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Front cover:
Eastgate, Harare: close-up of façade (Photo: Wide Angle)
Back cover:
Aerial view of Bevcan facility, Springs (Photo: Barrie Williams)

Eastgate is Zimbabwe's largest commercial office and retail development, and the first large modern building in Southern Africa to use natural ventilation and passive cooling without mechanical air-conditioning. In collaboration with the client and architect, Ove Arup & Partners undertook the mechanical as well as the structural and electrical engineering design for the project, the thermal performance of which since the building opened has been close to that predicted.

During the last 20 years Arups has developed considerable expertise in the design of swimming pools. This article discusses the ventilation and water treatment systems for Sydney International Aquatic Centre's unprecedented array of four pools, including an Olympic-standard competition pool and 850m^2 of leisure waters, and looks forward to further development of the system design at the Bangkok Aquatic Centre, now under construction for the 13th Asian Games.

To replace the ageing Free Trade Hall, the City of Manchester wanted a new concert hall to match the world's finest, as a home for the Hallé and its other orchestras. For the 2400-seat Bridgewater Hall, Ove Arup & Partners acted as geotechnical, structural, and full building services engineers, while Arup Acoustics created the acoustic environment for the performance of classical symphonic, choral, and organ music.

For this new flagship can-making facility at an industrial township some 60km from Johannesburg, Arup (Pty) Ltd were responsible as principal agents to the client, Metal Box South Africa, for project administration and assistance with site masterplanning as well as the civil, structural, geotechnical, mechanical, and electrical design, and quantity surveying. After four phases and five years' work, the plant is operating to its full production capacity of some 5000 cans per minute.

Eastgate, Harare, Zimbabwe

Fred Smith

1. Front entrance.

Introduction

Modern office buildings in Southern Africa are generally air-conditioned, which means importing capital plant. This makes the air-conditioning sensitive to currency fluctuations, as it costs some 15-25% of the building total, and spare parts are sometimes difficult to acquire.

For much of the year, Harare's climate is characterised by generally sunny, warm days and cool nights with temperature swings of 10-14°C, so an acceptable inside environment without conventional air-conditioning was considered possible. To achieve it in a real building, however, needed belief by both developer and professional team. Such an opportunity arose in 1991 with the initial planning for Eastgate, Zimbabwe's largest commercial office and shopping development. The brief was for a relatively inexpensive building with acceptable comfort levels in the offices, without air-conditioning, and without compromising the aesthetics and overall quality of rentable space. The client's bold concept was matched by the architect's enthusiasm, and to these factors was added Arups' experience as structural, mechanical and electrical engineers.

The closely co-ordinated design between, and total commitment of, everyone involved made achievable this first building of its kind in Africa.

Project outline

Eastgate fills a city block near the edge of the Harare CBD. 140m long by up to 70m wide, it consists of two narrow, nine-storey blocks orientated east/west and separated by a 16m wide covered pavement with a glazed roof 35m above. The ground and first floors accommodate 5600m^2 of shops with the remainder given over to 26 000m^2 of offices, the top floor level just within 30m above ground to avoid the by-law requirement - and expense - of sprinklers to the offices. 332 tenant parking bays occupy two levels below ground, with 93 bays for visitors at first floor on the north side of the building.

Lattice beams spanning over the covered pavement support the glazed roof. Linking the blocks together at each level are four sets of open steel bridges, hanging from substantial bridge beams which contain lift motor rooms and water tanks at roof level. These are spaced at about 35m centres along the building length. At second floor level the cross-bridges are linked by a suspended 'skywalk' running the length of the covered space; this houses the commissioners' desk and security point and is the main entry level to the offices. Access to the skywalk is from the ground level pedestrian mall by an escalator midway along the building length.

Mechanical engineering

The engineers contributed in many ways to meeting a brief unique in Zimbabwe. The site was large (8500m^2) and the three building forms considered (short/squat, tall/narrow, long/thin) all had advantages and disadvantages.

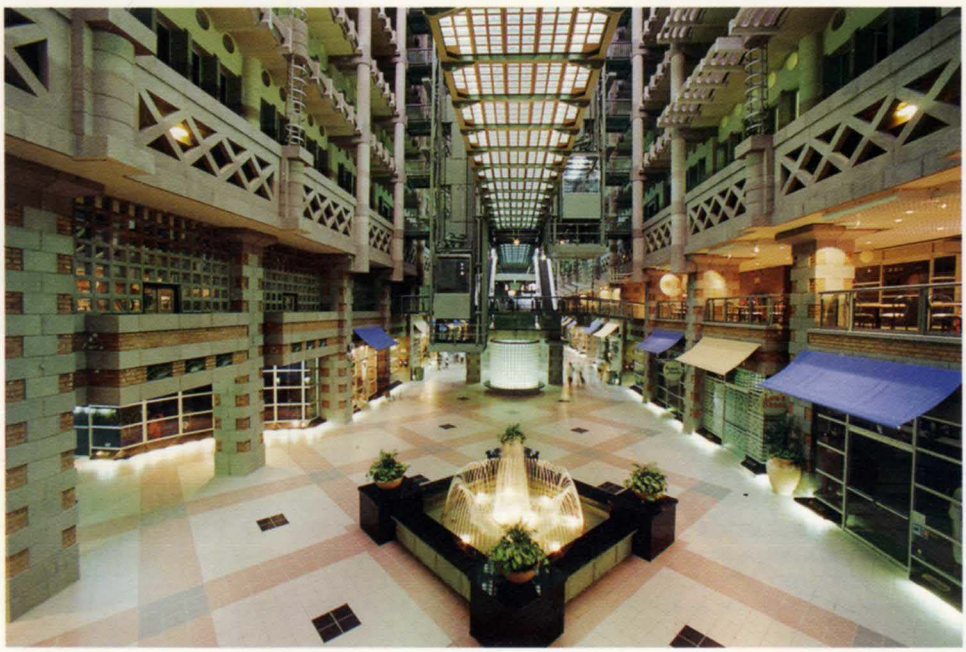
Environmentally, a short, squat building has the smallest surface area and is least susceptible to external conditions, but its deep spaces need constant artificial light, creating high electricity consumption. A tall building would have good access to natural light throughout but cost more to build and run (eg lifts, etc), and need automatic sprinkler protection. For this site, two long narrow blocks gave both the required bulk and good natural lighting possibilities. By orientating them along the city's east-west axis, solar gains were limited. Being near the equator, only the east and west façades are subject to strong direct sun.

The environmental engineer's main aim was to achieve thermal comfort in the occupied space, whilst limiting capital and running costs. Ways to limit internal and external heat gains were investigated, as well as methods of cooling the building using night-time ventilation.

Moderating external heat sources

In a moderate climate like Harare's the major external heat source is solar gain through glazing, and also indirectly from sky and ground reflectance. This radiation cannot easily be shaded, so glazing was limited to c25% on the north and south façades. To investigate ways to minimise solar heat gain, a computer model was used to simulate the solar path, together with various side and top shading devices, and to predict internal temperatures. A difference of 1°C in peak internal temperature was predicted between a well-shaded, 25%-glazed, north-facing façade and one with 50% glazing.

A combination of in situ concrete and double-thickness brick in the exterior walls moderates temperature extremes, and generally light-coloured finishes reduce heat absorption. Precast concrete semi-arch hoods projecting over windows provide external shading, as well as inter-floor fire barriers. Internal venetian blinds allow occupants to limit indirect solar heat gains and external glare when necessary. In the covered street, finishes are as pale as possible so that reflected natural light can penetrate the full office depth, while office interiors are also light-coloured to render both natural and artificial light sources more effective. The combination of clear glass, light finishes, and Harare's natural bright sky provides good natural light in the offices.



2. The suspended 'skywalk'.

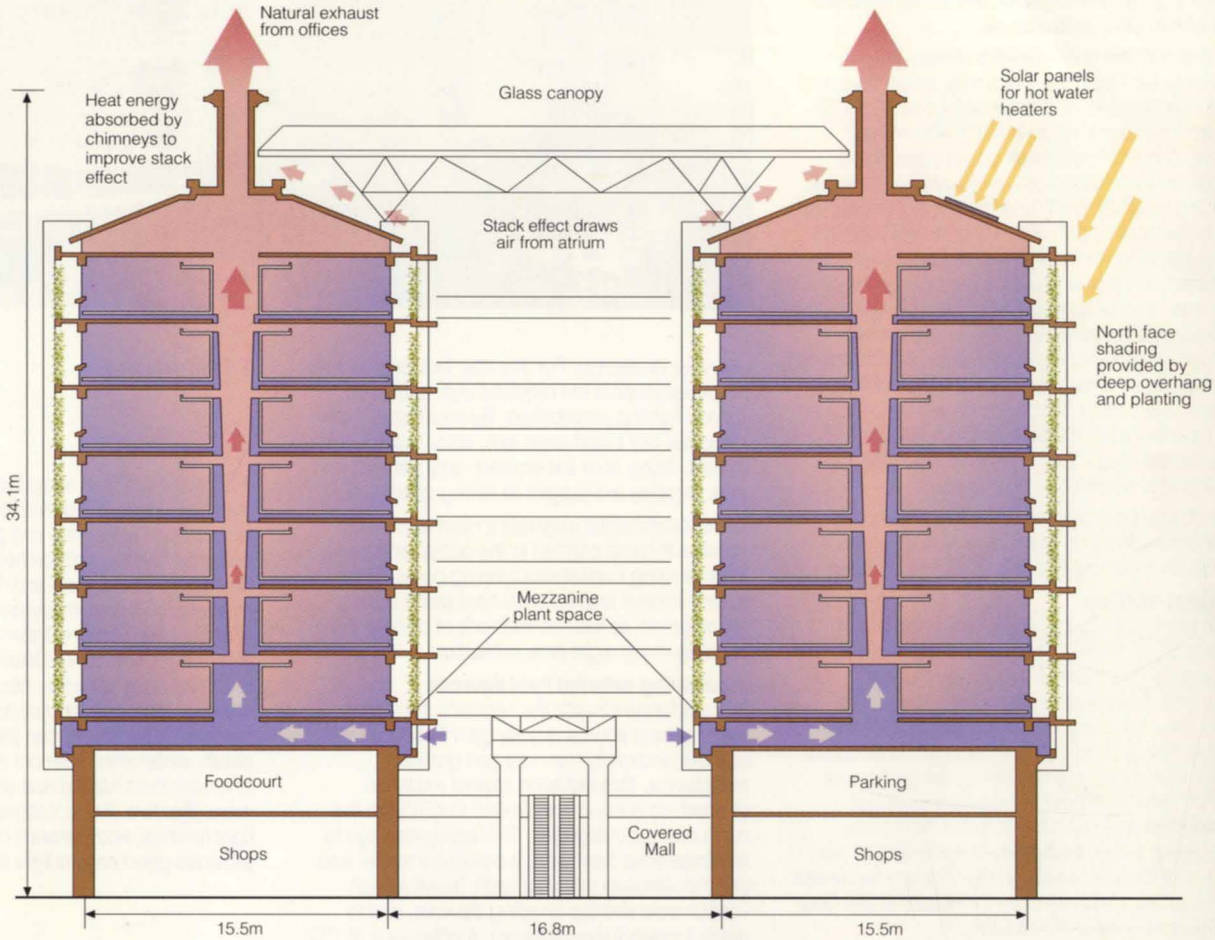
Moderating internal heat sources

The main constant internal heat-source is artificial lighting. The office ceilings are barrel-vaulted, which suggested uplighting to give a very uniform lighting level, but its penalty was reduced efficiency. Computer modelling indicated a half-degree rise in peak temperature when the lighting load changed from 18W/m^2 to 25W/m^2 (representing a switch from downlighting to uplighting to achieve the same level of 400lux in the working zone), but most of this additional load was offset by putting the fluorescent starting gear in the offices' exhaust air path. In the offices, exposed structural concrete elements are a major design feature, forming an articulated surface to increase the exposed area of heavy mass elements. This gives the building structure further capacity to absorb heat from the rooms, with the vaulted concrete slab soffits absorbing most of the radiant and convective heat emitted by the fluorescent uplighters. In this way almost none of the heat from the lights enters occupied space.

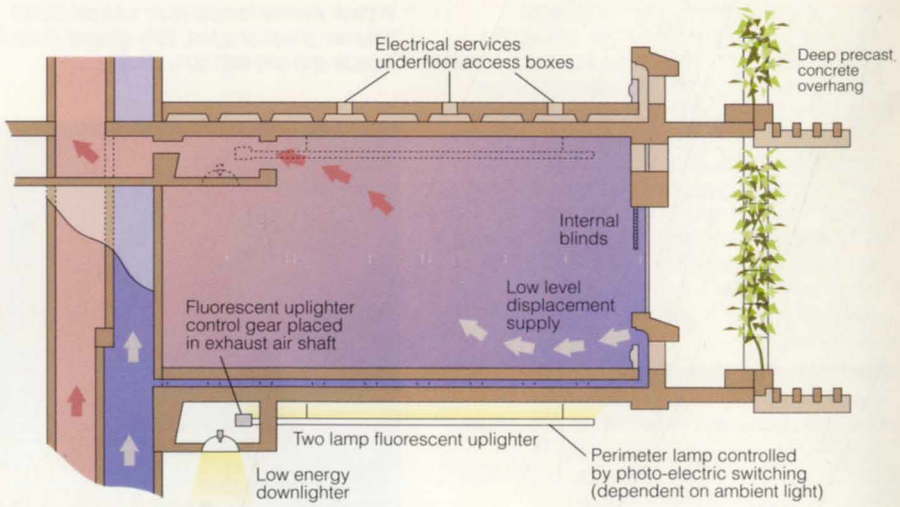
Winter heating

Individual electric room heaters can be turned on by occupants. Power is switched automatically on a half-hour cycle alternately between north and south wings so that overall consumption and peak demand are reduced. Only the low volume fans operate whilst the heaters are on, thus limiting the energy required to heat incoming air. A time switch to heater power is over-ridden by a thermostat which prevents operation above a predetermined ambient temperature.

