'felt' by the structure. In effect, due to the structure's inertia, the blast pressure comes and goes before the structure can respond in terms of any stress induced in its elements.

By contrast, if T and T_N are more closely matched the structure will 'feel' more of the applied pressure - more of the resistance is transferred to the stiffness term in the above equation. The structure will respond to the blast load even up to twice the applied pressure for a certain range of T/T_N.

As an analogy, consider one of those Strongest Man in the World competitions. When Geoff Capes tries to pull a massive truck up a hill from a standing start he doesn't give a sudden yank on the rope and expect it to move. If he did, the inertia of the truck would resist the most powerful tug even he could muster. But if he applies a steady load he can get the truck slowly rolling, eventually to the point where its inertia works with him as it gathers pace.



3.
Maximum response of elastic system for triangular load pulse.

In the context of building elements, a pane of glass is usually small in scale, relatively light, reasonably stiff, and has a short natural period of vibration, which spells trouble under blast load. The window will be able to respond rapidly to the blast pressure and be significantly loaded by it. Glass is also brittle, and thus we have all the ingredients to explain why broken windows are so common in explosions - and the single greatest source of injury.

Interestingly, it is sometimes the suction or negative phase of the blast pressure that breaks windows. This is less intense than the positive pulse which precedes it but has a much longer duration. Windows seem sometimes to be pushed inward by the positive pressure but not to the point of brittle failure. The pane then starts to return to its original position, still intact, when along comes the negative phase to impose a relatively sustained suction in the direction it is already travelling, with the result that it shatters outward into the street.

Those parts of a building with a long period compared to the blast duration, like the overall stability system or a long-span floor beam, will have a limited response to the blast. If the stability system - eg concrete shear walls or a braced steel frame - feels little of the applied load then its deflection will be small and hence the stresses generated in it will be small. The outcome is that overloading the stability system of a well-engineered steel or concrete building by bomb blast pressures is unlikely for all but the largest credible explosions at close proximity.

Primary structures ***can*** be damaged by a large bomb, but the designer's objective is to ensure as far as possible that damage is limited in its extent by the overall robustness of the structure - that the extent of any collapse is not ***disproportionate*** to its cause. The Chamber of Shipping in St Mary Axe, built in 1967, had the lack of robustness sometimes found in buildings of that era (Fig 4).

Fig 5 shows a building in Beirut that lost much of its lower structure but avoided total collapse - a good illustration of the maxim often quoted by Arup consultant Francis Walley, one of the most experienced engineers in the field of blast effects, that 'structures only collapse when every possible load path has been removed'.

4.
Blast damage to the Chamber of Shipping in St Mary Axe.

In the UK, the lessons learned from the accidental gas explosion in 1968 at Ronan Point led to Building Regulations and design codes which provide the framework and tools for designing robust structures with alternative load paths to reduce the risk of catastrophic collapse. By contrast, US codes - outside seismic zones at least - appear to allow conditions for an outcome like the collapse of the Federal building in Oklahoma in 1995 following the loss of a major element at low level.

Protection objectives

What can a designer do to reduce the risk to those in and around a building in the event of an explosion? One answer is to build heavy concrete bunkers or fortresses, but buildings are occupied by people who, to be comfortable and able to function, need light, air, and an awareness of the world outside. A reasonable balance must be struck between blast protection and all the other criteria for a successful building.

The starting point is thus for the designer and client - the developer, owner or tenant - to agree on the level of threat to be considered and the objectives of any blast protection measures. Threat assessment is a specialist task: there is an almost infinite range of possible combinations of device size and distance to which a building might be exposed. The purpose of threat assessment is to agree on one or more combinations of size and location to be protected against.

The blast protection objectives themselves must be realistic - to expect any commercial building to withstand unscathed a large vehicle bomb immediately outside the front door is a non-starter - and may also include things like business continuity as well as life safety.

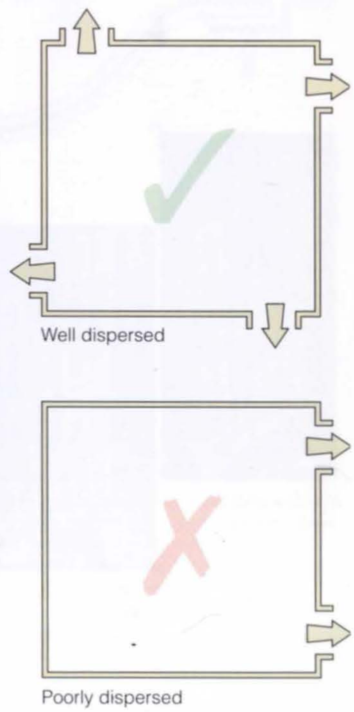
5.
Much lower structure can be lost but total collapse still avoided.

