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Innovate Green Office: a new standard for sustainable buildings

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The Innovate Green Office in Leeds, UK was awarded the highest ever Building Research Establishment environmental assessment method (Breeam) score of 87·55%. While previous exemplar sustainable buildings have been constructed for owner occupiers, this project is a demonstration of a sustainable commercial office built speculatively by a developer. The £5·5 million, 4350 m^2 building demonstrates a wide range of novel techniques for reducing resource consumption and carbon dioxide (CO_2) emissions both in construction and use. Featuring passive environmental design, the building eschews bolt-on sustainable technologies in favour of good insulation, thermal mass and daylight to reduce emissions of CO_2 to 20% of a conventional office building. Importantly, savings in energy and water consumption at a time of increasing volatility in energy costs also provide savings in operating cost, making the building commercially attractive.

1. INTRODUCTION

It is now widely accepted that man-made emissions of carbon dioxide (CO_2) are responsible, at least in part, for climate change. Worldwide CO_2 emissions from energy consumption were first tackled politically with the 1997 Kyoto Protocol. In the UK, the Energy White Paper published in May 2007[1] acknowledged the long-term energy challenge of 'tackling climate change by reducing CO_2 emissions both within the UK and abroad' and aimed, as one of four energy policy goals, 'to put ourselves on a path to cutting CO_2 emissions by some 60% by about 2050, with real progress by 2020'.

Data published in the March 2007 edition of *Energy Trends*[2] show that emissions of CO_2 in 2006 were 5·25% below 1990 levels, the benchmark for the Kyoto protocol reductions, but had increased by 1·25% over 2005 levels. Buildings are responsible for a little over 40% of UK CO_2 emissions. However, a recent revision to the Building Regulations part L, conservation of fuel and power[3] only targets a 25% reduction in emissions from new buildings over the previous regulatory requirement. Given that typically only 1% of the building stock is constructed or replaced annually, clearly new buildings need to achieve vastly reduced CO_2 emissions if the sector as a whole is to make any significant contribution to achieving the long-term goals.

The delivery of sustainable buildings in the UK is further hampered by the fact that a large proportion of new buildings is delivered through a speculative or development route. As developers rarely retain any interest in the operation of a building beyond practical completion, there is no incentive for investment in resource conservation beyond the bare minimum required by regulation. Furthermore, sustainable buildings are not seen to provide any commercial advantage in terms of rental return; in fact, they are often perceived as too risky for the speculative market.

Project developer Innovate Property Ltd operates serviced offices in a number of UK locations, typically on out-of-town business parks. In a highly competitive market, the developer identified that increasing public interest in sustainable development could create a new opportunity for energy efficient offices, in addition to operational savings from reduced energy costs. The Innovate Green Office in Leeds was developed in joint venture by Innovate and Yorkshire Forward, the regional development agency; the design and construction teams are listed in Table 1. The aim of the project was to deliver a genuinely sustainable office building capable of being reproduced within a conventional commercial funding framework.

2. PHILOSOPHY

The project demonstrates a step-change in commercial building design and a fresh approach to the design process. The building is designed to achieve a very high level of energy conservation through passive environmental design rather than trying to address problems associated with conventional design by adding renewable energy technologies.

An engineering-led design exercise produced an environmentally and commercially sustainable prototype building design in response to the client's brief. The team's approach was to examine each element from first principles and assess its benefit to the overall building performance rather than bolting sustainable features onto a conventionally designed building. This resulted in a design that utilised proven building technologies, assembled to provide an optimum solution. The building developed from a fusion between the first principles of sustainability and the client's need for flexible space.

The floor plate was developed to provide a sub-divisible planning module of 1·5 m and a plan depth of 13·5 m, giving two 6 m deep office zones with 1·5 m central circulation (Fig. 1). This allowed the space to be divided down to a minimum cellular office size of 18 m^2. The floor to ceiling height was fixed at 3 m to maximise penetration of daylight into the plan and allow headroom for air stratification within the space.