Ventilation and passive cooling



3. North/south section showing the two blocks linked by the covered mall.



4. Cross-section through typical office.

The decision to use natural or forced ventilation had a major bearing on the building design. Natural ventilation implies opening windows, with consequent noise and dust pollution, wind, heat loss during winter, and security problems, but mechanical ventilation implies significant running costs. The chosen design approach was to develop a pattern of air shafts and air voids, integral with the structure, which would allow cool air to enter the building at its base and warm air to discharge at roof level. The building would be cooled by the flow of cool night-time air drawn through the slightly warmer building. Shafts were sized to take advantage of the natural stack effect, although in the end locally-produced fans were installed to ensure that the system could be more easily balanced.

Fans draw fresh air into the plantrooms at mezzanine level some 10m above ground floor in the covered street, which has cleaner air than the surrounding main roads. Via filters in the plantroom, the air passes to the offices through the network of concrete and masonry ducts in the central spine core of each wing. There are four major supply air zones corresponding to the building's four faces, taking into account the varying external solar gain experienced on each face. Air passes through the voided concrete floor and enters the office space through low-level grilles on the external wall under each window. The office floors comprise in situ concrete slabs with vaulted soffits to form the ceiling. On these were placed precast concrete stools, with short protrusions on the underside to increase surface area and also create turbulent flow in the supply air stream. Since the concrete is at a fairly constant 20°C, the heat exchange cools incoming air in summer and warms it in winter.

Shops

There is a public food court on the first floor, and retail units on both ground and first floor levels. Mechanical ventilation provides adequate comfort level for most shops, but tenants can have air-conditioning installed if required. Outside walls and shop fronts are shaded with overhangs to limit solar penetration, ventilation air entering shop fronts via permanently open grilles, allowing night-time ventilation. Lights are in a false ceiling, and manufactured with slots so that the heat they generate enters the ceiling plenum rather than the occupied space. Tenant-controlled extract fans remove heated air from the ceiling plenum and exhaust it to the outside. At night they are left on during summer, and turned off most of the time in winter.

Office bay under construction, above 5: precast heat exchange sections being grouted into place, and below 6: Finished screeding to precast stools.

This use of passive cooling, a first for Zimbabwe, uses principles similar to those employed in a range of UK buildings, from Arup Associates' CEGB offices near Bristol[1] to the new Inland Revenue HQ[2]. During the cool nights, the system continues to operate, flushing stored heat from the building, using Harare's typical daily temperature swing of 10°-14°C to cool the structure.

A range of Arup computer programs were used to determine the most effective night-time ventilation rate, a balance between improved thermal conditions and the increased capital costs of larger ventilation plant and increased distribution space. Computer modelling was also used to determine the sensitivity of the ventilation scheme to the heat transfer performance, insulation of heat sources, and building materials. Eventually, a mock-up of a typical office bay was built to test the ventilation and passive cooling system, and experiments showed 10 air changes/hour to give the best balance between cooling achieved and power consumed. Fans were selected accordingly.

In addition, low volume fans were installed to provide daytime ventilation of about two air changes/hour in the occupied space, which meets occupants' minimum fresh air requirements. The lower daytime air change rate reduces the impact of high outside daytime temperatures and extends the storage period of the night-time cooling energy in the building structure. By thus varying the supply air quantity, the computer model predicted a 1°C reduction in daytime peak internal temperature.

Other advantages were assessed against the additional capital cost of the low flow rate fans, including:

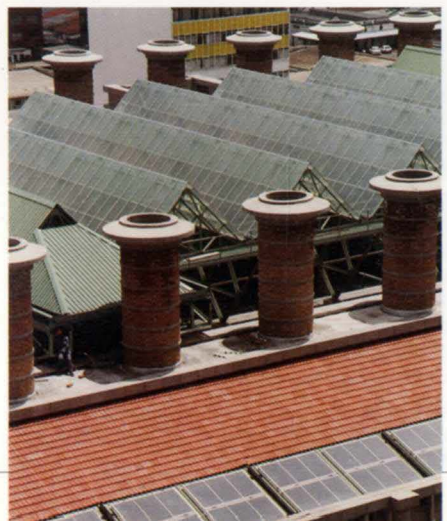
- restricting larger energy-using fans to night-time when electricity is cheaper (and lower maximum demand)
- reducing the cost of sound attenuation for the supply fans because the large volume flow rate fans will generally be working when the building is empty
- reducing air speed through the supply air grilles during the day, thus encouraging displacement ventilation in the offices (enhanced by maximising floor-to-ceiling heights within architectural constraints).

Displacement ventilation was adopted to supply air to the offices during daytime. This enabled the designers to take advantage of the fairly steep temperature gradient between low and high levels to improve comfort further in the occupied space.

Extracting the heat

Ventilation air is exhausted naturally by buoyant convective effects, with no mechanical assistance. Exhaust air exits the offices through high level bulkheads in the building core and then passes sideways to wide vertical exhaust shafts, where velocities are around 2m/s; this made exhaust fans unnecessary, the 'stack effect' removing exhaust air. The natural pressure differential across the exhaust air stack is enhanced by the exhaust 'chimneys' protruding from the top of the building. Their surfaces are heated by the sun, lowering air pressure at the outlet to draw air upwards through the chimney. The architect has called the exhaust chimneys 'solar accelerators' - probably the most appropriate description of their function.

7. Solar accelerators!



The covered pavement

Here, the major functions are to provide a sheltered shopping area in the base of the office blocks and solar shading to the internal office façades, and to prevent convective heat build-up of the warm air rising from the atrium below. The glazed canopy above the space between the two office blocks is raised over 4m above the adjacent roofs, creating more than 800m^2 of open space along its edges through which warm air is drawn out of the atrium by natural stack effect. The ends of the atrium are protected by waterproof louvre enclosures; these stop rain coming in and allow ventilation of the atrium.

The combination of open roof canopy and louvred ends to the atrium allows strong natural ventilation in the atrium area but minimises any wind tunnel effect. This large air change rate maintains the atrium at normal ambient outdoor temperatures throughout most of the year, and therefore does not generate additional heat in the offices. Light-coloured venetian blinds on all office windows have several functions: they stop solar gain thus reducing internal temperatures, they absorb sound, which improves overall acoustics, and they make for privacy.

Car parking

Car parking above ground is normally preferable to limit the need for mechanical ventilation, but parking requirements dictated the need for a basement. Supply fans draw air from the covered pavement into plantrooms at the centre of the basement. Air enters the car park at points along the full length of the basement central services core, is extracted from brickwork plenums along both external walls, and discharges outside at mezzanine level. The brickwork plenums were required as a drained cavity for the perimeter retaining wall but, slightly enlarged, could be used as air plenums, thus replacing extensive metal ductwork systems.

Solar water heating

Hot water is supplied to tea kitchens only. None is provided to the office toilet blocks, and water for the shops and food court is heated locally by electric hot water heaters. The water for the kitchens is heated centrally by solar exchangers as primary energy source, backed-up by electric elements in the storage tanks. Time switches control the secondary electric heating so that it can only be energised during the night-time off-peak period where charges are lower. In this way energy consumption and costs have been reduced further. Solar heating effectively reduces the electrical maximum demand and hence electricity rates.

Structural engineering

The structure is predominantly reinforced concrete except for the steelwork roof level beam structure to the covered pavement and all suspended links, stairs and lift cores. Shear walls give north/south stability to the office blocks, while in the 140m long east-west direction, it is provided by a column/beam sway frame. Such a system has uniformly distributed points of stiffness and enables larger spacing of movement joints - a single central one in this building.

Foundations

Two proposals were tendered, a concrete strip and a piled scheme using groups of the augured 600mm diameter piles then available in Zimbabwe. On return of tenders an alternative was proposed with large diameter (up to 1.5m) piles and imported machinery and expertise, now available due to the Zimbabwean economy opening up. This scheme had cost and program advantages. Similarly, an alternative was proposed for the basement retaining structure, initially designed as a 300mm thick concrete wall. Here a soil-nailed, augured pile wall with gunite arches between the piles was proposed and accepted.

8 left: Close-up of roof steelwork showing bridge beams and glazed roof support.

9 right: The atrium showing suspended link bridges, lift shafts, and stairs.

Office floors

The office structure was the part most influenced by architectural and thermal design considerations. Each wing has a central service core with tea preparation areas, storerooms, toilets, and vertical risers for water, sewerage, and electrical services. The floor here is a double slab structure incorporating the main horizontal air ducts connecting to the vertical supply and exhaust stacks. There is a one-way spanning floor slab between the central core and the external façade beams. This slab is vaulted with an off-shutter finish, its top surface forming the base for the precast concrete stools (see 'Ventilation and passive cooling' panel on previous page). A screed was laid over the stools to form the surface on which the floor finish - tiles or carpet - was laid.

The covered street and skywalk

Planning constraints required the ground floor mall to be considered as a covered street or pavement, which required its ends to be open but weather-protected by louvres. No structure except for the escalators and escape stairs interferes with this street at ground level.

The skywalk comprises trafficable glass blocks set into 75mm thick precast concrete panels, suspended on a steel frame. The structural aluminium handrails were custom-designed to incorporate all electrical and lighting requirements.

To allow movement between the office blocks, all the suspended structures are released horizontally at their supports through sliding movement joints. The main bridge beams are supported on elastomeric bearings. Jacking points allow replacement of bearings in the future.

The structure of the link bridges and skywalk allows for redundancy to permit replacement of cables if necessary. The entire structure can tolerate removal of any single cable without distress except for the wide section of the skywalk which would require temporary support off the ground floor. For these hanging structures the cables are all relatively 'stiff', which helps to ensure that each cable carried a known (and generally equal) load. Installing the cables was therefore very much a levelling exercise with no requirement for stressing or 'tuning' of cables. The cables themselves have a factor of safety = 6.0.

Electrical engineering

Design of the electrical engineering services was closely co-ordinated with the architect and other engineering disciplines to enable optimum design of the passive cooling system as well as other electrical requirements.

High voltage supply and distribution

Electricity is supplied via a dedicated 11kV radial feeder from Zimbabwe Electricity Supply Authority's 33kV/11kV Manica Control sub-station; ZESA's existing ring circuit to the area had insufficient capacity for Eastgate's demands and much planning and input from the engineers and ZESA was required to overcome the problems.

Medium voltage and sub-mains reticulation

The sub-mains distribution is via predominantly low smoke and fume-sheathed cables, carried by a network of horizontal racks and trays in basement areas to dedicated vertical electrical risers for distribution to sub-mains distribution boards and control panels throughout the building. A cost comparison between cable and a rising busbar system showed cable to be more economical for the building's long, low-rise form. Individual sub-mains circuits are each metered at the main switchboard position, enabling the landlord to monitor and charge tenants for electricity consumed.

Lighting

Basement, mezzanine and roof level

Here, lighting designs centred around providing the cheapest and most effective design for durability, ease of maintenance, and low running costs. Generally, luminaires with fluorescent lamps (both standard and compact) provided the necessary illumination levels and met these criteria.

Where possible, individual fittings were supplied via an unswitched three-pin socket for improved ease of maintenance.

Shops

These have suspended modular ceilings into which recessed fluorescent luminaires with prismatic diffusers were installed. Special task, signage, and decorative lighting techniques were provided to each shop to meet individual tenant requirements during fit-out.

Covered pavement

This space had to be a 'state-of-the-art' mall in line with current worldwide retailing trends. Following detailed and complex calculations, over 30 different luminaires were specified by the engineer as part of the mall lighting design required to meet the client's expectations. The lighting was an integral part of the mall design and the overall result has been very successful.

Offices

The barrel vault ceiling suggested uplighting to enhance the ceiling profile and create a quality lighting environment. A mock-up of the proposed solution was prepared and a luminaire, through many alterations and modifications, was developed specifically for the application. A special feature of the office lighting is that half the total luminaires can be automatically controlled

depending on external ambient lighting levels. For much of the year the external light levels are enough to illuminate the narrow offices. A four-stage, highly calibrated photo switch at roof level provides an energy-saving solution which also helps reduce office heat load.

Small power, telecommunications, and data services

The voided floor prompted by the passive cooling design also houses a versatile and flexible small power, telecoms and data services system, able to accommodate any partition and furniture layout and avoiding skirting trunking. It consists of a network of galvanised trunking and conduits linking underfloor boxes equipped with 13A switched socket outlets, telecoms outlets and a facility for data control, wherever required.

Fire alarm

A conventional hard-wired system utilising manual and automatic detection as well as electronic alarm sounds was installed, offering both protection of property and life functions. 104 fire alarm zones communicate to central panels which in turn link to a single mimic panel at the Commissioner's Desk on the skywalk.

The fire alarm system, which is an integral part of the Building Monitoring System installed at the Commissioner's Desk, also includes an associated public address and voice alarm system. This covers the ground and first floor public areas, providing secure, fail-safe, and highly intelligible pre-recorded emergency speech broadcasts. An over-ride fireman's microphone completes the system.

The size of Eastgate prompted concern about safe evacuation in case of fire. The engineers decided on a 'staged evacuation' system, allowing for the safe removal of occupants in controllable stages from various parts of the building. Zones nearest a fire are obviously evacuated first with less affected zones controlled by the fire alarm control system then vacated in a prioritised order.

10. Shopping area.

Building performance

Construction took from January 1993 to April 1996 when tenant occupation began, ending in September. The ventilation systems are being handed over to the on-site building operational staff as they are commissioned, and a programme to monitor office climate has been instituted as well as a survey of energy consumption.

Thermal performance record data

Arups themselves moved into Eastgate as tenants, and have been monitoring various elements of the environmental conditions in the offices using both an electronic dry bulb temperature data logger and a wet bulb thermometer. The former records several dry bulb temperature readings simultaneously and can be downloaded to a PC for graphical plotting of the output data. Results to the time of writing have been variable due to on-going building commissioning and some early operational problems. However, the plant has now been operated for extended periods and recordings taken have concluded that the building is performing at least as well as predicted, if not better. Two examples illustrate performances on days with very different weather conditions. Fig 11 (26 September 1996) is a good example of the cooling that can be achieved on a hot day with a diurnal temperature swing of about 10°C and a low ambient temperature the night before. 4.5°C of cooling was achieved on this particular day. The respective lines for low, internal, mid, and high level temperatures indicate the displacement ventilation within the office space. Respective heights above floor for these curves are 0.5m, 1.0m, 1.8m, and 2.3m. 14 October 1996 (Fig 12) experienced a small diurnal temperature swing of about 5°C when the night-time ambient temperature did not fall below 20°C, and this resulted in a reduced cooling of less than 2°C.