Threat assessment and defining blast protection objectives are part of a process to select not precise design parameters but an approximate position on the scale of possible events from which to develop measures consistent with those objectives. This should then result in a building which offers greater protection not only from the agreed threats but a wider band of all the possible events than would be the case if no added protection were provided.

This of course should be done before the design progresses too far, so that fundamental changes in the building can be implemented without abortive work. For example is there any way to increase the distance of the bomb from the building - the stand-off distance - identified in the threat assessment? In the battle against blast effects every metre added to the stand-off counts. At close proximity and leaving aside local effects, the peak blast pressure is, broadly, inversely proportional to the cube of the distance, so anything that can be done to maximise stand-off such as vehicle and pedestrian barriers is of great value.

Other things to be treated with caution and even designed out at this stage are floors bridging over public roads, re-entrant features like partially enclosed courtyards, and even deep window recesses. All these exacerbate blast effects, due to confinement and reflection of the blast wave. Another issue to consider during early planning is access. Ideally, doors should be well dispersed around the perimeter to allow evacuation in the direction considered the safest, either before or after an explosion (Fig 6).

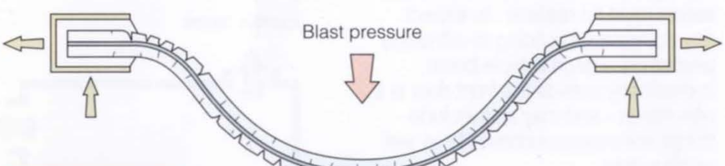
6.
Escape routes.



Having settled on the threat, the protection objectives, and building layout, more detailed engineering can follow. But here opinions on how to proceed diverge. A topographical computer model of the building and its surroundings can be constructed, and then fluid dynamics software used to evaluate the blast pressures and impulses at points around the building for each of the agreed threats. However, the sheer complexity of modelling with confidence the influence of adjacent buildings - plus the uncertainties of bomb location, size and efficiency - undermine the value of such an exercise. The response of the various building surfaces to the blast wave, which might include failure of some, can significantly affect the propagation of that blast wave. Merely representing these as rigid and unyielding surfaces may produce misleading results.

Deriving specific blast pressure characteristics and the response of particular elements do have a place in the engineer's armoury when designing blast protection, but the limits on analysis in topologically complex city centres have to be recognised. There are no exact answers when designing blast protection and no established codes - rather, it is most effective to apply engineering skills based on sound principles backed up by empirical data, with perhaps some pragmatic analysis when appropriate.

7.
Membrane action in laminated glass.



Practical protection

Windows

Each layer of a building, from the outside in, can be helped to withstand external explosions. Starting with windows, conventional annealed glass shatters into sharp jagged shards which - thrown deep into a building or falling from it - cause most of the injuries in an explosion and do so over a wide area. An alternative is laminated glass, a sandwich with a membrane or interlayer between two sheets of conventional glass. In an explosion the glass may still break but it remains stuck to the interlayer rather than forming loose shards. Anti-shatter film (ASF) stuck on the inside is another way of reducing shards and is often used as a quick, relatively cheap retrofit measure. It does however have a limited life, typically 5-7 years, after which it needs to be replaced.

The other great potential benefit of laminated glass is that, if well anchored into properly designed frames themselves robustly fixed back to the building structure, the interlayer will stretch under blast load but remain intact to the limit of its ductility. Although the glass itself shatters and the window has to be replaced, blast pressures do not enter the building (Fig 7).

Secondary laminated glazing inside existing windows can be effective as a retrofit. Although this can take up precious floor space, installation may be simpler and faster than replacing existing windows and frames.

Undoubtedly blast-resilient glazing in both new and existing buildings is the single most effective way to reduce the risk of blast injury to occupants. For many buildings the design of blast-resistant windows can be based on empirical guidance for generic types of device such as 'suitcase bomb', 'car bomb', 'small van bomb', and so on. There *are* occasions though, particularly for buildings which might be primary targets, when more elaborate numerical analysis can be justified - and afforded. Fig 8 shows LS-DYNA 3D modelling, in which a window is subjected to a blast loading beyond its capacity. To reduce the computing effort, only the bottom left-hand quarter of the window has been modelled but included are the properties of the glass, the interlayer, the perimeter frame, and the sealant joining the glass to that frame. The window begins to deflect, starts to tear away from its frame, and finally detaches completely.