Design team	
Developer	Innovate Property/Yorkshire Forward
Architect	Rio Architects
Sustainability consultant	King Shaw Associates
Structural engineer	Scott Wilson
Building services engineer	King Shaw Associates
Project management	Mirus Management Services
Cost consultant	Mirus Management Services
Construction team	
Main contractor	GMI Construction Group
Mechanical & electrical sub-contractor	Goodmarriot & Hursthouse
Mechanical & electrical sub-consultant	Hoare Lea (Leeds)
Pre-cast concrete sub-contractor	Buchan Concrete
Termodeck system	Tarmac

Table 1. Design and construction teams

Load-bearing concrete wall panels, frame and pre-cast floor were chosen for the construction in order to maximise the thermal mass of the building available to moderate the internal environment. External insulation systems were chosen for the walls, roof and ground floor, allowing the complete thermal mass of the building to be engaged with the interior.

It became apparent that, although the intention was to design an exemplar low-energy building, within the target market there would be an expectation of air conditioning; an entirely naturally ventilated building could therefore prove too great a commercial risk. A solution was to adopt a mechanical ventilation system that would actively use the thermal mass with a small amount of mechanical cooling to limit summer temperatures to 26°C.

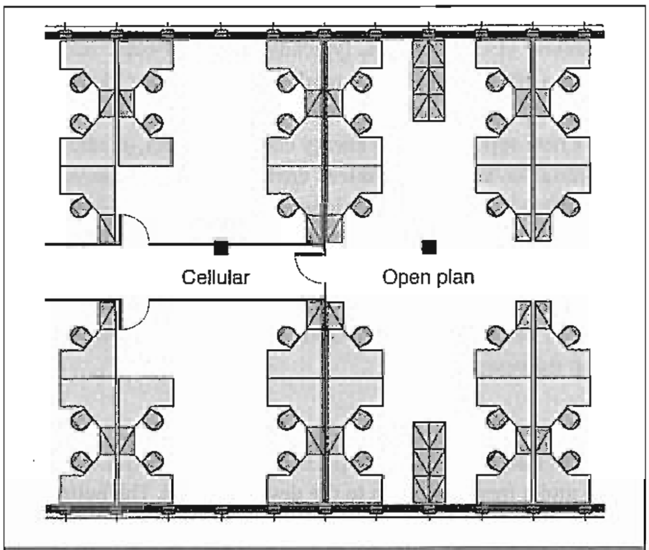

Fig. 1. Generic office planning grid

Having honed the design and performance of the theoretical building, the principles were then applied to the specific plot on Thorpe Park, a business park on the outskirts of Leeds (Fig. 2). Yorkshire Forward worked with Innovate to fund a proportion of the costs of prototyping the sustainable features and construction methods. In particular, the building was prototyped and extensively analysed using environmental simulation software.

3. BUILDING DESCRIPTION

The building comprises two office wings separated by a glazed atrium (Fig. 3). After allowing for the number of car parking spaces demanded by the planners, the accommodation schedule of 4350 m^2 required multiple storeys. The primary orientation is north–south so that the long elevations face east and west. The building was developed linearly to fill the available footprint so that the accommodation would fit into five individual office floor plates. This allowed the development of a three-storey wing and a lower two-storey wing on the east side.

The atrium was designed to minimise the surface area in relation to the enclosed volume while still maintaining sufficient daylight