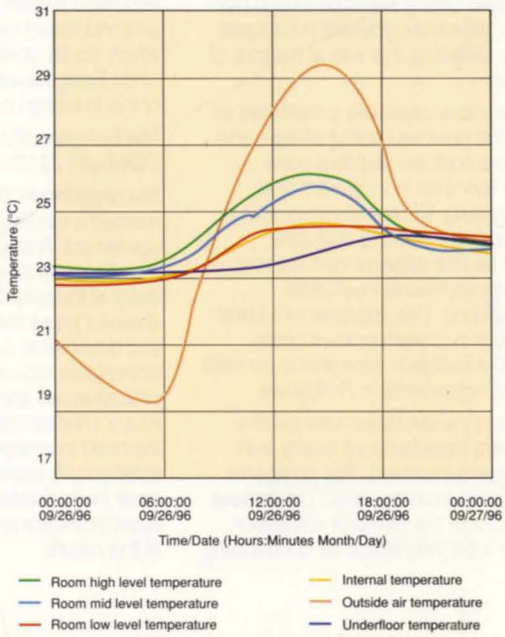
Energy consumption

Actual energy consumption readings are available after the first six months of building operation. To make a direct comparison between Eastgate and similar air-conditioned buildings, it was necessary to ignore the energy consumption of the shopping and food court areas by deducting sub-meter readings.

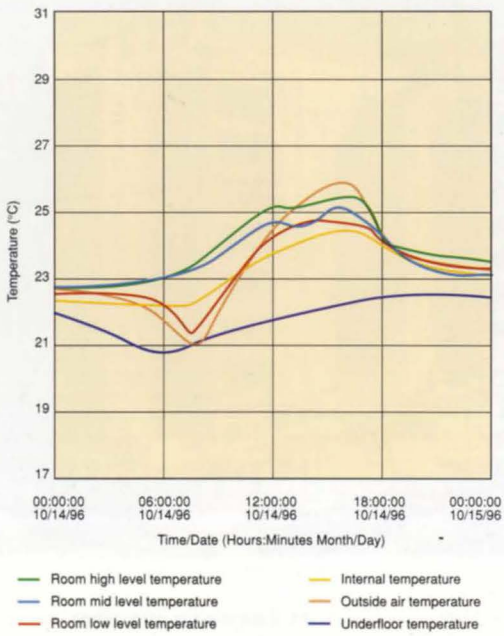
The results are very favourable showing that Eastgate has a power consumption of 9.1kWh/m^2 compared with a sample of six other Harare developments vary from 11kWh/m^2 to 18.9kWh/m^2, and thus an energy consumption per unit area of 48%-83% of other typical CBD air-conditioned buildings.

It is difficult to compare Eastgate with other buildings on the basis of peak demand because of the many additional features that make it unique in Zimbabwe, ie extensive shopping areas with feature lighting, shopping mall lights, food court cooking appliances and ventilation fans, escalators etc. However comparison of peak demand meter readings to date suggests that Eastgate has a maximum demand per unit 10% lower than the average for six other buildings considered.

Absolute conclusions on energy efficiency will not be drawn until energy consumption readings for the first full year of operation are available and are modified so that direct comparisons can be drawn. However readings to date clearly conclude that Eastgate out-performs other Harare buildings of similar quality and size.



11. Temperature vs time: 26 September 1996.



12. Temperature vs time: 14 October 1996.

13. Close-up of atrium link bridges.

Costing

From the developer's viewpoint, capital cost as well as running and maintenance is obviously vitally important in assessing project viability. Although suspended ceiling and mechanical plant costs were very significantly reduced in Eastgate by omitting air-conditioning, this was at the cost of additional structure.

The office floor structure especially constituted an important part of the passive cooling design, and as such it was more complex and thus more expensive than a floor slab in a conventional air-conditioned building. Clearly no two buildings are identical, but current building cost data show Eastgate to be little different from the cost expected for an approximately equivalent air-conditioned building. This, together with lower energy consumption and maintenance costs, clearly indicates the Eastgate approach to be valid for future similar developments in Zimbabwe.

Most components in the ventilation and passive cooling system were manufactured locally, with less than 10% of items imported. This compares with more than 30% in average HVAC installations. Furthermore the cost of the Eastgate installation was about 10% of a full mechanical air-conditioning system for the same building. The components, including control elements, are relatively simple devices to make the system easy to maintain. The capital costs and energy consumption of the ventilated system compare favourably with an air-conditioned system, a similar-sized example of which would have cost approximately Z$25M when Eastgate was tendered, with about Z$8.5M of this in foreign currency.

The Eastgate office ventilation system tendered at Z$3M with Z$120 000 in foreign currency.

The requirement to omit mechanical air-conditioning needed a modified approach to the standard fee agreement. A proposal to handle the more work/less capital cost situation was put to the client at the outset, with an understanding that should it prove inappropriate, it could be reviewed and modified at completion. In the event, although acceptable recovery factors were achieved for structural/civil and electrical commissions, Arups' mechanical involvement clearly indicated the need to renegotiate the original fee. This was satisfactorily undertaken, and the Eastgate experience thus provided a basis on which to derive an appropriate fee structure for future commissions of this nature.

14. Eastgate fills a city block.

Conclusion

Eastgate is unique not only to Zimbabwe but in the region as well. Indeed, there are relatively few published accounts of passive cooling used to the same degree of sophistication elsewhere. As such it is highly innovative and because it was being undertaken for the first time in Zimbabwe, it required considerable originality in design approach. It was essentially the engineering and quantifying of well-known thermal principles, not applied previously to modern developments there.

As noted, preliminary climate measuring results show the office environment to be close to expected comfort levels. It is anticipated that once commissioning is complete and fans are being operated optimally, results will be further improved. The passive cooling was achieved using readily available local materials and construction skills. There was no need to import specialist equipment and although the floor construction was unusual, it was an achievable way of using traditional materials.

The early available data indicate clearly that there will certainly be a saving in running and maintenance costs. The reduced energy requirements effect a direct monetary saving while the relative simplicity of the mechanical plant, namely fans, avoids expensive imported spares - and all achieved at an overall building cost comparable to a similar air-conditioned building. The economic significance of this is that it will help contain building costs, and thus rentals and all the associated downstream costs. It is also clear that reduced energy demands and reliance on air-conditioning have significant environmental implications.

As for the impact of all this on building aesthetics, Eastgate shows the architect to have created a unique building that can stand on its own anywhere. He managed to satisfy the requirements of the mechanical engineer for heat reduction in a way that gives refreshingly new character and interest to the façade.

Whilst the concept was initiated using experience gained by Arups in the UK, its development and detail design were undertaken in Zimbabwe. Software developed by Arup Research & Development in the UK was used in the initial mathematical modelling to verify parameters, but otherwise every aspect of the design process and construction was done in Zimbabwe, which augers well for this approach to office design in the future.

References

(1) DOWSON, Philip. Offices. *The Arup Journal, 12*(4), pp2-23, December 1977.

(2) BERRY, John, *et al.* The New Inland Revenue Centre, Nottingham. *The Arup Journal, 30*(4), pp11-17, 4/1995.

Credits

Project manager and building developer:
Old Mutual Properties, Zimbabwe

Architect:
Pearce Partnership

Structural, civil, mechanical and electrical engineers:
Ove Arup & Partners
John Crack, Olga Djuric-Peric, Joas Musoko,
Jon Rapley (structural)
Andy Marks (civil)
Menino da Silva, Mark Facer, Peter Gundry, Andrew Moore,
Nigel Nichols, Daniel Phillips, Darrel Strobel (mechanical)
Steve Done, Shaun Landman (electrical)

Quantity surveyors:
Hawkins Leshnick & Bath

Building contractors:
Costain Sisk Joint Venture

Illustrations:
1, 2, 8 -10, 13, 14 : Wide Angle Inc (Pct) Ltd
3, 4, 11,12: Nigel Whale/Martin Hall
5 - 7: Margaret Waller

International aquatic centres, Sydney to Bangkok

Paul Stevenson

Overview

Arups have been involved in the design of swimming pools for many years, at first through structural engineering only. Later, this developed into an integrated building engineering approach[1] with the aim of achieving for clients:

- improved environmental conditions, particularly in air quality, water quality, and air and water temperature
- reduced energy consumption, costs, and levels of manning and building maintenance
- greater 'user-friendliness' for all ages and conditions of swimmer
- increased life-span of the building and services.

A milestone project was the complete structural and environmental services design for Ponds Forge International Sports Centre[2] at Sheffield - completed in 1991 for the World Student Games - which included a 50m x 25m international pool and a 5.8m deep diving pool. In July of the same year, Arups' Sydney office began a building services consultancy with particular strength in swimming pool design.

A little earlier in 1991 Sydney, as part of its bid for the year 2000 Olympic Games, had decided to build a new aquatic centre in the inner western suburbs at Homebush. The selected site, Sydney Olympic Park, Homebush Bay, was to house in one area most of the Olympic facilities, including for the first time in the Games' history all the competitors. Civil & Civic, who were successful in their tender to design and build the aquatic centre, began appointing consultants in late 1991. With Arups' new building services consultancy up and running, the firm was in the right place at the right time to submit proposals for service elements in the project, and was appointed for two aspects: as designers of the pool water treatment systems and as 'aquatic experts'. The firm was also appointed for the civil engineering design.

In September 1993, the head of the International Olympic Committee (IOC) announced that Sydney had won its Olympics 2000 bid. By this time many potential venues for the Games were designed or under construction, and the Sydney International Aquatic Centre was already complete and setting the highest standards for both elite competition and community swimming facilities. The head of the IOC was so impressed that he called it the best swimming pool he had ever seen, and as Olympics Chief he has had the opportunity to visit all the world's major international swimming facilities. No wonder that in the first four months some 350 000 Sydney-siders visited the centre, and that since then attendances have been consistently high.

Following the success of the Sydney Aquatic Centre, the architects - Philip Cox Richardson & Taylor in association with Peddle Thorpe Architects - and Arups were invited by the International developer/contractor Christiani & Nielsen to support them in their bid for the 13th Asian Games, Bangkok. It was successful, and this latest Arup aquatic centre project is currently under construction.

1. Sydney International Aquatic Centre from the air.

Sydney International Aquatic Centre

Introduction

'Aquatic experts' was an unusual role whereby Arups, as the only team member with substantial swimming pool design experience, assisted all the other design team members in their work. The ventilation, condensation, and corrosion concepts, in particular, were all provided by the firm. As the project developed, Arups was also appointed to design many of the building's unusual features, including the movable boom, the floating adjustable floor, the practice diving bubble, the Leisure pool configuration, and all the leisure features.

Key experience had been gained on the Sheffield Ponds Forge project, which Civil & Civic visited as soon as they were awarded the contract, and used as a benchmark in many of their briefs to consultants.

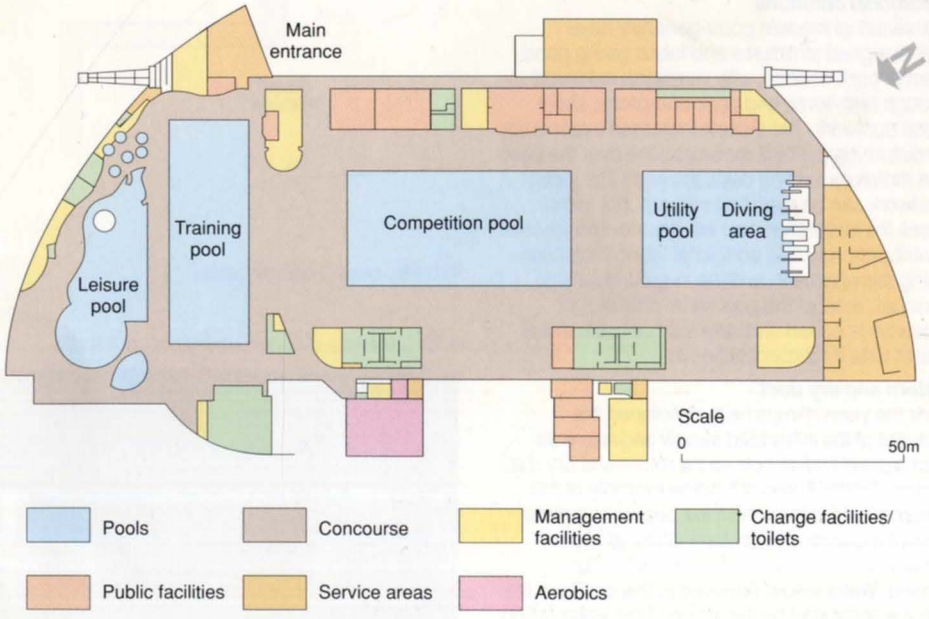
The benefits to the design team of the Ponds Forge experience were many and included the unique modified ventilation system, the roof form, corrosion and material selection, water treatment and distribution analysis, heat recovery techniques, movable floors and boom designs, leisure feature design and leisure pool configuration.

Each of these aspects formed an excellent basis for review and development to the substantial benefit of the Sydney project.