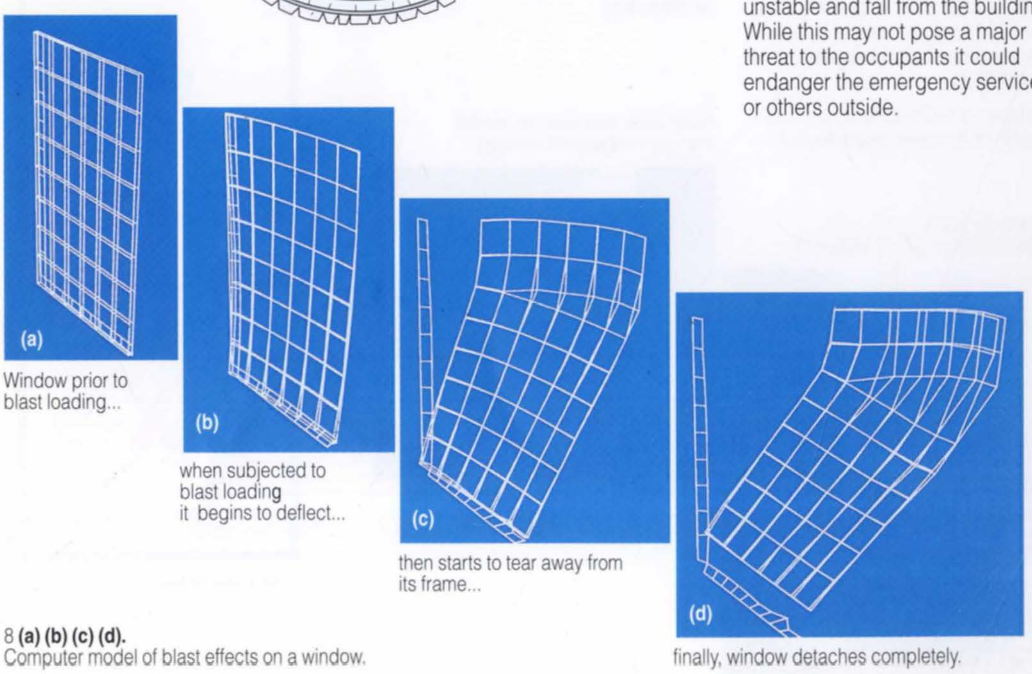
Other cladding

The unglazed cladding elements also need to be considered. There is little point installing blast-resistant windows if what surrounds them fails and allows blast pressures in.

Lightweight metal systems can be designed to take advantage of the material's ductility to absorb blast energy. Alternatively heavy cladding, eg precast concrete, may resist the blast through its inertia. In both cases the load paths back to the primary building structure must be provided by robust connections. Fig 9 shows some substantial stone clad precast concrete window surrounds blown inward due to failure of their connections to the main structure.

Blast-resistant windows or cladding should preferably be designed to span from floor slab to floor slab (Fig 10). With this arrangement blast forces are resisted directly by the overall stability system. If the windows or cladding are connected to columns these will have to be designed to resist horizontal blast forces as well as the vertical loads they already carry.

Stone cladding or stone-faced precast cladding is sometimes fixed to buildings in small panels with a support at each floor level carrying a number of panels stacked one on top of another. The risk here is that if a lower panel is dislodged by an explosion those above will become unstable and fall from the building. While this may not pose a major threat to the occupants it could endanger the emergency services or others outside.



Window prior to blast loading...

when subjected to blast loading it begins to deflect...

then starts to tear away from its frame...

finally, window detaches completely.

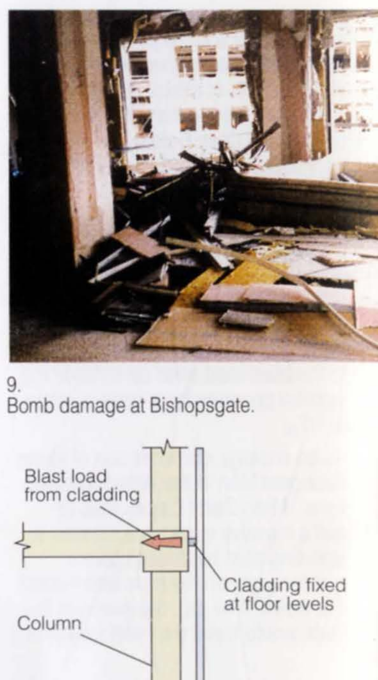
8 (a) (b) (c) (d).
Computer model of blast effects on a window.

