THE NEW PARLIAMENTARY BUILDING, WESTMINSTER

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Providing people with a quality indoor environment means full air conditioning with an energy use tag that we would rather not mention in the debate about environmental impact and sustainability. But is this really the case? Is it not possible to design mechanical systems so they use less energy than their naturally ventilated counterparts?

The law of conservation of energy means we can use the same energy repeatedly. As long as we are aware of how energy is degraded in quality and temperature terms, we can design systems that repeatedly recover and reuse energy. The catch often comes in the form of the high grade parasitic energy these systems themselves consume to achieve this process. This is where the use of passive building fabric environmental control has a major advantage because generally it uses natural energy flow mechanisms which need no parasitic energy for them to operate. Thus there emerges a strategy that seeks to maximise the use of passive environmental control and only supplement it where necessary with simple mechanical support.

This creates two major issues for the designer. Firstly, he must have complete faith in the physics of passive environmental control. This is difficult for someone who is used to the reassurance that a mechanical system can provide in the form of a last minute pulley belt change to enhance performance. Secondly, it requires considerable time to design mechanical and control systems from scratch without the standard systems rules-of-thumb upon which he normally relies.

This paper describes a project where the design time and full design team commitment allowed the conventional approach to indoor environmental control for a polluted central urban site to be re-examined. The end result is a design that takes the principles of passive design, simple mechanical systems and integrated design, to achieve an energy use target of 75% less than typical, and less than best practice naturally ventilated alternatives.

Introduction

In energy consumption terms mechanical environmental control has inherent disadvantages compared with natural ventilation and passive control. Natural systems also have a simplicity and a cost advantage that can only increase as the techniques of advanced natural ventilation are developed. However until such time as the true environmental impact of the so called individual freedom to use the internal combustion engine is acknowledged we will be compelled to provide internal environments behind sealed facades. Added to this, the obligation to achieve a more sustainable future reinforces the need to make the most of urban concentration, not only in terms of perserving the countryside, but also to reduce transport environmental impact. Thus we will need to develop environmentally aware design solutions for these urban centres.

However mechanical systems do have the potential to provide as good an energy consumption performance, if not better, than the current generation of naturally ventilated alternatives. The catch is that we must be prepared to change the conventions to which we normally design these systems.

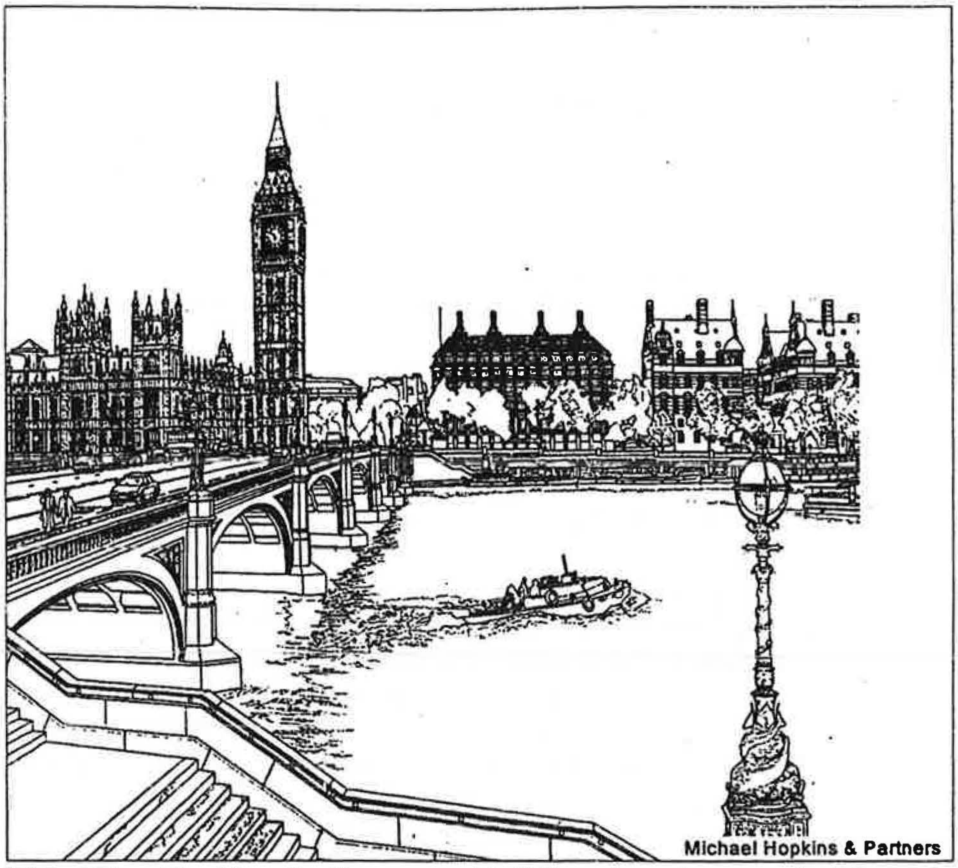
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Figure 1 The New Parliamentary Buildingviewed across the Thames

When presented with a polluted urban site, rarely does a designer have the time to investigate in sufficient detail the physics of indoor environmental control and to develop from first principles complementary systems. The design periods and fees normally conspire to ensure we have to make decisions based on systems for which the design logic is already codified. Thus it becomes a matter of matching the building form and user needs to a system, be it VAV, fan coils, split DX or displacement, etc.

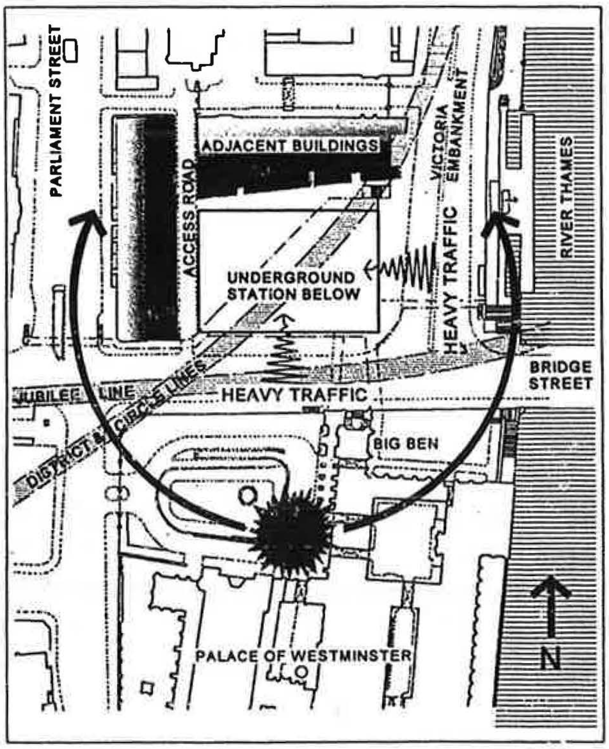

Figure 2 The site

The New Parliamentary Building located over the new Westminister Jubilee Line underground station, has had a six year period prior to site construction and has provided a unique opportunity to re-examine how the indoor environmental control can be provided.

