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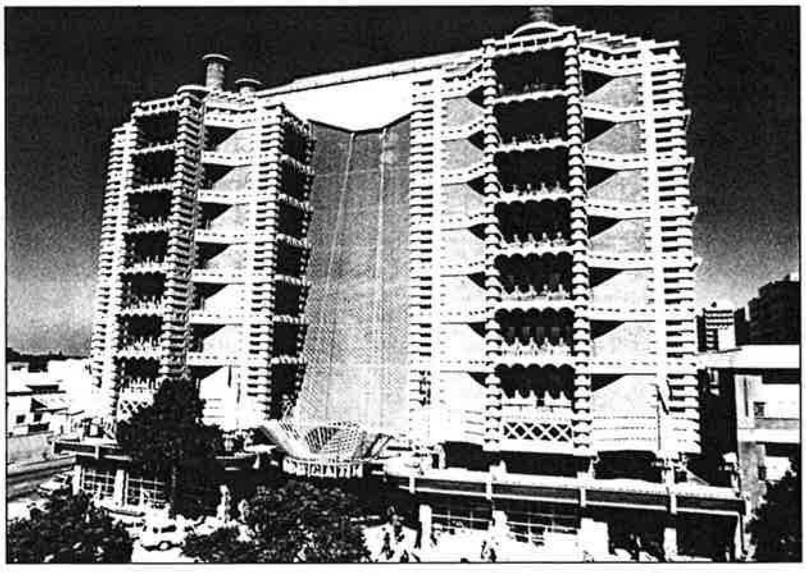
Most modern office blocks in Southern Africa are air conditioned, for obvious reasons, but some developers are eager to find ways of reducing the capital cost of these projects. Fred Smith of Ove Arup Partnership reports on one particularly innovative project in Zimbabwe where passive cooling met the brief

Out of Africa

IMPORTING PLANT into Southern Africa has serious cost implications, particularly with air conditioning which can account for as much as 25% of a building's total cost. Currency fluctuations give developers major headaches 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 10-14degC, 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.



Spanning

■ Eastgate fills a city block near the edge of Harare. 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 5,600m2 of shops with the remainder given over to 26 000m2 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 above 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.

Unique

■ The mechanical engineers contributed in many ways to meeting a brief unique in Zimbabwe. The site was large (8,500m2) 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 would 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

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extends the storage period of the night-time cooling energy in the building structure. By thus varying the supply air quantity, the Arup computer model predicted a 1degC 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.

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 as 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.

Fo the winter months, individual electric room heaters are supplied. 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 pre-determined ambient temperature.

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 facades, 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 800m2 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.

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.

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.

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.

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

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> "A fee structure was set for future commissions of this nature"

are very favourable showing that Eastgate has a power consumption of 9.1kWh/m2 compared with a sample of six other Harare developments vary from 11kWh/m2 to 18.9kWh/m2, 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.

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.

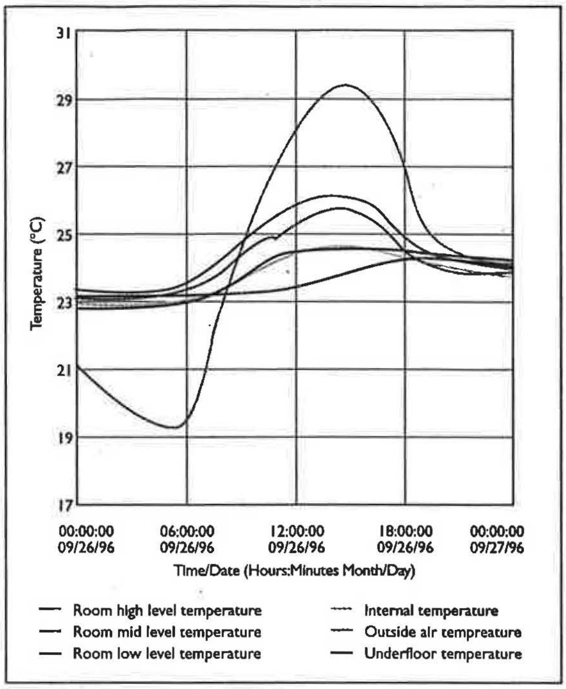
Most components in the ventilation and passive cooling system were manufactured locally, with less than 10% of items imported. This compares with more than 30% in average HVAC installations. Furthermore the cost of the Eastgate installation was about 10% of a full mechanical air conditioning system for 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.