The structure itself

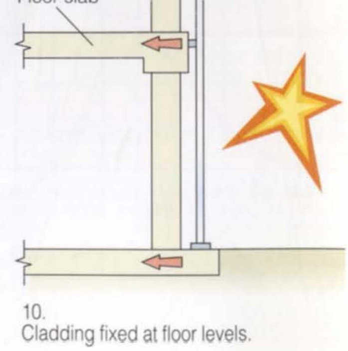
Steel or in situ concrete frames designed and constructed to current UK codes generally perform well under blast loads. Local damage can be severe, with columns or slabs 5m or less from the explosion destroyed or badly distorted, but overall collapse is rare. Some relatively simple modifications to normal construction practice will improve the blast resilience of such structures, but even with these measures, repairs and member replacement may still be required: the designer's aim is to avoid *disproportionate* damage, not eliminate damage completely[1].

In any framed structure the beam-to-column connections are critical. In a concrete frame, reinforcing bars projecting from a beam can be anchored into the upper and lower sections of a column rather than just into the concrete at the junction of the two structural elements where local damage may occur. In steel, 'belt and braces' can add resilience, with a bolted end plate *and* a welded seating cleat below each, designed to support a full beam load on their own.

Other issues for structural designers include the ability of floor slabs to resist upward loads from blast. Areas of the first floor slab may not actually need reinforcement at their top faces to resist normal downward gravity loads, but if blast pressures enter the ground floor there may be an uplift on the first floor slab above, which could then fail if it has no top reinforcement.



9.
Bomb damage at Bishopsgate.



10.
Cladding fixed at floor levels.

Fig 11 shows the underside of a first floor slab, in this case cast on metal decking in a steel-framed building, where blast pressure has bowed the slab upwards and caused the bottom flange of the beam - normally in tension - to buckle in compression.

The structural designer also needs to be wary of how precast concrete elements would behave in an explosion, and to be particularly careful that they are well tied to other robust structural elements.

Bomb shelter areas

Shelter areas for inward evacuation have been promoted by English police and others, at least since the City of London bombings, but the concept of inward evacuation seems not to be advocated by the police in Northern Ireland where evacuation and dispersal away from the scene of the threat is, apparently, the preferred procedure. This may be a reflection on differences in building density between Belfast and central London, particularly regarding tall buildings.

While, despite Manchester and Omagh, it is probably unrealistic to think of sheltering a transient population of shoppers during a bomb threat, there *is* a strong argument for using shelter areas by office occupants at least in the centres of major cities.

What constitutes a bomb shelter area? The minimum criteria are:

1. *Adequate structural robustness* is unlikely to be found near the building perimeter. Robustness in this context means not only that local collapse of the main building structure is unlikely but that there is plenty of protection from blast debris provided, for example, by concrete or dense masonry walls. If access is adequate, basements can be ideal, though smoke venting arrangements sometimes provide a route for blast pressures to enter.

2. *Rapid access to the shelter* is required prior to the explosion and diverse escape routes needed afterwards.

3. Considering that occupants may have to shelter for, say, two hours before an explosion and another hour or so afterwards, *a density of around* $0.8m^2$*/person* would be reasonable.

4. *Fresh air and some degree of temperature and humidity control* are essential for people in a shelter for a lengthy period. The increased occupant density may require ventilation and cooling provision to be enhanced above that provided for normal usage. Obviously the route for fresh air into the shelter should be located so that it does not itself act as a means for blast pressure to enter.

5. *Basic public health needs* must be provided - by chemical toilets and stocks of bottled water if need be.

6. *Communication must be maintained with the emergency services outside.* Telephones lines to the shelter which leave the building at widely separated locations, and preferably connected to different networks, should be set up. Mobile phones may be ineffective in a basement.

7. *Emergency lighting in the shelter and its access routes* should be powered by self-contained batteries in case of mains failure from the explosion.

Clearly for a multi-storey building the basement, if one exists, may offer insufficient space for all occupants, but it may be possible to create a shelter area or areas at the upper floors where blast pressures will probably be less severe and the distances that their occupants have to travel will be less.