The central urban site is dominated in pollution terms by the automobile (Figure 2). The brief demanded the highest quality internal room conditions in terms of air quality, temperature and acoustics for MP office, select committee and ancillary accommodation (Figure 3).

At the conceptual stage the project started with an analysis of the major ambient energy flows entering the building, how they could circulate through it and finally, how they would exit. The architecture, together with the engineering services systems, was developed to complement these flows. Added into this process was a brief requirement for a building with a minimum fabric design life of 120 years, so cost in use, material durability, replacement strategy, and effective use of space, all became significant design factors. It was interesting to find that the building fabric and systems embodied energy, particularly due to the strategy of reduced cyclical refurbishment, is significantly less than normal practice energy consumption over 120 years. Consequently the holistic approach to reduced energy use not only points to developing methods of reducing running consumption but also suggests the need for far longer building design lives.

The New Parliamentary Building
'Portcullis House'

- Mostly cellular accommodation
- Sellect Committee & ancillary accommodation
- 10 m²/person office occupancy
- 2.5 m²/person meeting rooms
- 10 W/m² office machine cooling
- NR35 office background office noise level
- NR30 meeting room background noise level
- 350 lux background lighting level
- 22±2°C room temperatures
- 30-70% room relative humidities
- Smoking permitted
- Meeting rooms to broadcasting standards
- 120 year building design life
- Low building energy consumption

Figure 3 Key aspects of the brief

Starting with the pre-requisite of a sealed facade to the site boundary, the design aimed to use fully the passive abilities of the building's form and materials to maintain the indoor climate. Projects like the naturally ventilated Inland Revenue Centre, Nottingham[1] successfully demonstrate that by maintaining room temperatures significantly below outside peaks, room exposed thermal mass has more than adequate cooling capacity without needing supplementary cooling. Building services systems were therefore considered for their capabilities to compliment these passive abilities, and to recover energy. Thus at the earliest stage a strategy was established with the architect so that:

- the facade as a 'living wall' provides the means for modifying and using external influences,
- room conditions are controlled by the fabric thermal performance,
- window solar performance is based on the room passive cooling capacity, which in turn is based on the extent of exposed thermal mass and night ventilation abilities.
- the facade and the roof are part of an integrated ducted ventilation and heat recovery system, and
- groundwater is used as a means of cooling warm summer fresh air.

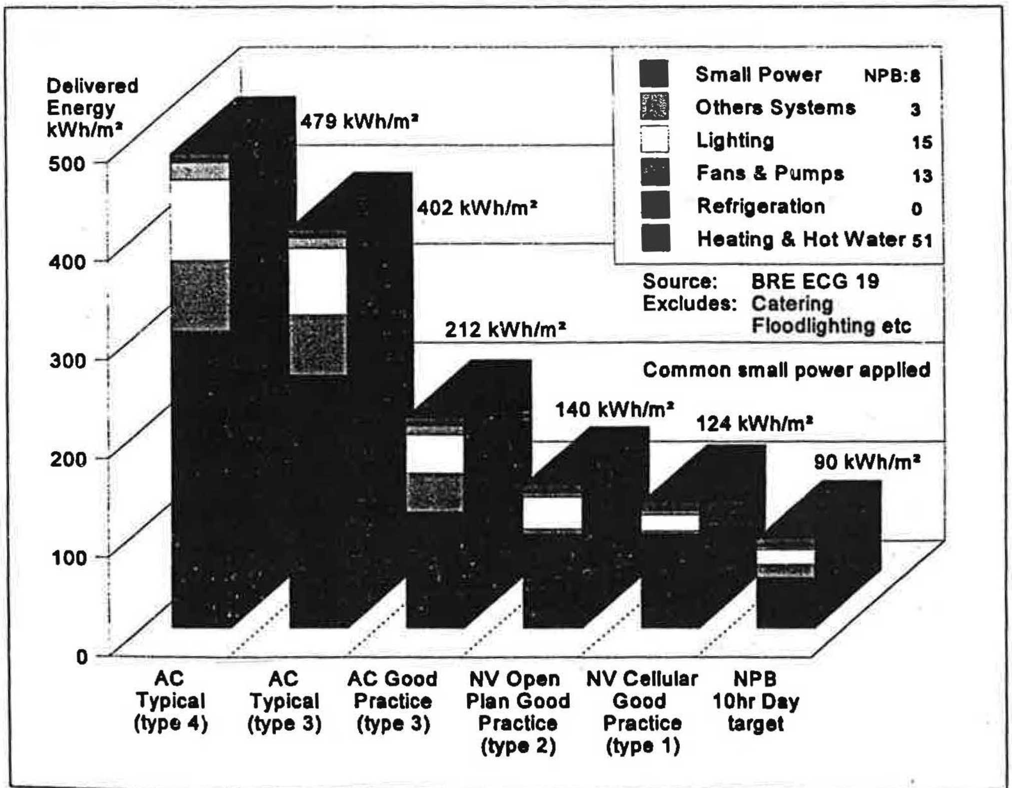

Figure 4 Comparisons with calculated energy consumption target

The aim was to produce an inherently more stable room environment than the norm that addresses a full range of physical and perception comfort aspects, and which 'fails safe' if any parameter moves out of the range assumed by the design.

In global environmental terms the result is a design that has an energy consumption target of 90 kWh/m² per annum (based on a 50 hour week including ventilation, heating, cooling, lighting, office small power and miscellaneous electrical power allowance). This contrasts with a typical (type 3[2]) air conditioned building with comparable use which would be expected to use 402 kWh/m² per annum. As a comparison a good practice naturally ventilated building would be expected to consume between 124 and 140 kWh/m² per annum (Figure 4). In carbon dioxide emissions terms [3][4] the building reduction equates to more than 2600 tonnes per year.