Fig. 2. East elevation

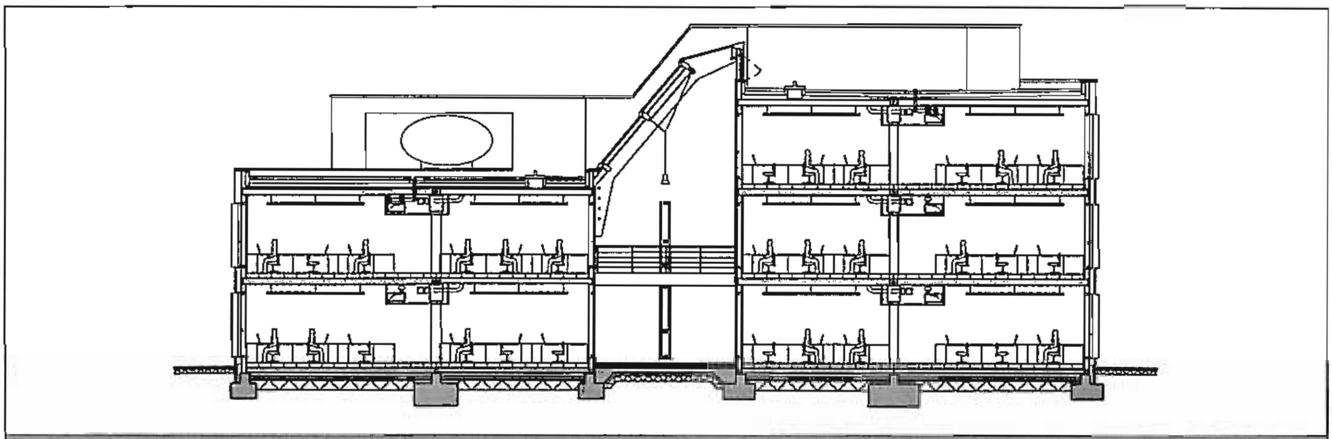

Fig. 3. Cross-section

for offices at the centre of the building. Stepping up the office wings from east to west reduces the visual scale of the building from the road, allows early morning sunshine to penetrate the pitched glazed roof and thus pre-warm the atrium space, and allows better daylight penetration into the heart of the building by increasing the visible sky angle.

The two office wings are offset, creating space for the simple glazed entrance to the south west corner. The remaining three gable ends provide articulation to the blocks. It is here that the spiral escape stairs, main duct risers and air handling units are located. The building is finished externally with a white render and panels of timber cladding to the gables (Fig. 4). Vertical external solar shades on the long elevations are manufactured in pressure-laminated timber. Fenestration to the offices is eliminated on the north and south façades, minimising thermal loss and solar gain.

The east and west façades of the office wings are identically elevated and the detailing continues through into the atrium, the only differences being the level of insulation applied and specification of the glazing internally and externally. This provides visual continuity through the glass façade of the atrium, enhancing the feel of an open, outdoor space.

Fig. 4. North elevation

A conscious effort was made to contain the building services plant (housed at roof level) within elliptically shaped fibre-reinforced polymer shrouds. The enclosures are visually locked into the gable end composition by a wrapped concrete element. External works were designed to use the natural site topography and features to minimise earthworks. The hard landscape uses permeable paving with a lined pond and a natural wetland area to enable storm water to be disposed of on site rather than discharging to offsite drainage.

4. PASSIVE DESIGN

The building was designed with a concrete structure to provide high thermal mass—a key element in the environmental performance strategy—with the whole building designed as a thermal store. The frame consists of load-bearing pre-cast wall panels, pre-cast floor planks and a single, central column line. A pre-fabrication route was chosen for the structure in order to provide a high-quality internal finish, thus allowing the mass of the concrete to be exposed directly to the internal environment. This also provided a number of additional benefits due to the tighter tolerances and quality control that could be achieved. The nature of the structure enabled window openings to be optimised within the wall panels and provided the frame, thermal mass, airtight construction and weatherproof envelope all in a single component. Additionally, offsite fabrication allowed the concrete to be specified with pulverised-fuel ash (PFA) cement replacement, Lytag aggregates and recycled reinforcement.

The concrete structure is externally insulated with glued polystyrene blocks and a through coloured render finish substantially to exceed the requirements of building regulations at 0·15 W/m^2 per °C. Four windows, conforming to the 1·5 m planning module, are set within each pre-cast concrete wall panel using solar control low-emissivity glass in timber frames to achieve a U value of 1·65 W/m^2 per °C. The roofs are insulated and waterproofed with a single-ply membrane to achieve a U value of 0·10 W/m^2 per °C and the lower roof on the east wing is finished with a crushed brick aggregate, planted with sedum.

Overall, the level of insulation achieved reduces heat loss through the building fabric by 60% in comparison to one constructed

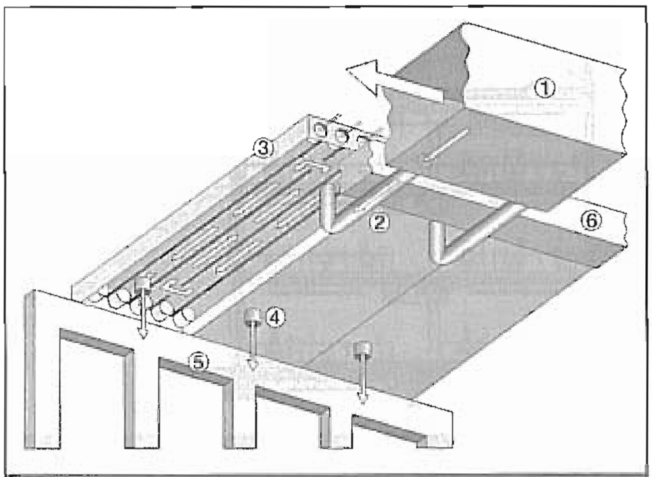

Fig. 5. The Termodeck air supply system: 1, primary air supply duct; 2, terminal air supply duct; 3, Termodeck adapted floor plank; 4, air supply grille; 5, load-bearing wall panel; 6, central supporting beam

under the 2006 edition of the Building Regulations part L. The heat loss is thus reduced to a point where internal gains from occupancy can provide the majority of useful heat.