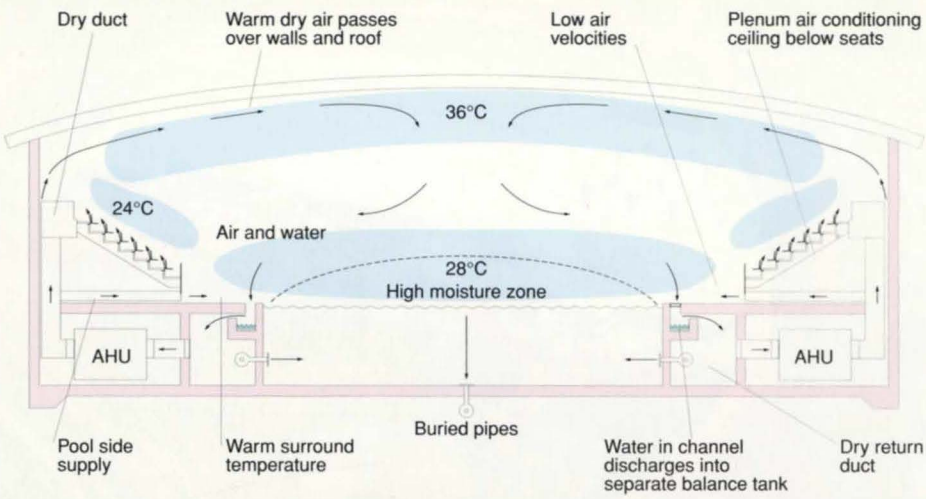
Building details

Under a barrel vault roof spanning some 70m, several pools are housed: the Competition and Utility pools in the main hall with permanent seating for 4400 spectators, and the Training and Leisure pools in the leisure hall. This wide combination is reputedly unparalleled in the southern hemisphere and probably the world. Their details are as follows:

- Competition pool: 51.5m x 25m, 10 lanes, 2-3m deep; used for 50m and 25m short-course competitions. A 1.5m wide floating movable boom can divide the pool into two 25m pools.
- Utility pool: 33m x 25m, 3-5m deep; used for 25m short course/training, and diving with 10 boards up to 10m high
- Training pool: 50m x 18.2m, 1.2-2.5m deep; used for 50m training and general leisure activities. A 33m long adjustable floor can vary the depth from 0m to 2.5m.
- Leisure pool: 850m^2 of leisure waters, including areas for learning and for babies and toddlers, and various water effects/rides.



2. 1992 site schematic. The disposition of principal areas was unchanged as built.



3. Final ventilation strategy (summer conditions).

6. Competition pool with the Leisure pool in the background.

There is a range of support facilities for all the pools, including accommodation for officials, stores, changing areas for both competitors and the public, marshalling areas, massage facilities, a diving hot tub, spas, saunas, steam rooms, meeting rooms, aerobic areas, and fully-equipped weight training rooms. A key objective of the design was to produce a facility that met long-term community needs as well as strict Olympic Games requirements. This was particularly relevant to seating, where by removing the east wall and extending the seats up an extensive eastern earth bank, the normal permanent capacity of 4400 can be temporarily increased to 12 500 for the Games.

Ventilation systems

The brief

The following criteria had to be met:

- air temperatures over the water surfaces and on the pool surrounds to be maintained at about 27°C, ie 1°C above the water temperature
- air temperatures in the spectator areas to be at comfort conditions: around 23°C
- ventilation to assist in preventing condensation
- energy consumption and running costs to be as low as possible.

Conventional ventilation systems for swimming pools provide a common high temperature throughout the whole space, so it was clear that a conventional solution would not be appropriate here and that an original concept had to be developed.

Traditional solutions

Conventional modern pools generally have well-designed structures and fabric giving good thermal performance, with ventilation achieved through high-level, and corrosion-prone, sheet metal ductwork. The system increases evaporation by disturbing the high moisture zone over the pool and therefore running costs are high. The metal ductwork can be replaced with grp, but in most cases the installation cost will double. The system contributes very little additional fabric protection. Using this approach, with no in-ground service trenches, most of the pool water distribution pipework is buried and very difficult to access at a later date for inspection/repair.

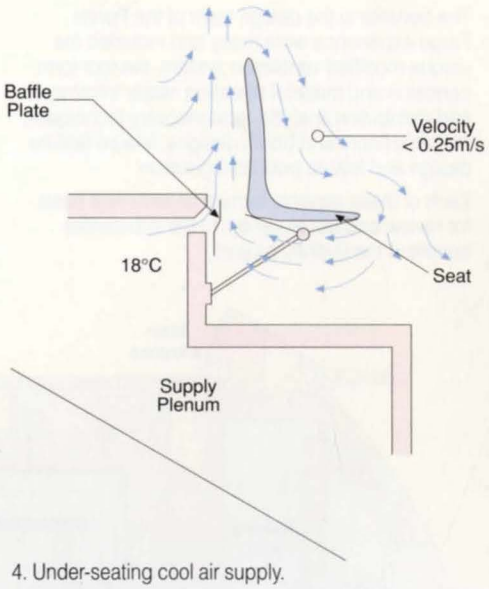
Return and dry duct

Over the years, Arups have developed the concept of the integrated supply and return air duct system known now as the return and dry duct system. Ponds Forge is a prime example of this. Return air is removed from the pool at its highest level of moisture and contamination, ie at pool surface level, via the level deck water return grating. Water also is removed at this point but the two are separated by the action of the water falling into the return water channel, the return air being drawn off at high level via slots in the return air duct.

As the duct acts as a low velocity plenum with negligible pressure drop, air distribution through the high pressure drop slots is self-balancing, requiring no commissioning.

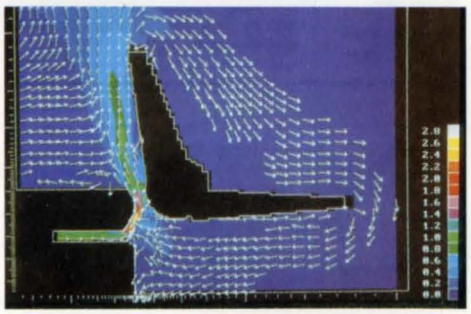
Equally, the supply air is distributed by another self-balancing plenum, this time supplying warm, dry air at high velocity up over the walls and roof to provide a level of fabric protection whilst keeping air movement in the occupied zone to a minimum. Comfort levels are therefore high.

The return and dry duct concept became the basis of the solution at Sydney, modified to suit the shape of the building and the large spectator areas with the supply air at high level at the rear of the spectator seating. This solution, however, only addressed part of the brief, namely the control of condensation and air temperatures above the water and on the pool surrounds. The different comfort requirements of spectators and swimmers required further development of the system.



4. Under-seating cool air supply.

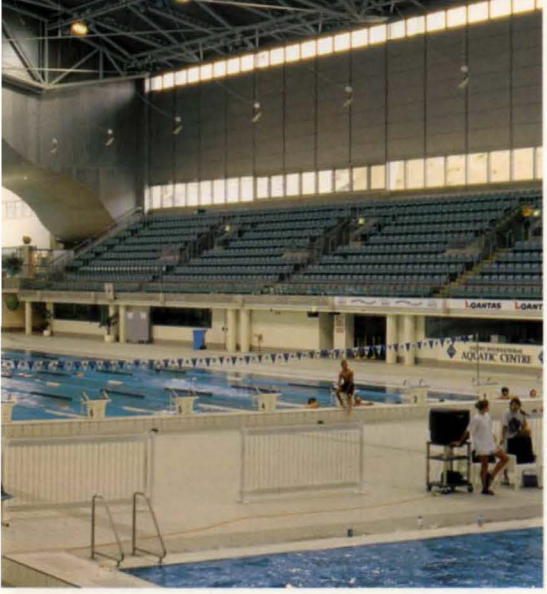
5. CFD analysis of under-seating cool air supply.



Spectator air-conditioning

Various solutions were proposed by the design team, including traditional overhead supply systems. However, initial computational fluid dynamics (CFD) analysis by Arups indicated these to be inappropriate and unable to provide a separate spectator environment. Arups proposed displacement ventilation, whereby cool air (at about 20°C) is introduced below the seating at a relatively low velocity.

Further CFD studies showed this proposal to be promising, and it was put forward as the design concept to be fully developed and tested. The final under-seating air supply detail was a 'baffled air slot', later developed through further CFD studies by Sydney University. Various types of inlet were investigated, including a rear-of-seat supply, a perforated plate supply, and the baffled air slot;

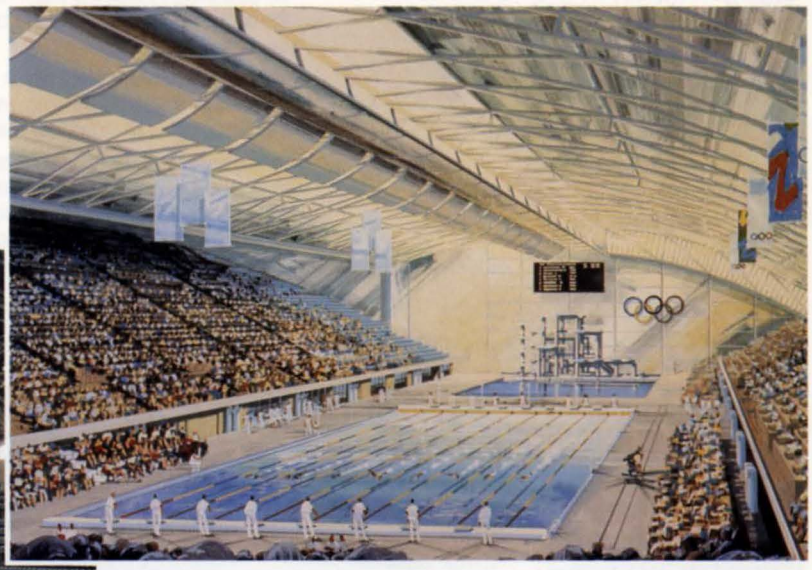


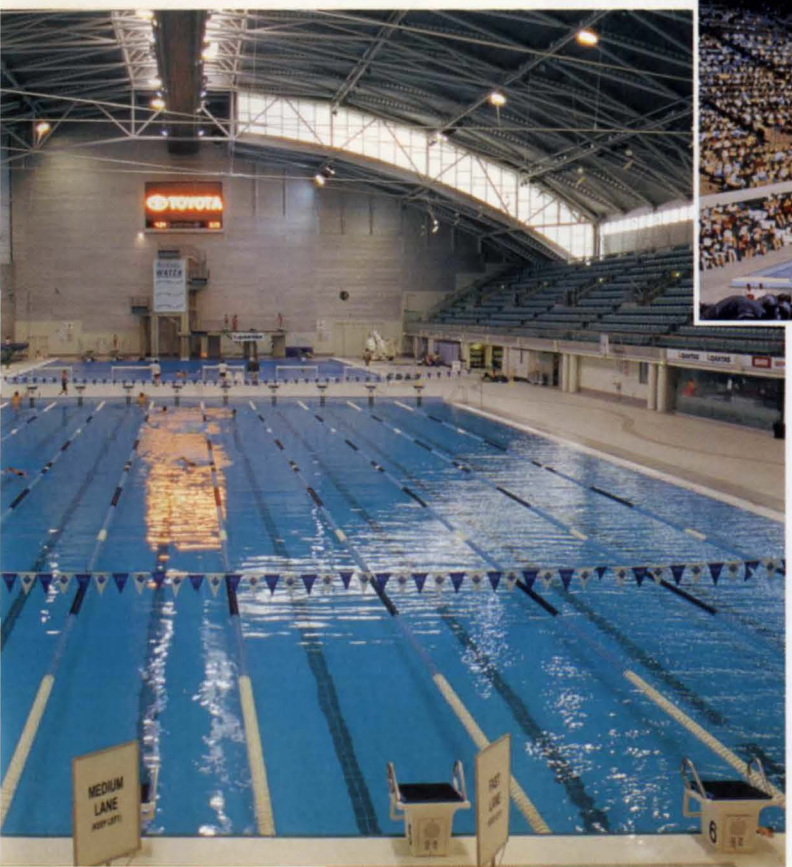
7. Utility pool, showing the removable wall for Olympic seating extension.

CFD and physical full-scale modelling showed the latter to give the best air distribution and comfort conditions. A problem identified by the CFD modelling was that there appeared to be a tendency for the cooler spectator microclimate to drift down onto the pool surrounds. This was addressed and offset by introducing a warm air supply between the seating and pool surrounds.

The final result is a unique air distribution system employing warm air to walls, roof, and pool surrounds, providing a low maintenance and low energy system whilst allowing architectural freedom through the lack of exposed ductwork. Air-conditioning to spectators is optional and when operating provides a cool microclimate in an otherwise hot and humid atmosphere suited to bathers rather than fully-clothed spectators.

9. Main hall with extended seating for Olympics.





8.
Main hall, with Competition pool in the foreground and Utility pool in the rear.

Water systems

The brief

Exacting criteria in the water treatment systems were also imposed, including meeting Fédération Internationale de Natation Amateur (FINA) regulations, water distribution to minimise effects on swimming speed, also 'second to none' water quality and energy consumption as low as financially possible.

An important consequence of the FINA regulation requirement was that residual chlorine levels in the pool should not exceed 0.6 parts per million (ppm). Traditional chlorine-only plants require residual chlorine levels around 2ppm, so a more advanced solution was required.

Disinfectant selection

Disinfection and pool water chemistry are the most important aspects of a water treatment system and fundamental to designing, installing, and operating the pool. Chemical treatment is necessary to kill - via an oxidation process - the bacteria, viruses, spores, cysts, etc, that might be present in the water.

Various disinfection chemicals were considered, including chlorine donors, ultraviolet and ozone. Table 1 demonstrates the comparative effectiveness of disinfectants against various organisms. Ozone clearly has a very quick kill time - at 0.1ppm dosing rate, the contact time to kill all bacteria is in seconds, whereas chlorine and bromine need up to 3000 times longer to obtain the same kill. Due to the FINA requirement for low residual chlorine it was soon established that only an ozone disinfection plant could achieve this. For such a system, a chlorine donor is still required, but only for stopping cross-infection in the pools, and this can be achieved by residual chlorine levels of less than 0.6ppm. Sodium hypochlorite was selected as the residual chlorine donor.

Table 1

Organism	Disinfectant	Dose (ppm)	Lethal effect (sec)
Coliforms	Bromine	0.1	18 000
	Chlorine	0.1	15 000
	Ozone	0.1	5
Spores of B. Subtilis	Bromine	1.4	10 000
	Chlorine	1.4	9000
	Ozone	0.05	30
Virus strains	Bromine	0.25-1.0	12 000
	Chlorine	0.25-1.0	10 800
	Ozone	0.05-0.5	120

An ozone system has the following specific advantages:

- The clarity and quality of water are very high.
- The kill of bacteria and viruses takes place outside of the pool.
- It has low levels of combined chlorine compounds.
- There are no smells, or respiratory or eye irritations.
- The atmosphere is less aggressive due to less-contaminated air.
- High air recirculation saves ventilation costs.
- Sterilisation is better.
- Adjacent areas are not affected by chlorine smells.
- Ozone is a micro-flocculant resulting in better filtration.