The Building Facade

The cladding system has to provide a solution to the apparently conflicting requirements for an outdoor view, room daylight control, passive and active solar energy collection, excess solar heat protection, the minimising of room heat loss, ventilation supply and extract, and room heat recovery (Figure 5).

The fenestration super-glazing consisting of triple panes with cavity ventilated blinds. The outer double glazed unit is argon filled with a low emissivity (low E) coating to retain winter heat. The inner cavity contains retractable dark louvre blinds designed to maximise the absorbed solar heat. This cavity is ventilated with a proportion of room extract air and acts as a solar collector. The blind material and finish were specifically chosen to maximise short wave solar absorption and minimise long wave heat loss in association with low E coatings on the glazed surfaces either side of the ventilated cavity. This arrangement results in less than 25 W/m² summer solar heat gain across the floor area of a 4.5m deep perimeter room. In shading performance terms the glazing system is comparable with external shading, but in energy efficiency terms exceeds it because of its solar heat recovery ability.

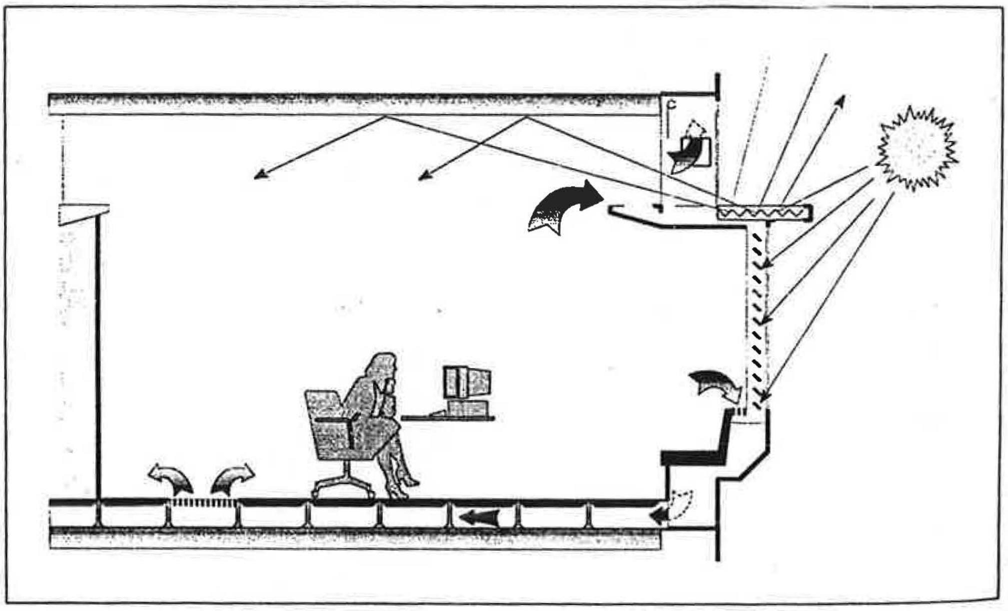

Figure 5 The facade

The window arrangement uses a lightshelf to preserves room daylighting when solar shading is in use to avoid the 'blinds down, lights on' scenario. This permits a larger glazed area because without luminaire heat gain, the room can cope with more solar gain. Although a typical lightshelf does not increase the total daylight introduced into the room, it significantly reduces internal to perimeter contrast and increases daylight usability, and with it reduces luminaire electrical consumption. The particular lightshelf form has a corrugated reflective surface designed to maximise high altitude diffuse skylight reflections, but to reject the lower altitude direct shortwave sun radiation. This arrangement has the added benefit of almost doubling the daylight levels in north facade rooms facing other buildings little more than 8m away (Figure 2).

In many senses the facade is a highly active system. It has many elements serving a wide variety of functions at differing levels and for differing orientations. Yet it is predominantly a passive system, with the only moving component being the occupant operated blinds across which the ventilation air is drawn.

Cooling

To satisfy the brief requirement for an occupied room temperature range of 22±2°C but using passive cooling, needed an in-depth understanding of the constantly changing heat flows into, within and then out of the room. All of this is non-steady state, with heat flows in and out occurring at differing times related to the room thermal capacity and a variety of time constants. The facade of high overall thermal resistance means that most of the room daytime heat gain is retained, so for a large proportion of the year there is a heat excess to be managed. This heat is stored, first to deal with the night heat loss and to avoid boost heating prior to morning occupancy, and then to allow night ventilation to remove surplus from the building.

The exposed room surfaces are used for the heat storage and heat load shifting purpose because of their ability to function with small temperature difference changes and to take full advantage of both radiated and convective heat transfer. The floor void thermal inertia is also used although predominately this has a supply air temperature stabilisation effect. Having a heat transfer coefficient related only to convective heat, the void has less than half the cooling effect of room surfaces visually exposed to heat sources. Each room has a barrel vaulted white concrete ceiling together with dense raised floor tiles and architect designed 50mm precast wall panels. The high thermal capacity room surfaces have a density range between 50 and 200kg per m² provided at the area of approximately 2.5m² per m² of room floor area.

It is worth noting that in structural terms the building is of modest weight. A building that uses the thermal mass largely on a daily timescale, at best, uses it to perhaps a 50mm depth of dense material. The design originally explored the option of hollow core type floor slabs. However most of this form of thermal capacity is remote from the heat transfer surfaces to be fully effective and is not in the most suitable position to be fully used from the structural viewpoint. Consequently the design moved on to develop a wave form shell type slab of nominal 100mm thickness with significant reductions in building weight. The key issue is not the amount of mass, but its position and the extent of exposure to the room heat gains, particularly by direct radiant heat exchange. As a result a thermally heavyweight building easily can be structurally lightweight.