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.

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.



▲ **Close monitoring of temperature performance allows accurate energy consumption analysis**

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. It managed to satisfy the requirements of the mechanical engineer for heat reduction in a way that gives refreshingly new character and interest to the facade.

Whilst the concept was initiated using experience gained by Arups in the UK, its development and detail design were undertaken in Zimbabwe. Software from 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. ■

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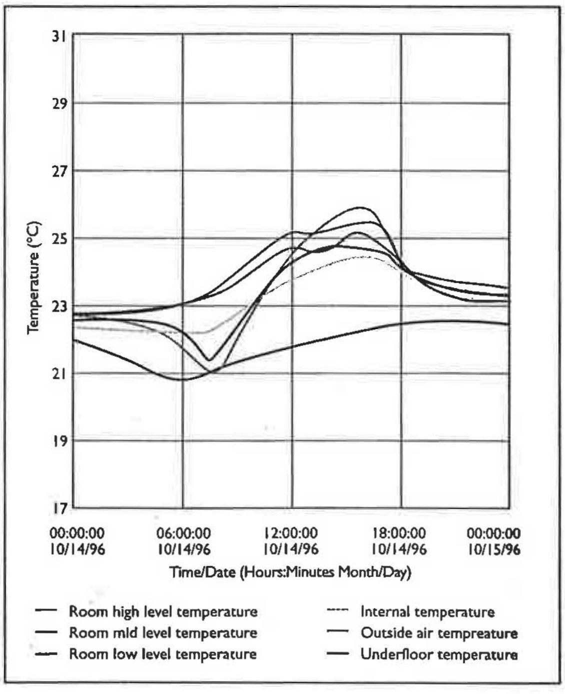
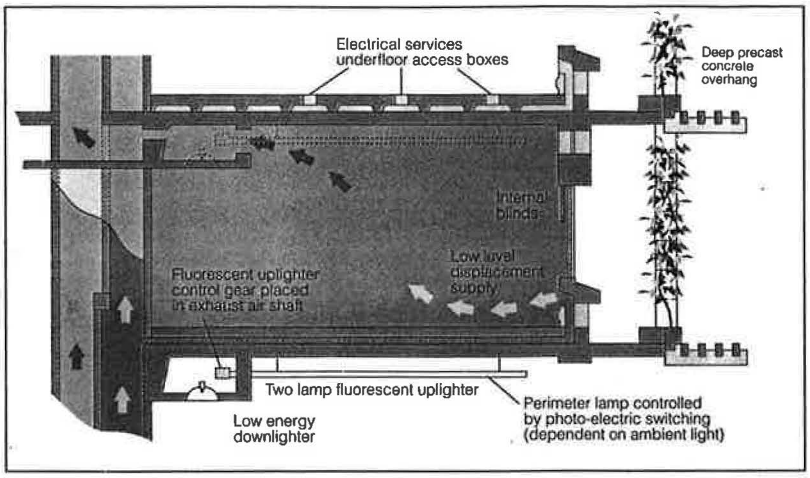
Results in the early stages were variable, but longer-term readings improved ▼





facades 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.

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 facades. 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 1degC in peak internal temperature was predicted between a well-shaded, 25%-glazed, north-facing facade 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.

Blinds

■ 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.

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.

Ventilation and passive cooling

■ 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 20degC, the heat exchange cools incoming air in summer and warms it in winter. During the cool nights, the system continues to operate, flushing stored heat from the building, using Harare's typical daily temperature swing of 10deg-14degC to cool the structure.

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

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