The concrete structure is exposed internally, with a simple paint finish, allowing its high thermal mass to regulate the internal environment. The specific heat capacity of the concrete is much higher than that of air inside the building. Thus, by exposing the concrete surface, as heat is released into offices from people, electrical equipment and solar gain, energy is transferred from the air to the concrete and the temperature rise of the combined system is much lower than if the heat had been absorbed by the air alone.

To further increase the thermal mass available in the building, the floor and roof slabs use Termodeck.[4] Termodeck is a proprietary system from Tarmac Ltd, in which the hollow cores of the pre-cast planks are cross-connected internally by core drilling to create a serpentine labyrinth through which ventilation air passes (Fig. 5). This additional contact between environmental air and the interior of the floor planks engages virtually the entire mass of the concrete, not just that which is exposed at the external surfaces.

5. HEATING VENTILATION AND AIR CONDITIONING SYSTEMS

The building is mechanically ventilated with balanced supply and extract to provide 15 l/s per person of fresh air for the design peak occupancy of 420 people. In order to minimise the energy required to heat fresh air and to utilise casual heat gains from occupancy, the air handling units incorporate heat recovery wheels. Approximately 80% of the heat available in the exhaust air is collected and delivered into the fresh air. The supply air is then circulated through the floor/roof slabs before entering the occupied spaces. Thus any difference in temperature of the air and concrete in the floors causes the air to absorb or give up heat, regulating the supply air temperature to the space and allowing any surplus heat gains (e.g. from people, computers) to be stored in the thermal mass for later beneficial reuse.

Any additional requirement for heating is provided by a high-efficiency boiler plant incorporating a combined heat and power (CHP) unit. This system, in addition to generating the building's baseload electrical demand, also provides cooling tri-generation from waste heat through a matched absorption chiller.

In summer the building is cooled using similar principles. Fresh air ventilation is provided via the floor/roof slabs. If the outside air is warmer than the building, it is cooled by contact with the thermal mass thus moderating the supply air temperature. Ventilation continues overnight, with cool outdoor air to draw out any excess heat stored in the thermal mass, recharging it for the following day.

If the exhaust air is cooler than the fresh air, the thermal wheels can be used to remove some of the heat; if it is warmer than the fresh air, the thermal wheel system is stopped and the heat exhausted from the building. In peak summer conditions, the gains may exceed the building's capacity passively to reject heat; in this case the chiller is energised. However, the thermal mass is again essential as the installed chiller capacity is less than half of the peak cooling load. A predictive control algorithm runs the chiller overnight to store additional cooling in the thermal mass to be drawn on during the day, while the chiller continues to operate. The chiller thus runs continuously at full load for extended periods—the ideal scenario for utilising heat from the CHP unit.

Unusually, the air handling units also incorporate a recirculation path in addition to the heat recovery wheels. Thus, at night when the building is empty and there is no requirement for fresh air, heat recovery can be achieved by recirculating the air directly. This increases the heat recovery to 100% and, because of the arrangement of the units, bypassing the thermal wheels reduces the air path resistance allowing the ventilation to be delivered by just the supply fan, thus reducing the fan energy consumed when the building is empty.

Originally it was hoped to procure pre-cast floor planks in 1·5 m widths to correspond to the planning module, thus ensuring absolute consistency in the air delivery via the floor slabs. However, this proved to be uneconomic as the standard plank width of manufacturers is 1·2 m. The arrangement of the labyrinth within the cores of the planks thus had to be altered in some circumstances to ensure that the grill locations corresponded to the planning module. The result is that the location of the grilles relative to partitions varies occasionally in the smallest sub-division of cellular offices; the overall ventilation rates had to be increased slightly in order to ensure that all areas would receive sufficient fresh air.

The building's heating and cooling is provided from a gas-fired tri-generation plant, comprising a gas-fired reciprocating engine driving an electrical alternator with cooling jacket and exhaust heat recovery, two high-efficiency gas boilers for heating the building from cold, an absorption chiller energised by heating water and a small electric chiller for support in peak conditions.