An important part of the design process was the tolerance analysis checks used to obtain an understanding of what are first order and second order thermal design parameters. What these demonstrated is the remarkable robustness of thermal mass passive cooling. Typically, the effect of doubling the machine heat gains for part

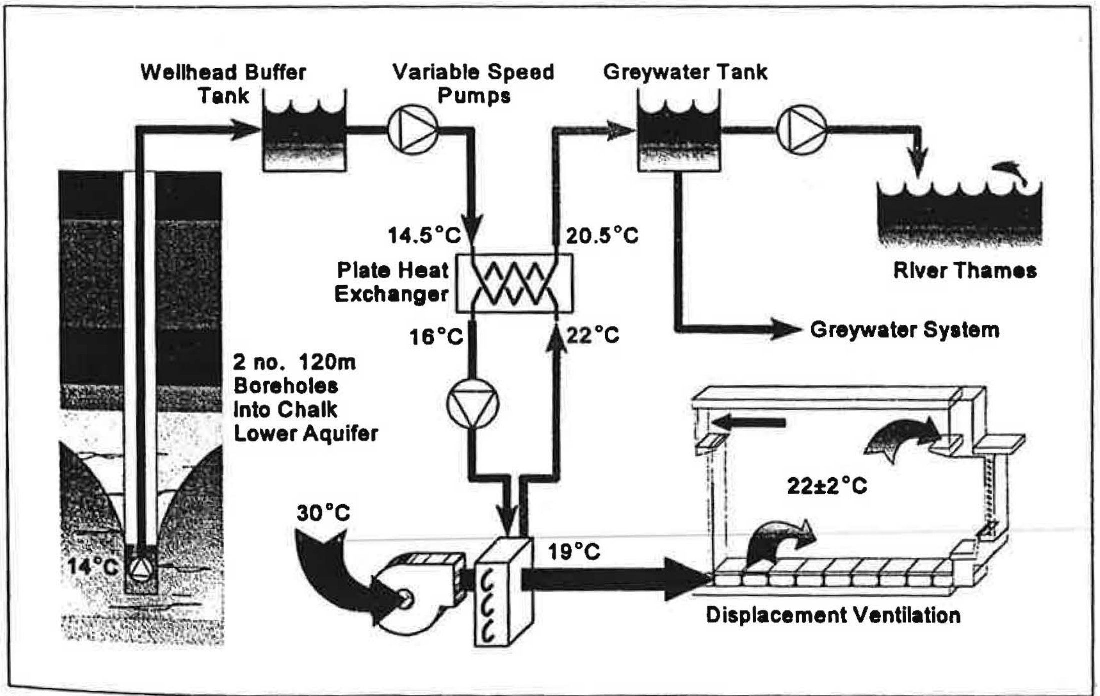

Figure 6 Groundwater cooling

of a day is so small as to be virtually unmeasurable in terms of room dry resultant temperature. Doubling it all day and every day has less than 1°C effect. This shows the inherent overload capacity of passive thermal mass cooling. Likewise two days of peak summer heatwave hardly registers an effect, simply because any slight increase in room temperature swing from day to night significantly increases the mass heat storage capacity. This overload capacity is greater than that provided by a conventionally sized room air conditioning unit.

The room thermal capacity handles the internal room heat gains. However for fresh air ventilation when the outside air is above 19°C, groundwater at about 14°C is drawn from two on site boreholes to cool the air down to room temperature (Figure 6). Groundwater is located at two levels below the site, the upper watertable related to the River Thames, and the lower in the chalk aquifer at about 50m below ground level. The upper groundwater flow is disrupted by building foundations and made-up ground and would have insufficient yield. On the other hand the lower groundwater is almost potable quality and, with modern borehole acidation techniques, has the potential to yield up to 30 l/s per borehole. With industry no longer drawing water from this lower aquifer, the hydrostatic level below central London is currently rising at about two metre a year, so making it an ideal cooling water extraction source. When coupled to the temperature needs of a displacement ventilation system this cooling can be used without any mechanical refrigeration enhancement, thus avoiding all issues of refrigerant ozone depletion and related global warming. To make further use of this natural resource after it is used for cooling, the groundwater feeds a greywater system serving toilet cisterns, to reduce the building's demand for refined mains water.

The cooling system has been designed to minimise the groundwater needed. All heat exchangers are selected to maximise groundwater temperature pickup and minimise flow rates. Variable volume pumping and two port control valves are used to maximise return temperatures so extracting the maximum cooling effect. The expected groundwater temperature gain is about 6°C so any surplus could be safely discharged into the River Thames with minimum effect on the river ecology. Ironically there will be times when the design peak discharge temperature is cooler than the river water!

The original intention was to draw water from the two boreholes in a run and standby configuration. The duty pump would operate overnight to charge basement tanks in preparation for the peak cooling period during the following day. However, as a result of a design review, the adopted strategy runs both boreholes together to meet the peak demand. Advantage is taken of the building's thermal inertia which means it would take somes days during a peak summer period before there is any significant effect on room conditions. This approach avoids the need for large costly tanks with their plant space requirement, and uses the aquifer storage ability as the daily water level pull-down is recharged each night. It also avoids the control complications of trying to