Ozone/chlorine system options

Ozone cannot be stored but must be manufactured on site in the quantities required. Three types of ozone system, with different costs and characteristics, were considered:

- single-vessel, to provide filtration, ozone reaction, and de-ozonising all in one vessel
- two-vessel, which separates out the sand filtration from the ozone process so that the water is first filtered in the first vessel, where ozone is added, and then in a combined reaction and de-ozonising vessel, the water reacts with the ozone and is then removed by a de-ozonating medium
- a separate-vessel system which separates out the three processes - filtration, reaction, and de-ozonising - into individual vessels.

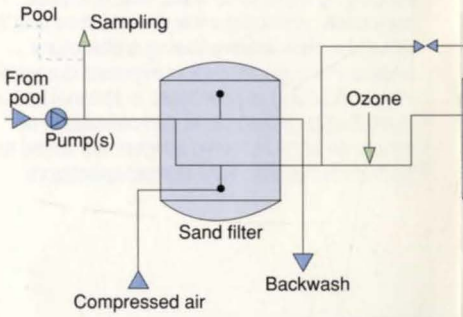
The two-vessel system was selected for all pools. The single-vessel system was inflexible and had a lower performance, whilst the separate-vessel system was very expensive, giving only marginally better water quality than the two-vessel system.

11. External view from

Ozone gas is dangerous in high concentrations and the recommended exposure limit is 0.1ppm: levels of 50ppm for 30 minutes can be fatal. Ozone can be injected into the system by pressure or vacuum. Here, the latter was selected for safety reasons, as any leaks in the system will draw air in and not leak ozone into the atmosphere. Also for safety reasons, a detector was installed in each plantroom to warn against ozone leaks.

Partial ozone

Normally when an ozone system is employed, 100% of the pool water circulated is ozonised. However, due to the large cost of an ozone installation, some systems have a partial ozone application, commonly referred to as a 'slipstream ozone' system. This ozonises only some of the circulated pool water, which is then mixed back



12. Two-vessel

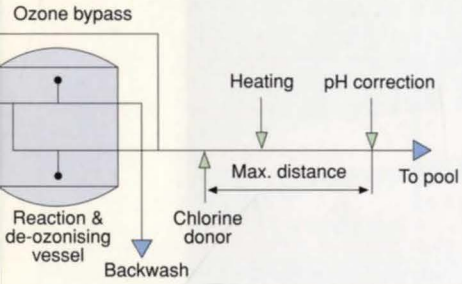
13. Water

10. Leisure pool, including various water rides.

the Leisure pool end.

into the system. This system operates as a normal one with de-ozonisation, but the central plant is much cheaper than in a full ozone system. The amount of pool water ozonated in these systems varies between 15-25%; to date this level has been somewhat arbitrary and the success of pools with these installations has been variable.

Quantitative studies on partial ozone were undertaken in the UK in 1990, taking into account the pool application, bather load, water volume, ozone dosage, bather/m3 water, turnover, flow rates, water depths, ozone dosage per bather, etc. One particular study by the UK Electricity Council demonstrated that adding a slipstream ozone system to an existing chlorine pool was effective, with many advantages only normally associated with a 100% ozone system. At Sydney, there was



ozone system.

eatures.

14.
Utility pool variable speed main pump and standby 594m³/hr.

scope for a partial system, but only for the large-volume, low-bather occupancy, Utility pool.The design of a partial ozone system is not documented so here the design had to be formulated from first principles. The result was an ozonation percentage approximately twice that of most slip-stream systems in the UK. Those, however, were based on empirical calculations, and the Sydney design team was confident that the level of 50% ozonation on a lightly-used pool was correct at that stage in partial ozone system development. The Sydney project had a larger margin of safety than general public pools and the 50% ozonation achieves the desired margin. Tests during use of the pool confirmed Arups' analysis, with the ozone generation plant only ever reaching a maximum of 80% full load.

Filtration

Swimming pool water cannot be considered satisfactory if the pool lacks clarity; this can be due to:

- excessive bather pollution
- inadequate filtration and circulation
- external contamination
- inadequate or incorrect use of chemicals
- air bubbles.

Filtration's primary function is to remove turbidity to achieve acceptable standards of clarity, and conventional systems with pressure sand filters can deliver filtration rates of 10m/hr - 46m/hr. The higher the velocity, the fewer vessels are needed and so the cheaper the plant. For public pools like Sydney's, the rates (vessel velocity) should not exceed 30m/hr, which ought to give excellent filtration. Facilities are provided to reduce the quantity of water filtered at lightly-loaded times, during competitions, or overnight, resulting in reduced filtration rate and substantial running cost savings.

Three basic types of vessel were identified as appropriate to the Aquatic Centre:

- steel above-ground vessels
- grp above-ground vessels
- concrete in-ground vessels.

Many disadvantages have been identified with concrete vessels, whilst extensive corrosion is not uncommon in steel; grp vessels have over the years developed as competitors to steel because they do not corrode. They are more expensive, but cost-effective in the long term due to reduced maintenance. This being the case, concrete and steel vessels were rejected, with life-cycle costing reinforcing the selection of grp vessels. 22 in total were installed at the Aquatic Centre, with the largest standing over 4m high and measuring 3.7m in diameter.

Water distribution

Distribution of water in swimming pools is a very important factor in obtaining satisfactory water conditions. Here, it was important for surface velocities to be as slow as possible in the Competition pool so as not to impede swimming speeds. The first step was to establish the quantity of water circulating around the system; this depended on bather load and pool depth.

Table 2

Pool	Turnover	Flow rate	Bathers/day
Competition pool	3.5hrs	939m³/hr	5628
Utility pool	5.2hrs	594m³/hr	3564
Training pool	3.0hrs	620m³/hr	3716
Leisure pool	1.49hrs	672m³/hr	4028

Table 2 shows water turnover, flow rates, and maximum bathers permissible each day for the Aquatic Centre. These rates are averaged for the whole of each pool to establish the total water flow the plant must handle. In each pool, a zonal water supply system was adopted where each area of each pool was treated separately, with its own measured, treated water supply according to the varying depth of the water.

It is important to ensure that fresh supply water reaches all parts of a pool, with particular attention to corners, shallow pools, and leisure pools. In general the lower the residual chlorine content in the pool water, the better the distribution has to be, ie chlorine pools have residuals of about 2.0ppm and ozone pools have chlorine residuals of about 0.6ppm. Therefore it is important to have better distribution in ozone pools.

Three systems were considered:

- side inlets (only common to the UK and Europe)
- bottom inlets (only common to Australian pools in various forms)
- a combination of bottom and side inlets (seen as a promising solution to good distribution whilst minimising surface water velocities).

As for water removal, by allowing 70% surface draw-off and 30% bottom draw-off, the pool surface and floor is kept very clear and a good balance obtained.

To prove that the proposed water distribution was effective, a full CFD analysis was carried out by the University of New South Wales, the technique's first use on designing pool water distribution systems. Analysis of all three systems confirmed that the selected side/bottom inlet combination would provide both good distribution and low surface water velocities. During commissioning, tests using dyes confirmed the CFD analysis results.

pH correction

Various types of pH correction were identified, including hydrochloric acid, sodium bisulphate, CO_2, and sodium hydroxide. CO_2 was chosen, mainly because its use would not add to the total dissolved solids (TDS) level.

Water heating

At Sydney, water heating to all pools is from a central gas-fired system via high efficiency, pipeline, stainless steel plate heat exchangers. In addition, surplus waterside heat rejection from the underseating air-conditioning system forms the primary heating system via separate plate heat exchangers when the air-conditioning is in operation.

Pumping systems

The major users of energy are the pumping systems, due to the very large quantities of water at high pressure being pumped 24hrs/day. Various systems were investigated including:

- fixed-speed electric: three one-third size electrically-driven pumps per system.
- variable-speed electric: a full-duty variable speed pump with a two-speed standby pump
- gas-driven engine: two full-sized gas engine-driven pumps per system.

Gas-driven engines were investigated because large amounts of heating are required year round and the surplus heat from the engines would be rejected into the main boiler return, providing heat to the pools. In this way the heat from the engines can be used for the whole of the complex and not just to heat the pool water. A fixed-speed system is be the most usual, so was used as a base to analyse capital and running costs. Payback periods were calculated, which showed gas-driven engines to be good against fixed-speed electric pumps but not when compared with the variable-speed alternative. The latter, with the two-speed standby, was viable against fixed-speed pumping, and was therefore adopted for the Competition pool. A similar analysis for the remainder of the pools resulted in variable-speed pumping being adopted throughout.

15. Practice diving bubble.

Other water-related features

As already noted, Arups was also appointed for many other features including:

- The 25m movable boom for the Competition pool: this basically consists of a stainless steel, part-floating and part-spanning structure clad in grp sections. Synchronised electric drives are fitted to both ends of the boom to make moving it more manageable.
- A 33m x18.2m floating floor for the Training pool: the largest of its type in the world, this is constructed from buoyant grp sections held down at any water level by stainless steel cables connected to cable drums and electric drives in a nearby plantroom. The use of the floor makes the Training pool very flexible in use.
- A practice diving bubble: capable of discharging 1000 litres of air at a pressure of 1000kPa, this creates a very large surface bubble under any one of the diving boards. Lasting four to five seconds, this is enough time to give a 'soft landing' to a practice dive gone wrong.
- Leisure features including a 35m flume, a rapid river ride, a variety of water jets and numerous bubble features.

Arups also played a significant role in the layout of the Leisure pool and all its features.

Summary

The ventilation and pool systems at the Sydney Aquatic Centre are almost certainly unique, and represent the highest level of design. Advanced computer technology was used extensively to develop an unprecedented integration of systems in a swimming pool.

The ventilation/air-conditioning strategies provide separate macro- and microclimates, achieving comfort conditions for both spectators and bathers. At the same time, the systems provide some fabric protection from condensation by wall/roof washing, and lower humidities due to low air distribution velocities. The air distribution systems are inherently corrosion-free due to their integrated nature and the hall is devoid of the usual exposed high-level ductwork.

The pool water treatment systems are of the highest quality. Because of the two-stage ozone/chlorine system, eye, throat, and ear irritations do not occur in the pool as would be the case if the system were chlorine-only. The partial ozone system for the Utility pool is very successful, producing high quality water with the plant generally not exceeding 80% of its capacity. The distribution systems have been arranged so that no parts of the pool are left stagnant, but with surface currents at a minimum to avoid adverse effects on competitive swimming. Filtration at low velocity results in clear water with 50m visibilities, substantially in excess of FINA regulations. Energy consumption is at a minimum with only microclimates being air-conditioned and variable-speed pumping employed.

13th Asian Games, Bangkok

Following the design team's success in acquiring this project, the architects Cox Richardson and Arups were appointed. Arups' scope of works included all of the structural elements, the pool water treatment systems and some elements of passive and acoustic designs.

The 13th Asian Games will be held in 1998 and the project is now well under construction for completion early next year. The total site covers some 800ha, with a sports/entertainment sector, and village/residential sector for 10 000 athletes. The sports facilities include a main stadium seating 20 000 spectators, a velodrome, archery and shooting fields, and the naturally-ventilated aquatic centre, which will seat up to 6500 spectators.

The aquatic centre, which is open-air with a shade roof, houses three main pools:

- Competition pool: 50m x 25m, 10 lanes, 2-3m deep, and to be used for 50m and 25m short course competitions
- Utility pool: 33m x 25m, 3-5m deep, and used for 25m short course/training and diving, with 10 boards ranging in height up to 10m
- a warm-up pool: 50m x 25m, 2m deep throughout, and used for 50m training and warm-up before competition starts.

Many of the highly-developed water facilities provided for the Sydney project have been employed and developed for the Asian Games Aquatic Centre. Water distribution is similar throughout the pools, with some development of the service pipe distribution which here will be fully encased, thus reducing the need for expensive expansion devices.

The water treatment systems are comparably world-class, and the systems and plantrooms have been designed to accommodate a full two-stage ozone system, although the ozone part of the plant is likely to be installed at a later date.

A diving bubble has also been designed for use during practice diving: it will be slightly larger than the Sydney system, to accommodate even more wayward diving.

Heating is always an issue with swimming pools, particularly so in Bangkok with the constant high air temperatures creating a cooling problem for large parts of the year. Left to their own devices, the pools would be likely to exceed temperatures of 30°C. As FINA regulations only permit world records in water temperatures of up to 26°C, something had to be done.

This is not a common problem and calculating the amount of cooling required by the pools meant the development of a specific computer program capable of analysing the effect of solar radiation on swimming pools.

The system solution relies on a combination of reverse cycle heat pumps to provide heating and cooling, supplemented by additional gas-fired boilers for the few cooler times of the year.

16. Artist's impression of Bangkok Aquatic Centre.

Conclusion

The combination of the advanced air and water systems described earlier contributed substantially to the success of the Sydney Aquatic Centre, described by some as the 'best in the world' It is one of a long progression of swimming pools that Arups has been involved in, and over 20 years' development in pool design has resulted in refined solutions which continue to develop through successive projects. The Asian Games project, which will be the subject of a full *Arup Journal* article in due course, has given the design team new challenges, particularly with its virtually unprecedented cooling needs, but it has every prospect of being another world-class competitive swimming venue.

References

(1) GURNEY, Des, *and* STEVENSON, Paul. An integrated design approach to the modern low energy swimming pool. *The Arup Journal, 19*(1), pp12-15, April 1984.

(2) BROWN, Mike, *et al.* Ponds Forge International Sports Centre. *The Arup Journal, 26*(2), pp3-7, Summer 1991.