A special control programme was written for the plant to maximise the hours of use of the CHP engine in response to thermal loads. In a conventional control strategy, the plant will respond quickly to satisfy any small changes in demand. Boilers have very good modulating controls and can be energised and shut down quickly, whereas a CHP generator has a fixed output and constant stop/start operation quickly leads to coking up of the cylinders. Thus, under a conventional control scenario, boilers would respond first to meet a small change in demand and may well satisfy this before sufficient load develops to justify starting the CHP.

The very high thermal mass in this building creates a slow response to changes in energy input and allows thermal energy to be stored without being expressed as significant changes in internal temperature. The building controls have been set up with wide dead-bands to take advantage of this fact. When there is a demand for thermal energy in any of the building's control zones, whether heating or cooling, the building management system examines all the other zones that are within their dead-band to establish whether they have the capacity to absorb additional energy that can be used later.

This look-ahead function allows the system to build up a larger overall demand than would be required to meet the single zone alone and can therefore start and run the CHP engine, rather than fire a boiler at reduced load. The CHP unit then continues to run until the original demand is satisfied *and* all the zones have been raised to the extreme of the dead-band. The thermal energy that is stored in this way is then available to maintain the space condition for an extended period until the load has again built up sufficiently to re-start the CHP system.

6. LIGHTING

Advances in lighting technologies have made significant improvements in the overall efficiency of lighting installations, but the demand for high lighting levels in offices still results in high electricity consumption. In fact, once the energy consumption for heating and cooling was reduced by the introduction of passive design, the energy needed for conventional lighting quickly became a dominant factor.

The main elevations of the office wings are orientated east and west in order to maximise daylight potential. On a south-facing elevation it is necessary to provide *brise soleil* to shade windows from peak midday solar gains. However, a *brise soleil* also reduces available daylight by reducing the vertical sky angle. With east and west orientations, shading is provided instead by vertical fins between the windows, blocking sunshine at oblique angles to the windows but maintaining the vertical sky angle. It was determined that to achieve the same shading factor as vertical fins on the east and west elevations with a conventional *brise soleil* on a south elevation would reduce the available daylight by 35%.

The window size and frequency were designed to conform to the 1·5 m planning grid and to achieve a minimum average daylight factor in the offices of 4·5%. With this daylight factor, full artificial lighting to maintain internal design luminance of 450 lux is only required for 10% of the working year. As external daylight levels rise, artificial lighting progressively dims until sufficient daylight is available and then the lights turn off. There is typically sufficient daylight available for the lights to remain switched off for 66% of the working year. From a more detailed analysis of the building zone by zone, it is estimated that lighting will only be required for 20% of working hours at the equivalent of full-load operation.

7. WATER

The building features a vacuum drainage system for conveying waste from toilets (WCs) to the sewer. A central system maintains all of the waste pipework under vacuum against valves in the WC pans. When a WC is flushed, the valve opens and the waste is discharged by air pressure with minimal consumption of water to wash the pan. Once sufficient volume has been accumulated, the waste vessel is pumped out to a conventional drain. This system reduces the volume of water consumed per flush from 6 l for a conventional WC to 1·2 l. This in turn allows virtually all of the water required for WC flushing to be harvested from rainwater.

A storage tank below ground at the south end of the building collects rainwater from the roof. The rainwater is treated and delivered on demand to the vacuum drainage system and WCs by a pressurisation pump set. Overflow from the rainwater tank and surface run off is discharged to a series of swales and a soakaway pond at the edge of the site. Hand basins use low water consumption fittings and the urinals are waterless. The overall sewage volume discharged from the building is expected to be reduced by 75% and the use of mains water for sewage is virtually eliminated.

8. CARBON PERFORMANCE

The performance of the building was compared against published benchmarks for office buildings in *Energy Consumption Guide 19, Energy Consumption in Offices.*[5] This publication defines four basic types of office building and presents the performance of typical and good practice buildings.

Interestingly, the developer had previously built a similarly sized serviced office on a business park outside Nottingham, the energy performance of which, over its first two years of operation, precisely matched the typical benchmark for a standard air-conditioned office. The direct experience of owning and managing this office therefore provided the developer with a baseline from which to judge the building.