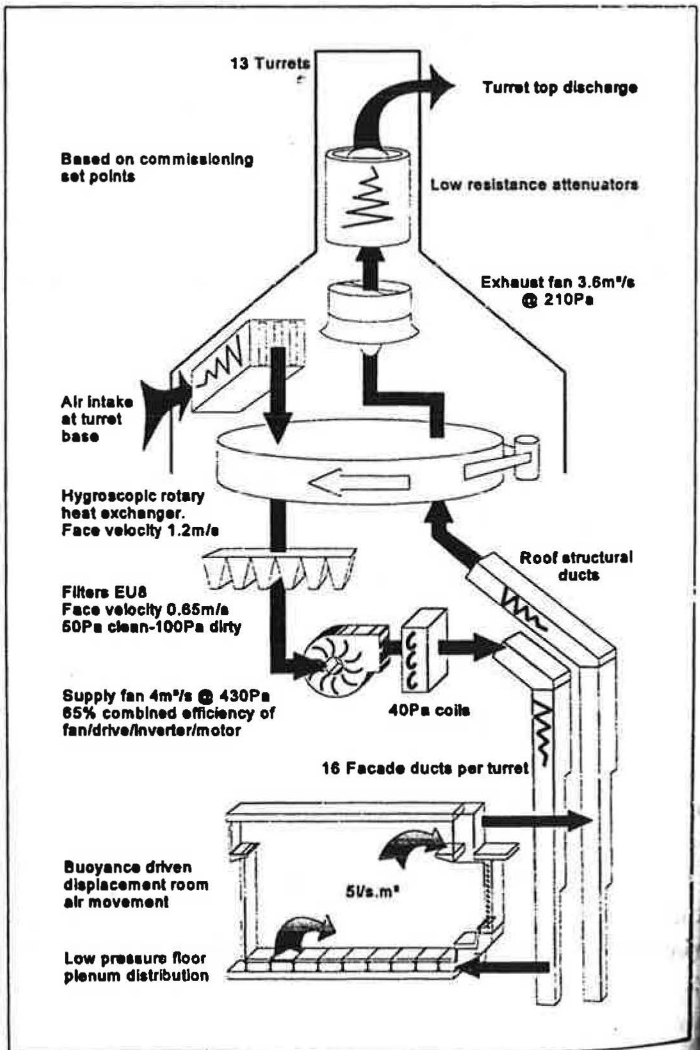

Figure 7 Mechanical ventilation

anticipate how much cooling, and hence stored water, would be needed to meet the following day's cooling demand. Various options for returning the warmed groundwater back into the lower aquifer to use the chalk thermal capacity overnight were considered. In the end, for simplicity, and because there is no method of easily verifying the predicted performance, this was not pursued.

Ventilation System.

The mechanical ventilation system provides 100% outside air to each room by way of a network of linked floor plenums on each floor and vertical ductwork in the facade (Figure 7). The major benefit mechanical ventilation has over natural ventilation is its ability to provide high efficiency heat recovery. Not only does the system allow year round ventilation with generous quantities of outside air together with satisfying the higher heating needs of displacement ventilation, but it also permits the recovery of solar heat from the window system, the occupants, their electrical equipment and the room radiators. The heat recovery devices are rotary heat exchangers located in each of the roof top turrets, operating at an efficiency of 85% (Figure 12). They are of the hygroscopic type to recover moisture from the exhaust air and reduce winter supply air humidification requirements. Concerns about exhaust air to supply air contamination were discounted after review of their successful use in Scandinavian hospitals.

Very low pressure loss air handling and duct system components have been selected to achieve a ventilation energy use target of 1 Watt per litre of air supplied. This compares with typical fan energy use of between 2 and 3 Watts per litre. To achieve this means avoiding long duct runs and, in particular, minimising bends, duct expansions and control dampers. This led to the low pressure plenums arrangement and duct linking of all roof air plant (Figure 8). The fan total pressure generated by supply and extract fans added together is only 640Pa with a fan efficiency (fan, drive, motor and inverter combined) of 65%. Typically the air handling plant component face velocities are 1.2m/s, with 0.65m/s across the filters. The fans have variable speed inverter drives so that they can be commissioned to match the actual duty and avoid the sizing and selection margins becoming a lifelong energy penalty. The specification gave both the maximum allowable fan total pressures together with the lower commissioning setpoints alongside the normal sizing duties. The normal night time ventilation rate is set at half of daytime flows to provide adequate night cooling. Instead of switching off half the roof turret air plant, all are run at half speed because this greatly reduces the required fan pressure and hence power requirements, as well as increasing coil and heat recovery efficiencies.

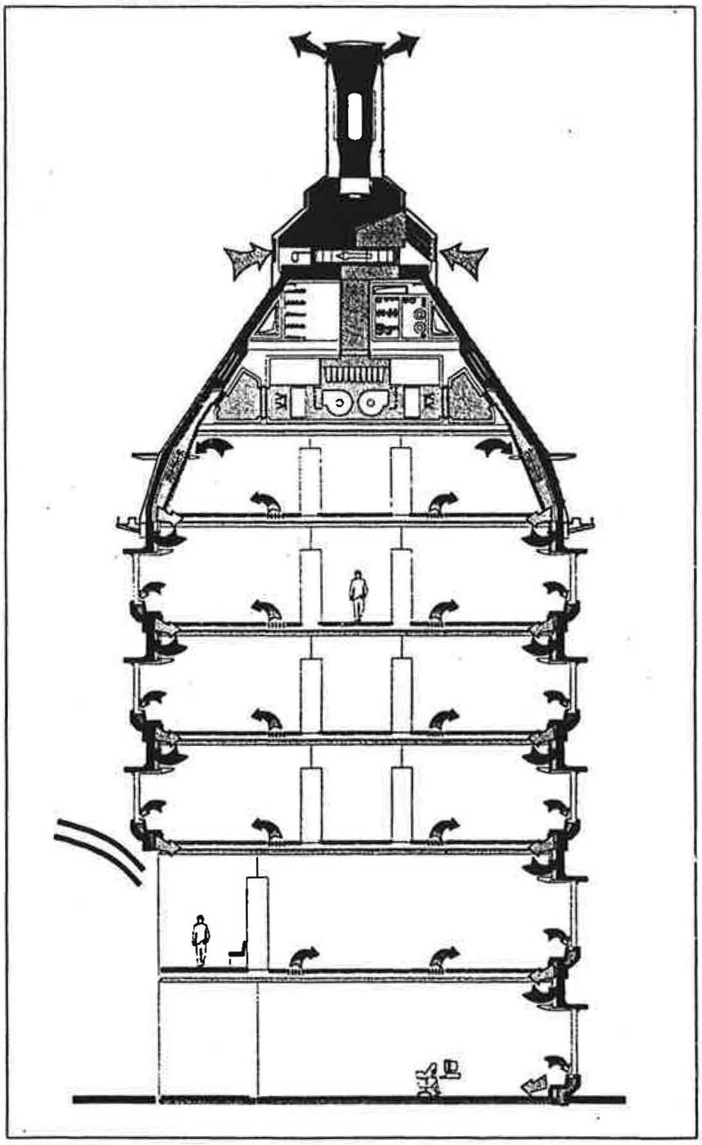

Figure 8 Section through air handling turret

Ventilation system flexibility was of prime importance. Too often heating and ventilation systems are stripped out long before most of the components need replacing due to alleged room use and arrangement changes. The objective was to find a single system that could serve most different room types, then avoiding each change of room use prompting a services refit. To achieve this the distribution ductwork and extract is integrated into the window surrounds and hence the building and partition grids, while the floor plenums with its associated raised floor tiles are intended to allow flexibility in siting supply diffusers. To complement this the system supplies only 100% fresh air with no recirculation of extracted air. So whatever a room contains now or in the future, be it for meeting rooms, print/copy equipment, heavy smoking, general office use or simply a need for removing furniture off-gassing, the system is appropriate. Not only does this make the services more compatible with the long life of the building fabric, but it also reduces the embodied energy content of the normal engineering services cyclical replacement throughout the building lifetime.