If shelter areas are to be used successfully it is essential that inward evacuation procedures are practiced regularly and are unambiguously different from those for fire evacuation. During a bomb threat building occupants and managers will inevitably be in a state of anxiety. Those drawing up contingency plans for the use of shelter areas should aim ideally for a single procedure which can be implemented whatever the threat rather than a matrix of responses to different threats which would require someone to make critical judgements under circumstances with which they are unfamiliar.

Building services

Services can be severely damaged by bomb explosions. The consequences of this damage mainly relate to the speed with which the building can be reinstated and business recommenced with adequate life safety systems in place as well as reasonable occupant comfort. As noted earlier, ventilation ductwork can route blast pressures into the building and when designing new buildings supply and exhaust louvres at low level should be avoided if possible. Blast valves or dampers which react extremely rapidly to an incoming pressure pulse and close off the louvre can be fitted, but they are expensive and require additional space which may not be available in a commercial building.

The best protection for incoming power, gas, water, and telecommunications to a building is duplication and physical diversity so that a bomb in one place cannot take out the entire system.

Some financial organisations, disruption of whose IT networks even briefly would have enormous implications in terms of loss of business, have set up duplicate facilities in different buildings so that if one is disabled by a bomb staff can transfer to the other and carry on. The investment in IT hardware alone by such organisations can make it worth blast-protecting main equipment rooms even if the rest of the building's fittings are severely damaged. Fig 12 shows part of the blast protection Arups recently engineered to a computer room using pressed steel panels of a type used for blast walls in the offshore industry.

Conclusion

Urban terrorism is with us for the foreseeable future. Engineers, architects, and their clients have a new design issue to consider for even the most innocent of buildings. Complex analytical procedures may help the design of blast protection in some situations but, as in any branch of engineering, there is no substitute for sound principles allied with appropriate materials.

Reference

(1) INSTITUTION OF STRUCTURAL ENGINEERS. The structural engineer's response to explosion damage. ISE, 1995.

Credits

Illustrations:
1, 13: Peter Mackinven
2, 3, 6, 7, 10: Martin Hall
4: Michael Courtney
5: Courtesy *FX* magazine
8: Michael Willford
9, 11, 12: David Hadden

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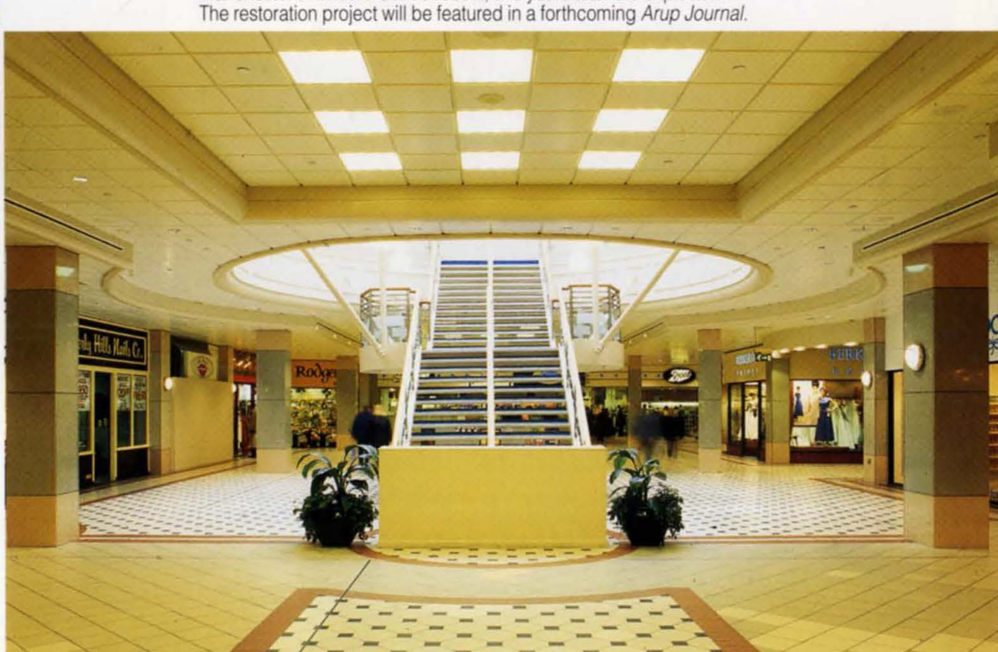
11.
Blast uplift at St Mary Axe.

12.
Blast protection to computer room.

13.
Manchester's Arndale Centre rebuilt, two years after the explosion. The restoration project will be featured in a forthcoming *Arup Journal*.



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