The predicted energy demand for heating, ventilating, lighting and cooling the building will be responsible for annual emissions of just over 22 kg CO_2/m^2 (Fig. 6). This is comparable with the good practice benchmark for naturally ventilated buildings and represents a reduction of 80% against the typical air-conditioned benchmark and the developer's previous building.

9. BREEAM

First established in 1990, the Building Research Establishment environmental assessment method (Breeam) is a tool to assess the environmental performance of both new and existing buildings. It is regarded by the UK's construction and property sectors as the measure of best practice in environmental design and management. The building was assessed under Breeam for Offices 2005[6] and achieved a score of 87·55% (Fig. 7)—which in 2007 was the highest score for any building assessed under any form of Breeam.

10. FINANCIAL PERFORMANCE

The construction budget for the building was approximately £1225/m^2. This figure includes additional costs of approximately

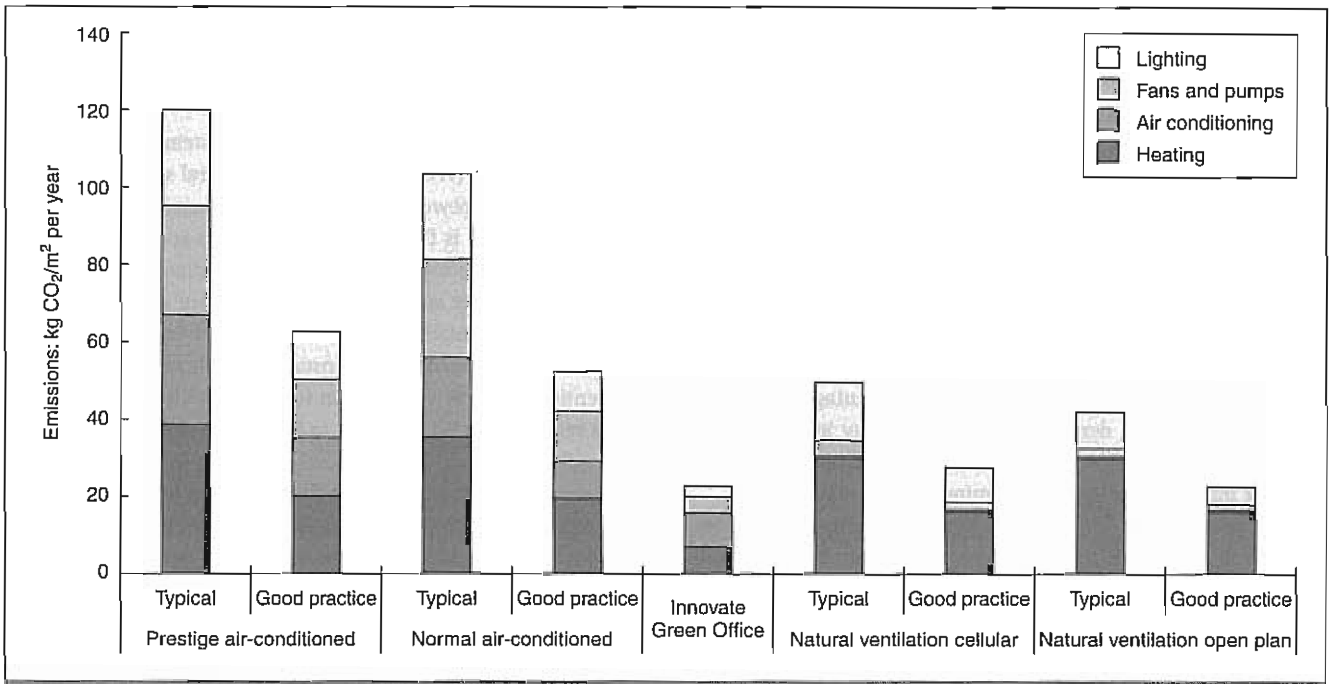

Fig. 6. Carbon index benchmarks for UK office buildings

£185/m^2 over a conventional building budget for environmental enhancements, principally

(*a*) pre-cast concrete construction
(*b*) Termodeck adaptation of floor slabs
(*c*) improved insulation
(*d*) improved glazing, solar shading and lighting control
(*e*) CHP system
(*f*) vacuum drainage and rainwater harvesting.

The cost of enhanced environmental performance for the building is thus of the order of 17·5% above the cost of a conventional office building. There was an additional one-off cost of approximately £11·75/m^2 for enhanced design fees and prototyping costs that would not be incurred on future buildings to this model.