The system operates at constant volume and constant temperature. Room temperature control is provided by the room thermal inertia supplemented by radiators in winter so that modulation of supply temperatures or air volumes to each room is avoided. Operating the ventilation as a variable air volume was considered, particularly as most of the hardware is provided. However this was discounted because ductwork pressures are so low that it is doubtful pressure sensors would register a meaningful and predictable proportional band. Besides this, the energy benefits of VAV over the very low pressure constant volume syatem are small. To cap it all, the added VAV controls complexity was viewed as a definite disadvantage.

Room air distribution is by low velocity displacement, chosen because of its low fan pressure needs and its supply temperature direct compatibly with the groundwater cooling source. With a supply air temperature of 19°C, the groundwater can provide adequate cooling whereas it would be inadequate for the lower supply temperatures of alternative air conditioning solutions. The room air supply diffusers can be manually throttled down to 50% air flow by the occupant. The throttled air is redistributed through the plenums to the rest of the system with the aid of flat performance curved backward curved centrifugal fans without any need for complex automatic controls.

Heating

For most of the year a significant proportion of the building will have internal heat gains, from occupants, machines, lights and beneficial solar gain, that more than satisfy the fabric heat loss. Heating of the outside supply air then becomes the more constant heating demand. Consequently the ventilation system design centred on developing its ability to recover heat from all the internal heat sources and the window solar collectors, allowing heat recovery to do most of the ventilation heating.

A perimeter heating system is provided, albeit that the room heat losses are low because the extract ventilation copes with the heat loss through the glazing. It was felt important to provide individual occupants with some ability to trim room

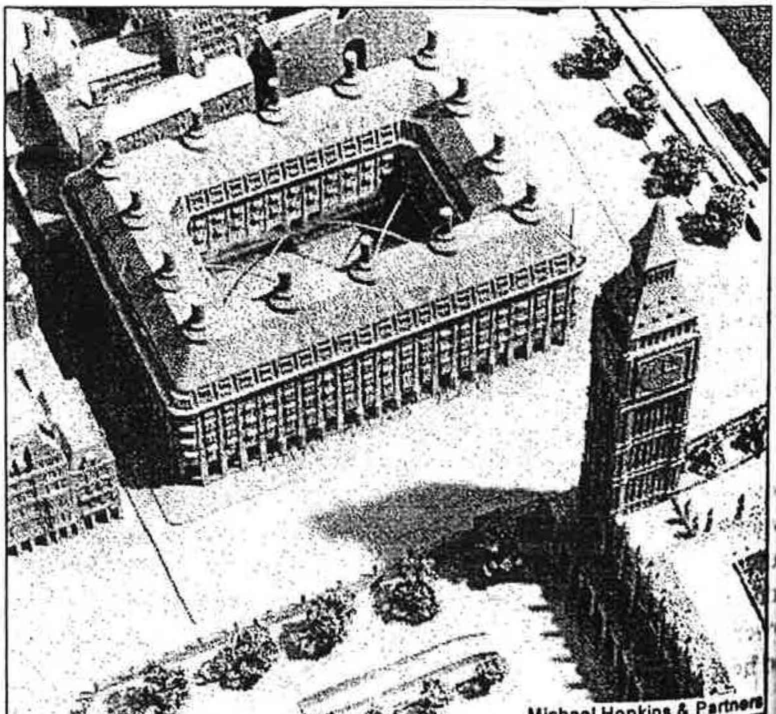
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Figure 9 Aerial view of model from the south east temperatures to their own preferences. The system has variable water volume with thermostatic valves on the room heat emitters allowing the system to throttle in response to beneficial internal and solar heat gain and provide that temperature trim control.

The water has 70°C flow and 50°C return design temperatures to promote flue gas condensation efficiency in the condensing natural gas boilers that supply the heating. Compared with standard UK practice, the use of a 20°C temperature drop almost halves the mass of water to be circulated round the building and, coupled with normal pipe sizes, lowers the pressure loss by almost four fold. Typical pipe sizing is on the basis of 50Pa /m which results in conventional sizes but significant pump power reductions. Thus, for this 23000m^2 building, the duty pair of perimeter heating pumps generates a head of only 40kPa with a peak energy consumption of 450W each. The low pressure head also allows thermostatic radiator valves to operate with a 1°C proportional band without the proliferation of pressure reducing valves on each branch with their accompanying pressure head requirements.

The room heaters are perimeter radiant panels. Finned tube natural convectors were originally considered, but although they adequately dealt with perimeter heat loss, when used with displacement ventilation the heat too easily entered the extract air without reaching room occupants. By using a largely radiant heating emitter occupants can adjust their comfort temperatures independent of the ventilation air temperature.

Courtyard

The New Parliamentary Building consists of 14m deep cellular accommodation arranged around a central glazed courtyard some 50m long by 25m wide (Figure 9). Opening windows overlook the courtyard where the bulk of the main building provides a barrier to noise from beyond the site. The courtyard itself is covered at second floor level to provide a conservatory type central circulation space with facilities for eating, exhibitions and seating. The space is naturally ventilated using roof opening vents, and has high performance roof glazing and all other room surfaces of high thermal inertia. Underfloor heating provides a consistent winter radiant heat output to offset the glazing area. The underfloor heating draws its flow from the heating system return water thus further lowering the water temperature entering the boilers and enhancing their flue gas condensation effect. The selection of conservatory type furnishings and hard finishes, and the contrast with rooms elsewhere in the building, seek to influence the occupant's expectations and perceptions towards a more relaxed thermal comfort range.

Individual control

An occupant's ability to trim their personal environment has been identified by a considerable amount of recent building feedback research as crucial to building occupant satisfaction[5]...[9]. This forms a key aspect of the design (Figure 10). The design strategy is one of delegating as many of the immediate room control functions as possible directly to the occupant.