Credits

Client:
Public Works Department

Architect:
Philip Cox Richardson & Taylor
in association with
Peddle Thorpe Architects

Contractor:
Civil & Civic

Pool treatment, 'aquatic experts', and civil engineers:
Ove Arup & Partners Sydney
Paul Stevenson (pool systems)
Henk Buys, Keith Caldwell,
Tony Phillips, Peter Thornton (civil)

Illustrations:
1: NSW Department of Public Works
2-4,12: Jon Carver
5, 16: Ove Arup & Partners Sydney
6-8, 11, 13-15: Richard Drew
9: Courtesy of the Architects
10: Patrick Bingham-Hall

Bridgewater Hall, Manchester

David Anderson David Harrison Allan Iles Brian Lieberman Steve Peet

Introduction

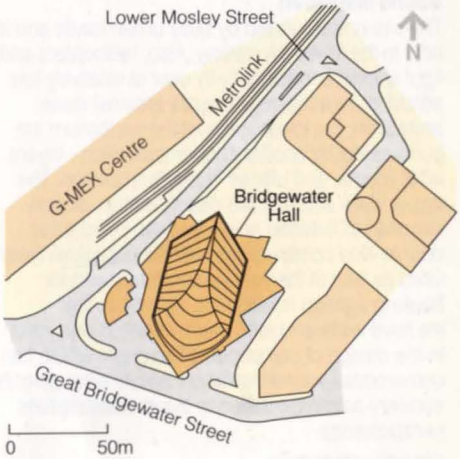
Manchester's celebrated Hallé Orchestra had for many years played in the Free Trade Hall, a venue much loved but not of the highest acoustic or comfort standards. In the late 1980s the City Council decided to make a new purpose-built concert hall the focal point of the 'Bridgewater Initiative' to redevelop - with office blocks as well as the new hall - an area of brown land, then used as a car park, to the immediate south of the city centre. It was in a key position, next to the G-Mex Exhibition Centre[1] and between the city centre and the up-and-coming Castlefield area, and the Council decided to procure the project on the basis of a developer/architectural competition.

The design was for a 2400-seat hall, with visitors entering the building through a dramatic glass prow (Fig 1), and the main services plant located in a glass-clad, free-standing tower to provide acoustic isolation from the concert hall (Fig 2).

A team comprising the developers Beazer, the architects RHWL, the theatre consultants Techplan, Ove Arup & Partners as structural and building services engineers, and Arup Acoustics, won the competition, but because of the changing economic climate the scheme did not proceed until 1991, and then on a revised basis in which the office blocks (undertaken as a distinct Arup Manchester office project) were separated and subsequently let. The original successful design team was appointed by Manchester City Council to complete the design so that tenders could be obtained. The successful contractor would become responsible for the design by entering into agreements with the design team, an arrangement referred to as a 'switch'. Laing North West won and, as planned, each member of the design team except the quantity surveyor who was retained by the employer, entered into agreement with Laing North West.

Work commenced on site in summer 1993 and Bridgewater Hall was completed in summer 1996, when a successful test concert was held in June.

The formal opening was on 4 December 1996 by Her Majesty the Queen, accompanied by HRH the Duke of Edinburgh, after which they attended a gala concert.



1 above: The 'prow' at dusk, viewed from the north.

3. Site plan.

2. Rear view from south west, showing free-standing services tower.

4.
Spring box
with cover off.

5.
Foundation column
with spring on pile cap (right).
On the left is one of the
undercroft air ducts.

6. The site, looking west, in October 1993.
Some columns already have caps and spring bearings in place.

Protection from external noise

The need for quiet

Silence - or complete absence of intrusive noise - is an essential acoustic component; anything audible can break the bond between audience and performance. Background noise should be minimised also so that the full dynamic range of the music can be appreciated. For Bridgewater Hall PNC15 - approximately the threshold of hearing (ie silence) - was used as the design criterion.

Sound insulation

The site is surrounded by busy urban roads and is next to the Metrolink railway. Also, helicopters and light aircraft occasionally fly over at relatively low altitudes. To achieve adequate external noise protection, the lower levels of the auditorium are surrounded by ancillary accommodation - foyers, artist rooms, and offices - to form a cocoon. The upper walls and roof are clearly visible, directly exposed to external noise, and are substantial double skin constructions with large cavities (also used as part of the ventilation system and for housing lighting hoists, etc). As well as the massive walls and roof, much attention was paid to the design of components like doors which can compromise sound insulation, and to arranging the ancillary accommodation to avoid inappropriate juxtapositions.

Vibration isolation

The auditorium is some 30m from the Metrolink railway (Fig 3). Both railway and concert hall are founded on sandstone bedrock, through which vibration transmits readily; if it transmits into a building structure, floors and walls will radiate low frequency 'rumble'. Vibration isolation of the Metrolink was investigated but could not be incorporated due to the imminent start of railway construction, so isolation of the concert hall was necessary.

Although the auditorium is the only space requiring protection from railway vibration, it was determined that the entire building should be isolated, thus avoiding an extensive (and costly) separation joint between sensitive and non-sensitive structure. Detailed on-site vibration surveys when the Metrolink began operation confirmed the need for isolation and indicated that very high performance would be required. This was achieved by carefully designed control of the vibration response of the structure, and by the use of an isolation system with a very low natural frequency.

Vibration isolation systems for buildings and structures often utilise elastomeric bearings or pads. In this case, steel springs were selected because they can achieve a lower natural frequency (3-5Hz) and hence a better isolation performance. The helical steel springs are housed within steel top and bottom plates, forming a 'spring box' (Fig 4). An array of 280 spring boxes were placed on top of the foundation columns (Fig 5) and the superstructure constructed above the springs. One advantage of the spring box design is that it allowed the units to be pre-compressed at the factory - typically to 80% of the expected dead load. Most of the construction could then be carried out without the need for temporary propping to prevent spring deflection. As the building neared completion, the spring units deflected beyond the pre-compression to their final deflection (c20mm shorter than the unloaded case). The sound insulation and vibration isolation successfully excluded train noise and traffic noise from the hall.

Structure

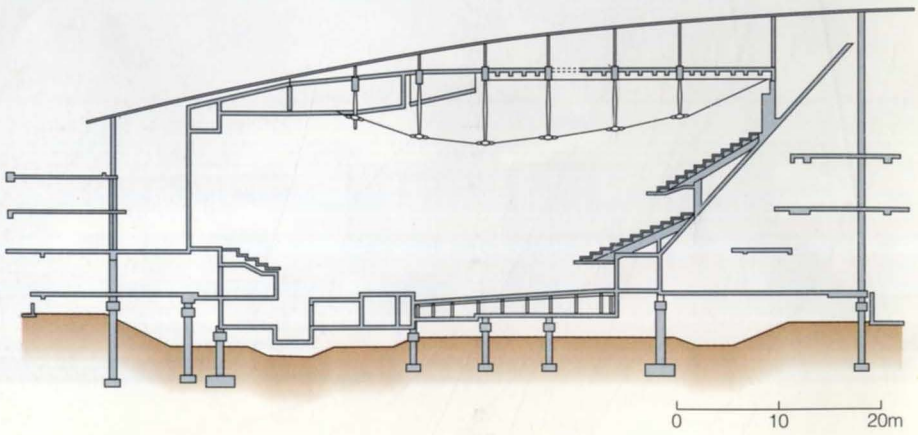
Foundations

The solution to the problem of vibration from the Metrolink explains the unusual choice of foundation system. Pad footings constructed through up to 7m of glacial till and made ground spread the load from circular foundation columns to the weathered bunter sandstone which underlies the site. The columns (Fig 6) are sleeved through the ground with a compressible foam which limits vibration transmitted from the backfill. Most columns are 600mm in diameter and support vertical loads only, but 34 (from a total of 159) are 1m wide and designed to cantilever from their pad to cater for horizontal forces. They project from the ground into the vast undercroft used to distribute services beneath the building. Within this space, the top of each column is capped to provide a base for the bearings to carry the full 25 000 tonne weight of the building; these bearings contain the coiled springs that absorb residual vibrations from the ground.

Walls

Above the level of the offices which surround the inner in situ concrete wall of the auditorium , the outer skin for insulation against air-borne sound is a limestone-clad second concrete wall, the space between being utilised to accommodate ducts from the hall's air-conditioning system.

7 below: Long section.

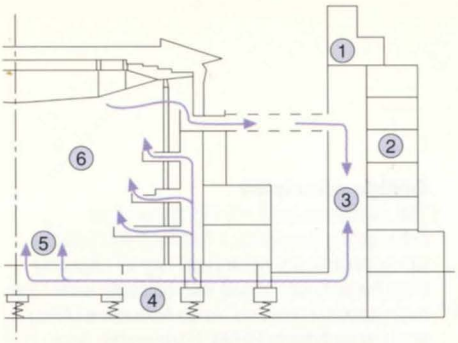


8. Close-up of roof support steelwork.

Roof

The auditorium roof is a spectacular arrangement of two way-spanning trusses supported on slender columns (Fig 7) close to the perimeter of the 35m x 50m space. The top chord of each truss is a plate girder acting compositely with its in situ concrete encasement, and supporting the precast concrete panels that form the faceted inner skin of the roof. The bottom chord is made up of groups of high strength steel bars connected by steel castings to the slender cruciform struts which space it from the top chord (Fig 8). All these elements are readily visible from within the auditorium and make the roof structure an interesting feature for concert-goers.

Although at tender various schemes were considered for erecting this roof, the contractor elected to scaffold the auditorium fully and construct the trusses in their final position, propped from this falsework. This led to the interesting situation whereby the foundation bearings under the stalls area, which were sized to suit the loads from the stalls only, would be considerably overloaded in the temporary condition. Whilst they were strong enough for this, it was felt that the additional deflection of the springs might cause unacceptably high distortions in the structure, and confuse setting-out levels of the roof. To overcome this, the affected bearings were wedged open until the roof had been depropped and the scaffold struck. Worries about movements of the roof during depropping proved unfounded: it behaved exactly as predicted.



1 Chillers
2 Plant tower
3 Vertical AHUs
4 Undercroft
5 Underseat supply
6 Auditorium
7 High level extract

9. Services diagram.

Sound insulation is again maintained by a two-skin construction, the outer skin comprising precast planks in aerated concrete supported on a steel frame off the top chord of the roof trusses. The void between the two layers of roof is used for distribution of services and for access to the winches that support lighting suspended within the auditorium.

Plant tower

This free-standing structure, containing the boilers, chillers, associated pumps, booster sets, water storage tanks and calorifiers, is a quadrant on plan, formed by an in situ concrete unbraced frame, arranged on nine levels, each of which houses a specific area of equipment.

Two vertically-arranged air-handling units (AHUs) are sited adjacent to, and laterally restrained by, the plant tower (Fig 9). They supply large volumes or air at low velocities (again for acoustic reasons) to the auditorium building. In common with all services which cross the joint between the non-isolated plant tower and the auditorium building on its acoustic bearings, a flexible connection is provided at this point. On each side of this connection, and again to limit transmission of vibration, the services are suspended from the structure with spring hangers over a distance appropriate to the stiffness of the pipe, duct or cable in question.

The plant tower joins the auditorium building again at high level, where return air ducts are supported from a services bridge. The connections at each end of the bridge were designed to accommodate movements from the differential deflections of the plant tower and auditorium building, and to incorporate resilient materials to maintain the acoustic separation of the two buildings.

Mechanical systems

The building services systems were designed to stringent noise and vibration limits to ensure that the PNC15 criterion within the hall is not exceeded.

The auditorium is air-conditioned by means of a displacement system. The AHUs by the plant tower are arranged both vertically and horizontally; running in parallel and connected by a plenum chamber they each deliver 11m^3/s of conditioned air at low velocity through a distribution system of acoustically-lined ducts within the undercroft and discrete risers to air plenums under the auditorium seats at each level (Figs 10 &11). Low velocity displacement outlets below each seat distribute the air evenly throughout the auditorium, providing thermal comfort and fresh air for the audience. Comfort for the performers is provided by similar outlets behind screens around the stage. Return air is collected through concealed grilles at high level in the auditorium, using a series of plenums with interconnecting ductwork within the roof buffer zone connecting to the AHUs via the exposed high level link bridge between the hall and the plant tower.

The technical rooms, containing dimming and amp racks, and musical instrument rooms are air-conditioned by local close control units. The function room and sponsors lounge are air-conditioned by individual air-handling plants within the ancillary plant room in the undercroft.

The front-of-house foyers and back-of-house areas utilise passive solutions to provided a comfortable environment for the occupants, with mechanical ventilation provided to all internal rooms. In addition to the foyers being naturally ventilated, a system of mechanical ventilation assists during periods of hot weather with spot cooling to the bar areas. The main kitchen, food preparation, kitchenettes and toilets are mechanically ventilated.

The central heating plant consists of three 750kW gas-fired steel tube boilers with pressure jet burners connected in parallel, providing constant temperature low pressure hot water to the AHUs with variable temperature, outdoor compensated, to radiators. The central cooling plant cmprises two 400kW reciprocating chillers with remote air-cooled condensers, plus a 40kW semi-hermetic air-cooled chiller for low load operation, connected in parallel, providing constant temperature cooling to the air handling plants and local close control units.

Energy recovery through run round coils, and free cooling through enthalpy control, have been incorporated within the larger energy usage air-handling plants. The auditorium fresh air requirement is controlled by CO_2 measurement of the return air.

A building management system controls and monitors the operation of the building's services.

10. Hall interior, April 1994. Forms for floor trenches to deliver conditioned air to grilles beneath stalls seats are in place, prior to concrete casting.

11. Stalls seat showing acoustic baffle, with underseat air grille.

Acoustic design

Rob Harris

The acoustic brief

Manchester wanted its new concert hall to be world-class, of a standard to enhance performances by the finest international orchestras including the resident Hallé and the other frequent users: the BBC Philharmonic and the chamber-sized Manchester Camerata. The brief also required the hall to cater for non-orchestral events - but without compromising the acoustic for its primary function, the performance of classical, symphonic, choral and organ music. The last two uses were particularly significant: Manchester has a great choral tradition, and the centrepiece of the auditorium is the major new pipe organ, built in the traditional way by Danish craftsmen at Marcussen & Son.

Speech and light entertainment events rely on a high quality sound system designed by Techplan.