The reduction in energy consumption achieved in this building is predicted to provide a running cost saving of £13·65/m^2 annually (at January 2007 energy prices) compared with the developer's previous building. Reductions in water and sewage charges (due to the use of rainwater and vacuum drainage for toilet flushing) are expected to provide further savings of about £0·95/m^2 per annum. The expected rental return from the office space is governed principally by local competition and is expected to be in the region of £140–£160/m^2 annually.

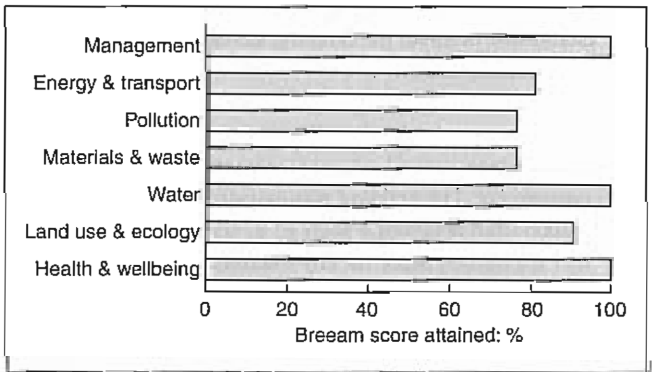

Fig. 7. Breeam score

Reductions in energy and water supply costs achieved in this building represent an increased yield of around 10%. While this is not yet equal to the proportional increase in capital cost, it is expected that, as concern over climate change grows, a demand for ethical buildings will emerge that will provide the additional return in the form of premium rentals. Nevertheless, between design and completion of this project the predicted energy cost savings rose by 40%, purely as a result of energy market inflation. It is suggested, therefore, that it cannot be long before investments in such buildings will be fully justified not only in terns of carbon savings, but also financial return.

11. OPERATIONAL PERFORMANCE MONITORING

The School of Civil Engineering of the University of Leeds was commissioned to monitor and analyse building performance as a PhD research project over the first 2·5 years of operation. The information to be collected includes

(*a*) a final analysis of the recycled material content of the building
(*b*) insulation and infiltration achieved at the building envelope
(*c*) performance of the building environmental and lighting systems
(*d*) performance of the CHP system
(*e*) proportion of water use collected from rainwater
(*f*) post-occupancy satisfaction feedback.

Early data gathering has already been used to refine the building commissioning and operational procedures as well as to rectify some minor faults in the control sensors.

Unfortunately, the building has only been partly occupied since completion of the tenants' fit-out in April 2007; as of December 2007 the space was only 20% occupied. Thus, at the time of writing, there are insufficient operational data to validate fully the design predictions and no data for a fully occupied building. Nevertheless, it is the intention to publish the results of the monitoring exercise in order to provide feedback on the success of the various environmental improvements to the building together with lessons learned for the future.

12. CONCLUSIONS

The Innovate Green Office joins an established cohort of exemplar low-energy buildings in the UK. The design of such buildings is complex and commercial development programmes rarely allow sufficient time for designers to undertake the necessary detailed analysis of all possible options. Conventional design often pays scant attention to engineering the building envelope, beyond achieving the bare minimum required by regulation, and then uses building services installations to solve problems built into the fabric. To develop buildings for passive environmental control requires significant attention to the building fabric and active systems must be designed to act in harmony with the building's inherent thermal characteristics.

Three key factors contributed to the commercial and environmental success of the project—a client prepared to take the necessary time and risk, a source of funding for the one-off costs of prototyping and development, and the early involvement of engineers in the design. Critical to the success was the engagement of the environmental and building services engineer at the pre-feasibility stage. This allowed all of the initial decisions on building location, form, massing, spatial organisation and construction to be informed by performance as well as cost and commercial issues. Early use of a building performance simulation—and its continued use throughout the development—permitted design and value engineering decisions to be made with full knowledge of the performance impacts throughout the building systems.

A recent international symposium[7] suggested that reductions in greenhouse gas emissions of the order of 60–80% may now be necessary to prevent dangerous anthropogenic changes to the climate system, and that delaying action by 20 years could increase the level of reductions required by a factor of 3–7. The project is a clear demonstration that the UK construction industry can deliver buildings now, using currently available techniques and products, to achieve reductions in environmental impact of the scale called for and far beyond that currently required by regulation or proposed by government policy.

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