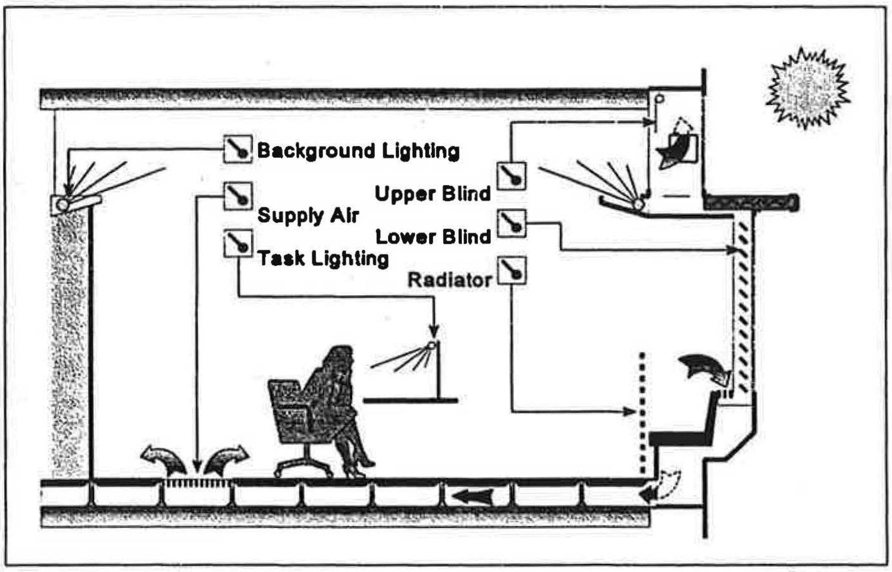

Figure 10 Occupant control

Thus each room has manual control of:

- Vision window venetian blind
- Clerestory window roller glare control blind
- Luminaire switching on and off
- On/dim/off override of luminaire daylight auto-dimming
- Thermostatic radiator valve
- Throttling ventilation supply air
- Opening windows in rooms overlooking the central courtyard.

The building fabric and services are intended to provide range limits within which room conditions are either allowed to float or respond to occupant trim control. With the main thermal environmental control being passive or manual, the BMS role is restricted to one of controlling the main heating and ventilation systems plant.

3D Computer Model

The site constraint of having to accommodate a major underground station occupying most of the site from ground level down had a significant influence of the building design. The normal urban solution of basement primary services distribution to each core was not available, instead the primary distribution is located in the roof voids. The building's vertical cores have no foundation support below them because of the station box, so they are suspended from transfer structures also located in the roof void, through and round which, the primary distribution is integrated. The historic location and ground level sight lines also constrainted the roof profile and so complicated these distribution spaces to the extend that none are orthogonal in plan or section.

Over the six year design period key members of the design team developed the integrated roof and core spaces design solutions. It required personnel with a particular aptitude for visualising in three dimensions and their continuity of involvement over the design period. As the project moved into the construction stage the issue then became one of disseminating this design information to the far greater range of people involved. As a direct result the benefits of constructing and maintaining a 3D computer model was identified.

After a review of the industry and those capable of developing a construction stage model, the mechanical trade contractor was given the role of maintaining a 3D computer model. To date it has largely been the role of services coordinator which has driven the developments of practical 3D modelling within the construction industry. For this project the result is a 3D model that contains all the building services, the structural element envelopes and related architectural aspects (Figure 11). It has become a valuable tool for describing the building spaces to the many trade

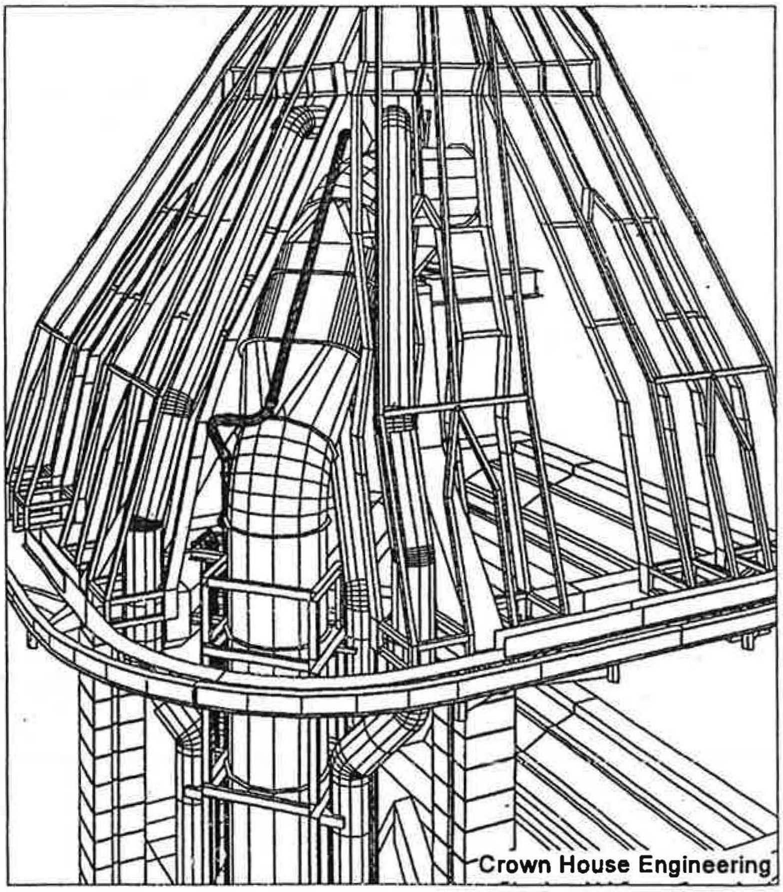
Crown House Engineering

Figure 11 Part of the 3D computer model contractors and for them to develop their own coordinated working drawings. The mechanical trade contractor has also used the model to develop the prefabricated building services assemblies and demonstrate to the team the installation procedures and their space requirements.

Prefabrication

The site constraints, together with matters of site possession and the need to minimise the site construction period, set the early design objective of maximising off-site pre-fabrication. All structural stone columns, concrete floors, cores, cladding, and roof are prefabricated and merely assembled on-site. This philosophy was also applied to the building services.

The roof air plant, roof primary services distribution, vertical cores, on-floor secondary services run-outs are all prefabricated multi-service modules. Many are pre-installed into structural and cladding elements for delivery to site as integrated units. Most are to be lowered in through the roof before it is finally topped-out and made watertight. Pre-insulated and tested pipework is mounted alongside electrical busbars on common racking for installed into all the floor voids.