Design criteria

Several independent but related subjective descriptors are used by concert hall designers; most (but not all) are quantified by technical criteria:

- Ample REVERBERANCE is important in a symphonic hall. Inadequate reverberance results in a too 'dead' or 'dry' acoustic. This requires a mid-frequency reverberation time (RT) of around 2.0s, which was achieved in Bridgewater Hall.
- WARMTH, similarly favoured by musicians and audience, is provided by a rise in the low frequency RT. Bridgewater Hall has a strong bass line (in marked contrast to many major UK concert halls).
- CLARITY must be carefully balanced with reverberance and warmth, to ensure neither over-brightness nor an over-rounded, 'muddy' sound. Clarity comes from strong 'early' reflections following the direct sound to the listener. In the design this was assured by minimising the effective acoustic width of the hall, leading to a high ceiling.
- Halls with strong early lateral reflections also provide good SPATIAL IMPRESSION, a desirable aural broadening of the source. Given the 'wrap-around' geometry at Bridgewater, chosen to provide intimacy by minimising the average listener distance to the performers, the sense of spatial impression varies in different seating locations.
- LOUDNESS is important to provide an exciting and compelling sound and to allow the conductor a wide dynamic range. This required careful limitation of sound absorption (above what is unavoidably provided by the performers and audience themselves).
- A pre-requisite of a great performance is good performing conditions. Optimum ENSEMBLE is achieved by providing appropriate 'early' reflections between performers including the organist, the choir and the conductor. The architectural difficulty of views of the organ from the gallery being obstructed by ensemble reflectors was beautifully solved by elegant glass reflectors which also carry the platform lighting.

Design principles

The design as built refined the original competition proposal: a hall for 2400 people (an economically necessary higher capacity than the acoustic ideal) with all seats within the main acoustic volume. Arup Acoustics (AAc) and the architects RHWL Partnership, took features of the 'shoebox' form - relatively narrow stalls, and 'cue-ball' reflections from overhanging balconies - without the excessive length inevitable in a modern shoebox for 2400 listeners. From the 'vineyard' form is taken the concept of breaking up the seating into blocks (like vineyard terraces), hence introducing additional wall surfaces to provide early reflections, enhancing clarity and spaciousness.

The RT criteria set the volume requirement at not less than 24 000m^3 (the final volume was 25 000m^3). It was therefore logical to expose the steel compression structure within the acoustic volume, giving architectural expression to the structural function. The internal geometry of the precast concrete roof was developed between AAc, Ove Arup & Partners, and RHWL to provide appropriate sound diffusion; an interesting feature is the lighting bridge, which is exposed when necessary for non-orchestral events but retracts out of sight during concerts. A palette of sound-reflective materials was specified: timber (good psychoacoustically), stone, concrete, and fibrous plaster.

Evaluation methods

The overall form of the hall was developed primarily from the combined experience of the AAc and RHWL designers, including listening and performing in, and empirical comparison with, other major concert halls (of both good and poor reputation).

The design was then tested and developed using two main techniques:

- ODEON, an analytical acoustical simulation computer model
- a 1:50 scale acoustic model.

The ODEON model used is undoubtedly one of the most complex computer models ever devised for a concert hall. 500 reflecting surfaces are incorporated, with over 300 000 acoustic ray paths calculated and analysed. The acoustic scale model, constructed and tested in-house by AAc, proved highly valuable in four roles:

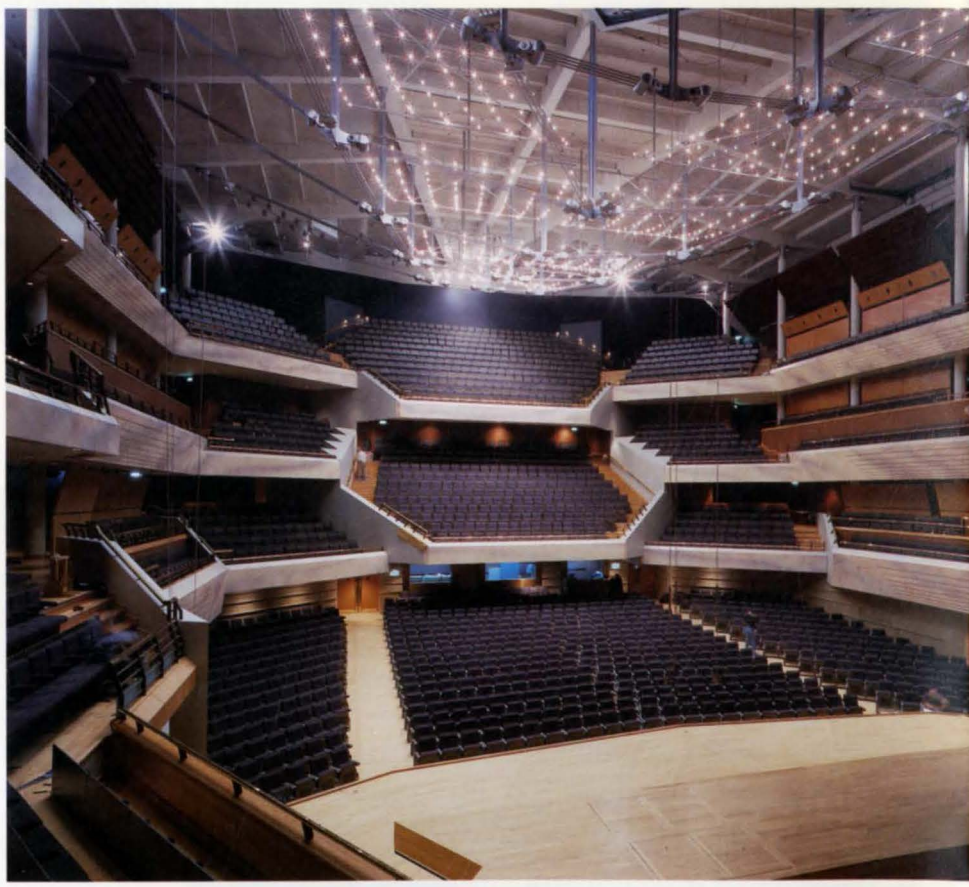
(1) as an acoustic scale model, using MIDAS impulse analysis software

(2) for acoustic ray path tracing using a laser source and calibrated mirror system

(3) for volume estimates by the infill technique (filling the whole space with plastic beads, calibrated in a 1:50 scale bin); and not least

(4) as a visualisation model for the acoustic consultant, architect, and client.

Both techniques provided impulse responses (visual representations of the arrival of sound at the listener as a function of time) and numerical values for the technical criteria.



13. The auditorium seen from the choir seats.

Acoustic testing

As is normal in major auditoria, individual elements like seats (with and without audience) were tested for acoustic performance. Prior to handover of the building, several test rehearsals and a (near-capacity) test concert were held. These provided both subjective and objective data for subsequent acoustic tuning of the hall prior to the opening season. This period also saw the first recording in the hall, Holst's *The Planets*, with the BBC Philharmonic.

The acoustic designer's input to a concert hall does not end with the first performances. Orchestras need time to adjust to a new acoustic, and listening evaluation continued throughout the first season.

12 below: Acoustic scale model.

15.
Interior of 'prow', showing part of sculpture by Deryck Healey.

14. Performing area viewed from the auditorium.

Electrical systems

Though electrical and mechanical services are an important element in any development, a world-class concert hall raises additional challenges. Acoustics being a major consideration, investigations at the early stages of design were carried out to meet Bridgewater Hall's stringent demands. Electrically, the main issues were:

- location of plant
- cable routes and physical sizes
- type of lighting
- specialist lighting control
- vertical transport
- fire alarms
- needs of the disabled.

The maximum demand was calculated to be 1500kVA (1380kW), though measurements during some of the first concerts have not exceeded 650kW, which equates to 270W/seat.

Facilities have been included for rock concerts, which would increase demand to the maximum. Load is derived from a 6.6kV/400/230 single cast-resin transformer rated at 1600kVA, and provision for linking in an external standby generator up to the maximum demand has also been included.

The various acoustic considerations forced tight parameters on main cable sizes, lamps and luminaires, dimming equipment, and locations of electrical equipment.

The lighting inside the auditorium is 100% tungsten and all dimmable, with facilities for stage lighting in the form of booms and distributed sockets throughout, all individually wired back to lighting control. The foyer areas are mainly tungsten-lit; these are also dimmable, whilst the back-of-house spaces and the offices are principally compact and linear fluorescent. Lighting to the artists' areas is mainly tungsten. Floodlighting and amenity lighting were provided to all external areas. The emergency lighting system uses the normal luminaires, together with their controls (including dimming), connected to an uninterruptible power supply at 230V AC, rating 70kW, using sealed lead acid batteries for three hours.

Vertical transport is provided by two 1250kg 1.6m/s passenger, one 1600kg 1.6m/s goods/passenger, and one 630kg 0.63m/s goods electrically-driven lifts, with motor rooms at the basement level. Once more, special consideration was given to acoustic constraints. There is also an external hydraulic 1600kg 0.63m/s lift, serving two levels.

An analogue addressable fire detection system has been provided to L1 standard, using the secure public address system for evacuation. Operation is manual in selected areas during a performance.

Distribution of external television signals, in-house video/audio, show relays, and satellite television signals are provided, and a voice/data system has also been installed. Throughout the building, distribution routes for outside broadcast cables have been incorporated, together with power supplies from the concert hall distribution. A security system incorporating closed circuit television, monitoring all external and some internal doors, is also in place.

The lightning protection that has been provided uses the metallic roof and all structural elements.

Reference

(1) McGRATH, John. G-Mex Exhibition Centre, Manchester. *The Arup Journal, 23*(1), pp22-23, Spring 1988.

16. Bridgewater Hall can accommodate the largest works in the repertoire: combined forces from Manchester and Sheffield perform Mahler's Eighth Symphony on 29 September 1996.

Credits

Client:
Manchester City Council

Architect:
Renton Howard Wood Levin (RHWL)

Consulting engineer:
Ove Arup and Partners Frank Allum, Derek Bedden, Stefano Bosi, Bill Cleary, Pat Clowry, Gerry Eccles, Martin Fenn, Step Haiselden, Bob Hide, David Hughes, Fred Ilidio, Jo Massey, Tim McCaul, Chris McCormack, Neil Noble, Steve Peet, Shirin Yoosoofsah (structural)
Lee Carter, Alan Foster, Dennis Harrison, Allan Iles, Andy Jarvis, Paul Sherlock (mechanical)
Geoff Balrow, David Harrison, Trevor Wheatley (electrical)
David Carroll, Brian Lieberman, Norman Snow (public health)
Jane Collins (geotechnical)
Geoff Powell (controls)
Barbara Gill (administration)

Acoustic consultant:
Arup Acoustics David Anderson, Richard Cowell, Rob Harris, Raf Orlowski, Joan Watson

Theatre consultant:
Techplan

Lighting consultant:
Lighting Design Partnership

Consulting engineer for canal works:
Deakin Callard & Partners

Main contractor:
Laing North West

Structural steelwork contractor:
Fairport Engineering Ltd

Building services contractor:
Bailey-Sulzer

Illustrations:
1: Len Grant, courtesy Bridgewater Hall
2, 4, 5, 8, 10-15: Peter Mackinven
6: David Hughes
3, 7: Martin Hall
9: Jon Carver
16: John Peters, courtesy Hallé Concerts Society

The Bevcan facility, Springs, South Africa

Barrie Williams

Introduction

Canned drinks - hitherto a luxury - are increasingly affordable by South Africans, and this has led to a huge increase in demand and justification for new and upgraded can-making facilities throughout the country. Metal Box South Africa Ltd anticipated this potential market increase some years ago and embarked on a major construction and refurbishment programme.

Their plants at Durban, Cape Town and Rosslyn were upgraded with new production equipment and in 1991 they commissioned a new world-class flagship facility at the Nuffield industrial township of Springs some 60km from Johannesburg, with Arups as principal agent.

Prior to the Springs project, the firm had been involved in a number of can plant schemes for Bevcan involving possible new plants at Vereeniging and Gaborone in Botswana, and a plastic bottle plant at Clayville, also near Johannesburg. For various reasons none of these was built, the client finally settling for the new facility at Springs.

Five years on, the last of four construction phases has been completed:

(1) a single can-making production line with spatial provision for a further line, a coil store, 11000m^2 of warehousing, an in-plant central services building, ancillary plant buildings, offices and staff facilities (1991-92)

(2) a separate can end-making facility on an adjoining site comprising a combined warehousing and manufacturing area, coil store, ancillary services buildings, offices and staff amenities (1992)

(3) the addition of two further can-production lines in a fully-integrated extension to the original production line and requiring extension of the coil store and central services spine and further ancillary process areas, all totalling approximately 11000m^2 (1995-96)

(4) an 8500m^2 warehouse extension (1996).

1. Administration block: front entrance.

2. End plant exterior.

Can-making technology

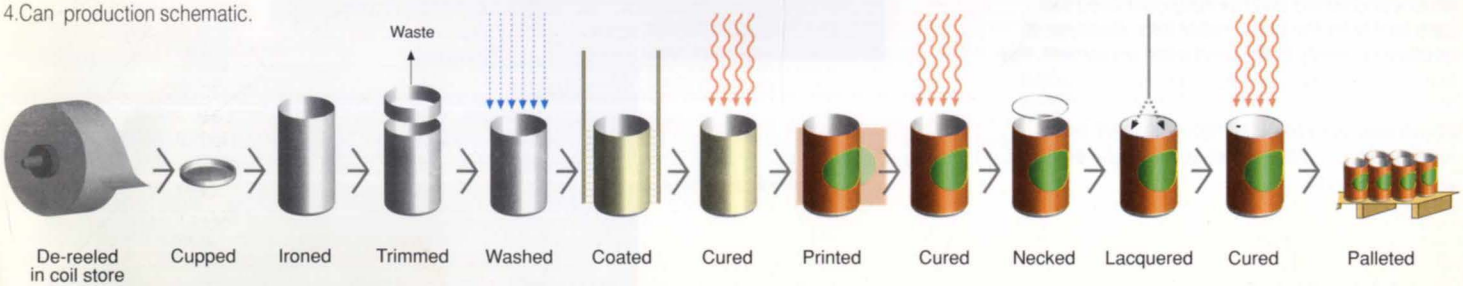
The latest high-speed processes for making two-piece cans (ie can ends and bodies) use a combination of brute force and sophisticated high technology. The equipment ranges from heavy, vibrating plant for stamping and body-making (including 'cupping' and shaping the can body from flat discs punched from coiled sheet), to the high-speed decorating and coating machines. The process is totally automated, with only minutes elapsing between stamping the initial disc from the 11 tonne tin plate coils, to the fully decorated can arriving in the warehouse palletised, ready for despatch. Downstream sensors control upstream process equipment to ensure a balanced flow throughout each production line. In-line inspection devices include a perforation detector (and reject ejector) for the cans, an enamelrater that examines the quality, consistency, and thickness of paint coating, and another piece of equipment that takes five video shots of each can as it passes, compares them to standard pictures, and rejects those not conforming. All these carry out their functions as the cans pass at a rate of 25/sec.