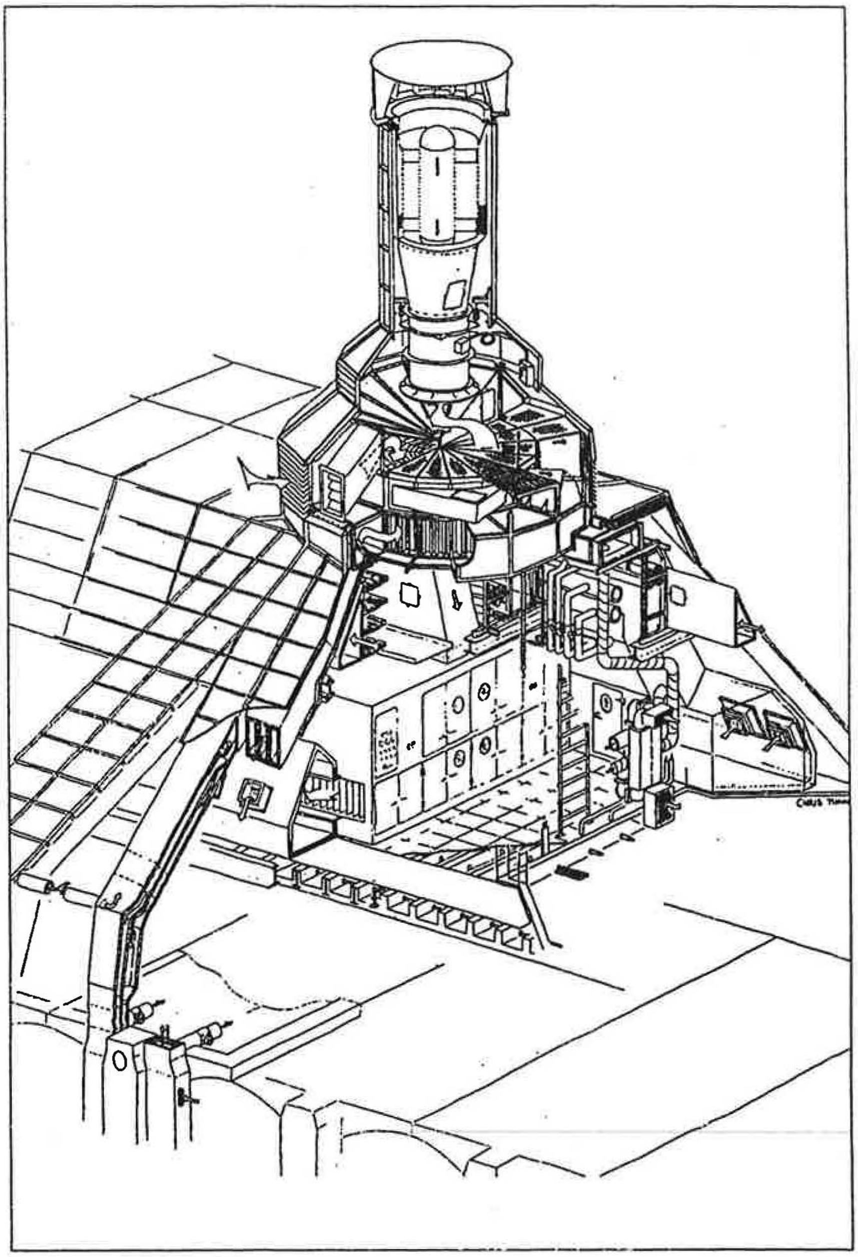

Figure 12 Design drawing of air handling turret with pre-fabricated plant

To achieve this extent of services pre-fabrication it was necessary to consider this and specify it as a construction option in the original design. It requires a early understanding of the influence of pre-fabrication assembly size, shape, repetition, cage clearance, installation methods and programming. This approach ideally needs accessible, well layed out and regular services ducts and spaces without intruding structure. If extensive pre-fabrication can be achieved the benefits are many, including better and more consistent quality, less material and man-hour waste, and more control over programme aspects. As it becomes more established the future potential is even greater, with more industry recognised standardisation, semi- and full automation / robotics based on batch production techniques, as well as a more stable and skilled workforce.

One of the main selection criteria for the mechanical trade contractor was their pre-fabrication experience. Consequent to his involvement the extent of pre-fabrication on the project has further developed as its benefits over conventional site based works have become more evident.

Conclusion

The New Parliamentary Building design process has allowed a radical review of how a high quality internal environment can be achieved. The more one has the opportunity to closely examine from first principles how we can provide an appropriate internal environment the more there is a realisation of the wide potential for addressing the serious environmental and resources issues currently facing our society. Many of the conventions to which building services are designed are due for change to reflect these changing expectations. This project has identified a wide range of new benchmarks that can significant change the built form with a view to future sustainability.

To date the assumption has been that a facade sealed to cope with external pollution means air conditioning with an energy consumption a factor of two times or more greater than that for natural ventilation. However buildings that integrate the building environmental approach with simple mechanical support have the potential to achieving as good a level of room comfort and use as much as 75% less energy than typical full air conditioning and less than their naturally ventilated counterparts. The challenge is to design building fabric and systems that make use of natural energy grading and flows to maximise its reuse, but in a way that dramatic reduces the parasitic energy the systems themselves consume to achieve it.

In principle the adding of heat recovery gizmo and complexity to conventional systems and pursuing headlong into the latest system fashion is likely to have only a minor effect on energy and resource use. But there is the opportunities to achieve a step change.

If we wish to accept the challenge, the potential is there for us to develop and to lead future building design to reflect society's changing agenda. The zero energy[10] building may be closer than we think as buildings with inherently low energy use are coupled to the rapidly maturing techniques of building photovoltaics and wind energy harvesting .

Acknowledgements

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Lighting consultant:	Bartenbach Licht Labor, Austria
Construction manager:	Laing Management Ltd
Mechanical trade contractor:	Crown House Engineering.

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[10] Zero energy building. Suggested definition: Building that generates as much non-fossel fuel sourced energy as the energy it consumes. It may at times export surplus generated energy which it re-imports at a later time, thus it is a nett zero user of imported refined fuel.