Currently, the economic viability of can production in South Africa favours steel coated with tin for can bodies rather than aluminium - and it is interesting to note that nearly 60% of steel cans are recycled here. At the completed Bevcan plant the three production lines turn out some 5000 cans per minute (1.8bn cans per annum). Such modern plants run with a minimum of human involvement and can feel eerie, with seemingly millions of cans going their various ways to the next process on conveyor lines without a person in sight! This is probably just as well, as the few that are involved (highly-trained machine tweekers and nursemaids) have to suffer an ambient noise level of 110dB.

In the production area environment there is not only noise but also vibration, heat, fumes, caustic effluent, and plenty of scrap metal - all to be engineered away. The end-making plant, however, is a much cleaner operation, using aluminium as against the tin plate for cans. As no decoration or corrosion protection is involved there are no applicators and drying ovens and far fewer piped services. The high speed forming equipment is fully enclosed to contain the excessive noise produced and is currently able to produce 2.3bn ends per annum.

3. Coil store area.

4.Can production schematic.



Design team

The client's project management and process design was undertaken by Bevtech, their technical services division responsible for new developments and upgrading existing Metal Box facilities in South Africa. Arups were responsible as principal agents for project administration, assistance with site master planning, all construction engineering, quantity surveying, and resident engineering. The architectural sub-consultants, RFB Consulting Architects, were responsible for overall aesthetic co-ordination and all the domestic people areas. On Phases 3 and 4 Van der Walt and Barry were responsible for electrical work and fire detection.

Site preparation and layout

The location was previously farmland, and Arups' geotechnical investigation revealed collapsing soils up to 3m deep overlying ferruginised laterite strata of varying thickness; the possibility of a perched water table was also identified. The site was therefore prepared for general construction by pre-collapsing the upper strata using an impact roller, up to 35 passes being required in places. The main foundations, and particularly those to the reciprocating can cupping and bodymaking machines, were founded on the laterite.

Numerous solutions for the site layout were examined, the principal objective being optimum placement of all the subsidiary services around the production area, while at the same time providing good vehicle access plus circulation and space for contiguous future expansion. The rapid subsequent development of the site took up virtually all the latter except for a possible extension to the end-making plant.

Building construction

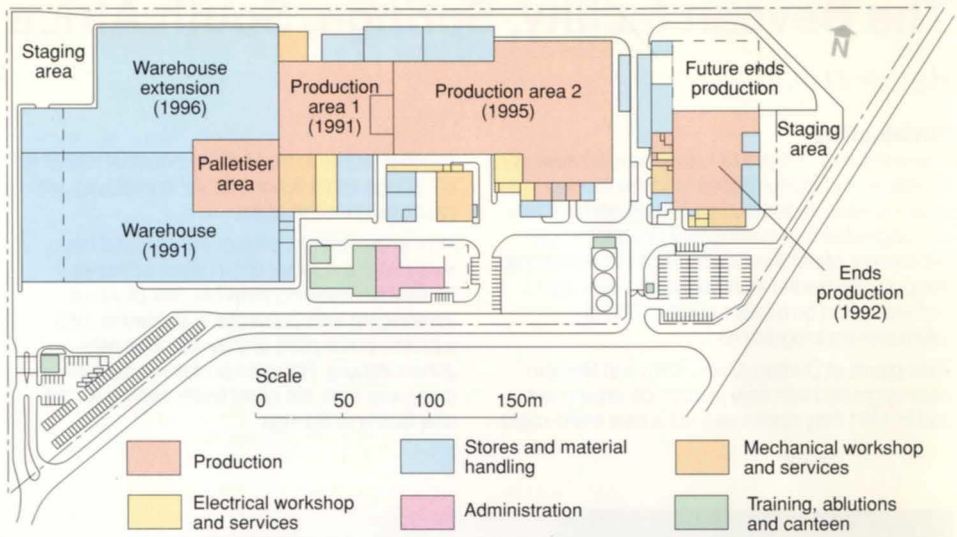
Architecturally, the aim was an economical, unifying, and attractive aesthetic for all the buildings by using a common approach to form and use of materials and colour. Steel-framed construction with brick dado walls was used for the large structures, with the ancillary buildings generally having a concrete frame and roof slab with brick infill panels.

Generally, castellated steel portal frames spanning up to 40m were used over the production areas, whilst the warehouse has a unique all-tubular roof structure comprising triangular lattice purlins and main girders surmounted by roof monitors. The roof steel mass for the 24.6m square column grid is a very economical 18.3kg/m^2, as the rigid triangular components required no secondary bracing.

The 2.5° roof slopes were clad in colour-coated galvanised steel standing seam sheets up to 73m long, which are very difficult to handle if access is limited. On the final warehouse extension, and after the sheets were rolled on site, intensive labour methods were employed to carry each individual sheet, 30 men to the sheet, 150m out into the veld and then to slide them up a sloping scaffold ramp on to the roof. It did not save much in terms of crane hire cost but gave temporary employment to some out-of-work locals.

The industrial floors were of 175mm thick unreinforced concrete with a dry shake surface hardener. The most consistent and acceptable (level accuracy II) floors were achieved by casting large panels, not strips, of about 450m^2.

The central services building houses production offices, print services, lacquer cleaning areas, and an air-conditioned and humidity-controlled tool care facility for the body maker dies. Because of its close proximity to the production equipment, this building required sound attenuating construction and was fully air-conditioned. The open roof area above was used as an air-handling plant area, feeding directly into the roof space of the adjacent production areas.



5.Site plan.

The production buildings contain extensive mezzanine floors, used mainly for can conveying to the process equipment. Steel open grid flooring was selected as the best medium to provide planning flexibility and air movement.

Reciprocating machine foundations were successfully isolated from the surrounding founding material following detailed calculation of the dynamics involved and provision of the required thicknesses of insulation material (Tico pads).

Building and process services

The mechanical brief required the design of systems to control the environment in production areas, offices and certain auxiliary facilities.

A major portion of the mechanical work involved providing air quality and comfortable working conditions as well as the many piped services needed.

The production area ventilation and air-conditioning requirements were solved by using an upwards air displacement system which was developed from a study of the building and the characteristics of the processes it was to house.

The main considerations were the type of mezzanine floor grid used, the location of occupied zones at ground floor level, and the need to displace process heat and fumes with a minimum of dilution. Certain process machines that create large heat or pollutant loads, eg ovens and spray machines, were fitted with direct extract systems.

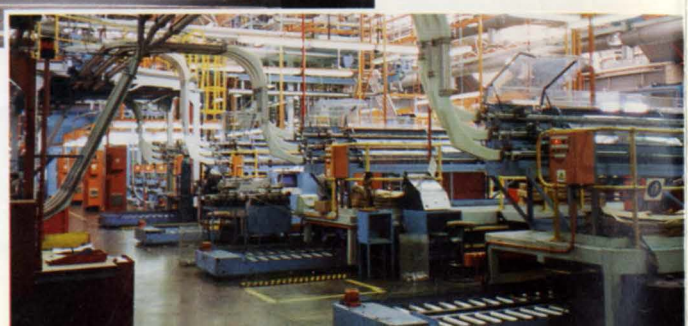
To minimise initial construction costs the design philosophy used mechanical displacement ventilation as the initial solution. The system is however designed to be upgraded with evaporative cooling should the client desire it. The displacement system consists of eight constant volume, fan and filter air-handling units (AHUs) with additional space to incorporate evaporative cooling if required. The AHUs supply a total 184m^3/sec of air into a network of plena and ductwork. The number of air changes provided in the new production area below the mezzanine amounts to 15 per hour, which translates to about six changes for the total volume.

The final air distribution is via Krantz outlets located below mezzanine level and around the perimeter of the building. These outlets provide 100% outside air at low level, the upwards displacement of the vitiated air being obtained by roof level extraction fans.By pumping in more air than is extracted, an overpressure has been created which limits the amount of dust entering the building.

Air temperature and quality are controlled by increasing the supply air through progressive switching of the AHUs. The proportionally high static pressure drop of the diffusers combined with the flat performance characteristics of the fans enables the system to balance itself at the different flow rates without the need for complex controls or excessive use of dampers.

In the production areas the air-handling system is interlocked with the fire detection system so that in the event of a fire, supply air is stopped but the fire-protected extract fans and cabling continue to function.

6. Warehouse interior.



7. End plant interior.

The mechanical brief also included piped services to the process machines, consisting of compressed air, vacuum, chilled water, gas, domestic water, machine oils, and lacquer distribution systems. All of these had to be integrated and co-ordinated with ventilation ducts, fire protection, power supplies and lighting. This aspect was particularly important in the highly congested areas below the mezzanine floor and the tight confines of the below-ground body maker tunnel, where can conveyors also had to be contended with.

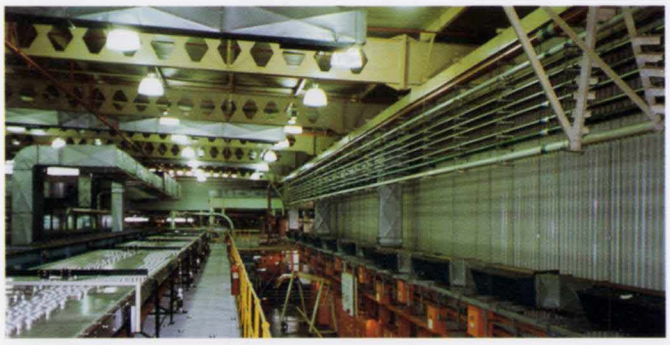
The compressed air facility incorporates six rotary screw compressors providing a total of 3000 litres/sec of dried, oil-free air at a pressure of 8 bars.

All areas are fully sprinkler-protected to Ordinary Hazard (5mm/min), as defined by the SA Fire Regulations 10th edition rules, except the warehouses which are classified as Extra High Hazard (12.5mm/min). Fire water supply is from two 1.28M litre storage tanks and electric and diesel standby pump sets which serve separate sprinkler and hydrant reticulation systems. Fire detection operates throughout the facility with appropriate rate of rise or smoke detectors, and control and slave indicator panels are located at strategic points throughout both plants. The newer phases and now the original warehouse utilise fully addressable detectors.

The line control equipment room for lines 2 and 3 has an underfloor plenum to provide a cooling air flow through the control panels. This plenum is fire-protected by CO_2 flooding, which is again electrically interlocked with the supply air fans, the extract louvres, and smoke detectors.

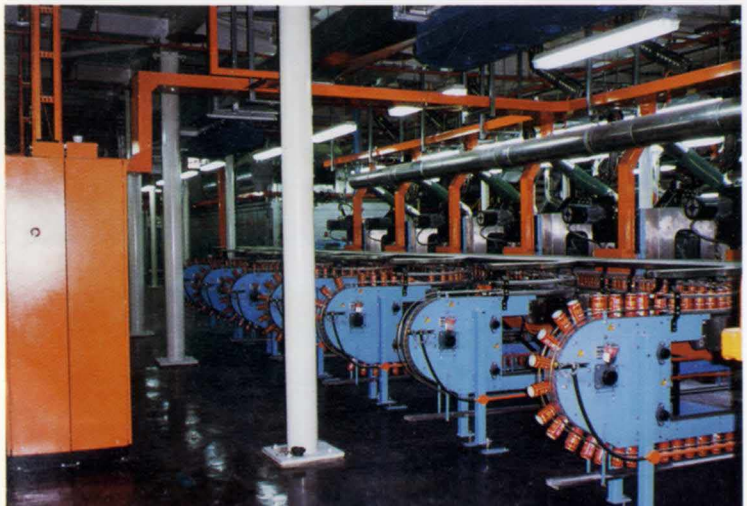
8. Cupping press area.

9. Body making area.



10. Mezzanine above body making area.

11 below:
Cans during processing.



Electrical services

The total electrical demand is 15MVa. The site has a duel 22 000kVa supply which is reticulated to the outdoor transformer banks of the can plant and end plant, the latter cross-linked to provide security of supply within the site to both facilities. A power factor correction system is installed in both plants. For phases 3 and 4, power is distributed to the process equipment and main distribution boards by busbar, giving a cleaner and more flexible system than cabling.

The lighting combination of mercury high bay luminaires with acrylic diffusers and special below-mezzanine fluorescent lamps has created lighting with excellent colour rendition. In the plant, lux levels are 450 in the production area and 300 in the warehouse.

The site is particularly exposed and subject to lightning which caused many false alarms due to surges in the long cables connecting the fire detection panels. Optical fibre cables are being installed to avoid this problem.

Conclusion

The tight programmes set by the client often meant that construction had to start before the detailed design was completed. On occasion this led to a certain amount of frustration, which was only to be expected, but in general there was excellent co-operation throughout between the design team and the client. In the end he has been well satisfied, with the most advanced plant of its kind in the southern hemisphere. In particular, special thanks are due to the client technical team led by Derek Brown, Graham Lloyd, Richard Stegman, Willie Saaijman, and plant manager Eric Redelinghuis.

Credits

Client:
Metal Box South Africa Ltd

Principal agent, civil, structural, geotechnical, mechanical and electrical engineers, and quantity surveyors:
Arup (Pty) Ltd Roger Hayim, Jan Hofmeyr, Elaine Lawrie, Gerry O'Brian, Johannes Ramapela, Denise Sanderson, Richard Shedlock, Elvira Tessa (structural/ building)
Pat Hing, Karl Lyndon, Roy Morris, Simon Oliver (mechanical)
Ric Bennett, Paul Monk, Doug Walton (civil)
Sidney de Jongh (electrical)
Bruce Bulley (geotechnical);
Sean Hong, Mohammed Parak, Martin Woodley (quantity surveying)
Neil Glenn, Geof Green (resident engineers).

Architectural consultant:
RFB Consulting Architects (Phases 1 and 2)

Electrical consultant:
Van der Walt and Barry (Phases 3 and 4)

Illustrations:
1-3, 6-12: Barrie Williams
4, 5: Jon Carver

12. Street landscaping.

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